Universidade de Lisboa
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Towards an Epistemology of Medical Imaging

Margherita Silvia Di Marco

Doutoramento em História e Filosofia das Ciências
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Tese orientada pela Prof.ª Dr.ª Olga Maria Pombo Martins e pelo Prof. Dr. Andrea Pinotti, especialmente elaborada para a obtenção do grau de doutor em História e Filosofia das Ciências e em Filosofia, em cotutela entre a Universidade de Lisboa e a Università degli Studi di Milano

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To the loving memory of Angela, my mother

The scientist [...] cuts open the visible body to look at its interior or catches hidden objects by means of all sorts of sophisticated equipment that deprives them of their exterior properties through which they show themselves to our natural senses.

H. Arendt – *The Life of the Mind*

Then he flung himself into his chair, and drew out his keepsake, his treasure, that consisted, this time, not of a few reddish-brown shavings, but a thin glass plate, which must be held toward the light to see anything on it. It was Clavdia's X-ray portrait, showing not her face, but the delicate bony structure of the upper half of her body, and the organs of the thoracic cavity, surrounded by the pale, ghostlike envelop of flesh.

T. Mann – *The Magic Mountain*

What is the use of a book thought Alice, without pictures or conversations?

L. Carroll – *Alice's Adventures in Wonderland*

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Abstract

The objective of this dissertation is to contribute to the development of an epistemology of medical imaging. My central thesis is that medical imaging does not merely produce more or less accurate pictures of the inner organs, it rather transforms the living body into a scientific object by changing its very visibility. The imaging apparatus turns the body into a visual object that can be observed under experimental conditions: unlike the real body, it can be filed, retrieved, shared, measured and manipulated in several ways. Alongside this main thesis there are two others: firstly diagnostic images – like all scientific images – are actual cognitive instruments, epistemic objects inscribed within theoretical contexts and experimental practices. Secondly, an image of the inner body has diagnostic meaning and value only in the scope of a specific conceptualization of the body and its ailments. Accordingly, if we are to develop an epistemology of medical imaging, we cannot limit our analysis to diagnostic images *qua* images, we also have to understand them *qua* diagnostic instruments.

This is the reason why I take into examination the historical and conceptual conditions of possibility of radiography – the first medical imaging technology, invented in 1895 – in the first chapter of the dissertation. My aim is to understand which medical theories and practices had to be at work in the nineteenth century for those shadow-images produced by the X-ray apparatus, to be perceived and employed as diagnostic devices. I argue that the diagnostic relevance of radiography is rooted in the conceptualization of body, disease and diagnosis put forward by clinical anatomy, as early as the end of the eighteenth century. I also defend the idea that the stethoscope, developed in 1816, was the material and intellectual predecessor of medical imaging, because it introduced a primitive form of mediated perception in medical diagnosis, and allowed the clinician to explore the inner body of the living patient from the outside, extracting from it signs of illness. The stethoscope was only the first of a vast array of instruments invented in the nineteenth century to visualize different aspects of the inner morphology and physiology of the living body. Each of these instruments fulfilled specific diagnostic aims and posed distinct epistemological problems, but all of them shared some commonalities: they were meant

to replace the subjective sensations of patients and doctors with objective indices of health and disease; they created visual records of the inner body that could be filed, retrieved and shared among physicians; they required the development of a specialized language agreed upon by a community of experts; they created a progressive physical separation between the body of the patient and the body of the physician. It was in this complex scenario of medical practices, objects, images and ideas that radiography appeared and progressively acquired its diagnostic function.

In the second chapter, I take into account the early developments of medical photography in order to understand how the early technology for the production of mechanical images entered and influenced the domain of medicine. The main theoretical references in this chapter are Charles Sanders Peirce's semiotics (in particular his classification of signs in indices, icons and symbols) and Walter Benjamin's reflections on the photographic series (mechanical production and reproduction of an image and of the body it represents), on the intrinsic analytic and dissecting potential of photography (the photographer as a surgeon), and on the optical unconscious (photography as a prosthesis that enriches and transforms our sensorial experience). Drawing on these authors, and analyzing the works of early physicians-photographers in psychiatry, dermatology, neurology and physiology, I show that the photographic series collected in medical journals, manuals and hospital archives produced a clinical gaze in the Foucauldian sense. I also argue that the photographic series was part of a larger experimental apparatus, which encompassed the patient, the camera and the observer, and whose aim was to turn the body and disease into a visual object available for scientific analysis.

In the third chapter, I discuss the problem of the invisible referent, that is, I analyze the processes whereby photographs that reveal invisible phenomena are endowed with meaning. This is likely to be the fundamental problem of all scientific imaging. When the referent of a picture is invisible, the iconic mode of signification fails, because in this case the image produced by the mechanical or electronic apparatus does not look like anything we already know, it resembles nothing. So, how do we know that the object we see in the photograph – e.g., a cell or a tubercular lesion – is *really* there and does *really* look like that? Drawing on the theoretical analysis developed in the previous chapter, I maintain that the visualization of the invisible entails a peculiar combination of the indexical, iconic and symbolic modes of signification. My reasoning opposes Lorraine Daston and Peter Galison's idea of mechanical objectivity, and demonstrates that their notion of mechanical objectivity as the moralizing suppression of subjectivity is a caricature of the actual ideas and practices developed by the scientists of the nineteenth century to deal with the problem of visualizing the invisible. The argument is articulated in three moments, corresponding to the analysis of the problem of objectivity and image signification in microphotography, chronophotography, and radiography.

In the fourth chapter, I argue that images are cognitive tools and that representation and observation are never an act of automated repetition, they always entail a creative component. As in the previous chapter, part of my discourse is built in contrast with Daston and Galison, challenging their claims about the passive nature of representation. For these authors, up until the development of digital technologies for image manipulation, scientific images were mere representations of the world, focused on copying nature. Computer images, on the contrary, are presentations, because the observer can virtually manipulate them so that they show the object in ever changing ways. I criticize this classification of scientific images with historical and theoretical arguments. From the historical point of view, I show that at least since the sixteenth century there have been attempts to create images that can be actually manipulated by the observer. From the theoretical perspective, I draw on a variety of literature spanning from art theory to neuroscience, to demonstrate that the very notion of a passive representation is unsustainable, because images always engage the observer in an embodied act of perception, which elicits not only visual, but also tactile sensations and motor reactions. Moreover, I argue that Daston and Galison's emphasis on nanoimaging as the only technology that allows manipulating the object of study during the process of image production is misleading. In fact, even when they do not reach the peaks of technological sophistication that characterizes nanoimages, scientific images are the result of some manipulation of the natural object they represent. A scientific image cannot be a passive copy of nature, because it is part of an experimental *praxis*, whose goal is to understand natural phenomena, not just to reproduce them. To corroborate this idea I explore actual scientific practices of image signification, taking into account written documents (semiotic analysis of a radiology article) and material practices (laboratory ethnography describing the interpretation of electrophoresis images in a molecular biology laboratory, and description of an example of signification of electron microscopy pictures). From this analysis three remarks can be put forward: (1) the process of signification of scientific images has a distributed character, because it can involve different persons, objects and activities; (2) scientific images can be considered experimental tools, in the sense that scientists and physicians handle them in several forms in order to explore different aspects of their object of study; (3) scientific images are to be under-

stood as controlled, artificial phenomena produced with the aim of redefining the visibility of natural objects.

In order to clarify this latter idea, in the final chapter I introduce Gaston Bachelard's concept of phenomenotechnique. Although the idea of phenomenotechnique cannot be directly applied to medical imaging, there are two characterizing elements of this concept that provide important insights for conceptualizing medical imaging. The first is the idea that in order to study a natural phenomenon, scientists must previously transform it into a scientific object. The second, closely related to the former, is that scientific experience is by necessity mediated, and such mediation has both an intellectual and material character. This means that the development of instruments and new technologies is not a second-order product of science, it is part and parcel of the scientific process. Technology is embedded into science, because our scientific grasping of the world is necessarily mediated by instruments; scientific instruments, in turn, are materializations of a vast body of scientific knowledge and practices (in the case of digital imaging this knowledge has an eminently mathematical character). Thus, science and technology are reciprocally constituted. On these grounds, I propose a description of medical imaging in terms of phenomenotechnique, using this concept as a key word around which to reorganize the ideas previously discussed. Firstly, I resort to the concept of phenomenotechnique to gain insight into how diagnostic images mediate the physician's sensory and intellectual experience. Secondly, I give an account of diagnostic images as artificial phenomena (visual reconfigurations of non-visual signals) that work as simulations of the patient's body, and that reify different domains of knowledge (from medicine to physics and engineering). Finally, I argue that the proper and efficient signification of a diagnostic image requires a phenomenotechnique of the observer. To recognize the signs of disease in an image of the inner body, one has to master the explicit and implicit rules necessary to make sense of the novel sensory domain produced by the technological apparatus. This implies abandoning spontaneous modes of perception and signification to engage in a process of educated perception. The expert viewer goes through a formal and informal training that deeply transforms natural vision, by placing the act of watching within a wide epistemic network that encompasses both theoretical and practical knowledge.

Key-words: epistemology; history of medicine; image theory; medical imaging; photography; radiography.

Resumo

O objetivo deste trabalho é o de contribuir para o desenvolvimento de uma epistemologia da imagiologia médica. A minha tese central é que a imagiologia médica não produz meramente imagens mais ou menos precisas dos órgãos internos, antes torna o corpo vivo num objeto científico ao modificar a sua própria visibilidade. As tecnologias de imagiologia tornam o corpo num objeto visual que pode ser observado em condições experimentais: ao contrário do corpo real, pode ser arquivado, recuperado, partilhado, medido e manipulado de variadas formas. Esta tese é acompanhada por duas outras: em primeiro lugar, as imagens diagnósticas, como todas as imagens científicas, são efetivamente instrumentos cognitivos, objetos epistémicos inscritos em contextos teórico-práticos específicos. Em segundo lugar, uma imagem do interior do organismo tem significado e valor diagnóstico apenas no âmbito de uma dada contextualização do corpo e da doença. Por conseguinte, se queremos desenvolver uma epistemologia da imagiologia médica, não podemos analisar as imagens de diagnóstico simplesmente como imagens, mas também como instrumentos médicos.

É por isso que no primeiro capítulo da dissertação tento compreender quais foram as condições de possibilidade históricas e conceptuais da radiografia – a primeira tecnologia de imagiologia médica, inventada em 1895. O meu objetivo é o de entender quais as teorias e práticas médicas que estavam em jogo no século XIX, que permitiram que umas imagens que mostravam sombras do interior do corpo fossem percecionadas e usadas como um instrumento clínico. Defendo que a relevância diagnóstica da radiografia está enraizada na conceptualização de corpo, doença e diagnóstico estabelecida pela anatomia clínica já em finais do século XVIII. Defendo também que o estetoscópio, desenvolvido em 1816, foi o precursor material e intelectual da radiografia, pois introduziu uma forma primitiva de perceção mediada no diagnóstico médico, e permitiu ao médico explorar a partir do exterior, o interior de um corpo vivo, extraindo sinais de doença. O estetoscópio foi apenas o primeiro de um vasto conjunto de instrumentos inventados no século XIX para visualizar diferentes aspetos tanto da morfologia como da fisiologia do corpo humano. Cada um desses instrumentos respondia a objetivos de diagnóstico específicos e punha problemas epistemológicos distintos, mas todos partilhavam alguns aspetos comuns: eles deveriam substituir as sensações subjetivas de pacientes e médicos por indicadores objetivos de saúde e doença; criavam registos visuais do interior de um corpo vivo; necessitavam do desenvolvimento de uma linguagem especializada fruto de um acordo da comunidade médico-científica; criaram uma progressiva separação física entre o corpo do paciente e o corpo do médico. Foi neste cenário complexo de práticas, instrumentos, representações e ideias médicas, que a radiografia apareceu e progressivamente adquiriu a sua função diagnóstica.

No segundo capítulo examino o nascimento da fotografia de modo a entender como a primeira tecnologia de produção de imagens mecânicas entrou nas teorias e práticas médicas. A principal referência teórica neste capítulo é a semiótica de Charles Sanders Pierce, em particular a sua classificação dos signos em índices, ícones e símbolos, e as reflexões de Walter Benjamin sobre as séries fotográficas (produção e reprodução mecânica de uma imagem e do corpo que ela representa), sobre o intrínseco potencial analítico e de "dissecção" da fotografia (o fotógrafo como cirurgião), e sobre o inconsciente ótico (a fotografia como uma prótese que enriquece e transforma a nossa experiência sensorial). Baseando-me nestes autores e analisando os trabalhos dos primeiros médicos-fotógrafos em psiquiatria, dermatologia, neurologia e fisiologia, mostro que as séries fotográficas colecionadas em revistas médicas, manuais e arquivos de hospitais, produziram um "olhar clínico" no sentido Foucauldiano. Defendo também que a série fotográfica era parte de um dispositivo experimental mais vasto, que abrangia o paciente, a câmara fotográfica e o observador, e cujo objetivo era tornar o corpo e a doença num objeto visual, disponível para análise científica.

No terceiro capítulo discuto o problema do referente invisível, isto é, analiso os processos através dos quais é atribuído significado às fotografias que revelam fenómenos invisíveis. Este é provavelmente o problema fundamental de toda a imagiologia científica. Quando o referente de uma imagem é invisível, a modalidade de significação icónica falha, porque neste caso a imagem produzida pelos instrumentos (sejam eles mecânicos ou eletrónicos) não se parece com nada que conheçamos já. De facto, podemos dizer que não se parece com nada. Então, como podemos saber que o objeto que vemos na fotografia – por exemplo, uma célula ou uma lesão tubercular – está *realmente* lá e tem *realmente* o aspeto do que vemos? Baseando-me na análise teórica desenvolvida no capítulo anterior, defendo a ideia de que a visualização do invisível comporta uma combinação peculiar das modalidades de significação de índice, ícone e símbolo. A minha argumentação é construída em oposição à ideia de objetividade mecânica de Lorraine Daston e Peter Galison, e demonstra que a noção de objetividade mecânica como a supressão moralizante da subjetividade, defendida por estes

historiadores, é uma caricatura das ideias e práticas desenvolvidas pelos cientistas do século XIX para lidar com o problema de visualizar o invisível. A argumentação é articulada em três momentos, correspondendo à análise do problema da objetividade e significação das imagens na área da micro-fotografia, crono-fotografia e radiografia.

No quarto capítulo defendo que as imagens são instrumentos cognitivos (no sentido forte, não metafórico da palavra instrumento) e que representação e observação nunca podem ser atos de repetição automática, porque comportam sempre uma componente criativa. Como no capítulo precedente, parte da argumentação é construída em contraste com Daston e Galison, desafiando as suas posições acerca da natureza passiva da representação. Para estes autores, até ao desenvolvimento das tecnologias digitais, as imagens científicas eram meras "re-apresentações" do mundo focadas em copiar a natureza. Com o desenvolvimento das tecnologias digitais, porém, as imagens passaram a ser "apresentações", porque através dessas imagens o observador pode visualizar o objeto representado de muitas maneiras, e manipulá-lo virtualmente. A minha crítica a esta posição é baseada em argumentos históricos e teóricos. Do ponto de vista histórico, mostro que pelo menos desde o século XVI houve tentativas de criar imagens que podem ser de facto manipuladas pelo observador. Do ponto de vista teórico, apoio-me numa vasta literatura que vai desde a teoria da arte às neurociências, para demonstrar que a própria noção de representação passiva é insustentável, porque as imagens envolvem sempre o observador num ato de perceção corpórea, que provoca sensações não só visuais, mas também táteis, bem como reações motoras. Além disso, mostro que é enganadora a ênfase posta por Daston e Galison no *nanoimaging* como a única tecnologia que permite a manipulação do objeto de estudo durante o processo de produção da imagem. De facto, mesmo quando não atingem os picos de sofisticação tecnológica que caracteriza as nano-imagens, as imagens científicas são o resultado de alguma manipulação do objeto natural que representam. Uma imagem científica não pode ser uma cópia passiva da natureza, porque é parte de uma *praxis* experimental, cujo objetivo é o de aprender algo acerca dos fenómenos naturais, não apenas reproduzi-los. A fim de corroborar esta ideia, analiso algumas práticas concretas de significação de imagens científicas, tomando em conta documentos escritos (análise semiótica de um artigo de radiologia) e práticas materiais (etnografia de laboratório sobre a interpretação de imagens de eletroforese em biologia molecular, e descrição de um caso de significação de imagens de microscopia eletrónica). Esta análise permite fazer três observações: (1) O processo de significação das imagens científicas é um processo distribuído, e pode incluir várias pessoas, ações e instrumentos; (2) As imagens científicas podem ser consideradas instrumentos de investigação, no sentido em que cientistas e médicos as manipulam de várias formas, para explorar aspetos diferentes dos seus objetos de estudo; (3) As imagens científicas devem ser entendidas como fenómenos artificiais controlados, produzidos com o intuito de redefinir a visibilidade dos objetos naturais.

Para esclarecer e aprofundar esta última ideia, no capítulo final introduzo o conceito de fenomenotécnica de Gaston Bachelard. A ideia de fenomenotécnica não pode ser aplicada diretamente à imagiologia médica. Não obstante, há dois elementos caracterizantes deste conceito que fornecem ensinamentos importantes para uma filosofia da tecnologia e, consequentemente, para uma epistemologia da imagiologia médica. O primeiro é a ideia de que, para se estudar um fenómeno natural, os cientistas devem previamente transformá-lo num objeto científico. O segundo, estreitamente relacionado com o anterior, é o de que a experiência científica é necessariamente mediada, e que essa mediação tem um caráter tanto intelectual como material. Isto significa que a construção de instrumentos e o desenvolvimento de novas tecnologias não é um produto secundário da ciência, mas sim parte integrante do próprio processo científico. A tecnologia está integrada na ciência, porque o nosso entendimento científico do mundo é necessariamente mediado por instrumentos; por outro lado, os instrumentos científicos são materializações de um vasto conjunto de conhecimentos e práticas científicas (no caso da imagiologia médica este conhecimento tem um caráter eminentemente matemático). Portanto, ciência e tecnologia são constituídas reciprocamente. Com bases nessas considerações apresento uma conceptualização da imagiologia médica em termos de fenomenotécnica, utilizando este conceito como palavra-chave que permite reorganizar as ideias desenvolvidas anteriormente. Em primeiro lugar, recorro ao conceito de fenomenotécnica para explicar como as imagens de diagnóstico medeiam a experiência sensorial e intelectual do médico. Em segundo lugar, descrevo as imagens de diagnóstico como fenómenos artificiais (reconfiguração visual de sinais não visuais) que funcionam como simulações do corpo do paciente e que incorporam diferentes áreas do conhecimento (da medicina à física e engenharia). Finalmente, defendo que a significação correta e eficiente de uma imagem de diagnóstico requer uma fenomenotécnica do observador. Para reconhecer os sinais de doença numa imagem do interior do corpo, o médico tem de dominar as regras implícitas e explícitas necessárias para extrair um sentido do novo domínio sensório produzido pelo dispositivo tecnológico. Isto implica abandonar a perceção espontânea para entrar num processo de educação da perceção-significação que molda as capacidades sensoriais do observador. O observador especializado é um observador que

tem feito um percurso formativo que transforma profundamente a visão natural, colocando o ato de olhar dentro de uma vasta rede epistémica.

Palavras chave: epistemologia; história da medicina; imagiologia médica; fotografia; radiografia; teoria da imagem.

Riassunto

L'obiettivo di questo lavoro è quello di contribuire allo sviluppo di un'epistemologia dell'*imaging* medico, intendendo con questo termine sia le immagini utilizzate a fini diagnostici, sia le tecnologie che le producono. La mia tesi principale è che le tecnologie di *imaging* medico non si limitano a produrre immagini più o meno accurate degli organi interni e di alcuni processi fisiologici, ma piuttosto trasformano il corpo in un oggetto scientifico, operando un cambiamento profondo della sua visibilità. Gli strumenti di *imaging* mutano il corpo in un oggetto visivo che può essere osservato in condizioni sperimentali. A differenza del corpo reale, tale oggetto può essere archiviato, consultato, condiviso, misurato e manipolato in varie maniere. Questa tesi di fondo è accompagnata da altre due: (1) Le immagini diagnostiche, come tutte le immagini scientifiche, sono veri e propri strumenti cognitivi, strumenti epistemici integrati in un quadro teorico-pratico specifico; (2) Un'immagine che rivela l'interno dell'organismo ha significato e valore diagnostico solo nell'ambito di una specifica concettualizzazione del corpo e della malattia, di conseguenza uno studio sull'epistemologia dell'*imaging* medico non si potrà limitare a esaminare le immagini diagnostiche in quanto immagini, ma dovrà analizzarle anche nella loro veste di strumenti di diagnosi medica.

Per questo motivo nel primo capitolo della dissertazione traccio le linee generali delle condizioni di possibilità storiche e concettuali della radiografia – la prima tecnologia di *imaging* medico – inventata nel 1895. Lo scopo è quello di comprendere quali teorie e pratiche mediche dovessero essere vigenti alla fine del XIX secolo, affinché immagini che parevano ombre del corpo interno potessero essere considerate strumenti diagnostici. La spiegazione da me proposta è che la rilevanza diagnostica della radiografia si fonda sulla concettualizzazione di corpo, malattia e diagnosi resa operativa dall'anatomia clinica già alla fine del XVIII secolo. Seguendo e supportando questa linea di ragionamento mostro che lo stetoscopio, inventato nel 1816, può essere considerato il predecessore materiale e intellettuale dell'*imaging* medico perché introdusse una primitiva forma di mediazione sensoriale nel campo della diagnostica e permise al medico di esplorare dall'esterno le profondità del corpo del paziente, estraendone segni

di malattia. Lo stetoscopio è solo il primo di una vasta famiglia di strumenti inventati nel XIX secolo per visualizzare diversi aspetti della morfologia interna e della fisiologia del vivente. Sebbene ciascuno di questi strumenti rispondesse a specifiche necessità diagnostiche e ponesse specifici problemi epistemologici, si possono identificare alcune caratteristiche comuni: tutti avevano come obbiettivo quello di sostituire le sensazioni soggettive dei pazienti e dei medici con indici oggettivi di salute e malattia; tutti creavano registri visivi dell'interno del corpo umano che potevano essere archiviati, recuperati e condivisi da diversi medici; tutti richiedevano la creazione di un linguaggio specializzato, condiviso da una comunità medico-scientifica; tutti creavano una progressiva separazione tra il corpo del paziente e il corpo del medico. È in questo complesso scenario di pratiche, oggetti, raffigurazioni e idee che la radiografia fece la sua comparsa e acquisì la sua funzione diagnostica.

Nel secondo capitolo prendo in esame la nascita della fotografia, al fine di comprendere in che modo la prima tecnologia di produzione meccanica di immagini influenzò la medicina. I principali riferimenti teorici di questo capitolo sono dati dalla semiotica di Charles Sanders Peirce, in particolare la sua classificazione dei segni in indici, icone e simboli, e dalla riflessione di Walter Benjamin sulla serie fotografica (produzione e riproduzione meccanica di un'immagine e del corpo in essa rappresentato), sull'intrinseco potenziale analitico e di dissezione della fotografia (il fotografo come chirurgo), e sull'inconscio ottico (fotografia come protesi che arricchisce e trasforma l'esperienza sensibile). Basandomi su questi autori e esaminando i lavori dei primi medici-fotografi nell'ambito della psichiatria, dermatologia, fisiologia e neurologia, mostro che le serie fotografiche raccolte in riviste mediche, manuali di studio e archivi ospedalieri produssero uno sguardo clinico in senso foucauldiano. Sostengo, inoltre, che la serie fotografica faceva parte di un più ampio apparato sperimentale che includeva il paziente, la macchina fotografica e l'osservatore il cui scopo era trasformare il corpo e la malattia in oggetti visivi che potessero essere sottoposti ad analisi scientifica.

Nel terzo capitolo discuto il problema del referente invisibile, ossia analizzo i processi attraverso cui le immagini fotografiche di oggetti invisibili vengono dotate di significato. Probabilmente questo è il problema fondamentale di qualunque tipo di *imaging* scientifico. Quando il referente di una fotografia è invisibile, la modalità iconica di significazione non può essere messa in atto, perché nell'immagine prodotta dallo strumento (sia esso meccanico o elettronico) non possiamo riconoscere nessuna similitudine con l'oggetto rappresentato. Di fatto, potremmo dire che in questi casi l'immagine non assomiglia a nulla. Come sappiamo, dunque, se l'oggetto che vediamo nella fotografia – per esempio una cellula o una lesione tubercolare – è *davvero* là, e possiede *davvero* l'aspetto mostrato dall'immagine? Sulla scorta dell'analisi teorica sviluppata nel capitolo precedente, difendo l'idea che la visualizzazione dell'invisibile richieda una peculiare combinazione delle modalità di significazione indicale, iconica e simbolica. La mia argomentazione è costruita in opposizione al concetto di oggettività meccanica proposto da Lorraine Daston e Peter Galison. In particolare, dimostro che l'idea di oggettività meccanica come soppressione moralizzante del soggetto proposta dai due storici è una caricatura delle idee e pratiche sviluppate dagli scienziati del XIX secolo per risolvere il problema della visualizzazione dell'invisibile. La mia argomentazione si articola in tre momenti, corrispondenti all'analisi del problema dell'oggettività e della significazione delle immagini in tre diversi ambiti: microfotografia, cronofotografia e radiografia.

Nel quarto capitolo affronto il problema del valore cognitivo delle immagini, sostenendo che le immagini sono strumenti epistemici (nel senso forte, non metaforico della parola strumento) e che rappresentazione e osservazione non sono mai atti puramente automatici, perché richiedono sempre una componente creativa. Come nel capitolo precedente, parte del mio discorso è una refutazione della posizione di Daston e Galison, in particolare per quanto riguarda le loro affermazioni sulla natura passiva di certe rappresentazioni visive. Secondo Daston e Galison, infatti, fino allo sviluppo delle tecnologie digitali, le immagini scientifiche erano mere *ri-presentazioni* [*re-presentations*] del mondo, miranti a copiare la natura. Con la comparsa del digitale, invece, si è passati a un'epoca in cui le immagini sono *presentazioni* [*presentations*], perché attraverso di esse l'osservatore può visualizzare l'oggetto in mutevoli forme, manipolandolo virtualmente. La mia critica a questa posizione è basata su argomenti storici e teorici. Sul piano storico mostro che i primi tentativi di creare immagini mediche manipolabili risalgono almeno al XVI secolo. Sul piano teorico, ricorrendo alla letteratura prodotta in campi così diversi come la teoria dell'arte e le neuroscienze, dimostro che la nozione di ricezione passiva di un'immagine è insostenibile, perché le immagini coinvolgono sempre l'osservatore in un atto corporeo di percezione che sollecita non solo sensazioni visive, ma anche sensazioni tattili e reazioni motorie. Inoltre, sostengo che l'enfasi posta da Daston e Galison sul *nanoimaging* come l'unica tecnologia che permette di manipolare l'oggetto durante la fase di produzione di un'immagine è fuorviante. Infatti, anche nei casi in cui non raggiungono le vette di sofisticazione tecnologica proprie delle nano-immagini, le immagini scientifiche sono sempre il risultato di una manipolazione dell'oggetto naturale rappresentato. Un'immagine scientifica non può essere una mera copia della natura, perché è sempre parte di una *praxis* sperimentale il cui obiettivo è comprendere un fenomeno naturale, non solo riprodurlo. Per corroborare questa idea analizzo alcune pratiche concrete di significazione di immagini scientifiche, prendendo in esame documenti scritti (analisi semiotica di un articolo di radiologia) e pratiche materiali (etnografia di laboratorio riguardante l'interpretazione di immagini di elettroforesi in biologia molecolare e descrizione di un caso di significazione di immagini di microscopia elettronica). Questa analisi permette di fare tre osservazioni: (1) Il processo di significazione delle immagini scientifiche è un processo distribuito; (2) Le immagini scientifiche possono essere considerate strumenti di ricerca, nel senso che scienziati e medici le manipolano in varie forme al fine di esplorare aspetti diversi del loro oggetto di studio; (3) Le immagini scientifiche vanno comprese come fenomeni artificiali controllati prodotti allo scopo di ridefinire la visibilità degli oggetti naturali.

Per approfondire meglio quest'ultima idea, nel capitolo finale introduco il concetto di fenomenotecnica sviluppato da Gaston Bachelard. La nozione di fenomenotecnica non può essere applicata direttamente all'*imaging* medico, ma alcuni degli elementi che caratterizzano il concetto bachelardiano offrono spunti importanti per pensare l'*imaging* medico. Il primo di questi elementi è l'idea che per studiare un fenomeno naturale, lo scienziato deve innanzitutto trasformarlo in un oggetto scientifico. Il secondo elemento, strettamente legato al primo, è che l'esperienza scientifica è necessariamente mediata, e tale mediazione ha un carattere intellettuale e materiale. Questo significa che la costruzione di strumenti e lo sviluppo di tecnologie non sono un prodotto della scienza, ma piuttosto un elemento interno al processo scientifico. La tecnologia è integrata nella scienza, perché la nostra apprensione? scientifica del mondo è necessariamente mediata da strumenti. Gli strumenti, a loro volta, sono materializzazioni di un vasto corpo di conoscenze e pratiche scientifiche (nel caso dell'*imaging* digitale tale sapere ha un carattere eminentemente matematico). Scienza e tecnologia, dunque, si costituiscono reciprocamente. A partire da queste considerazioni propongo un descrizione dell'*imaging* medico in termini di fenomenotecnica, utilizzando tale concetto come parola chiave attorno alla quale riorganizzare le idee discusse in precedenza. In primo luogo ricorro al concetto di fenomenotecnica per spiegare come le immagini diagnostiche mediano l'esperienza sensoriale e intellettuale del medico. Successivamente descrivo le immagini diagnostiche in termini di fenomeni artificiali (riconfigurazione visiva di segnali non visivi) che funzionano come simulazioni del corpo del paziente e che materializzano ambiti della conoscenza differenti (dalla medicina alla fisica, passando per l'ingegneria). Infine, mostro che la significazione corretta ed efficace di un'immagine diagnostica richiede una fenomenotecnica dell'osservatore. Per riconoscere i segni di malattia in un'immagine dell'interno del corpo è necessario padroneggiare le regole

implicite ed esplicite che permettono di dare senso al nuovo dominio sensoriale prodotto dalla tecnologia. Ciò implica un abbandono dei modi spontanei di percezione-significazione e il passaggio attraverso un processo educativo che modula le capacità percettive. L'osservatore specializzato è un osservatore che ha preso parte a un processo di formazione che trasforma profondamente la visione naturale, inserendo l'atto del guardare all'interno di una vasta rete epistemica che include conoscenze teoriche e pratiche concrete.

Parole chiave: epistemologia; *imaging* medico; fotografia; radiografia; storia della medicina; teoria dell'immagine.

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Introduction

Since its initial proposal, this dissertation has gone through a deep reformulation of both the object of study and the method of investigation. Developed within the context of an interdisciplinary research project called Image in Science and Art,[1] my early ideas for a doctoral thesis revolved around the artistic use of medical imaging technologies. The objective was to understand how medical imaging has transformed our perception and first-person experience of the inner body, both at an individual and social level. The main question was to understand if our experience of the body changes, once we can look inside it without having to cut it open. Do we relate differently to our own body, and to the bodies of other people, if we perceive them as potentially transparent rather than ineluctably opaque? The working hypothesis was that the study of artworks related to medical imaging technologies could provide valuable insights into such problems. The rationale underlying this approach was that, as expression of an individual, artworks can help disentangling questions related to body visualization and personal identity. At the same time, as cultural objects, they can be used as instruments of analysis to explore social notions of body and technology.[2] Thus, the initial research plan did not focus on medical images *per se*, but rather on the meanings these images acquire outside the medical setting. It concerned the first-person perception of the inner body mediated by images, rather than the epistemology of medical imaging.[3]

[1]The FCT research project Image in Science and Art (PTDC/EAT/64201/2006), directed by Prof. Olga Pombo, began in 2007 and ended in 2011 with the exhibition "CorpoImagem. Representações do Corpo na Ciência e na Arte", held in February and March 2011 in Lisbon, at the Pavilhão do Conhecimento-Ciência Viva.

[2]See Coulombe, 2006.

[3]In the first year or so of my doctoral research, I attempted a comprehensive survey of the artists who work with medical imaging. The task proved unattainable, but nevertheless it was possible to outline a general view of the multiple ways whereby visual artists encapsulate medical imaging in their work, both at the conceptual and formal level. The results of this early phase of the research were published in the article "Inside the body: Medical imaging and visual arts" (Di Marco, 2012a), and in a chapter of the book *Representações do Corpo na Ciência e na Arte* (Azevedo Tavares, 2012) published within the context of the aforementioned FCT research project. Both texts are in the Appendix attached in electronic format to this dissertation.

The change of conceptual focus derived from the need to extricate and clarify the multiple meanings that tend to grow around medical images. In fact, if an image arises not only different interpretations, but also different emotions,[4] it is because it is inherently ambiguous. In order to unravel the origins of this ambiguity, it was necessary to understand the material and conceptual genesis of medical imaging. That is, it was necessary to understand how such images are produced and endowed with meaning in their native context, clinical medicine. In the course of my research this historical, conceptual, and epistemological analysis became the central object of the dissertation. In other words, an inquiry into the extra-medical meaning of medical imaging morphed into a study on its epistemology. More precisely, it morphed into a study that aims at clarifying the relationship between the images produced by medical imaging technologies and the body they make visible.

Before saying more about the questions approached in this dissertation and the methodology employed, it is important to clarify what is meant by medical imaging. The term medical imaging refers to a vast array of images and imaging technologies developed since the end of the nineteenth century to provide indirect visual access to the inner organs (morphological imaging), and to some physiological or molecular processes (functional imaging). The first of such technologies was radiography, invented by the German physicist Wilhelm Roentgen in 1895. Since then, a number of different imaging modalities have emerged, and they have completely redefined the visibility of the interior of the living body. Nowadays Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and ultrasound scanning allow visualizing inner structures with astonishing detail, while Positron Emission Tomography (PET) and functional MRI (fMRI) allow visualizing the metabolic activity of different biological tissues, including the brain. Medical imaging is generally used for diagnostic aims. However, it can also serve research purposes, as in the case of neuroimaging in cognitive science, or rather mundane goals, as in the case of fetal ultrasound, which is routinely performed not only to check the health conditions of the fetus, but also to let parents enjoy the experience of seeing their prospective baby on the screen.[5] In my study I focus on the diagnostic use of medical imaging. This is

[4]The art historian and image theorist James Elkins remarks that, unlike other scientific images, which can be strictly informational, medical images tend to show vestiges of expressive meaning, because they can evoke questions of life and death, gender and sexuality, pleasure and pain. See Elkins, 1995, 556.

[5]See Chudleigh, 1999; Mitchell, 2001; van Dijck, 2005, Ch. 6. Fetal sonograms are particularly interesting images, from both an epistemological and sociological perspective. Before the introduction of ultrasound scanning for pregnancy monitoring, the presence of the unborn could be felt only by the pregnant woman. Since it has become visible, however, the fetus has acquired a new status. On the one hand, it has become an object of study, as well as a medical subject (fetal medicine). On the other hand, it has acquired a new identity and individuality,

why I will often use the expression diagnostic images. I also employ the designations mechanical images, radiological images, and medical images as loose synonyms, even though, strictly speaking, the term medical images encompasses a much larger domain of images, including, for instance, anatomical drawings.

A peculiarity of medical imaging is that the images it creates seem to render the body transparent. Intuitively, we think that the medical relevance of diagnostic images depends on the fact that they are faithful representations of the inner body, but, as soon as we set out to study them in terms of diagnostic instruments and, more generally, in terms of cognitive objects, we come across a number of problems: What do these images represent, *exactly*? And how do they represent? Do they work by mimesis? If we do not know how their referent looks like, how can we trust their representational value? Are these images portraits of the inner body? Or are they maps? If they are portraits, are they the portrait of someone (a person) or of something (a disease)?

These questions, present already in the first version of my doctoral project, turned out to be much more difficult to answer than I had initially assumed. In fact, although there are several works on medical imaging from the perspective of cultural studies[6] and anthropology,[7] very little has been published about medical imaging epistemology. Indeed, unlike historians and sociologists, philosophers of science have traditionally neglected images and, until relatively recently, in both continental and analytic philosophy the reflection on visual representation has been a preserve of aesthetics and art theory.[8] For what concerns the specific domain of medical imaging, the philosophers of science who have paid attention to this topic have typically focused on the use of neuroimaging in cognitive science and, to a lesser extent, psychiatry.[9] However, to the best of my

entering as a silent actor into a set of relationships between medical practitioners, parents and society. The effects of this transformation on the creation of a new social and juridical subject has been widely investigated by sociological and anthropological literature. Feminist authors, in particular, have repeatedly analyzed the role of fetal scans in the increased medicalization and commercialization of pregnancy, in the strengthening of ideologies of good motherhood, in the creation of the fetus as an autonomous individual independent from the mother's body, and in the debates surrounding abortion. See, for instance, Petchesky, 1987; Duden, 1993; Taylor, 1998 and 2008; Morgan and Michaels, 1999; Morgan, 2009; Roberts, 2012.

[6]See Zwijnenberger and van de Vall, 2009; van Dijck, 2005; Natale, 2008, 2011, 2012; Stephens, 2012.

[7]See 2004; Radstake, 2009; Müller-Rostock, 2009; Estival, 2009, 2010.

[8]This situation has been changing over the last decade. See, for instance, Pombo and Di Marco, 2010; Pombo and Gerner, 2010; Carusi, 2011, 2012. In the analytic tradition see French, 2003; Perini, 2005ab, 2006, 2012.

[9]See Kosslyn, 1999; Bogen, 2002; Taraborelli, 2003; Roskies, 2007; Huber, 2009; Huber and Huber, 2009, Mole and Klein, 2010; Klein, 2010. Even in the book *Medical Imaging and Philosophy. Challenges, Reflections and Actions* (Fangerau *et al.*, 2012), all the articles that deal with epistemology refer to neuroimaging.

knowledge, virtually nothing has been published on the philosophy of medical imaging as a diagnostic instrument.[10]

Objectives and methodology The main objective of this dissertation is to contribute to the development of an epistemology of medical imaging. My central thesis is that medical imaging does not merely produce more or less accurate pictures of the inner body, it rather turns the body into a scientific object by transforming its very visibility. Simultaneously it aims at reducing illness to a visual entity. Medical imaging does not simply make visible the inner organs, it actually presents the body in such a way that it becomes possible to extract relevant diagnostic information from it. This is why I maintain that the images produced by medical imaging technologies are more akin to simulations than to portraits. The imaging apparatus turns the body into a visual object that can be observed under experimental conditions: unlike the real body, it can be filed, retrieved, shared, measured and manipulated in several ways.

This thesis is accompanied by two others: first, diagnostic images, as all scientific images, are actual cognitive instruments. They are epistemic objects inscribed within theoretical contexts and experimental practices. Second, an image of the inner body has diagnostic meaning and value only in the scope of a specific conceptualization of the body and disease. This means that, in order to put forward an epistemology of medical imaging, to develop a theory of technology-mediated images and technology-mediated perception is not enough. One must also clarify the medical concepts and practices that provide the substratum for the whole process of production and signification of diagnostic images.

Medical imaging is to be understood both as an imaging technology and as a diagnostic practice, hence, as an object of philosophical analysis it must be approached from different perspectives. For this reason in my research I resorted to literature from a variety of disciplinary fields, such as image theory, semiotics, history and philosophy of medicine, and history and philosophy of science. The aim was to put forward an epistemology of medical imaging that accounts for the *poietic* rather than *mimetic* nature of visual representation, as well as for the fact that through medical imaging the human body is embedded

[10] An exception is the doctoral dissertation *Signal into Vision: Medical Imaging as Instrumentally Aided Perception*, defended by Nola Semczyszyn at the University of British Columbia in 2010. Drawing mostly on analytic philosophy of art and perception, Semczyszyn appeals to theories of pictorial representation to explain how medical imaging represents and how we access its content. I refer to her work in Chapter 5, Section 5.2.2. Overton *et al.*, 2011, focuses on the problem of the relation between diagnostic images and verbal language, and the creation of ontologies associated to software tools to improve communication among radiologists, other health professionals, and patients.

into an empirical apparatus, which encompasses medical instruments, medical knowledge, and clinical practices.

For what concerns the methodology, I relied chiefly on historical and conceptual analysis. On the one hand, I studied the genesis, development and transformation of concepts such as disease and diagnosis; on the other hand, I critically applied philosophical concepts developed by different authors to problematize and examine my objects of research (e.g., the production of mechanical images and the visualization of the invisible). The study of original scientific documents, such as medical treatises and medical journals' articles was indispensable for understanding how medical imaging has progressively imposed itself as a fundamental diagnostic method, and how illness has become a visual object. Thus, I relied on documents' analysis to unravel how the diagnostic meaning of images was generated in the scope of actual scientific and clinical practices and debates. The emphasis on material scientific practices was reinforced, whenever possible, by resorting to literature from laboratory ethnology and anthropology.[11] Also, since this work is about images, I devoted much attention to the iconographic apparatus of the documents I examined, employing iconographic and semiotic analysis.

As mentioned above, given the multifaceted nature of the epistemological problems posed by medical imaging, I had to draw on concepts and ideas developed by a variety of thinkers. In particular, I follow Charles Sanders Peirce's truth-value theory of photography to better understand how mechanically produced images were conceptualized in the nineteenth and early-twentieth centuries.[12] Moreover, I resort to his semiotics, in particular his classification of signs into indices, icons and symbols, to develop a tool for semiotic analysis that I employ at various points of the dissertation to investigate the processes of signification of different kinds of instrument-generated images that visualize invisible referents (from microphotographs to radiographs and PET scans).

I explore at length the idea that optical media such as photography and cinema are prostheses that enrich and transform our sensorial experience through Walter Benjamin's notion of optical unconscious. Benjamin remarked that photography and cinema allow for manipulations of space and time that are precluded to natural perception. Consequently, these imaging technologies endow us with enhanced mechanical senses that allow exploring completely new facets

[11] See Chapter 4, Section 4.2.3, and Chapter 5, Section 5.2.3.

[12] In my study I payed much attention to photography because when radiography appeared, at the turn of the nineteenth century, it was perceived as a particular kind of photography. Hence, to understand how radiography was conceptualized, it is necessary to look at the photographic practices and theories of the time.

of nature.[13] I combine the concept of optical unconscious with Peirce's semiotics to discuss the problem of the invisible referent, that is, the question of how we can make sense of images that are meant to visualize invisible phenomena. Besides the idea of optical unconscious, two other aspects of Benjamin's reflection on photography and cinema proved fruitful for my investigation on medical imaging. One is his seminal discussion of the cognitive effects of the mechanical reproduction of images; the second is his account of the objectifying nature of photography, which he compares to the dissecting activity of the surgeon. I draw on his considerations on these subjects to elaborate an account of the role played by photographic series in creating a new clinical gaze, and to reflect upon the role played by photography and radiography in turning the human body into a scientific object.

The idea of mechanical objectivity, developed by the historians Lorraine Daston and Peter Galison,[14] offers me the opportunity to engage with the problems of image realism and objectivity through polemical reasoning. These authors developed an articulated taxonomy of scientific images aimed at demonstrating the historical character of objectivity, which should be considered one of the many epistemic ideals that can drive scientific work in different historical periods. Mechanical objectivity, they argue, has been the main epistemic ideal between the 1830s and the 1920s. It prescribed the strenuous suppression of the subjectivity of the image makers, and put harsh limitations on image interpretation, too. In order to refute this account of what it means for an image to be objective, and to clarify what sort of photographic realism was embraced by the scientists of the late-nineteenth and early-twentieth centuries, I develop a number of arguments concerning the relationship between objectivity and intersubjectivity, as well as between mechanically produced images and imagination. Similarly, Daston and Galison's characterization of virtual and haptic images gives me the opportunity to critically delve into the problem of the embodied and material dimension of scientific images' production and fruition.

A concept I came across in a late phase of my research is Gaston Bachelard's "phenomenotechnique."[15] Bachelard developed the idea of phenomenotechnique to account for the fact that, in advanced physics and chemistry, scientific entities (e.g., the Zeeman effect, perfect crystals, atomic isotopes) are not found

[13] See Benjamin, 1939, 266.

[14] The historiographic work of Daston and Galison is guided by strong epistemological assumptions. Indeed, together with the philosopher Ian Hacking, they are considered among the most prominent exponent of so-called historical epistemology, an approach to the study of scientific knowledge that emphasized the historical development of scientific concepts and objects, as well as of scientific disciplines and styles of reasoning. See Hacking; 2002, Kusch, 2011; Sturm, 2011.

[15] Bachelard, 1931, 18.

in nature ready made. They must be produced in the laboratory as technical phenomena. They are the materialization of mathematical rationality or, as Bachelard put it, of a mathematical noumenon. In other words, through phenomenotechnique, science creates its own phenomena in a process of progressive rationalization of the real. Through this process science leaves behind the world as it is understood by commonsensical experience and received mental habits, and sets free "a surrationalism that will multiply the occasions for thinking."[16] If rigorously interpreted, the notion of phenomenotechnique cannot be applied to medical imaging and diagnostic images, for reasons I discuss in detail in the dissertation. Yet, the analysis of this concept offered me an additional stimulus for thinking medical imaging. In fact, not only it provides specific insights for reflecting on contemporary medical imaging, wherein mathematical algorithms for image acquisition and reconstruction play a fundamental role; more importantly, it works as an organizing concept, which helps bring together and refine the different ideas and intuitions developed in the various steps of my research.

Plan of the dissertation The dissertation begins with an analysis of the historical and conceptual conditions of possibility of medical imaging. By outlining an archaeology of radiography, I will try to understand what medical theories and practices had to be at work in the nineteenth century, for a technology that produced shadow-images of the inner body to be perceived and employed as a diagnostic instrument. I will suggest that when radiography appeared, at the turn of the twentieth century, it engendered less a theoretical than a technological revolution, because its diagnostic relevance was grounded in the conceptualization of body, disease and diagnosis put forward by clinical anatomy at the end of the eighteenth century. Following Michel Foucault's *The Birth of the Clinic*, I will maintain that it was with the work of the French clinicians Xavier Bichat and Jean-Nicolas Corvisart that diagnosis became a matter of eliciting signs from the inner body and that *visibility* became a fundamental epistemological and perceptual category of medicine.[17] I will also defend the idea that the stethoscope, invented by Théophile Laennec in 1816, was the material and intellectual predecessor of radiography, because it introduced a primitive form of mediated perception in medical diagnosis, and allowed the clinician to explore from the outside the inner body of the living patient, extracting signs of disease.[18] In the course of the nineteenth century, several ways of understanding

[16]Bachelard, 1936, 7, my translation.

[17]See Foucault, 1963, 166.

[18]The stethoscope is used to auscultate the patient. Auscultation is a basic clinical examination. It consists of listening to the sounds produced by the heart and by the air that circulates in the respiratory organs.

the functioning of the body and the ontology of disease emerged. I will show that these theoretical transformations went hand in hand with the development of different instruments, from the microscope to the sphygmograph, which visualized different aspects of both the morphology and physiology of the human body. Each of these instruments fulfilled specific diagnostic aims and posed distinct epistemological problems, but all of them shared some commonalities: they were meant to replace the subjective sensations of patients and doctors with objective indices of health and disease; they created visual records of the inner body that could be filed, retrieved and shared among physicians; they required the development of a specialized language agreed upon by a community of experts; they created a progressive physical separation between the body of the patient and the body of the physician. It was in this framework of medical ideas and practices that X-ray imaging appeared and progressively acquired its diagnostic function.

In the second chapter I examine the early developments of medical photography in order to understand how the first technology for the production of mechanical images entered the domain of medicine. Although photography is not considered a diagnostic instrument proper, it is important to explain how it influenced the way doctors looked at the patient's body and visualized disease. The main theoretical references in this chapter are Peirce's semiotics and Benjamin's reflections on the optical unconscious, the mechanical production and reproduction of images, and the intrinsic analytic and dissecting potential of photography and cinema. Drawing on these authors, and analyzing the works of early physicians-photographers in psychiatry, dermatology, neurology and physiology, I will show that the photographic series collected in medical journals, manuals and hospital archives, produced a new visibility of the patient's body by creating an updated version of the Foucauldian clinical gaze. According to Foucault, the clinical gaze was born in the hospital wards, because that was the place were the individual body of each patient became a public and visible body that could be compared to many others, finding out similarities and differences that helped organizing a variety of signs, symptoms and anatomical lesions into nosological categories. I will argue that the photographic collection allowed to replicate this sensorial experience and cognitive operation from a distance. I will also demonstrate that the photographic series was part of a larger experimental apparatus, which encompassed the patient, the camera and the observer, and whose aim was to turn the body and disease into visual objects, available for scientific analysis.

In the third chapter I discuss the problem of the invisible referent, that is, I analyze the processes whereby photographs that reveal invisible phenomena are endowed with meaning. This is likely to be the fundamental problem of all scientific images. When the referent of a picture is invisible, the iconic mode of signification fails, because in this case the image produced by the mechanical or electronic apparatus does not look like anything we already know, it resembles nothing. So, how do we know that the object we see in the photograph – e.g., a cell or a tubercular lesion – is *really* there and does *really* look like that? Drawing on the conceptual analysis developed in the previous chapter, I will defend the idea that the visualization of the invisible entails a peculiar combination of the indexical, iconic and symbolic modes of signification. My reasoning is built in opposition to Lorraine Daston and Peter Galison's idea of mechanical objectivity.[19] According to Daston and Galison, for the scientists of the nineteenth century, photographs were unerring records of reality. Consequently, the researcher should restrain from any intervention during image production, avoid any subjective interpretation, and let the image speak for itself. This aim was purportedly reached by endorsing strict procedural protocols in the different phases of production and publication of scientific photographs. I will show, however, that the notion of mechanical objectivity is a caricature of the actual ideas and practices developed by the scientists of the nineteenth century to deal with the problem of the visualization of the invisible. The argument will be articulated in three moments, corresponding to the analysis of how the problem of objectivity and image signification was managed by scientists who worked with microphotography, chronophotography, and radiography.

In the fourth chapter I argue that images are cognitive tools and that representation is never an act of mechanical repetition, it always entails a creative component. As in the previous chapter, part of my discourse is built in contrast with Daston and Galison, challenging their claims concerning the passive nature of representation. For these authors, scientific images can be classified in three categories: traditional, virtual and haptic images. Traditional images are all those images that cannot be manipulated on a computer screen; virtual images are digital images associated to computer algorithms for image manipulation; while haptic images are images whose production requires the actual manipulation of the object during the imaging process (for Daston and Galison, this definition only applies to nanoimages). Traditional images, they say, are mere *re-presentations* of the world, because they are "focused on copying what already exists,"[20] while virtual and haptic images are *presentations*, because they display their objects in ever changing ways. Accordingly, traditional images work

[19]See Daston and Galison, 1992, 2007.
[20]Daston and Galison, 2007, 383.

as "evidences," while virtual and haptic images are "tools."[21] I will criticize this classification of scientific images with historical and theoretical arguments. From the historical point of view, I will show that at least since the sixteenth century there have been attempts to create images that can be actually manipulated by the observer, resorting to paper flaps that can be lifted revealing different layers of a representation. From the theoretical perspective, I will draw on a variety of literature spanning from art theory to neuroscience, to demonstrate that the very notion of a passive representation is unsustainable, because images always engage the observer in an embodied act of perception, which elicits not only visual, but also tactile sensations and motor reactions. Moreover, I will argue that Daston and Galison's emphasis on nanoimaging is misleading. In fact, even when they do not reach the peaks of technological sophistication that characterizes nanoimages, scientific images are the result of some manipulation of the natural object they represent. A scientific image cannot be an automated copy of nature, because it is part of an experimental praxis, whose goal is to learn something about natural phenomena, not just to reproduce them. This position will be further corroborated by the analysis of actual scientific practices of image signification, taking into account written documents (semiotic analysis of a radiology article) and material practices (laboratory ethnography).

In the last chapter, I wrap-up the different arguments discussed throughout the dissertation, and apply them to contemporary medical imaging. I do so by first analyzing and subsequently re-elaborating Bachelard's concept of phenomenotechnique. As already mentioned, the idea of phenomenotechnique cannot be applied to medical imaging in rigorous terms. However, there are two characterizing elements of this concept that provide important insights for a philosophy of technology and, consequently, for an epistemology of medical imaging. The first is the idea that in order to study a natural phenomenon, scientists must previously re-create it as a scientific phenomenon, and this requires the creation of artificial objects. The second, strictly related to the former, is that scientific experience is by necessity mediated, and such mediation has both an intellectual and material character. This means that the development of scientific instruments and technologies is not a second-order product of science, but rather part and parcel of the scientific process. Technology is embedded into science, because our scientific grasping of the world is necessarily mediated by instruments; scientific instruments, in turn, are materializations of a vast body of scientific knowledge and practices (in the case of digital imaging this knowledge has an eminently mathematical character). In other words, science and technology are reciprocally constituted. On these grounds I will propose a description

[21] Daston and Galison, 2007, 385.

of medical imaging in terms of phenomenotechnique, using this concept as a key-word around which to reorganize the ideas previously discussed. Firstly, I will resort to the concept of phenomenotechnique to gain insights into how diagnostic images mediate the physician's sensory and intellectual experience. Secondly, I will give an account of diagnostic images as artificial phenomena (visual reconfigurations of non-visual signals) that work as simulations of the patient's body, and that reify different domains of knowledge (from medicine to physics and engineering). Finally, I will argue that the proper and efficient signification of a diagnostic image requires what I call a "phenomenotechnique of the observer." To recognize the signs of disease in an image of the inner body, one has to master the explicit and implicit rules necessary to make sense of the novel sensory domain produced by the technological apparatus. This implies abandoning spontaneous modes of perception and signification to engage in a process of educated perception. The idea that we only recognize what we know and that we need to know in order to see is a truism in both contemporary psychology of vision and philosophy of science, and the relevance of education in shaping the scientist's ability to see has been acknowledged and discussed by philosophers as diverse as Karl Popper and Thomas Kuhn. The idea of a "phenomenotechnique of the observer," however, helps stressing some specific features of the education of vision related to the medical use of machine-mediated images, and I will use it as a conceptual tool to analyze the complex and extended epistemic network that envelops diagnostic images and makes them intelligible.

To unravel this extended epistemic network is a necessary precondition for understanding the tendency of diagnostic images to produce a proliferation of meanings that span beyond the clinical domain. The images produced by medical imaging technologies are open to multiple processes of signification because of their inherent complexity, and they are complex because they embody multiple domains of knowledge, because they alter the visibility of the body, and because they invite the beholder to abandon or rethink ingrained habits of visual perception.

Chapter 1

Disease and diagnosis in the 19th century

Within the history of medicine, radiography and its cognate visualization technologies (e.g., ultrasound imaging, Computed Tomography, Magnetic Resonance Imaging, Positron Emission Tomography) stand at the crossing of perceptive and cognitive strategies developed to deal with two different problems. The problem of representing the inner body as an object of scientific knowledge (thus, a universal object), and the problem of accessing the body in order to diagnose a specific ailment of an idiosyncratic individual. While the first endeavor dates back at least to 3000 BC,[1] the second became a major concern for physicians only in the early-nineteenth century, and went hand in hand with a profound redefinition of the concepts of disease and diagnosis. Additionally, within the history of diagnostic techniques – which is strictly related to the history of the concept of disease – diagnostic images blend together two complementary strategies for accessing the inner body: (1) the indirect (mediated) collection of invisible signs from internal organs, made possible by instruments like the stethoscope and the sphygmograph, and (2) the direct visual access to the inner body through optical devices, like the vaginal *speculum* and the laryngoscope, which exploit natural corporeal orifices (endoscopy). We can say that diagnostic images combine (1) and (2) because they provide an *indirect visual access* to the inner body, based on the collection of invisible signs from the internal organs. More precisely, they are visual representations based on non-visual (or non-optical) properties of the inner body.[2]

[1]See Cazort et al., 1996; Cosmacini, 1997.

[2]I will elaborate on the issue of the visual-mimetic configuration of non-visual data in Chapter 5, where I give some details on the physical processes underlying the production of different diagnostic images. For the moment it is enough to recall that while natural vision and analog photography depend on the absorption and reflection of electromagnetic waves in the frequency of visible light by the surface of the objects (optical property), an imaging

This means that, if we are to develop an epistemology of diagnostic images, we cannot limit our analysis to the problems of visual representation, but we have to consider medical imaging as part of a wider group of tools (or technologies) used to *extract information* from the healthy and the diseased body. Moreover, we have to understand which concepts of disease and body underlaid the use of such tools and were, in turn, reinforced by them. That is to say, we should try to disentangle the reciprocal shaping of ideas, natural objects, and instruments.

It is widely recognized that the introduction of radiography in clinical practice marked a major turning point in the history of medicine. According to the historian of medicine Stanley Reiser, it opened a new visual era in medical practice. For Reiser, medical imaging "changed the ways patients and doctors experienced illness [...] and caused medicine to see its task and itself differently."[3] Similarly, in her much quoted book *Screening the Body*, visual studies scholar Lisa Cartwright claims that radiography accomplished "a quite literal disintegration of the body,"[4] which transformed the way illness is perceived by both medical practitioners and patients. Indeed, unlike the majority of medical innovations developed during the nineteenth century, from the stethoscope to the germ theory, X-ray images exerted an almost immediate impact on medical practice. To understand this phenomenon, stressed by many historians of medicine, it is important to emphasize that radiography neither acquired its epistemic relevance in a void, nor redefined the notion of disease and the (medical) representation of the body out of nothing. Quite the contrary.

In this chapter I defend the view that for what concerns the domain of medical diagnosis, radiographic techniques entailed less an epistemological revolution than a technological one, since its primary diagnostic relevance is anchored to the conception of body and disease (localizationist paradigm) put forward by clinical anatomy, at the dawn of the nineteenth century. Moreover, radiography enriched the armamentarium of research and diagnostic techniques developed during the nineteenth century in order to transform medicine from *ars curandi* into a full-fledged empirical science, on the model of physics and chemistry. This entailed the reorganization of the concepts of body and disease around facts and basic units that could be measured and compared. Accordingly, it became necessary to produce objective representations of the body, through instruments that

process like radiography exploits the electromagnetic waves in the frequency of X-rays and their differential absorption by the internal and external structures of our bodies (non-optical property). If the skin absorbed the X-rays like the bones do, or if all the inner bodily structures had the same opacity to X-rays, then it would be impossible to see into the body by means of a radiograph.

[3]Reiser, 2009, 14.

[4]Cartwright, 1995, 108.

could bypass both the patient and the doctor's sensorial limitation and subjectivity, in formats that could be shared among different observers, in different places and times. Since a specific sensible perception and rationality had developed during the century, medicine was ready to immediately take on radiography when it appeared in 1895. There is no doubt that since then medical imaging has gone a long way, yet, I think that many of the conceptual problems put forward by ultrasound imaging, Computed Tomography (CT), Magnetic Resonance Imaging, (MRI) and Positron Emission Tomography (PET) are rooted in the nineteenth century's attempt to produce a new, specific *expressivity* of the body. That is, to force it (or to allow it) to express its forms, motions, first constituents, and ailments clearly and unmistakably.

1.1 From symptoms to lesions

In the text "L'élaboration du diagnostic," Peitzman and Maulitz describe the making of a diagnosis as a complex process of "divination" [*divination*]. The doctor has the task to put some order in the confusion of signs and symptoms manifested by the patient, with the aim of answering the complex question: "What is wrong with this person?" This requires the implementation of a number of "cognitive and methodological negotiations." Such negotiations occur within the constraints of the biological information and technical resources available at any given historical moment, as well as on the basis of cultural preferences and of the unstable notion of disease. A notion that, as Peitzman and Maulitz say, is "formulated and reformulated, framed and reframed [...] [t]hrough a dynamic and tireless play between reality, taxonomy and technique, between what is *to be seen*, what we *see*, and what we *see with*."[5] In the case of radiography, what is *to be seen* is a lesion, a nodule, a proliferation of cells within an organic tissue; what we *see* is a shadow of the lesion or of the nodule, what we *see with* is the radiographic apparatus and the trained eye. Hence, in the case of radiography what is to be seen largely depends on the notion of disease put forward by clinical anatomy. For this reason, before turning to medical technology (what we *see with*) it is necessary to expound some fundamental concepts of clinical anatomy, because it was against the background of these concepts that the first diagnostic technologies acquired their meaning.

Clinical anatomy emerged at the dawn of the nineteenth century, through what Michel Foucault, in his seminal *The Birth of the Clinic*, has described as a mutual redefinition of Morgagni's pathological anatomy, dating back to 1761,

[5] Peitzman and Maulitz, 1999, 169.

and of the clinical method that had been developed in French hospitals during the second half of the eighteenth century.[6] Clinical anatomy actually succeeded in bringing together two conflicting, but ultimately complementary, forms of knowledge. The clinical method, characterized by "a neutral gaze directed upon manifestations, frequencies, and chronologies, concerned with linking up symptoms and grasping their language," and pathological anatomy, which located diseases in the "mute, intemporal bodies"[7] of the corpses. Based on the interpretation of signs and symptoms, clinical medicine was at its origins a discursive, analytic practice pertaining to the domain of history. On the contrary, pathological anatomy was interested in forms, colors, and positions. It belonged to geography.[8] The redefinition of the clinic into clinical anatomy required the materialization of symptoms and signs into anatomical lesions, while for pathological anatomy it was a matter of integrating the logic of the taxonomy of disease (nosology) and pathology's evolution into the tangible space of the inner body. As Xavier Bichat famously wrote in his *Anatomie générale appliquée à la physiologie et à la medicine*, of 1801:

> You may take notes, for twenty years, from morning to night at the bedside of the sick [...] and all will be to you only a confusion of symptoms, which, not being united in one point, will necessarily present only a train of incoherent phenomena. Open a few bodies, this obscurity will soon disappear, which observation alone would never have been able to have dissipated.[9]

In this statement Bichat summed up the longstanding problem of traditional clinic of organizing symptoms – primary sensorial data collected at the bedside – into a coherent and reliable body of knowledge, linking them to a concrete, observable entity. He followed the path of the founder of pathological anatomy, Giovanni Battista Morgagni, who in 1761 published the treatise *De sedibus et causis morborum per anatomen indagatis.* It was a five volumes work containing hundreds of case histories supported by autopsy findings, which aimed at correlating symptoms with organs' structural alterations. The idea to associate organic lesions to disease symptoms was quite groundbreaking because, at the time, the organic lesions found while dissecting a cadaver were considered an effect of death (decomposition) rather than a cause of the disease. Morgagni agreed with his colleagues that the forces initiating the illness resided outside of the body, but he thought that organic lesions were the effect of a chain of events initiated by such forces, and at the same time the proximate cause that

[6]See Foucault, 1963, 122ff.
[7]Foucault, 1963, 126.
[8]See Foucault, 1963, 126.
[9]Bichat, 1801, vol. 1, 60.

determined the actual manifestation of the illness within the patient's body.[10] His treatise was praised by his contemporaries, but it had scant influence on medical thought and practice of the time. On the one hand, there was clinicians' traditional distrust of anatomy;[11] on the other hand, with its emphasis on organs and lesions, Morgagni's approach could not be easily integrated into the nosological systems of the eighteenth century, still based on the Hippocratic vision of the body as an integrated whole. Although by the middle of the century the doctrine of humors was loosing its strength, challenged by new physiological theories mostly based on the circulatory or the nervous systems, the actual space in which the disease manifested itself was the living individual, not an organ or a body part.[12] Within this cognitive framework, lesions that merely pinpointed the effect of disease on the organs conveyed little information. In order to be assimilated into the clinical thought, a new vision of clinical medicine and a new conceptualization of the anatomical lesion had to be put forward. These epistemological ruptures took place in the French hospitals in the years after the Revolution.

A redefinition of bodies and places According to medical historian W.F. Bynum, the *annus mirabilis* for modern medicine was 1794, with the institution of the new *écoles de santé* in Paris, Montpellier and Strasbourg.[13] In these new schools, which integrated medical education into a single system, all students were trained both in medicine and surgery. The immediate objective of this measure was to ensure that the army medical professionals could deal with wounds, infections and fevers alike, but it also had an extremely important consequence on medical thinking, because, as Bynum states:

> It taught generations of students to conceptualize disease as surgeons would: in terms of anatomic structures, the solid parts, local lesions. This systematic integration created the ambiance for the emphasis on pathology, physical diagnosis, and clinico-pathological correlation, which are the hallmarks of hospital medicine.[14]

[10]See Reiser, 1978, 16-25; Grmek, 1999, 148-149. Like the famous clinicians of his time, François Boissier de Sauvages and William Cullen, Morgagni refused to speculate on the ultimate causes of pathologic phenomena, but unlike them he opted for topographical ordering (*a capitem ad calcem*, from the head to the lower extremities) rather than Linnaean nosology. See Bynum, 1994, 30-31.

[11]For Thomas Sydenham it diverted physicians' attention form diligent patient's observation and recollection of the disease history; for Boissier de Sauvages, who actually performed many autopsies, *post mortem* lesions were too variable and unstable to provide reliable knowledge.

[12]See Bynum, 1994, 29-31.

[13]This new system of medical education was consolidated in 1803 with Georges Cabanis' hospitals reform.

[14]Bynum, 1994, 26.

Bynum's claim that surgery played a seminal role in laying the foundations of clinical anatomy is corroborated by the fact that both Xavier Bichat and Jean-Nicolas Corvisart, the pioneers of clinical anatomy, had been surgeons before turning to medicine.[15] And their disciple Théophile Laennec, who systematized a fundamental part of clinical anatomy's nosology, in the preface to the second edition of his seminal *Traité de l'auscultation médiate* (1826), explicitly wrote: "For what concerns diagnostics, I made an effort to put internal organic lesions at the same level of surgical ailments."[16]

However, Foucault defends that the epistemic rupture entailed by the medical reforms of the Revolution was caused not so much by the approximation of medicine and surgery, as by the reorganization of hospitals into clinics, where medical care, research and education merged.[17] In the wards of the clinic, the gaze of the doctor could easily pass from one body to the other. It was no more a medicine of the individual, articulated with a private practice, but a medicine that could and would compare individuals, in a public space. In this new context clinical observation became "a gaze of the concrete sensibility, a gaze that travels from body to body, and whose trajectory is situated in the space of sensible manifestation."[18]

The hospital became the *locus* of proper medical knowledge, because it was the place where all the phenomena that compose the disease (signs, symptoms, and anatomical lesions) could be observed by an all encompassing eye. On the one hand, the hospital provided a "dense concentration of diseased humanity"[19] that allowed comparing different medical cases, an activity that simultaneously required and promoted the introduction of probabilistic thinking in medicine.[20] On the other hand, hospitals provided systematic and easy access to the cadavers, immediately after decease, and this allowed performing more rigorous autop-

[15]Educated under the *ancient régime* (thus before the medical teaching reforms), they had been two of the most distinguished pupils of the surgeon Pierre-Joseph Desault, who trained his students at the Hôtel Dieu. Besides perfoming surgical interventions, Desault's students had to take care of patients in the hospital wards and keep accurate medical records. See Bynum, 1994, 8-9.

[16]Laennec, 1826, vol. 1, xxv.

[17]As charity institutions financed by the rich, the hospitals rested on the liberal principle according to which by paying for the poor to be sheltered an treated, the rich was also making possible and advancement of medical knowledge whereby he himself could one day take advantage. The hospital, Foucault says, was an ambiguous domain "open to the indifference of experiment," where pain could become a spectacle "by virtue of a subtle right that resides in the fact that no one is alone, the poor man less so than others, since he can obtain assistance only through the mediation of the rich." Foucault, 1963, 83-84. In the hospital of the late-eighteenth century, the poor literally paid for his life with his body. In fact, the admission to the hospital implicitly entailed that physicians had the living and dead body at their disposal.

[18]Foucault, 1963, 120.

[19]Bynum, 1994, 43.

[20]See Foucault, 1963, 97-98.

sies to keep track of organic lesions. Within the physical and conceptual space of the hospital it became possible for Bichat to renew pathological anatomy. It also became possible for Corvisart to envisage a medical practice in which the systematic analysis of the symptoms that could be observed in the patient went hand in hand with the active elicitation of physical signs through percussion.[21] At the same time, both symptoms and physical signs could be checked through autopsy. Hospitals became the place were medical knowledge was actively produced. Indeed, the historian and philosopher of medicine Mirko Grmek remarks that although in the early-nineteenth century hospitals changed from asylums for the paupers and all sorts of "deviants" into actual medical places, they were less "health factories" than "factories for teaching and learning," due to the relative impotence of the therapeutics of the time.[22]

Both Bichat and Corvisart had a clinical concept of disease: they related the disease (the manifestation of a typical train of symptoms) with the organic lesions, but they did not identify the former with the latter, because symptoms were the very "essence" of the disease.[23] Accordingly, making a diagnosis was to recognize a specific configuration of symptomatic phenomena. Bichat's endeavor was a nosological one, but he introduced two elements that proved fundamental for the development of clinical anatomy: (1) he selected the tissue as the primitive unit of pathological analysis; (2) he re-conceptualized the relationship between life, death, and disease, so that it became possible to track the dynamic history of an illness in the fixed geography of the corpse.

The tissue, a new unit of analysis The choice of the histological structure as the basic functional unit resulted from the need to connect function and morphology, and was related to the observation that we find the same kind of tissue in different organs and that, in turn, each organ is composed by different tissues. As a consequence, the tissue can work simultaneously as the unifying structure of the organism and the analytic unit that makes possible to establish general pathological categories. It is an ubiquitous element that presents a certain range of variations. As Foucault puts it: "In his *Traité des membranes*, Bichat imposes a diagonal reading of the body carried out according to expanses of anatomical resemblances that traverse the organs, envelop them, divide them, compose and decompose them, analyze them, and, at the same time, *bind them*

[21] Percussion is a technique for physical examination which consists of eliciting sounds from the patient's thorax by hitting his or her back with a finger.

[22] Grmek, 1999, 148-149.

[23] Grmek, 1999, 148.

together."[24] Bichat understood organs as histological "functional folds,"[25] consequently, both their characteristics (morphological and functional), and their disorders could be described through the combination of a limited set of properties. This methodological choice allowed a more refined analysis compared to the organ-based pathological anatomy of Morgagni. Moreover, while Morgagni had associated the notion of lesion with that of effect produced by the external forces that caused illness, for Bichat it became an ordering criterion, "the point from which the pathological organization radiates."[26] A site along which one could observe the organization of the disease, a spatial entity, rather than a temporal one. Importantly, disease was no longer conceptualized as an external event that would strike the body wherever possible letting its marks, it was the body itself that became ill because it underwent a process of degeneration, a sort of death within life.[27]

This new conception of disease transformed the conceptualization of the cadaver as source of medical knowledge and influenced the way of understanding the relation between death, life, and disease. Foucault contrasts the traditional conception of death with that put forward by Bichat. In the medicine of the eighteenth century, he says, death was the limit that erased both life and illness: in the cadaver the traces of death and disease melted in an "indecipherable disorder." Pathological anatomy, as a "technique of the corpse," had to put order in that disorder, defining a more rigorous, instrumental notion of death.[28] At first, an elementary solution to this problem was offered by the very organization of the hospitals. Here, in fact, it was possible to perform autopsies right after the decease, when the traces of illness had not been confounded yet by the grossest effects of death (organic decomposition).[29] Besides, taking up an idea of the British anatomist John Hunter (1728-1793), Bichat made an important distinction between phenomena connected with the disease itself, and phenomena related to the relatively autonomous process leading to death (mortification). This meant that death was not an absolute endpoint, but rather a multiple process distributed both in the time (the duration of life) and the space of the body. Death itself could be the object of an analysis of chronological events (sensorial extinction, slowing down of brain activity, and so on) organized into a specific spatial distribution along the relay of heart, lungs and brain.[30] In practical terms it implied the difficult but not impossible task of

[24]Foucault, 1963, 129.
[25]Foucault, 1963, 128.
[26]Foucault, 1963, 140.
[27]See Foucault, 1963, 153-156. See also Cosmacini, 1997, 329.
[28]Foucault, 1963, 141.
[29]See Foucault, 1963, 141.
[30]See Foucault, 1963, 142.

comparing the cadavers of people dead from different causes, in order to find out which events were common and appeared in the same order, and which were variable. Once its specific mechanisms and processes were defined, death could no longer be considered a confounder of disease. Foucault remarks: "The system of functional dependencies and normal or pathological interactions [was] also illuminated by the detailed analysis of these deaths." It could be recognized, for example, that while lung failure immediately affects the heart, cerebral disturbances have no such direct effect. Thus, death became an instrument that "act[ed] as a point of view on the pathological, and makes it possible to fix its forms and stages." It could no longer be conceived of "as a screen (functional or temporal) separating it from the disease, but as a spontaneous experimental situation providing access to the very truth of the disease, and to its different chronological phases."[31]

From surface phenomena to underlying lesions With Bichat, organs became an heterogeneous and yet ordered surface. Death was divested of its meaning of absolute closure and became an instrument of empirical knowledge. But if disease is a manifestation of the continuous death of tissues, then superficial phenomena (signs and symptoms) are no longer all there is to know about a disease, nor its privileged indicators. Signs and symptoms acquire a new meaning in that they point to a lesion concealed in the depth of the body. It is here that the passage from *clinical medicine* to *clinical anatomy* occurred. In this new theoretical framework, making a diagnosis was no longer (or not only) a matter of connecting symptoms, it became reasonable to elicit bodily signs that could denounce an underlying lesion. Diagnosis became a matter of probing the interior of the body, and the perceptual and epistemological structure of medicine became that of an "*invisible visibility.*"[32]

In this new perceptual and epistemological structure, which is still with us today, the exploration of the inner body as a source of diagnostic information acquired a meaning it could not have had before. The recognition of the disease was no longer a matter of organizing its visible manifestations, but rather of taking to the surface hidden phenomena, to let them express themselves. Therefore, the doctor had to actively stimulate or even fabricate the signs that pointed to the disease.[33] This opened the way to physical examination (also called objective examination), and to a vast range of diagnostic technologies. As pointed out by Grmek, while pathological anatomy was meant to *explain*

[31]Foucault, 1963, 143.
[32]Foucault, 1963, 166, italics in the original.
[33]See Foucault, 1963, 162.

the diseases, clinical anatomy was meant to *diagnose* them. The making of a diagnosis in the context of clinical anatomy became an inductive process carried out on the grounds of a semiology of vision, touch and hearing. The doctor had now to "guess" the state of the inner organs, a state that could be directly observed only *post mortem*. In Grmek's words: "[With clinical anatomy] medical diagnosis becomes hypothetical: it states the probability of a specific lesion, often not accessible to observation. It is a sort of indirect pathological anatomy, performed on the living and without dissection."[34]

1.2 In search of hidden signs of disease

In the same years in which Bichat founded modern pathological anatomy, taking on and transforming the work of Morgagni, Corvisart retrieved and made sense of percussion. This technique for physical examination, developed in 1761 by the Austrian physician Leopold Auenbrugger, consisted in actively eliciting sounds from the patient's chest by hitting it with a finger. According to the quality of the pitch, a trained ear could recognize, for example, the presence of an accumulation of fluid in the lungs or around the heart, or a consolidation of the pulmonary tissue. As Reiser explains:

> For Auenbrugger the morbid sound *he elicited from the body*, not the patient's thoughts or his physical appearance, was the most dependable index of the nature and course of chest disease. [...] He advocated a technique that removed the personality and physical appearance of the patient from their earlier central place in the evaluation of illness. [...] Just as Morgagni concentrated on identifying disease-produced alteration of internal structures in the dead body, Auenbrugger searched for such altered structures in the living. The two men were equally concerned with finding *objective evidence of disease*, and both were convinced that understanding the relation of a specific structural change to a specific illness was the key to learning medicine.[35].

Thus, some forty years ahead of its time, Auenbrugger's method contained a quite radical conceptual transformation, because it implicitly posited a direct link between the anatomical lesion and the disease. Moreover, it implied that subjective symptoms and visible signs where no longer to be considered the cornerstones of diagnosis: if the origin of the lesion lied inside the body, then the physician had to actively evoke some sort of perceptible manifestation from the inner organs. However, as in the case of Morgagni's pathological anatomy, in the middle of the eighteenth century clinicians could not make much sense

[34] Grmek, 1999, 151.
[35] Reiser, 1978, 20.

of a technique that pointed to some hypothetical and hidden manifestation of disease. At the time of its invention (which, has it happens, occurred in the same year as the publication of Morgagni's *De Sedibus*), percussion went largely unnoticed, and although the prominent clinician William Cullen mentioned it, he did so only to dismiss it.[36]

Now, in the new, localizationist medical framework that took shape within the French clinic, percussion acquired new relevance. In 1808 Corvisart translated Auenbrugger's synthetic pamphlet *Inventum novum ex percussione thoracis* in an annotated version. He added detailed descriptions of the quality of the sounds generated by percussion and the related anatomical lesions that he observed at the autopsy. Corvisart, like Bichat, still identified disease with a set of symptoms, not with an anatomical lesion. As explained by Foucault, he used the lesion to *confirm* the symptoms, not to predict them.[37] However, he explicitly brought into medical practice the idea that the physician should actively elicit signs of disease from the patient's body. Within this new method, the search for signs of the disease required that the doctor transformed auditory patterns into spatial (i.e., visual) analogues that matched a hypothetical histological lesion. In the rise of the anatomo-clinical school, physicians used percussion to produce sounds from the inner body, and these signs provided indirect evidence on the condition of the organs. The semeiotic art of perceiving and interpreting sounds was re-defined, improved, and systematized by Laennec, with the invention of the stethoscope and the publication of the monumental *Traité de l'auscultation médiate.*

1.2.1 Laennec's stethoscope: mechanical mediation begins

Invented in 1816, the stethoscope was basically a wooden cylinder with a longitudinal hollow core: the doctor placed one top on the patient thorax and put his ear to the other end. In this way sound waves are transmitted better, and noises coming from the patient's body become, at least in principle, more easily discernible for the physician. Technically, mediated auscultation (i.e., auscultation by means of a stethoscope) differs from percussion in that it does not imply an active elicitation of sounds from the patient body, and it requires the interposition of an instrument between the patient and the doctor's sensorial organs. Like in percussion, however, the rationale for using the stethoscope as a diagnostic instrument is that of associating specific sounds to mental images

[36] See Bynum, 1994, 35.
[37] See Foucault, 1963, 135.

that hypothetically point to actual organic lesions, which in turn correspond to a disease.

The idea of a sort of synaesthesis between hearing and vision is patent in the instrument name (from the Greek *stèthos*, chest and *skopèo*, I see), and the metaphor of vision was recurrent in the medical literature between 1820 and 1850, when the idea of "seeing" a disease by listening through the stethoscope was largely endorsed by the promotors of mediated auscultation. "We anatomise by auscultation (if I may say so), while the patient is yet alive," wrote one physician, and in the preface to the first English translation of Laennec's treatise, John Forbes claimed: "[auscultation] is a window in the breast through which we can see the precise state of things within."[38] This confidence in the scopic powers of the stethoscope was backed by the studies of Laennec, which had shown a close correspondence between the sounds coming from the chest of hundreds of diseased individuals, and the lesions revealed by their autopsies (Figure 1.1).

As his teachers Bichat and Corvisart, Laennec studied and worked in an *hôpital géneral*, where he had access to the dissecting rooms and to many seriously ill patients, those paupers who "offered" their bodies to science in exchange for a shelter and basic care. Dividing his time between the hospital lanes and the morgue, he could systematically examine a vast number of cases. In 1819, he published the first edition of the *Traîté de l'auscultation mediate*, where he painstakingly described the characteristics of the sounds he perceived by auscultation and their relations to the damaged tissues he observed *post mortem*. Remarkably, his descriptions of clinical cases covered not only the different stages of a disease, but also the variations observed in people with different physical makeups. In the introduction to the *Traîté*, he claimed:

> The diseases of the thoracic viscera are very numerous and diversified, and yet have almost all the same class of symptoms [cough, dyspnea, expectoration]. The consequence is, that the most skillful physician who trusts to the pulse and general symptoms, is often deceived in regard to the most common and best known complaints of this cavity.[39]

Laennec's critique of the diagnostic method based on general symptoms was not contingent on the idiosyncrasies of chest anatomy and ailments. It mirrored that seminal concept of clinical anatomy, according to which diseases cannot be understood and defined through transient symptoms that disappear as soon as the vital functions come to a stop. They should rather be understood and defined through the recurrent lesions observed in cadavers. This idea was expounded by G.L. Bayle (colleague of Laennec and disciples of Bichat and Corvisart) in

[38]Both authors are quoted in Reiser, 1978, 30.
[39]Laennec, 1826, 2.

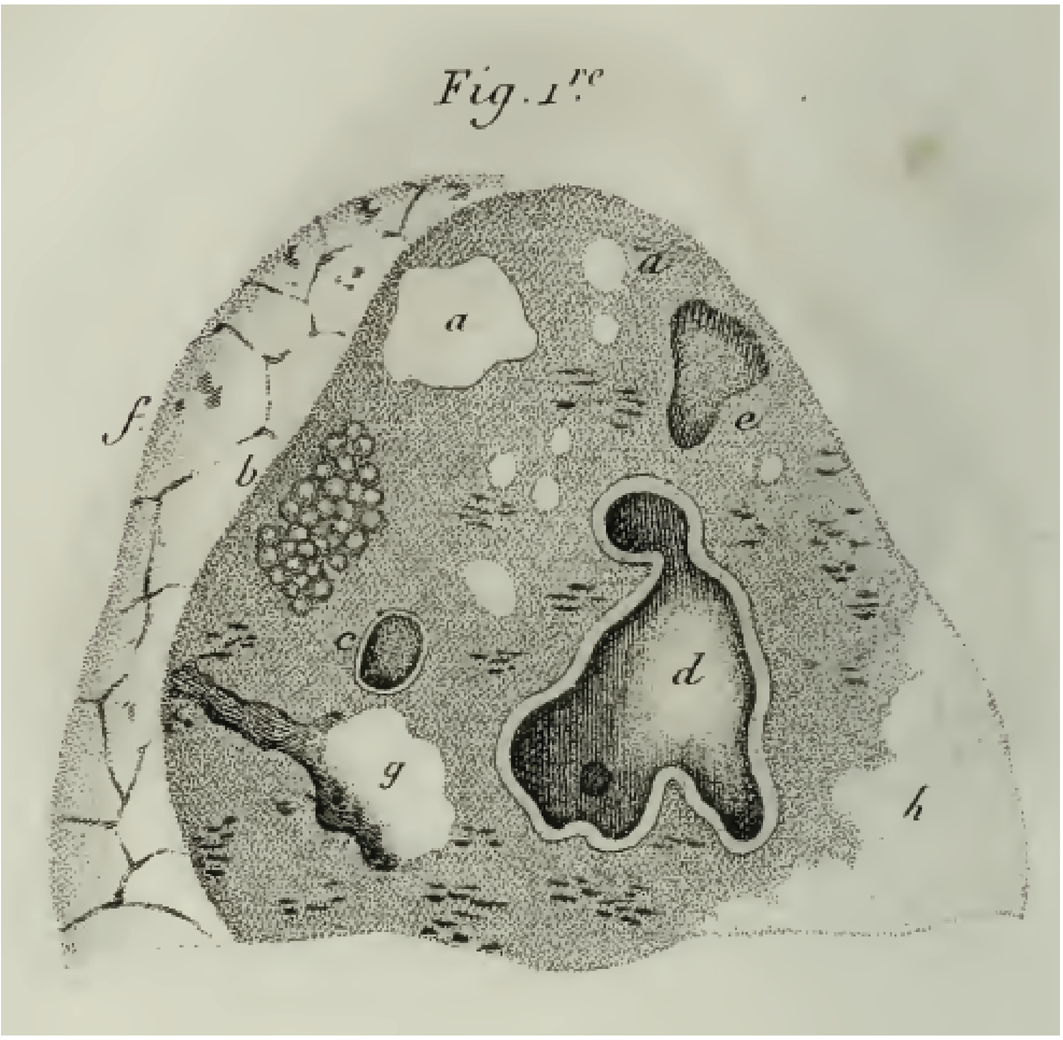

Figure 1.1: Figure representing different forms of tubercular matter and some of its effects. (a) Developed tubercle, completely yellow; (b) group of early tubercles, whose exterior is still grey and semi-transparent; (c) small cartilaginous cyst which contained tubercular matter and that discharged its content due to its own softening; (d) tubercular excavation completely empty and covered by two membranes [...]; (e) Small tubercular excavation completely empty and uncovered; (f) part of the external surface of the lung; (g) partially softened and empty tubercle; (h) tubercular infiltration starting from the pulmonary tissue. T. Laennec, *Traité de l'auscultation mediate*, 2nd Edition, 1826, Paris, Plate II, Fig. 2. Original caption, my translation. Public domain.

his doctoral thesis in 1802. In a text published a few years laterBayle wrote: “individuals must be regarded as phthisic who are neither feverous, nor thin, nor suffering from purulent expectoration; it is enough that the lungs should be affected by a lesion that tends to disorganize and ulcerate them; phthisis is simply that lesion.”[40] It was through the works of Laennec and Bayle that phthisis ceased to be “phthisis,” that is, a condition defined by manifest symptoms of consumption, and became “tuberculosis,” which consists in the presence of “tubercles” (characteristic lesions) in the lungs or in other organs, for example, the bones or the kidneys.[41] This transformation was not accomplished overnight. The words phthisis and consumption were still in use in medical literature at the end of the nineteenth century, which is an evidence of how long it can take for radical changes to be accepted by the medical community and integrated into daily practice. That notwithstanding, a new direction for medicine was set.

An epistemological rupture With the invention of the stethoscope and with the publication of the *Traité de l’auscultation mediate* (in particular, the second edition of 1826), the conceptualization of disease as organic lesion became operative, because it had a proper diagnostic instrument and its nosology. This is why medical historian Giorgio Cosmacini has called the stethoscope a “philosophic instrument, connected to an epistemological rupture.”[42] Cosmacini also stresses the fact that since the stethoscope was the first diagnostic instrument of general use “it transformed the practice of medicine, helped changing doctors’ perception of illness, and inaugurated a tendency to widen the distance between doctor and patient, introducing between them the first, rudimental technological apparatus.”[43] This transformation was by no means an anodyne process, and it triggered a heated debate. The medical community did not consensually accept it, neither in the academic circles nor in actual medical practice. On the one hand, there were Laennec’s supporters (mostly out of France), who considered mediated auscultation not only an extremely valuable diagnostic tool, but also an indispensable instrument for transforming medicine into an empirical science, in which causal connections could be verified through laboratory evidences (in this case the laboratory was the morgue), and whose precision was comparable

[40] Bayle, 1810, 8-9, quoted in Foucault, 1963, 138-139.

[41] According to Grmek, the official “birth certificate” of the modern anatomo-clinical concept of disease is to be found in G.L. Bayle’s doctoral thesis and in the second edition of Laennec’s treatise, organized according to the anatomo-clinical definition of the chest ailments. Grmek, 1999, 150.

[42] Cosmacini, 1997, 329, my translation.

[43] Cosmacini, 1997, 329, my translation.

to that "attainable in some of the higher branches of physics."[44] These doctors, as their mentor Laennec, were generally highly dismissive of patient's narrative, considered untrustworthy and of little clinical (hence, medical *tout court*) relevance. On the other hand, there were physicians who dismissed the stethoscope, considering it a quite useless, if not ridiculous, instrument. Many other practitioners, even if less interested in general medical theory, could simply make no sense of auscultation. Transforming into a diagnosis ephemeral sounds – that Laennec and his successors had subdivided in endless tones – was no easy task, and to rely on usual techniques as patient's story, observation and manual inspection of the chest seemed far more secure.[45] Furthermore, even among doctors who appreciated the method of auscultation, there were many who found mediated auscultation difficult to perform, and felt that they would be better off with the naked ear, rather than the stethoscope. Indeed, it was not clear if the stethoscope actually improved the reception of sounds from the chest.

Instrument-mediated perception In the second edition of his treatise Laennec himself recognized that for doctors who had little experience with the instrument, direct auscultation might be easier and more fruitful. He nevertheless advocated the superiority of the mediated technique, and his arguments were of different orders: moral, practical, and medical. For what concerns the moral aspect, Laennec observed that: "[Immediate auscultation] is always inconvenient both to the physician and patient; in the case of females it is not only indelicate but often impracticable; and in that class of persons found in hospitals it is disgusting."[46] Concerning the practical reasons, he specified that there are points of the body where it is impossible to apply the ear directly (e.g., on the axilla, or under the female breast), and that the strong pressure on the chest required by the application of the naked ear for immediate auscultation is uncomfortable for the patient and thus "gives rise to extraneous sounds from the contraction of the muscles."[47] Finally, he briefly expounded the medical argument:

> Moreover, some of *the most important of the stethoscopic signs have for one of their causes the stethoscope itself*. Thus, perfect pectoriloquism, which consists in the transmission of the voice through the tube of the instrument, is changed, in the trial of immediate auscultation, into a simple resonance, stronger no doubt than in the natural condition of the parts, but such as to be with difficulty discriminated from oegophonism and bronchophonism. For these and other reasons I do not hesitate

[44]J. Taylor, Introductory lecture on the opening of the medical session of 1841-1842 in University College, quoted in Reiser, 1978, 30.

[45]See Cosmacini, 1997, 327-331.

[46]Laennec, 1826, 4.

[47]Laennec, 1826, 26.

> to affirm, that the physicians who shall confine themselves to immediate auscultation, will never acquire great certainty in diagnosis, and will every now and then fall into serious mistakes.[48]

Hence, Laennec claimed that the stethoscope itself was one of the *causes* of the most important signs of disease that could be perceived through it. Does this mean that he believed that the stethoscope *created* the signs of disease (and, eventually, the disease itself)? No. What Laennec was saying is that "perfect pectoriloquism" – a specific sign that the pulmonary texture around the main excavation had undergone considerable condensation accompanied by the formation of further cavities – *was* "the transmission of the voice through the tube of the instrument," characterized by a specific clarity and intensity. Immediate auscultation (without the interposition of the stethoscope) would still reveal a thoracic resonance stronger than that one would hear if the organs were healthy. However, the quality of the perceived sound would not allow to discriminate perfect pectoriloquism from other signs such as oegophonism or bronchophonism, indicators of other specific forms of necrobiosis. Hence, the instrument caused the signs of disease to appear more clearly to the human senses, and in a more varied range of tones, thus allowing for finer distinctions. This means that it created finer audible patterns and a range of possible gnoseological constructs compatible with them.

According to the French physician and epistemologist François Dagognet, Laennec's invention was groundbreaking because it provided an instrument that, in spite of its simplicity, was able to convey valuable information not just about heart and lungs' anatomy but, more importantly, about their functionality. Through the stethoscope the trained doctor could "fix, on the basis of an uninterrupted natural language [of the chest], the place, the volume, the nature and the evolution of the disease."[49] However, Dagognet stresses that the stethoscope's translation of the natural language of the body was trustworthy only to the ear of those who were able to decode it.[50] Well before the diffusion of photography and the invention of radiography, the stethoscope introduced in medicine the question of instrument-mediated perception and mediated observation. Inventing the stethoscope, using it and making sense of it, were activities that implied different forms and different levels of mediation. In the first place, doctors had to agree that mediated experience was as valuable as (if not more valuable than) direct experience. They should trust the instrument and believe that it gave access to some information relevant for the diagnosis. Moreover, since medicine is meant to be a relationship between a doctor and a patient,

[48]Laennec, 1826, 26-27.
[49]Dagognet, 1986, 100, my translation.
[50]See Dagognet, 1986, 100.

turning the stethoscope into a full-fledged medical tool also implied that patients recognized the authority of the instrument in the hand of the doctor. This meant that the patient too, and not only the practitioner, had to believe that the signs collected by the physician through this new medium – signs which the patient himself could not perceive – were as truthful as the symptoms he or she could actually feel and display.

The stethoscope as a *medium*

I will elaborate on the concept of mediation from different perspectives in the development of this thesis. Here I just want to begin to introduce the problem and make some preliminary remarks on the basis of what I consider the most salient features of mediated auscultation.

1. In auscultation (mediated or immediate) sounds from the inner body are taken as valid proxies of the disease. Through a quite complex and articulate cognitive process, the doctor converts thoracic sounds in mental images that match the anatomical lesions revealed by pathological anatomy, which, in turn, coincide with a certain disease. Hence, the sound perceived by the doctor becomes a *medium* of the condition of the patient's internal organs and tissues. It is a *medium* because it conveys indirect evidence of an invisible condition (in the specific case of tuberculosis, the presence of tubercles).

2. The stethoscope in itself transmits a range of tones (e.g., pectoriloquism, oegophonism, bronchophonism) that could not be perceived just by placing the ear right on the patient's body (they are the specific sound of breathing or voice passing through a wooden cilinder). It mediates the sensorial experience of the physician enhancing his or her hearing capabilities. That is, it is a *medium* between the auditive system of the doctor and the sounds emitted from within the body of the patient. Thus, the stethoscope is a differential transmitter (a go-between) of sounds produced by the inner organs.

3. Auscultation and the stethoscope are thinkable and epistemically sound within the localizationist paradigm of clinical anatomy, which entails that we accept the cadaver as a *medium* for the living, diseased body. In clinical anatomy, in fact, the dead body is considered more reliable than the living one in manifesting the signs of disease, since *post mortem* anatomical lesion are stable testimonies of the transient event of illness (with its related and overt symptoms) experienced by the patient. In other words, within the

localizationist paradigm of clinical anatomy the corpse becomes a *medium* of the living being in that it constitutes the material support of the signs, traces and marks of the disease.[51] In other words, it replaces the living body. It is a *medium* because it allows the pathologist to observe the inner body in all its details (as I will show in Chapter 3, with the invention of radiography X-ray images replaced the cadaver as *media* of the inner body, with the advantage of granting access to the interior of the living body).

4. Once the signs collected by the doctor become more relevant than the patient's transient and subjective symptoms in defining and diagnosing the disease, the very experience of illness becomes potentially mediated. In a sense, we can say that the doctor becomes the *medium* (and the oracle) of the patient's experience, that is, the doctor enters in contact with and gives voice to what happens inside the patient's body bypassing the patient himself.

In relation to this latter point, it could be objected that it has always been the case, since only the physician, and before him the priest and the magician, has the social authority to tell the patient what is going on within the sick (and the healthy) body. Before the institution of modern clinical diagnosis, however, the doctor had to rely exclusively on the patient's narrative, in addition to manifest bodily symptoms and signs, in order to establish what was going on with that specific person. Modern clinic did without the patient's story and symptoms, it diagnosed the disease before it could even manifest itself. Laennec praised the stethoscope of allowing "to detect or even to suspect, diseases in their very commencement,"[52] when the patient was not aware of them, yet.

Historians of medicine have reported that many patients were embarrassed, perplexed or even frightened by the stethoscopic examination. At the same time, most of them were amazed by the ability of the physician to tell what was happening inside the body from sounds inaudible to the patient himself.[53] This is why Dagognet locates in the stethoscope the beginning of a medicine that, in its ideal limit, will be without patient, without doctors and, paradoxically, without disease.[54] Without patient, because technology enables medicine to discover the disease independently from, or even in spite of, the confusion of subjective symptoms (most symptoms are unspecific, and some diseases are simply asymptomatic). This becomes possible because technology, even in the

[51]For a very interesting analysis of the body as material *medium* of inscription of different signs and images see Belting, 2001.
[52]Laennec, 1826, 3.
[53]See, Reiser, 1978, 36; Cosmacini, 1997, 329-330.
[54]See Dagognet, 1986, 100.

very primitive form of the stethoscope, forces the disease to come to the surface, making abstraction of the patient's lived experience. Without doctor, because the ideal diagnostic technology exposes so clearly the disease that no hypothetical inference is required. It speaks the "truth" of the disease and needs no potentially faulty interpretation. Without disease, because an ideal medicine catches the disease even before it appears, and diverts the natural course of pathological events.

1.3 Endoscopic visions

With the French school of clinical anatomy, physical diagnosis became a tenet of medical practice. Semeiotics, the search of signs of disease through percussion and auscultation was just one form of physical examination. The others were, and still are, anatomical exploration, performed through palpation or with endoscopic tools, and functional diagnosis. Anatomical exploration shares the localizationist paradigm of semeiotics, but implies a different kind of sensorial contact with the disease: the doctor can touch (through the skin) a swollen liver by palpating the abdomen, or see a polyp on the vocal cords by means of a laryngoscope.[55] Many endoscopic devices, which allowed looking literally into the body exploiting its natural orifices, were developed by surgeons during the nineteenth century.

Although archaeological testimonies show that anal and vaginal specula were already familiar to ancient Greek and Roman physicians, the first attempt to actually *illuminate* the inner organs was made by the German surgeon Philipp Bozzini, between 1804 and 1805. He officially presented his invention, which he called *Leichtleiter* (light conductor), to the Austrian Faculty of Medicine in Vienna, in 1806, raising harsh criticism and a heated controversy.[56] In his analysis of the origins of modern endoscopy, the historian of science Claudio Pogliano shows that the negative reaction to this new instrument was due to a number of reasons,[57] including different conceptions of the relative epistemic cogency of vision and touch. While Bozzini claimed that vision renders more certain even the touch of the most trained expert, and that "only seldom are the other senses prepared to dispense with its assistance,"[58] the director of the Vienna Faculty

[55]See Peitzman and Maulitz, 1999, 180.

[56]See Reiser, 1978, 51; Bynum, 2006, 169-170; Pogliano, 2011, 52.

[57]The *Leichtleiter* provided a good visualization of the pharynx and nasal cavities, but when employed in other orifices, the illuminated spot was too small to provide valuable information. In addition, it was very difficult to operate. Institutional factors also hampered Bozzin's invention: supported by the progressive *Josephsakademie*, it was harshly criticized by the more conservative Faculty of Medicine. See Pogliano, 2011, 57-58.

[58]Bozzini, quoted in Pogliano, 2011, 53.

of Medicine, who wrote a negative report on the *Leichtleiter*, maintained that, in order to receive the best treatment, "the patient should place his confidence in the judgement of a reasonable doctor and the *hand* of an experienced investigator."[59] It seems also reasonable to suppose that a technique which required not only to touch, but literally penetrate into the living body generated some moral discomfort both in doctors and patients (for the latter the discomfort was also physical, given that endoscopy is a very painful examination).

Touch *vs.* vision In spite of the institutional resistances, Bozzini's work paved the way for further research. First successes came in 1812, with Anthelme Récamier's vaginal speculum, and in 1822, with Pierre Ségalas' urethrocystoscope. However, the main developments occurred between the 1830s and the 1860s, when the otoscope, the urethroscope, the laryngoscope, and the ophtalmoscope appeared. And yet, even if endoscopy was making significant technical progresses, still in 1855, on occasion of a demonstration of the use of the urethroscope by his inventor, Antonin Jean Desormeaux, a former teacher of his commented: "One can see very well with your instrument, but what is there to see, really?"[60] Indeed, endoscopy was not unanimously accepted by French physicians. Pogliano mentions the criticisms of Félix Guyon, a prominent professor of urology in Paris, who repeatedly expressed his conviction that in most cases skilled touch coupled with clinical intuition would gather enough information without the aid of artificial devices. In his *Leçons cliniques sur les maladies des voies urinaires*, published in 1881, Guyon claimed that one should not consider a great progress in medicine the simple fact of being able to see something which until then had been usefully perceived by the sense of touch. Sight, he argued, will tell us nothing about the consistence and sensitivity of a constriction of the urinary tract, and it will say even less on its extension. Consequently, he warned his students that even if the techniques to illuminate the urethra and the bladder (endoscopy) would improve in the future, they could never do without the "endless resources of touch."[61] Guyon was suspicious of the mediation between doctor and patient (and between doctor and the signs of disease) introduced by the endoscope, with its systems of lenses and mirrors. His mistrust, however, was not so much about the instrument, but more substantially about the epistemic virtues of vision. In a time in which the confidence in the cognitive accountability of sight was gaining momentum, thanks also to the progressive diffusion of photography, he insisted on that sensorial experiences are

[59] Quoted in Pogliano, 2011, 57.
[60] Desormeaux, 1865, 8, my translation.
[61] Guyon, 1881, 625.

interchangeable only to a limited extent, and that certain information provided by the sense of touch (e.g., consistence and sensitivity of a section of an organ) could not be replaced by eyesight. He was ready to admit that in the human body only a few organs, or sections of organ, are available to direct touch, but he nevertheless stressed the fact that endoscopy could supersede haptic examination only in organs like the eye and the larynx, which could not be touched at will.[62]

Guyon's position did not pass the test of history, as the current developments in video-endoscopy definitely demonstrate. Not only has vision largely replaced the sense of touch in diagnosis, but also the development of telesurgery seems to prove that a whole reversibility of touch into sight is actually possible. However, we can take Guyon's reluctance about vision as a source of medical knowledge as an indicator of how complex was the process that led to the "dematerialization" of the body characteristic of modern medicine. Vision, we know, is the sense of distancing and objectivation par excellence, while touch is the sense of proximity, whereby the observer melts with the perceived object.[63] For Guyon, the very texture of the organ and its sensitivity were essential components of medical perception. According to him, touch granted a form of *direct* knowledge that vision, being physically removed from its object, could not entail. Yet, Desormeaux, who was also a surgeon, in his *De l'endoscope*, of 1865, praised vision unconditionally (he opened the book with a quotation from the fifth paradox in Cicero's *Paradoxa Stoicorum*: "Nosquoque oculos eruditus habemus"), and claimed that compared with the advancement of general pathology and of the clinical study of different organs, urology scored far behind, mostly because until the invention of the endoscope the urinary tract had been inaccessible to vision. He placed the endoscope among the means – which also included percussion and auscultation – that allowed medicine to explore human organs *directly*, by extending and perfecting the doctor's senses.[64] Clearly, two very different notions about what count as direct observation, and about the primacy of vision in the acquisition of medical knowledge were at stake.

1.3.1 The case of the ophtalmoscope

Within the domain of endoscopic devices, the case of the ophtalmoscope, designed in 1851 by Hermann Von Helmholtz, is particularly interesting, because unlike the other endoscopic tools, it did not need to be inserted into the human body. Almost fifty years before the discovery of X-rays, this invention enabled

[62]See Guyon, 1881, 621.
[63]I develop the topic of the relation between touch and vision in Chapter 4, Section 4.1.
[64]See Desormeaux, 1865, xi and 1-2.

physicians to visually explore a (small) part of the living inner body from the outside. Thanks to the ophtalmoscope, anatomical causes of eye's pathologies, which previously could be seen only in *post mortem* autopsy, became easily visible *in vivo*. Moreover, it did not simply allowed the visualization of the inner eye (retina, optic nerve head, and eye's arteries), but also proved valuable in the indirect diagnosis of diseases of the kidneys and arteries, as well as of some neurological conditions.[65] With this instrument, the physician could see both *in* and *through* the eye: *in*, because it became possible to actually look at the inner structures of the organ of vision; *through*, because on the basis of the alteration of some of these structures it was possible to infer the state of other parts and functions of the body.

As already noted in the case of Laennec and auscultation, an aspect of physical diagnosis particularly praised by physicians was the fact that it freed the diagnostician from patient's subjective testimony. In the case of the ophtalmoscope, for example, it became easier to diagnose astigmatism in persons who could not read.[66] To stress this point, Reiser quotes a physician who, on the occasion of a meeting of the American Medical Association, in 1894, wrote that the ophtalmoscope reduced the physician's dependence "on the faltering judgment of the untrained patient, substituting therefor the skill of the expert who, reasoning from scientific data, is thus able to fit glasses in less time and more accurately with consequent satisfaction to himself and his patient."[67] This sentence exemplifies quite well some fundamental ideas about the relationship between body, first-person experience, and knowledge that informs scientific medicine. In fact, if medicine is a science, then it requires a specialized knowledge and a specialized language developed within a community of peers, who collect, share, and elaborate scientific data (in this case the lesions or malformations revealed by the ophthalmoscope), and cannot rely on the imprecise words that a patient normally uses to describe the experience of illness. All the patient can do is to describe symptoms, but scientific medicine can track disease even before symptoms appear, and a great deal of its efficacy comes from this possibility. With the ophtalmoscope, for example, the nosology of eye diseases changed, because the instrument revealed a range of different lesions that could not even be imagined before. At the same time, both the prevalence (the total number of cases of disease in a given population at a specific time) and curability of these diseases were redefined.[68] In fact, if a disease can be detected in an early stage, before the patient can feel or display any clear symptom, its prevalence

[65] See Bynum, 2006, 169.
[66] See Reiser, 1978, 47.
[67] H.V. Wuerdemann, 1894, 341, quoted in Reiser, 1978, 49.
[68] See Bynum, 2006, 167.

will rise. Simultaneously, since many disorders incurable in their advanced stage can still be treated when discovered in their pre-symptomatic state, curability will improve. In turn, the prevalence of secondary diseases, that is disease associated with other pathological conditions, will decrease. Instrument creates new perceptions of the body that do not only reorganize medical knowledge creating new nosological entities, but also redefine the very meaning of being ill.

1.4 Looking into the microscopic body

A different way of accessing the inner human body, much less obvious than endoscopy, came from the microscope. With the improvement of the compound microscope[69] and the development of microtomes, cellular staining, and fixation methods, by the late nineteenth century the microscopic dimension entered the realm of diagnostic medicine in two very different areas: (1) cellular pathology, which entailed a refinement of clinical pathology; and (2) microbiology, which broke completely with clinical pathology and put forward a new conception of disease, rotted in the germ theory. While in the first case the microscope transformed the body into a jigsaw puzzle of minute interwoven pieces, in the second it turned the body into a porous and fluid entity, open to the attacks of external invisible pathogens.

1.4.1 Cellular pathology

Cellular pathology was first theorized in 1858 by the German pathologist Rudolf Virchow. With the help of the microscope and of histochemical analysis, Virchow demonstrated that cells found in diseased tissues were modifications of normal cellular types.[70] On these grounds he posited that it was the cell, and the disruption of its functions, the primary *locus* of disease. Consequently the work of microscopists – carried out in the laboratory, far away from the patient's body – became fundamental for studying these invisible units of life.[71] Virchow worked within the localizationist paradigm and considered his ideas the natural development of Morgagni, Bichat and Laennec's morphological views of the disease. However, he did not restrain his analysis to the structural changes of the impaired cell, but rather insisted on the importance of chemical and physical alterations. Although he believed that the organism's vital properties could not

[69]The first compound microscope was built in 1595, but the first scientific book on microscopy was Robert Hook's *Micrographia*, published in 1665. In the 1670s Anton Van Leeuwenhoek described sperm cells, bacteria and protozoa. Achromatic lenses (corrected for chromatic aberrations) became available only in the early nineteenth century.

[70]See Grmek, 1999, 155.

[71]See Reiser, 1978, 79.

be completely reduced to physics and chemistry, he nevertheless thought that living organisms function according to chemical and physical laws, and that on the basis of these laws it is possible to understand the mechanisms of disease. Bynum remarks:

> By urging doctors to think about disease in terms of cells, Virchow emphasized process rather than result. Looking at the cell behaviour in diseases placed the pathological centre-of-gravity towards the beginning, rather than at the end stages of a disease. [...] The anatomo-pathological definitions of many diseases remained pretty secure, but notions of cause and mechanisms also came to the fore. [...] The microscope as well as the dissecting scalpel became constant tools of the pathologist. Stains, microtomes, and fixation methods were developed, enabling thin sections of tissues to be cut and different kinds of cells to be more clearly differentiated.[72]

One of the most relevant practical outcomes of this new conceptual approach was that it became possible to discriminate malignant tumors from the benign ones, with enormous consequences in terms of prognosis and therapeutics (the surgeon would operate the tumor only if the pathologist declared it malignant). In turn, observing thin layers of tissue under the microscope became a specialized activity, and for the first time emerged the figure of a clinician who spent his time in the laboratory, rather than in the hospital wards, and made his diagnoses away from the bedside.

With Virchow, the cell became the ultimate morphological and functional unit of life, an idea that he summarized in the precept *omins cellula e cellula* (all cells come from cells). However, Grmek points out that even though he started from a localizationist assumption, Virchow had a dynamic view of the disease and the concept of *Krankheitsprozess* was a tenet of his thought. He explicitly maintained that the aim of pathology was to study vital activity under its deviations and hindrances. As his contemporary Claude Bernard, Virchow saw no intrinsic difference between health and disease, physiology and pathology, and his thought played a seminal role in the debate about the antinomies whole-part, solid-fluid, process-state, structure-function.[73] To him, the organism was a combination of cells, and disease was the sum and the result of cellular affections. It was inside the cell that the *ens morbi* resided, because the cell reacted in different ways to internal and external stimuli (physical and chemical) that could determine a pathological condition.[74] The *ens morbi*, the disease, was a possible state of the cell (Figure 1.2).

[72]Bynum, 2006, 121-122.
[73]See Grmek, 1999, 155.
[74]See Grmek, 1999, 155-156.

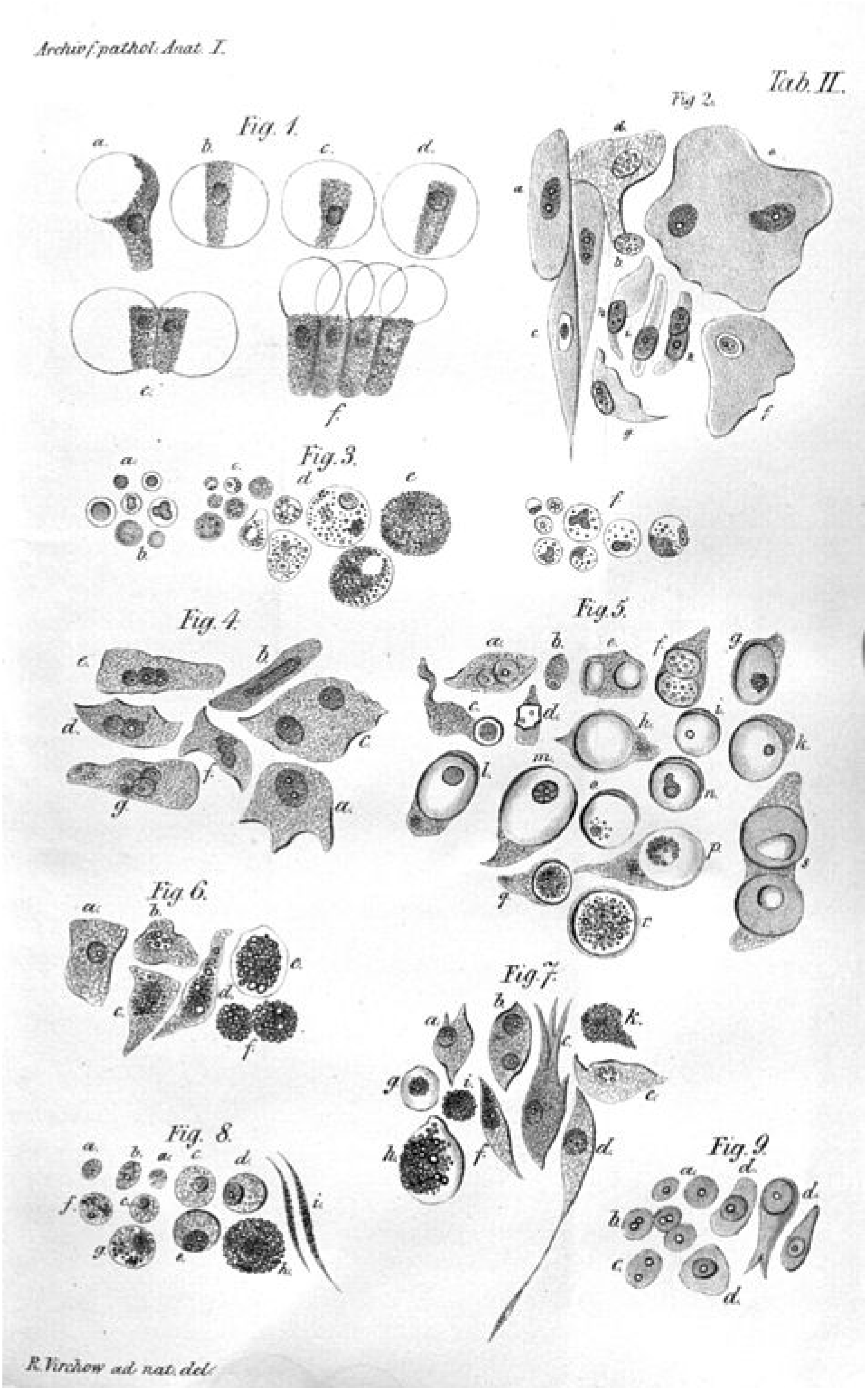

Figure 1.2: Illustration of Virchow's cell theory. *Archiv fur Pathologische Anatomie und Physiologie* (now *Virchows Archive*), 1847, first issue. Wikimedia Commons.

1.4.2 Microbiology

Microbiology and the related germ theory of disease gained momentum some twenty years after cellular pathology. It presented a quite different vision of disease and, consequently, of the body. While cellular pathology focused on the internal pathological process (pathogenesis), the germ theory was centered on the external causes (etiology) of disease, which was seen as the result of the interaction between two living beings, namely, a human being and a parasite. More precisely, at least according to Grmek, the germ theory of disease implied a biologic, non-anthropocentric vision of illness, in which "the infectious disease is nothing but a specific aspect of the food chain of organisms."[75]

Ideas about the existence of "atoms" of biological material that could transmit disease were already discussed in the sixteenth century,[76] but it was only in the second half on the nineteenth century, with the discoveries of Louis Pasteur and Robert Koch, that the microbial theory established itself as a complete medical doctrine and the microscope became an indispensable diagnostic tool. In particular, Koch's successes in isolating the bacteria responsible for cholera, anthrax and tuberculosis, in the 1880s, encouraged many clinicians to redefine the diagnostic process, identifying the micro-organism, with the diagnosis. For these doctors the disease acquired a specific ontological status, because the germ *was* the disease. Within the germ theory of disease, elusive cognitive clues like signs and symptoms were replaced by the certainty of the microbiological test. Tuberculosis was no more an illness specified by its characteristic symptoms (phthisis), nor a specific histological lesion revealed by auscultation and the histological examination (the tubercle), it was rather the infection provoked by Koch's bacillus (*Mycobacterium tuberculosis*). As a consequence of this redefinition, a number of apparently different ailments, like pulmonary phthisis, scrofula, and white tumor of the knee became particular forms of the same disease.[77] Diagnosis was made in the laboratory, growing colonies of bacteria on Petri dishes, staining them and observing them under the microscope. As in cellular pathology, which required the specialization of pathologists who cut, stained and analyzed histological samples, with the germ theory a new figure of clinician emerged: the specialist in bacteriology who could deal with cell cultures and microscopic images. A medical specialist who did not spend time at

[75] Grmek, 1999, 160.

[76] Girolamo Fracastoro published his *De contagione et contagiosis morbis* in 1546, and prior to Luis Pasteur's work on silkworm disease, in 1835-1836, Agostino Bassi had suggested that it was caused by the microorganism muscardine. Favus (a skin disease) and anthrax were known to have, respectively, different microbic origins. In 1840 Jacob Henle defended that many diseases were probably caused by a *contagium vivum* (living contagion). See Cosmacini, 2007, 232; Bynum, 1994, 128; Reiser, 1978, 78-79.

[77] See Grmek, 1999, 160.

the bedside of the patient, but rather examined little fragments of his or her body, or minuscule particles that infected it.

With the development of microscopy, the perception of the body mediated by mechanical instruments entered a new phase. The body could still be thought of as an ordered landscape of organs, but in order to reveal its constituting elements and expose the structure of cells, one should walk away from it and enter the laboratory, where an array of instruments and experimental techniques allowed the visualization of the invisible. In terms of perception of the human body, this implied recognizing that it was opaque not simply because its inner organs were concealed by the skin, but also because its very components as well as its parasites were extremely minute. An image of the body removed from any possible natural perception came to the fore.[78]

1.5 Functional anatomy: disease in numbers and graphs

In the same years in which Virchow developed cellular pathology, Claude Bernard was revolutionizing functional anatomy while creating experimental medicine. To him, function not structure was the key to understand the living body and disease was no more to be understood as a static entity (the anatomical lesion), but rather as the alteration of a process. Indeed, like Virchow, Claude Bernard thought that the difference between the physiological (normal) and the pathological state was of quantitative rather than qualitative order.[79] This meant that, as Cosmacini puts it: "function and disfunction, physiology and pathology constituted a graduated, measurable *continuum*."[80] Within this vision, the relation between tissue and disease was deeply transformed: the lesion of a tissue was irrelevant as far as it did not affect its function, while an impaired function did not necessarily lead to a structural alteration, even though it produced a state of disease.[81]

[78] I discuss in depth microscopic images and microscopic vision in Chapter 3, Section 3.2.

[79] See Grmek, 1999, 157. Grmek points out that before Bernard and Virchow, François Magéndie, Bernard's teacher, had already defended that pathology was physiology under special conditions.

[80] Cosmacini, 1997, 343, my translation. It should be noted that Bernard's conceptualization of disease as a mere quantitative modification of normal (healthy) states, has been criticized by Georges Canguilhem (1966) on both conceptual and empirical grounds.

[81] Anatomo-pathologists were already aware of this problem, and they tried to solve it by reducing the impaired process to an alteration of the structure. According to Laennec, the fact that some diseases did not present any clear morphological alteration did not mean that their origin was not anatomical, it barely meant that pathological anatomy was still an imperfect discipline and thus was not able to reveal all the possible anatomical alterations that could vex the human body. Nevertheless, for what concerns mental illnesses he was willing to accept

Now, while the description of structure implies the recourse to space only, the description of a process entails space and time, thus requiring different research methods and instruments. Moreover, if pathology differs from the healthy state by degree, and not by some fixed property, then measuring quantities becomes important both for understanding disease and for making diagnoses. For medical research, the second half of the nineteenth century was the time of Bernard's experimental pathology, with his laboratory experiments on living animals, and of Etienne-Jules Marey's graphic method, which included studies on blood circulation (with the sphygmograph) as well as on animal locomotion (with the invention of chronophotography and instant diagrams).[82] Accordingly, in the domain of medical practice, it was the time in which new diagnostic strategies were developed. They were based on graphic and quantitative methods, and their aim was to record such elusive data as breathing, blood pressure, heartbeat or temperature. As noted by Reiser, in this renewed epistemic context, "the statement of the body's vivifying activities in numbers and graphs provided a factual transcription of pathology equivalent to the discovery of an anatomical lesion."[83] In clinical anatomy the corpse was intended to be the *medium* that made visible the disease located in the tissues and organs; in physiology a new form of visibility was put forward: graphs were perceived as faithful inscription of vital functions, and numbers were taken as exact quantifications of vital parameters.

Although clinical anatomy and physiology were very different endeavors – they looked at different things using different methods, different languages and different images – they shared the same goal, namely providing a good representation of the state of health of a human body. Bichat and his disciples, thanks to the concept of disease as death within life, were able to track the continuum life-disease-death fixing the transient history of the illness in the secure geography of the corpse. Bernard and the other physiologists, working on the continuum between the normal and the pathological could bracket death, and re-conceptualize the disease as a range of possible vital states. While the anatomists had been forced to come to terms with the geography and history of the dying tissue, physiologists needed to come to terms with the quantities and degrees of the functions of the body, in order to capture them in their pathological state. The solution to this problem was to measure functions and fix them

that the lesion could directly concern the vital principle, and consequently could never be observed. See Grmek, 1991, 151.

[82]Claude Bernard published the two volumes of his *Léçons de physiologie expérimentale appliquée à la medicine* between 1855 and 1856; Etienne-Jules Marey published *La méthode graphique dans les sciences expérimentales, et principalement em physiologie et medicine* in 1878.

[83]Reiser, 1978, 91.

in numbers and graphs. Instruments as the spirometer, the thermometer, the sphygmometer and the sphygmograph gradually entered the diagnostic toolbox.

1.5.1 The spirometer

One of the first attempts to make "a numerical portrait"[84] of the patient was made in the 1840s by John Hutchinson, an English surgeon, with the invention of the spirometer (Figure 1.3). This device measures lungs capacity on a graduate scale, thus transforming the process of breathing into a precise and visible quantity.[85]

Hutchinson tested his instrument on more than 2,000 individuals (26 women), most of whom were healthy, and in 1846 published a monograph where he presented his results organized in charts and tables, putting in relation lungs' vital capacity,[86] age, height, weight and profession (Figures 1.4 and 1.5). He reached the conclusion that his quantitative method not only detected lung diseases at an earlier stage than auscultation or percussion, but was also a reliable instrument for judging men's overall physical fitness. Just like Laennec had praised the exactitude of the stethoscope, Hutchinson claimed: "When all these [quantitative] observations are made, and noted in a book properly headed, *the state of the person examined is then expressed in the unerring measure of figures – which immediately presents to the eye a certain state of things*."[87] Yet, in spite of Hutchinson's confidence, it took many years before the spirometer became part of respiratory medicine's routine.[88]

As the other vital indexes, lungs' vital capacity is basically a statistical indicator, that is, it acquires clinical meaning only by comparing the data concerning the members of a population with specific characteristics. Now, for integrating a statistical index into medical practice, physicians should grant numbers a far higher epistemic import than they did in the 1840s. At that time,the very idea that knowledge based on the laws of chance was as valuable as knowledge based on the deterministic comprehension of phenomena was still under construction.[89] However, even if probabilistic thinking took a long time to be

[84] Reiser, 1978, 91.

[85] The spirometer consists of a tube – through which the patient has to breath – connected to a balanced receiver, which is elevated by each increment of expired air inside a graduated pipe. A slightly modified version of Hutchinson's device is still in use today.

[86] Vital capacity is the quantity of air expelled by the greatest voluntary expiration following the deepest inspiration. It is still used as a first line test for evaluating pulmonary functionality.

[87] Hutchinson, 1846, 244.

[88] As remarked by Bynum, this was true for the majority of diagnostic techniques, whose passage from elite experimentation to general practice normally took quite a long time. See Bynum, 2006, 169.

[89] For a study on how statistical and probabilistic thinking eroded determinism during the nineteenth century, see Hacking, 1990.

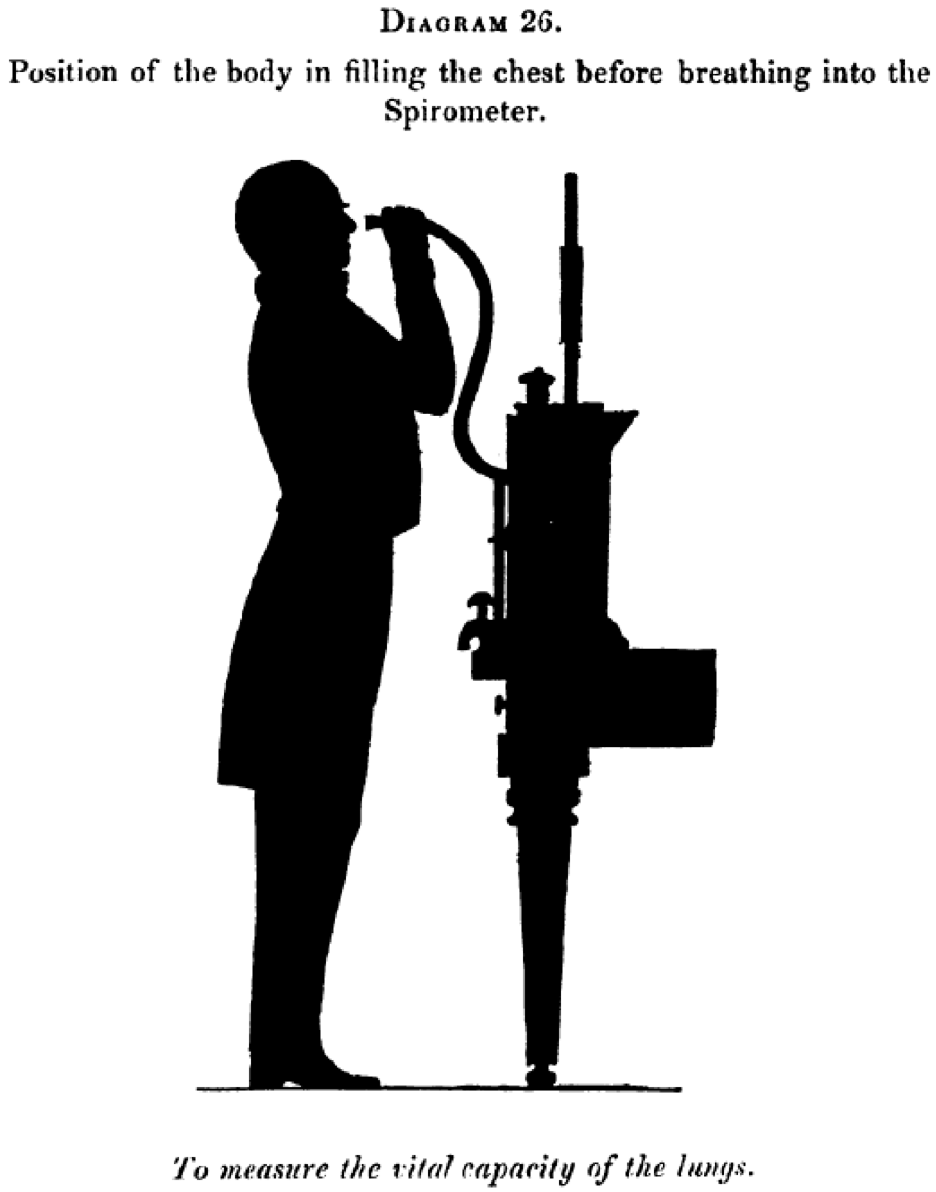

Figure 1.3: Silhouette illustration of how to position the patient's body in relation to the spirometer in order to perform the respiratory test. From J. Hutchinson, 1846, 236.

A.—Table of the Mean Vital Capacity of 15 different Classes, or 1923 Cases considered as healthy.

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	0 to 5 ft.		5 ft. to 5 ft. 1 in.		5 ft. 1 in. to 5 ft. 2 in.		5 ft. 2 in. to 5 ft. 3 in.		5 ft. 3 in. to 5 ft. 4 in.		5 ft. 4 in. to 5 ft. 5 in.		5 ft. 5 in. to 5 ft. 6 in.		5 ft. 6 in. to 5 ft. 7 in.		5 ft. 7 in. to 5 ft. 8 in.		5 ft. 8 in. to 5 ft. 9 in.		5 ft. 9 in. to 5 ft. 10 in.		5 ft. 10 in. to 5 ft. 11 in.		5 ft. 11 in. to 6 ft.		6 ft. to 6 ft. +	
	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.	Cubic inch.	Cases.
Seamen	151	5	206	1	192	7	219	1	218	10	213	9	217	15	226	14	229	15	239	11	258	18	273	12	270	6	246	2
Fire-brigade	..	..	..	..	..	..	..	..	210	1	208	2	218	20	215	17	231	26	231	20	237	3	260	1	249	2	..	..
Police, Metrop.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	234	4	228	33	226	46	248	22	234	13	262	12	281	11
Ditto, Thames	158	1	..	..	..	..	..	..	187	6	206	9	228	9	222	15	246	17	250	10	240	5	257	3	..	..	..	..
Paupers	151	7	166	3	162	10	180	10	174	21	191	20	189	19	210	10	187	9	199	10	262	1	240	3	..	..	..	..
Mixed class	80	1	185	1	162	5	181	5	185	17	191	16	192	20	210	20	222	28	238	16	246	14	238	7	269	9	..	..
Grenadier Guards	..	..	..	..	..	..	168	1	..	..	218	1	199	2	..	..	228	7	233	22	240	16	232	11	253	9	258	14
Compositors	..	..	..	..	176	3	165	2	196	5	188	6	208	7	227	5	215	8	214	6	231	3	..	..	253	1	..	..
Pressmen	..	..	152	1	..	..	..	..	..	..	213	2	203	8	204	3	223	7	245	1	239	4	247	2	..	..	..	..
Draymen	..	..	..	..	..	..	..	..	..	..	..	..	192	1	241	1	218	3	223	4	245	1	261	6	248	4	..	..
Gentlemen	..	..	..	..	145	1	161	1	156	7	177	9	189	14	208	10	208	18	208	16	236	8	254	12	250	5	262	5
Pugilists, &c.	..	..	..	..	202	1	218	2	218	1	211	4	217	3	267	3	206	1	243	2	273	3	272	5	248	2	..	..
Horse Guards	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	255	30	275	26
Mean of first series	135	14	177	6	173	27	184	22	193	68	208	78	204	118	224	102	220	172	229	164	246	98	254	75	255	82	260	62
Chatham recruits	..	..	167	1	181	1	..	..	189	1	..	..	233	19	238	67	247	38	251	22	266	16	236	2	261	5	284	3
Woolwich marines	..	..	..	..	..	..	..	..	..	..	216	3	223	7	233	99	235	192	240	130	246	75	250	39	263	18	276	9
Miscellaneous	..	..	180	1	..	..	194	4	198	4	180	4	196	10	222	18	213	9	230	13	226	12	..	..	259	7	236	6
Total mean under each height	135	14	175	8	177	28	189	26	193	73	201	85	214	154	229	286	228	411	237	329	246	201	247	116	259	112	276	80

Figure 1.4: An example of Hutchinson's tables. Here vital capacity is presented in relation to professional activity and stature. From J. Hutchinson, 1846, 156.

ON THE RESPIRATORY FUNCTIONS. 155

DIAGRAM 2.

The vital capacity, in relation to height, on 1923 healthy cases.

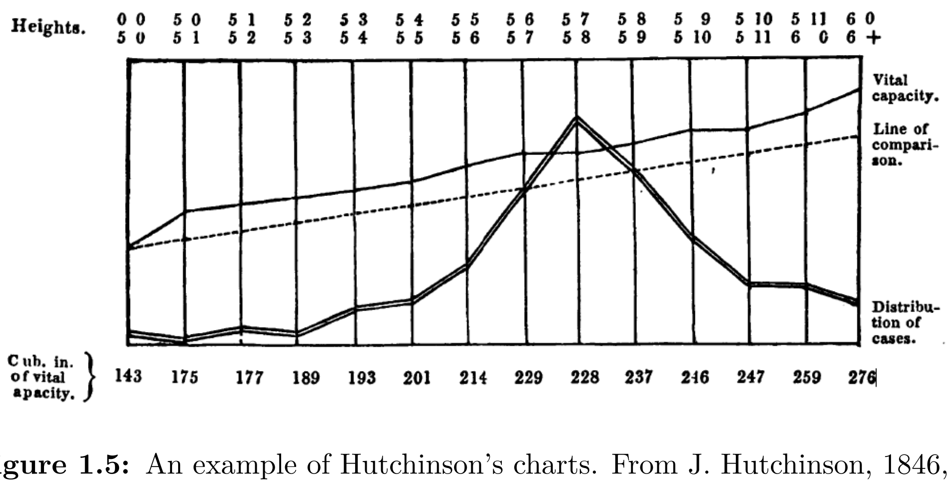

Figure 1.5: An example of Hutchinson's charts. From J. Hutchinson, 1846, 155.

integrated in medical knowledge at large, it constituted since the beginning an important aspect of hospital medicine. According to Foucault, French clinicians started to re-conceptualize incertitude in medicine already by the end of the eighteenth century, under the influence of the work of Pierre-Laplace,[90] and an elementary form of statistical method was introduced in clinical medicine in the 1820s by Pierre Louis, whose *méthode numérique* was aimed at improving both diagnosis and therapy. For what concerns diagnosis, Louis developed the idea that the recollection of subjective symptoms through patient's narrative should be guided by specific questions, and he tried to objectify each sign of disease by numeration.[91] Probabilistic and statistical thinking fitted well the redefinition of disease as a segment, or a degree, on the continuum from the normal to the pathological, characteristic of laboratory medicine. In that context, Hutchinson's endeavor was particularly interesting in that it was the first attempt to define a diagnostic index that could be measured only by a mechanical device and that had to be studied in a systematic way using the conceptual and methodological tools of statistics.

1.5.2 The thermometer

Compared to the spirometer, the use of the thermometer became common in a relatively short time after the publication of Carl Wunderlich's treatise on body temperature and disease, in 1868.[92] According to Reiser, Wunderlich's text, with its comprehensive analysis of the relation between temperature and disease, was crucial in convincing physicians that a quantitative estimate of fever was valuable for diagnosis.[93] In fact, although thermometers had been available since the seventeenth century, in the 1860s only a few doctors, and mostly in hospitals, used it. This happened for conceptual and practical reasons. Conceptually, fever had been traditionally considered a disease in its own right, and not the symptom of something else. It was diagnosed touching or observing the body, and classified on the basis of the patient's pulse, skin complexion, sweating or chills. Indeed, Foucault stressed the fact that the discussion of the theory of essential fevers occupied a good twenty-five years at the beginning

[90]According to Foucault, with the work of P.J.G. Cabanis and other clinicians who subscribed the philosophy of the *idéologues* inspired by the analytical method of the Abbé de Condillac, "medicine discovered that uncertainty may be treated, analytically, as the sum of a certain number of isolatable degrees of certainty that were capable of rigorous calculation." Foucault, 1963, 97.

[91]See Reiser, 1978, 32-33; Cosmacini, 1997, 350n; Grmek, 1999, 152.

[92]C.A. Wunderlich, 1868, *Das Verhalten der Eigen Wärme in Krankheiten.* Wunderlich's analyses were based on the measurements from about 25,000 patients over several years.

[93]See Reiser, 1978, 114.

of the nineteenth century,[94] and it was only when the metamorphosis of fever from disease into symptom was accomplished that temperature could be assimilated to other vital indexes and treated statistically. A confirmation of the fact, emphasized by many historians of medicine, that the sheer availability of a technology does not entail its immediate use, and that a new diagnostic technique can be integrated into medical practice only when its results make sense within the scientific context of the moment.[95] At the technical level, what restrained doctors from taking up thermometry was the fact that the first thermometers[96] were cumbersome instruments, difficult to use, and with low accuracy. Additionally, they used different temperature scales, and this made the comparison of data extremely difficult.

However, by the time Wunderlich published his treatise, these problems had been overcome: the thermometer could be easily used and data from different subjects, or from the same subject at different times, could be easily compared. For the German clinician, thermometry had quite a few characteristics that made it a superior diagnostic approach in relation to other diagnostic methods. Compared to patient anamnesis it had the advantage that temperature could "neither be feigned nor falsified,"[97] while compared to percussion and auscultation, it provided quantitative data, thereby offering "materials for diagnosis which are incontestable and indubitable, which are *independent of the opinion or the amount of practice or the sagacity of the observer*."[98] Moreover, in contrast with spirometry and lungs vital capacity, it measured a phenomenon that, although ever changing, was more clearly related to the disease. Tracking variations in body temperature, Wunderlich maintained, would allow defining the natural laws of fever in diseases as diverse as typhus, neuroses, or injuries of the spinal cord.[99] The temperature graph portrayed the disease, and in this portrait neither the patient nor the doctor could spoil the objectivity of the representation by introducing their subjective feelings or lack of skills. In fact, since the thermometer was simple to use and provided an automatic output, a new figure could enter the diagnostic arena: the unskilled measurer. While a qualitative

[94]See Foucault, 1963, Ch. 10. According to Foucault, the debate on the essential fevers was the final step in the definition of anatomo-clinical perception. Fever, in fact, questioned the very being of the disease in its relation to the lesional phenomena.

[95]See, for instance, Faure, 2005, 22-23; Bynum, 2006, 169.

[96]The first thermometer was probably build by Galileo, between 1593 and 1597, while Santorio Santorio, who built his thermometer in1625, is credited for having extensively attempted to measure the temperature of the human body. See Reiser, 1978, 110-11.

[97]Wunderlich, 1868, vi. It should be noted that distrust of patients' subjective reports was a tenet of clinical medicine, and it was quite common already in the eighteenth century. See Peitzman and Maulitz, 1999, 176-177.

[98]Wunderlich, 1868, 48.

[99]See Wunderlich, 1868, 51.

description of fever required a highly educated sense of touch and an adequate vocabulary, a precise quantitative measure was necessarily mechanical, and was expressed in numbers on a graduate scale. In this scenario, the unskilled measurer was valuable not only because he or she would save time to the doctor, but also because, as argued by the author of an article published in the *British Medical Journal* in 1868, not having any previous theory about temperature and disease, he "would see things as they really occurred."[100] Portable and easy to use, the thermometer was finally adopted by a large number of doctors, and it encouraged the growing belief that the physiological conditions of health and disease could be measured precisely.[101]

Confidence in the mechanical recording of phenomena, and in the virtues of the naïve eye of the unskilled observer, were part of the scientific ethos of the second half of the nineteenth century,[102] so it is not surprising that it also permeated medicine, which, as already noted, was struggling to become a full-fledged empirical science at least since Sydenham's time. It should also be noted that with the thermometer, and with Wunderlich's conceptualization of temperature as a marker of the course of diseases, for the first time appeared the idea that the doctor could collect physical signs for diagnosis and follow-up without being at the bedside. The stethoscope had introduced the first mechanical mediation between doctor and patients, but it still required a physical proximity and continuity. With the thermometer, this continuity was potentially broken, since the physician could touch, as it were, the patient's body even being far away from him.

1.5.3 The sphygmometer and the sphygmograph

If we think about the relationship between vital indices and the instruments used to measure them, we observe different dynamics. The very idea of lungs capacity as a medical concept with a specific diagnostic meaning could not exist without an instrument that measured it,[103] while body temperature passed from being a disease (fever), to be a qualitative generic symptom, and with the thermometer, it eventually became a quantitative index. On the contrary, for what concerns the pulse, the proxy of blood circulation and heartbeat, the diagnostic

[100] Quoted in Reiser, 1978, 117.

[101] See Reiser, 1978, 119.

[102] A famous and much debated account of "mechanical objectivity" have been provided by Lorraine Daston and Peter Galison in Daston and Galison, 1992 and 2007. On the same topic see also Galison 1998 and 1999. I criticize Daston and Galison's idea of mechanical objectivity in Chapter 3.

[103] More precisely, the idea that the lungs could contain a certain volume of oxygen already existed, but without a proper instrument that actually measured such volume it was impossible to use lungs capacity as a diagnostic marker.

index existed long before the invention of its measuring device. Indeed, pulse has been the first index of bodily function, known both by Western and Eastern physicians.[104] In the second century AD, Galen had developed a complex doctrine of the pulse, but in the nineteenth century only a few doctors relied on pulse taking for their diagnoses. It did not depend only on the fact that by then Galen's theories had lost currency, but also on the fact that a semiology of the pulse demanded great sensorial training and experience, in addition to an exquisite sense of touch, which most practitioners lacked.[105]

Pulse-feeling machines Attempts to build an instrument that would help recording the pulse date back at least to 1450,[106] but the first effective device was developed in 1834 by the physician Julius Hérisson, who called the instrument sphygmometer. It allowed visualizing the intervals between pulse beats, as well as the duration and force of contractions, by transmitting the impulse of the heart beat to a column of mercury. In the memoir in which he presented the sphygmometer to the Institut de France, Hérisson enumerated its advantages, praising with special emphasis the fact that – besides making possible a more precise monitoring of the pulse, recorded by a mechanical device rather than by subjective touch feelings – it enabled "the physician to *write down in his note book*, an exact description of the state of the pulse."[107] Pulse feeling, so difficult to describe in words, could be finally expressed in the clear language of numbers. This would allow comparing the state of heart and arteries in the same subject under normal and pathological conditions, as well as during the course of the disease. Moreover, the numbers on the graduated scale of the sphygmometer provided a description of the pulse that could be shared by different people simultaneously, or even in different places at different moments. This was an advantage not only in medical consultations, but also in medical education: students could judge pulse motions with their own eyes (as variations of the mercury's column), rather than rely on the verbal description of the sensations of their teachers. Finally, the sphygmometer would create a common language for describing pulse beat, because, as Hérisson put it: "the instrument being the same every where, the measure obtained at St. Petersburgh will be perfectly understood at Paris."[108]

[104]The Chinese Maijing (pulse manual) dating back to the third century AD, classified twenty-four kinds of pulse. See Cosmacini, 1997, 159 and 160n.
[105]See Reiser, 1978, 97.
[106]See Reiser, 1978, 96.
[107]Hérisson, 1834, 11.
[108]Hérisson, 1834, 14.

In a few pages Hérisson sketched some fundamental epistemological problems: the question of mechanical objectivity *versus* human sensorial subjectivity; the possibility of accessing at different times and places the same information as a condition for inter-subjectivity; the creation of a common language among the members of a scientific community, rooted in the use of the same instruments. In terms of medical practice these epistemic issues mirrored the problem of defining a stable, reproducible semiology that could improve diagnosis. Moreover, as remarked by Dagognet, the sphygmometer allowed the clinician to measure the force that propels the cardiac wave, without needing to penetrate the vessels, thus without trespassing the body's boundaries. It allowed "to know quickly and from without what was going on within."[109]

Pulse-visualizing graphs Although Hérisson's instrument, too cumbersome and difficult to use, never entered into medical practice, it gained various supporters and many physiologists worked to its improvement.[110] One of the most notable innovations in the domain of pulse examination was the invention of the sphygmograph. First designed by the German physiologist Karl Vierodt, it was perfected by the French physiologist Etienne-Jules Marey, in 1860. This device provided a graphic representation of the pulse: it measured the frequency of the blood flow and visualized its rhythm and form (duration and amplitude). Interestingly, although in the publication in which he presented his invention Marey warned the readers that the sphygmograph was not ready yet for being used as diagnostic tool,[111] it nevertheless attained a relative diffusion within the medical community. This success probably depended on the fact that, as the sphygmometer, the sphygmograph provided a visible record of the pulse, but contrary to Hérisson's device, Marey's was small, portable, and relatively easy to operate. Additionally, the sphygmograph – the first of Marey's "inscribing

[109] Dagognet, 1986, 105, my translation.

[110] Eventually, in 1896, the Italian Scipione Riva-Rocci designed the modern blood pressure cuff (sphygmomanometer). This instrument was portable of easy application, reasonably accurate and produced automatic results. Widely used today (often in its computerized version), this instrument played a pivotal role in defining the semiology of one of the most common diseases of our time: hypertension. As remarked by Faure, the sphygmometer is a good example of how a diagnostic technique can go beyond revealing a disease, it can create one. This phenomenon, he maintains, does not depend on the technique itself, but on social factors. The sphygmometer has been in use in Paris clinics since the 1860s as physical sign of several illness, but its use spread widely and contributed to create the notion of hypertension only by the end of the nineteenth century. By then health insurances, born in England in the eighteenth century, had about one million clients in France. Health insurances were interested in foreseeing diseases (predictive medicine), and thus developed different methods to estimate the risk of disease. Measuring arterial tension was one of these methods: hypertension became first an indicator of risk and in time a full-fledged disease. See Faure, 2005, 24.

[111] See Marey, 1860, 32.

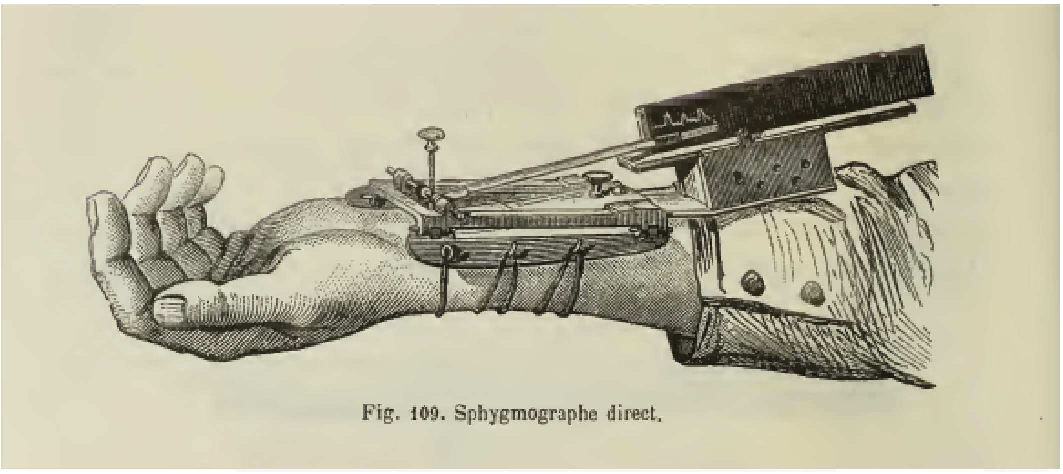

Figure 1.6: A direct sphygmograph designed by Marey. E.-J. Marey, *La circulation du sang à l'état physiologique et dans les maladies*, Paris, 1881, 214.

devices"[112] – capitalized on the growing interest and confidence in measuring machines and in what Marey himself dubbed "graphic method."[113]

As remarked above, if in clinical anatomy the organic lesion was the stable mark of disease in the dead, for the proponents of functional anatomy the sphygmograms were permanent, visible records of a transient, on-going activity (Figures 1.6 and 1.7).

In this regard Marey wrote:

> The inscribing devices measure infinitely small lapses of time; the most rapid and the feeblest movements, the least variations of forces, cannot escape them. *These devices penetrate the intimate functions of organs where life seems to consist of ceaseless motio*n. All these changes in the activities of forces are translated by the *graphical method* into an arresting form that we could call *the language of the phenomena themselves*, as it is superior to all other modes of expression.[114]

As the great majority of his colleagues, Marey believed that mechanical devices provided perfect records of reality. Through his graphic method first, and with chronophotography later, he tried to probe the continuous motion of inner life by revealing the invisible.[115] Although the sphygmograms never became part of diagnostic routine, they introduced a very important idea in medicine, namely that vital functions could leave a trace on a sheet of paper, and this trace was generally understood as the direct imprint of the phenomenon into

[112] Marey, 1878, iii.
[113] Marey, 1878.
[114] Marey, 1878, iii.
[115] I discuss this problem in detail in Chapter 3, with specific reference to Marey's graphic method and chronophotography in Section 3.3.

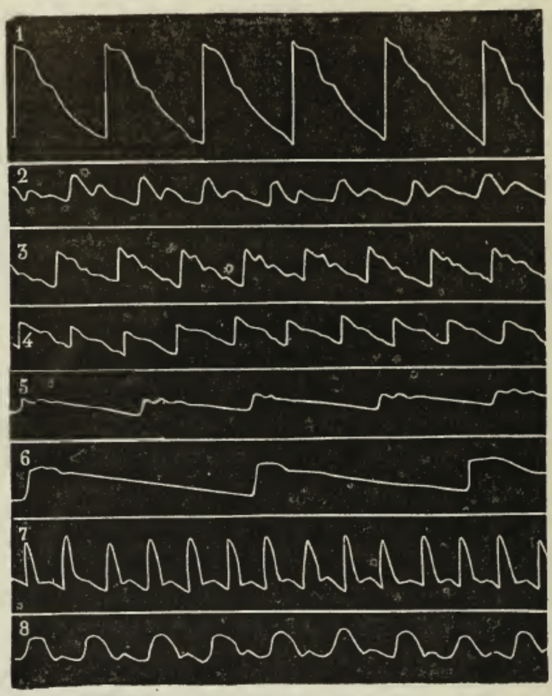

Fig. 112. Quelques tracés du pouls recueillis avec le sphygmographe direct. — 1. Pouls sénile avec hypertrophie du cœur. — 2. Pouls de la fievre typhoïde. — 3. Colique de plomb. — 4. Péricardite. — 5. Convalescence. — 6. Pouls sénile rare. — 7. Fièvre hectique. — 8. Anévrysme disséquant de l'aorte.

Figure 1.7: Example of sphygmograms. E.-J. Marey, *La circulation du sang à l'état physiologique et dans les maladies*, Paris, 1881, 216.

a visual form.[116] Marey's sphygmograms did not record quantitative data, but they nevertheless managed to "materialize" such an elusive index as arterial tension.[117]

1.5.4 Objectivity and the physiological gaze

With the spirometer, the thermometer, the sphygmometer and the sphygmograph mechanical instruments entered steadily into the domain of medical diagnosis. These devices were meant to measure bodily functions through vital indices (e.g., the pulse or the vital respiratory capacity). The vital indices, in turn, helped to define the "position" of a given person on a physiological scale that ranged from the normal (health) and the pathological (disease). In the characteristics of the deviations from the normal states, physicians hoped to find the natural laws of the disease that would lead to a rigorous, certain diagnosis. Thanks to physiology, the medical gaze expanded its inventory, fragmented more and more its object, and took a radically new perspective on what

[116]The graphic method reappeared in diagnostic practice in a new form and with a renewed importance in the first decade of the twenty century, with the invention of the electrocardiograph.

[117]See Dagognet, 1986, 110.

could be revealed by the inner, living body. Moreover, an articulated idea of what an objective representation of the body is became operative. All the instruments described above measure different bodily functions, but they share a fundamental feature: they make visible through graphs or numbers dynamic processes of invisible nature, allowing their permanent record. In this way the vital indices become objective data.

Objectivity here works at different levels. On the one hand, it is understood as the suppression of the subjectivity of the patient's narrative describing his or her symptoms and sensations (a process that began with Laennec's mediated auscultation), as well as the suppression of the sensorial subjectivity of the doctor that potentially impaired the examination of physiological indices or the search for symptoms. It is very difficult to describe and note down the quality of, say, the pulse measured by touch, but its intensity and duration become immediately accessible to different people when it is translated into an increase of mercury on a graded scale or into a line on a sheet of paper. In this respect, the machine provides objective data in the sense that it produces data that are open to collective, inter-subjective scrutiny. These records can travel from place to place, they can be copied and compared. On the other hand, objectivity is understood as the adequate correspondence between representations (graphical or numerical) and phenomena. In other words, objectivity becomes a synonym for truth, and objective representation is a correct, truthful representation. Marey believed that his inscribing devices spoke the "language of phenomena themselves"[118] and most of his contemporaries agreed with him. This idea was certainly reinforced by the development of photography. However, as I will show in Chapters 2 and 3, the belief that mechanical devices spoke the very language of natural phenomena was multifaceted and quite more complex that it might seem at first sight.

[118]Marey, 1878, iii.

Chapter 2

The beginnings of medical photography: visualizing illness

In the previous chapter it was argued that in the course of the nineteenth century Western medicine conceptualized the human body and its diseases in several different ways, and that these conceptual transformations were intertwined with the development of a range of diagnostic instruments. All these instruments, from the scalpel of the pathologist to the measuring instruments of the physiologist, had the aim to make the inner body and its functions accessible from the outside, thus in a way or another, *visible*. Visibility was indeed the imperative set by clinical anatomy at the outset of modern medicine. And visualization, in the form of anatomical and microscopy images, endoscopic inspections, as well as graphs and tables of numbers, became a mark of medical practice well before the invention of radiography. I went through a analysis of medical diagnostic techniques and technologies, in order to outline the epistemological background against which to frame radiography as a diagnostic tool belonging to a avast and heterogeneous medical tradition. Yet, radiography belongs also to another line of filiation, namely, medical photography. Hence, in the present chapter I explore how photography was co-opted in medicine shortly after its invention, and how it affected the way physicians looked at the patient's body.

Photography never was a diagnostic instrument proper, yet with its promise to provide a perfect visual record of reality, it was perceived as the natural allied of all morphological sciences, including medicine. By outlining the early development of medical photography I try to understand how the photographic technology was embedded in medical theories and practices. To this aim, I draw on Charles Sanders Peirce's conceptualization of photographs as indices *and* icons, because it encapsulates quite well the nineteenth-century discourse on photography, simultaneously offering conceptual categories that help examining that very discourse. I integrate Peirce's intuitions with Allan Sekula's analysis of how early photographic portraits could work according to the indexical or symbolic mode of signification. I also draw on Walter Benjamin's considerations on the optical unconscious and the intrinsic analytic potential of photography, as well as on his idea (largely borrowed from other theorists such as László Moholy-Nagy and Béla Balász) that photography works as a prosthetic sense, which enriches and transforms our sensory experience. I argue that, although virtually all the scientists and medical doctors of the nineteenth century praised the mimetic realism of photographic image, they often used the new optical medium to produce pictures of such abstract entities as pathological conditions. More precisely, they used photographs to train their ability to extract general, abstract features of disease from the contingent pictures of singular individuals. In this sense, we can say that they used photographs to visualize the invisible. I also maintain that the body represented in these photographs is not the body as we see it. It is a body reconfigured as part of an experimental apparatus in which patient, camera and observer are components of a larger structure (which includes the archive and the medical journal) capable of producing scientific and medical evidence.

2.1 Londe: medical photography in practice

In the preface of his book *La photographie médicale*, of 1893, Albert Londe, pioneer in scientific photography and director of the photographic service of the Hôpital de la Salpêtrière,[1] claimed that photography was "one of the most beautiful discoveries of mankind."[2] He believed that the photographic laboratory would soon become a necessary facility for any hospital, and envisaged the creation of photography courses in medical schools. Photography, Londe maintained, with its ability to keep track of transient states was an invaluable tool for medical research and practice,[3] and he consistently backed this claim by making

[1] At the time Londe worked there, the Salpêtrière, a female insane asylum, hosted about 5,000 patients, many of whom institutionalized for life (Jean-Martin Charcot, director of the hospital for many years said that it was a sort of living museum of pathological conditions). See Sicard, 1995, 19.

[2] Londe, 1893, ix, my translation. For Londe photography was both a discovery and a science in its own right. To the contemporary reader, the idea that photography can be considered a science, rather than a technique (or technology), might sound strange. However, we should consider that for those who were involved in the development of photographic instrumentation and practices, photography posed an open problem in applied science. The very activity of taking pictures was bounded with the problem of understanding how the whole process functioned. This understanding, in turn, was related to the study of the physical and chemical phenomena that subtended the working principles of the apparatus.

[3] See Londe, 1893, 3.

a list of the actual and possible applications of photography to medicine and physiology. Photography, he said, was the necessary iconographic complement of the patient's file in all those cases in which the morphological presentation and evolution of the disease were relevant (e.g., deformities and wounds). It could be used to record endoscopic examinations, as well as surgical and obstetrical interventions, in a much more precise way than any written description, and the visual records could be shared and retrieved at any time for further study. In the same way, photography could improve the much honored tradition of pathological anatomy, by enabling the comparison of the lesions revealed by different autopsies. For what concerns the study of histology and cytology, it would allow to preserve "*authentic and enduring* records"[4] of tissues that were doomed to perish in a short time. Moreover, in the case of the study of nervous and mental pathologies, in which the observation of unexpected and quick movements was paramount, photography could provide access to new fields of knowledge, while in the domain of physiology it had the great advantage of allowing the recording of body motions without directly interfering with the subject under examination (Londe collaborated with Etienne-Jules Marey in the development of chronophotography).[5] Furthermore, Londe contended that photography had an eminently pedagogical quality because, by facilitating the production of large collections of images, it fostered observational skills in students and taught both students and qualified physicians how to recognize permanent and recurrent features within the intrinsic variability of the morphological alterations provoked by pathology. As he put it: "Photography provides different ways to *multiply* the original picture, without loosing any of its *tracts of sincerity and truth*".[6] Londe concluded his introductory list of applications of medical photography mentioning its relevance in the medico-legal context. In this case, however, rather than praising the evidential role of the photographic image, he emphasized its emotional power: put under the eyes of judges and jury, the shocking pictures of a face disfigured by a lethal wound would discourage any feeling of pity for the author of the crime.[7]

Within the list of medical applications of photography expounded by Londe, I would like to focus on two points: (1) the use of photographic records in the individual patient's file, and (2) the pedagogical relevance of collections, or series, of images. For what concerns the second point, it is important to emphasize

[4]Londe, 1893, 6, my translation.

[5]Chronophotographs are pictures taken in extremely rapid sequences, above the temporal resolution of the eye. The first successful attempts to produce this sort of images were accomplished by the photographer Eadweard Muybridge in the United States and by the physiologist Etienne-Jules Marey in France. I analyze in detail Marey's work in Chapter 3.

[6]Londe, 1893, 6, my translation.

[7]See Londe, 1893, 6 and 215.

that it was through the series, the gallery of images, that photographs acquired a diagnostic meaning. By training the eye, the photographic series taught to recognize the *facies* of a disease at a glance.[8] In fact, as Walter Benjamin will later remark, the series is endowed with two antithetic properties: it gives visibility to the exceptional, and simultaneously fosters our "sense for sameness,"[9] our ability to recognize, or extract, recurrent patterns within a variety of singular phenomena. The series of photographs, collected in specialized journals, books of case studies or file archives, has the function to stimulate a sort of inductive process whereby a general visual rule (the *facies* of the disease) is derived from a set of individual occurrences. Hence, there is a movement from the particular to the general.[10] In medicine, however, general knowledge needs always to be referred to an individual case. More precisely, there is always a tension towards the construction of a science of the individual, because the field of action of the physician is a specific person. This is why Londe recommended to keep photographic records of patients in their medical file. In explaining the rules for the proper making of medical photographs, Londe insisted that it was always necessary to produce sets of images of the same patient, because this was the only way to keep track of the evolution of his or her condition over time and under different stimuli.[11] Only through sets of images it became possible "to rigorously establish [pathological] types that corresponded to specific affections."[12] Photography promised to foster the advancement of medicine because it offered an opportunity to shift from the general rule to the particular case with relative ease.

As we will see in this chapter, establishing a human type for specific diseases was one of the main purposes of early medical photography. We can consider this endeavor as the visual analogue of the attempts to organize and inscribe disease within the body pursued by all the diagnostic technologies developed during the nineteenth century. Similarly to the stethoscope, the thermometer, the sphygmograph and all the other diagnostic devices discussed in Chapter 1, medical photography was meant to objectify the body, to turn it into a scientific object that could be described through the combination of simplified, measurable, standard elements. It was thus necessary for medical photography to have a standard, seemingly neutral aesthetics, corresponding to a specific visual code. Such aesthetics was summarized by Londe in a few rules: he recommended to

[8]See Londe, 1893, 74-77.
[9]Benjamin, 1936, 256.
[10]This means that the photographic series had not simply a pedagogical value (transmission and sharing of knowledge), but also a scientific value proper, for it helped to construct new knowledge by induction.
[11]See Londe, 1893, 66.
[12]Londe, 1893, 5.

photograph the body according to an ordered sequence,[13] against a uniform dark grey background "against which the naked body stands out very clearly,"[14] and with the camera placed right in front of the subject, in order to avoid any deformation. Not surprisingly, this was also the aesthetics of ethnography and criminology, two social sciences that received great impetus between the 1870s and 1880s. In these disciplines, too, what was at stake was the creation of objective, scientific portraits of the average man (or woman).

Londe's book, a reference text written more than fifty years after the introduction of photography in medicine, can be considered a compendium of the accepted wisdom about scientific photography in the late nineteenth century. The high value attached to the specific ability of the camera to produce faithful visual records, its eminently documental character, is patent in Londe's list of medical applications of photography. For him, as for his contemporaries, the camera was a "wonderful recording instrument,"[15] and photographs were "truthful images" [*images fidèles*][16] of the world. Tellingly, even Charles Baudelaire's condemnation of photography in the *Salon of 1859* was chiefly grounded in the idea that the camera is a picture-making machine characterized by "an absolute material exactitude."[17] For the poet, photography was a device that *merely* recorded trivial external reality, and therefore it could certainly be the "very humble servant"[18] of the sciences and the arts, but it was divested of any creative and artistic potential.[19]

2.2 Photographs as indices *and* icons

To better understand Londe and Baudelaire's conception of photography, without limiting ourselves to certify their endorsement of photographic realism, it is useful to refer to the semiotic conceptualization of photography put forward by Peirce. Indeed, it seems to me that Londe and Baudelaire, as virtually all their contemporaries, implicitly subscribed to the Peircean truth-value theory of photography. According to the American phylosopher, photographs, especially instantaneous photographs, are simultaneously *icons* and *indices*. They are indices because they are physically connected to their referent, as a thumbnail to the finger or the smoke to the fire. At the same time they are icons, because

[13] Namely, the whole body view from front, sides and behind, the head alone, the hands, the feet and the lower limbs, and, finally, detailed images of the skin.
[14] Londe, 1893, 66.
[15] Londe, 1893, 6, my translation.
[16] Londe, 1893, 68.
[17] Baudelaire, 1859, 261, my translation.
[18] Baudelaire, 1859, 261, my translation.
[19] See Baudelaire, 1859, 254-263.

their meaning depends on their resemblance to the object they represent. More exactly, in the case of photography the iconic mode of signification of the sign directly springs from its indexical mode. Peirce wrote: "Photographs [are] produced under such circumstances that they [are] *physically forced to correspond point by point* to nature."[20] And also: "A photograph [...] *owing to its optical connection with its object*, is evidence that that appearance corresponds to reality."[21] That is, the truth-value of photographs is predicated on their physical mode of production. Indeed, it is interesting to consider Peirce's idea of photographs as iconic indices in the light of a description of the photographic process provided by one of its inventors, Henry Fox Talbot. In 1844, in his groundbreaking photographic album *The Pencil of Nature*,[22] Talbot wrote:

> The idea occurred to me [...] how charming it would be if it were possible to cause these natural images imprint themselves durably, and remain fixed upon the paper! [...] Now, light, where it exists, can exert an action, and, in certain circumstances, does exert one sufficient to cause changes in material bodies. Suppose, then, such an action could be exerted on paper; and suppose the paper could be visibly changed by it. In that case surely some effect must result having a *general resemblance to the cause which produced it*.[23]

As a matter of fact, photographs were the product of two distinct processes: an optical process, that led to the production of an image in the camera, and a chemical one, that allowed to fix and reproduce on a sensitive surface the image cast upon it by the lens. This chain of physicochemical phenomena preserved, through a stream of causal relations, a resemblance between the object that had produced an image within the camera, and the image that had been finally fixed on the sensitive plate. The very materiality of the photographic process bounded the iconicity of the picture to its indexicality, and it was the source of its perceived realism.

Peirce did not developed a theory of photography in its own right, but he used photographs as examples of how signs can signify. Although it is beyond the scope of this dissertation to explore in detail Peirce's semiotics, I will resort to his classification of signs into icons, indices and symbols as a conceptual and methodological tool for part of my analysis of photography and medical imaging in the following chapters For Peirce, the sign is a unity of what is represented (the

[20] Peirce, CP 2.281.

[21] Peirce, CP, 4.447.

[22] Together with the Frenchman Louis Daguerre, Henry Fox Talbot is credited for being one of the inventors of photography. *The Pencil of Nature* was the first book ever published in which illustrations were printed through a photographic process. The book was composed of six installments released between 1844 and 1846, and included 24 calotype prints.

[23] Talbot, 1844, n.p.

Object), how it is represented (the Representamen) and how it is interpreted (the Interpetant). More exactly, the Representamen is the sensible form taken by the sign (it is also called sign-vehicle); the Interpretant is the sense made of the sign (it can be understood as a translation of the primitive sign into a further, more developed sign in the mind of the interpreter); and the Object is the referent, that is, something beyond the sign to which it refers (importantly, the objects puts constraints on the sign's possibility to signify). The classification of signs in indices, icons, and symbols depends on the quality of the relationship that connects Object, Representamen, and Interpretant.[24] This relationship, or mode of signification, is characterized by different degrees of conventionality, with indices at the bottom of the scale (where, ideally, no convention is involved in the process of signification) and symbols at the top. Thus, a sign is a *symbol* if it is connected to its object by a convention, which, as such, has to be learned and agreed upon.[25] Instances of symbols are language in general, numbers, the Morse code, and nautical flags. An *index*, on the contrary, relates to its referent via a physical or factual connection.[26] For example, a footprint is an index of a person walking on a trail, because it is the physical imprint let by the foot, and pain can be an index of disease. Finally, a sign is an *icon* when it has a relation of resemblance with its referent.[27] Similarity is the defining feature of iconicity, and indeed, Peirce also terms such mode of signification likeness. Instances of icons are pictorial portraits, scale models, but also metaphors, synthetic aromas, and imitative gestures.

Peirce's precise thoughts about the nature of icons, indices and symbols changed and became more complex overtime, as far as he developed his sign theory. In particular, he came to realize that it was virtually impossible to find any pure instance of icons and indices, and that these signs were always partly symbolic or conventional.[28] This alerts us about the fact that not only we cannot treat photographs as pure indices, but we should not even consider them as simple combinations of index and icon. Indeed, as we will see in this chapter and in the following one, the symbolic or conventional component of the mode of signification of photographs and radiographs plays a fundamental role in

[24]See Atkin, 2013, and Chandler, 2007, 39-44.

[25]"A *Symbol* is a sign which refers to the Object that it denotes by virtue of a law, usually an association of general ideas, which operates to cause the symbol to be interpreted as referring to that Object." Peirce, CP 2.249.

[26]"An *Index* is a sign which refers to the Object that it denotes by virtue of being really affected by that Object." Peirce, CP 2.248.

[27]"An *Icon* is a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not." Peirce, CP 2.247.

[28]See Atkin, 2013.

endowing these images with meaning.[29] The interplay between the indexical and symbolic modes of signification is crucial to an understanding of photography and other forms of scientific imaging technology, especially when it comes to the visualization of the invisible.

Indexicality and likeness Before exploring at length the problem of the visualization of the invisible, I task I undertake in this chapter and in the next one, I want to insist on how powerfully the idea of resemblance was entrenched with that of indexicality in the earliest conceptualizations of photography.[30] For Londe and his contemporaries, the epistemic authority of photography came from its indexical nature, from its being a direct imprint of nature. This physical contiguity was the guarantee of iconic exactitude, of perfect resemblance: the photographic image was epistemically meaningful because it was identical to its referent and it was identical to its referent because it was its direct physical imprint. In other words, the photograph was perceived as scientifically meaningful (that is, objective and endowed with cognitive value) because it was an icon, but it was an icon only in so far as it was an index (that is, its ontological status secured its truth-value). This conflation of the indexical and iconic nature of photography was quite productive, for it allowed scientists to use these images in flexible (sometimes conceptually conflicting) ways.

Embedded in Londe's apparently naïve photographic realism we can in fact discern a range of instrumental uses of photography. As highly contingent images, taken directly from the body of the patient and referring to no one but *that* patient, photographs are important complements in the medical file, for they keep memory of what the doctor saw with his own eyes, with a fidelity and detail that a written description could not convey. In this case, what was at stake was the ability of the photograph to be identical to its referent. And it was still the contingency of the photographic picture that conveyed its evidentiary and emotional meaning in the murder trial.[31] In this instance what mattered was the indexical nature of the photograph not only in the strictest sense of be-

[29]In Peirce's semiotics the meaning of a sign is not contained within it, but arises in its interpretation. Moreover, the object is crucial to the meaning of the sign (it puts constraints on the sign). Hence the meaning of a sign includes both its reference and its sense. See Chandler, 2007, 33.

[30]Of course, the notion of "resemblance" is very problematic and controversial. It is rooted in a mimetic-realistic conception of "likeness," as if this were an intrinsic property of the image, rather than an anthropological and cultural construct. That is, it is a conception which does not take into account that what counts as similar to something else is not only species-specific (what counts as similar for a human being is not recognized as such by, say, a dog or a fly), but also culture-specific. The need to resort to the symbolic mode of signification to interpret a photograph can be considered a symptom of the fact that the iconicity of a picture, its likeness, is not as self-evident and self-contained as one might believe on first thought.

[31]See Londe, 1893, 6 and 125.

ing an evidence of the crime, but also in what concerned the emotional cogency of the index. It was because they knew, by virtue of common sense, that *that* slaughtered person was *really* and *necessarily* before the camera, and because they felt that *that* body was in metonymical relation with the photographic plate, that the members of the jury would be revolted by the photograph much more than by any painting or drawing, no matter how realistic.

However, photographs are not only about what we can see with our own eyes. They are also about what we struggle to see (the elusive movements of the neurological patient), or what we cannot see at all (the all too rapid movements studied through chronophotography). In these cases the iconic aspect of the photograph is taken to a level that goes beyond visual resemblance, and can acquires a diagrammatic function. Also, the contingent nature of the photograph fades, or is tamed, once pictures are collected in organized series (in reviews or atlases). In this case the medical value of the camera resides not so much in its ability to provide exact records of specific occurrences, but rather in the fact that it allows to easily multiply images. Hence, it allows to create those visual galleries, those pathological and teratological collections that ideally would allow the recognition of general prototypes, the *facies* of each and any disease.

2.3 A new optical truth

Since its official invention, in 1839, photography has been simultaneously an instrument and an object of research (scientific and artistic alike), but until the turn of the century photographs continued to be conceived of as the fixation of the image of the camera obscura, thus as an imprint of the visible. Although in their practice the scientists used photography in very creative ways and demanded of photographs to reveal much more than the surface of objects, their conceptual (and rhetorical) discourse on photography essentially revolved around the idea of "perfect and truthful record"[32] of visible phenomena.[33] Benjamin, in his *Little History of Photography*, of 1931, ascribed this lack of conceptual variety to the tumultuous development of the new technique, "which long precluded any backward glance."[34] More specifically, he considered the theorization of photography put forward before the 1920s "entirely rudimentary,"[35]

[32]Diamond, 1856, 24.

[33]We can find some meaningful exceptions in the writings of the physicist and philosopher Ernst Mach and of physiologist Etienne-Jules Marey. Both were interested in the use of photography for the study of dynamic phenomena. Mach expounded his ideas on photography in the article "An account of scientific applications of photography," of 1893.

[34]Benjamin, 1931, 507.

[35]Benjamin, 1931, 508.

because based on two misconceptions: on the one hand, the conviction that a photograph was nothing more than a mirror image of the visible world; on the other hand, the attempt to legitimize (or delegitimize) photography in the face of traditional painting.[36]

This vision was challenged by theoreticians and practitioners of photography and cinema of the 1920s and 1930s, who developed a broad reflection on the specific cognitive and analytic power of the new optical media.[37] For instance, for the Hungarian artist and theorist Lázló Mohly-Nagy, Benjamin's friend and main exponent of the photographic movement New Vision [*Neues Sehen*], the task of the camera was to provide a new, enriched way to perceive and understand the world. Moholy-Nagy emphasized the ability of photography to provide "an unbiased optical vision" [*eine unvoreingenommene Optik*], that is, a vision not bound to the association laws that rule over natural perception.[38] The camera allowed to enlarge and frame the field of view in ways the human eye could not. Indeed, for Moholy-Nagy, the distortions produced by the lens and by all sort of photographic experimentation, from oblique views to superimpositions, should not be considered photographic errors, but rather important epistemic devices that, by severing all habitual connection between vision, imagination and judgement, would reveal a new "optical truth" [*das Optisch-wahre*], which would precede any subjective stance.[39] As pointed out by media scholar Antonio Somaini, Moholy-Nagy's strong statements about the objectivity of the camera, which clearly did not take into account the subjectivity and intentionality of the photographer, are to be understood in the context of the reflection on the epistemic cogency of photography and cinema that animated the debate about these media in the 1920s. For the Russian film maker and theorist Dziga Vertov, for instance, the camera had specific analytic properties that revealed what he called *Kino-Pravda* (literally, film-truth), i.e., the reality of life that escaped common perception. Similarly, the formalist Osip Brik, in the essay *What the*

[36]Benjamin maintained that photography could not be judged according to the categories of painting, for it actually overturned those categories. He particularly criticized what he considered to be a "fetishistic and fundamentally antitechnological concept of art," that is, a concept of art grounded in the idea of divine inspiration, detached from any historical and material context. Benjamin, 1931, 508.

[37]See Somaini, 2010, ix-lvi; Pinotti and Somaini, 2012, xxv-xxviii; Landeker, 2005 and 2006.

[38]See Moholy-Nagy, 1925, 5. In the introduction to the Italian edition of Moholy-Nagy's *Malerei Photographie Film*, Antonio Somaini points out that already in 1844 Henry Fox Talbot had hinted at the idea of unbiased vision, by stressing that photography does not discriminate between a chimney sweep and the Apollo of the Belvedere. See Somaini, 2010, xxxix. In *The Pencil of Nature*, commenting on the plate with the view of the boulevards at Paris, Talbot wrote: "The instrument [the camera] chronicles whatever it sees, and certainly would delineate a chimney-pot or a chimney-sweeper with the same impartiality as it would the Apollo of Belvedere." Talbot, 1844, 18.

[39]See Somaini, 2010, xxxix-xl.

Eye Does Not See, of 1926, maintained that photography and cinema did not have to imitate the human eye, but rather unveil what the human eye is unable to see. The same line of thought was hold by French avant-garde film directors such as Germaine Dulac, who considered cinema a sort of microscope focused on life, Abel Gance, who challenged traditional vision with multiple projections and frame superimpositions, and Jean Epstein, for whom cinema, through montage, slow motion, time-lapse, and reversed projection, could radically reconfigure our experience of space and time. Within the German speaking context, to which both Moholy-Nagy and Benjamin belonged, Béla Balász thought of cinema as a new sense organ, which entailed new sensorial faculties and thus paved the way to the advent of a new visual culture [*visuelle Kultur*]. This new visual culture, Balász posited, entailed a distinctively modern way to see the world, and over time would lead to a reconsideration of the epistemic import of human sensorial faculties.[40] For Balász, as for Moholy-Nagy, the new optical media could be considered prosthesis of the human *sensorium*, for they reorganize, integrate and perfect our senses.[41]

2.3.1 Pictures from the optical unconscious

Balász and Moholy-Nagy's intuitions on the epistemic and analytic possibilities of the camera were condensed by Benjamin in the metaphor of the "optical unconscious," expounded in the essays *Little History of Photography* and *The Work of Art in the Age of Mechanical Reproduction*. In the latter he wrote:

> With the close-up, space expands; with slow motion, movement is extended. And just as enlargement not merely clarifies what we see indistinctly "in any case," but brings to light entirely new structures of matter, slow motion not only reveals familiar aspects of movements, but discloses quite unknown aspects within them [. . .]. Clearly *it is another nature which speaks to the camera as compared to the eye. "Other" above all in the sense that a space informed by human consciousness gives way to a space informed by the unconscious.* [. . .] Whereas it is a commonplace that, for example, we have some idea what is involved in the act of walking (if only in general terms), we have no idea at all what happens during the split second when a person actually takes a step. [. . .] This is where the camera comes into play, with all its resources for *swooping and rising, disrupting and isolating, stretching or compressing a sequence, enlarging or reducing an object. It is through the camera that we first discover the optical unconscious*, just as we discover the instinctual unconscious through psychoanalysis.[42]

[40]See Somaini, 2010, xl-xliii.
[41]See Somaini, 2012, 206.
[42]Benjamin, 1939, 266.

Figure 2.1: Adiantum pedatum. Maidenhair fern, young rolled-up fronds enlarged 8 times. Photogravure after K. Blossfeld, *Urformen der Kunst*, Berlin, 1928, Plate 55.

For Benjamin, photography gives access to the optical unconscious, a visual domain that escapes unaided perception, primarily through the reconfiguration of space, by means of close-up, enlargement, reduction, isolation, and all the possible manipulations of perspective, focus, times of exposure, development, and print. In the review of Karl Blossfeld's photography book *Urformen der Kunst. Photographische Planzenbilder* – a magnificent gallery of black and white close-ups of plants, whose forms were rendered in the slightest details – Benjamin noted that the enlargement of what is already macroscopic, for instance a bud or a leaf, grants access to completely new forms, just as the enlargement of the microscopic world (Figure 2.1). And he wrote: "These pictures reveal an unimagined treasure trove of analogies and shapes from the world of plants, something only photography could achieve."[43]

It is worth stressing that, although Benjamin never wrote specifically on scientific photography, he understood very well the scientific value of the new optical medium. More than this, he was convinced that – by virtue of its analytical properties – photography fostered the interpenetration of art and science. In the essay on the work of art he went as far as to state that one of the revolutionary functions of film was to demonstrate that "the artistic uses of photography

[43]Benjamin, 1928, 350.

Figure 2.2: A man walking. Photogravure after Eadweard Muybridge, 1887. Wellcome Library, London.

are identical to its scientific uses."[44] This strong claim was accompanied by a footnote in which Benjamin drew an analogy between photography and Renaissance painting. As Renaissance painting had made use of anatomy, perspective, mathematics, meteorology, and chromatology, and in turn, had contributed to the development of these disciplines, so photography required the integration of both scientific and artistic expertise, and had the potential to revolutionize both science and art.[45]

A critical aspect of the revolutionary potential of photography laid in the fact that it opened the way to the manipulation of time. The example of the "split second when a person actually takes a step"[46] in the passage about the optical unconscious quoted above is clearly a reference to chronophotography, whereby the continuous flow of time is arrested and decomposed into instants (Figure 2.2). And once set in motion through cinematic projection, photographs can literally show the impossible: time, and thus the natural course of phenomena, can be stretched, compressed, or even reversed. In the review of Blossfeld's photography book, Benjamin argued: "Whether we accelerate the process of a plant's growth using time-lapse photography or whether we present its form magnified forty times, in either case *new worlds of images erupt like a geyser from points of reality where we least expect to find them*."[47] This sentence not only exemplifies how the time of natural phenomena can be manipulated by photography, it also helps understand what Benjamin meant when he said that

[44]Benjamin, 1939, 265.
[45]See Benjamin, 1939, note 37.
[46]Benjamin, 1939, 266.
[47]Benjamin, 1928, 350, original translation modified.

the nature that speaks to the camera is "other" from the nature that speaks to the eye, nevertheless it is no less real.[48] The world becomes "other" because the way our perception structures our apprehension of the world and its phenomena is reinvented: we have new mechanical senses through which we can explore dimensions of reality that we could not even conceive of before. And through this new mechanical perception we discover "entirely new structures of matter."[49]

Benjamin's ideas on the optical unconscious and the reconfiguration of the perception of space and time were grounded in his analysis of photography and cinema (enlargement, slow motion, time-lapse, and so on).[50] In this account, the ability of the camera to disclose the optical unconscious (the unknown, the unexpected) seems to depend chiefly on highly conscious processes of photographic manipulation and experimentation, such as enlargement, time-lapse, slow motion, and so on. Still, in the early days of photography many were fascinated by another property of the photographic process, namely, its ability to capture perfectly visible aspects of everyday life that had not been noticed by the photographer. Photography theorist Joel Snyder explains that: "the authors of the earliest descriptions of daguerreotypes dwelled on the profusion of detail carried on the surface of the mirrored plate, noting, for example, puddles or stray reflections that had gone unnoticed at the time the plate was made."[51] Photography had the surprising ability to show aspects of the visible world, at the visible scale, and within the range of the eye resolution that the eye did not catch. In this case we can talk of an optical unconscious revealed by the camera, not by rearranging space and time, but by bypassing the neuro-psychological associative laws of natural vision. It is the optical unconscious corresponding to Moholy-Nagy's idea of unbiased vision. Such unbiased vision was made possible by the (partial) independence of the camera from the photographer.[52] For Moholy-Nagy there was a fundamental divide between photography (mechanical images in general) and hand-made representations. In his view, paintings and drawings always bear traces of the author's will, or at least of his or her perceptual schemes. For him, the activity of painting and drawing was inherently limited by the laws of human perception. In representing the world, the painter cannot show more than he or she has perceived. Even if the artist de-

[48] Benjamin, 1939, 266. See quote above.

[49] Benjamin, 1939, 266.

[50] For a very interesting discussion on how early scientific cinema influenced the space and time perception of spectators', and exerted a strong impact on the early theories of cinema, see Landecker, 2005 and 2006.

[51] Snyder, 1998, 391.

[52] Moholy-Nagy considered the camera as completely independent from the photographer. We cannot forget, however, that it is always a human agent who selects a specific lens, time of exposure, perspective, and so forth. A photographic image, like any other mechanical image, can never be completely independent from the human operator.

picted an imaginary world, this would still be in a way or another linked to the functioning of the human psychology and neurophysiology. Photography, on the contrary, seemed to break the bond between the image and the human producer. The developed plates could show something that might well be in front of the camera, but that the photographer had not seen for a multiplicity of reasons (from simple lack of attention to any other form of natural limitation or impairment of human perception). In this sense we can say that photography has an inherent analytic, anatomizing quality, and an enormous potential to transform perception. Of course, in contrast to the idea that painting and drawing are heavily limited by the rules of natural perception, one could take a psychoanalytic stance and claim that every artwork is first and foremost a representation of the artist's unconscious. Or, alternatively, one could maintain that the hand of the artist is guided by formal and ideal determinants that allow to reveal aspects of the world that escape ordinary perception. In this respect, art in itself can transform our way of seeing objects no less than photography and other optical media. In this dissertation, however, I am specifically interested in mechanically produced images, thus I do not explore how image production in general impinges on our perception of the world.

2.3.2 The photographer as anatomist

A suggestive description of how photography and cinema bring about a transformation of sensory experience is provided by Benjamin in the essay on the work of art, in the famous metaphor of the cinematographic operator as surgeon:

> How does the camera operator compare with the painter? In answer to this, it will be helpful to consider the concept of the operator as it is familiar to us from surgery. The surgeon represents the polar opposite of the magician. The attitude of the magician, who heals a sick person by a laying-on of hands, differs from that of the surgeon, who makes an intervention in the patient. The magician maintains the natural distance between himself and the person treated; more precisely, it reduced it slightly by laying on his hands, but increases it greatly by his authority. The surgeon does exactly the reverse; he greatly diminishes the distance from the patient by penetrating the patient's body, and increases it only slightly by the caution with which his hand moves among the organs. [...] Magician is to surgeon as painter is to cinematographer. *The painter maintains in his work a natural distance from reality, whereas the cinematographer penetrates deeply into its tissues.* The images obtained by each differ enormously. *The painter's is a total image, whereas that of the cinematographer is piecemeal, its manyfold parts being assembled according to a new law.*[53]

[53] Benjamin, 1939, 263-264.

In the two figures of the surgeon and the magician Benjamin embodied a number of dialectical antinomies that characterized his reflection on perception, namely, first *vs.* second technique; proximity *vs.* distance; appearance *vs.* play (*Schein* and *Spiel*); cult value of the auratic artwork (the artwork still invested of its magic-sacral properties derived from its being unique and inscribed in an authoritative tradition) *vs.* exhibition value of the non-auratic work, (the work reproduced in series, freed from any ritual meaning, easily transportable and accessible to the masses).[54] Here, however, I focus on the figure of the surgeon as exemplification of the analytic, enquiring gaze of the camera.

Unlike the magician-painter, who intervenes on the patient (corresponding to the object to be represented) from the distance of his sacral authority, the surgeon-cameraman, from the proximity of his technical competence, penetrates with his hands and his eyes straight into the body. The painter creates a "total image," an image that requires of its author to always keep the necessary distance from its object in order to be able to see it. Ideally, once the work is completed, the beholder will see what the painter saw. On the contrary, the lens of the cameraman, for Benjamin, is like the gaze of the surgeon, a haptic gaze, a gaze in action. This is so because in the making of a film the cameraman has the option to zoom in and out, to chose different planes, to stop time or to make it move faster. Moreover, the frames must be further edited (the film is literally cut into sections that are subsequently reassembled or discarded), so that the final stream of images will appear to the eye of the spectator not as it had been seen by the cameraman,[55] but as it was manufactured by a team of people working under a film director. The cinematographer creates an image which is "piecemeal" because it is necessarily the output of the composition of "manyfold parts" (the different shots) "assembled according to a new law," namely the laws of cinematographic narrative. Similarly, the surgeon, in the lineage of the anatomist and the clinician, does not contemplate the body from without, he literally cuts and stitches its parts according to the rules of anatomy and physiology. Thus, the cinematic gaze is much more akin to the scientific way of looking at the world than to artistic contemplation, or even to natural vision. It is a structured, analytic way of seeing that dissects and recombines the elements of reality according to its own rules, dictated by the purpose of investigation. In the *Little History of Photography*, Benjamin hinted again at the proximity between photography and medicine when he claimed: "Details of structure, cellular tissue, with which technology and medicine are normally concerned – all

[54] See Pinotti and Somaini, 2012, 11.

[55] As a matter of fact, at the time of shooting the cameraman sees no image stream at all, but rather a number of individual events.

this is, in its origins, more native to the camera than the atmospheric landscape or the soulful portrait.[56] And he immediately added:

> Yet at the same time, photography reveals in this material physiognomic aspects, image worlds, which dwell in the smallest things – meaningful yet covert enough to find a hiding place in waking dreams, but which, enlarged and capable of formulation, *make the difference between technology and magic visible as a thoroughly historical variable.*[57]

That is, getting closer and closer to its object, in accordance with its specific analytic habit, photography has stripped the world of its magic (which does not mean that it has stripped it of its beauty) and replaced "waking dreams," by definition elusive and impalpable, with enlarged images, from which we can pick up the smallest details. The surgeon has finally overruled the magician, for technology has shortened the distance between object and observer, between the invisible and the visible, the unknown and what is "capable of formulation." In Benjamin's terms, photography has "suck[ed] the aura out of reality."[58]

2.3.3 Image series and the *aura* of the body

Benjamin's concept of aura is a complex one, and he elaborated on it from different perspectives. In *The Work of Art in the Age of Mechanical Reproduction* the notion of aura encapsulates a node of intertwined properties of the artwork before the age of its mechanical reproducibility. It is the here and now of the work of art, that is, "its unique existence in a particular place,"[59] which determines its distinctiveness and authenticity, but it is also its permanence in time, which entails its transmissibility and the related value as historical testimony. In the same text Benjamin also defines the aura as an irreducible distance between the artwork and the observer.[60] An unbridgeable distance created by the fact that the work of art belongs to a tradition whereby it derives an authority and a cult value that set it beyond the reach of the beholder. Mechanical reproduction, and the mass-production that goes with it, strips the artwork of its aura, because through the proliferation of cheap copies it obliterates its here and now, jeopardizing simultaneously its uniqueness, authenticity, historical meaning and cult value. The aura, however, is not just a property of the works of art. Natural objects can be auratic too. Benjamin defined the aura of a natural object as "the unique appearance of a distance, however near it may be."[61] But if the

[56] Benjamin, 1931, 512.
[57] Benjamin, 1931, 512.
[58] Benjamin, 1931, 518.
[59] Benjamin, 1939, 253.
[60] See Benjamin, 1939, 255 and 1931, 253-256.
[61] Benjamin, 1939, 255, see also Benjamin, 1931, 518.

aura of a natural object is the irreducible distance between the object and the beholder, then, just as the works of art, natural objects loose their aura when we get very close to them, and look at them with the analytic, anatomizing gaze of science.

Now, if we try to apply the concept of aura to the domain of medical representations, we find that the whole endeavor of Western medicine since the birth of the clinic can be seen as a laborious attempt to peel the aura away from the human body. The anatomist not only obliterates the distance of the observer and cuts directly into the body, but thanks to all the techniques put in place to explore the inner organs from without, the human body has entered a specific domain of mechanical visibility and reproducibility. With the stethoscope Laennec put the body of the patient at a distance by interposing an instrument, but he did so in order to gain a deeper access into the heart and lungs (the same happened with the endoscopic devices, meant to visualize other inner organs). With the microscope cellular pathologists pushed their senses down into the cell. With the thermometer, the sphygmometer and all the other measuring instruments, records from the inner body could be easily taken, copied, and sent from one doctor to the other, so that, ideally, there was no longer the need to be in the presence of the original (the patient) to make a diagnosis. Of course, this whole process was progressively enhanced by the subsequent development of imaging technologies that replicate our body, or parts of it, in countless samples. However, unlike the work of art, which loses its unique existence due to the proliferation of its reproductions, the uniqueness of the human body is not undermined by its copies (a human body does not lose its uniqueness just because its portrait can be reproduced indefinitely). The uniqueness of a human body fades instead in the repetition of the series, more precisely, when it becomes just one picture among many other pictures of human beings (similarly, as human beings we lose our singular identity when we become part of a crowd, a multitude, and as such we can be studied in statistical terms).

We have seen in Section 2.1 that Londe recommended to take patients' pictures in sets, because it was the best way to bring to the fore the *facies* of the disease. Within the pathological series, in fact, each singular body becomes the rough copy of an inexistent original. Interestingly, Benjamin wrote the following:

> The destruction of the aura is the signature of a perception whose 'sense for sameness in the world' has so increased that, by means of reproduction, *it extracts sameness even from what is unique*. Thus is manifested in the field of perception what in the theoretical sphere is noticeable in the increasing significance of statistics.[62]

[62]Benjamin, 1939, 256, see also Benjamin, 1931, 519.

The creation of series of images made possible by mechanical reproduction spurs our quest for similarities, our tendency to make associations, to discover analogies and common patterns. Because of the proliferation of images of each and any object, we can exercise our "sense for sameness" on a virtually endless visual domain, and therefore we are able to standardize even what is unique. Just as statistics extracts averages and distribution trends by collecting and analyzing singular events, so our perception, trained by the continuous flux of images, learns to extract resemblances between individual visual instances. And is it not the systematic, methodic and organized search for "sameness" in what is unique, a mark of the scientific way of organizing the world?

In Benjamin's reflexion on the perception of sameness it is possible to establish an interesting parallel with the anatomo-clinical perception as described by Foucault. For Foucault, the clinical gaze became possible in the hospital, were the eye of the doctor could easily encompass endless series of diseased bodies, which in some cases would be eventually anatomically dissected. In the wards of the clinic the unique, individual patient became a public and visible body that would be compared to other bodies in order to find out similarities and differences, and thus organize disparate signs, symptoms and anatomical lesions into taxonomical categories. In a way, the mechanical production and reproduction of images impinged on everyday life perception as the hospital had impinged on medical perception. It normalized the world, and made it accessible in a way similar to the way in which clinical anatomy had normalized the human body and gained access to it.

Benjamin's analysis of photography and cinema provides relevant conceptual tools for understanding the epistemic value of these optical media: the idea of an analytical potential proper to the technology itself, the idea of optical unconscious, the notion of aura, and its connection with the issue of the recognition of similarities within a series of images. In considering the photographic apparatus as inherently analytic and aimed at the invisible, Benjamin offers a firm ground to understand how the technology works and how it impinges on human perception. Yet, we still have to ask ourselves how photographs were made meaningful. We have to understand how the potentiality of the technological *medium* was actualized in the decades that followed the invention of photography. In particular, within the scope of this dissertation, we aim at understanding how photographs acquired their epistemic relevance, and thus their usefulness in the context of medicine. In other words, taking for granted the ontological properties of photography put forward by Benjamin, we must now understand how they were made operative and meaningful by early medical photographers. To this aim I turn to Sekula's idea that the physiognomic and phrenological paradigms played a fundamental role in defining the meaning of photographic portraits in the nineteenth century, and that the photographic realism professed by the beholders of the time was connected to specific archival practices that operated according to the indexical or to the symbolic modes of signification.

2.4 Bodies, archives, and the photograph as symbol

In the work "The Body and the Archive," of 1986, photographer and theorist Allan Sekula defended the view that if we are to understand how photography became epistemically relevant in the nineteenth-century scientific discourse about the body, we need to take into account two factors. First, we have to consider that by the mid of the century physiognomy and phrenology worked as a unified hermeneutic paradigm, which governed both scientific and artistic portrayal.[63] Second, we have to understand the photographic realism professed by the scientists of the time in terms of "instrumental and technical realism,"[64] embedded in specific scientific and technical practices.

This means that we cannot really understand the emergence of photography as a truth-apparatus, if we think of it only as a product of the optical empiricism provided by the camera. It is fundamental to take into account that the outputs of the camera were integrated into a pre-existing theoretical framework (physiognomic and phrenological theories), as well as into an archive, that is, into a theoretical and material system that allowed to collect, organize, and retrieve each photograph whenever necessary.[65] Sekula summarizes the specific properties of the photographic archive as follows: "In structural terms, the archive is both an abstract paradigmatic entity and a concrete institution. In both senses, the archive is a vast substitution set, providing for a relation of general equivalence between images." And still: "The capacity of the archive to reduce all possible sights to a single code of equivalence was grounded in the metrical accuracy of the camera."[66] Hence the archive, as the specialized journal or the case studies collection, was a material institution that organized series of photographs. At the same time, it was the embodiment of a theoretical paradigm (phrenology and physiognomy), which allowed to select, organize and

[63]Sekula, 1986, 11.
[64]Sekula, 1986, 16.
[65]Sekula claims that: "Since physiognomy and phrenology were comparative, taxonomic disciplines, they sought to encompass an entire range of human diversity. In this respect, these disciplines were instrumental in constructing the very archive they claimed to interpret." Sekula, 1986, 12.
[66]Sekula, 1986, 17.

interpret individual pictures within the series. Working as a "substitution set," it allowed to substitute images for real bodies. In this way it helped finding out visual equivalences and relations among individuals. It did not simply fostered what Benjamin called our "sense of sameness,"[67] but it imposed a quite strict code of vision and classification. This code bounded the viewer to interpret the photograph in a univocal way, and at the same time it dictated how the actual bodies should be. To put it differently, physiognomy was the conceptual framework that justified and required the constitution of the archive, and the archive, in turn, provided physiognomy with a standard gauge whereby it could position each single body within a larger ensemble.[68]

"Realist" and "nominalist" approaches to photographic meaning Yet this project of photographic classification of human types was made difficult by the "messy contingency"[69] of photographs. Such contingency could be tamed following a *realist* or a *nominalist* approach, each approach corresponding to a specific way of endowing photographs with meaning.[70] Within the realist approach, which posited the real existence of species and types, the circumstantial and idiosyncratic features of each picture could be distilled, as it were, into one typical or characteristic image (through a process of visual abstraction and synthesis). On the contrary, within the nominalist approach, which denied the reality of generic categories (if not as mental constructs), it was necessary to develop a filing system that allowed to retrieve a concrete individual picture whenever needed. Sekula exemplifies the nominalist stance with the work of the French criminologist Alphonse Bertillon, and the realist position with the composite portraitures by the British statistician and pioneer of eugenics Francis Galton. Through these examples he links the nominalist approach to the indexical mode of signification, and the realist approach to the symbolic mode.

In the 1880s, Bertillon created a practical signaletic system (known as *Bertillonage*) for keeping a record of criminals (Figure 2.3). Each offender was identified by photographs showing frontal and profile views of the face and whole body, in addition to the details of individual markings, such as tattoos and scars. An attached written file specified the salient characteristics of the personality of the individual. According to Sekula, Bertillon, with his accurate morphological measurements and classifications, "reinvent[ed] physiognomy in precise nonmetaphysical ethnographic terms."[71] The body reproduced in the signaletic

[67]Benjamin, 1939, 256. See also Section 2.3 above.
[68]See Sekula, 1986, 17.
[69]Sekula, 1986, 17.
[70]See Sekula, 1986, 18.
[71]Sekula, 1986, 30-33.

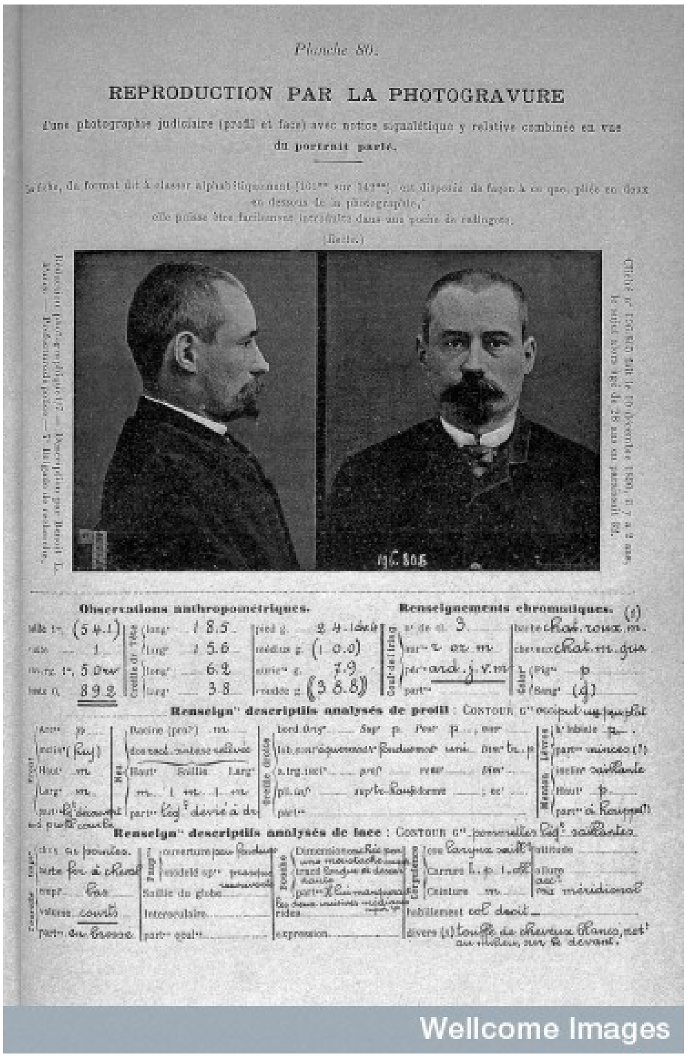

Figure 2.3: Example of signaletic photograph, A. Bertillon, *Instructions signalétiques. Album*, Melun, 1893. Wellcome Library, London.

photographs expressed nothing but its own appearance, and it was this appearance that allowed to recognize each specific criminal. On the contrary, Galton firmly believed that the body revealed the true nature of the individual, and in fact he developed his composite portraits within the scope of a larger eugenic project, aimed at defining typical classes of human beings.[72] His peculiar photographic technique was an attempt to merge optical and statistical procedures, in order to create a mechanical and statistical method that would allow to identify the real physiognomy of different groups of individuals. It consisted of re-photographing portraits of subjects belonging to a given group on a single photographic plate. Each photograph received a fractional exposure corresponding to the inverse of the total number of images in the sample. As a consequence, the individual idiosyncratic features faded away, due to underexposure, and what remained was a blurred configuration of the features which recurred in all the subjects. This mechanical method was meant to replace human judgement in the recognition of the fundamental features of a human *typus* (Figure 2.4).

Drawing on Peirce, Sekula describes Bertillon's endeavor as grounded in the indexical order of meaning of photography, whereby each photograph is the physical trace of a contingent, material referent that actually exists in the world. Galton's, on the contrary, was based on an attempt "to elevate the indexical photographic composite to the level of the symbolic, thus expressing a general law through accretion of contingent instances."[73] Yet, since Galton believed that physiognomy revealed the true metaphysical nature of the individual, he did not understand his technique of composite portrayals as a mere mechanization of visual pattern recognition; he took it as a mechanization of the inferential reasoning that leads to the formulation of general laws. Thus, in Peircean terms, the composite portraits were meant to work as symbols, because they referred to their object by virtue of a universal category.[74] On the contrary, in *Bertillonage*, each photograph literally corresponded point by point to its referent (the body of the criminal), and was intended to always refer to that and only that referent. In the system of composite portraits, the final photograph embodied a synthesis

[72]As most social scientists of his time, Galton was obsessed with the idea of establishing the physiognomy of the insane, the criminal and the Jew, but he also searched for the *typus* of the consumptive.

[73]Sekula, 1986, 55. In Peirce's semiotics, a symbol is defined as "a sign which refers to the Object that it denotes by virtue of a law, usually an association of general ideas, which operates to cause the Symbol to be interpreted as referring to that Object." Peirce, CP, 2.249.

[74]Galton certainly did not conceive of his general physiognomic laws as conventional correspondence rules. He was firmly convinced of the reality and correctness of the laws he could extract by operating the process of composite portraiture.

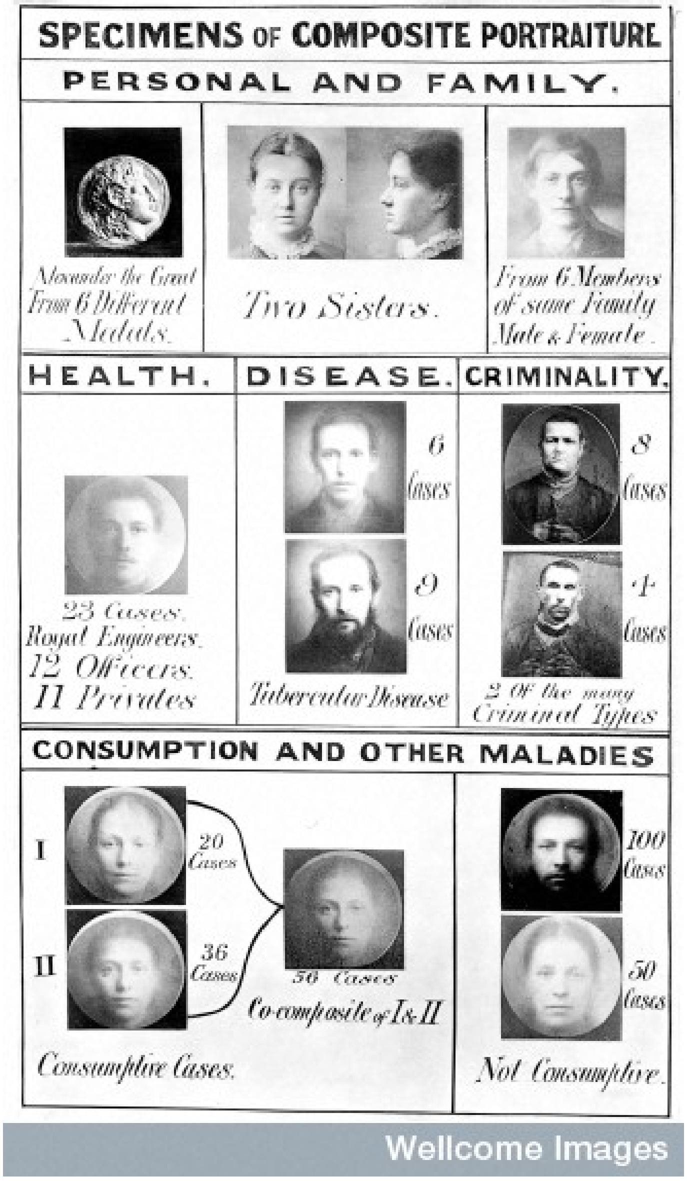

Figure 2.4: Specimens of composite portraiture, F. Galton, *Inquiries into Human Faculty and It's Development*, London, 1883, Frontispiece illustration. Wellcome Library, London.

of the images of many referents, and it was intended to refer to an indefinite number of individuals on the basis of their resemblance to the synthetic image.

Sekula' analysis is particularly useful because Bertillon and Galton's work are extreme examples of two opposite, yet complementary forms of making sense of and using photographs not only in the social sciences (and pseudo-sciences), but also in medicine. *Bertillonage* can be taken as the epitome of the nominalist approach (which denies the reality of generic categories and focuses on singular, actual instances). Here the photograph works as an index and the archive is used to properly assign an individual to his or her signaletic picture, in order to check and certify his or her identity. In this case, the task of photography is to ratify a univocal correspondence: one criminal-one picture.[75] There is no hidden truth beyond this correspondence, or more precisely, the photograph cannot say anything that goes beyond such correspondence. We could say that in this case the contingency of the photographic image prevailed over the theoretical ambitions of the physiognomic paradigm. And in fact, Sekula argues that Bertillon's reinvention of physiognomy in nonmetaphysical terms had the ambition to constitute a real science of the individual. That is, a science that established for each individual the idiosyncratic rules of his or her appearance and behavior. This science, however, could only be a descriptive, ethnographic endeavor, since it would not allow to (it was not meant to) infer universal laws about the countenance and actions of all human beings. Yet, used in this way, the photograph and the archive would help the criminologist, as well as the ethnographer or the physician, to carefully follow the transformations occurring on the body of a singular individual. Photography identified the individual. When Londe recommended to keep photographic records in the patient's file, he had in mind this specific use of photography.[76]

Galton's endeavor went in precisely the opposite direction to Bertillon's. If for Bertillon the fundamental function of the archive was to associate one portrait to one and only one individual, for Galton a collection of photographs became useful and scientifically meaningful as far as it allowed to make abstraction of particular instances and generate the universal face of the mentally ill, the consumptive, the criminal, or any other possible group of human beings. Through the technique of the composite portrayals, Galton collapsed several photographs of the archive into one, so that the contingency of each singular portrait could literally fade away to give way to the *typus*. Composite portrayals were not portraits of human beings, they were portraits of conceptual

[75]This function of photographs and of the photographic archive perfectly fits Peirce's definition of photographs as signs that are "produced under such circumstances that they [are] physically forced to correspond point by point to nature." Peirce, CP 2.247.

[76]See Section 2.1 above.

categories, general ideas. Galton, however, believed that such categories were as real as the bodies that were classified. He worked in strict accordance with the physiognomic framework, and the originality of his work resides in the fact that he tried to automate the abstract thinking that leads from the particular to the universal. He did so by attempting to treat visual information in statistical terms. In this sense, he literally conceived of his photographic technique as a nomological machine, a mechanical device that reproduced the laws of human nature.

Although physicians did not necessarily subscribe to Galton's purpose of mechanizing clinical judgement, they nevertheless shared with him a fundamental assumption, namely, that working on series of photographs one could perform the same kind of observations, apply the same patterns of reasoning and judgement, and reach the same conclusions, as if one was working with series of actual individuals. In other words, it was possible to substitute the body of the actual person for its photographic image. This implies that it was necessary to believe in the indexical nature of photography in order to believe that the archive could reveal a universal truth. For Galton the individual photograph *per se* could not point to a universal human *typus*, and this is why he had to develop a system to produce a composite image. The individual photograph would just contain the truth of the individual instance it represented. For a universal truth to emerge, it was necessary to combine different pictures. Galton and Bertillon shared the same beliefs about the ontology of the photograph (it was a perfect imprint of the real object, burden with contingency), but they diverged on the epistemology of the archive. Galton worked according to a realist stance, while Bertillon followed a nominalist approach. Galton wanted to develop a science of the individual in the sense of a science of typical classes of human beings (identification and definition of human categories). Bertillon, on the contrary, aimed at a positivist science of the individual as ethnography of the particular, which withdrew from any generalization. Accordingly, Galton's endeavor was envisaged as science (criminology), while Bertillon's was deemed a technique (criminalistics). The former looked for *the* criminal (or *the* consumptive, *the* insane, etc.), the latter looked for *this* or *that* offender.

Now, if in the enforcement of law criminalistics could do without criminology,[77] in medicine the analysis of a single photographic portrait acquired diagnostic cogency only when it could be referred to a general image of the disease. Hence, in medicine the two epistemological approaches concerning the archive

[77]In this case the aim was to verify the identity of the suspect and to check if he or she had already been charged, in the past, for other crimes. The photograph said *who* the person was, not *how* he or she was.

had to work in tandem, and if a physician was to use photographs as diagnostic devices he had to continuously shift between the general (realist) and the particular (nominalist) approach. In the following sections I analyze how these two instances were realized in actual medical practice, taking into examination the work of different pioneers of medical photography.

2.5 Physiognomic laws and therapeutic portraits

As shown above, the phrenological and physiognomic theories provided a fundamental epistemic paradigm for making sense of photographic portraits, hence it does not come as a surprise that psychiatry was one of the first clinical disciplines that tried to put photography in the service of diagnostics. In fact, if the human character and mental faculties expressed themselves through facial configuration and in the form and measures of the head (the tenets of physiognomy and phrenology, respectively), then photographs would be the ideal diagnostic and nosological instrument. The photographic portrait could be the empirical evidence of the visual symptomatology of psychosis.

The first attempt to systematically use photography to record the physiognomy of the mentally ill for clinical use was carried out by the British psychiatrist Hugh Welch Diamond, superintendent of the Female Department of the Surrey County Asylum. Importantly, he was also a founding member of the Royal Photographic Society. In 1852, Diamond produced a photographic series of *types of insanity*, and four years later he gave a talk at the Royal Society in which he expounded what he considered to be the three functions of photography in the diagnosis and treatment of mental illness.[78] Photography, Diamond maintained, could record the appearance of the insane for study (physiognomic paradigm); it could be used in the treatment of patients, by presenting them a strikingly accurate self-image; and it could be valuable in case of re-admission (the photographic portrait would confirm the identity of the patient and recall to the doctor's mind the case and its treatment).[79] Hence, the photograph was simultaneously embedded in a gnoseological structure (the physiognomic theory), a therapeutic protocol, and a controlling apparatus. For what regards the diagnostic function, it was conceivable because, by catching the expressions and countenance of the patient with perfect accuracy, it allowed the psychiatrist to evaluate the corresponding mental state with the highest precision. However,

[78]Historian Jennifer Tucker remarks that Diamond used his photographic albums not only for medical purposes, but also to promote scientific photography. His work circulated among photographers, beyond the medical community. See Tucker, 2005, 18-19.

[79]See Diamond, 1856.

the individual portraits could work as diagnostic tools only by looking at them against the universal and normative physiognomic framework. Hence, Diamond had to believe that there existed a physiognomic *typus* for each mental condition, and that the photographic series, by gathering together several individual instances, would allow to distill general, universal features that identified different groups. In this respect he subscribed to what Sekula has identified as the symbolic meaning of photographs, epitomized by Galton's composite portraitures. On the contrary, when he suggested that the inmates' portraits could be used as a reference in case of re-admission, Diamond was clearly thinking of photographs in indexical terms, as Bertillon would do some decades later. More importantly, it was within that conception of photographs as indices of individual identities and histories that Diamond could envisage the use of photography as diagnostic and therapeutic tool. The photographic portrait could have a therapeutic effect as far as both the physician and the patient believed in the perfect realism and truth-value of the camera (I will elaborate more on the therapeutic use of Diamond's photographs below).

As most scientists of his time, Diamond was bold in his claims about photography. In the paper delivered to the Royal Society he stated:

> The Photographer secures with *unerring accuracy* the external phenomena of each passion, as the really certain indication of internal derangement, and exhibits to the eye the well known sympathy which exists between the diseased brain and the organs and features of the body. [...] The Photographer catches in a moment the permanent cloud, or the passing storm or sunshine of the soul, and thus enables the metaphysician to *witness and trace out the connection between the visible and the invisible* in one important branch of his researches into the Philosophy of the human mind.[80]

In this quote Diamond summarizes his convictions on both psychiatry and photography. In accordance with the physiognomic paradigm, he firmly believed that there was a correspondence between the physical appearance and countenance of a person and her psychological state. Mental disease, which is in itself invisible, became visible on the surface of the body. Hence the metaphysician, that is, the thinker who tried to understand phenomena of intangible nature such as human nature, had to look at the slightest bodily manifestations if he was to accurately map, classify, and eventually understand, psychiatric disorders. In this physiognomic framework, photography played the same role that neuroimaging currently plays in neuropsychiatry, which tries to map mental disease into functional areas of the brain. Photography, with its purported "unerring

[80] Diamond, 1856, 20.

Figure 2.5: Patient at Surrey Asylum, case identified as "religious melancholy." Calotype by H.W. Diamond, 1852.

accuracy," had the ability to catch even the slightest manifestation of the soul, being it a lapse of anger or an instant of joy. And through the attentive analysis of these superficial manifestations, the psychiatrist could trace the thread from the visible surface (the body) to the invisible source of disease (the psyche).

Diamond hoped that through the creation of image repositories of patients with different psychiatric conditions, it would be finally possible to define and classify mental diseases on the firm grounds of the "silent but telling language of nature," which is more powerful than any "laboured description."[81] Each portrait would function as an exemplar of the disease, a characteristic *typus*, which embodied the fundamental and recurrent features of the pathological state. Here the individual was again obliterated, it became an occurrence within a series, or the impersonal, characteristic specimen of a disease. As epistemic instrument at the service of the physiognomic theory, each portrait could function at two levels. On the one hand, it worked as an exemplar of the disease, as a dried leaf or flower in the herbarium of a botanist. It represented a characteristic *typus*, which embodied the fundamental and recurrent features of a given mental condition, e.g., mania or melancholia (Figure 2.5). On the other hand, it could be embedded in two different series of images: (1) a sequence of portraits of various patients affected by different mental illness, and (2) a sequence of portraits of

[81] Diamond, 1856, 19-20.

the same patient at different stages of the disease. In the first case, by putting in contrast characteristic representatives of a variety of mental pathologies, the photographic series was meant to make more visible the idiosyncratic features of each exemplar, thus making the individual picture more eloquent and reinforcing its meaning. In the second case, the series showed the transformations that might occur within the same patient, thus adding a temporal, dynamic dimension to the study of the disease. From this multiplicity of uses of patient's portraits emerges, once again, the unresolved tension between the will to represent the universal features of a disease (to identify a *typus*) and the need to deal with singular, idiosyncratic individuals.

As seen above, in the discussion of Londe's ideas on medical photography and Sekula's analysis of archival strategies, it seems that early medical photographers (and, more generally, scientists) tried to come to terms with the problem of the relation between the general and the particular by creating different forms of photographic series. On the one hand, they produced series of pictures of different patients affected by the same ailment, in order to visualize the *general* (universal) morphology of a disease; on the other hand, they gathered series of pictures of the same patient, in order to reconstruct the history of the disease in that *specific* individual. These two movements correspond to the realist and nominalist modes of signification, respectively. They show how, in medicine, two irreconcilable philosophical positions are forced to come to terms. Medicine, as a practice, has to treat idiosyncratic unique individuals, hence, it must work according to a nominalist approach. However, medicine, as a science, has to extrapolate universal features from individual cases, and is thus forced to work by induction, according to an ultimately realist mode of signification.

2.5.1 Clinical cases: articulating pictures and words

The search of a *typus* for a group of patients, corresponding to the *facies* of the disease, was certainly the main core of the use of photography in medicine in the nineteenth century, and the most common and widely available form of archive was the collection of photographically illustrated clinical cases. The publication of clinical cases in journals and atlases was meant to train the sort of reasoning and intuitive judgement that Galton tried to automate with his composite portraits. A fundamental aspect of clinical cases, however, is that images are wedded to a text, sometimes as mere examples, sometimes as non verbal arguments. In this case, in order to understand the functioning of photography as epistemic device, we must look also to its relation with the accompanying text.

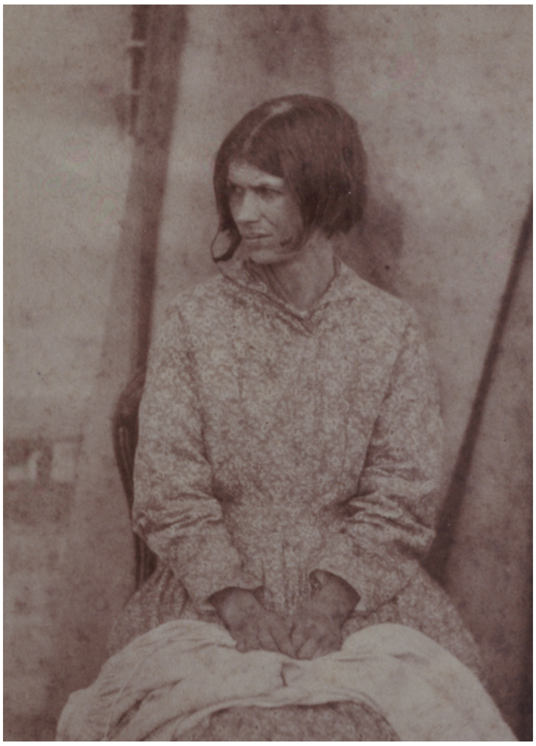

Figure 2.6: Patient at Surrey Asylum, case identified as "melancholia passing on to mania." Calotype by H.W. Diamond, 1852.

John Conolly, a major figure in the reform of the British asylums system (he introduced the non-restraint system in the Hanwell Asylum), used Diamond's photographs in a series of essays on clinical cases published in 1958. In the clinical case *Melancholia passing on to Mania*, he referred to the portrayal of one patient (Figure 2.6) as follows:

> [I]n the present instance the patient, after being insane some months, and then falling into utter despondency [...] was in transition towards mania. [...] Her story is but one in a larger chapter of such which London furnishes. She gained a small livelihood by the occupation of a sorter and folder of paper, and lived but poorly. After a confinement she had an attack of puerperal mania, lasting about six months; her conversation was generally incoherent, and her actions were sometimes impulsive and violent. [...] The photograph, taken when the state of melancholy was passing into that of excitement, retains something of the fixedness of attitude and expression in the first state; as in the arms held close to the body, and the position of the lower extremities, and in the downward tension of the cheek. The body is thin, and the hair is lank and heavy. [...] The forehead is wrinkled with some strong emotion, and the eyebrows, although corrugated, have not the tense contraction toward the nose which is observable in many cases of melancholia [...].[82]

[82]Conolly, 1858, 47-48.

This long quote shows well how the photograph, together with its description and interpretation, was embedded in a narrative structure that encompassed the life history of the patient (she was working-class, poor, she had a baby), and her clinical history (she had been previously confined, she had suffered from puerperal mania). Through the physiognomic paradigm, these discursive elements were mirrored and literally embodied in the expression and countenance of the woman, and the possibility of a correspondence between image and text was warranted by the existence of a standard physiognomic vocabulary. Fixed attitude, contracted arms and hands, tense cheek and wrinkled forehead were the signposts of mental illness: madness expressed itself on the body by clamping it through the contraction of all the muscles. Conolly, just like Diamond, believed that the photographs spoke the telling language of nature, but that language would make sense only to those initiated to the nuances of the physiognomic descriptive vocabulary and its system of correspondences. It was because Conolly knew the clinical history of the patient, and he possessed a necessary and exact lexicon, that he could extract the signs of a specific form of mental derangement from the photograph. The meaning of the picture was deeply entrenched with the written discourse that surrounded and sustained it. Images and words confirmed and reinforced each other, constituting a continuous and coherent epistemic structure.

2.5.2 Ambiguous, intimate portrayals

As mentioned earlier, however, for Diamond the portraits of his patients were not only nosological instrument, they were also therapeutic resources. Anticipating by more than a century some of the intuitions of the psychodynamic approach, the psychiatrist-photographer defended that by looking at the accurate self-image provided by the photographs, the patients would be encouraged to undergo the necessary treatment. In the communication delivered at the Royal Society in 1856, Diamond reported that the photographic portraits had produced a positive effect on some of the women under his care. Confronted with such realistic images of themselves, patients were impelled to react to their condition. Diamond also claimed that once cured, they showed amazement, and sometimes amusement on seeing the pictures taken during the unfolding of their disease. He believed that those very images might serve as a reminder of passed suffering and would engender “the most lively feelings of gratitude”[83] for the recovery. The photographic image became an instrument of self-knowledge and reflexivity.

[83]Diamond, 1856, 21.

According to the historian of medicine Sander L. Gilman, the rationale of Diamond's course of treatment was directly grounded in the shocking impression of reality that photography arose in the patients (and, more generally, in all the earlier viewers of photographs). The photographic plate confronted the patient with a new, startling perception of herself, and this perception seemed so unnaturally real that it was supposed to put in motion a process of self-reflexivity.[84] "The nineteenth-century alienist" Gilman claims, "saw the patient-observer as sharing the implication of the photographic image, the startle effect that accompanied the introduction of this new medium of representation."[85] Hence, the patient was not merely an object of study. On the contrary, she was supposed to partake the gaze of the clinician and turn it upon herself, not in the sense of perceiving herself as an anonymous object of scientific inquiry, but rather in the sense of developing a form of self-reflexivity. In other words, Diamond's therapeutic program broke with the dichotomy between observer and observed established by clinical anatomy, and acknowledged the patient's competence to directly interact with her own image. Of course, the way these women interacted with the photographs and with their meaning was deeply influenced by the medical setting, and it is hard to say if the sort of self-reflexivity promoted by Diamond was normative or liberating (we might reasonably assume that this depended on the singular case). Yet, it was certainly an approach that presupposed a degree of psychological autonomy and self-awareness in the mentally ill, a presupposition that was clearly absent in the so-called visual psychology developed twenty years later by Jean-Martin Charcot, at the Salpêtrière. Here the patients were used as actual experimental specimens and thus asked, or even forced, to perform their hysteric attacks in front of Charcot, his assistants and the public who crowded his Tuesday lectures (I discuss the iconography of the Salpêtrière later in this chapter).

Diamond's double protocol, nosological and therapeutic at the same time, implied an inherent tension between the objective and subjective meaning of the photograph, because the patient was asked to observe her subjectivity made visible, hence objectivized, by the photographic apparatus. In this sense we can say that the pictures from the Surrey Asylum are ambiguous and unsettling, for they occupy a middleground between the portrayal of a unique individual, invited to self-reflexivity, and the scientific evidence.[86] We will never know

[84]See Gilman, 1993, 355-356.

[85]Gilman, 1993, 355.

[86]It is interesting to note that physicians were concerned about the dangers of letting circulate medical photographs outside the hospital. In 1863, the psychiatrist Legrande du Saulle envisaged the creation of photographic records of the kind implemented by Diamond, but he stressed the importance of destroying the images once the patient was discharged from

Figure 2.7: Patients at Surrey Asylum. Calotypes by H.W. Diamond, 1852.

what these portraits really meant to the women represented in them, what they really saw in those carefully composed images. To the untrained contemporary observer, they are quite quizzical pictures. The brow of the young woman described by Conolly is certainly furrowed. She looks perplexed, preoccupied, and resigned, all at the same time, but the intensity with which she stares at something going on outside our field of view drags us outside of the photograph, rather than into the intimacy of her emotional state.

Even more enigmatic is the image of a girl with a laurel wreath and a blanket (Figure 2.7, left). The wreath was a common adornment in early photographic portraits, but it was normally associated with a corresponding scenario and clothes. Here, however, it stands out in stark contrast with the dark blanket, which could be a mark of the hospital as well as a fake cape for a bizarre theatrical scene. The girl seems to look attentively at someone outside of the photographic set, as though waiting for instructions, and unless we assume that the eccentric attire was a mark of her behavior, we have no clue about the reasons for her admission into an insane asylum. The lady with a white ribbon (Figure 2.7, right) seems to get closer to our current idea of psychiatric patient: her eyes wide open look somewhere beyond us, and her tightened lips – together with the crossed arms that enclose her body in a large shawl and the lace that fastens the straight motionless hair – seem to keep at bay an inner sorrow. In figure 2.8, the uncombed hair and the crumpled clothes of the patient might possibly reveal her alleged hysteria, and yet, the mix of sadness, weariness and irony that shows through her face remains indecipherable. Our attention is

the asylum. He was afraid that photographs could end up on the market with a potentially disrupting effect on both the diseased person and his or her family. See Sicard, 1995, 18.

Figure 2.8: Patient at Surrey Asylum. Calotype by H.W. Diamond, 1852.

caught by the ring on her left hand (what Roland Barthes would identify as the *punctum* of this photograph), which points to her life outside the asylum, her family, her private history.

There is a decorous calm in the bodies of these women, which contrasts starkly with the spectacular bodies of the hysterics depicted by Charcot in collaboration with his assistants and photographers. Unlike Charcot's patients, captured in the uncontrolled agitation of their seizures, Diamond's ladies stand still, posing for the photographer in profound concentration, whether they look into the camera or to some invisible event removed from our field of view. Art historian Martin Kemp has remarked that Diamond's pictures were staged within the aesthetics (framings, backgrounds, posing) of the photographic portrayal of his time,[87] and indeed, most of them could find their place in a family album. Looking at these photographs we do not see clinical cases, we rather have a feeling similar to that described by Benjamin in relation to David Octavius Hill's portrait of the Newhaven fishwife. Benjamin wrote:

> In Hill's Newhaven fishwife, her eyes cast down in such indolent, seductive modesty, there remains something that goes beyond testimony to the photographer's art, *something that cannot be silenced*, that fills you with an unruly desire to know what her name was, *the woman who was*

[87] See Kemp, 2006, 292.

> *alive there, who even now is still real and will never consent to be wholly absorbed in 'art.'*[88]

As the Newhaven fishwife, the women from the Surrey Asylum tell us that they were "alive there." They assert their presence, their life. It is a life that has passed away for long now, and yet it left its sparkle there, indisputable. The photograph captured that instant of life that cannot be erased, because it has already happened, it is accomplished, and nothing can un-make it. As in the case of the Newhaven fishwife, the presence of the women from the Surrey Asylum in front of the camera goes beyond the photographer's art (and the scientific categories of the psychiatrist), imposes the sheer reality of their existence, and make us wonder about their names, their real lives.

2.6 Dermatology: the struggle for realism

Together with psychiatry, the other clinical specialty that immediately sized upon photography was dermatology. As discussed in Chapter 1, clinical anatomy revolutionized medicine by positing the internal, hidden lesion as the origin of any disease. In the case of dermatology, however, there was no hidden lesion to look for: the lesion was at the surface, consequently its very visibility was the symptom, the sign and the diagnosis at the same time. Accordingly, photography was immediately perceived as an ideal recording and diagnostic tool for dermatologists. Dermatology is a discipline of total visibility, hence, for the dermatologist, the superficial gaze of the camera perfectly fitted with the eye of the clinician. The closeup, the selection of details on the very surface of the body, *was* the clinic. Not surprisingly then, it was a dermatologist, Albert Hardy, who coined the expression "photographic clinic" [*clinique photographique*], in 1867.

With its ability to carefully record what the eye of the doctor saw, photography was an ideal means of communication and knowledge sharing: pictures circulate easily, and rare skin diseases started to travel in effigy across countries. Moreover, thanks to its capacity to keep record of what is unnoticeable, it fostered the observation of new phenomena. Therefore it was thought that it could help in both diagnosis and nosology. Yet, media theorist Monique Sicard points out that with the introduction of photography in dermatology uncertainty tended to prevail over knowledge. In the absence of well established taxonomical frames, in fact, the accumulation of scattered visual data lead to the proliferation of painstakingly detailed descriptions, which had little use for actual medical practice.[89] For some years discussions about the proper identi-

[88] Benjamin, 1931, 510.
[89] See Sicard, 1995, 15, and 1998, 149.

fication of papules, pustules, spots and the like burgeoned, in the attempt to establish an ever more specific terminology. The debate went as far as to raise Hardy's preoccupation that the proliferation of images could paradoxically lead to an arid nominalism, with dermatologists more preoccupied in labeling the manifestations of the diseases rather than understanding and treating them.[90]

Hardy, in collaboration with his intern A. de Montméja, was the mentor of the first photographically illustrated medical review, the *Clinique photographique de l'Hôpital Saint-Louis*, which was published in fourteen issues between 1867 and 1868, when all the installments were collected in a single volume atlas.[91] This work had an explicit pedagogical intent. In the preface Hardy explained that the objective of the publication was to provide medical students and practitioners with a visual aid to train the eye in the recognition of skin diseases. To this aim each pathology was sketched out in a short verbal description and exemplified by a photograph. Photographs, with their alleged realism, were supposed to have a higher degree of exactitude, compared to other forms of illustration, and leave a stronger mnemonic impression. In order to assure his readers about the accountability of the images, Hardy specified that all the pictures had been skillfully created by his assistant, "who combine[d] an in depth knowledge of skin diseases to an indisputable talent as photographer and colorist." The plates, he insisted, "represented nature caught in the act."[92] Yet, in spite of the absolute visibility of skin diseases, to catch them in the act, that is, to represent them faithfully, was a real challenge for photography. Actually, the attempt to truthfully depict the skin called into question the very axiom of photography's fidelity to nature. The most obvious difficulty came from colors. How much realistic could be a representation that reduced the endless palette of the real world to a fading scale of grey? Color shadows of the skin lesion are a relevant diagnostic elements in dermatology, but good quality and affordable color photography became available only as late as 1950s.

Between fiction and reality Undoubtedly, in terms of realism, photographs lagged far behind another form of dermatological representation, the so called *moulages*. Used as teaching tools and research documents, *moulages* were three-dimensional wax models of skin diseases, characterized by the astonishing, haptic naturalism distinctive of wax sculptures. After being casted directly from the

[90]See Sicard, 1995, 15, and 1998, 149.

[91]Hardy became familiar with the dermatological applications of photography in 1866, when he came to know the work of Alexander Belmanno Squire in London. He consequently asked his student de Montméja to work on this new imaging technique and in a very short time they created the *Clinique Photographique*. See http://www.bium.univ-paris5.fr/histmed/medica/dermato.htm (retrieved on Aug 16, 2013).

[92]Hardy, 1868, n.p.

patient's body, these models were painted and, in many cases, real hair, nails and clothes fabric were added to reinforce the appearance of real life.[93] Compared to photographs, however, *moulages* were cumbersome, fragile, took much space, and were difficult to transport. Crucially, they were not mechanically reproducible and could not be produced in large series.

Still, in spite of all the obvious differences that separate wax models from photographs, the excessive, disturbing naturalism of the *moulages* finds an odd counterpart in the iconography of the *Clinique photographique*. In fact, in order to overcome the problem of color, de Montméja had to retouch each photographic plate with watercolors, a common practice at the time, creating hybrid images that attempted to merge photographic and pictorial realism. These hybrid pictures expose a contradiction that apparently eluded both scientists and photographers in the nineteenth century. On the one hand, photographs were trusted on the basis of their indexical nature, more specifically, on the basis of the belief that the realism of a photograph scored above the realism of a painting, because the photographic image was the result of a direct imprint of nature on the sensible plate; the photograph was perceived as a natural object, the un-mediated appearing of reality on a photographic plate. On the other hand, those who actually produced the photographs realized that in order to really look like reality, the photographic image had to be retouched, using traditional artistic techniques as watercolor. That is, far from being unproblematic imprints of nature, dermatological photographs required intense labor in order to become similar to the real objects they were meant to represent.

That notwithstanding, the earliest practitioners of photography did not discuss or problematize the contradictions arising from their ideas about photography (perceived as imprint of nature) and their actual practice (intensive labor to make photographs look similar to reality). We could say that they were not disturbed by the ambiguity of the new optical medium. They trusted and praised its fidelity to nature, even though they were quite aware of its actual limitations. In this regard, photography theorist Geoffrey Batchen has argued that in the early days of photography the ontological status of photographic pictures was understood as complex and unstable, wavering between fiction and reality.[94] Through the analysis of Hyppolite Bayard's *Self-Portrait as a Drowned Man* (1940), an ostensibly staged (hence fake) photographic portrait

[93]Wax *moulages* were produced and used between the 1890s and the 1950s for clinical collection and medical training. They were completely let aside only in the second half of the twentieth century, when the quality of color photograph substantially improved, allowing for a more powerful visual realism. See Schnalke, 1995 and 2004.

[94]Batchen, 1999, 202.

that depicted the photographer as if he had died by drowning,[95] Batchen shows that the photograph was understood as both perfomative *and* documentary, a natural object *and* a cultural artifact.[96] In a similar vein, Sabine Kriebel has pointed out that during the nineteenth century the conception and reception of the photographic image was "bifurcated."[97] On the one hand, photographs were perceived as the product of a technical process, and the camera was conceived of as a picture-machine whose mechanical functioning was a warrant of objectivity. On the other hand, the language used to refer to photographs was often based on nature, as if they were quasi-natural objects (common expressions were "sun pictures" and "impressed by nature's hand"). They were "taken" from nature in quite the same way as naturalists took their specimens from the wild.[98]

The pictures of the *Clinique photographique*, with their superimposition of two media (photography and watercolor) produced an involuntary and unsettling carnivalesque effect (Figure 2.9), and yet they provided medical evidence. Used to illustrate the discursive description of the different pathologies (in the pagination of the atlas each image follows its corresponding text), these photographs were meant to transform living and suffering individuals into the representative of a disease. Embedded as they are in the structure of the atlas, the bodies and the faces of the patients became part of a scientific discourse, an argumentation grounded in an optical empiricism. Nevertheless, if we remove them from this context and look at them outside of the series of clinical cases, those images taken almost a century and a half ago, still convey private histories of suffering and shame. They are two-sided. On one side they are scientific models (of the disease), on the other they are portraits (of the singular patient). In other words, these photographs embody the problem of the relationship between a scientific representation which is, by definition, the representation of a general instance, and the representation of an individual, a particular case, with its unicity and idiosyncrasies.

[95]Hyppolite Bayard claimed to have invented photography before Daguerre, and that he had been persuaded by a friend of Daguerre to postpone the announcement of his findings. Consequently he missed the opportunity to be recognized as the inventor of the medium. In 1840 he reacted to this injustice by creating a portrait of himself as a drowned man. He accompanied the photograph with the following caption: "The corpse which you see here is that of M. Bayard, inventor of the process that has just been shown to you. As far as I know this indefatigable experimenter has been occupied for about three years with his discovery. The Government, which has been only too generous to Monsieur Daguerre, has said it can do nothing for Monsieur Bayard, and the poor wretch has drowned himself. Oh the vagaries of human life...!"

[96]Batchen, 1999, 202.

[97]Kriebel, 2007, 8.

[98]See Kriebel, 2007, 8.

Figure 2.9: Female patients affected by impetigo (left) and pemphigus foliaceus (right). A. Hardy and A. de Montméja, *Clinique photographique de l'Hôpital Saint-Louis*, Paris, 1868.

Educating vision and emotion Spurred on by the success of the *Clinique photographique*, in 1869 de Montméja together with another intern, J. Rengade, improved the equipment of the Saint Louis' photographic studio and created the *Revue photographique des hôpitaux de Paris*. In the introduction to the first issue of the new publication, the two physician-photographers wrote that they had "the honor to publish the most baffling cases collected in Paris hospitals," and they defined their photographic station "the meeting point of what is more interesting and rare in pathology."[99] Indeed, the *Revue photographique* was a collection of clinical cases of the most striking and upsetting dermatological and teratological diseases of the time, carefully documented and illustrated. Commenting on the work of de Montméja and Rengade, Robert Pujade, philosopher and theorist of photography, has argued that looking at this kind of publications (the *Revue photographique* was quickly followed by similar journals) one has the impression that photographs replaced the ancient cabinet of curiosities, with their collections of exotic specimens, whose nature and classification was uncertain.[100]

In Renaissance Europe, cabinets of curiosities were assortments of objects of all kinds. They might include stuffed animals, horns, skeletons, minerals,

[99] de Montméja and Rengade, 1869, n.p.
[100] See Pujade, 1995.

herbaria, as well as artworks, religious and historical relics, automata, ethnographic specimens, and so forth. Some cabinets of curiosities were precursors to museums, but often the most bizarre biological specimens found their final destination in freak shows. Freak shows, which started to be popular in Europe already in the second half of the sixteenth century, put on display all kinds of biological oddities, with particular emphasis on unusual human beings (e.g., very large or very small persons, hermaphrodites, siamese twins). As a matter of fact, medical teratological photographs, with their visual violence, look more like freak shows than cabinet of curiosities. This is probably the reason why Cartwright has argued that early medical photography, with its hideous iconography, fed the voyeuristic pulsions of the medical community.[101] Pujade, too, wonders in what these catalogues of deformities could help the advancement of the medical science. Yet, his answer is quite different from Cartwright's. He suggests that teratological photographs were actually meant to train doctors' perception. This training was not aimed at recognizing recurrent patterns of a disease, but rather at getting used to the horror and revulsion aroused by the deformity of the human body, in order to become able to accomplish the task of the scientist, that is, to observe with detachment.[102] For Pujade, it was not a matter of voyeurism or of de-humanizing the doctor or the patient, it was rather a methodological, pedagogical necessity of transforming "a catastrophic body into an observable phenomenon," carrying out a transition "from a fantastic dimension of appearances to an observable reality."[103] The clinical glance, to be effective, had to get used to obliterate the instinctual impulse of pity and disgust, so that the underlying medical phenomenon could come to the fore.[104] The education of the eye became an education of emotions.

The expressive dimension of the dermatological portrait acquires its full extent in the photographs of Félix Méheux. This photographer, employed at the Hôpital Saint-Louis between 1884 and 1904, was at the same time praised and criticized for his pictures.[105] Trained as a painter and not as a clinician, he cre-

[101]See Cartwright, 1995. For an interesting analysis of the relationship between the nineteenth-century freak shows and contemporary medical documentaries, see van Dijck, 2005, 20-40.

[102]See Pujade, 1995, 92.

[103]Pujade, 1995, 93, my translation.

[104]The problem of the medical freak show is not just a concern of modern scholars in visual studies. Already at the time when pathological photography appeared critics from within the medical domain pointed out that many of the pictures that were published had no scientific relevance. As early as 1865 the *British Medical Journal* charged the editors of *The Lancet* with obscenity, for publishing a photograph of a man with two sets of genitals, and in 1886 another author questioned the avail of taking photographs of morbid specimens which, compared to the corresponding drawings, seemed to show nothing but morphologic chaos. See Kemp, 2006, 279.

[105]See Pujade, 1995, 90-91, and Sicard, 1998, 150-151.

Figure 2.10: Syphilitic alopecia (left). Pigmentation probably caused by photosensitization due to a cosmetic product (right), F. Mehéux, ca. 1884-1893.

ated his images from the perspective of the visual artist. Through a skillful work with light, shadows, and framing, he deliberately composed photographs which did not just exemplify the pathology, but were first and foremost portraits of the diseased individual, conveying a personal history and an intimate suffering (Figure 2.10). As noted by Pujade: "[In the work of Méheux] the artistic gaze puts on stage the simple presence of subjects who pose for the 'alopecia areata decalvans', the 'herpetic diseases', or the 'fetal ichthyosis', with the result of burdening with beauty the image of their catastrophic condition."[106] Like allegoric figurines, the women and men of these portraits stand for something else than themselves, they pose as images of a disease, but the choice of focus and framing, the darkness that surrounds them, the small details (a ring, a curl), direct our look towards a human being, not a clinical case. It is not a matter of aestheticizing the disease, there is neither morbid voyeurism in these photographs, nor moralizing intentions. What happens is that the narrative, personal dimension of the portrayal overrules its informational content. Not surprisingly, then, physicians acknowledged and appreciated the uncanny beauty of Méheux's portraits, but some of them accused him of not being scientifically sound, because his pictures were not produced according to standardized protocols (the rules summarized by Londe in his book of 1893), but rather according to artistic

[106] Pujade, 1995, 91, my translation.

canons.[107] The shattered humanity of Méheux's portraits was perceived as apt for contemplation and emotion, not for scientific observation and examination.

Photography might well be endowed with an inherent analytic or dissecting quality, but in order to be scientifically meaningful and acceptable, photographs had to be inscribed within a proper aesthetic canon, a visual code which imposed standardized protocols of framing, lighting, exposure, pose and distance between camera and sitter. This visual code had the aim to produce an effect of aesthetic neutrality, that is, to convey the feeling that photographs were blank from the stylistic and interpretive point of view. This, however, was a paradoxical project, because at the very moment in which such visual rules were implemented, a specific style of depiction was born. A style that possibly responded to specific needs of clarity, standardization, and reproducibility, but that was also aimed at displaying its objectivity.

2.7 Duchenne de Boulogne: electricity meets photography

In the same period in which de Montméja dealt with the difficulties of reproducing the surface of the body and Diamond developed his physiognomic program, the neurologist Guillaume Duchenne, known as Duchenne de Boulogne, was experimenting with what he called "electrophysiological photographs,"[108] in search of the the laws that govern the muscular underpinning of both motion and emotion. A founding father of clinical medicine, Duchenne, who worked at the Salpêtrière, specialized in muscular and neurological disorders. He was the first to describe pseudo-hypertrophic muscular paralysis (which today is known under the name of Duchenne muscular dystrophy) and he studied extensively progressive muscle atrophy and atrophic paralysis in children. His study of emotions was in part a consequence of his research on muscular conditions, since the muscles of the face, the place where human emotions show through, are often affected by amyotrophic diseases.

Scientific observation through photography It is important to note that, as pointed out by Sicard, Duchenne's method was simultaneously electrophysiological *and* photographic.[109] The electrophysiological protocol required the application of a low intensity current to a circumscribed area of the body, in

[107]See Sicard, 1998, 150.
[108]Duchenne, 1862a, n.p.
[109]See Sicard, 1998, 133.

order to elicit the contraction of a single muscle. By provoking controlled contractions within an experimental setting, it became possible to disentangle the mechanisms that underly muscular syndromes and their morphological and functional manifestations. The electrophysiological experiment, however, required the support of photography in order to produce adequate scientific observations. Both visual expressions and the movements and positions characteristic of muscular diseases often last just a glimpse, thus, if one is to study them systematically, it is necessary to fix them in an enduring image. In his *Album de photographies pathologiques*, of 1862, Duchenne wrote: "These are deformities that appear and disappear only when performing certain movements. Often the patients have difficulties in carrying out the movements [...]. I had to, so to say, seize upon these deformities and abnormal movements by means of instantaneous photography."[110] Photography, with its ability to grasp and fix fleeting phenomena, and with its reproducibility, made possible to collect and compare the visible effects of the invisible contraction of the muscles of the face and limbs. Without the photographic record it would have been impossible to develop electrophysiology: the production of a transient phenomenon acquired experimental relevance only as far as it could be fixed in a permanent image.

Thus, the documental character of photography, its ability to preserve the "honesty and truth" of the temporary phenomenon, as Londe put it,[111] made the electrophysiological experiment relevant. Still, although he professed an unconditional trust in the recording powers of photography, Duchenne was also well aware that the technology in itself had little epistemic relevance if it was not coupled with a trained eye and embedded in a larger medical knowledge. In the introductory note to the *Album* he claimed that only photography could show the true nature of the deformities and the incoherent movements caused by the disease. However, he warned that photography would speak the language of nature only if who was representing the pathological phenomenon understood it, and he held explicitly that the photographer had to be physiologist and pathologist (this was actually the reason why he had become a photographer himself).[112]

Duchenne's pathological photographs show naked bodies, often seen from the back. Accompanied by a detailed caption and by a description of the medical case, they demand of the observer an analytic attitude, in search of the signs, more or less dramatic, that bear testimony of the disease and that, to the trained eye reveal a physiological mechanism, a diagnosis and a prognosis. Unlike in the

[110] Duchenne, 1862a, n.p, my translation.
[111] Londe, 1893, 6.
[112] See Duchenne, 1862a, n.p.

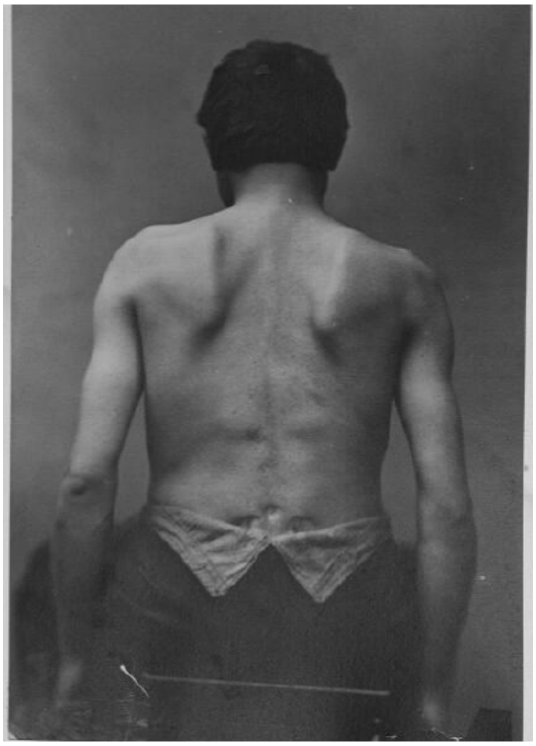

Figure 2.11: Muscular atrophy, Duchenne de Boulogne, *Album de photographies pathologiques*, Paris, 1862, Figure 9. Public domain.

case of Diamond's portraits, these pictures the context of production is explicitly scientific. Naked and deformed, set against a neutral background, framed within the information of the captions, these bodies are clinical cases. Of course, in the instances in which we see the faces we still wonder who that person really was, when we see a striking deformity we might feel overwhelmed, but before a slightly asymmetric back we look for the details, analyze the form, and ask ourselves what might be the clinical meaning of those rounded marks at the base of the column (Figure 2.11).

Construction of an aesthetic canon for medical photography With the pictures of the *Album de photographies pathologiques*, Duchenne contributed to define the aesthetic code of medical photography, characterized by naked bodies against neutral backgrounds. As mentioned above, it was an aesthetic canon of ostensible visual neutrality, similar to that of ethnographic research and criminal records, also aimed at establishing a metric of the human body. However, it was with the plates of the grimacing faces of *Le Mécanisme de la physionomie humaine*, also published in 1862, that he left an indelible mark in the history of scientific iconography (Figure 2.12). As the title explains, in this work – divided in two parts, the first addressed to scientists, the second to visual artists – Duchenne set out to describe the mechanisms of human physiognomy, that is,

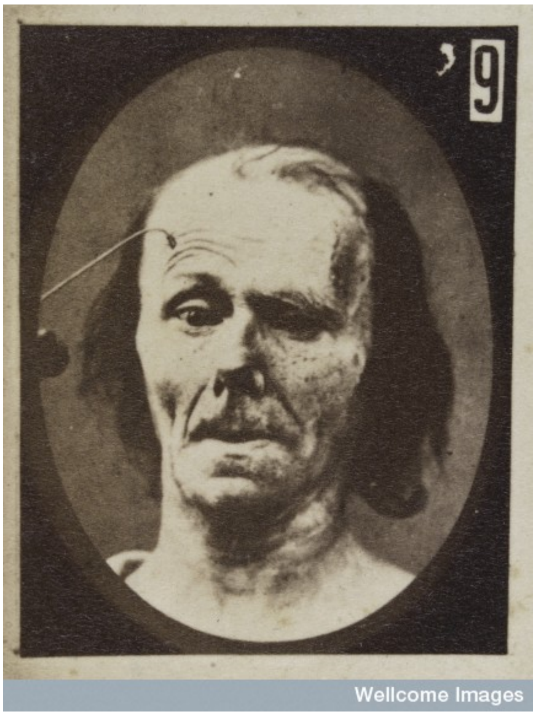

Figure 2.12: The facial expression of profound attention on the human face being induced by electrical current. Duchenne de Boulogne, *Le Mécanisme de la physionomie humaine*, Paris, 1862, Plate 1, figure 9. Wellcome Library, London.

to understand the physiological rules that govern the expression of emotions. His method consisted of triggering muscular contractions with electrical probes and recording the resulting grimaces by means of photography. He thus created an extensive visual gallery of what he considered to be the mechanical expressions of inner emotions.

Art historian Martin Kemp has defined *Le Mécanisme de la physionomie humaine* "the most remarkable of all the photographically illustrated books in medical science before 1900," and he has remarked that the portraits of the old shoemaker of the Salpêtrière, who was Duchenne's favorite model, "are visually striking as the often exaggerated portrayals in the drawn manuals of expression."[113] Yet, although Duchenne mentions the painter Charles Le Brun among the predecessors of his visual research, he does so just to stress in what respect his endeavor was different. Namely, he insisted on the fact that while the artist merely represented the different physiognomical conformations produced by passions, he, as a neurologist, wanted to understand the physiological mechanisms that ruled the movements of the face that made emotions visible.[114] He stated: "By tracing the pathway from the expressive muscle to the soul that puts it into action, I was able to study and discover the mechanism, the laws

[113]Kemp, 2006, 289.
[114]See Duchenne, 1862b, 2.

of human physiognomy,"[115] and "[by means of electrophysiological experiments] we understand how each passion is always delineated on the face by the same muscular contractions, and neither fashion nor whim can make them change."[116]

For Duchenne, the laws of the expression of emotions coincided with their mechanism of motion. In this respect I think that Kemp misses the point when he writes:

> [Duchenne's] instrumental analysis of the expression of emotions achieves compelling visual results, yet the definition of the subject's emotional state remains that of the observer, because the 'sitter' was not actually experiencing that particular emotion at the time of the making of the image.[117]

Here Kemp implies that Duchenne failed to represent the *true* emotion of the subjects of his experiments, because they were not feeling *that* emotion when the picture was taken. This was not, however, what Duchenne was attempting to achieve. He was not concerned with exploring the real nature of emotions. He had no doubt that emotions reside in the soul, and that it is the soul which under natural circumstances triggers the muscular movements that lead to the expression of emotions. Tellingly, he did not talk of "emotional states" but rather of "motions of the soul." Working within the framework of positivist and mechanist philosophy, Duchenne understood the laws of nature, including the expression of emotions, in terms of mechanical laws. He did not question the idea that emotions spring from the soul. His point was that through electrostimulation one can activate the muscles just as the soul does. And this is exactly the reason why under electrostimulation a person can *express* an emotion even though he or she is not actually *feeling* that specific emotion. Duchenne's work revolved around the idea that, given that the soul needs the muscles to find a visible expression on the surface of the body, then by studying the muscles one can understand the mechanical laws that underpin the expression of emotions. Kemp comments on Duchenne's photographs as if they were artistic portrayals, but they were not.

A more pertinent criticism to Duchenne's approach came from Charles Darwin. In *The Expression of Emotion in Man and Animals* (1872), Darwin repeatedly mentioned Duchenne and reproduced some of his electrophysiological photographs. He acknowledged the importance of the work of the French neurologist and praised his research, but he pointed out that Duchenne had overstated the relevance of the contraction of a single muscle in the expression of emotion.

[115] Duchenne, 1862b, xii.
[116] Duchenne, 1862b, 51.
[117] Kemp, 2006, 290.

More importantly, Duchenne had not understood that expressions had not been inscribed on the human face by God at the moment of Creation, they were rather the result of an evolutionary process. For Darwin, Duchenne's pictures were relevant in that they allowed the comparison of human and animal expressions. The laws of these expressions, however, were to be found in their common ancestor and not in muscular activity.

Models not portraits As aptly observed by Sicard, Duchenne's mechanical faces – like Marey's human machines that appeared a couple of decades later – are *models not portraits*.[118] They are "experimental creations of a series of photographs that mimic reality without necessarily being similar to it, but that allows understanding its operating principles."[119] This is an extremely important point, an essential feature of all modern medical imaging. If in Diamond's portrayals patients were still endowed with their here and now, their aura, their unique humanity, Duchenne started a process of visual abstraction and analysis of the human body by means of photography. On the one hand, the patient's body became part of the experimental setting and was integrated into the imaging apparatus, in order to constitute a scientific object proper (the patient, the electric devices, and the photographic studio are bound together to form the experimental setting). On the other hand, the mimetic properties of mechanical images, although routinely praised, became secondary, or disappeared altogether in the context of more and more complex experimental forms of photographic visualization such as those discussed by Benjamin and the other theorists of his generation (enlargement, slow-motion, and so on).

2.8 Charcot: the aesthetics of hysteria

Duchenne's innovative approach to photography and photographic experimentation was taken on by his most famous student, Jean-Martin Charcot, who became director of the Salpêtrière in 1862. Charcot, considered the founder of modern neurology, was the first to describe multiple sclerosis and a number of other neuro-degenerative pathologies. Convinced that hysteria (one of the most elusive mental diseases since the times of Hippocrates), was also a neurological disorder, he developed the most famous and debated iconography of hystero-epileptic patients ever. Images were fundamental in Charcot's research and teaching. His anatomo-clinical method consisted of two steps: the first focused on the clinical description of the neurological condition, complemented

118 See Sicard, 1998, 34.
119 Sicard, 1998, 134, my translation.

by drawings or photographs that documented the static deformities of chronic diseases, as well as the evolving signs of acute illnesses. The second focused on anatomical and microscopic analysis, and here, too, visual representation was widely used to document his findings.[120] Working from within the tradition of clinical pathology, Charcot considered visual documentation a pivotal element to his effort to describe and categorize neurological disorders. As Gilman puts it: "To describe was to understand, to describe in the most accurate manner meant to avoid the ambiguity of words, and to rely on the immediate, real image of the sufferer."[121]

Under Charcot's direction the Salpêtrière enrolled several artists, sculptors and photographers (he appointed Londe as superintendent of the photographic station of the hospital).[122] At the Salpêtrière patients were regularly photographed as part of their neurological evaluation, and as Charcot's clinical interests moved increasingly towards the study of dynamic disorders, with hysteria ranking in the first place, in the 1880s his photographers developed sequential and time-lapse photographic methods. This was a major break in the history of photography. Photographs, whose main characteristic was that of freezing time, were now used to record the duration of movement, with the result of transforming motion and time in a sequence of self-contained instants.

Several thousands of photographs of mentally deranged and geriatric patients were taken between the 1870s and the 1910s, and they were collected in two different publications, the *Iconographie photographique de la Salpêtrière* and the *Nouvelle iconographie de la Salpêtrière.* The first, published between 1875 and 1880 was a limited edition of hand-pasted photographs that documented various disorders, but had a strong emphasis on epilepsy and hysteria. The second, appeared between 1888 and 1918 was a large circulation journal that reported neurological case studies based on pictorial documents (photographs or drawings). In the introduction of the first volume of the *Nouvelle iconographie*, the editors (Paul Richer, Gilles de la Tourette, and Albert Londe) wrote:

> With the aid of this immediate record [drawings and photographs], we are able to freeze the abnormality, to decompose the various abnormal movements one by one, and thereby capture the disorder with precision. [...] We can also say that with the aid of instantaneous photography, we are able to *capture and dissect on the sensible plate abnormal movements that were impossible to analyze* with all the desirable precision using the clinical examination only.[123]

[120] See Coetz, 1991, 241.
[121] Gilman, 1993, 352.
[122] See Goetz, 1991; Pujade, 1995, 91-92.
[123] Richer, de la Tourette, and Londe, 1888, i-ii, my translation.

This insistence on the ability of photography to freeze and dissect movement is symptomatic of the methodological problems that Charcot and his assistants met in their research on neurological diseases in general, and hysteria in particular. They wanted to use photographs to see what the eye could not catch.

The malleability of the symptoms of hysteria made it a very difficult object of study, and already in Charcot's time many physicians questioned its very status as *real* disease. In order to be recognized as such, hysteria had to show observable symptoms, and since its symptoms were fleeting, they needed photography to be stabilized. Frustrated in his search for the organic, neurological substrates of hysteria, in fact, Charcot had been forced to fall back on an epiphenomenalist, clinical account of the regularities of this disease, focusing on its external manifestations. In this way he believed he could find the relationships that would place hysteria within the taxonomy of an extended family of related deficits, all governed by known physiological laws, such as hemilateral anesthesias, *grandes paroxysmes*, palpitations, Saint Vitus dance, tertiary neurosyphilitic infections, and so on.[124] In this project photography became a taxonomic as well as diagnostic instrument. As noted in an early review of the *Iconographie photographique*, the camera was as necessary for the study of hysteria as the microscope was for histology.[125]

While Diamond had tried to understand and classify insanity as a psychological disorder, on the basis of the patients' facial expression, posture and attire, Charcot was committed to a comprehensive clinical scrutiny of hysteria, which included motor and sensory symptoms, tics, epileptiform seizures, somnambulism, contractures, and a range of other pathologic behaviors.[126] Accordingly, if at the Surrey Asylum patients were represented within the boundaries of the decorum of the bourgeois portrayal, at the Salpêtrière they were captured in their crises (often instigated by the medical staff) in hallucinated and hallucinating instant pictures, at moments in which they looked out of control, both mentally and physically. As a consequence, Charcot created his own image of hysteria, made of twisted bodies, contracted limbs, ecstatic figures and crying faces (Figures 2.13 and 2.14).

This iconography inevitably shocks the viewer, and it is difficult not to perceive it as voyeuristic. The women of the Salpêtrière have been described both as victims of relentless medical misogyny and violence,[127] and as protagonists of a mute resistance to institutional power, brought about by simultaneously se-

[124] See Porter, 1993, 258.
[125] See Gilman, 1993, 352.
[126] See Porter, 1993, 257.
[127] See Didi-Huberman, 1982.

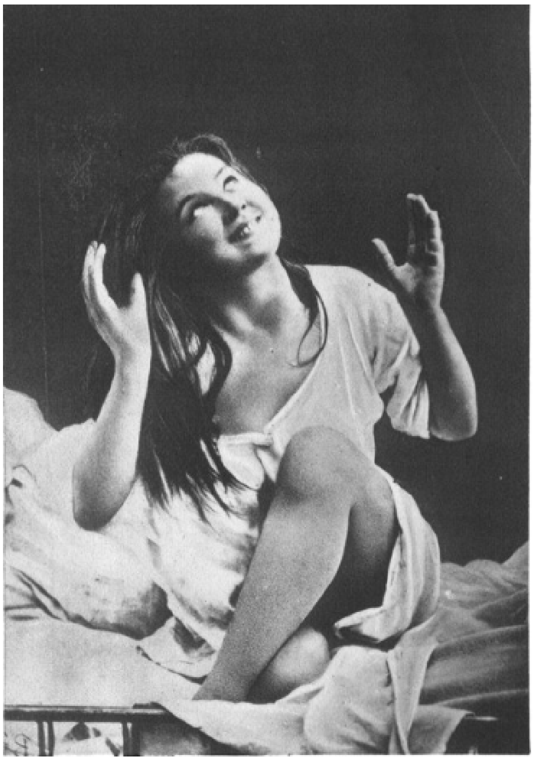

Figure 2.13: Passional attitudes (ecstasy). Photograph by Bourneville and P. Regnard, *Iconographie photographique de la Salpêtrière*, Paris, 1878, Plate 23.

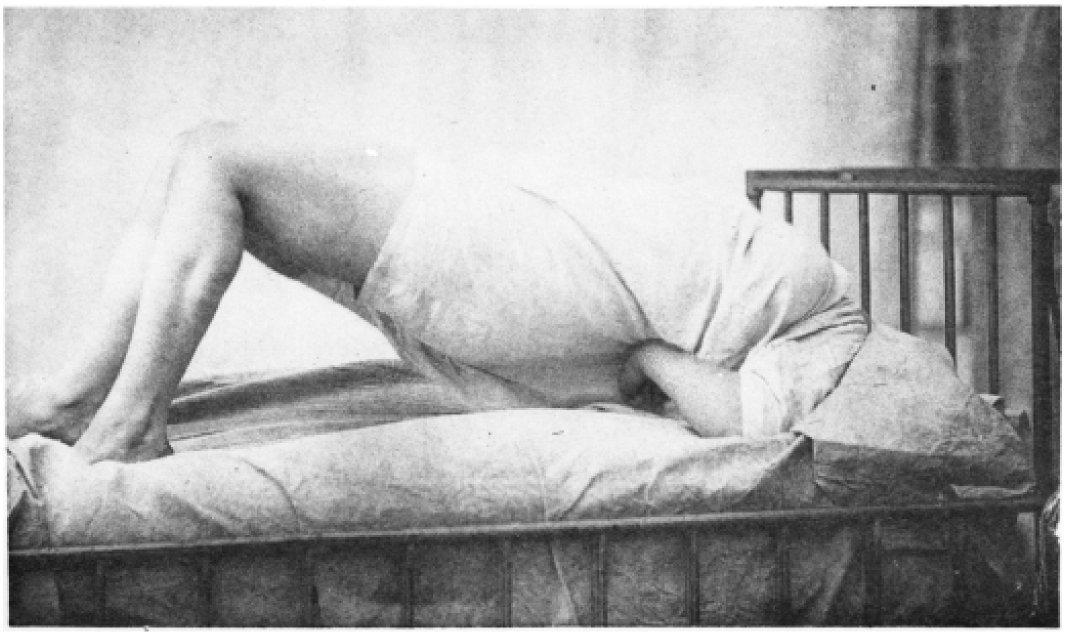

Figure 2.14: Hystero-epileptic seizure. Photograph by Bourneville and P. Regnard, *Iconographie photographique de la Salpêtrière*, Paris, 1879-1880, Plate 3.

ducing and duping the doctors through theatrical enactments of the disease.[128] These two interpretations are not necessarily mutually exclusive. Blanche, Augustine, and the other "star hysterics"[129] of the Tuesday Lectures were victims of a controlling and repressive apparatus, not exempt from misogynist and violent overtones, and they protected themselves and asserted their agency with the instruments at their disposal, by seducing and duping their doctors. Medical historian Roy Porter writes:

> The hysteria that Charcot studied - or, better perhaps, that he and his patients co-produced - was a palimpsest of a performance, many layered with meanings. It bespeaks the utter docility of the body, under the charismatic authority of mind (above all, the robot behavior of the hypnotized). It marks deflected, oblique protest - a resistance that, incapable of verbalization, was converted into somatic signals of violence and burlesque.[130]

To be studied, to become scientific evidences, these "somatic signs of violence and burlesque" had to be captured on the photographic plate. That is to say, Charcot and Londe had to find a way to make the still photographic image *move*. And they needed to convey not simply motion (even though dissected in its instantaneous still sequences), but a violent motion charged of scientific meanings, since these pictures were meant to be instruments for the study and the diagnosis of hysteria.

In a commentary on the aesthetics of Charcot's photographic enterprise, Kemp maintains that the iconography of the Salpêtrière was consciously inscribed within the tradition of the history of art, and relied on the rhetorical and theatrical resources developed in painting over the centuries. He states that: "This is particularly true of the depiction of women, who express emotions in ways familiar through generations of paintings and sculptures of sensually ecstatic martyrs."[131] It is well known that Charcot had a broad artistic culture, and he explicitly relied on art as a form of scientific evidence.[132] That notwithstanding, to reduce the aesthetics he developed throughout his photographic

[128]See, for instance, Gilman, 1993, 346-349, and Porter, 1993, 255-260.

[129]Porter, 1993, 257.

[130]Porter, 1993, 256-257.

[131]Kemp, 2006, 293.

[132]To address the criticism of the numerous physicians who contended that the dramatic manifestations of hysteria going on at the Salpêtrière were feigned, or even created by mental suggestion, Charcot published *Les démoniaques dans l'arts* (1887), and *Les difformes et les malades dans l'art* (1889). In these works Charcot attempted to demonstrate that behaviors similar to those observed at the Salpêtrière could be found in medieval and mannerist artworks (mostly paintings and bas-relief) depicting demonic possession or spiritual ecstasy. Charcot, however, failed at convincing the skeptics. One of the reasons was that he relied exclusively on religious art, and was not able to find any equivalent in historical and genre painting. See Goetz, 1991, 423-424.

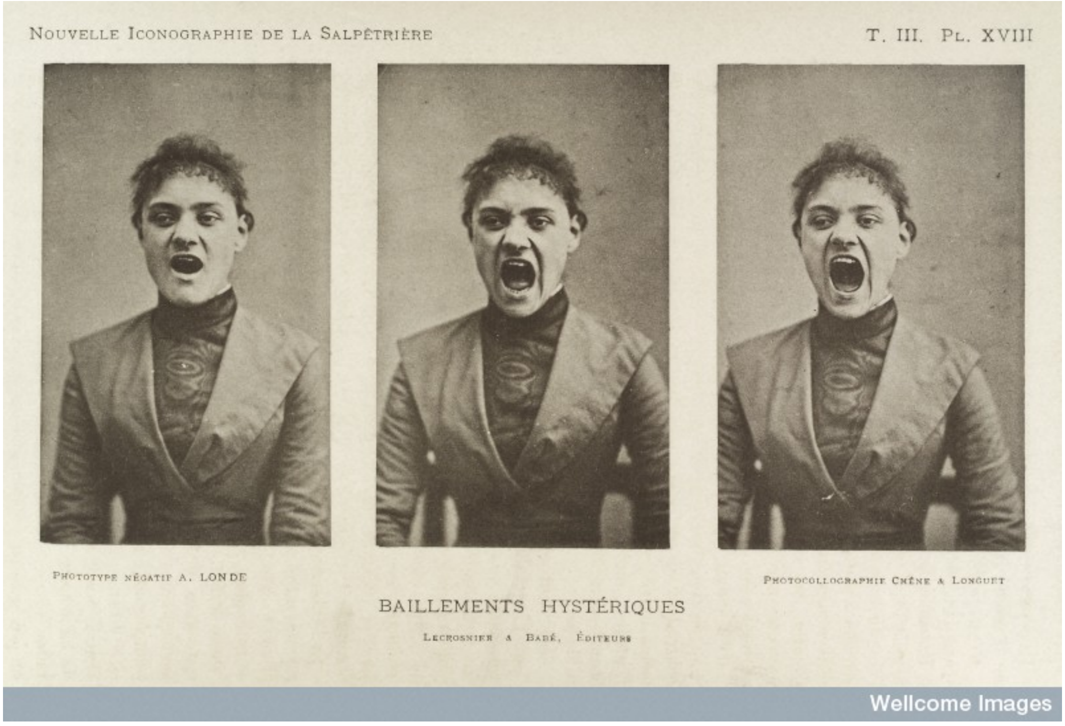

Figure 2.15: Hysterical woman yawning. Photograph by A. Londe, *Nouvelle iconographie de la Salpêtrière*, Paris, 1890. Wellcome Library, London.

endeavor to the inscription within the artistic tradition of the (mostly religious) iconography of ecstatic or possessed figures, is to belittle the epistemic ambition and meaning of that very aesthetic. Charcot complied with the methodological choice to focus on a range of pathological movements rather than on more subtle facial expressions. Through his photographs of uncontrolled bodies he defined a specific aesthetics of hysteria, which, in turn, reinforced and influenced the definition and recognition of the characteristic symptoms he wanted to track down. Hence, there was a very tight connection and bidirectional influence between the aesthetic qualities of the pictures and their epistemic dimension. Tellingly, the iconography of the hysteric body produced at the Salpêtrière progressively moved from more or less conventional, recognizable portraits (Figure 2.15) to pictures of floundering naked bodies twisted against the black curtains of the photographic studio (Figure 2.16). As in the work of Duchenne's, there was a shift from the mimetic dimension of the photograph to its abstract, analytic function, which entailed a transition from the portrait to the scientific model. As his teacher, in order to accomplish his project Charcot had to reconfigure the body of his patients into a component of the experimental photographic apparatus.

The idea that medical imaging embeds the human body into a larger experimental apparatus is a key concept of this dissertation, and will be further developed in the remaining chapters. Also, I will expand on the idea that

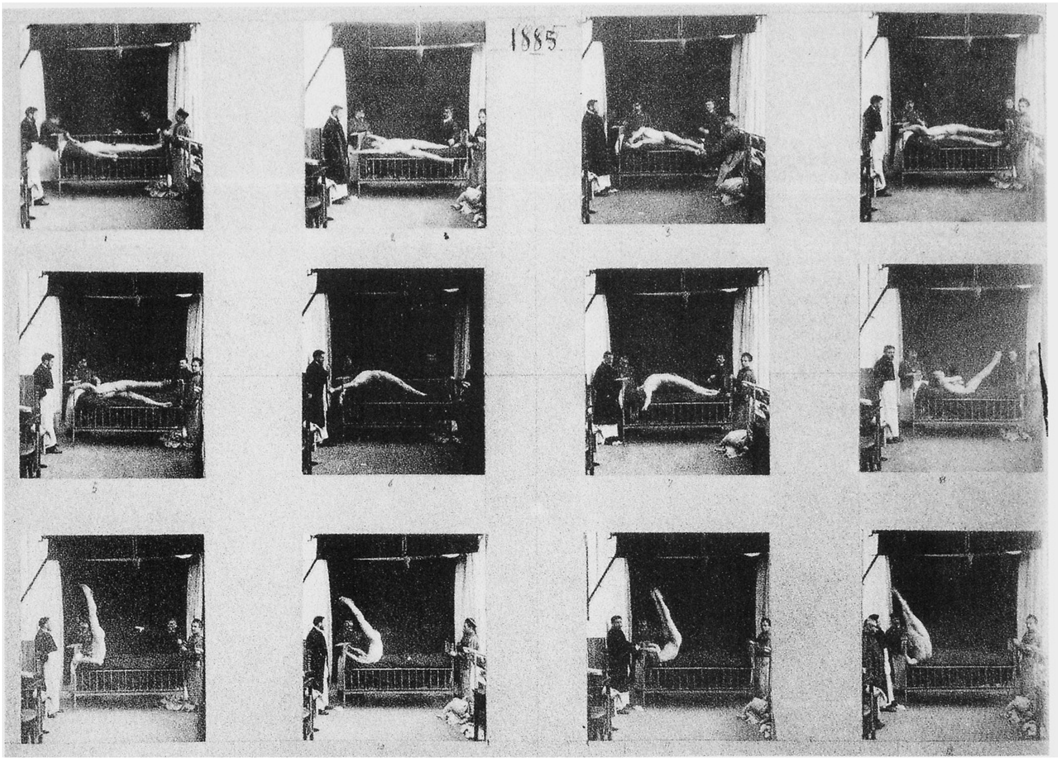

Figure 2.16: Episode of male hysteria. Photograph by A. Londe, *Nouvelle iconographie de la Salpêtrière*, Paris, 1888.

medicine, like biology and physiology, deals with the problem of creating images of invisible objects and phenomena (Chapter 3); that the mimetic images provided by photography are routinely transformed into diagrammatic representations (Chapter 4); and that photography has an analytic potential, which exploded with the introduction of digital technologies (Chapter 5).

Chapter 3

Photography, radiography, and the visualization of the invisible

As discussed in the previous chapter, since its origins medical photography has dealt, one way or another, with the problem of producing pictures of something that is not directly visible. In some cases, namely in psychiatry and neurology, the problem laid in the fact that the visual dimension of the disease under study was elusive. Consequently, a form of visibility had to be actively produced through predefined theoretical constructs (for instance, phrenology and physiognomy in psychiatry), or by developing devices that could produce a specific expressivity of the body (as in the case of electrophysiology). Even in dermatology, the clinical discipline devoted to the surface of the body and therefore to eminently visible diseases, the aim of photographic collections was less to record the individual, idiosyncratic condition of a specific patient (what Sekula calls the "nominalist" mode of signification),[1] than to establish a human type, an abstract entity, corresponding to a disease ("realist" mode of signification in Sekula's account). More precisely, photographic series were meant to reveal the *facies* of a pathological condition, that is, its characteristic yet general features. In the photographic series the uniqueness of the patient's body was ideally obliterated, and illness showed itself as an objective, visible fact.

In the present chapter I discuss how photography was used to deal with other forms of invisibility, namely, the invisibility of extremely small objects (microphotography), very fast phenomena (chronophotography), and macroscopic objects concealed inside the body (radiography). My main goal is to discuss the semiotic and epistemological problems encountered by the late-nineteenth-century physicians and scientists who used photographic processes to create images of different invisible objects and phenomena. The questions I address

[1]See Sekula, 1986. See also Section 2.4.

are: what kind of pictures were these? Through which modes of signification were they made meaningful? Could they be considered iconic images, taking into account that in many cases it was impossible to corroborate their "likeness" with an actual referent? What sort of photographic realism could be endorsed by the photographers of the invisible? This set of questions is coupled with another one: could all these scientists genuinely rely on mechanical objectivity, as has been influentially defended by the historians of science Lorraine Daston and Peter Galison?

Drawing on the theoretical analysis of photography developed in Chapter 2, I show how the iconic, indexical and symbolic modes of signification were combined in order to make sense of microscopic, chronographic and radiographic pictures. As in the previous chapter, this theoretical approach is intertwined with a historical one. That is, I sustain my conceptual analysis and epistemological arguments with the examination of historical literature (both primary and secondary sources) concerning representational and experimental practices. Starting from a critical appraisal of Daston and Galison's claims about the late-nineteenth century discourses about mechanical images, I demonstrate that the idea of mechanical objectivity is far too poor to account for the richness of practical and conceptual strategies put in place to produce and make sense of the photographs of the invisible. In the light of this historical analysis, I suggest that the notion of mechanical objectivity should be replaced, on the one hand, with that of intersubjectivity sustained by operational conventions; on the other hand, with the idea of mechanical sensibility. Finally, closing the circle with the claims I made in Chapter 1 about the relationship between X-ray diagnostics and clinical anatomy, I show how the process that led to make sense of radiographs was indebted to Bichat's conceptualization of the cadaver as proxy of the living body, and to the clinical gaze that was born in the hospital at the dawn of the nineteenth century.

3.1 Truth-to-nature, mechanical objectivity, and trained judgment

A relevant part of the discussion developed in this chapter is built against the concept of mechanical objectivity put forward by Daston and Galison in a series of works published between 1992 and 2007.[2] Consequently, the first thing to do is to provide a brief outline of the ideas of these authors.

[2]See Daston and Galison, 1992; Galison, 1998; Galison, 1999; Daston and Galison, 2007.

	18th to early-19th cent.	Late-19th to early-20th cent.	20th cent.
Danger to knowledge	Drowning in details	Altering a fact to support a theory	Being straitjacketed by mechanical procedures
Epistemic virtue (epistemology)	Truth-to-nature	Mechanical objectivity	Trained judgment
Images	Reasoned images	Mechanical images	Expert images
Scientific persona	Genius	Will-abnegating worker (manufacturer)	Trained expert

Table 3.1: Daston and Galison's historical taxonomy of epistemic virtues and their corresponding images.

Daston and Galison have developed the concept of mechanical objectivity in the scope of their attempt to demonstrate the historical character of objectivity. They defend that objectivity is not a transhistorical feature of science, but rather one among many possible epistemic ideals. Epistemic ideals can change over time because they emerge in reaction to what, at a given moment in history, is perceived as an obstacle to the acquisition of knowledge, or a "danger to knowledge."[3] In Daston and Galison's view, epistemology, understood as the normative discipline that prescribes how to attain reliable knowledge, is inseparable from ethics, the discipline that prescribes how to form and control the self. Accordingly, epistemic ideals, or virtues, are guiding principles that shape how scientists work, how they build their scientific identity (scientific self or persona), and how they define the goals and methods of science.[4] Building on these premises, the two authors construct a historical taxonomy of the epistemic virtues from the eighteenth to the twentieth century (Table 3.1). They support their assertions with an analysis of how scientists produced images for atlases and other reference books, and what they claimed about such images. They justify this methodological choice by arguing that atlases are systematic compilations of scientific working objects. Atlases, they remark, are meant to guide generations of observers, and thus they set standards for scientific practice (what to look for, how to look at it, how to describe and represent it). Moreover, atlases are the result of the collaboration among researchers distributed over time and space, hence they exemplify believes and practices of a scien-

[3]Daston and Galison, 376-377.

[4]Epistemic virtues are "norms that are internalized and enforced by appeal to ethical values, as well as to pragmatic efficacy in securing knowledge." Daston and Galison, 2007, 40.

tific community.[5] Daston and Galison's taxonomy of epistemic virtues can be summarized as follows:

1. The ideal of *truth-to-nature* emerged in the late-eighteenth century as a weapon against the danger to be overwhelmed by the details of the monstrous variability of nature. In accordance with Enlightenment sensationalist psychology, the self was perceived as fragmented and excessively receptive. Hence, in order to secure knowledge, the savant – who worked in strict relationship with the artist-illustrator – had to actively control sensations, by selecting and interpreting them. The scientific persona corresponding to the virtue of truth-to-nature was the *genius*.

2. The ideal of *mechanical objectivity*, on the contrary, aimed at the suppression of subjectivity. It appeared around the 1830s and seemingly guided scientists until the 1920s, acting against the hindrances of the post-Kantian self, perceived as too active and eager to impose its interpretations and hypotheses on the world. The core demand of mechanical objectivity was to "let nature speak for itself,"[6] which implied that images had to be produced according to strict mechanical protocols.[7] Photography was not a precondition for the emergence of mechanical objectivity, but it nevertheless played a seminal role as paradigmatic form of mechanical imaging technology. The scientific persona corresponding to the epistemic virtue of mechanical objectivity was an automaton, a *will-abnegating worker*.

3. Finally, by the 1930s the ideal of *trained judgement* emerged, partly in reaction to mechanical objectivity. Drawing support from the many theories of the unconscious that blossomed at the turn of the twentieth century, trained judgment downplayed the importance of the unbending application of procedural routine proper of mechanical objectivity, and put high values on educated intuition, the "physiognomic sight"[8] that comes with training and a long acquaintance with an object. The scientific persona shaped by trained judgement was the *trained expert*, a self-confident professional who trusted his or her own intuitions, which could be educated

[5]See Daston and Galison, 2007, 19-27. In my view, it is dubious that one can take the rules which prescribe how to make, compose, and present images in atlases as proxies for the epistemic ideals that govern the making of science as a whole. I develop this criticism in Section 3.4.3.

[6]Daston and Galison, 1992, 81.

[7]"Objectivity in its mechanical guise emerges as a ferociously austere, self-denying virtue, a virtue present when all the special skills, intuitions, and inspirations of the scientist could be quieted and nature could be transferred to the page without intervention or interpretation." Galison, 1999, 19.

[8]Daston and Galison, 2007, 314.

and refined by studying and working in renowned schools and scientific institutions.

In opposition to both truth-to-nature and trained judgment, self-erasing was the characterizing feature of mechanical objectivity. In Daston and Galison's words: "In the making of images, the taking of measurements, the tracing of curves, and many other scientific practices of the latter half of the nineteenth century, self-elimination became an imperative."[9] They base this strong claim in the textual analysis of the introductions of a considerable number of nineteenth-century atlases, and in the discussion of a few debates about scientific images whose right to claim objectivity was contentious.[10] Yet, historical and conceptual analyses of the same period provided by other authors show that if mechanical objectivity as suppression of the observer ever existed, it was far from being an overarching ideal, and that a much more nuanced approach to the mechanical production of images was actually in place. In the following pages I criticize the notion of mechanical objectivity and the alleged divide between mechanical objectivity and trained judgment through the analysis of three case studies: the use of photography in microbiology, chronophotography, and radiography.

3.2 Microphotography: intersubjectivity *vs.* mechanical objectivity

Microphotography was one of the earliest applications of photography in science. Indeed, it was through the microscope that photography entered the domain of medicine.[11] Both bacteriologists and cellular pathologists, who in the second half of the nineteenth century promoted new conceptions of disease and new ways of practicing medicine, relied on the combination of an old and a new technology (the microscope and the photographic camera) to back their discoveries. As Sicard puts it: "At the edge of knowledge, microscopy met photography."[12]

3.2.1 The myth of the faithful record

In February 1840, just a few months after François Arago's official presentation of the invention of photography at the Académie des Sciences, Alfred Donné, a physician and bacteriologist who gave microscopy classes in Paris, showed to

[9] Daston and Galison, 2007, 196.

[10] For example, the diatribe between Camillo Golgi and Santiago Ramón y Cajal about the individuality of neural cells. See Daston and Galison, 2007, 115-120, and 183-184.

[11] See Sicard, 1995, 11-12.

[12] Sicard, 1998, 122, my translation.

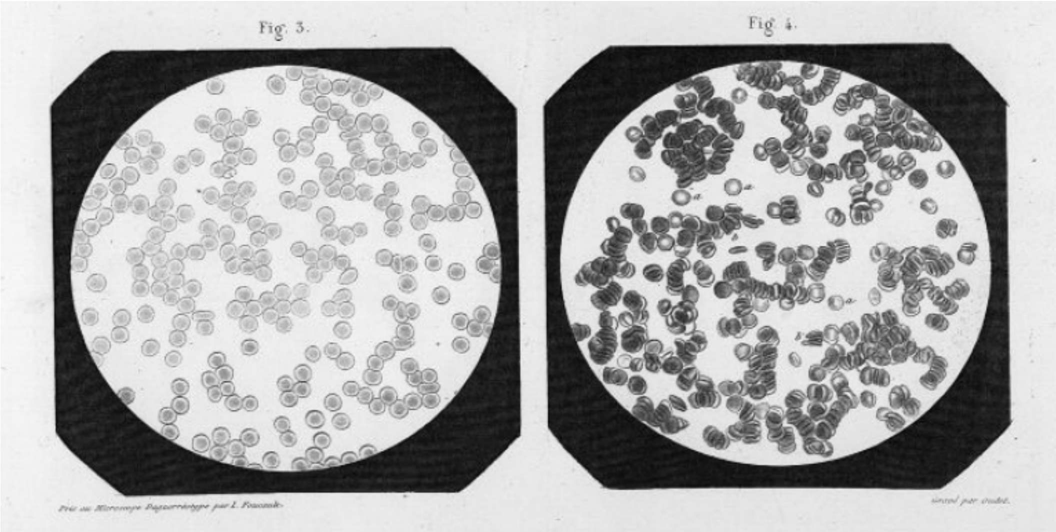

Figure 3.1: Blood corpuscles. Etchings produced after the original daguerreotypes. A. Donné and L. Foucault, *Cours de microscopie complémentaire des études médicales. Atlas exécuté d'après nature au microscope-daguerréotype*, Paris, 1845. Detail of Plate II. Public domain.

the same distinguished audience the first microphotographs (or better, microdaguerreotypes)[13] of different natural specimens, ranging from organic sediments to sections of bone and tooth tissues.[14] Shortly after, his assistant and amateur photographer Léon Foucault took microdaguerreotypes of other biological samples like blood cells, mucus, and zoosperm (Figure 3.1). Donné's work in medical photography was trailblazing. In the introduction to the first edition of his *Cours de microscopie complémentaire des études médicales*, of 1844, he remarked that while the natural sciences, such as botany and entomology, had been quick in taking up microscopy as a relevant research tool, medical doctors had rejected it for a long time, considering microscopic observations a form of "chimeric vision,"[15] a pure illusion. Thus, for Donné, photography was first of all an invaluable instrument for persuading physicians of the reality of what appeared under the microscope. He wrote:

> How, indeed, could anybody refuse to acknowledge the reality of the images provided by the microscope, [...] when *the object imprints itself*, it

[13]The daguerreotype process, invented by Louis Daguerre, was the first successful photographic process, and consisted of fixing the image of the camera obscura on iodine-sensitized silver plate. Daguerreotypes were fragile, expensive objects and could not be reproduced in series. Shortly after the announcement of Daguerre's invention, in England W.H. Fox Talbot presented the calotype process. Unlike daguerreotypes, calotypes are produced through a negative-positive process on paper (a paper negative and a paper positive), they are less prone to deterioration, more easily reproducible and affordable. However, it was only in the twentieth century, with the introduction of 35-millimeter celluloid film, that the positive-negative process became really efficient and thus photographic images became endlessly reproducible.

[14]See Sicard, 1995, 11 and 1998, 121.

[15]Donné, 1844, 3.

> fixes itself on the plate without the help of the art, without any intervention of the human hand, by the only effect of light, and *always identical up to the smallest details to the image perceived by the observer under the microscope*?[16]

Donné, as virtually all his contemporaries, considered photography a direct imprint of nature, "a material image printed by nature itself."[17] This does not mean that he was not aware that both the microscope and the daguerreotype create artificial visual effects. Sicard reports that Donné and Foucault – both preoccupied with the pedagogical difficulties of training physicians in microscopy – knew very well the practical difficulties related to the use of microdaguerrotypes, and actually asked themselves how to sensibly use these images as tools for partaking knowledge.[18] As a matter of fact, daguerrotypes have a good definition, but they have a low sensitivity for red, and this, at a time in which the most important histological dyes were cochineal and carmine, carried a major technical limitation. Moreover, in order to look at the silver plate properly, one had to incline it at a specific angle, and therefore for the untrained eye proper observation could be quite difficult.[19] That notwithstanding Donné was confident that what the daguerreotype showed was "identical" to what the microscopist saw, and this would allow sharing microscopic vision. In spite of all the actual divide between reality and its photographic representation – a divide that was particularly deep in the early days of photography – photographs were immediately perceived as "the evidence of the present or past existence of a reality that resembles to them."[20] For Donné, photography produced representations that were as accurate as the quantitative methods used in physiology and, accordingly, he believed that it could be extremely useful for medical diagnosis.

Still, regardless of Donné's pioneering work, microphotographs became an accepted tool within the scientific community only in the 1880s, thanks to the work of Robert Koch. As the historian of science Olaf Breidbach has shown, Koch conceptualized and used photographs as an instrument to cross-check microscopists' observations, rather than an unquestionable imprint of reality, and in so doing he fostered the creation of experimental standards and a common way of seeing among bacteriologists. It was ultimately on these grounds that microphotography became a fundamental instrument for bacteriology.[21]

The problem of sharing microscopic observations was one of Donné's main concerns, and before turning to photography, he had developed a sun microscope

[16]Donné, 1844, 36-37, my translation.
[17]Donné, 1845, 10.
[18]See Sicard, 1995, 12.
[19]See Sicard, 1998, 124.
[20]Sicard, 1995, 12, my translation.
[21]See Breidbach, 2002, 222

which projected the image of the specimen under analysis on a screen. This ingenious system, however, was hampered by its dependence on the availability and quality of natural light. As seen above, Donné thought that microphotographs granted the solution to his search for a shared microscopic sight, but, according to Breidbach, until well into the 1880s, the majority of microscopists did not believe that photography could provide reliable representations of their specimens. Paradoxically, such distrust was a consequence of the excessive enthusiasm professed by some of the early defendants of microphotography. Breidbach explains that those arguing in favor of microphotography saw photographs as *a reality in their own right*. The consequence was that pictures, and not the original samples, became the primary object of microscopic analysis. Instead of trying to optimize the photographic processes, these practitioners set out to dissect the hidden qualities of the images, because they assumed that what they saw on the photographic plate was a perfect reproduction of the world, or more emphatically, the world itself captured by the camera.[22] Many introductions to scientific microphotography were published in the 1860s, and in general they were not devoted to a specific subject. As Donné's atlas, they were collections of photographs of different microscopic objects, and their aim was to demonstrate what microphotography could show, rather than to tackle a well defined scientific problem. Breidbach points out that in the manuals published in this decade, three main arguments were put forward in favor of the new imaging technology: (1) microphotographs allowed better measurements of the sample; (2) they showed details which were invisible when looking through the microscope; and (3) they were free from the bias of the observer.[23]

The rationale underlying the first claim was that microphotographs, more practical to handle than actual microscopic preparations, granted precise measurements even in the case of complicated objects. Critics of photography, however, stressed that this putative advantage could be very well attained by employing a camera lucida, an optical device widely used by microscopists at the time, which required much less technical effort than early photography.[24] The second argument, namely that photography showed *more* than the microscope, derived from one of the properties of photography largely praised by Benjamin, i.e., the possibility of enlargement. In this respect, Breidbach reports that in a publication of 1868, the naturalists Oscar Reichard and Carl Sturenburg explained that they obtained high magnification by re-photographing a microphotograph put under the microscope. The process was repeated twice and this

[22]See Breidbach, 2002, 222.
[23]See Breidbach, 2002, 230-231.
[24]See, Breidbach, 2002, 231.

allowed to allegedly attain magnifications of 8000x/30,000x, at a time in which the best microscope could provide a maximum enlargement of 2000x. Through this procedure granularity and other physical properties of the photographic negatives became salient, but Reichard and Sturenburg – as many of their colleagues fascinated by photography – did not take these elements for artifacts produced by the enlargement. On the contrary, they assumed that they were actual properties of the biological specimen made visible by microphotography.[25] In their approach, it was the photographic camera, and not the microscope, that provided relevant information about nature. As Breidbach explains: "The photograph gave the world its own quality, set apart from those things actually seen in the microscope."[26] Photography was the ultimate scientific instrument, the one which set the paragon of truth and reality. On this very ground was founded the third claim, according to which photographs were objective because independent from the photograph maker's subjectivity. For the proponents of this idea of objectivity, microphotographs were the proper representation of what actually existed in nature, for the details of the image were not restricted to those deemed relevant or particularly important by the observer.[27]

3.2.2 The problem of the invisible referent

This conception of photography, founded on the assumption that the photographer is a passive agent in the production of pictures, fits the definition of mechanical objectivity as suppression of subjectivity proposed by Daston and Galison. As seen above, according to Daston and Galison, the ideal of mechanical objectivity emerged in the second half of the nineteenth century and was characterized by the scientists' strenuous attempt "to eliminate the mediating presence of the observer."[28] In the account provided by the two historians, mechanical images, of which photographs represented the most accomplished example, granted objectivity for two reasons. On the one hand, they by-passed human judgement, which tended to select the details of objects or phenomena to be represented; on the other hand, they overcame the limitations of human senses and drawing abilities, which undermined the accuracy of observations and representations, respectively. Mechanical objectivity was clearly predicated on the *indexicality* of the photographic image, because its independence from the photographer and its pictorial accuracy (iconic mode of signification) were

[25]See Breidbach, 2002, 233.
[26]Breidbach, 2002, 234.
[27]See Breidbach, 2002, 231. This is the conception of photography that was later theorized and brought to the artistic arena by Moholy-Nagy, with his idea of unbiased vision and his experimentation with the photographic medium. See Section 2.3.
[28]Daston and Galison, 1992, 82.

a consequence of the fact that the image was produced through an automated process that physically forced, to use Peirce's words, a correspondence between sign and referent. And yet, this account of the objectivity of photography (and mechanical images in general), which Daston and Galison present as an overarching scientific ideal and guiding principle for the scientists of the late-nineteenth and early-twentieth centuries,[29] was far from being unanimously endorsed by bacteriologists. In fact, when it came to the study of the microscopic world, the epistemic authority of photographs could no longer rely on the combination of indexical and iconic modes of signification, because, being the referent invisible, it was impossible to certify any resemblance. Indeed, Breidbach shows that the idea that microphotographs were objective simply by virtue of being a mechanical imprint of nature had little currency among the majority of microscopists. Evidence of this, he maintains, comes from the fact that microphotographs were almost completely absent from micro-morphological and histological papers prior to the late 1880s, even though inexpensive methods for photographic production and printing became available in the 1850s and 1870s, respectively.[30]

Objectivity from operational conventions As a general rule, the scientists who worked with microscopes were very much aware of the many variables involved in their observations. They knew that the selection, preparation, fixation, and staining of the specimen, together with the optical properties of each microscope, played a seminal role in determining the results of any observation of the invisible world. Accordingly, they would not subscribe easily to the idea that a microphotograph showed the objective, true features of a microscopic entity (e.g., a bacterium or a plant cell) merely by virtue of being mechanically produced. The act of looking at a specimen under the microscope was just the last of a chain of actions that started with the very complex tasks of selecting, collecting and preparing a sample suitable for microscopic observation. Hence, for those who studied the microworld, the ideal of objectivity had to be by necessity much more specific and elaborated than the ideal of suppression of the observer described by Daston and Galison. For the majority of microscopists, as Breidbach shows, an objective representation was not simply a mechanical image, but rather "a reliable reproduction of a microscopic preparation,"[31] and it could be attained "by the extent to which the image seen in the microscope [could] be accurately reproduced and its reproduction technically controlled."[32] This implied not only that the photographs had to be taken under controlled

[29]See Daston and Galison, 2007, 174-190.
[30]See Breidbach, 2002, 226 and 234.
[31]Breidbach, 2002, 235.
[32]Breidbach, 2002, 235.

conditions, but also that the whole process of sample fixation, staining, handling, and conservation had to be in line with explicit rules and standards. In other words, objectivity was not an effect of the use of a mechanical technology, but rather the result of operational procedures. The whole process of microbiological investigation had to be carried out within a set of *operational conventions*.

Now, signs that signify by virtue of learned conventions are *symbols*. Peirce's definition, however, refers to the conventions entailed in the process of signs' interpretation, not production (although he stresses that the object puts constraints on the sign's ability to signify). This is probably the reason why the authors who suggest that microscopic imaging has to be understood in terms of symbols rather than icons, emphasize the fact that one has to learn the conventions that allow to interpret the images (conventions related to the way of seeing), and do not elaborate much on the topic of the relevance of conventions in the very production of such images.[33] I think, however, that if we pay attention to the fact that in the processes of image making conventions are embodied in standard procedures and methodologies, we are in a better position to understand how the symbolic and indexical orders of signification are entangled when it comes to assign truth-value to an image of invisible entities. In other words, we have to keep in mind that the meaning of a microphotograph depends on the fact that we trust it as an index (mechanical imprint), only as far as it has been produced according to well defined conventions, that is, experimental standards. The application of operational conventions in the phase of image production is an essential component of the scientists' trust in images, and creates the basis, both material and epistemological, for the definition of a symbolic mode of signification in image interpretation.

It was this specific version of objectivity grounded in operational conventions, put forward by Koch in the 1880s, that led to the acceptance of microphotography as a meaningful scientific tool in bacteriology.[34] Koch did not explicitly contest the idea that photographs provided an accurate reproduction of reality. However, he understood the epistemic potential of photography in strict relation with the specific characteristics, problems, and needs of his field of research. In a paper published in 1886, he wrote:

> It must be remembered that [in bacteriology] we have to do entirely with microscopic objects, and that two observers with the microscope cannot *see the same object simultaneously* and form a joint opinion with regard to it [...]; and as all microscopists know, even the slightest turn of the fine adjustment causes so small an object as a bacterium either to

[33]See, for example, Serpente, 2011.
[34]See Breidbach, 2002, 243.

> disappear entirely from the field, or to appear with different markings and shadows. Agreement will always be facilitated when the observations are made with the same instrument, that is to say, with the same illumination, the same objective, and the same magnifying power. But if the *conditions under which the microscopic object is seen* are very different, [. . .] *if the preparation and staining of the object is dissimilar*, if moreover it is mounted in fluids of different degrees of refrangibility, how can anyone wonder when one microscopist asserts that the object as seen by him is quite different from that described by another? [. . .] Photography, on the contrary, gives the *microscopical picture once and for all, and reproduces it without the slightest error, in exactly the same focus, magnification, and illumination as when it was taken.*[35]

For Koch, photography was capital to investigation in microbiology, because it warranted that two or more researchers, even if working with different microscopes in different places, could observe the same thing, under the same experimental and observational conditions. They would see the same cellular culture under the same focus, magnification, and illumination. In other words, they would construct the same image and, consequently, the same scientific object.

Objectivity from intersubjectivity Photography provided a permanent record of a phenomenon that otherwise could be observed by only one person at the time. It allowed intersubjective evaluations, by assuring that all subjects were looking at the same micro-organism or, more precisely, to the same picture of a given microscopic sample, produced and handled under standard conditions. Such a picture could be retrieved at any moment for later comparisons and could travel long distances, reaching new observers. In a field like microbiology, that in the second half of the nineteenth century was still immature but burgeoning, microphotographs were invaluable means for communication within the scientific community. Bynum has remarked that: "Koch's pioneering photomicroscopy [...] helped in the search for standards, which were so important in the last, heady decades of the [nineteenth] century, when new pathogenic organisms were being announced every few months."[36] Microphotographs were paramount in creating a common practice and a common vision among microscopists. These photographs could not rely on the likeness with the referent (iconicity) to secure their epistemic authority, because there was no way to directly assess any similarity. Neither could such authority come exclusively from their indexicality. As shown by Breidbach, the indexical mode of signification was not enough to make mechanical images meaningful, useful, and accepted in the microbiologists' community. To meet this goal, microphotographs had to be

[35] Koch, 1886, 20.
[36] Bynum, 1994, 129.

embedded in a specific set of conventional practices that created the conditions for a symbolic mode of signification grounded in indexical premises. This means that for microbiologists, the idea of objectivity of photography bore a profound relation with the notion of intersubjectivity. The sharing of conventions can be in fact considered a precondition for intersubjective evaluations. A photograph was objective in the sense that it was intersubjective, and it was intersubjective because it was produced according to well defined standards. Importantly, it was acknowledged that the photograph did not necessarily show the real object (e.g., a bacterium), since it could show artifacts as well. That is, the notion of photographic objectivity was severed from that of photographic realism as a mark of truth. To better understand this point it is useful to resort to Patrick Maynard's distinction between depiction and detection, and the further elaboration of such distinction put forward by Laura Perini.

3.2.3 Depictions and detections

Maynard defines photography as a technology that exploits light and other radiations to mark surfaces.[37] A fundamental feature of his theory of photography is that photographic images can be used *as depictions* or *to make detections*. We use photographic images as depictions when we rely on their mimetic properties in order *to imagine that we see* the object through the image; we use photographic images to make detections when we use them as *sources of information*. For Maynard, the depictive and detective functions can be separated, but in most cases we rely on the depictive character of photographs to make detections: "Photography might be most simply characterized as the site of historically the most spectacular interaction of depictive and detective functions."[38] For instance, when I look at a photograph of my sister or of the Tour Eiffel, I detect my sister or the Parisian monument via the depiction provided by the photograph. I imagine that I am seeing that person or that object through the picture. However, what is depicted does not always coincide with what can be detected. Maynard uses the example of King Kong to clarify this point. A photograph of King Kong is a photographic depiction of a giant ape, but one cannot use it to detect an ape, because the colossal gorilla known under the name of King Kong never actually existed. In this case one can use the photograph to detect a disguised actor, a big puppet, or a virtual reality animation, but not the subject-matter depicted in the photograph or in a movie.[39] This

[37] Maynard defines material images as physical states of a surface, and he calls them "markings" or "marked surfaces." See Maynard, 1997, Ch. 1

[38] Maynard, 1997, 120.

[39] See Maynard, 1997, 114.

means that what can be detected in a photograph, and the level of accuracy of such detection, depends to a large extent on the background information that the observer possess.

This is why the philosopher of science Laura Perini argues that Maynard's distinction between photographic depiction and detection can help us understanding scientific imaging only if we think of detection as independent from, or at least problematically related to, depiction. In fact, although scientists largely rely on photographic evidence in their experimental work, they are often in the situation of possessing very little background information about the depicted object.[40] Perini remarks that when knowledge about an object is scant, "using photographs as depictions is often a threat to detection, because it fosters a way of working with the image that needs have no connection with the kind of information it actually presents."[41] Seeing (recognizing) something as depicted incorporates a number of assumptions, and what appears as depicted does not always correspond to what should be detected. A typical instance in which depiction is detrimental to detection is that of microscopy artifacts. Perini discusses the concrete example of an electron microscope photograph showing a putative mesosome (dense structure) inside the bacterium *Bacillus subtilis*, published in the *Journal of Bacteriology* in 1964.

The problem of artifacts When the authors of this article on *B. subtilis* observed a dense structure inside the bacterium, they thought that it was an organelle with some biological function, whose presence was related to the protoplast state of the bacterial cells, and they named it mesosome. Subsequent analyses, however, demonstrated that the alleged bacterial organelle was, in fact, an artifact. The biologists had used the micrographs as a depiction of *B. subtilis* and this had led them to make a wrong detection: they took an artifact for a real organelle. In this case, to use the photograph to imagine to see the real object through this picture was not the right path to detection. In order not to be mistaken it is necessary to keep in mind that when our knowledge about an object is limited, extracting information about such objects from depictions can be misleading. To avoid the pitfall, the researchers should have taken the micrograph simply as a depiction of the structure of a sample specifically prepared for electronic microscopy, rather than a direct depiction of the bacillus they were studying. Under this caveat, they could just claim that the image allowed to detect small dense regions inside the prepared specimen, because this was indeed the only information that one could extract from the micrograph. To know

[40] See Perini, 2012, 151-152.
[41] Perini, 2012, 153.

something about the origins and function of that dense region – whether it was material that clumped up during sample processing, or an actual organelle in the cytoplasm of *B. subtilis* – required a number of additional observations and experiments. Only in this way, and not simply relying on the perceived realism of the electron microscope image, it becomes possible to clarify the relationship between what is depicted in the micrograph and which structures really belong to the natural specimen.[42] The biologist can certainly imagine that he is looking at a bacterium, but he must be aware that he is looking at it through the electron microscope and through the sample. It is a depiction that is twice removed from its object. Accordingly, if one is to extract reliable information from microscopic images, one has to approach the depiction in a quite restrained way, keeping in mind that it shows a processed specimen, and not the ultimate object of one's research (the microscopic entity). If one looks at an object through the double mediation of the microscope and of the treated sample, then both the conditions of operation of the optical device and the conditions of preparation of the specimen must be standardized, otherwise we could never replicate and share our observations. This leads us back to Koch's insistence on the standardization of both samples' preparation and microphotography procedures, which allowed him to develop an operational notion of photographic objectivity, independent from general claims of photographic realism.

The nineteenth-century bacteriologists who endorsed Koch's vision of microphotography did certainly believe in the reality of the microorganisms they studied, yet their belief was not primarily grounded in photographic depiction, but rather in a complex set of laboratory practices concerning the isolation, growth, and preparation of the samples. Ultimately, it was this set of practices that allowed them to make detections (i.e., to extract information) from photographic images. In this respect, it is worthy to remember that according to Koch's famous "postulates" for the demonstration of the parasitic nature of a disease, a microorganism had to be: (1) "constantly present in characteristic form and arrangement in the diseases tissue;" (2) it should also be "isolated and grown in pure culture;" and (3) it had to be "shown to induce the disease experimentally."[43] Microphotographs could play an important role in the first step, but they had little or no relevance in the second and in the third. I will come back to the relationship between images and laboratory practices in Chapter 4, where I discuss Ian Hacking's idea that scientific representations are deeply entrenched with a larger range of experimental interventions.

[42]See Perini, 2012, 155.

[43]F. Loeffler, quoted in Bynum, 1994, 128. Loeffler was a pupil of Koch's. Koch took his postulates from his teacher Friedrich Henle, who had expressed them in an implicit form in his essay *De miasmata et contagia* of 1840.

3.3 Chronophotography: revealing the optical unconscious

Chapter 2 ended with an image from the *Nouvelle iconographie de la Salpêtrière* that shows a naked body in the grip of convulsive movements against a black background. Commenting on this picture I pointed out that in his attempts to capture motion, Charcot followed in the steps of his teacher Duchenne de Boulogne, who used photography to produce models in order to study the mechanical principles of movement rather than produce portraits of the human body. However, the definitive transformation of the human body into a diagram by means of photography was accomplished by another French physician, Etienne-Jules Marey, with his studies on animal locomotion. Importantly, Marey was a physiologist not a clinician. His preoccupation was to understand movement in general, rather than as a specific symptom of some pathological condition. He was not involved in diagnosing specific patients, and thus he could give up altogether the personal, individual dimension of medical photography, its dimension of portrait, so to say. He wanted to understand the general functioning of the human machine, and to this end he needed to set aside all its contingent idiosyncrasies.

An important analysis of Marey's chronophotographic method has been provided by Snyder, in the article "Visualization and Visibility," of 1998, written in response to Daston and Galison's idea of mechanical objectivity. I showed above that the ideal of mechanical objectivity paid a very poor service to the credibility of microscopys during the 1860s. Microphotographs were widely accepted as valuable scientific evidence only when Koch replaced the idea of mechanical objectivity (conceived as the suppression of the subjectivity of the observer and mimetic realism) with the idea of intersubjectivity supported by shared laboratory practices that summed up to operational conventions (microphotography provided a common controlled vision of the microscopic world). Snyder shows that also in the case of chronophotography the idea of mechanical objectivity is completely misleading. Chronophotographs, he notes, were not meant to suppress any subjectivity, for the simple reason that that they showed something that no human observer could ever see (this observation holds true also for microphotography, because it shows an invisible referent).

3.3.1 Subjectivity superseded

At the outset of "The Image of Objectivity," Daston and Galison quote a passage from Marey who, in the book *La Méthode graphique dans les sciences expérimen-*

tales, after surveying the countless visual instruments available to the scientist of the late nineteenth century, concluded:

> There is no doubt that graphical expression will soon replace all others whenever one has at hand a movement or a change of state – in a word, any phenomenon. Born before science, language is often inappropriate to express exact measures or definite relations. [Images recorded by mechanical instruments, on the contrary, speak] the language of the phenomena themselves.[44]

Daston and Galison comment on this quote as follow:

> "Let nature speak for itself" became the watchword of a new brand of scientific objectivity that emerged in the latter half of the nineteenth century. At issue was not only accuracy but morality as well [. . .]. *Marey and his contemporaries turned to mechanically produced images to eliminate suspect mediation.*[45]

Here "suspect mediation" stands for the inevitable amount of idealization, interpretation, or lack of precision that a human observer introduces in any description, verbal or visual of a phenomenon. For Daston and Galison, the scientists in the late nineteenth and early twentieth centuries praised mechanical representation, because they saw in it a way to suppress the subjectivity of the observer. In the case of Marey's images of movement, however, the suppression of subjectivity was not an issue. As Snyder puts it:

> Most of Marey's work does not fit the mold Daston and Galison make for it. [. . .] For the most part, Marey did not conceive of his precision instruments as impartial mediators substituting for and improving upon an observer's eye or an illustrator's hand. His mechanically originated graphs and photographically generated pictures are visualizations of displacements charted against precisely determined units of time. *These movements fall outside the scope of human detection* and accordingly, their inscriptions cannot be characterized as especially accurate visualizations of what might otherwise have been registered by an illustrator or scientist.[46]

When the machine records and displays something that falls squarely outside the realm of human sensibility (for example, vectors of motion as in the case of many of the works of Marey's), then the act of observing is fully displaced

[44] Marey, 1878, iii.

[45] Daston and Galison, 1992, 81. It should be noted that the discussion of Marey's texts, which in the article of 1992 had a prominent role in the argumentation of Daston and Galison's, disappeared from their book of 2007. Although in the book the idea of mechanical objectivity is presented in a much more articulated and nuanced form than in the article, the authors do not touch upon, hence do not provide any answer to, the objections raised by Snyder.

[46] Snyder, 1998, 379.

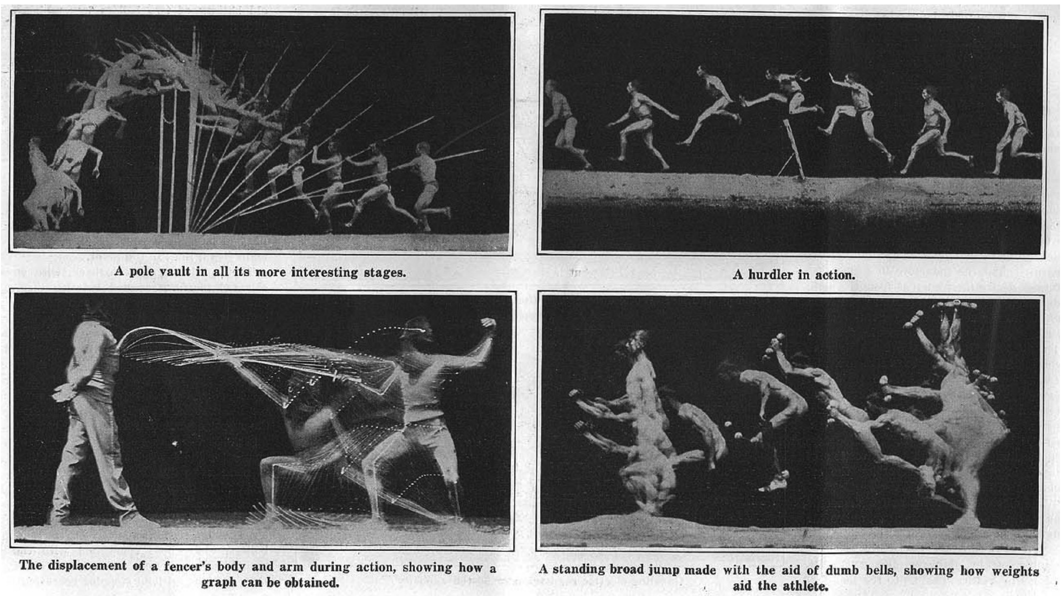

Figure 3.2: Examples of chronophotographs by E.-J. Marey.

from the subject to the machine. Hence it makes no sense to talk of objectivity as suppression of subjectivity. In this case the subjectivity of the observer cannot be at stake, simply because there is no way in which he or she could access the phenomenon under study with the unaided senses, no matter how patient and accurate he or she might ever be. The machine does not merely show with inhuman precision what a human observer would see anyway through his or her subjective (and unaided) senses. Under these circumstances the machine completely substitutes for the human subject, and thus the activity of the mechanical apparatus takes part in the very construction of what can be seen. In Snyder's words: "In Marey's program, the visualized data produced by the inscribing mechanisms have no existence apart from their realization."[47] That is, they only exist as mechanically generated data (Figures 3.2 and 3.3).

When Snyder says that the visual data produced by Marey's machines have no existence apart from their realization, he means that they would not exists *qua* visible entities if there were not a machine capable of producing them. This happens because the data produced by certain instruments (e.g., a sphygmograph or a high speed camera) make visible phenomena that are not visible in their own nature. Of course, this does not mean that the phenomenon itself (e.g., arterial tension or rapid motion) does not exist, but that it becomes visible only by means of a machine. What is at stake here is the source, or origin, of the image, that is, the object or phenomenon represented. If I make a drawing or take a photograph of, say, a leaf, the origin of the image I produce is visible in its own right, it exists as a visible entity in the world independently from my

[47]Snyder, 1998, 383.

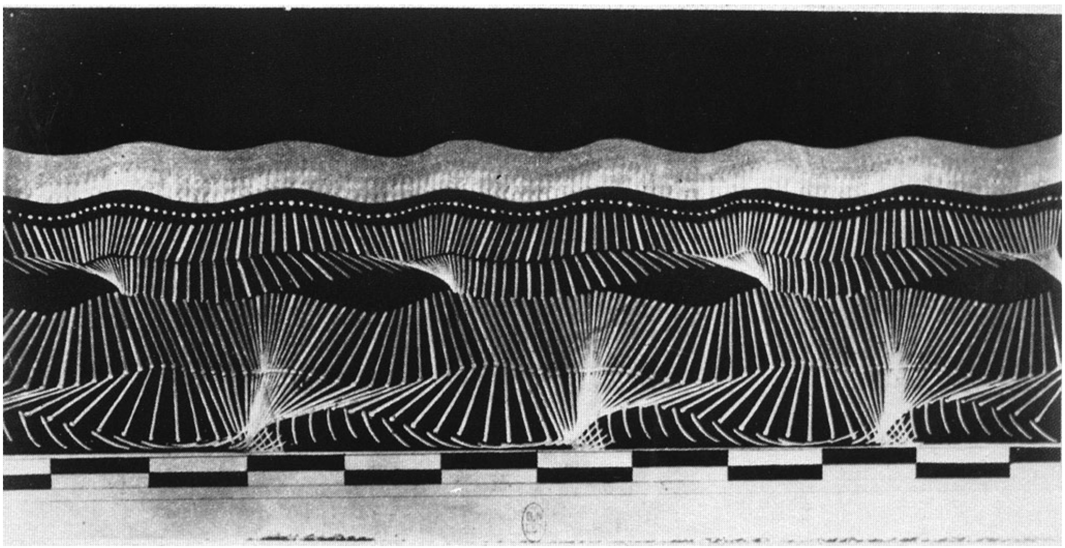

Figure 3.3: Images of a runner reduced to a system of bright lines for representing the positions of the limbs (geometrical chronophotograph). Photograph by E-J. Marey, 1886.

representation. On the contrary, if I measure blood pressure with a sphygmograph I make visible a phenomenon that could not be seen otherwise (although it could be perceived by the sense of touch). The blood tension graph is an image originated by a non visual process (the pressure exerted by the blood flow on in the arteries' walls) by means of an instrument (the sphygmograph). Yet another case is that of rapid movement. Movement in itself is a visible phenomenon, but I can see the instantaneous position of a limb only by means of chronophotograph or slow motion film. In what follows I explore the problems and implications of these forms of visualization.

Mechanical diagrams and chronophotography In the course of his research career Marey worked with two kinds of "instant diagrams,"[48] as he sometimes called his images of motion: mechanical diagrams and chronophotographs. We have already seen in Chapter 1 that he was the inventor of one of the first sphygmographs, in 1860, and that in the following years he invented a number of other recording devices, developing a complex graphical method for the study of almost any physiological activity.[49] He put mechanical diagrams aside only in 1882, when he turned to chronophotography. Among the instruments that constituted the armamentarium of the graphical method, Snyder makes a distinction between the sphygmograph, used to measure the pulse, and the ex-

[48]Marey, 1878, iv.

[49]Among Marey's inventions we can mention the myograph, which measures muscular contraction, the dromograph, for the monitoring of blood flow, the cardiograph, and the polygraph, an instrument that measured different physiological functions at the same time.

Figure 3.4: Man with experimental shoe. E.-J. Marey, *Le Movement*, Paris, 1894, Engl. translation, New York, 1895, Figure 4.

perimental shoe (figure 3.4) used in the study of animal locomotion. In the first case, we have a device that actually replaces a human sense (i.e., touch),[50] while in the second we deal with an instrument that simultaneously detects, transmits and charts specific aspects of movement, namely, the duration, phases and intensity of the pressure exerted on the ground by each foot during walk. These features of locomotion could never be perceived by a human observer. The experimental shoe and the graphs it produced allowed the French physiologist to empirically study the walk of a man or the gallop of a horse in terms of levers, fulcrums, forces and positions – i.e., in terms of mechanical work.[51] Snyder makes an important point about these graphs when he says:

> Marey's method might seem to introduce, in the case of rapid animal locomotion, the possibility of finding novel graphic expression for phenomena that had always been conceived in visual terms, but he was

[50]It should be noted, however, that the functions of the sphygmograph went beyond the mere replacement and improvement of the subjective sense of touch, for it made the measuring of pulse quantifiable, retrievable and publicly available, independently from the presence of both the patient and the doctor. See Section 1.5.3.

[51]See Snyder, 1998, 386-388.

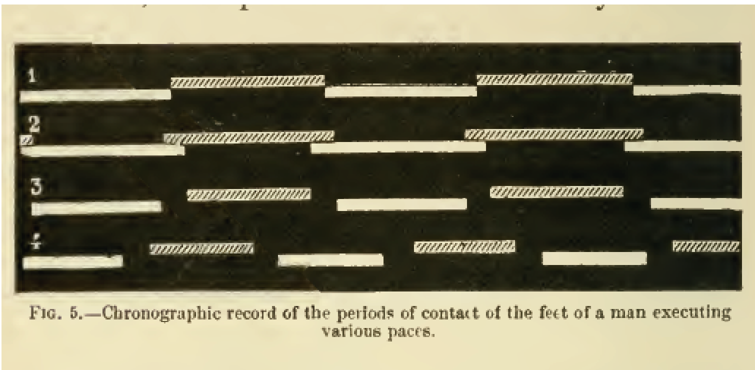

Figure 3.5: Diagram of the sequence and duration of the footfalls during four different forms of walking. The contact of the right (left) foot is represented by a white (diagonally shaded) line. E.-J. Marey, *Le Movement*, Paris, 1894, Engl. translation, New York, 1895, Figure 5. Public domain.

> not, in fact, interested in determining, for example, what a horse at full gallops *looks like*; he wanted, rather, an accurate analysis of the mechanics of animal locomotion. [...] Marey's machines produce data about phenomena – about the highly qualified subject of investigation (e.g., the relation of forces at specific instants of a full gallop), but these data are entirely artifactual, the products of machinery and a conceptual scheme – mechanics – that give intelligibility to the inscribed curves. Whatever the charts may be, they are not illustrations of the movements of horses' legs; when properly deciphered, they are records of work performed by them.[52]

What Marey was visualizing in his experiments was not an unqualified, natural expression of motion, but rather motion according to some specific parameters of mechanics. Animal locomotion was transalted into diagrams that gave information about work, forces, distances, displacement vectors and so on, and these are *concepts, not visible forms.* The natural phenomenon was broken down into artifactual analytical data (corresponding to specific mechanical concepts) in order to become accessible to the sensorium of the physiologist. Animal locomotion is certainly a visible phenomenon, and Marey's graphs and chronophotographs are certainly visual inscriptions of movement, yet they do not work according to any mimetic principle, that is, *they do not show what we see or could see* if we paid enough attention. They give visible form to something that falls beyond human visual perception, but these forms do not look like what we see when we look at a man or a horse moving (Figures 3.5 and 3.6). They do not mimetically represent movement, they gauge it.

[52]Snyder, 1998, 387, italics in the original. In a note Snyder stresses that the adjective "artifactual" refers to the data charted in the graphs, not to movements themselves. Movements are facts independent of the observer even though we can study them only by way of visualizations generated by an experimental device. See Snyder, 396, note 6.

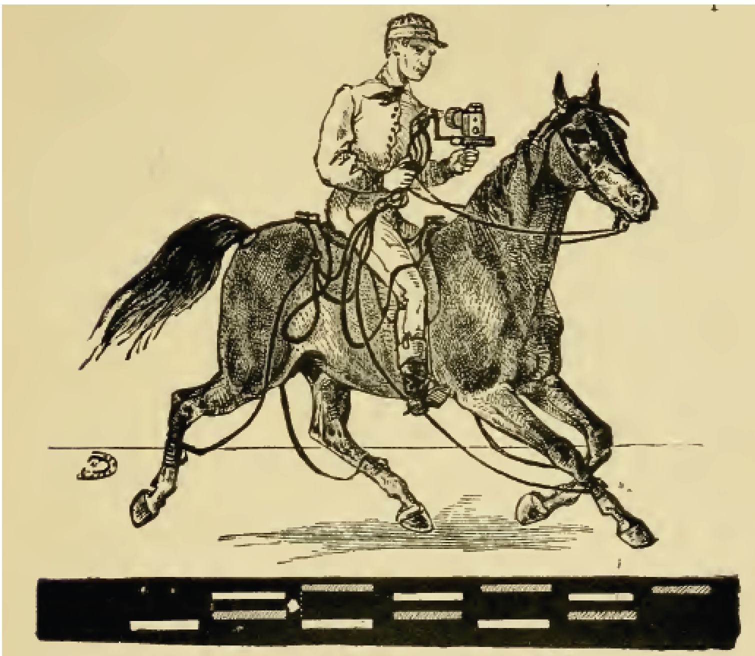

FIG. 7.—Horse at a *full trot*. The point indicated on the chart corresponds to the position of the horse represented in the figure.

Figure 3.6: Diagram of the sequence and duration of the footfalls of a horse at a full trot. E.-J. Marey, *Le Movement*, Paris, 1894, Engl. translation, New York, 1895, Figure 7. Public domain.

What referent for chronophotography? Snyder points out that, if it is unproblematic to say that charts, graphs and diagrams do not look like any physical object (as a matter of fact they are not meant to represent physical objects),[53] it is more difficult to accept the claim that a chronophotograph does not look like anything. A chronophotograph is a photograph, and photography, by definition, produces pictures of objects that stand in front of the camera.[54] Hence, the question is: if one claims that photography shows with unerring precision the visible world (as we have seen, this was a common conception in the nineteenth century, and Marey subscribed to it), how can one also claim that it shows things that cannot be seen, because they do not exist as material objects in the world? In the discussion of dermatological photography (Section 2.6), we have already seen that the early proponents of photography understood the ontological status of the new optical medium as complex and malleable. Similarly, Snyder argues that contradictory views on photography had large currency in

[53]See, for example, figure 3.5. It is a diagram of the sequence and duration of the footfall during four different forms of walk. White lines represent the contact on the ground of the right foot, while diagonally shaded lines represent the contact of the left foot. It is a representation of human steps that does not *look like* a person walking. It represents the sequence and duration of footfalls, two concepts (sequence and duration), which have no corresponding physical object. A different example might be that of a graph representing the increase of unemployment over the last five years. There is no physical object corresponding to unemployment, and the graph cannot *look like* it.

[54]See Snyder, 1998, 389.

the nineteenth century, and he considers Marey an "ideal commentator"[55] exactly because the French physiologist held nearly all the conflicting positions on photography maintained by his contemporaries.[56] In one page of his book *Movement*, of 1894, referring to the problem of perspective, Marey could claim that photography reproduces "the appearance of natural objects, as seen by looking with one eye only," and a few pages later, discussing the chronophotographs of a rotating brass band (Figure 3.7) he could state: "In reality we are dealing with a hypothetical figure, which finds no counterpart in Nature."[57] How to reconcile these seemingly contradictory positions? Part of the answer suggested by Snyder impinges on the technical evolution of the photographic medium. Early photography, he argues, with its long times of exposure helped to corroborate the cognitive primacy of vision: the image on the photographic plate displayed what a bystander or the photographer would have seen from behind the camera at the time of exposure, "if only he or she had carefully attended to the scene."[58] Until the 1880s, when instantaneous photography became widely available, every photograph was a still life, and it was perceived as a mirror reflecting a static superficial reality. The sensible plate would fix what the eye could see. With chronophotography the reciprocal corroboration of photography and human vision no longer applied. In Snyder's words:

> Such pictures work against the conception of photographs as reproducing the appearance of objects. And so here we enter another new domain of mechanical sensibility, which permits us to see, though only in pictorial form, what happens in front of us – before our eyes. [...] [With chronophotography] the observer is left wobbling between what is visible to the naked eye and photographically depictable and what is unseeable by the eye but nonetheless reproducible by chronophotographic means.[59]

Chronophotographs confront the viewer with the paradox of a photograph that shows something that is right in front of him, and yet remains invisible. This paradox belongs to the domain of the optical unconscious theorized by Benjamin and exemplified by the famous pictures of galloping horses. For ages equestrian painters had pictured "flying gallop" with the horse completely detached from the ground when its four legs are extended. And this is indeed what *we believe we see* when we look at a galloping horse. In 1878, however, Eadweard Muybridge published the photography sequence *Silhouettes of Horses in Motion*, which revealed that, during gallop, horses are detached from the ground when the

[55] Snyder, 1998, 390.
[56] See Snyder, 1998, 390.
[57] Marey, 1894, 19 and 31, quoted in Snyder, 1998, 391.
[58] Snyder, 1998, 391.
[59] Snyder, 1998, 393.

four legs are bent. Moving horses are certainly visible objects, and yet there are aspects of their motion that deceive our eyes. Imaging machines endow us with "mechanical sensibility,"[60] that is, they allow us to explore objects and phenomena that fall beyond the reach of unaided human senses.

3.3.2 Mechanical sensibility

By conceptualizing photography in terms of *mechanical sensibility* we adopt a perspective that is diametrically opposed to Daston and Galison's idea of mechanical objectivity as suppression of subjectivity. Within the framework of mechanical objectivity, the image produced by the machine is a mechanical copy of the visible word, and the scientist is the passive recipient of such image. On the contrary, if we think in terms of mechanical sensibility, the imaging apparatus acquires creative properties. It produces images that can reveal the invisible, rather than merely reproduce what is already visible, and it engages the scientists in a productive relation. In fact, it is the scientist (or a collective of scientists) that designs and operates the imaging apparatus and, in turn, through such apparatus his senses are improved. With chronophotography the camera is no longer a picture-machine that produces likenesses, it becomes an instrument wedded into an experimental setting and a theoretical structure, that gauges the world and its phenomena going beyond the experience provided by unaided senses.

Yet, I think that it is important to note that this paradox of a photograph that shows the invisible was already implicit in the endeavors of all the medical photographers discussed in the previous chapter. All of them, from different perspectives and with different photographic strategies, used the superficial eye of the camera to disentangle a range of non visual phenomena. In the context of clinical medicine, Duchenne looked for the laws of emotions, Charcot tried to track down the neurological underpinning of hysteria, and Diamond claimed that in the search for the causes of mental illnesses, photography would enable the metaphysician "to witness and trace out the connection between the visible and the invisible."[61] Even in dermatology, the domain of the surface of the body and therefore of total visibility, photographs deeply influenced nosology, by taking permanent track of details that went usually unnoticed.

Microphotography, by coupling the camera to the microscope, entered the realm of the extremely small, but with the work of Marey's, photography departed from the tradition of photographic realism in an unprecedented way. He

[60]Snyder, 1998, 393.
[61]Diamond, 1856, 20.

claimed: "Although chronophotography represents the successive attitudes of a moving object, it affords a very different picture from what is actually seen by the eye when looking at the object itself," and added: "[these] images *appeal rather to the imagination than to the senses*."[62] As seen above, Marey was not bothered by the brisk divide between the idea of photography as producer of perfect visual correspondences with what we can see, and photography as a device that produces imaginary pictures. According to Snyder, this lack of problematization was a sign of the little theorization undergone by photography in the nineteenth century. This may well be the case, but I think that the contradiction disappears if we recall Peirce's idea that the iconic status of photographs is predicated on their indexicality.

Symbolic indices and prosthetic senses If a photograph is an icon by virtue of its being an index (in Peirce's definition a photograph is *physically forced* to correspond point by point to nature),[63] there is nothing that prevents us from accepting that it can correspond to nature in points that are not directly visible to the human eye. To put it differently, if the epistemic authority of photography lies primarily in its indexical relation with nature, then resemblance with the represented object becomes an ancillary feature. Consequently, it is not contradictory to take photography as a medium that shows the appearance of things (icon), and that can *also* show phenomena that fall beyond the scope of natural vision. While in the former case the photograph is a sign that works as *index* and *icon*, in the latter it can work as *index* and *symbol*. In the case of microphotography, I inscribed the symbolic mode of signification of the image within the operational conventions of laboratory practice. In the case of chronophotography, the symbolic dimension of the picture depends chiefly upon a specific theoretical framework that conceives of continuous movement as the sum of instantaneous components, and thus allows to study motion through the visual fragments of a continuum. In the geometrical chronophotograph shown in Figure 3.3 we see an index of the position of moving limbs, but the image that we see is not an icon, because it does not look like a man running, at least not according to a criterion of similarity with what we can see with the naked eye. Yet, for Marey it was a valuable tool for studying human locomotion according to the principles of mechanics.[64] Another example is provided by the

[62]Marey, 1894, 304, quoted in Snyder, 1998, 391.

[63]See Peirce, CP 2.281. See also Section 2.2.

[64]Marey subscribed to positivist philosophy and was a firm opponent of biological vitalism. He nevertheless criticized traditional mechanistic accounts of life, maintaining that they had failed because they used as models machines such as pumps, levers, and ropes, that do not rely on an integrated engine as source of motive force. On the contrary, modern machines,

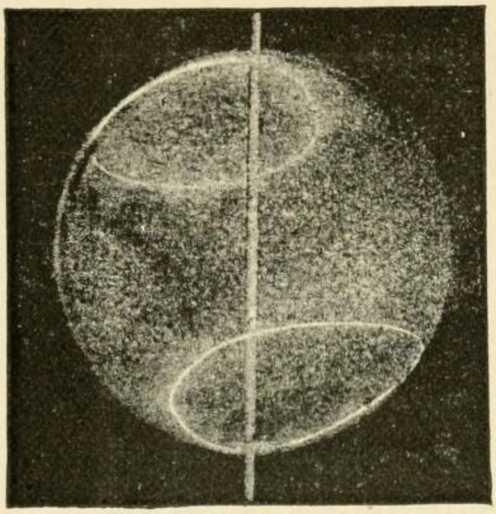

Fig. 24.—Paradoxical appearance of a sphere engendered by the rotation of a brilliant metallic thread.

Figure 3.7: Chronophotograph of a semicircular arc of polished brass rotating around a vertical axis. The rings visible on the opposite portions of the sphere are produced by the reflection of sunlight by a specific point of the rotating arc. E.-J. Marey, *Le Movement*, Paris, 1894, Engl. translation, New York, 1895, Figure 24. Public domain.

chronophotograph of a rotating brass band shown in Figure 3.7. Here we see a sphere with two bright rings at each pole, but the actual object is a semicircular arc of polished metal in fast rotation. What we see in the picture is an optical illusion, a trace of the band movement. In this case, if we analyze the image according to the criteria of mechanics, we can say that the photograph produces a map of the trajectory of the rotating body and the reflection of light at specific points of such trajectory, but it would make little sense to say that it resembles the movement of the brass arc and the reflection of sunlight.

What is problematic, then, is not to accept that the photograph can show what we see and also what we cannot see. The real difficulty at this point, as we have seen in the case of microphotography, is to set the terms of comparison to evaluate the meaning and correctness of what the photographic plates shows. And since there is no way to asses the resemblance of the image with its actual referent, we need to rely on the indexical and symbolic modes of signification. With microphotography it was a matter of establishing standards of sample preparation, conservation, and observation. In the case of chronophotography it was necessary to embed the image in a specific theoretical framing of motion, namely, mechanics, which allows to decompose motion into velocity vectors. As remarked by Snyder, chronophotography was an analytic device that split

with their engines that demand specific sources of energy are effective proxies of the "animal machine." Marey, 1873. See also Dagognet, 1987.

movement in its instantaneous components, and reduced the body to a system of fulcrums and levers. In this sense, it required of the observer an effort of imagination to recompose movement as a synthetic continuous process.[65] More generally, it assumed a way of looking that was different from natural vision, which relies on the iconic mode of signification, and required instead a way of looking that had to be learned (symbolic mode).

To make his point Snyder brings to our attention a comment of Marey's on Muybridge's equestrian chronophotographs. Marey wrote that although the positions of gallop revealed by the American photographer at first appeared unnatural, they eventually "have taught us to *discover attitudes in Nature which we are unable to see for ourselves*, and we begin almost to resent a slight mistake in the [traditional] delineation of a horse in motion."[66] As Benjamin, Moholy-Nagy and the avant-garde film directors of the 1920s, Marey envisaged chronophotography as a prosthesis of natural perception, an instrument that would reconfigure, improve and transform our vision and, accordingly, our understanding of the world. Photography, according to Marey, would teach us to see in a different way. As Benjamin put it three decades later, it would grant us access to the optical unconscious, by making visible those aspects of the world that escape the bare senses. The education of the eye foresaw by Marey had nothing in common with the suppression of the subjectivity of the observer. It implied, on the contrary, an active training of imagination and, in the last instance, a deep transformation of our sensory apprehension of the world.

3.4 X-rays and the transparent body

When radiography was invented, at the end of 1895, it was perceived as a further innovation in an already rich domain of scientific images, optical technologies and experimental practices. In his book on the medical technologies of the nineteenth century, Reiser wrote that radiography "catapulted medicine into a visual age."[67] Yet, it should be stressed that this transformation capitalized on an already existing and extremely rich visual culture. The century had started with a new way of looking at the inner body, promoted by clinical anatomy. By its end doctors could visualize the human body (from the outside and from the inside), its functions, and its impairments in completely new ways that ranged from endoscopy to physiological tables, passing through the lenses of the camera and the microscope. With the invention of radiography a new form

[65] See Snyder, 1998, 394-396.
[66] Marey, 1894, 395, quoted in Snyder, 1998, 391.
[67] Reiser, 2009, 14.

of clinical anatomy became possible. X-rays dramatically improved medicine's diagnostic capability and, unlike what happened with many of the previous medical innovations, the diagnostic potential of this discovery, which in fact occurred outside the realm of medicine, was instantly realized.

Wilhelm Roentgen discovered X-rays quite serendipitously, and invented radiography in the process of testing and documenting his unexpected findings. Like many other physicists of his time, he was engaged in exploring the properties of electrical discharges and cathode rays using Crookes' tubes. The accepted history goes that one evening, while operating a tube covered by black cardboard, he noticed that some rays escaped the apparatus, leaving a faint glow on a fluorescent screen that somebody had forgotten on the bench nearby the Crookes' tube. Surprised by this phenomenon, he replicated it several times, placing a number of objects between the tube and the photographic plates. Some of these objects, as books, blocks of wood, and rubber bands, left the rays pass through and sensitize the photographic screen; some others, as leads and other metal objects, blocked them. These properties were definitely not the properties of cathode rays: Roentgen had found a new kind of rays, which he dubbed X-rays with the X of *ignoramus*.[68]

In the days following his discovery Roentgen took radiographs of many other objects, including the left hand of his wife Bertha, which became a real icon of the time. It should be noted that Roentgen did not actually use the term "radiograph." He dubbed his images *skiagraphs* or *skiagrams*, which literally means an image formed by the shadow of an object.[69] Indeed, shadows, and not well delineated and contrasted figures, were what one could see in the X-ray photographs. The terms radiographs and radiography quickly appeared in the literature, together with many others, such as shadowgraphs, roentographs, katographs, electrographs, fluorographs and so forth. Such variety of names remained in use for many years, and it is symptomatic of the novelty of X-ray images. These images were so new that they did not even have a proper name, although many referred to them as *new photography*. The instability of the terminology went hand in hand with the provisional nature of the knowledge that surrounded radiographs.[70] Within the scope of physics and technology it was not clear how radiographs were *produced*: on the theoretical hand, physicists who studied the composition and behavior of matter did not know exactly what X-

[68]See Kevles, 1997, 17-21; Reiser, 2009, 21; Friedman and Friedland, 1998, 115-132.

[69]Roentegen, 1896.

[70]It has been noted that as doctors grew comfortable interpreting X-ray images, they were less prone to refer to them as shadows. By 1900 the British journal *Archives of Clinical Skiagraphy* had changed its name into *Archives of the Roentgen Ray*. The terms skiagram and skiagraph disappeared altogether after the 1920s. See Lerner, 1992, 387.

Figure 3.8: The bones of a hand with a ring on one finger, viewed through X-rays. Roentgen, W.K., 1895. Photoprint from radiograph. Wellcome Library, London.

rays were and which physical principles underlined the appearing of radiographic images; on the practical hand, it took much effort and time for the radiographic technology to stabilize. Within the scope of medical activity, although the usefulness of radiographs seemed obvious, it was not evident how they should be actually *used*, that is, interpreted and integrated within clinical practice.

3.4.1 X-ray vision

When Roentgen published the results of his research, radiographs were received as the heralds of a sensorial revolution. They were astonishing pictures, which represented a triumph for science and a challenge to the conventional notion of vision and visibility. The X-ray photograph of Frau Roentgen's living skeleton wearing her wedding ring (Figure 3.8) was published all around the world, in physics and medicine journals, as well as in popular magazines, causing great excitement inside and outside the scientific circles. Until the 1920s, when the hazardous nature of radioactivity became clear and safety rules for the production of radiographs were endorsed, instructions to build a radiographic apparatus were available in both engineering and photography journals. Virtually, any interested person, amateur or professional, could work with X-rays, and the most enterprising photographers added radiographs to their gallery of portraits. Educated ladies offered X-ray pictures of their hands or chest to their lovers, and at amusement parks and fun fairs, people could see their own bones in real time through a fluoroscope. As a whole, radiographs were perceived not just as powerful medical devices, but as actual portraits.

Thomas Mann's novel *The Magic Mountain*, of 1924, provides interesting insights into the socio-cultural but also emotional impact of X-ray imaging. Dr. Hofrat Behrens, the director of the sanatorium in the Alps where the story takes place, explained to his bewildered patients that radiography was "anatomy by the means of light,"[71] but for Hans Castorp, the young hero of the novel, radiographs were both omens of death and romantic keepsakes. When he was invited to take a look at the radiograph of his cousin's chest, Hans had the uncomfortable feeling of being intruding into his intimacy and peering into his imminent death, but later on in the story, he kept a radiograph of Clavdia Chauchat as a fetish of his love for her.[72] Far from being perceived only as objective medical records, X-ray images were endowed with several extra-scientific meanings. Indeed, as described by the historian of science Bettyann H. Kevles, radiography had a great impact on both popular and high culture in the early twentieth century. Kevles points out that the X-rays' ability to turn visible what was hidden by the skin was quickly associated to the notion of X-ray vision, the power to peer not only through the skin, but also through clothes and walls. The idea of transparency associated to the human body triggered voyeuristic imagination, as if transparency meant nudity. Several humorous cartoons on this theme appeared in the popular press, and some manufacturers advertised their radiographic products with pictures of naked ladies standing in front of an X-ray screen, as if they stood in front of a mirror.[73] A more sophisticated version of the idea of X-ray vision can be found among modernist artists. Kevles quotes from the *Technical Manifesto of Futurist Painting*, published in 1910:

> Our growing need of truth is no longer satisfied with Form and Colors as they have been understood hitherto. [...] Who can still believe in the opacity of the bodies, since our sharpened and multiplied sensitiveness has already penetrated the obscure manifestation of the medium? Why should we forget in our creations the power of our sight, capable of giving results analogous to those of the X-rays?[74]

[71] Mann, 1924, 225.

[72] Media scholar José van Dijck argues that *The Magic Mountain* can be considered an *ante litteram* cultural analysis of the tremendous social impact of the new visual system inaugurated by the X-rays. On the one hand, Mann reflects on the use of radiography in the diagnosis of tuberculosis, inducing the reader to reconsider the dichotomy between instrument and observer, object and representation, science and art. On the other hand, he piercingly describes the erotic imaginary associated to X-ray imaging. See van Dijck, 2005, Ch. 5.

[73] See Kevles, 1998, 17-30; Cartwright, 1995, Ch. 5.

[74] Quoted in Kevles, 1998, 130. The manifesto was signed by the Italian painters Umberto Boccioni, Carlo Dalmazzo Carrà, Giacomo Balla, Gino Severini and Luigi Russolo.

For avant-garde artists, radiography was a metaphor of the mathematical and scientific achievements that since the final quarter of the nineteenth century had shattered the positivist view of knowledge and reality, as well as a formal model for expressing their novel conceptions of vision and space, matter and force, visibility and invisibility.[75] In the hand of these artists, X-rays became a formal device whereby the human body was dissolved into lines of force, transparent surfaces, and dissected volumes. They deployed the analytical functions described by Benjamin in relation to photography and cinema.

3.4.2 *Oculis subjecta fidelibus*

Roentgen himself was never interested in the medical potential of radiography. It seems that he discussed the issue only once, on occasion of a lecture given to the Würzburg Physical-Medical Society, shortly after his invention. He reached the conclusion that the avail of X-rays for medicine was very limited, because he thought that since all the soft tissues of the body have the same density, they would leave a uniform, uninformative shade on the radiographic plate.[76] On the contrary, the very first comment published in the lay press (*Die Presse*, Wien, January 5, 1896), showed considerable optimism about the diagnostic potential of X-rays imaging. The journalist wrote: "we can foresee that one day these rays will be so perfect that [...] they could be of immeasurable help for the diagnosis of countless diseases other than those of the bones."[77] The enthusiasm of the Austrian reporter was shared by a handful of physicians who started to make radiographs as soon as the discovery went public. Roentgen published his preliminary report on X-rays on December 28, 1895, and within a few days the first medical radiographs appeared. At the technical level, the transition from photography to radiography was smooth. As an imaging device, radiography was considered a special kind of photography, one that exploited X-rays rather than visible light to create images on a sensible surface. Indeed, in the early years of radiology, photographers contributed to the development of the new technology as much as physicists, engineers, and physicians. Medical photographers were very quick at learning how to make radiographs. Londe, for example, set up a radiographic laboratory at the Salpêtrière as early as January 1896, and shortly after he was appointed director of the Department of Radiology of the Parisian hospital.[78]

[75] See Lamata Manuel, 2010.

[76] See Friedman and Friedland, 1998, 125-126.

[77] Quoted in Posner, 1971, 233.

[78] See Sicard, 1998, 211. Since so many different professionals were involved in the making of radiographs, an important debate arose about *who* was entailed to make (and interpret) them. In France, for example, the issue was raised already in December 1896 by Antoine Béclère,

In April 1896, the *British Medical Journal* began to publish the *Archives of Clinical Skiagraphy* and appointed a "special commissioner for investigation of the application of the new photography to medicine and surgery" (a Mr. Sydney Rowland). In the first issue of the *Archives* Rowland wrote:

> The progress of this new Art has been so rapid that, although Prof. Roengen's discovery is only a thing of yesterday, it has already taken its place among the approved and accepted aids to diagnosis. At the first moment, the statement that it had been found possible to penetrate the fleshy coverings of the bones, and to photograph their substance and contour, seemed the *realization of almost an impossible scientific dream.* [...] At the present time, we are in the position to obtain a visible image of every bone and every joint in the body. [...]
>
> Whatever may be the scientific explanation of the exact character of the X rays, the value of their discovery to surgeons and physicians is inestimable. By means of the new radiation it is now possible to render visible certain of the interiors structures of the living body, and their precise conditions of disease or of health can be *objectively demonstrated, and facts which heretofore could not be known or guessed at by a complicated system of inference, are now oculis subjecta fidelibus.*[79]

This quotation captures quite well the enthusiasm with which the medical world, or at least part of it, received the discovery of the X-rays. As Rowland put it, it was a scientific dream that came true. It was finally possible to gain a definitive visual access to the inner body, and thereby attain objective demonstrations of conditions that the traditional inferential method of medicine could never reveal. For Rowland, radiography was objective because it offered visual evidence of something that, under natural conditions, was hidden to the human senses. His idea of objectivity was explicitly rooted in the sheer equivalence between objective and visible (*oculis subjecta fidelibus*), therefore his trust in the objectivity of radiography depended implicitly on the fact that X-rays made available to human perception something that otherwise would be strictly concealed, namely, the bones and joints of a living person.

For Rowland, objectivity was related with the very possibility of *seeing* something and of sharing such vision, rather than with the sheer automatization of the process of image production. However, although his excitement was widely shared within the medical community, the integration of radiography in routine clinical practice was neither uncontroversial nor instantaneous. The new technology was almost immediately adopted in surgery, especially in the domains of

the virologist-immunologist founder of French Radiology. Béclère, as many other physicians, argued that both radiography and radiotherapy should be controlled by medical specialists, but the conflict of competences went on until 1934, when a law established that a medical degree was needed to use X-rays for diagnostic and therapeutic aims. Similar measures were adopted in all countries where hospitals had radiographic facilities.

[79] Rowland, 1896, 3 and 9.

military medicine[80] and dentistry, but it took a few years before it could make some impact on internal medicine. This is not surprising if we consider that, as Roentgen had warned, soft tissues are scarcely opaque to X-rays and that, given the poor quality of the early radiographs, it was much easier to identify bullets, bones and teeth than soft organs, such as the lungs and the heart.

The difficulties in visualizing the lungs were particularly compelling, because lungs were the most important seat of tuberculosis, one of the most common and deadly diseases of the eighteenth and nineteenth centuries. However, medical historian E. Posner has shown that the attitude of the medical community in respect to such hindrances was not uniform. In an early comment on the Roentgen rays, the British scientific journal *The Electrician*, reported: "with the stethoscope it has become possible to listen to the working of the human frame, with the new radiation it is to be hoped that the human frame will become – *to skilled vision* – something akin to transparent."[81] Thus, radiography, with its ability to reveal the inner body, was immediately associated to the stethoscope, which was the leading diagnostic technology of the time, at least for chest diseases. Commentators in the medical press, however, were quite cautious, and in the issue of the *British Medical Journal* that appeared on February 1, 1896 a doctor wrote that only "the uneducated imagination" of lay people could dream of immediate benefits from the X-rays in the domain of tuberculosis and thorax diseases.[82] At the beginning of the 1920s some medical textbooks still expressed skepticism in relation to the ability of X-rays to reveal pulmonary tuberculosis before the manifestation of symptoms and physical signs. As a telling example, Posner reminds that in the eight edition of *The Principles and Practice of Medicine*, of 1920, the renowned clinician William Osler (one of the founding professors of the Johns Hopkins Hospital School of Medicine) maintained that a careful clinical examination would normally say more than any radiograph, and disparagingly wrote: "radiographers need the salutary lesson of the Dead House to correct their Visionary interpretation of shadows."[83] To Osler, radiographs were mere shadows, and the only way to gain true knowledge of disease remained pathological anatomy.

French doctors, in general, seemed more optimistic. Already in 1897, the *Revue de la Tubercolose et de Pneumologie* reported on the work of L. Douchard and colleagues, at the Hôpital Charité in Paris, saying that thanks to their "*belles*

[80]Italy was the first country to use X-rays on the battlefield: in May 1896 field hospitals in the east Africa war were equipped with X-ray units. In the following year the British sent field-type X-ray apparatuses to the Balkans and Afghanistan. See Kevles, 1997, 39.

[81]The Electrician, 1896, 36:448, quoted in Posner, 1971, 233.

[82]See Posner, 1971, 233.

[83]Quoted in Posner, 1971, 234.

radiographies" they had been able to detect tuberculous lesions that had been missed by percussion and auscultation. And although Bouchard himself thought that the new method had limitations similar to those of physical examination, the author of the article was much more confident and expressed no doubt that radioscopy would have allowed for earlier diagnosis of tuberculosis.[84]

3.4.3 Radiography and the challenges of internal medicine

Tuberculosis, a leading cause of death until the discovery of penicillin (1929), was since the beginning a major field of investigation for radiographers, but it was only by the beginning of the First World War that X-ray technology was stable enough to allow for a significant advance in chest radiology. Until then, the work of doctors and technicians had been hampered by relevant technical shortcomings. Indeed, technical problems were a strong limiting factor. In 1949, a radiologist wrote: "For the first five years X-ray apparatus was more an interesting toy than a weapon of value in medicine [...] looking back, it seems remarkable that any results could be obtained with such makeshift and unreliable apparatus – still more remarkable the range of examinations attempted and their comparative success."[85] As a matter of fact, especially when it came to soft tissues, it is surprising that physicians could see something at all in early radiographs. Not only the image quality was very low, but most physicians, even among those actively engaged in the development of the new technology, did not always know what they were looking for when they looked at a radiograph. A telling example of such difficulties is provided by the frontispiece of the book *Practical Radiography*, published in 1896. It proudly displayed "The Human Heart *in situ*" (so went the caption), but the heart it showed was upside down, and so it remained in consecutive reprints for twenty years.[86]

So, how do we explain the faith of the early proponents of radiography in those blurred, distorted images? What could justify their stubbornness, their will to see something relevant in images that very often proved to be quite deceiving? To answer these questions we have to take into account two factors. One is that radiography was automatically granted the same epistemic authority as photography; the other is that radiography joined a field, instrumental diagnostics, that was in full development (as shown in Chapter 1), and collected the enthusiasm of the youngest and most dynamic part of the medical community. As remarked by Rowland, radiographs transformed the invisible structures and hypothetical impairments of the inner body into something that

[84] See Posner, 1971, 234.
[85] Barclay, 1949.
[86] See Posner, 1971, 234; Kevles, 1998, 92.

was "*oculis subjecta fidelibus.*"[87] For medicine, which had long been struggling to become a full-fledged empirical science, the possibility of transforming indirect evidence into visible facts looked like a very reliable way to acquire secure and well founded knowledge. Additionally, we can speculate that for physicians, used to deal with ambiguous signs and symptoms, the lack of clarity in radiographic images did not represent a strong argument against the possibility of gaining useful knowledge through them. This does not mean, of course, that there was unanimous agreement among doctors about the evidentiary power of X-ray imaging. As mentioned above, although surgery and dentistry were very quick at integrating radiography in daily practice, in internal medicine the process was longer and much more complex. Those clinicians who engaged in the diagnosis of diseases with undefined morphology, or characterized by functional rather than morphological features were often skeptical about the diagnostic relevance of radiography.

In internal medicine, similarly to what had previously happened with microphotography and chronophotography, the corroboration of the content of the image was a complex issue, because it was necessary to endow with meaning images whose iconic dimension was problematic. It goes without saying that it was relatively easy to verify the similarity between an X-ray image and a broken rib, but in which sense could one say that a shadow in the radiographic plate looked like a tubercular lesion or an aortic aneurysm? For radiographs too, a number of cognitive strategies ranging from technology stabilization and standardization to the development of interpretive ability had to be put in place to produce clinical meaning.

3.4.4 On the interpretation of X-ray images

The visual appearance of radiographs gave an immediate impression of transparency, and yet one had to *learn to see* before one could see something meaningful in these images. In 1903, J.F. Halls Dally, one of the British pioneers of clinical radioscopy, wrote in *The Lancet*:

> A good radiograph in some respects may be said to resemble a painting by Turner. Without *intuition or previous study* the one is almost as incomprehensible as the other, but as we gaze the wealth of detail rises before our vision, until finally we are able *to interpret the meaning of streaks and shadows that to the untrained eyes are meaningless.*[88]

In 1905, C.L. Leonard, an American surgeon who used radiography to improve the differential diagnosis of ureteral calculus argued:

[87] Rowland 1896, 9. See quotation above.
[88] Halls Dally, 1903, 1806.

Figure 3.9: J.M.W. Turner (1775-1851), *Rain, Steam and Speed – The Great Western Railway*, 1844. National Gallery, London.

> In considering the accuracy of this method [radiography] the *personal equation of the individual operator must be taken into account.* Although this diagnosis depends for its accuracy upon its mechanical method of obtaining results, those results will not be accurate unless it is employed properly. The *skill and experience of the individual operator* with this method must be taken into consideration in every case and his percentage of error estimated. [...] [It is] *clinical experience that renders the operator capable of translating the diagnosis accurately from* a radiographic plate.[89]

These two quotes help understanding what it means, exactly, that one had to *learn to see* in order to find something clinically relevant in radiographs. Halls Dally explicitly talked of the need to learn to interpret the "streaks and shadows" that appear on the radiographic plate. To him, the content of the image was neither self-evident nor self-explanatory. One had to actively and accurately interpret the radiographic shadows in order to recognize meaningful shapes. To put it differently, one had to reconstruct the *right* forms within the mists of the radiographic plate, and to reach this end one had to put in relation the X-ray shadows with other images (material or mental) of normal and pathological anatomy. If one was to interpret an image, one had to mobilize a wealth of explicit and implicit knowledge, which Halls Dally called "previous study" and "intuition," respectively.

By comparing a radiograph to a painting by J.M.W. Turner (Figure 3.9), Halls Dally not only offers a vivid visual metaphor of the difficulty of seeing well delineated objects in a radiograph, he also points to the fact that interpreting

[89] Leonard, 1905, 1634 and 1636.

is by necessity a creative activity, open to qualitative nuances.[90] This entails that as far as the observer becomes more experienced he or she can learn to see more details. At the same time, it implies that different observers might pay attention to different elements. In this case, their interpretations will differ without this necessarily entailing one of them to be wrong. Another possibility is that different beholders can understand the same visual elements in distinct ways, while the same observer could revise his or her interpretation over time. Halls Dally had no doubts about the possibility to establish a correct, stable interpretation of a radiographic image. In fact, he went as far as to claim that: "Although observers may differ widely as to the interpretation of evidence based on tactile and auditory impressions, ocular evidence in most cases admits of no difference of opinion."[91] In this, he partook in Rowland's assurance about the objective nature of vision. Yet, he was aware that vision was inextricably linked to interpretation, and that the process that led to the proper understanding of the streaks and shadows on the radiographic plate was not an automatic, merely optical operation. He knew that without training pattern recognition and clinical judgment one could see nothing but elusive shapes.

The skillful operator Leonard, too, was conscious of the fact that the meaning of radiographs was neither explicit nor transparent, and he resorted to the metaphor of translation to warn the reader that the making of a diagnosis from an X-ray plate was not a passive task. One does not read the diagnosis straight into the image, one has to carry on an accurate translation (which is always an interpretative process), in order to transform what is seen in the radiograph into knowledge of what is happening within the patient's body. But, how does one learn to perform such translations? For Leonard, as for Halls Dally, one

[90] J.M.W. Turner (1775-1851) was an English Romantic painter whose style is regarded as an anticipation of Impressionism. He was known by his contemporaries as "the painter of light." The artist and curator Lawrence Gowing has described Turner's work as "the indefinite transmission and dispersal of light by an infinite series of reflections from an endless variety of surfaces and materials, each contributing to its own color that mingles with every other, penetrating ultimately to every recess, reflected everywhere." Gowing, 1966, 21.

[91] Halls Dally, 1903, 1803. Halls Dally optimism about differences of opinion concerning ocular evidences was somewhat unjustified. Already in the 1920s doctors started discussing the problem of errors in the interpretation of radiographs, and a radiologist wrote that one source of error was the "thoughtless belief in the infallibility of the roentgen ray by the medical profession as a whole." Musser, 1923, 252, quoted in Reiser, 1978, 189. And in 1947, the first systematic study on the magnitude of variation in the interpretation of X-ray films showed that in about one-third of cases different doctors differed with their interpretations, and even the same doctor watching the same radiographs at different times differed in his interpretation about a fifth of the time. See Reiser, 1978, 189-190. The advancement of technology has not solved the problem, as shown by the rich literature that deals with the problem of error in radiography. See, for example, Sabih, et al., 2011; Alexander, 2010; Kundel, 2006; Griscom, 2002.

needed clinical experience, with its combination of practical skills and theoretical knowledge. Still, if one is to rely on radiographs to make a medical diagnosis, to formulate the right interpretation or to establish the right translation is not enough. In the first place one has to produce the *right* image. Halls Dally implicitly hints at this problem, because he talks of a "good radiograph," but it is in the quote from Leonard that we find an explicit reference the process of image production. In fact, he insists on that the accuracy of the radiographic method depends chiefly on the "skill and experience of the individual operator,"[92] because the mechanical system of image production can be accurate only as far as it is "employed properly."[93] As the image has to be interpreted in order to acquire meaning, so the mechanical apparatus has to be skillfully operated in order to produce a trustworthy image. This was particularly true at a time in which the technology was still under development, and doctors and technicians worked by trial and error, dealing with the unpredictable behavior of new instruments and processes. As Posner put it, the early history of radiography was "a story of erratic electric supplies, nitrous fume-producing cell batteries, ineffective electrolytic rectifiers, and temperamental gas tubes."[94] The technology to produce radiographs was as novel as the images themselves, and as such it required the same ingenuity and critical judgment. The apparatus was mechanical, but it was not a self-operating agent. Images did not emerge passively from machines, they had to be actively produced, and they had to be produced in the right way.

3.4.5 Mechanical images and trained judgment

Halls Dally's and Leonard's clear awareness of the need to use clinical experience and critical judgment both in the production and interpretation of radiographs is at odds not only with Daston and Galison's idea of mechanical objectivity, but also with their claim that another epistemic virtue, namely trained judgment, emerged *after* mechanical objectivity and as a backlash against it.[95] As explained in the introductory section of this chapter, according to Daston and Galison, mechanical objectivity was the overarching ideal that regulated the making and use of scientific images between the second half of the nineteenth and the first decades of the twentieth centuries. It prescribed to suppress the intervention of the scientist in the process of image production and reproduc-

[92]Leonard, 1905, 1634. It should be noted that when Leonard talks of an "operator" he means the physician himself, who took the radiographs with the help of an assistant technician.
[93]Leonard, 1905, 1634.
[94]Posner, 1971, 238.
[95]See Daston and Galison, 2007, 18 and 377.

tion, since the ultimate goal of the scientific endeavor was to represent the exact appearance of the object as recorded by the mechanical apparatus. Any human interference with the photographic camera, the radiographic machine, or any other recording device had to be minimized, so that the subjectivity of the observer-operator would not affect the direct imprint of nature on a sheet of paper or any other sensible support. Mechanical objectivity also imposed rigorous self-restraint in the interpretation of images. Ideally, Daston and Galison say, images had not to be interpreted at all, and in those cases in which interpretation was unavoidable, it should be performed according to rigid and standardized procedures.[96]

According to Daston and Galison's chronological taxonomy of epistemic ideals, by the third decade of the twentieth century, partly in reaction to mechanical objectivity, the principle that governed science became one of trained judgment. To use their own words: "[By 1920s] the edict of mechanical objectivity to abstain from all interpretation turned out to be sterile."[97] Unlike mechanical objectivity, trained judgment prescribed to produce, reproduce, and interpret images by resorting to the tacit knowledge acquired through practical training. Interpreted images, the form of representation corresponding to trained judgement, were still produced by mechanical devices and respecting good laboratory practices, but subjective interpretation, fed by accurate training, was no longer seen as standing in stark opposition with scientific rigor and objectivity.[98] Comparing mechanical objectivity and trained judgment, Daston and Galison maintain that for the scientist who subscribed to the ideal of trained judgment, judgment was "an act of cultivated perception and cognition was associated with a picture of reading that was both anti-algorithmic and antimechanistic."[99] And they specify:

> Scientific image judgment had to be acquired through a sophisticated apprenticeship, but it was a labor of a very different sort from the rehearsed moves of the nineteenth-century mechanical objectivist. Interpreted images got their force not from the labor behind automation, self-registration, or absolute self-restraint, but from the expert training of the eye, which drew on a historically specific way of seeing. Scientific sight had become an 'empirical art.'[100]

Now, the articles from Leonard and Halls Dally clearly show that even at the time of alleged mechanical objectivity, clinicians who worked with radiographs

[96]See Daston and Galison, 2007, 315, 321, 328, 344.
[97]Daston and Galison, 2007, 344.
[98]See Daston and Galison, 2007, 314.
[99]Daston and Galison, 2007, 331.
[100]Daston and Galison, 2007, 331.

were clearly aware of the many variables the operators had to take into consideration when making a radiograph, of the ambiguity of the shadows they had to make sense of, and of the complexity of the conditions they wanted to diagnose. This is to say that they did not believe that radiographs were imprints of reality *sic et simpliciter*. Even when they praised radiography as being more objective than other diagnostic instruments, Halls Dally and Leonard did not claim that objectivity was the suppression of the judgment either of the observing subject, or of the image maker. They did not recommend the blind application of procedures in the process of image production, quite the contrary, and they did not take objectivity for self-evidence. They explicitly acknowledged that the skill and experience of the operator were paramount, and invited their colleagues to learn to interpret radiographs, to translate images into diagnosis on the basis of study, educated intuition, and clinical experience. Importantly, they were not innovators in this respect. Their predecessors, the pioneers of photography, had followed the same approach. As pointed out in Chapter 2, Duchenne de Boulogne became a photographer himself because he was convinced that photography would let nature speak for herself only if the image maker was well acquainted with the phenomenon that was to be recorded,[101] and the whole point of all medical photographic publications of the nineteenth century was to train the eye of the observer, in order to improve his physiognomic sight and his clinical judgment.[102] Contrary to Daston and Galison's claims, scientific sight has always been, by necessity, an *empirical art*, and possibly no one was more conscious of this than physicians, whose commitment to intuitive medical judgment not only long predated the twentieth century, but was also constitutive of the very authority of medical profession.[103]

Legitimization of scientific photography in the nineteenth century It is true, as Daston and Galison stress, that in the introductions to photographic atlases the nineteenth-century authors reiterated over and over again that they had let nature imprint itself, without intervening on the photographic plate. However, it should be remarked that they also praised the skill of the photographer. Hardy, for example, eulogized de Montméja's "indisputable talent as photographer and colorist,"[104] and Donné emphasized that the results attained

[101] See Section 2.7.

[102] In this same line of criticism, in a review of Daston and Galison's book Theodor Porter has pointed out that: "If all the confusing details of a real photograph are preserved [complying with the edict of mechanical objectivity] – if seasoned judgment in its preparation is disbarred – the need for expert discernment among those who consult the images becomes all the more pressing." Porter, 2008, 644.

[103] For a criticism to Daston and Galison along similar lines see Porter, 2008.

[104] Hardy, 1868, n.p.

by his photographer Léon Foucault were "remarkable."[105] In an essay on the role of photography in science, published in 1882 in the journal *Photographic News*, the anonymous author not only highlighted the relevance of technology and of the photographer's technical skill, he also stated that the making of a scientific photograph inevitably involved aesthetic choices, judgments and interventions.[106] Moreover, one should not forget that, as remarked by the historian of photography Jennifer Tucker, the expression "judging eye" was coined by Victorian photographers to refer to the great skill and different kinds of knowledge that one had to develop in order to make good photographs.[107] All these documental evidences contradict Daston and Galison's claim that the work of scientists in the late-nineteenth and early-twentieth centuries was governed by the ambition to attain mechanical objectivity, and that only during the twentieth century "the espousal, celebration, and cultivation of trained judgment"[108] imposed itself as a new regulative ideal that supplemented objectivity.

Objectivity was never purely *mechanical*, neither in the practice nor in the discourses of scientists. In her book *Nature Exposed. Photography as Eyewitness in Victorian Science*, of 2005, Tucker has convincingly disputed the strong assumption, common among historians, that in the nineteenth century the authority of photography was unchallenged. By examining scientific, technical and popular nineteenth-century literature on scientific photography, she provides plenty of evidence that concepts of skill (both visual and manual), judgment, and human agency informed what counted as objective and subjective during the Victorian era. Referring explicitly to Daston and Galison's article of 1992, Tucker argues that: "Although nineteenth-century faith in photography was powerful, the idea that people over a hundred years ago accepted photographs at face value is exaggerated and misleading."[109] Gathering testimonies from different sources (scientific journals and congress reports, but also popular lectures and magazines), Tucker demonstrates that Victorians – both scientists and the general public – were keenly aware of the manufactured nature of photographs. Most of them also knew that the production of mechanical images required intense skilled labor. Indeed, in the process of professionalization of scientific photography, those who promoted this new medium as a scientific tool stressed the importance of qualified knowledge that had to be coupled with artful craft. How to make proper data with a scientific instrument, Tucker remarks, was a topic of great concern at the time photography emerged.

[105]Donné, 1844, 36.
[106]See Tucker, 2005, 259.
[107]See Tucker, 2005, 60.
[108]Daston and Galison, 2007, 321.
[109]Tucker, 2005, 4.

A paradigmatic case is provided by spirit photography, because it proved how misleading the unconditional association of mechanical representation to objective and scientific evidence could be. Defendants of spiritualism, in fact, tried to draw on the claims about the mechanical objectivity of photography to reinforce their contention that spirit photographs were direct proofs of an otherwise unseen reality. Thus, in order to reject the belief that it was possible to photograph spirits and ghosts, scientists were forced to explicitly argue that mechanical objectivity was not *ipso facto* scientific and trustworthy.[110] "Throughout the nineteenth century," Tucker notes "people debated truth claims based on photographs and, in the process, established the criteria by which a photograph could be accepted as scientific evidence. These debates erupted in laboratories, observatories, and scientific meetings as well as at world's fairs and in courtrooms, illustrated periodicals, and spiritualist séances."[111] Indeed, as shown in Chapter 2 and in the discussion of Marey's ideas about photography in Section 3.3, people in the nineteenth century held quite contradictory views about mechanically produced images. They maintained that photography was the pencil of nature *and* that one had to be a skilled photographer to produce pictures that looked like the original object; they were ready to say that photography faithfully reproduced the appearance of objects *and* that it created hypothetical images. This ambiguity, however, is less a testimony of a lack of sophistication in the understandinhg of photography, than a symptom of the complex nature of photography itself.

Recognizing the unknown Another important aspect overlooked by Daston and Galison is that early photographers and early radiographers, as well as those who developed other technologies for visualization, such as cloud chambers or stellar spectrographs, were creating images that no one had seen before. They were literally creating new phenomena and, accordingly, they had to learn to see anew. Now, how could they produce anything new, and learn to see anything at all, if they had restrained themselves from applying judgment and interpretation? How could they have invented and perfected a panoply of imaging technologies, if they had been afraid to intervene? How could they have ventured in the wide range of examinations they performed with erratic apparatuses and blurred images, if they had been the shy, will-abnegating workers afraid to interfere with machines and images described by Daston and Gali-

[110]See Tucker, 2005, Ch. 2. In Ch. 3 and Ch. 4 Tucker analyses the case of photography in meteorology and bacteriology, respectively, and in Ch. 5 she focuses on the question of scientists' disagreement in the interpretation of images, drawing on the specific case of planetary photography (Mars, in particular).

[111]Tucker, 2005, 6.

son?[112] They argue that the fact that under mechanical objectivity scientists did actually resort to intervention and judgment cannot be used as a counter-argument against the claim that mechanical objectivity was an epistemic *ideal*. Ideals, they rightly argue, are never fully accomplished, nevertheless they regulate people's behavior.[113] This is quite obvious, since it directly proceeds from the definition of ideal. However, it seems to me that it cannot be used as an argument to refute strong historical and conceptual counter-evidences, as those put forward by Breidbach, Snyder and Tucker concerning photography, and by my examples from radiography.

Some problems with Daston and Galison's methodology In a review of *Objectivity*, the philosopher of science Martin Kusch has noted that Daston and Galison exemplify mechanical objectivity on the basis of the analysis of about seventy non-geographical atlases[114] (although they say that almost two thousand were published between 1830 and 1930), but they do not provide any quantitative data about the alleged rise and fall of the various epistemic virtues, or their role in different disciplinary fields. They select and synthesize their sources in ways that are not transparent, and "a critical reader might well feel that she is asked to take a lot – perhaps too much – simply on trust."[115] The very choice to use as primary sources scientific atlases and manuals is problematic.

As a matter of fact, atlases are supposed to fix knowledge and consolidate scientific practices. This is why they work as references or guides. Atlases and manuals have, in general, an eminently pedagogical function. However, the ideas and practices involved in the production, selection and presentation of images aimed at stabilizing knowledge are not necessarily the same as the ideas and practices involved in the production and handling of images aimed at generating new knowledge. Atlases, and particularly what scientists write in the introductions to these atlases, are not necessarily the best route to understanding how images actually work in the construction of new knowledge.[116] Tucker remarks that Daston and Galison's choice to focus on atlases, letting aside other

[112] Porter makes a similar criticism. He comments that it is quite surprising to see the period between 1850 and 1920, the golden age of public science and of scientists's public role, depicted as an era of mechanical objectivity. In Daston and Galison's construal, mechanical objectivity prescribed absolute self-restrained from making assertions that could not be demonstrated impersonally (mechanically). The regulatory ideal of mechanical objectivity, by Daston and Galison's own admission, summed up to intellectual timidity and an ethos of self-abnegation. Porter ironically wonders: "Were Huxley, Helmholtz, and Bernard paralyzed by anxieties regarding the validity of their own insights and interpretations?" Porter, 2008, 645.

[113] See, for example, Daston and Galison, 2007, 321.

[114] Namely, atlases of anatomy, bacteriology, neurology, pathology, physics, and zoology.

[115] Kusch, 2009, 129.

[116] For similar criticisms see Porter, 2007 and 2008.

scientific media, hampers from the outset the possibility to make general claims about what scientists really thought, and how they actually worked. She points out that, exactly because atlases serve as descriptive guides to idealized scientific identities, a sort of conduct books for scientists, they cannot help to shed light on crucial questions about actual scientific practice, which is related less to atlases' production than to their reception and use. To make her point she ironically comments: "We do not really accept that nineteenth-century women lived according to prescriptive literature."[117]

The aim of this extensive critique of Daston and Galison's notion of mechanical objectivity was not to deny that in the second half of the nineteenth, and well into the twentieth century, scientists, artists and the lay people were utterly fascinated by machines and automation. I do not dispute that in many cases mechanization of data recording was associated to the idea of objectivity as suppression of the subjective idiosyncrasies of a human observer or measurer. I rather wanted to stress that Daston and Galison make too strong a case for mechanical objectivity, as if it were a uniform and universal dogma. We fail to understand how automation and the development of measuring and imaging devices transformed science and scientific practice during the nineteenth century, if we do not take into account that the struggle to adhere to standards of mechanical objectivity was deeply entrenched with an equally important struggle for intersubjectivity, the development of a mechanical sensibility (prosthetic senses), and the acute awareness of the importance, in the empirical sciences, of skilled operators and educated interpreters.

This completes my critical remarks concerning the relationship between mechanical objectivity and trained judgment. Now it is necessary to understand how radiographers faced the problem of image corroboration, and through what specific strategies and practices they endowed radiographs with diagnostic meaning and relevance.

3.4.6 Making sense of shadows

As seen above, the integration of radiography in clinical medicine was a complex and relatively long process. Bernike Pasveer, a scholar in Science and Technology Studies, has convincingly argued that the fact that internal medicine was much slower than surgery in making sense of radiography depends only in part on technical difficulties and image poor quality. This was just one aspect of the problem. Equally important was the fact that X-rays did actually open a new visual world, and traditional anatomical knowledge (normal or pathological)

[117]Tucker, 2008, 655.

gained through autopsies could only partly help making sense of the shadows on an X-ray plate. Pasveer suggests that if surgery, dentistry and orthopedics were quicker than internal medicine at taking on radiography, it was not only because shrapnels, teeth and bones are more radio-opaque than the lungs. It was also because recognizing the anatomical look of the skeleton in a radiograph requires a less radical sensorial and cognitive transformation than connecting the anatomical image of dead body organs to the shadow of living ones.[118] As she puts it: "The X-ray images were trusted for their ability to represent reality, but in the pre-Roentgen era *reality looked enormously different* from the shadows that were now said to be mirroring the inner parts of patients."[119] One telling example of this transformation of what reality should (or could) look like, is that of the stomach and intestine as represented in anatomy atlases or seen through a skiagram. In 1910, in fact, the use of bismuth, an X-ray opaque substance that can be safely ingested, showed that the stomach, often horizontal and curved in the cadaver, is generally vertical in the living, while the intestine, which in the dead occupies a relatively fixed position, in the living can occupy almost any place in the abdomen.[120]

As argued in Chapter 1, clinical anatomy and the localizationist paradigm it entailed was a necessary precondition for making sense of radiology, nevertheless anatomical knowledge gained through cadavers' dissection did not always smoothly overlap with the anatomy revealed by the X-rays. As Laennec had needed a highly educated ear to be able to use the stethoscope, radiographers needed a highly educated eye. One had to develop a *skilled vision*, as many commentators of the time asserted. This process of education of the eye was much more than sensorial training. Pasveer distinguishes four phases in the process that turned the shadows of X-ray plates into meaningful and useful diagnostic images: (1) Technology control and stabilization; (2) Validation of the visual content of radiographs by comparing them with real organs; (3) Comparison of the information acquired through X-ray images with that provided by other diagnostic techniques; (4) Comparison of different X-ray images. These steps partially overlap both in time and content (problems to be solved), but each of them corresponds to a specific method for shaping the content and meaning of shadow images.

Technology stabilization The first step in the process of X-ray imaging signification involved experimentation with technology. This phase occupied

[118]See Pasveer, 1989, 361.
[119]Pasveer, 1989, 361.
[120]See Reiser, 1978, 65.

about twenty years since the discovery of Roentgen rays, and was meant to stabilize and standardize machines and practices. X-ray workers (physicians, physicists, engineers, and photographers) experimented with photographic apparatuses, materials, procedures, and X-rayed a wide range of objects, so that the whole system could be finally controlled, black-boxed (the radiologist would no longer need to know how the technology worked in order to use it) and routinely operated without major problems. In other words, the aim of this phase was to warrant the liability, reproducibility and comparability of X-ray images, distinguishing the shadows produced by the object under examination, from the artifacts introduced by the machine or the procedure.[121] Pasveer points out that the early articles on the use of Roentgen rays in medicine reflected the exploratory character of the work of physicians and technicians at that time.[122] Before describing clinical cases and discussing the diagnostic meaning of the images, they specified what tubes had been used, the amount of current, the length of the exposure and the respective positions of tube, photographic plate and patient. At the beginning these descriptions did not have prescriptive functions, but in time they became sets of operational rules: how to use an apparatus with certain characteristics; to position the patient in a specific way; to accustom the eyes to darkness if one was working with fluorescent screens rather than photographic plates, and so on.

As already mentioned, one of the advantages of producing medical visual data was that they provided information that could be easily retrieved, shared, and compared. The production and use of these data, however, demanded standardization of objects and actions. It also demanded a proper language to describe the new reality that had entered the medical domain. Patients had to be positioned "screen to back", "screen to chest", "lateral oblique;" and a normal thorax would present a "well-defined median opacity" with a lateral "transradiant area."[123] Pasveer remarks that all these sentences could simply not exist in the medical vocabulary before the discovery of X-rays. There would have been no meaning attached to them.[124] This was true not only for internal medicine, but also for surgery and orthopedics. Radiographs enabled surgeons to view, for the first time, preoperative bony fragments and the postoperative opposition. In the long run these visual criteria replaced older methods of

[121]Of the more than 1,000 articles and fifty books published on X-rays in 1896, more than two thirds treated technical issues, while the remaining third was on clinical and surgical subjects. See Pasveer, 1989, 379.

[122]See Pasveer, 1989, 369.

[123]Halls Dally, 1903, 1801.

[124]See Pasveer, 1989, 365.

physical examinations in the evaluation of fractures and of the success of the intervention.[125]

Image external validation The second moment described by Pasveer concerned the validation of the X-ray image by comparison with organs' direct observation. During this phase, which overlapped chronologically with the technological experimentation, the iconic dimension or radiographic imaging, that is, the resemblance between shadows and organs, was secured. Radiologists checked their interpretation of a radiographs through direct observation of the organs during a surgical procedure or at the autopsy, in a process which clearly followed the logic of Laennec's validation of the stethoscope and, more generally, of pathologic anatomy since Morgagni. Very similarly to how Laennec had checked the diagnosis he made by auscultation with the results of *post mortem* examinations, radiologists assessed their vision by comparing what they saw in the X-ray plate with what they saw in the actual body. It should be noted, however, that the task of radiologists was comparatively easier, because while Laennec had to match auditive with visual perceptions, they had to connect different visual objects, consequently it was relatively simple to find firm points of reference to link the image to the cadaver. Additionally, while auscultation was a solitary endeavor difficult to share at the intersubjective level (only one listener at the time could use the stethoscope), radiographs allowed different observers to watch simultaneously the same objects, so that the process of matching organs and their X-ray shadows had an overtly collective dimension. Radiographers used the organs to cross-check the images, and the images to cross-check their own vision. Pasveer remarks that, as anatomists and pathologists already knew, the cadaver was not always a faithful model of the living body. In the case of the lungs, for example, it was sometimes difficult to compare the shadow images of the living lungs with their anatomical appearance in the dead, because these organs tend to collapse when ventilation is interrupted. In this respect it should be highlighted that, as in the case of the visualization of the digestive system, the comparison of X-ray images with anatomical specimens was not only valuable in educating the eye and validating the content of radiographs, it also led to a reassessment of previous anatomical knowledge.[126]

As a general rule, it was soon clear that there were systematic mismatches between macroscopic anatomy and radiological images. In the X-ray images denser structures would screen the soft tissues, some elements that appeared in

[125] See Lerner, 1992, 388.

[126] Physiological facts were also questioned. In his article of 1903 Halls Dally contested, on the grounds of fluoroscopic observations, the widespread belief that the diaphragm flattened on inspiration.

the photographic plate did not correspond to anything that could be directly observed in the real body and, obviously, there was the problem of collapsing a three-dimensional complex structure in a multilayered bidimensional image. Moreover, according to the relative positions of cathodic tube, photographic plate and patient's body, some shadows came to the fore and others receded. To overcome these problems of visualization different solutions were implemented. On the one hand, procedures for taking the radiographs were standardized, in order to ensure images' reliability and comparability. On the other hand, to check the correspondence between organs and shadows, two methods were adopted. One consisted of tagging organs with metal coils before taking the radiograph; the other consisted of removing in a sequence different anatomical structures (e.g., visceral pleura and pericardium) from the cadaver and taking successive X-ray pictures, so that it became possible to recognize which shadow corresponded to which structure.[127] Furthermore, to teach visual skills and create a common way of seeing, radiographic atlases, manuals, and handbook were published, so that it could be possible to systematically compare images (the first radiology atlases and handbooks were published as soon as 1896). As a whole, an articulated complex of activities was put in place in order to guide the eye of the physician in the passage from the actual body to its shadow-image, so that anatomy and radiography could check on each other.

Comparison of different diagnostic techniques In order to transform radiographs into diagnostic instruments relevant to clinical practice, it was also necessary to show that it was possible to translate the information acquired with other, well established, diagnostic tools into the shadows of the X-ray plate. This was the third moment in the process of X-ray imaging signification. To illustrate this problem and the solutions that were put forward, Pasveer resorts to the exemplary case of the diagnosis of pulmonary tuberculosis. At the turn of the nineteenth century, this disease was diagnosed by the anamnesis of the patient and his family, by physical examination, and by bacteriological analysis. So, in order to give meaning to the shadow images of the lungs, it was necessary to integrate the new visual information into this pre-existing body of knowledge. But how to relate images with clinical data and levels of infiltration by bacteria? A common solution, Pasveer explains, was that of reporting in a sequence the clinical case (patient's anamnesis, symptoms, physical signs, bacteriology) and a description of the images, often accompanied by pictures. She specifically refers to the article of 1903 by Halls Dally mentioned above,[128] in which the

[127]See Pasveer, 1989, 371.
[128]See Section 3.4.3.

clinician-radiologist made a direct comparison between the visual appearance of a chest radiograph and the signs collected through traditional physical exams. For example, brightness in the X-ray image corresponded to hyper-resonance in percussion, trans-radiancy to normal resonance, dense shadow to a dull sound. Physical signs already had a well established diagnostic meaning, which was transferred to radiographs through these correspondences. That is, the diagnostic significance of X-ray images was built upon a symbolic mode of signification, by resorting to a conventional – although not arbitrary – system of correlations among different signs. I elaborate further on this point in Chapter 4, where I put forward a semiotic analysis of Halls Dally's article.

Image internal validation The final step of the epistemic authentication of radiography defined by Pasveer was the comparison of different radiological images. In my view, this process should be considered an act of *internal validation*. It warranted the inherent coherence of the new visual system and sanctioned its relative autonomy from other diagnostic strategies (subjective symptoms and physical signs). This passage could be accomplished by capitalizing on the amount of knowledge acquired in the earlier phases, which at a certain point of the process became implicit. That is, radiologists came to a point in which they were reasonably confident that the apparatus they used was reliable, that a regimen of correspondences between radiological images and normal and pathological anatomy subsisted, and that radiological images had proper clinical relevance. It became fundamental to learn to recognize healthy organs, normal variations, and pathological states by simply looking at the radiograph. This process required the comparison of images. In this task, as we have already seen in Chapter 2, collections of images gathered in journals and atlases were extremely valuable tools. Pasveer points out that in medical journals of the first decade of the twentieth century the description of a normal chest "for the sake of comparison"[129] was standard, but by 1910 the specialized readers were expected to be already familiar with it.[130] Once the boundaries between normal morphological variability and overt pathological states had been settled, normal and pathological variability did not need to be verified over and over again, it became part of the given knowledge of radiology.[131]

On these premises it can be said that X-ray images acquired an inherent cognitive content, reaching the status of autonomous epistemic objects. It was on the basis of this relative autonomy that radiographs became what Reiser

[129]Pasveer, 1989, 376.
[130]Pasveer, 1989, 376.
[131]See Pasveer, 1989, 374-377.

has called “the transcendent instrument of visualization in medicine.”[132] Transcendent because, at least virtually, a whole, self-contained system of visual knowledge about the body could be built comparing images: images of the same person at different stages of a disease, as well as images of different patients affected by the same disease (all radiographs were produced following roughly the same protocols).

3.4.7 Radiography and the legacy of clinical anatomy

The lesson of Bichat on how to use a cadaver as a trustworthy representation of the living body was implicitly recovered in this crossed comparison of images. Tellingly, it was with the First World War that radiography made a major step forward. As the hospitals for the clinicians at the beginning of the nineteenth century, the war provided an enormous field of experimentation and study on X-rays from both the technical and medical point of view. At the technical level, the need of operating the X-ray apparatus in the war field demanded the development of portable, reliable and easy to handle instruments, as well as the training of a large number of technicians;[133] at the clinical level, the war gave doctors the opportunity to submit to radiological scrutiny a very large and relatively uniform population of young men. In doing so they did not only trained their eyes to recognize hidden bullets and shrapnel, they actually gained cumulative experience in looking into the human body by means of radiological images. Once again thorax examination and the diagnosis of tuberculosis was of particular importance. As noted by Kevles, war doctors submitted to radiological examination hundreds of thousands of recruits, in a sort of unplanned mass screening, and discovered that almost half of them suffered from some form of chest disease.[134] The very idea of mass screening became possible, something that would have been quite implausible with the stethoscope and other techniques of physical examination. Radiography, in fact, allowed examining and comparing images rather than real people, and this provided considerable practical advantages. Pasveer argues:

> The comparison of the shadow-images with each other was an activity that violated the nineteenth-century romantic view of the uniqueness and wholeness of disease and patients. Patients had to become interchange-

[132] Reiser, 1978, 58.

[133] In France, Marie Curie designed an apparatus for the battlefront and created a school where she trained hundreds of X-ray operators (more than 150 were women). Similarly, in the United States the Roentgenological division of the Army Medical Corps was strengthened, Radiology schools were set up in several cities and American physicians were sent to attend special classes in Paris and Tours. See Kevles, 1997, 72-74.

[134] See Kevles, 1997, 72-79.

> able, reproducible, quantifiable, and the disease had to be "isolated" from its bearer.[135]

Yet, as we have seen in Chapter 1, the "romantic view of the uniqueness and wholeness of disease and patients" had already been largely eroded all along the nineteenth century. Beginning with clinical anatomy, which equated disease and histological lesion or cell degeneration (cellular pathology), and passing through physiology, with its proliferation of vital indexes, medicine had carried on an enormous effort to objectivize the human body and its illnesses.

From bodies to images and back At the very beginning of the nineteenth century, the medicine of the individual started to be translated into hospital medicine. It was then that the hospital became, as Foucault wrote: "a neutral domain, one that is homogeneous in all its parts and in which comparison is possible and open to any form of pathological event, with no principle of selection or exclusion. In such a domain everything must be possible, and possible in the same way."[136] The standardization of images had exactly the same function: to circumscribe a neutral visual space against which the pathological could emerge within the variations of the boundaries of the normal, *and* within the variations of the pathological itself. It was at the intersection of these two sets of variations that the trained expert could recognize, at a glance, an individual disease. If the gaze of the clinician travelled from body to body in the hospital wards, the gaze of the radiologist travelled from image to image. This became possible because a vast system of references had been set. It was a composite system, made of methodological and technical standards, scientific societies, specialized journals, handbooks, and atlases. In this way a bulk of new implicit and explicit knowledge spread out within the scientific community of X-ray workers (physicians and technicians). With clinical radiography, the anatomizing power of photography and its ability to foster our "sense of sameness"[137] merged into tangible objects, which fixed on a celluloid plate the shadows of our living inner body.

Radiography, the younger surprising daughter of photography transformed the inner body into a seemingly transparent, portable and reproducible object. X-ray images stripped the aura of the human body for good. They did not get simply closer and closer to it, they entered it. As a true analytic and dissecting device, they became a full-fledged medical *medium* of the body. To clarify this

[135] Pasveer, 1989, 374-375.
[136] Foucault, 1963, 109.
[137] Benjamin, 1936, 256. See Section 2.3.

point it is useful to compare X-ray vision with the salient features of Laennec's mediated auscultation that were expounded in Chapter 1.

1. While in mediated auscultation the stethoscopic sounds convey indirect evidence of the histological lesion, with the X-rays the diagnostic instrument seems to directly show the lesion, that is, the disease (from this point of view the conceptual dependence of radiography on clinical anatomy is patent).

2. With radiography, the senses of the physicians are not just enhanced. To see a lung distended by air or a moving diaphragm is simply beyond the possibilities of the human eye. These images do not exist in the realm of natural vision. The X-ray machine is a *medium* of human vision not in that it improves it, but in that it supersedes it. The stethoscope, too, helped hearing better and provided a finer spectrum of sounds that went beyond those perceivable by the naked ear. However, a well trained clinician can do without the stethoscope and gather comparable sensory information by unmediated auscultation. X-ray imaging, on the contrary, shows something that no naked eye could ever see. In a sense, the X-ray machinery has its own way of seeing, independent of the human one, and yet in a continuum with it. It brought photography and cinema to a further degree of revelation of the optical unconscious.

3. Like mediated auscultation, traditional diagnostic imaging makes sense only within a localizationist medical paradigm, in which the disease is strictly associated to the anatomical lesion. However, while in clinical anatomy the cadaver became the *medium* of the living body, because it was the material support on which the disease presented itself as a mark, a lesion, with the introduction of radiography and its further developments, the corpse could be finally set aside, since the disease presented itself directly on the photographic plate. As a consequence, the image became a *medium* of the body because it stood in the place of the body and, even more importantly, because it took to the surface what the body concealed. In some cases, it could also reveal a disease which had not yet expressed itself through symptoms and signs. The capacity of the image to act as an absolute *medium* of the living body has been taken to its full potential by contemporary digital imaging. Digital technologies allow performing on the image manipulations that would be impossible in the real body, as well as in traditional analogical imaging. With MRI, for instance, it is possible to manipulate image parameters, so that fat content is excluded and the biological structures of diagnostic interest become more visible.

4. Finally, as was anticipated by the stethoscope, with the introduction of X-ray imaging the experience of illness in itself could be potentially mediated, anticipated, reconfigured. In fact, one of the main advantages attributed to radiography by practitioners was that it enabled the doctor to make earlier diagnosis, if compared to physical examination and microbiological tests.

Proponents of mediated auscultation had made very similar claims about the stethoscope in relation to the diagnosis based on general symptoms. In the case of mediated auscultation, the doctor could become the *medium* of the patient's experience because, thanks to his trained senses and clinical knowledge, he could perceive signs of the disease of which the patient was still unaware. Nevertheless, the patient had to suspect that something was wrong, otherwise he or she would not even call for the doctor. However, since the invention of preventive medicine in the 1960s, people who undergo mass screening are all *apparently* healthy, that is, *potentially* ill. The diagnostic image will establish reasonable evidence for suspecting that one is sick rather than healthy, bypassing and anticipating any suspicion of disease that might be raised by the patient or the doctor.[138]

In the medicine of symptoms, the perception of disease was necessarily the subjective experience of the patient. With clinical anatomy we passed to a medicine of physical examination, with signs experienced by the doctor. With laboratory tests and diagnostic imaging, medicine tries more and more successfully to identify the disease at its very beginning or, better, before it even begins. This takes us back to Dagognet's observation that diagnostic technologies are aimed at pushing medicine to its ideal limit, that of a medicine without patient, without doctor and, in its ultimate development, without disease.[139] An ideal state in which medicine deals with perfectly transparent objects, in which body and disease are no longer individual, fluctuating experiences, but objective, observable, quantifiable, *and* foreseeable facts. In other words, medicine tries to bridge the gap between the real, lived body and the body constructed by science as an object of scientific research.

[138] The passage from being a healthy person to being a sick one is always frightening, sometimes disrupting. Susan Sontag captured very well the dramatic implications of this transition, which could occur at any moment of our life, when she wrote: "Illness is the night-side of life, a more onerous citizenship. Everyone who is born holds dual citizenship, in the kingdom of the well and in the kingdom of the sick. Although we all prefer to use only the good passport, sooner or later each of us is obliged, at least for a spell, to identify ourselves as citizens of that other place." Sontag, 1978, 3.

[139] See Chapter 1, Section 1.2.

Chapter 4

Scientific images are tools

In the previous chapter I examined the problem of the visualization of the invisible in nineteenth-century science by analyzing the cases of microphotography, chronophotography, and early radiographic imaging. I showed that the three Peircean modes of signification – indexical, iconic, and symbolic – were all co-opted to endow those images with meaning, and that the problem of corroborating the truth value of signs that represent invisible referents was tackled by standardizing experiments, imaging practices, and the rules for image interpretation. Part of my argument was built against Daston and Galison's notion of mechanical objectivity, which, as I demonstrated, is too poor to provide a satisfactory account of the theoretical frameworks and actual practices developed by nineteenth-century scientists and physicians in order to visualize invisible objects and processes. My arguments were mostly, although not exclusively, historical. In the present chapter, which is divided in two parts, I move to a more general, theory-oriented discussion of what it is to *work with* scientific images. In the first part I engage with the longstanding problem of visual representation, arguing that *to represent* is a *poietic* activity and not an act of mimesis or passive repetition. As in Chapter 3, I define my position in contrast with Daston and Galison's. By the end of their book *Objectivity*, in fact, it becomes clear that their theory of scientific images is built on a *passive* conception of representation, conceived of as reproduction and copy of reality. Hence, I use the discussion of such position as a heuristic path to sustain an opposite view, one which takes representation as a creative endeavor that engages image makers and observers in a range of sensorial and cognitive activities. In the second part of the chapter I further develop this idea along two axes of argumentation. Firstly, I discuss David Gooding's account of scientific visual thinking, because it provides a sound description of the trans-historical cognitive strategies adopted by scientists when working with images. Secondly, I argue that scientific and medical images must be understood as signs within semiotic networks, as well as components of empirical practices. Here, again, my approach is twofold. On the one hand, I resort to textual and visual semiotics to analyze how images acquire meaning by referring to other pictures and written signs. On the other hand, I draw on works from laboratory ethnography and philosophy of experiment to show that the signification of images is a process entrenched with experiential knowledge, that is, a form of cognition which demands an interplay of people, objects, instruments and experiments.

4.1 Representation as presentation

In the last chapter of *Objectivity*, Daston and Galison introduce the epistemic ideal of the twenty-first century, which they call "presentation."[1] Compared to the previous epistemic virtues (truth-to-nature, mechanical objectivity, and trained judgment), presentation entails a very deep transformation in scientific imaging, namely, the shift from a practice of mirror-like copy of objects (old-fashioned representation) to a practice of objects and images manipulation (presentation). Daston and Galison bring up their concept of presentation, as opposed to representation, by comparing traditional atlases, made of different sorts of printed images, with contemporary image repositories, based on digital archives of manipulable interactive pictures. According to the authors, two great divides separate the images collected in traditional atlases from those contained in digital archives: the former are to be *looked at*, and *re*-present something which already exists (they are copies, as accurate as possible, of reality); the latter, on the contrary, are to be *used*, and they *present* something that was not already there.[2] This account of how digital technologies impinge on the very nature of atlases entails an implicit theory of (scientific) images, according to which the development of digital technologies produced a fundamental transformation in the domain of images from both the phenomenological and epistemological perspective. Before computer graphics, images were something to be *looked at*, and they provided more or less accurate copies of something that already existed (representation). After computer graphics, images became something to be *used*, devices that can show to our eyes something that cannot exist outside of the image (presentation).

The conceptual pairs representation-presentation and looking-using are deeply entangled. However, for the sake of clarity I try to discuss them separately: first I explore and criticize the difference between images that *re*-present and images

[1] Daston and Galison, 2007, 383.
[2] See Daston and Galison, 2007, 382-385.

Traditional or printed atlases	**Digital atlases**
printed images	computer-based images
reasoned images, mechanical images, expert images	virtual images, haptic images
images cannot be manipulated by the observer-user	images can be manipulated by the observer-user
re-presentation	presentation
images to be *looked at*	images to be *used*
images-as-evidence	images-as-tools

Table 4.1: Daston and Galison's classification of atlases based on the technology of image production and display.

that *present*; subsequently I analyze the divide between images that are to be *looked at* and images that are to be *used*.

4.1.1 Traditional, virtual, and haptic images

For Daston and Galison, in traditional atlases one can find images produced according to the epistemic ideal of truth-to-nature, mechanical objectivity or trained judgment, but in any case one deals with images that are not supposed to be materially manipulated. They refer to these publications as traditional or printed atlases. The images displayed there can be, of course, reasoned images (produced according to the criteria of truth-to-nature), mechanical images (mechanical objectivity), or expert images (trained judgment), but in all cases they are static, untouchable representations. In digital atlases, on the contrary, one can find two kinds of images: virtual images and haptic images. A virtual image is any kind of digital image coupled to a software that allows the observer-user to zoom in and out, excise, rotate, or fly through the image, while a haptic image is an image produced by means of a technology that allows to actually manipulate the object under observation during the very process of image production (Table 4.1). I have already discussed at length traditional images in the previous chapter, thus here I focus on virtual and haptic images, with a particular emphasis on the latter.

An example of digital atlas based on virtual images is the Visible Human Project. Started in 1989 under the auspices of the American National Library of Medicine, the Visible Human Project is a collection of virtual, interactive images that offer a complete, anatomically detailed, three-dimensional representation of the normal male and female bodies (Figure 4.1). To create this atlas, the dead bodies of a woman and a man were first scanned by CT and MRI, they were subsequently cut into thin slices, and finally each slice was properly dyed

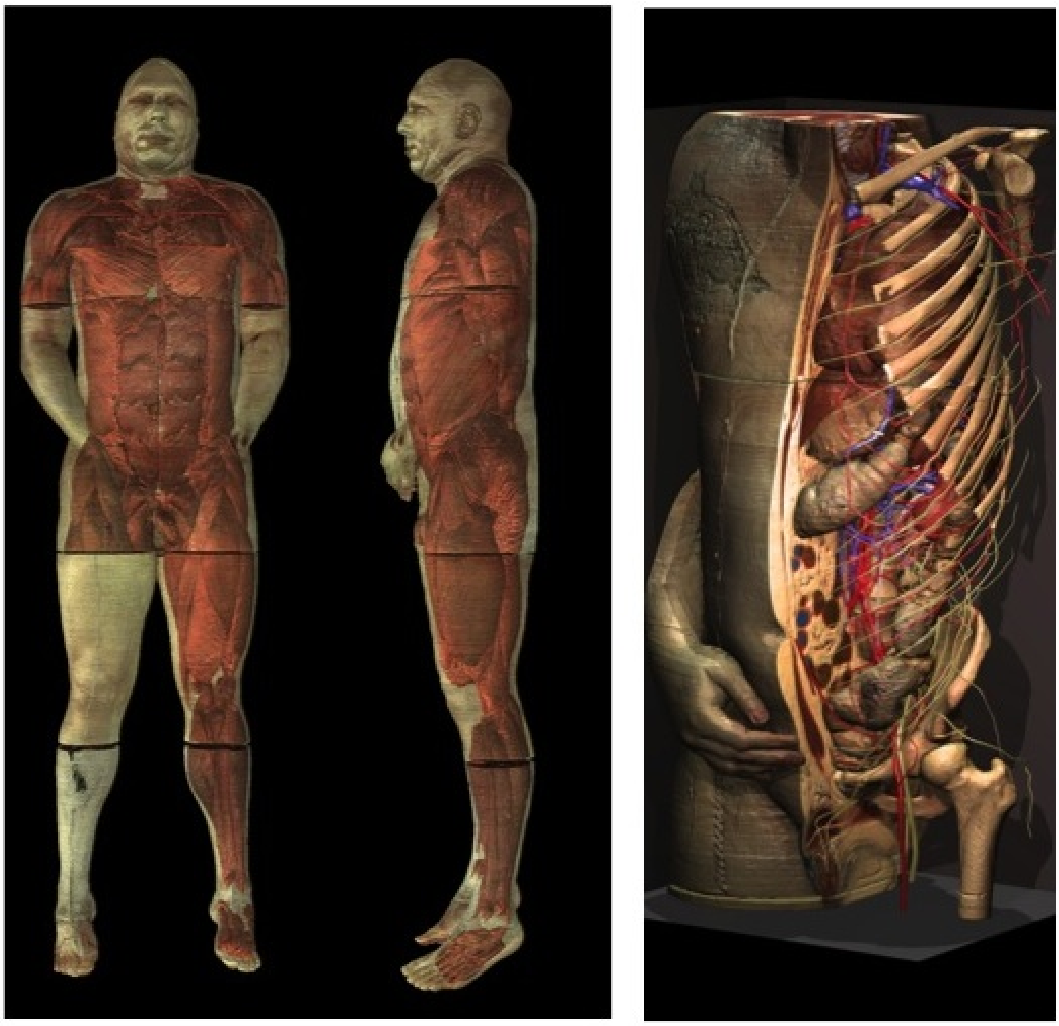

Figure 4.1: Examples of images produced using the Visible Human Project dataset. *Left:* Whole body reconstruction (muscular system and body surface), from escience.anu.edu.au/lecture/cg/CGIntroduction/medical.en.html. *Right:* Screenshot of a virtual, navigable image of the thorax, abdomen, and part of the pelvis. The original caption specifies that it contains more than 650 objects, it can be viewed from any direction, cuts may be placed in any number and direction, and objects may be removed or added. From Pommert, A. *et al.*, 2000.

and photographed. These different sets of images (photographs, TC scans, MRI scans), associated to image reconstruction and simulation algorithms, became the constitutive items of a digital database. They can be virtually manipulated for didactical purposes, e.g., in the study of anatomy, or for professional simulation of surgical interventions. Haptic images are not collected in proper atlases, but rather in image galleries available in universities, research centers, and industries' websites. A haptic image is, literally, an image that elicits the sensation of touch, or that can be actually perceived through touch. Daston and Galison use this term to refer to images produced resorting to nanotechnological imaging techniques. The peculiarity of these images is that in order to produce them, it is necessary to interfere with the nanostructure of the portion of matter that is visualized. In other words, in order to produce haptic images (or nanoimages), one has to manipulate the structure of matter at the nanoscale. Nanoimages are the only example of haptic images provided by Daston and Galison, and they use the terms haptic images and nanoimages interchangeably. So, what is so special about these images? How are they produced?

Scanning Tunneling Microscope (STM) and Atom Force Microscope (AFM) were among the first nanotechnologies to be developed. In STM the tip of a conductive tiny probe is used to scan a surface very closely. During this process the voltage difference applied between the probe and the surface produces a tunneling current (a flow of electrons) which is a function of the probe position, the applied voltage, and the local density of states of the sample. Thus, by measuring the current, we acquire information that can be displayed in visual form and that provides an image of the surface of the sample.[3] Daston and Galison put great value on the fact that the tip of the scanning probe can be used to manipulate nanostructures by literally interacting with one atom at a time. While looking at the image, one can move the atoms of the sample by using the very same instrument that is used to produce the image. Hence, one does really *touch the object* (although by means of a very particular probe) and *manipulate the image* simultaneously, for the manipulating and imaging processes coincide.[4]

For Daston and Galison, unlike other scientific images, whose function is to reproduce nature as faithfully as possible, haptic images create something that was not already there, hence they *present* something rather than merely *re*-present it. In their own words:

[3]The AFM works according to the same principles of the STM, but intead of monitoring a current, it measures the force caused by the interaction between the probe tip and the sample.

[4]See Daston and Galison, 2007, 383.

> In the context of the more engineering-inspired, device-oriented work that surrounds much of nanotechnology, images function less for representation than for *presentation*. [...] [B]ecause nanomanipulation is no longer necessarily focused on copying what already exists – and instead becomes part of a coming-into-existence – we find it makes more sense to drop the prefix *re-*, with its meaning of repetition.[5]

This is to say that what makes haptic images presentations rather than representations is the fact that with nanotechnology the interest of scientists and engineers has shifted from observation to manipulation. The activities of observing and manipulating a given object have merged into a single action, they occur at the same moment and using the same apparatus, and we assist to a move from the reproduction of reality to the production of a new reality. Haptic images, instantiated by nanoimages, are presentations rather than representations because they are images in which observation and manipulation of the imaged object coincide.

Daston and Galison, however, provide also another definition of presentation, which applies to virtual images. They say:

> Epistemically, these virtual atlases [created by the *Visible Human Project*] differed from the old medical atlases such as those of Jean Cruveilhier, Albinus, and William Hunter: using the navigation and image-modifying capability of the program, they could produce in a moment an image that no one had ever seen – this was not, *sensu stricto*, a matter of *re*-presentation.[6]

This means that for Daston and Galison an image can be considered a presentation not only if it allows to manipulate the specimen during the imaging process, but also if no one has never seen that specific image before (because it has been reconfigured by the viewer-user), or it presents objects or phenomena that no one has ever seen before.

However, once the definition of image-as-presentation is formulated in this way, it becomes difficult to understand, by Daston and Galison's own standards, why printed images such as drawings and analogical photographs do not count as presentations. On the one hand, if an image is a presentation if no one has never seen it before, then all original images could count as presentations independently from the technique of production and the material support of the image. In this case, speaking in rigorous terms, one should apply the term re-presentation, as synonymous of repetition, only to identical copies and reproductions of already existing images (I will develop the idea that each representation is a presentation in the following pages). On the other hand, if images

[5] Daston and Galison, 2007, 383.
[6] Daston and Galison, 2007, 390.

are presentations when they make visible obejcts and phenomena that could not be seen without the mediation of the image, then it is not clear why Donné's daguerreotypes, Koch's microphotographs, Marey's chronophotographs, or Halls Dally's radiographs cannot count as presentations, provided that all of them showed something that no one could have seen before the development of an adequate imaging instrument. This is what scientific images are supposed to do: to present us a world that we could not see otherwise.

4.1.2 Image manipulation before the digital era

What about the point, rightly stressed by Daston and Galison, that virtual images can be manipulated by the observer-user in very specific ways? To discuss this issue I will resort to a brief analysis of the same example used by the authors, the Visible Human Project. As stated in the website of the National Library of Medicine, the aim of this project is to provide an extremely faithful representation of the human body, so that medicine students can learn anatomy reducing as much as possible the need to dissect actual human corpses.[7] This has been, in general, the aim of all traditional anatomical atlases and of their three-dimensional elder cousins: anatomical wax or wooden models.[8] Being a virtual atlas, the Visible Human Project has transferred to the computer screen the third dimension which, in the past, could be afforded only by resorting to expensive, cumbersome, and fragile sculptures. Still, it is interesting to note that in Juan Valverde de Amusco's anatomical atlas *Vivae imagines partium corporis humani aereis formis expressae*, printed in 1566, there was an attempt to make printed images manipulable. Bound at the end of the atlas we find a pair of male and female figures composed of paper flaps that, when lifted, revealed the internal organs (Figure 4.2). What I want to emphasize here is that draughtsmen and painters have always dealt with the problem of rendering the multiple layers of three-dimensional reality in bidimensional representations, and the anatomical fugitive sheets were an ingenuous means developed to allow the atlas user to enter the body, by providing a rudimentary form of image navigation and manipulation. The Flemish engravers who produced the atlas illustrations were really pushing to the limit the possibilities of printed images to function as three-dimensional haptic objects. Valverde's example is by no means an isolated case, and it testifies to a conception of images – well before

[7]See www.nlm.nih.gov/research/visible/, retrieved on Jun 13, 2012.

[8]For a study of the role of wax anatomical models in medical education see Ballestriero, 2010; Hopwood, 2004; Schnalke, 1995 and 2004. Riva *et al.*, 2010, explore the relationship between anatomical illustration and wax modeling in Italy between the sixteenth and the early-nineteenth centuries.

Figure 4.2: Anatomical fugitive sheet bound at the end of Valverde, *Vivae imagines partium corporis humani aereis formis expressae*. Antwerp, 1566. Wellcome Library, London.

computer simulation – as something that had to be used, handled, by the atlas reader. There is no doubt that the material medium, paper, did not allow true manipulations, and its fragility made handling more a virtual possibility than an actual practice. Yet, it seems to me that the very existence of paper flaps attests to an active conception of both images and atlases. It is exactly because image manipulation was so limited, that at least since the mid-eighteenth century a great effort was put in the production of three-dimensional models for research and education. In this respect, a particularly interesting case is the work of the Italian anatomist and physiologist Felice Fontana.

Appointed director of the Florentine museum La Specola in 1775, Fontana supervised for many years the creation of a collection of anatomical wax models, whose production lasted for more than a decade. The collection soon acquired the status of international scientific reference, due to its aesthetic quality and anatomical accuracy. By the end of the 1780s, however, Fontana had become dissatisfied with wax models, which due to their fragility could not be manipulated by students. Consequently, he embarked in the construction of wooden models, which could be dismounted and put back together. Influenced by Étienne Bonnot de Condillac's theory of knowledge, which posited that three-dimensional vision is acquired through tactile experience,[9] Fontana thought that one could gain knowledge of the parts in relation to the whole body only by disassembling and reassembling it, because these activities gave sensible content to the cog-

[9] de Condillac, 1754.

nitive activities of analysis and synthesis.[10] He claimed: "[wooden body parts] can be handled, rotated into any position, and inspected at leisure. Plates, wax [models], or a cadaver lend themselves to these operations only with difficulty and unsatisfactorily."[11] Fontana wanted to build a fictional human body which, as the virtual body of the Visible Human Project, would allow students to navigate inside artificial viscera and manipulate them at leisure, overtaking the limits of both bidimensional representations and real, corpse-based anatomy. The project proved unattainable. The prototype life-size statue made of 3,000 independent wooden parts turned out to be extremely complex to build. Moreover, most of Fontana's colleagues, as well as his patron and employer, Peter Leopold, Grand Duke of Tuscany, did not concur with him about the necessity of replacing wax models, characterized by astounding realism, with wooden models, apparently less artistic or sophisticated. Fontana's project was visionary. Nevertheless, it provides a clear example of a form of anatomical representation that attempted to provide the viewer the illusory, yet tactile, experience of entering the body and observing it from the inside. Even more importantly, it was meant to give the opportunity to take the model's pieces apart and carry out an artificial dissection. This historical example corroborates my claim that manipulable representations are not a product of computer technology. The need to handle objects, or their reproductions, in order to understand their structure and functioning appears to be a fundamental, trans-historical feature of the human cognitive system. What is historical is the way in which such need for manipulable representations can be satisfied.

4.1.3 Aesthesiological considerations

The contrast between images that *re*-present and images that *present* is connected to the distinction between images one *looks at*, and images one *uses*. Daston and Galison call the former "images-as-evidence" and the latter "images-as-tools."[12] In their taxonomy, haptic images are tools par excellence, because they are produced using a technology that allows to literally touch atoms with the tip of a probe. Now, it is interesting to note that the polarity haptic-optic, translated into its spatial constituents proximity-distance, had already been used by Benjamin to discuss the tendency of photography and cinema to bring the beholder closer and closer to objects and people, stimulating a scientific, anatomizing gaze.[13] As we have seen in Section 2.3.2, for Benjamin, the photographic

[10]See Mazzolini, 2004, 56.
[11]Fontana, quoted in Mazzolini, 2004, 61.
[12]Daston and Galison, 2007, 385.
[13]See Benjamin, 1932, 519; 1939, 255.

gaze metaphorically touches and dissects objects and phenomena. It does so by enlarging what is small, sectioning what is continuous, accelerating what is slow, and slowing down what is too fast for human perception. Benjamin borrowed the concept of haptic image from the Vienna School of Art History, in particular from Alois Riegl. For Riegl, a history of artistic styles entailed a history of the way each style stimulates and organizes human perception. Accordingly, to write a history of styles was to analyze the distinct ways in which different images affect the observer and his corporeal relation with the work of art. Some styles, e.g., Impressionism, put the beholder at a distance, because only from the distance one can properly perceive the painting. In this case Riegl talks of a style that produces optical images. Other styles, e.g., Egyptian hieroglyphics, force the observer to get closer to the images and invite to close-up view. These are haptic images: the eye goes along the contours of the figures *as if* it was a finger.[14]

On the *poietic* function of representation Indeed, the topic of the entrenchment of optical and tactile sensations in aesthetic fruition is a classical theme in both aesthetics and art criticism. Art history is rich in anecdotes that illustrate how the phenomenological body, with its ability to grasp objects, to get close to them and to manipulate them, is mobilized by visual images.[15] Pliny the Elder in his *Naturalis Historia* described a contest between the Greek painters Zeuxis and Parrhasius: Zeuxis painted some grapes so perfectly that birds flew down to peck them, but Parrhasius painted such a realistic curtain that his adversary tried to draw it aside.[16] It goes without saying that in Pliny's history Parrhasius was honored as the best artist, because his work was so realistic that it had baffled not just animals, but also a fellow painter. In more recent times, the art historian and critic Michael Fried, describing Adolph Menzel's *Cemetery Among Trees, with an Open Grave* (1846-1847), wrote: "It leads us to project ourselves as if corporeally onto the nearest portion of the scaffold [...], or at least loose firm hold of the distinction between our implied situation [...] and the depicted scene."[17] And another art critic, Bernhard Berenson, ascribed Giotto's greatness to his ability to stimulate "the tactile consciousness"[18] of the beholder. Berenson maintained that: "Every time our eyes recognize reality, we

[14] See Pinotti and Somaini, 2012, xvi-xix.

[15] In recent art history and aesthetics the relationship between images and the phenomenological body is studied mostly in connection with the question of emotion and empathy. See, for example, Elkins, 1999 and 2001; Freedberg, 2007; Freedberg and Gallese, 2007.

[16] *Naturalis Historia*, XXXV, 15. I took this example and the followings from Cappelletto, 2010.

[17] Fried, 2002, 34.

[18] Berenson, 1896, 5.

are, as a matter of fact, giving tactile value to retinal impressions," and suggested that the artist's main duty "is to rouse the tactile sense, for I must have the illusion of being able to touch a figure, I must have the illusion of varying muscular sensations inside my palm and fingers corresponding to the various projections of this figure, before I shall take it for granted as real, and let it affect me lastingly."[19] For all these authors the realism of the image appeals to an embodied reaction and not to just a cognitive one: the beholder does not *recognize* the object represented by the image, he corporeally *experiences* it. In Pliny's story Zeuxis is moved to touch and draw aside Parrhasius' curtain, Fried feels like he is entering Menzel's drawing moved by empathetic impulsion, while Berenson makes a normative statement, claiming that art has to elicit tactile sensations if it is to produce lasting impressions.

These examples show how the sense of reality conveyed by images draws more on the *poietic* value of mimesis than on its *mimetic* function.[20] In this perspective, the image is productive because it engages the observer in the experience of a sensible object, not merely in the vicarious experience of the subject-matter of the representation. The experience of looking at an image is the experience of a human body that encounters the material body of the image and enters in a relation with it. Indeed, we can say that images are tools involved in the production of knowledge because they lay in between material reality and abstract thought. An image, notes the philosopher Jean-Jacques Wunenburger, is an ambivalent object, which occupies a middle ground between reality and thinking, the pure datum of sensible experience and its concept. An image is a real object in its own right, and at the same time it is the fiction of something that is there only in effigies, or that has simply left a trace on a sensible surface. An image, Wunenburger maintains, allows to reproduce and internalize the world in a plastic way: it can attempt to mirror it, but at the same time it modifies and transforms reality, creating fictional worlds. An image is a place of mediation and a point of convergence between a thing and a thought, it is an intermediate construction that partakes in the production of knowledge about the world and in its dissolution into imagination.[21]

Image perception and mirror neurons The aesthesiological intuitions present in art literature, from Pliny to Fried, passing through the Vienna School of Art History and Benjamin, seem to find empirical corroboration in recent neurological theories about the so called mirror neuron system. In apes and in humans

[19]Berenson, 1896, 5.
[20]See Cappelletto, 2010, 11.
[21]See Wunenburger, 1997, i.

the mirror neuron system occupies distinct cortical regions, which are activated when an action is observed, as well as when it is actually executed. This means that our brain reacts in the same way when we perform an action and when we observe it, and this simulation occurs even when we look at static images of actions. In fact, the same neurons are involved in the recognition of facial expressions, and they seem to underpin not only the understanding of actions, but also the comprehension of the intentions that underlie an action.[22] Moreover, brain imaging studies have shown that the observation of images of manipulable objects leads to the activation of canonical neurons in a cortical region that is assumed to be responsible for action control, rather than for visual objects recognition.[23] This neural mechanism has quite an intuitive explanation: to get hold of an object, one needs to be informed about its shape (one grabs a ball differently than a pen), thus the function of the sensory input is to enable us to perform the appropriate grabbing gestures. As a whole, these experimental data on mirror and canonical neurons corroborate an embodied approach to vision and spatial perception, and they suggest that there is nothing passive in the fruition of images, because images involve the observer in an active process of embodied imagination, a process of corporeal simulation. Within this perspective, vision becomes a function of the kinetic body, not an act of disembodied cognition. This does not mean, of course, that cognition and culture are not involved in the understanding and interpretation of images. To be aware of the biological, embodied dimension of image perception just adds another layer of complexity to our understanding of how we relate to, and interact with visual representations. In other words, the biological, cognitive, and cultural axes of perception should not be seen as mutually exclusive, but as interlocked in dynamic interaction.

Even without endorsing a neuro-reductionist epistemological stance, I think that we can find in experimental data insights relevant to the elucidation, enrichment, and possibly reformulation of some longstanding philosophical questions. The idea that spatial awareness is linked to motion and touch has a long history in philosophy of knowledge. For example, in his *New Theory of Vision* of 1710, George Berkeley argued that humans develop tridimensional vision only after they learn what it is to move around the world. According to Berkeley, in fact, our retinal vision is originally bidimensional, and it becomes three-dimensional only through a cognitive process whereby we learn to correlate tactile sensations

[22]See Freedberg and Gallese, 2007; Urgesi *et al.*, 2006; Johnson-Frey *et al.*, 2003.
[23]See Freedberg and Gallese, 2007; Ponseti *et al.*, 2006; Boronat *et al.*, 2005; Martin *et al.*, 1996.

with vision.[24] Similarly, in the *Treatise of Sensations* of 1754, Condillac maintained that the awareness of external objects, as well as the ideas of extension, distance, magnitude, and solidity depended on the sense of touch, and that the attribution of form and color hinged upon the motion of the eyes and the hand: to learn to see was to learn to coordinate sight and touch[25] (as seen above, Fontana translated Condillac's ideas on perception into a pedagogical theory).

Vittorio Gallese, one of the proponents of the mirror neurons theory, remarks that there are many points of contact between recent neurological claims concerning the motor nature of spatial awareness, and the theories developed by different philosophers of knowledge. He mentions Hermann von Helmholtz, who tried to substitute the Kantian notion of space as an *a priori* with the notion that this *a priori* consists of the manifold of possible orientations in space, which means that it is generated by exploratory behavior.[26] Gallese also highlights the affinities between the mirror neuron theory and the views on space perception elaborated in phenomenology by Edmund Husserl and Maurice Merleau-Ponty. Merleau-Ponty clearly linked space perception to motion and intentionality when he wrote that space is "[...] not a sort of ether in which all things float [...]. The points in space mark, in our vicinity, the varying range of our aims and our gestures."[27] In a similar fashion, for Husserl, we see things as tactile objects directly related to the lived body (*Leib*). It is the tactile lived body that provides the constitutive foundations of our cognitive self-referentiality, of our determination of reality. Yet, while Husserl considered the physiological body a material object, not directly involved in the phenomenological awareness of the lived body's relation with the world, contemporary neurophysiology suggests that this is not the case.[28] It seems, in fact, that at the neurological level there is no clearcut distinction between motion and cognition, because the same physiological processes that underpin the functioning of our body in the world (the sensory-motor system), also contribute to our awareness of the objects that the world contains, and of our own lived body as part of it. The world is not *out there*, we are intertwined with it. According to Gallese's theory of embodied cognition, which goes under the name of embodied simulation, action simulation integrates visual and auditive stimuli within a specific neural circuit. He

[24] Ian Hacking refers to Berkeley's theory of vision in the discussion of his idea of scientific observation as acquired skill. I present Hacking's position in Section 4.2.2.

[25] In his previous work, the *Essay on the Origin of Human Knowledge* of 1746, Condillac defended a less radical position. Though he already maintained that the cognitive faculties are developed as a consequence of sensation, he took sensation itself largely for granted and not as a learned skill. See Falkenstein, 2010.

[26] See Patton, 2012; Gallese, 2005, 26.

[27] Merleau-Ponty, 1945, 243.

[28] See Gallese, 2005, 27.

explains: "The sight of an object at a given location, or the sound it produces, automatically triggers a 'plan' for a specific action directed toward that location. What is a 'plan' to act? It is a simulated potential action."[29] This means that when a visual stimulus is presented to our perception, it evokes the inner *simulation* of the corresponding motor schema, which maps position in motor terms, independently from the existence of an actual action or movement. Gallese clarifies his conception of embodied simulation as follows:

> Simulation is not conceived of as being confined to the domain of motor control, but rather as a more general and basic endowment of our brain. It is mental because it has content, but it is sensory-motor because its function is realized by the sensory-motor system. I call it 'embodied' – not only because it is neurally realized, but also because it uses a pre-existing body-model in the brain, and therefore involves a non-propositional form of self-representation.[30]

Through embodied simulation we literally, although not materially, enter in contact with the world around us by moving within it and touching it. Accordingly, an image is not merely seen by the eye, it is experienced by the lived body. The lived experience, with its intertwining of visual and motor reactions is a *pre*-condition for any cognitive apprehension of the image content and meaning.

Some problems with the mirror neurons theory of image perception

This neurological account of embodied cognition is quite compelling especially because, by positing that lived experience is a precondition for the cognitive elaboration of images, it is congruous with our basic intuition that some sort of sensorial and physiological apprehension of the world must necessarily precede any cognitive-cultural operation. Still, intuitive as it might be, this assumption is problematic. The mirror neurons theory seems to fit nicely to our empathetic response to artworks, where we *recognize* bodies that could be *our* body, movements that could be *our* movements, and emotions that could be *our* emotions. However, it is much more difficult to understand how the neuro-motor system could be involved in the apprehension of scientific images which, at least in principle, are emotionally neutral. Even more importantly, we should remember that in the majority of cases scientific images show something that we cannot recognize as part of our ordinary world and of our lived experience. It could be claimed that in this case, as in the case of conceptual art, the neuromotor system is involved at the level of canonical neurons that, as seen above,

[29] Gallese, 2005, 27.
[30] See Gallese, 2005, 41-42.

underpin shape recognition and our capacity to manipulate objects.[31] Indeed, in medical images we might see objects that we recognize as something that can be actually touched (a bone, a vein, the liver). However, most scientific images show objects that cannot be grabbed as we grab a pen or a ball. Do we recognize a cell under the microscope as a seizable object? Or do we perceive it as undistinguished patches of colors, which acquire the shape of a cell only within a well-defined cognitive framework? In front of the image of an object that can be recognized only by someone provided with specific knowledge, the neuro-motor reaction of the competent observer will not be different from that of the naïve viewer? To put it differently, could not the neuro-motor reaction be, in this case, post-cognitive rather than pre-cognitive, through a sort of ricochet effect of the cognitive dimension on the neural dimension?

To the inexperienced patient, an arterial angiogram shows something akin to filaments, to the radiologist, it shows a pervious or occluded pipe (the artery), to the surgeon, an artery that, if occluded, can be stripped. Will the neuro-motor reaction of these three subjects be the same? Gallese and colleagues would probably answer that these different conscious perceptions come *after* a primordial embodied reaction, whereby both expert and inexperienced observers see something that can be grabbed. Yet, we do not grab in the same way a spreading filament, a pipe-artery, or an artery that we know to be firm or slippery under the lancet. So, it is difficult to organize an order of temporal priorities between cultural and embodied perceptions, and this might not even be the most relevant or instructive question. It might turn out that a more interesting philosophical and scientific challenge is to understand the entanglements of biological and cultural domains, rather than splitting them in sequential operations (theories about neuroplasticity and epigenetics seem to move in this direction). Thus, problematic as they might be, neuroscientific theories of embodied pre-cognition offer interesting arguments for thinking visual representation, because they blur the boundaries between cognitive-visual experience and bodily-haptic experience.

4.1.4 Manipulating images and objects

Although I rise objections to Daston and Galison's views on the divide between print and digital images, it is important to stress that, by emphasizing the embodied dimension of image fruition as a universal and fundamental aspect of our interaction with all kind of pictures, I do not intend to downplay the po-

[31] For the putative role of canonical neurons in the fruition of conceptual art see Freedberg and Gallese, 2007.

tential transformative effect of digital images on our sensorial perception; on the contrary. I think that digital technologies produce extremely powerful effects on our perception, and this happens for two reasons. On the one hand, digital images can stimulate to a very high degree the haptic dimension of image's perception (but this dimension concerns the perception of all images, not only of computer-generated images). On the other hand, they strengthen our ability to relate to virtual reality, by taking advantage of the fact that images, independently from the technology used to produce and display them, occupy a middle-ground between reality and imagination. It seems thus reasonable to posit that virtual images and the interactive devices that support them work by reproducing and amplifying our innate processes of embodied simulation. It would be unreasonable to deny that virtual images can be manipulated by both their producers and final users in unprecedented ways, and that virtual images manipulation provides us with novel sensorial and cognitive experiences. Yet, this does not mean that images could not be, and were not, manipulated before the digital era. Indeed, as Benjamin expressed so well with his metaphor of the camera operator as surgeon, photography and cinema brought to life a very specific practice of image manipulation. Zooming in and out, strong magnification, slow and fast motion were exactly the features of photography and cinema that compelled Benjamin to argue that they brought to light "entirely new structures of matter," and made us "discover the optical unconscious."[32] As mentioned in Section 3.2, a common practice in the early days of photomicrography was to re-photograph a microphotograph put under the microscope, in order to attain magnifications beyond the technical possibilities of the microscope optics.[33] This procedure proved scientifically unappropriate, because it magnified artifacts rather than the real specimen, nevertheless it attests to the intrinsic manipulability of images. Indeed, one of the reasons why scientists produce images is that one can perform operations on an image that could not be carried out on the real object.

Time-lapse cinema and image malleability If photography allowed to manipulate images in the spatial dimension, cinema allowed temporal manipulation. The historian and philosopher of media Hannah Landecker has shown that time-lapse microcinematography played a capital role in making possible the study of life phenomena and it contributed to the emergence of the idea that, at the microscopic level, life is characterized by relentless, frantic activ-

[32]Benjamin, 1939, 266.
[33]See Section 2.3.

ity.[34] This happened because many life phenomena, such as the movement of bacteria, the division of a cell or the blossoming of a flower have a temporal resolution well below the human sensory threshold or possibility of continuous observation. That is, they are too slow to be directly observed in their becoming. With time-lapse cinema this problem is solved by projecting an image sequence at a much faster frequency than that used to capture the individual frames. In other words, while with chronophotography and slow-motion cinema we can slow down very fast phenomena, with the time-lapse technique we can accelerate very slow processes in order to see their sequential unfolding, rather than the discrete stages of the process. We can visualize the motion of the stretching petals, rather than a bloom and, a few days later, an open flower. Through this technique one can manipulate the time of experiment, observation, and demonstration, condensing the long hours, or even days, of real-time observation into a very short film (acceleration through projection). Unlike chronophotography, which was meant to dissect movement into its instantaneous components, time-lapse cinema was meant to reconstruct a continuous phenomenon on the basis of instantaneous images. One of the first time-lapse microfilms was made by the Swiss biologist Julius Ries in 1907, to study the fertilization and development of a sea urchin. Ries made these two events visible by condensing the fourteen hours of the natural process (documented through photographs taken every seven minutes) into a two minutes film. The time of the living process was readjusted to the time of observation: through the careful manipulation of the time of static and dynamical modes of imaging, a morphological transformation that was too slow to be observed as continuous process, was brought within the range of human senses.[35]

These examples of photomicrography and microcinema show that image *malleability* largely predates digital technology. Indeed, we could say that malleability, or plasticity, is probably one of the reasons why images are so ubiquitous in science.

Nanoimages and objects malleability In making their case about images-as-tools, Daston and Galison state the following:

> In [...] haptic images, seeing and making entered together – unlike the more familiar image making that marked so many generations of science, holding fast to a two-step sequence. The older method meant *first* smashing a proton against an antiproton in an accelerator, *then* imaging the detritus for analysis in a bubble-chamber photograph or digital display. Or, in a very different domain of science, *first* preparing a tissue sample,

[34] See Landecker, 2005, 918-920.
[35] See Landecker, 2005 and 2006.

> *then* imaging it in the electron microscope. For early twenty-first-century nanoscientists, such after-the-fact representations were often entirely besides the point.
>
> Frequently, the nanographers want images to engineer things. In the first instance, these were *images-as-tools*, entirely enmeshed in making, much more than *images-as-evidence* to be marshaled for a later demonstration.[36]

Although these paragraphs can be easily subscribed for what concerns the definition of what makes nanoimages different from other microscopic images (they can be used to engineer things), it is quite problematic in its implications about images that do not belong to nanoscience. What does it mean that non-nano images are after-the-fact representations? Is it a technical statement or an epistemological one? If it is a technical statement, it simply means that when we use an imaging apparatus which does not involve nanotechnology, we have to prepare the sample first, and then we can make a picture of it. But is it true? To microinject a sample during observation is a common practice in microscopy (even with simple optical microscopes). Also, moving to a completely different scale, in Duchenne's *photographies éléctrophysiologiques* the patient's body was embedded in the experimental machinery, and literally wired to the electrostimulator. Was this not a form of physical manipulation, although not at the nanoscale, that occurred during the process of visualization of a specific phenomenon? (In this case, human expression of emotions).[37] So, in technical terms, the claim that only nanotechnology allows to manipulate the object during observation is not strictly correct.

Things become even more problematic if we take Daston and Galison's sentence about after-the-fact representations as an epistemological statement. They say that such representations are "*images-as-evidence* to be marshaled for later demonstration." I interpret their use of the term "demonstration" as referring to the fact that – unlike in the case of images-as-tools, where images are use to produce new phenomena – in the case of images-as-evidence, the image is used as a demonstration, an evidence, of the existence of a given phenomenon. For example, the existence of a bacterium with some morphological characteristic. But why should such demonstration occur *later*? Later in relation to what? The use of this temporal adverb conveys the idea that images-as-evidence (which, in this context, correspond to all images that are not nanoimages) are used as illustrations of something that has already been discovered or understood by other means. It is true that physicians suspected the existence of microorganisms already before they were able to see them with a microscope, and physicists

[36] Daston and Galison, 2007, 384-385, italics in the original.
[37] See Section 2.6.

had already made many observations and developed many theories about subatomic particles before they came out with the idea of smashing protons against antiprotons and visualize the result. Yet, in both cases visualization was part and parcel of the experimental process, not a subsidiary activity. Particle experiments would be incomplete, or better, useless without visualization, because they would be experiments whose results are concealed and inaccessible. Koch could not have developed his germ theory of disease without the images he saw under the microscope, which he fixed in drawings and photographs. Roentgen would have not discovered the X-rays if they had not left a trace on a sensible plate. He used those marks as evidences of his discovery, and he also used them as an instrument to study the behavior of the rays when passing through different objects and materials. Physicians and surgeons used radiographs as evidences of disease, and as means for entering with their eyes into the patient's body. And outside the domain of technology-mediated images, well before the development of computerized molecular modeling, the immunologist Paul Ehrlich used pictorial diagrams as real heuristic tools in the development and defense of his controversial side-chain theory of antibody formation.[38]

Daston and Galison put great emphasis on the fact that in nanoimaging object manipulation and vision occur simultaneously, and that the technology used for manipulation coincides with the technology for visualization. However, they do not provide compelling reasons to justify their claims about the allegedly unique epistemic status of nanoimages in relation to other scientific pictures. Most objects, independently from their scale and from the imaging technology, have to be manipulated in order to produce a scientific image. In my view, in a theory of scientific images this is more relevant than whether the visualization and manipulation occur synchronically or diachronically. Cells, microorganisms, and all sorts of living tissues have to be properly prepared to become visible under the microscope and in microphotographs;[39] an object has to be bombarded with X-rays to produce a radiograph; and a patient has to ingest bismuth for the radiologist to see the shape of the digestive system, in real time, on the fluoroscopic screen.

How are we to understand these practices if not as manipulations, interventions on natural objects aimed at turning them into objects for scientific visualization and analysis? Even images that do not reach the technological so-

[38]Ehrlich made his drawings public in the 1900 Croonian Lecture "On immunity with special reference to cell life," later published in the Proceedings of the Royal Society and widely cited. For a study of Ehrlich's pictures and their role in the development of immunological theory, see Cambrosio *et al.*, 1993 and 2005. Among studies of scientific images and the ways they are used by scientists, see Dagognet, 1986; Lynch and Woolgar, 1990; Baigre, 1996; Pombo and Di Marco, 2010.

[39]See Section 2.3.

phistication of nanomanipulation command some sort of actual handling of the object of study, and this happens because images are part of an experimental praxis, a complex set of activities whose aim is not merely to *copy* objects in the most accurate way, but to *learn* something about them. We can thus conclude that, even if we accept Daston and Galison's definition of images-as-tools as images that allow to manipulate the object of study during the imaging process, we cannot concur with them in applying this definition only to nanoimages. Many scientific images produced by means of some technological apparatus allow or require the manipulation of the sample during the making of the image. More exactly, the preparation of the sample should be considered part of the process of visualization. Still, I have to clarify first both the semiotic and experiential processes entailed in scientific images signification, in order to reinforce and make more precise my claims on the *poietic* nature of scientific representation. To say that representing is an active endeavor is not enough. An account of how this activity is brought about is necessary. To put it differently, it is necessary to explore how representation and meaning are interlocked.

4.2 From vision to meaning

As seen above, Daston and Galison's technology-driven dichotomy between images that *present* and images that *re-present* entails a passive understanding of representation. This way of conceiving representation not only overlooks the questions posed by disciplines as diverse as art theory, philosophy, and neuroscience; it also makes difficult to understand how the images that merely represent – allegedly burdened with passivity and repetition – can produce new knowledge as they actually do. In contrast with this view, I have defended the idea that scientific representations always entail some form of presentation. On the one hand, they command specific manipulations of the object of study; on the other hand, images themselves can be manipulated in order to better understand the represented object; finally, the viewer, too, is activated, so to speak, by the image both at the sensory and cognitive level. In the remainder of this chapter, I back my claims through the analysis of how images are used and endowed with meaning in actual scientific practice. My account is organized along three lines: first, I briefly summarize David Gooding's theory of scientific visual thinking, which has the merit of highlighting the trans-historical aspects of visual cognition without neglecting the cultural and local character of actual practices of visualization; second, I propose a semiotic analysis of the processes of image signification; finally, I introduce the idea that scientific images must be understood as essential components of experimental practices.

4.2.1 Six general features of scientific representations

Gooding, an historian and philosopher of science who has worked on the cognitive theory of scientific images and models, describes scientific representation as a practice where cognition and culture meet.[40] He remarks that, although many philosophers and scientists (physicists and mathematicians in particular) are convinced that science proceeds by eliminating sense experience in order to produce abstractions that can be formally manipulated, the growing importance of data visualization attests to our cognitive need to translate abstract or invisible data into objects or forms that can be manipulated and interpreted resorting to non-formalized visual skills.[41] For Gooding, it is possible to identify a distinct scientific "visual method" of thinking, whereby "images, narratives, meanings, arguments and objects" converge.[42] Such visual method, he argues, is trans-historical, in spite of the diversity of the local contexts of practices (different scientific disciplines and different imaging technologies). He states: "The existence of common features behind the diversity of visual representations suggests a common dynamical structure for visual thinking, showing how visual representations facilitate cognitive processes such as pattern-matching and visual inference through the use of tools, technologies and other cultural resources."[43] Gooding identifies six general persistent features of scientific visual representation:

1. Representations are *hybrid*, that is, in scientific visualization different modes of representation (visual, verbal, numerical, symbolic) are brought together to display an interpretation. The simplest and most straightforward example is the use of captions that describe explicitly what is to be seen in the image, but we can also think of the pointers and letters that are often superimposed on microscopy images to guide the gaze of the viewer, or the lines and points traced on bubble chamber photographs to clarify the trajectory of the tracks.

2. Representations are *multimodal*, that is, they combine information that comes from different sources and appeal to different sensory modalities. For instance, in maps color codes can be used to visualize temperature or altitude, while the functional differentiation of an anatomical structure could be displayed using different symbols.

[40] See Gooding, 2006.
[41] See Gooding, 2003, 263-268.
[42] Gooding, 2004a, 280.
[43] Gooding, 2004b, 551.

3. Representations are *plastic*, because they can be subjected to a wide range of variations that externalize, but also guide mental operations, and accommodate interpersonal communicative needs. For instance, a representation can be manipulated materially or mentally through operations such as rotation or color change, a photograph can be cut and worked in several ways, or it can be translated into a diagram. Although digital technologies enable specific forms of image plasticity, the plasticity of representation is primarily related to our cognitive needs, and not to the technique of image production.

4. Representational variation takes often the form of *recursive transformations* between bidimensional forms (patterns and diagrams), three- dimensional forms (structures) and four-dimensional representations (temporal transformations). For example, to reconstruct an extinct animal from fossil imprints, paleontologists typically take several imprints' pictures. From the photographs they will extract bidimensional diagrammatic representations that serve as a basis for three-dimensional modeling. However, the information provided by the bidimensional diagrams is not enough to reconstruct the morphology of the original specimen. It must be complemented with ecological, physiological, and biological information from different sources (e.g., knowledge about the physiology and behavior of similar organisms, or about the processes of mineralization of specific structures). Importantly, the process is not linear, but dialectical, because the knowledge generated at each step of visualization can lead to a reassessment of the previous passages and thus open new possibilities of representing, i.e., understanding, the object of study. Transformations can be informal or formalized.

5. Representational plasticity is *constrained*, because it has to respect transformation rules which might be explicit and articulated verbally, or embodied in representational techniques and technologies. Verbal rules are predicated on the background knowledge of the specific scientific discipline and on information derived from different sources. Representational rule encompass, for example, geometrical methods of image transformation, or computational methods for image reconstruction.

6. Representations are *distributed* in three different ways: (1) between minds (individuals) and machines, because researchers use instruments to produce and work with different kinds of images; (2) between the mental and the material (sensory) domain, because of the very double nature of im-

> ages; and (3) among individuals, machines, and organizations, because of the collective dimension of scientific knowledge.[44]

For Gooding, it is through the distributed character of visualization that the trans-historical cognitive domain intersect the socio-cultural dimension of every human endeavor. He argues that studies on practices of representation and visual thinking help to elucidate our comprehension of science as a distributed system under different perspectives. By providing information on how researchers produce, manipulate, and communicate with and about visual images, they undermine the traditional distinction between internal (mental) and external (public) representations. In doing so they foster the idea that science constitutes a "truly hybrid cognitive system,"[45] wherein the boundaries between collective and individual knowledge are blurred. Mental and material images work through a continuous interplay: material images can be generated by machines (their production does not involve a human agent), but they cannot be manipulated without engaging in mental processes. Mental processes, in turn, are proper of individuals, and nevertheless they are influenced by collective knowledge and communication. Additionally, studies in scientific visual thinking show that "representations are neither cognitively nor socially neutral."[46] At the social level, representations have to respect the conventions of a discipline and are necessarily inscribed in a wider cultural tradition (e.g., artistic styles), at the cognitive level, they have to accommodate different cognitive capacities and goals.

In the following sections I discuss how these general features are instantiated in specific cases of scientific representations. First, I analyze images in the context of the semiotic network of a scientific paper, examining the 1903 radiology article by Halls Dally already mentioned in Chapter 3.[47] I chose this article because it was published at a time in which the very meaning of X-ray imaging was still in the making, thus it offers a privileged vantage point to understand the processes of image signification. Subsequently, I look at images as components of experimental practices, extending my considerations from medical imaging to visualization technologies in molecular biology and microscopy, in order to highlight the instrumental, embodied, and collective dimension of scientific representation and visual thinking.

[44]See Gooding, 2006, 689-692; Gooding, 2004b.
[45]Gooding, 2006, 694.
[46]Gooding, 2006, 695.
[47]See Section 3.4.3.

4.2.2 Images as part of semiotic networks

According to the semiotician Françoise Bastide, a scientific article is, as a *whole*, "a technique of visualization for the public, for the scientific community concerned [with the problems of a field of knowledge]."[48] Through an article, the first-hand visual experience of one scientist, or of a limited group of scientists, becomes a larger, shared experience that can be discussed and related to a system of collective knowledge. This idea applies quite well to Halls Dally's paper, because the author, in his attempt to validate X-ray imaging as an effective diagnostic technology for pulmonary diseases, described quite accurately the actions and cognitive processes involved in chest radiographs signification, and made explicit a number assumptions that were subsequently internalized in medical knowledge through formal education and routine medical practice. Hence, by analyzing in detail this document we can have an idea of the processes that led to the definition of a wide range of conventions and cognitive strategies that made radiographic imaging meaningful for the doctors of the early twentieth century. In Halls Dally's article, the radiographic and fluoroscopic images are systematically translated into words, diagrammatic pictures, and tables, thus creating an elaborated semiotic network that accomplishes two functions. On the one hand, it transforms the streaks and shadows that appear on the radiographic plate or the fluorescent screen into anatomical images (the lungs and the heart) and physiological activities (respiration in the form of diaphragm movement). On the other hand, by putting in relation X-ray images with physical examination and the description of clinical cases (patient histories), images are invested with a concrete medical meaning. Thus, throughout the article we see at work the hybrid, multimodal, plastic character of representation, as well as the definition of the constraints for image interpretation, and the distributed nature of the whole endeavor.

Conditions of visibility Halls Dally's paper can be divided in two parts: one is aimed at establishing the primary conditions of visibility of the X-ray images of the thorax, while the other deals with the construction of their diagnostic meaning. Halls Dally's first concern was to clearly define the position of radiographic imaging within the context of respiratory medicine. He wrote: "In addition to the established methods of medical investigation of disease of the chest comprised under the headings of inspection, palpation, percussion, auscultation, and mensuration we now have at our disposal the Roentgen rays, a newer yet no less potent factor in diagnosis."[49] In a single sentence he stressed

[48]Bastide, 1990, 189.
[49]Halls Dally, 1903, 1800.

METHOD.

Radioscopy	=	Inspection.
Radiography		Palpation.
Stereoscopic { Radioscopy / Radiography }		Percussion.
		Auscultation.
Localisation		Mensuration.

RESULT.

Roentgen rays.		*Percussion.*
Brightness	=	Hyper-resonance.
Transradiancy	=	Normal resonance.
Faint shadow	=	Impaired resonance.
Dense shadow	=	Dulness.
Opacity	=	Absolute dulness (tanquam femoris).

Figure 4.3: Table of correspondences between X-ray imaging and physical examination of the thorax. In the upper part of the table, different methods of radiographic imaging (radiography and radioscopy, also called fluoroscopy) are equated to physical examination; in the lower part, the visual characteristics of X-ray images are put in specific correspondence with the sounds elicited in physical examination by percussion. From J.F. Halls Dally, 1903, 1800.

the novelty of the X-ray technology and put it in the context of, and in relation with, well known means of clinical diagnosis. Immediately after, he announced that he had the need to introduce a new terminology, so that "conceptions of new facts [might] find their adequate expression."[50] This point is fundamental, because a proper terminology is necessary not only to facilitate communication among physicians, but also, and primarily, to clarify and stabilize the very visual content of the images. It is easier to recognize a shape from blurred shadows if we have a name for it. On the one hand, to have a name is to have something specific to look for; on the other hand, to name what we see is to give it a meaning, to suggest and interpretation. However, before moving to the description and proper naming of the "shadow show"[51] of the normal and pathological thorax, Halls Dally laid bare the cognitive and material preconditions of signification of the images. For what concerns the cognitive level, he compared radiographic imaging with physical examination (Figure 4.3), resorting to the multimodal strategy of visual validation described by Gooding; for what concerns the material level, he presented in detail the apparatus and procedures for the production of the images, thus offering a good example of the distributed character of image making and visual cognition.

[50] Halls Dally, 1903, 1800.
[51] Halls Dally, 1903, 1800.

The comparison between radiographic imaging and physical examination already points to the diagnostic meaning of the images and locates them in a specific domain of knowledge. On the contrary, the technicalities about image production concern the very possibility to use mechanical images as reliable representations of the object of study (this section in Halls Dally's article corresponds to the the phase of technology control and stabilization described by Pasveer).[52] For instance, Halls Dally warned that if the patient's exposure was too long, or if the current intensity in the vacuum tube too high, then the anatomical structures that should appear dense would look transradiant (transparent). If the tube was placed too close to the patient's body, the shadows of the inner structures near to the tube would appear larger and more indefinite than those which were far.[53] The importance of these technical details lay in the fact that to use different technical parameters means to produce different images. That is, the image is not an unqualified copy of nature: it shows what it shows because it has been produced under specific conditions, and if those conditions vary, the image also changes. Mechanical images are highly contingent objects, whose variability can be tamed by setting technical standards (operational conventions).[54] Consequently, the definition, discussion and implementation of such standards for image production plays a fundamental role in the process of mechanical images signification.

Having settled the general preconditions for X-ray images signification, Halls Dally moved to the description of the radiograph of the normal, healthy thorax according to the new terminology he had previously mentioned. He suggested the adoption of the term "pleuro-pericardial lines" to refer to ill-defined streaks that appear alongside the mediastinal area and follow the outline of the heart. He remarked that in earlier publications those lines had been taken for lower bronchi and bronchioles, mediastinal glands, or visceral pleura, and referring directly to both the descriptions and images published by his colleagues, he exposed the shortcomings of their interpretations. The streaks, he argued, cannot be bronchi and bronchioles because of their position, and they cannot be caused by either mediastinal glands or the visceral pleura because they are still visible after removing part of the organ for *post mortem* radiography. The tentative nature of his own interpretation, however, was explicitly acknowledged by the radiologist. He wrote: "I venture to suggest (under correction) the term 'pleuro-pericardial lines' as being more expressive of what I take to be the origin of these

[52]See Section 3.4.4.

[53]Halls Dally, 1903, 1800.

[54]I discussed this topic at length in Chapter 3. In particular, in Section 3.2 I showed how the setting of experimental standard played an essential role in the process of signification of microscopy images.

shadows."[55] At the dawn of diagnostic imaging, to learn to see something into radiographs was envisaged as a collective process of iterative corrections, and the definition of what could be seen went hand in hand with the development of the terminology that allowed to discuss the new knowledge. By discussing alternative interpretations, radiologists checked on each other's ability to see, developed a specialized language, and built a collective way of seeing. This strategy, in more or less formalized forms is enacted each time a new imaging technique is introduced in medicine or in other fields of science.[56]

Building clinical meaning In the second part of the article, Halls Dally dealt with the problem of how to use radiographs as diagnostic tools. How to recognize pathological states by means of images? For the clinicians of the early-twentieth century the pressing question was: how to diagnose tuberculosis promptly and correctly using X-rays? Halls Dally suggested that early signs of pulmonary disease could be detected only by fluoroscopy, because this real-time visualization technique allowed to see the movements of the internal organs. A reduction in the mobility of the diaphragm, he maintained, was the earliest indication of tubercular lesions in the lungs. He explained: "Diminution in the extent of the excursion of the diaphragm will be noted in the great majority on the side most affected, the general rule being that in quiet and normal breathing the excursions are equal on the two sides, but on maximum respiration they are slightly greater in extent on the right than on the left side."[57] This description was accompanied by a table (Figure 4.4) that displayed the reference number of the clinical cases described in the article, the sex and age of the patient, the measurements of diaphragmatic mobility, and some qualitative

[55] Halls Dally, 1903, 1801.

[56] The problem of defining a shared language to describe images and their diagnostic meaning is still paramount in medicine, and various thesauruses and taxonomies have been developed to tackle this issue. RadLex (Radiology Lexicon), for example, is a general controlled vocabulary developed by the Radiology Society of North America, DICOM (Digital Imaging and Communications in Medicine) is an industry-driven standard for the production of medical imaging files, their storage and their transmission over networks, while BI-RADS (Breast Imaging-Reporting and Data System) is a standard way to describe breast imaging findings and results developed by the American College of Radiology (it exists in specific versions for mammography, ultrasound imaging, and MRI). More recently there have been attempts to replace thesauruses and taxonomies with ontologies, which are more dynamic and are meant to retain multiple layers of relationships between different terms (for an overview of the problems encountered in the integration of different lexicons and the development of an ontology see Overton *et al.*, 2011). The main objective of all these standards is to improve communication among health professionals an researchers, and to allow data retrieval for both clinical and research purposes. I think, however, that it would be interesting to analyze if and how these standards, by putting limits to the language, also influence the possible interpretations of an image. Does the definition of a standardized lexicon prescribe a specific form of seeing? Does it push medical vision from the qualitative to a semi-quantitative domain?

[57] Halls Dally, 1903, 1802.

Table showing the Range of Mobility of the Diaphragm in 20 Cases of Pulmonary Tuberculosis.

No.	Sex.	Age.	Measurements in inches. Quiet respiration.		Maximum respiration.		Remarks.
			Right	Left	Right	Left	
1	F.	24	⅝	½	2¾	2⅛	Early; left apex.
2	M.	35	¾	¾	1¾	1⅝	More advanced on the left side.
3	M.	27	1¼	1	2⅛	1⅞	More advanced on the left side.
4	M.	21	⅝	¾	2¾	2¼	Left fibroid; diaphragm one and a half inches higher on the affected side.
5	F.	24	⅝	¾	2⅝	3	More advanced on the right side.
6	M.	26	½	⅝	2	2⅝	More advanced on the right side.
7	F.	13	½	¾	2⅜	2⅝	Right side.
8	F.	33	½	½	2⅛	2½	More advanced on the right side.
9	F.	50	⅞	⅝	1¾	1½	Equal at both apices.
10	M.	30	⅝	¾	2¾	3	Early; more advanced on the right side.
11	M.	29	⅝	½	2¾	2½	Equal at both apices.
12	M.	44	½	¾	2¾	2¾	More advanced on the right side; diaphragm 2⅝ inches higher on the affected side.
13	M.	31	¾	1	1¼	1½	Late; more advanced on the right side.
14	M.	19	1¼	1⅜	3⅞	3⅝	Right apex.

Figure 4.4: Part of the table showing the range of mobility of the diaphragm in twenty cases of pulmonary tuberculosis described by J.F. Halls Dally (here only the lines concerning fourteen cases are represented). From Halls Dally, 1903, 1803.

annotations concerning diaphragmatic movements. In this case, the imaging device (the fluoroscope) was used as a measuring tool (because it allows to measure the movement of the diaphragm during respiration), and the table became a surface on which to visualize and organize different cognitive elements. More precisely: (1) quantitative information, corresponding to the measurements of diaphragmatic excursion (diagnostic indicator); (2) qualitative description of the diaphragm's movement, which re-connects the contents of the table to the visual nature of the original information provided by the fluoroscope; (3) qualitative information, indirectly provided through the numbers corresponding to the patient histories described in the text of the article. In turn, that verbal description referred to the corporeal dimension of physical examination, which engaged the bodies of the patient and of the physician, since the latter had to touch, tap, and literally listen to the body of the former. As a whole, through the table of diaphragmatic mobility, the visual dimension of diagnosis was explicitly and systematically put in relation with its narrative and quantitative dimensions.

A similar semiotic operation was performed with radiographs. The author did not compare X-ray imaging and physical examination only verbally as shown in Figure 4.3. He also provided a diagrammatic representation of the clinical cases, in which the results of physical examination were displayed *visually* alongside drawings of the radiographic images (Figure 4.5). As in the table analyzed above, where Halls Dally organized and endowed with meaning the measurements of diaphragmatic movement measured through fluoroscopy, in the diagrammatic drawings of Figure 4.5 different cognitive elements were brought together, namely: (1) the narrative, temporal dimension of the clinical case, to which each image explicitly refers through the indication of the case reference number; (2) the pictorial rendering of auscultation, based on a visual codification of the sounds perceived during auscultation ("impaired note", "dull note", "dry crepitation", etc.); (3) the pictorial simplification of the radiograph, where the diagrammatic representation of the shadows is accompanied by a verbal description ("faint shadow", "dense shadow", "opacity"). In this way the radiographic image was fully embedded in, and articulated with, the pre-existing knowledge about pulmonary diagnosis. At this point the complex relation between representation and meaning seems quite clear. However, we need to say more about these images.

From photographs to diagrams The choice of using drawings rather than prints of the X-ray images possibly depended on editorial and typographical reasons, but it also answered specific needs in terms of elaboration and trans-

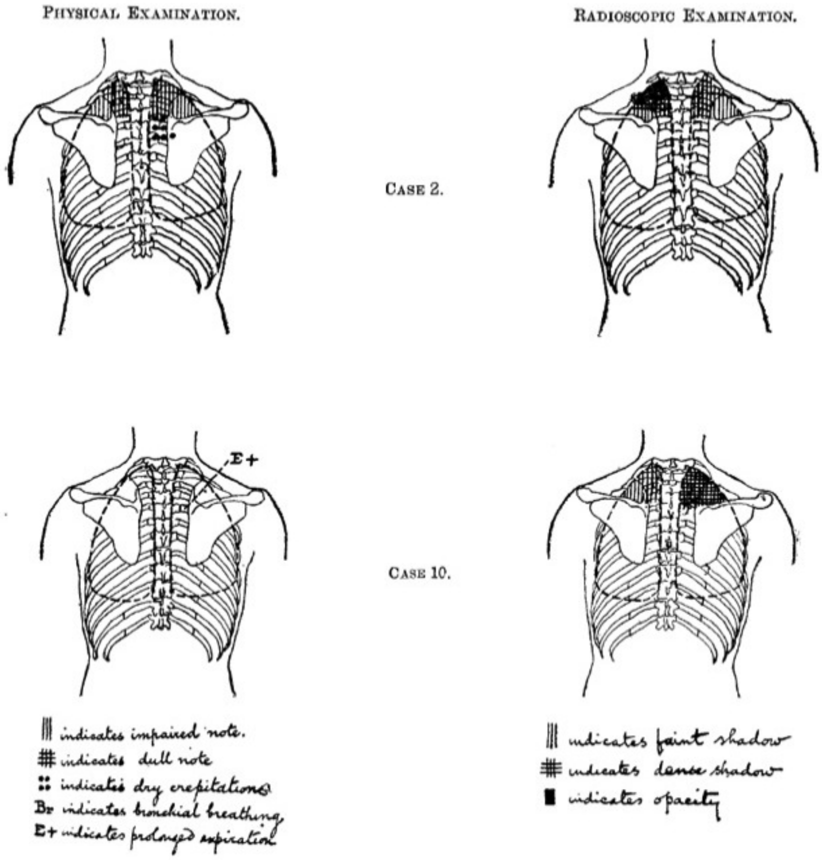

Figure 4.5: Examples of Halls Dally's diagrammatic drawings representing physical and radioscopic (fluoroscopic) examinations. From J.F. Halls Dally, 1903, 1805.

mission of information. At the outset of the article the author insisted on that radiographs are *shadows, not maps*.[58] Accordingly, they could not be read employing a univocal, fully formalized procedure, they had to be interpreted, and the proper interpretation could be brought about "only by careful and repeated observations."[59] Careful and repeated observations allow the radiologist to learn to recognize patterns which, coupled with other knowledge about the disease, can be translated into a diagnosis. To recognize patterns in the shadows is a skill that has to be learned. Using drawings with captions rather than radiographic images, Halls Dally provided a quasi-map, a clarification of the shadow-image, which in this way could be more easily integrated in, and articulated with the semiotic network of the article. This operation attest to the hybrid and constrained plasticity of scientific images (a very rich visual source is resolved into patterns that correspond to an interpretation). By selecting, reorganizing, and integrating with other sources of knowledge the visual content of the original image, the diagrammatic representation of the radiograph reduces its complexity and at the same time improves its explanatory power, because it displays a possible interpretation. In this regard, Bastide remarks that published scientific images tend to avoid the proliferation of meanings cherished by artists, and channel the reader into a codified (although not necessarily explicit) signification.[60] This codified signification, that we can call guided interpretation, can be made explicit through the association of a diagram to the original image. In this case, the diagrammatic depiction prevents the proliferation of meanings. It restricts the number of possible interpretations of the original image, because it contains and reveals the interpretation of the author of the image. Such interpretation can subsequently work as reference for other observers in the signification of other images in the same domain.[61] Compared to indexical images, such as photographs or radiographs, a diagram is a simplified representation. However, Bastide points out that, unlike indices, diagrams can integrate information from an elevated number of sources, adding a different kind of complexity to the original visual sign without reducing its cognitive accessibility. As she puts it: "[A] graph is probably more 'convincing' because it economizes the time and attention of the reader. If we compare it to a photograph, we see that a graph can

[58]See Halls Dally, 1903, 1800.

[59]Halls Dally, 1903, 1800.

[60]"The reading of the signification of a [scientific] photograph (with scarcely any relation to its aesthetic character) relies on the use of systems that semiotics calls 'semi-symbolic.' They couple a difference at the level of the signified to a marked difference at the level of the signifier." Bastide, 1990, 201.

[61]Bastide provides a detailed semantic analysis of the passage from photograph to diagram in Bastide, 1990, 213-220.

support many more dimensions than a photograph while remaining readable."[62] Halls Dally's composite drawings of physical and radioscopic examination offer an example of this semiotic process, whereby the confusing shadows of the original X-ray image are turned into a diagrammatic representation which is simpler than a radiograph and at the same time richer, because it gathers additional information from the physical examination.[63]

Paired representation The question of scientific images interpretation as a process whereby simplification and addition of complexity are not mutually exclusive has been further explored by the sociologist of science Michael Lynch. According to Lynch, the idea that diagrammatic renderings are simplifications of more dense images is useful, but it fails to account for the actual intricacies of the processes of transformation that lead from one representation to another. In the article "The externalized retina: Selection and mathematization in the visual documentation of objects in the life sciences" he states: "Instead of reducing what is visibly available in the original, a sequence of reproductions progressively modifies the object's visibility in the direction of generic pedagogy and abstract theorizing."[64] That is, diagrammatic drawings and other pictorial renderings of complex images such as radiographs or microphotographs do not simply select and show in a simplified way the visual content of the original image, they transform the very visibility of the original object to accomplish some pedagogical or theoretical aim. Lynch elaborates on his argument by examining how biologists make sense of, and teach novices to make sense of, pictures produced by electron microscopy. He remarks that they systematically resort to paired representation, which consists of placing diagrammatic renderings alongside an electron microphotograph, in order to orientate the viewer towards a particular interpretation of the raw image.[65] He separates such diagrammatic renderings in two categories: tracings (that he also calls diagrams) and models.

Tracings are pictorial renderings of specific photographs, while models represent general entities, by synthesizing what can be seen in various photographs, and by assigning visual codes to features, such as biochemical properties, that cannot be seen under any microscope. In other words, the model summarizes

[62] Bastide, 1990, 213-214.

[63] An additional level of complexity emerges if we consider the number of the clinical cases as part of the diagrammatic representation (see Figure 4.5). This would be consistent with the idea that it is the scientific article as a whole that works as visualizing device, and not just its individual components. We have to acknowledge, however, that the drawings remain intelligible even if we eliminate the case study reference. Indeed, the textual part of Figure 4.5 that is inherent to the intelligibility of the image is the caption, which provides the key to the symbolic mode of signification.

[64] Lynch, 1990, 181.

[65] See Lynch, 1990. On paired representation in electron microscopy see also Serpente, 2011.

visual, experimental, and theoretical information collected not only through different techniques, but also in different research projects.[66] Hence, while in the case of tracings we are in the domain of selection and simplification (Lynch uses the metaphor of the filter), in the case of diagrammatic models things are much more complex. Lynch emphasizes that such pictorial renderings are essential to how "scientific objects and orderly relationships are revealed and made analyzable."[67] Diagrammatic models do not simply entail the selection of some elements of the raw image, they also require the synthesis of new forms and the display of different sorts of information, because the model "strives to identify *in* the particular specimen under study the 'universal' properties which 'solidify' the object in reference to the current state of the discipline."[68] This goal is reached, according to Lynch's analysis, putting in place two representational operations: selection and mathematization.

The notion of selection (simplification and schematization of the original image) gathers four transformative practices that lead from one representation to another: filtering, uniforming, upgrading, and defining.

1. Filtering is the operation whereby the diagrammatic picture reduces the amount of visual elements present in the raw image. As Lynch puts it: "*Unused* visibility is simply discarded out of the picture."[69] Hence, this is a process of simplification which contains an implicit interpretation, because it is based on the selection of elements that are deemed important according to the aims of the research.

2. Uniforming entails the application of visual conventions in order to group elements that share some characteristic (morphological or functional), even if in the original image such elements might have variable dimensions, heterogeneous shapes, or occupy distant positions. Uniforming is an explicit form of interpretation, because it requires the decision to aggregate - by using the same pictorial code - different parts of the image.

3. Upgrading consists of highlighting certain shapes visible in the original image, in order to assign them a specific identity (i.e., the borders between distinct areas are made artificially clear and distinct), therefore it works in complementary opposition with uniforming.

[66] See Lynch, 1990, 168.
[67] Lynch, 1990, 154.
[68] Lynch, 1990, 157, italics in the original.
[69] Lynch, 1990, 161.

4. Defining consists of assigning linguistic labels and pointers to the diagrammatic image, so that the identity of each element is unambiguously established.[70]

All these operations are functional to mathematization, that is, they prepare the object (the original image, and through it, the original specimen), for mathematical operations. In Lynch the notion of mathematization has two interlocked meanings. On the one hand, it refers to the generalization from the specific features of an individual image (or set of images) to the general morphological and functional properties of a natural object. On the other hand, it refers to the set of geometrical and quantitative analyses that can be performed on images once they undergo the different processes of selection. In fact, once visual objects are properly coded, they can be aggregated, examined and compared in relation to a variety of features, such as line slopes, points distribution, recurrence of specific patterns, and so forth. Throughout this process "specimen materials are 'shaped' in terms of the geometric parameters of the graph, so that mathematical analysis and natural phenomena do not so much *correspond* as do they *merge* indistinguishably on the ground of the literary representation [provided by a textbook or a scientific article]."[71] In other words, the diagrammatic representation is not a pale mirror of the original image, or even of the natural object, it is not merely constituted by progressively reducing chaos. It is rather the product of an articulated set of operations that produce multiple forms of visibility.

Lynch encapsulates this idea in the expression "*eidetic* image."[72] The term is clearly adapted from Husserl's philosophy, but in Lynch's use it is stripped of its transcendental dimension and refers "concretely to the generalized or idealized version of an object portrayed in a visual document."[73] Hence, by eidetic image Lynch does not refer to a mental picture, but to material visual documents that synthesize and publicly display the knowledge and assumptions of a scientific domain. Importantly, he stresses that an image is always eidetic *in relation* to another image. That is, while the diagram is an eidetic image in relation to the microphotographs, a microphotograph can be considered eidetic in relation to the image one sees when peering through the microscope, because the photograph fixes a choice of magnification, framing, and so on. In turn, the microscopic slide (the prepared sample) is eidetic in relation to the original specimen, because it is prepared according to criteria for fixation and staining

[70] "Entities are not only made more like one another, they are more clearly distinguished from unlike entities." Lynch, 1990, 161.
[71] Lynch, 1990, 181, italics in the original.
[72] Lynch, 1990, 162.
[73] Lynch, 1990, 183.

that depend on the aims of the research. This leads us back to the idea of semiotic network, in which each isolated figure and form of representation acquires meaning within a system of internal and external comparisons that bound different images and, through them, vision and thinking. It also leads us back to the issue of the material preparation of the scientific image, which entails the transformation of the natural object into a scientific object.

4.2.3 Images as part of experiments

I used the idea of semiotic network to describe how the process of signification of scientific images (including diagnostic images) is related to the production and connection of different images and other print signs, such as words and tables of numbers. However, in the analysis of the first part of Halls Dally's article, I pointed to two moments in which the possible meaning of the image is connected not to other images or signs, but to material objects and activities: (1) when Halls Dally describes the machinery and the procedures for image production; (2) when in discussing the meaning of the alleged "pleuro-pericardial lines," he makes reference to other radiographs produced after removing *from the corpse* part of the organs under study. In both cases experiential knowledge is summoned to sustain visual and theoretical knowledge, and the two operations point to the distributed nature of scientific representation. In the first case, representation is distributed between instruments and operators; in the second case, between the radiology cabinet and the morgue, the living body and the corpse.

In order to interpret an X-ray image, the doctor has to know how it has been produced, and in those cases in which a mark on the radiographic plate cannot be unequivocally associated to an anatomical structure or a pathological state, he has to go back to the real body and manipulate it to make sense of the image.[74] This necessity to get out of the domain of images and enter the domain of material objects is particularly strong in the stages of development of a novel imaging technology. It tends to fade away once instruments and procedures have been black-boxed, and once the points of correspondence between images and bodies have been secured. However, the need to resort to the domain of material objects re-emerges each time an image obtained with a well known technology shows something unexpected. In the case of medical diagnostics the physician possesses a reasonable amount of knowledge about the imaged objects (human anatomy and physiology as well as pathological states). Thus, after

[74]The manipulation of the patient's body might consists in a biopsy, if the uncertainty concerns the diagnosis, or even in *post mortem* autopsy, if the uncertainty is about morphological and anatomical elements, as in the case described by Halls Dally.

excluding possible artifacts, he will try to make sense of the unexpected marks by searching some clue in the patient history. For example, the lung radiograph of a patient with mild symptoms of pneumonia might show lesions that look more serious than the symptoms would make one think. This could mean that the pneumonia is actually worse than it seems from the symptoms, that there is another pulmonary disease besides the pneumonia, or that the patient already suffered from pneumonia or another lung disease in the past and this left scars on the lungs after remission. In any case, the physician has at his disposal a number of additional tests to solve the doubts posed by the image. Things are even more complicated in basic research, where background knowledge about the object of study is scant and the range of possible interpretations much wider than in clinical medicine. Here the experiential and experimental dimension of image interpretation appears more clearly than in the case of the images produced in contexts in which the correspondence between the image and its referent is well defined.

Visual and experiential knowledge In a seminal ethnographic study conducted in a German laboratory of molecular biology in the late 1980s, Karin Knorr-Cetina and Klaus Amann have shown that the interpretive process carried out by biologists to make sense of DNA and RNA autoradiographs involves a whole "repertoire of chunks of visual and experiential knowledge."[75] Autoradiography, associated to gel electrophoresis, is used in molecular biology to analyze nucleic acids macromolecules (DNA and RNA) on the basis of their size and electrical charge. The electrophoresis gel is a thin layer of agarose with holes (called wells) at one end. To produce an autoradiograph, samples of macromolecules digested and marked with radioactive labels are loaded in the wells, and an electric current is turned on, creating an electric field that makes the negatively charged molecules move through the gel. Since smaller molecules move more easily through the pores of the agarose matrix, they are faster and thus migrate farther than the larger ones. As a consequence, after a given lapse of time molecules of different size will form distinct bands on the gel. Because the molecules have radioactive labels, if a sensible film is exposed to the gel, it will be marked producing the autoradiograph of the fragments of RNA and DNA arrayed on the matrix (Figure 4.6). It is important to note that the size of the molecule is not related to the dimension of the bands, but to their position on the gel, which is a direct function of the distance travelled during electrophoresis. This is why in order to calculate their dimension, it is necessary to analyze the location of each fragment in relation to a marker, a built-in visual reference

[75] Knorr-Cetina and Amann, 1990, 263.

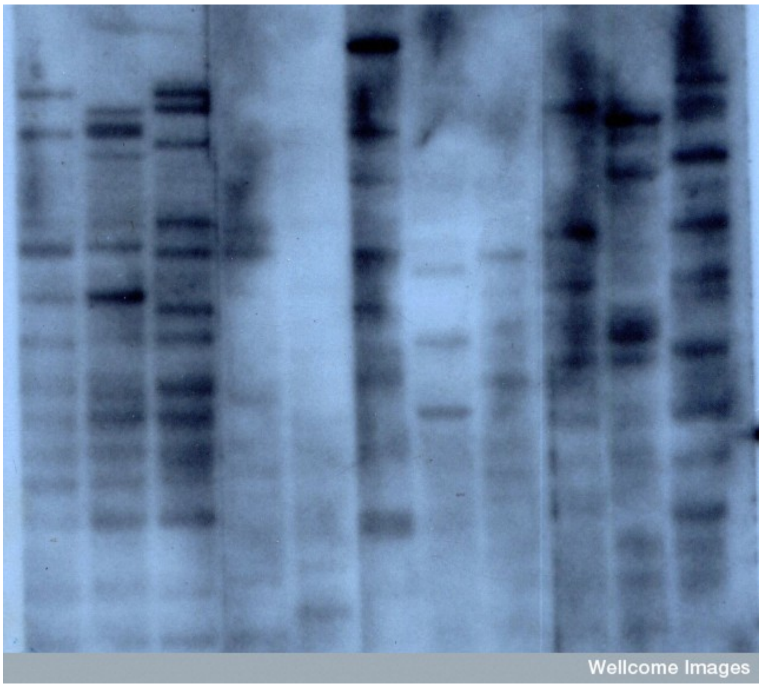

Figure 4.6: Example of gel electrophoresis autoradiograph (DNA fingerprint). Credit: Alec Jeffreys, Wellcome Images.

consisting in a mixture of molecules of known size which is run in one of the gel lanes.

Molecular autoradiograph is indeed quite a peculiar form of visualization: it is a measuring device (it is used to measure the size of macromolecules) in which only the relative positions of the traces left by the nucleic acids (and not their shape, thickness, or color) convey relevant information. Knorr-Cetina and Amann describe the interpretation of a problematic autoradiograph in which the bands were much more blurred than those shown in Figure 4.6. They illustrate it as a collaborative activity in which scientists analyze and discuss the image by referring to several sensory and cognitive objects and events, namely: (1) other autoradiographs produced in their own laboratory or published in journals; (2) different diagrammatic representations of DNA or RNA; (3) conceptual reconstructions of molecular processes; (4) technical design maps of the experiment of electrophoresis; (5) recollections and sensory impressions from the events occurred during the experimental procedures.[76]

In particular, commenting on points (4) and (5), Knorr-Cetina and Amann state: "Each data spot on a display is a mark from which invisible threads lead to particular occurrences in experimental processes – threads that participants

[76] Knorr-Cetina and Amann describe the talks in which biologists recollect sensory impressions from laboratory activities as "scenic descriptions," and they describe them as having a "curious *'gestural'* quality." They remark: "Scientists rarely argue in image-attached conversations. *In dissecting the object* [the image], *they prefer to point*." Knorr-Cetina and Amann, 1990, 263, italics in the original.

[scientists] pursue in image dissection."[77] That is, when an image is particularly resistant to interpretation, when its very visual content is difficult to decipher, scientists tend to retrace the whole process of image production. They look outside of the image, into a whole range of objects and activities that are part of the experimental setting. Indeed, the autoradiograph does not simply visualize the results of the experiment (which entails samples preparations and electrophoresis), it contains a range of information about various steps of the laboratory process. It says, for example, if the electrophoresis worked properly, or if the samples were treated adequately. It literally bears a trace, or a "signature," as Knorr-Cetina and Amann call it, of all those steps. An autoradiograph, they say, "is the result of an imaging technology that creates visible traces of invisible reactions."[78] Accordingly, although the goal of the electrophoresis is to measure the length of nucleic acids fragments, what the autoradiograph shows is a compound of information that points back to all the invisible reactions that preceded the impression of the X-ray film. As a consequence, in order to interpret the image one has to be able to reconstruct at least in part the wider experimental domain in which those reactions occur (for instance, to know if the amount of nuclease used to process RNA and DNA before the electrophoresis was enough, if the time of exposure of the X-ray film was adequate, and so forth).

As Knorr-cetina and Amann aptly put it: "[Biologists] treat images as self-contained subjects that *carry the analysis of an event within them*."[79] The autoradiography of gel electrophoresis is an example of a sophisticated imaging technique in which the problem of image signification is twofold. On the one hand, it is impossible to directly compare the information provided by the image with the object of study. On the other hand, due to the complexity of the whole experimental process that leads to the production of the autoradiograph, the causal relationship between object and image has not warranted stability and reproducibility.

Representing and intervening The analysis provided by Knorr-Cetina and Amann supports Ian Hacking's well known claim that, in science, representation and intervention are deeply enmeshed activities. In order to represent something, one has to manipulate instruments *and* the object of study.[80] Hacking's argument, rooted in the debate on scientific realism *vs.* anti-realism, is aimed at contrasting what he calls "the spectator theory of knowledge,"[81] that

[77] Knorr-Cetina and Amann, 1990, 274.
[78] Knorr-Cetina and Amann, 1990, 263.
[79] Knorr-Cetina and Amann, 1990, 262, italics in the original.
[80] See Hacking, 1983.
[81] Hacking, 1983, 130.

is, the idea that scientific knowledge is an abstract theoretical representation of the world. He criticizes this stance, claiming that any doctrine of knowledge based on the "contemplation between theory and the world" is doomed to lead to "an idealist cul-de-sac."[82] In order to avoid this dead end, he puts forward an instrumentalist theory of knowledge, according to which we can have a firm grip on reality, and get to know something about it, only when we intervene in nature, when we create new phenomena,[83] for example by spraying positrons and electrons on niobium droplets to increase or decrease their charge.[84]

Hacking's instrumental theory of knowledge informs his theory of observation and of scientific images. Images, he maintains, become intelligible not because we look at them very carefully and with a well defined preconceived theory about what we are going to see, but because we perform on and around them a number of interlocked different activities. He uses the example of microscopy images, and makes two fundamental, interrelated claims: (1) "You learn to see through a microscope by doing, not just by looking,"[85] and (2) "We do not in general see *through* a microscope; we see *with* one."[86] In both sentences Hacking points to the fact that seeing something under a microscope, that is, recognizing something meaningful and scientifically relevant, is not simply a matter of watching, it entails a range of bodily and instrumental activities. When we look for the first time through a microscope, all we see are patches of colors. Students in high school and university learn to recognize what they are seeing by exercising with reference microphotographs and drawings duly captioned. This is a good basic training for routine work, but it is not how we discover something new. If we are to learn something new about a specimen we are observing under a microscope, we will have to use several microscopes and several ways to prepare the specimens. We will need different images of the same sample, or of different samples of the same object, in order to compare them. The researcher interested in finding something new or in sorting out structures from artifacts has to learn to produce different images with a suitable instrument, under suitable conditions. Hacking draws a parallel between his idea that we see *with* and not *through* a microscope, and Berkely's theory of vision, according to which three-dimensional vision is an acquired skill correlated with the sense

[82]Hacking, 1983, 130.

[83]Curiously enough, Hacking never mentions the work of Gaston Bachelard who, in the 1930s, coined the term "*phénoménotechnique*" to refer exactly to the fact that modern science creates its own phenomena. I discuss the concept of phenomenotechnique in Chapter 5.

[84]"Now, how does one alter the charge on the niobium ball? 'Well, at that stage,' said my friend, 'we spray it with positrons to increase the charge or with electrons to decrease the charge.' From that day forth I've been a scientific realist. *So far as I'm concerned, if you can spray them then they are real.*" Hacking, 1983, 23, italics in the original.

[85]Hacking, 1983, 189.

[86]Hacking, 1983, 207.

of touch and with actual tampering with the world. He writes: "Whether or not Berkeley was right about primary vision, new ways of seeing, acquired after infancy, involve learning by doing, not just *passive looking*."[87]

Hacking works this idea through the example of the discovery of dense bodies in red blood cells. Dense bodies are small spots visualized in erythrocytes observed using low power electron microscopy. They are called "dense" simply because they are electron dense, which means that they appear at the electron microscope without any staining or preparation. When they were noticed for the first time, nobody knew if they were actual biological structure or just artifacts. To discriminate artifacts from real objects is a common problem in microscopy, and in visualization technologies in general. So, how do scientists know that what they are seeing is real and not just an erratic creation of the imaging apparatus? We have already encountered this problem in Chapter 3, discussing the question of depiction and detection in photography. We saw that Perini considers microscopy artifacts as paradigmatic stances in which depiction hampers detection, because they provide an example of how we can be mistaken by the apparent mimetic properties of an image. In Perini's analysis, scientists can overcome this pitfall by granting microscopy images a well circumscribed meaning, that is, by seeing them not as more or less indirect depictions of the real microscopic entity, but as depictions of the visual features of a sample prepared and visualized under specific conditions.[88] On the basis of this restraint and cautious vision, as it were, the biologist is motivated and entitled to carry on a range of different activities aimed at establishing if the forms observed under the microscope correspond or not to some actual quality of the natural object. In this respect, Perini's position overlaps with Hacking's. Still, in her account the epistemic warrant of mechanically-produced images relies primarily on the causal interaction between the object under study and the detector.[89] Hacking, on the contrary, tends to downplay the relevance of the microscope as mapping device.[90] He rather insists on the fact that when it comes to distinguish artifacts from reality, scientists implement different practical strategies: (1) they check if the same structures appear under different microscopes that work on the basis of unrelated – and well understood – physical processes;[91] (2) they construct objects with specific known features and they observe them with

[87]Hacking, 1983, 189.

[88]See Section 3.2.

[89]See Perini, 2006, 868.

[90]The microscopy image can be conceived of as "a map of interactions between the specimen and the imaging radiation." Hacking, 1983, 207.

[91]In the case of dense bodies the results of the electron microscope were checked with a fluorescence microscope.

a microscope;[92] (3) they manipulate the objects they want to observe, for example, by microinjecting them, and look at how these manipulations affect the image; (4) they cross the observations done with the microscope with the results from other sciences, namely biochemistry and crystallography, which can confirm if the structures that are visualized might correspond to specific chemical and physical properties.[93] This means, again, that scientists endow instrument-mediated observations with meaning not merely by looking at the mechanical record provided by the machine, but through a range of activities that combine theoretical and experimental work. Scientists are not remote spectators, they are hand-on sense-makers.

When doctors look at what might be a lesion revealed by a diagnostic scan, they judge their findings and weigh them against an idea they have formed about the lesion, a mental image which is the product of previous experience. The experiences on which this mental process is based relate to medical education (anatomy, physiology, pathology, and so forth), experiential knowledge of the inner body (direct observation of intraoperative findings or corpse dissection), comparison between images produced with the same imaging modality, and comparison between images and the results of other tests. In other words, the diagnostic meaning of a particular lesion in a particular image emerges from previous experience, which is constructed at both the historical-cultural (knowledge developed within the scientific community) and individual level (knowledge acquired and developed by the single practitioner). Books, articles, dissecting room and surgical table, images form the same patient or from different subjects, laboratory tests, discussions at ward meetings or conferences, all these objects and events enter the process of image interpretation. In the case of well known pathologies, black-boxed technologies, and experienced radiologists, the image becomes a self-contained epistemic object, and the doctor can *see* at a glance the disease in the radiographic plate (or, more likely, on the computer screen). Still, each time doubts arise, the practitioner can get outside of the image and consult other objects, machines, events, and people involved in the distributed process of signification and interpretation. Doctors work with images in order

[92] Hacking calls this argument "the argument of the grid," because he uses as example the metal grid employed by biologists to compare a specimen under an electron and a fluorescence microscope. Back in the 1980s, the procedure consisted of drawing on a paper a grid with a letter in each square, and then to photographically reduce it. The biologist, who knew exactly the characteristics of the grid, fixed the specimen on it and mounted the slice on the microscope. Through the microscope he would see exactly the grid he had constructed, with its lines and letters. Hacking concludes that, in this case, we have good reasons to believe that what we see under the microscope is a feature of the specimen and not an artifact because: we made the grid, we know that the manufacturing process is reliable, and we can check the result through different microscopes. See Hacking, 1983, 202-204.

[93] Hacking, 1983, 209.

to produce a specific visibility of the body and of the disease. This visibility is a presentation of the body and the disease under experimental conditions. It turns such complex entities into objects amenable to medical comprehension and practice. Images are tools pertaining to the larger toolbox of medical practice and they allow the physician to work on the human body and treat its diseases. Resorting to Lynch's notion of eidetic image, we could say that doctors produce an eidetic image of the human body not only because the radiograph fixes specific choices in terms of image production (radiation intensity, time of exposure, reciprocal position of body and machine, etc.), but also because it fixes a specific way of understanding (theorizing) both the body and disease.

In this chapter I approached the notion of *images as tools* by covering a long, somewhat heterogeneous route. I went through the discussion of the haptic, embodied dimension of image perception, engaged in the semantic analysis of how scientists make sense of photograph-like images, and finally dealt with the experiential and collective dimension of image production and signification. In the background always lingered the tension between material and mental representation, representations and objects, pictures and language, vision and gesture, images and laboratory practices. This unresolved tension is due, I think, to the ambiguous nature of images themselves. It depends on the fact that they are a go-between that links material and mental dimensions, presence and absence, sensible experience and concept. In the following chapter I engage more deeply with the idea that scientific images are *experimental tools*. More precisely, I expound the thesis that diagnostic images are to be understood as experimental devices because they present the body under *experimental conditions*, through a process that entails a specific reconfiguration of both body and illness. I do so by drawing on Gaston Bachelard's idea of phenomenotechnique. I apply the concept of phenomenotechnique to both medical images and bodies, in order to show how the lived experience of illness is effectively turned into a visual scientific object.

Chapter 5

Medical imaging as “phenomenotechnique”

Bachelard coined the concept of phenomenotechnique in the article “Noumène et microphysique,” of 1931, to describe the activity of mature sciences. In this text the philosopher claimed that the science of his time, characterized by the theoretical revolutions and empirical successes of quantum mechanics and space-time relativity, was no longer a *phenomenography* [*phénoménographie*].[1] That is, it was not a representation of the world based on the observation and analysis of natural phenomena. It was a “*phenomenotechnique*, whereby new phenomena are not simply found, but invented, created anew.”[2] This concept, further developed in *Le nouvel ésprit scientifique*, of 1934, became a fundamental category of Bachelard’s epistemology. To him, non-Euclidean geometry, relativity theory, quantum mechanics, and quantum chemistry are the outcomes of a science that has broken any relation with the data of our everyday experience. Referring to modern chemistry, Bachelard remarked that it had completely broken with ancient natural history, which described all sorts of natural matter (mineral, vegetal, animal) on the basis of collections of facts rooted in sensible data and connected through ambiguous relations of similarity. To study matter, Bachelard claimed, one has “to make *profession of facticity*,”[3] that is, one has to produce substances that do not exist in nature, and to re-make those that exist, in order to analyze them under the proper degree of purity.[4] He wrote:

> [In science] phenomena must be selected, filtered, purified, shaped by instruments; indeed, it may well be the instruments that produce the phenomenon in the first place. And instruments are nothing but theories

[1] Bachelard, 1931, 18.
[2] Bachelard, 1931, 18, my translation.
[3] Bachelard, 1953, 22, my translation, italics in the original.
[4] See Bachelard, 1953, 22.

> materialized. The phenomena they produce bear the stamp of theory throughout.[5]

Modern science does not *find* its objects in nature, it *realizes* them in the form of new physical effects (e.g., Zeeman effect),[6] purified chemical substances, synthetic molecules. It has broken with the primacy of primitive sense data proper of naïve realism and praised by positivist philosophers, and has turned into a "realization of the rational,"[7] characterized by the integration of theory and experiment, bounded in a dialectical relation.[8] For Bachelard, "science *realizes* its objects without ever just finding them ready-made. Phenomenotechnique *extends* phenomenology. A concept becomes scientific in so far as it becomes a technique, in so far as it is accompanied by a technique that realizes."[9] In other words, science must replace a phenomenology that describes natural phenomena[10] with a phenomenotechnique that inscribes the natural phenomenon within scientific rationality. To quote Bachelard again:

> A truly scientific phenomenology is [...] essentially a phenomenotechnology. Its purpose is to amplify what is revealed beyond appearance. It takes its instructions from construction [*Elle s'instruit par ce qu'elle construit*]. Wonderworking reason designs its own miracles. Science conjures up a world, by means not of magic immanent in reality but of rational impulse immanent in mind. [...] Scientific work makes rational entities real, in the full sense of the word.[11]

In his effort to elaborate a philosophy of science situated beyond the received traditions (positivism *vs.* formalism, empiricism *vs.* conventionalism, realism *vs.* idealism), which he considered the product of unjustifiable abstractions and generalizations,[12] Bachelard developed an original brand of rationalism that pointed towards an absolute mathematization of the world, but at the same time commanded the reification of reason into artificial material entities. In a text written in 1936 for the first and only issue of the Surrealist review *Inquisitions*, he wrote that human reason has to be turbulent and aggressive, in order

[5] Bachelard, 1934, 13.

[6] The Zeeman effect, named after the Dutch physicist Pieter Zeeman, is the effect of splitting a spectral line into several components in the presence of a static magnetic field. It was first produced by Zeeman in 1896, by holding a flame between strong magnetic poles.

[7] Bachelard, 1934, 5.

[8] Rheinberger aptly defines this relationship between theory and experiment as a dialectically constituted material-discursive circle. See Rheinberger, 2005, 316.

[9] Bachelard, 1938, 70, italics in the original.

[10] It is not clear if when Bachelard uses the term phenomenology in opposition to that of phenomenotechnique he is referring to the Husserlian tradition, or if he simply means "phenomenography," that is, the observation and description of natural phenomena based on primary sense data. I incline to the latter interpretation, but this is a problem open to debate.

[11] Bachelard, 1934, 13.

[12] See Bachelard, 1949, 5.

to found a *surrationalism.* It has to establish “an *experimental reason* capable of surrationally [*surrationellement*] organize the real, just as Tristan Tzara’s *experimental dream* organizes poetic freedom in a surrealist way.”[13] Rationalism must be untamed and experimental at the same time, it has to break with the real, in order to create new material objects and phenomena that are the only possible scientific reality. Based on a dialectical relation between rationalism and materialism, Bachelard’s epistemology is quite complex, and it would deserve a detailed discussion that I cannot put forward here (it would require another dissertation). What is important to stress in the scope of my work is that the technical realization of the rational was so relevant to Bachelard epistemology, that he was not afraid to call his rationalism *realism.* Of course, Bachelard’s realism, just as his rationalism, is of a peculiar sort. And indeed he uses the expressions “educated realism,”[14] “realism at one remove,”[15] or “technical realism” [*réalisme téchnique*][16] in opposition to common scientific realism. Bachelard’s realism concerns a reality that can be grasped only through the technical realization of the rational.[17] In *Le Nouvel esprit scientifique*, he explained:

> [Technical realism] has nothing to do with traditional philosophical realism. It is rather realism at one remove, conceived in reaction to the usual notion of reality, as a polemic against the immediate; it consists of realized reason, reason subject to experimentation [*un réalisme fait the raison réalisée, de raison expérimentée*]. The ‘reality’ to which this realism corresponds is not transferred into the realm of the unknowable *thing-in-itself*. It has a noumenal richness of quite another order. The thing-in-itself is a noumenon by exclusion of phenomena, whereas scientific reality, I would argue, consists in a noumenal context suitable for defining axes of experimentation.[18]

This idea of a non-Kantian noumenon appeared also in the 1931 article on microphysics where the notion of phenomenotechnique was first introduced:

> We could therefore say that mathematical physics corresponds to a noumenology quite different from the phenomenography to which scientific empiricism condemns itself. This noumenology implies a phe-

[13]Bachelard, 1936, 8, italics in the original, my translation.
[14]Bachelard, 1937, 3.
[15]Bachelard, 1934, 5.
[16]Bachelard, 1934, 5.
[17]Jean Gayon has called Bachelard’s scientific realism an “unprecedented realism” [*réalisme inédit*]. He remarks that during the development of his epistemology, Bachelard moved completely away from idealism, while submitting realism to a profound reformulation, through the separation of the concept of reality from that of thing. In Bachelard’s epistemology reality belongs to the realm of the noumenon technically materialized, not of nature. See Gayon, 1994, 22-23.
[18]Bachelard, 1934, 5-6, italics in the original.

> nomenotechnique whereby new phenomena are not simply found, but invented, that is, created anew.[19]

For Bachelard, the noumenon is not the unknowable thing-in-itself that lies beyond the phenomenon. It is the deep mathematical structure that shapes phenomena, the set of relations that inform reality and that are described by theoretical physics.[20] When we study nature at the scale of the infinitely small, Bachelard says, as in the case of microphysics and quantum chemistry, we cannot think anymore in terms of reality of *things*, we must think in terms of reality of organization, of *relations*.[21] These relations are described by the equations of advanced physics and, in turn, such equations allow designing the experiments that materialize the very world they describe.[22] It is not simple to provide an exact definition of the term noumenon as used by Bachelard. However, even without entering into the details of an exegesis of this concept, we can highlight the fact that Bachelard conceived the noumenon in a strict relation with phenomenotechnique. Regardless of how one exactly defines the noumenon, it has to be considered as a rational substratum that defines the lines of thought along which experiments can be envisaged and brought about. As seen in the quote above, to Bachelard any "noumenology implies a phenomenotechnique."[23] Rationality must be applied, in the sense that it has to be technically implemented. The objects of science are *real*, yet they are not *natural*: they are technically produced and theoretically invested entities.[24] Now, if scientific objects are rational constructs technically reified, then scientific instruments and technologies are not secondary products of science, but rather part and parcel of scientific activity.

By integrating technology (technical production of phenomena) into science, Bachelard drew a line between the reality of science and the reality of the natural world. In this vision, scientific reality belongs to the realm of the noumenon technically materialized, not of nature, and the role of phenomenotechnique is to realize mathematical rationality at the phenomenal level. Reason and technique enter a dialectical circle of reciprocal shaping. Bachelard gave several examples of materialization of mathematical rationality. For instance, if one is to study atomic isotopes, one has to produce them in the mass spectroscope,[25] and to study piezo-electric phenomena (i.e., the production of electricity by compression or dilatation of a crystal) one needs to work with an ideal, i.e. pure,

[19] Bachelard, 1931, 18-19, my translation.
[20] See Bachelard, 1931, 18-19.
[21] See Bachelard, 1931, 13.
[22] See Bachelard, 1931, 17.
[23] Bachelard, 1931, 19.
[24] See Rheinberger, 2005, 316.
[25] See Bachelard, 1949, 103.

quartz, which cannot be found in nature and must be produced in the laboratory. The crystal thus obtained, he explained "is not simply matter provided with geometrical properties. It is materialized geometry. The crystal created in the laboratory is not an *object*, really, it is an instrument."[26] For Bachelard, this synthetic crystal is a rational device that produces scientific phenomena, it provides the conditions for proper scientific observation and analysis.

The emphasis put by Bachelard on the creation of phenomena implies an emphasis on the role of instruments and technology in the production of scientific knowledge. Bachelard did not develop a philosophy of technology, yet, as already explained, the concept of phenomenotechnique entails a view of science application not as a mere byproduct of fundamental research, but as a constitutive element of the scientific process. Consequently, technology, in the form of scientific instruments and artificially produced phenomena, is embedded into science since the outset, because our scientific understanding of the world is necessarily mediated by instruments and scientific instruments are an embodiment of knowledge.[27] Discussing the processes whereby scientists select the relevant features of a phenomenon before they set out to study it, Bachelard noted that the role of technological apparatuses in scientific research is that of reducing and controlling the richness and interrelation of natural phenomena:

> The will to neglect is especially active in contemporary technology. A piece of apparatus can indeed be described negatively, if we may be allowed the expression, as well as positively. It is defined in terms of the perturbations it guards against, the technique isolating it, the assurance it gives that clearly defined influences can be neglected, in short in terms of the fact that it comprises a closed system. There is a whole complex of shields, casing, and immobilisers that fences in the phenomenon. All this assembled negativism that a piece of apparatus is in modern physics runs counter to the sloppy affirmations of the possibility of some undetermined phenomenological interaction.[28]

The technological apparatus required by advanced physics is a piece of "assembled negativism" because its function is that of remaking the natural phenomenon into a scientific one. Scientific instruments tame natural phenomena by reducing their variability, their interconnection with multiple related phenomena, and all the contingencies that influence their actual manifestations.

[26] Bachelard, 1949, 202, italics in the original, my translation.

[27] It is worth noting that for Bachelard mathematical models and calculus techniques are scientific instruments just in the same manner as the material instruments used in the laboratory. "Psychologically, tensor calculus is the matrix of relativistic thinking. Contemporary physical science has been created by this mathematical instrument, much as microbiology was created by the microscope. None of the new knowledge is accessible to anyone who has not mastered the use of this new instrument." Bachelard, 1934, 56.

[28] Bachelard, 1938, 221.

The task of scientific instruments and scientific rationality is that of isolating phenomena, dissecting them into fundamental components, and assuring their stability and reproducibility. In the laboratory the natural phenomenon is fenced. It becomes a "closed system" that can be manipulated and examined at will.

By constructing its own objects, modern science has transformed the very concept of phenomenon. A scientific phenomenon is no longer a datum, something exceptional and surprising that one finds in nature, it is rather an effect, something that is produced in the laboratory. In this way science creates the circumstances for producing objective knowledge, because a phenomenotechnique is a method of objectification of the real, a process whereby well defined objects and regular phenomena are created.[29] The reality of Bachelard's epistemology is a reality in which the world has been dissolved into rationality and re-materialized into experimental phenomena produced by technological apparatuses.

5.1 Diagnostic images and phenomenotechnique

Having discussed Bachelard's concept of phenomenotechnique, it is now necessary to explain how it can be applied to medical imaging. How does his vision of science as an activity that creates its own objects apply to the production of diagnostic images? According to Bachelard, phenomenotechnique is the process whereby science creates the technical entities it can study. In the case of medicine, the new objects created by the technological apparatus are images of the human body. Hence, one might claim that if these objects (the images) are new and artificial, because phenomenotechnically created, they have no correspondence with any real object (the body). In such case the application of the concept of phenomenotechnique to medical imaging would imply the absurd proposition that the imaging technology produces human bodies and diseases. More generally, it would imply that the whole activity of medicine consists of producing bodies and diseases as technical phenomena. The human body and its illnesses would thus become inventions of medicine technically implemented. This would be, indeed, the position of radical constructivists.[30] Since I do not endorse this perspective, I have to clarify how the concept of phenomenotechnique

[29]"In early instrumental knowledge, the same obstacle can be seen to arise as in ordinary objective knowledge: the phenomenon does not necessarily make its most regular variable available for measurement. On the other hand, as instruments are improved, their scientific product will be better defined. Knowledge becomes objective in proportion to it becoming instrumental." Bachelard, 1938, 217.

[30]See, for instance, Latour, 1984 and 1999, Ch. 5.

can help thinking medical imaging without falling into radical-constructivism. To this end, it is important to make some distinctions. For what concerns the application of the concept of phenomenotechnique to medicine, one must first distinguish between medical research and clinical practice. If we take into account medical research, in particular that branch of contemporary medical research based on molecular analysis, we can say that it works quite precisely according to the idea of phenomenotechnique. In the molecular laboratory, mechanisms of disease, immunological response, and therapeutical action are routinely produced as artificial phenomena in a variety of forms. This requires the manufacturing of a variety of entities, that range from cellular cultures to genetically engineered viruses, from model organisms, wherein human diseases are induced,[31] to computational simulations. Genes and biological molecules are the mathematical (or rather biochemical) noumenon of molecular medicine: genetic and molecular models provide the rational structures along whose lines new experiments can be conceived and artificial objects and phenomena produced.

The relationship between the concept of phenomenotechnique and medicine is less straightforward when it comes to clinical practice and, more precisely, to the part of clinical practice that deals with diagnosis. Unlike the medical researcher, the clinician is not engaged in explaining the fundamental mechanisms of health and disease. The daily work of the medical practitioner is not to produce experimental models of disease, but rather to recognize what disease affects a specific person. The practitioner does not creates artificial objects, he has to deal with that natural object which is the patient's body. Still, his access to such body and to his illness is by necessity mediated. He has to reconfigure the lived experience of illness in medical terms and within a medical praxis. His work is not to create a diseased body as a technical entity, yet he must reframe the natural phenomenon (the patient's body and his being ill) within medical rationality. In this endeavor the physician resorts to a vast array of instruments, including imaging technologies. In clinical medicine, the methodological imperative of phenomenotechnique to *create* the scientific object is transformed into the imperative to reconfigure the object of study under artificial and controlled conditions. This was indeed the founding principle of clinical anatomy, as articulated by Bichat at the turn of the eighteenth century.

[31] Model organisms are also called experimental models of disease and belong to a wide range of species. The most common are *Saccharomyces cerevisiae* (yeast), *Drosophila melanogaster* (fruit fly), *Caenorhabditis elegans* (roundworm), *Danio rerio* (zebra fish), *Mus musculus* (house mouse), and *Rattus norvegicus* (brown rat). Animal models employed to study human disease are usually selected because of their similarity to humans in terms of genetics, anatomy, and physiology, as well as for their unlimited supply and ease of manipulation. See Simmons, 2008.

Bichat set the foundations for the birth of clinical anatomy on the assumption that the confusion of symptoms presented by the living patient and recorded by the doctor at the bedside presented nothing but "a train of incoherent phenomena."[32] To impose a coherence on such disorder it was necessary to observe the cadaver, a proxy of the living body where the confusion of the disease is fixed in the form of an organic lesion. With the birth of the clinic, the lived experience of the patient was ideally let aside, and physicians had to learn make sense of illness on the basis of a newly defined geography of the corpse. It was still a phenomenography (as opposed to phenomenotechnique), but one that forced the pathologist to separate the disease from the ambiguity of its symptomatic manifestations. Anatomical dissection itself can be conceived as a technique that allowed to materialize a specific conception of disease, namely, the idea that a disease is an organic lesion rather than a train of symptoms. Accordingly, it commanded the development of countless technologies to explore the inner body and its functions. Every diagnostic technology introduced in clinical medicine enhanced the visibility of the body, and our knowledge about it, by introducing different layers of instrumental mediation between the observer (the physician) and the object of study and intervention (the patient).

It is exactly because the concept of phenomenotechnique emphasizes the mediated and instrumental character of scientific knowledge, that it can be useful for thinking medical imaging and diagnostic images. The concept of phenomenotechnique can provide important insights into the epistemology of medical imaging because, by highlighting the relevance of instruments in the production of scientific knowledge, and the indirect, mediated nature of scientific experience, it helps clarifying different issues concerning the relationship between technology and science. Consequently, it helps thinking the relationship between diagnostic images (the product of a technology), and medical knowledge (a specific form of scientific knowledge). To say that medical imaging can be thought resorting to the concept of phenomenotechnique does not mean, of course, that medical imaging is a straight example of phenomenotechnique. Thus, my aim is not that of fitting radiology into phenomenotechnique, but of combining this concept with the other concepts I have explored in the different chapter of this dissertation in order to reflect upon the epistemology of medical imaging. This means that I use Bachelard's phenomenotechnique as a point of departure, a stimulus for thinking. An intellectual inspiration rather than a set of stiff rules that must be applied point by point.

To Bachelard, scientific perception is the opposite of natural perception because it transcends the immediate and is always polemical in relation to common

[32] Bichat, 1801, vol. 1, 60. See Section 1.1.

sense knowledge.[33] This is why the scientific spirit has to be formed against natural mental habits.[34] In my appropriation, as it were, of the Bachelardean concept, I bracket the polemical aspect of scientific perception and highlight its artificial nature. I stress the fact that scientific experience transcends the immediate because, thanks to mechanical and electronic instruments, the scientist gains access to a sensorial domain, which is also an intellectual domain, that is precluded to natural perception. Understood in this way, the concept of phenomenotechnique can be applied to medical imaging and put in relation with Benjamin's optical unconscious. Imaging technologies create phenomena that reveal "entirely new structures of matter."[35] They extend natural perception and allow analyzing and dissecting reality from novel, unexpected angles.

As a large set of imaging technologies, medical imaging can be conceptualized in terms of phenomenotechnique because it produces artificial, controlled phenomena – diagnostic images – that help gaining knowledge about what happens inside the human body. The function of these images is to replace the actual patient's body when we need to answer specific diagnostic questions. Also, they transform the physician's perception, by providing instrumentally mediated access to his object of study, and they simultaneously turn a natural object (the human body affected by a disease) into a scientific object. Moreover, both the imaging apparatus and the images it produces can be considered reified theories for two reasons: on the one hand, especially in the case of digital imaging, they really materialize mathematical equations; on the other hand, they materialize a vast array of knowledge from different domains and, in turn, influence the development of this very knowledge. In what follows I argue in favor of these ideas along four lines of analysis:

1. Diagnostic images act as a technical *medium* of the human body, thus mediate the access of the doctor to the patient's body. By introducing an experiential and intellectual separation (the doctor looks at the body *by means of* the image) they make visible that which is concealed. By mediating perception they grant cognitive access to objects and processes that are otherwise hidden within the body.

2. Diagnostic images are a technical reconfigurations of the patient's body, in the sense that they selectively display information about the inner body in a way that is useful for diagnostic purposes. Although they often look like mimetic representations of the inner body, they are better understood

[33] See Bachelard, 1934, 12-13.
[34] See Bachelard, 1938, 33.
[35] Benjamin, 1939, 266. See Section 2.3.1.

as visual reconfigurations of non visual data that carry information about the internal organs and their functioning.

3. Diagnostic images are embodied knowledge, in the sense that they are the outcome of a technology that relies on theories, hypotheses, concepts, and material practices produced in different scientific fields, such as physics, chemistry, biology and medicine.

4. Diagnostic images are diagnostically meaningful only if the observer (the physician) has a proper training and is in command of adequate theoretical knowledge and practical skills, whereby he is placed at the core of an epistemic network.

5.1.1 Diagnostic images as a *medium* of the inner body

The idea that diagnostic instruments in general, and medical images in particular, are a *medium* of the patient's body has been defended repeatedly in this dissertation. Discussing the introduction of the stethoscope in clinical medicine, I argued that it marked the beginning of mediated perception in medical diagnosis. I showed that such mediation invested different levels of perception and relied on well-defined theoretical assumptions. In particular, the use of the stethoscope required the creation of a precise correspondence between the acoustic signals coming from the chest of the living patient and the anatomical lesions studied on the cadaver. These correspondences had diagnostic import because the organic lesions had been previously associated to specific pathological conditions. Through the network of correspondences between acoustic and visual signs, living body and cadaver, the lived experience of disease, which the patient could express through the narration of his or her symptoms, was turned into a collection of evidences that could be gathered and interpreted by the educated ear and eye of the physician. The lived experience of the patient was, at least in part, put aside in the diagnostic process. Concurrently, the immediate experience of the doctor was reshaped into a mediated experience that relied on the conceptualization of disease put forward by clinical anatomy, and that required a specific training of the ear. On these grounds, I maintained that the stethoscope was at the centre of an epistemological rupture.[36] That is, it was part of the complex and still ongoing process whereby Western medicine has attempted to mutate from *ars curandi* into an empirical science, on the model of physics, chemistry, and biology. In this respect we can say that clinical anatomy and the stethoscope set the premises for medicine to create its own

[36]See Section 1.2.1.

brand of phenomenotechnique. Namely, a phenomenotechnique that reformulates and mediates the way illness is perceived by the patient and the physician, in an attempt to turn both the body and disease into objective and measurable – although not mathematical – entities.

With the development of instruments such as the spirometer and the sphygmograph, the technical character of diagnostic mediation was refined through the definition of quantifiable indices of health and disease. With photography and radiography it acquired new peculiar features. For what concerns medical photography, I highlighted that it required the embedding of the patient's body into an experimental and theoretical apparatus. This was particularly clear in the electrophysiological portraits by Duchenne, whereby the human subject was literally wired to the electrical stimulator, and photographs turned the fleeting motions of the muscles into physiological evidence.[37] Similarly, in Marey's geometrical chronophotographs, the body of a running or jumping man was reduced to a system of fulcrums and levers (see Figure 3.3). This metamorphosis was achieved by dressing the runner in a black velvet costume, with silver lines marking the limbs and the key pivots, and by taking pictures with a camera that shot at a speed of 1/720 of a second. Through a technical expedient, the continuous movements of a running man were dissected into analytical components that could be imagined and endowed with meaning only within the theoretical framework of mechanics.[38]

Compared to medical photography and to the vast array of diagnostic instruments that preceded its invention,[39] radiography has a specific phenomenotechnical character, because it produced the first artificial phenomenon that made the interior of the living body visible. Of course, here the concept of phenomenotechnique is not used in a proper Bachelardean sense. I use it to emphasize the artificial nature of X-ray images (a point I develop in detail in the following Section), and its effects on our sensory perception. With radiographs the body became partially transparent, reproducible, and transportable. As a *medium* of the patient's body, radiography accomplished the work that had been started with the stethoscope. If the stethoscope mediated the access to the sounds from the chest, and through them to the organic lesions, X-ray images, going beyond the sensorial constraints of human vision, provided visual access to the signs inscribed by disease on the organs. By fixing such signs on a photographic plate, radiography turned them into public visual objects that could be collectively scrutinized and compared. Through an elaborated process of

[37]See Section 2.7.
[38]See Section 3.3.
[39]See Chapter 1.

signification,[40] radiographs became a self-contained system of visual knowledge about the inner body: that which was concealed by the body, could be revealed by the radiographic image. In this sense, radiography is a phenomenotechnique because it diverts the gaze of the physician from the natural object (the patient) toward an artificial phenomenon (the radiograph) that reconstructs the inner body on a photo-sensible plate, and this passage from the natural to the artificial is essential to the construction of new knowledge.

Importantly, the radiological image performs its cognitive function not because it is a copy of the body, but because it selectively shows some features of the inner tissues and organs. In the words of a radiologist:

> You might suppose that the value of a [radiological] picture increases with its visual similarity to the part of the body that it examines. But much of that information content will invariably be medically irrelevant at best, or detract from or even hide the diagnostically critical features. [...] A diagnostic imaging system must [...] be able to display the *specific*, distinctive aspects of a patient's anatomy or physiology that are causing a problem, and be *sensitive* enough to pick up even very faint signs of it.[41]

This means that the diagnostic value of a radiological image does not depend primarily on its similarity with the natural object (although such similarity plays an important cognitive role). Indeed, the more details pile up on the radiographic plate, the less readable the picture is, because much of the information it displays is not related to the pathological condition. The diagnostic meaning of the image depends to a large extent on the fact that it shows only certain anatomical or physiological features (e.g., soft rather than dense tissues or clusters of cells with a particularly enhanced metabolic activity) and that it reveals even the slightest alterations (e.g., a very small lesion). We could say that the imaging apparatus works as a sort of sieve that makes some information visible, while neglecting some other. By transforming the visibility of the body, it enhances its intelligibility.

5.1.2 Diagnostic images as visual reconfigurations of non-visual signals

Natural vision is based on the ability of our visual system to be stimulated by visible light[42] reflected by objects around us (the retina works as a transducer

[40] See Sections 3.4.5 and 4.2.2.

[41] Wolbarst, 1999, 6-7.

[42] Visible light corresponds to electromagnetic waves in the wavelength between 750 and 400 nm (low energy photons).

that converts patterns of light into neural stimuli). Similarly, photography relies on the fact that photo-sensible plates or films are impressed by light bouncing off the surface of things. Medical imaging works in an altogether different way, because it exploits non-optical properties of the inner tissues. Radiography and TC are based on the degree to which biological tissues attenuate X-rays;[43] ultrasound imaging relies on the tissues' echogenicity, that is, their ability to reflect ultrasound;[44] MRI is based on the magnetic properties of the protons of water molecules distributed within and around cells; and PET relies on the fact that certain metabolic activities induce the absorption of specific molecules that can be labelled with radioactive markers. Although each imaging modality works according to a variety of physical processes, they all share a fundamental commonality: they create images by *measuring* non-visual properties of the biological tissues. As the radiologist Anthony Wolbarst explains:

> [Imaging technologies] create medical images by following and recording, by some means, *the progress of suitable probes that are attempting to pass through a patient's body*. The body must be partially, but only partially, transparent to the probes. If the probes all slip right through bones and organs without interacting with them, like light through a pane of clear glass, no difference among the tissues can be visualized. Similarly, if their passage is completely blocked, nothing much shows up. But if we choose probes that are only somewhat absorbed, scattered, reflected, delayed, or otherwise affected, we may be able to detect small differences in how they interact with different biological materials. And *these differences can then serve as the raw material for the creation of diagnostically useful pictures.*[45]

Hence, in order to produce a medical image, a selective probe (X-rays, ultrasounds, radiopharmaceuticals, and so on) has to be sent into the body. Different probes measure different properties of the biological tissues (we can call such properties biological indicators),[46] the interaction between the probe and the biological indicator produces a signal (e.g., an attenuated X-ray beam or a delayed ultrasound), and the signal is recorded by a detector. Subsequently a converter translates this non-visual signal (the "raw material" for the creation of the image)[47] into a visual output. More precisely, an increased/decreased value of the signal produced by the interaction between the biological tissue and the probe is mapped out as increased/decreased luminosity on a radiographic plate or computer screen. Diagnostic images can be thus understood as maps of luminosity

[43] X-rays are electromagnetic waves with wavelengths of 10 nm or less (high energy photons).
[44] Ultrasounds are sound waves with a frequency higher than the upper limit of the human hearing range (20 KHz).
[45] Wolbarst, 1999, 8.
[46] See Bogen, 2002.
[47] See quote above.

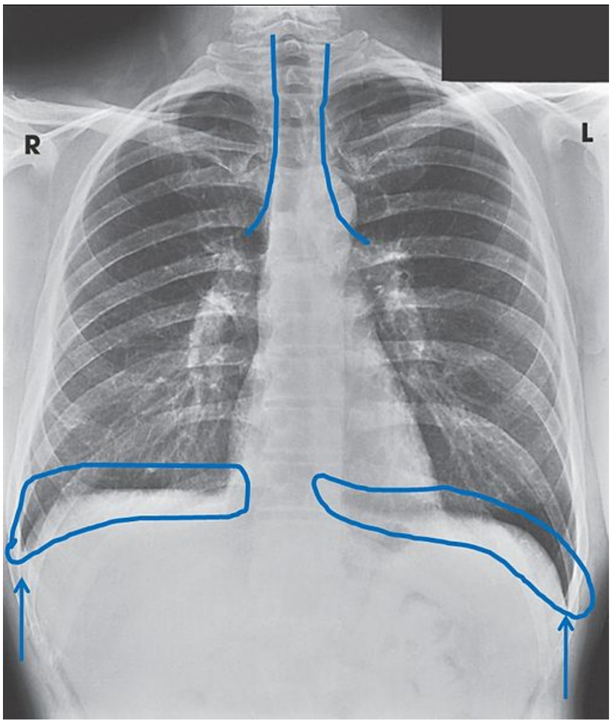

Figure 5.1: Radiograph showing air-filled trachea and lungs, diaphragmatic domes, mediastinal structures, and vascular markings. Arrows indicate costophrenic angles. Source: US Army medical training course. Wikimedia Commons.

values corresponding to the variations of a non-visual signal (in digital imaging the luminosity value of each pixel on the screen represents the values of the signal emitted by a corresponding voxel of tissue).[48] In contemporary imaging the whole process of detecting, converting, and mapping the original signal relies on advanced physics and mathematics.

Images from equations Radiography is the only imaging modality that relies on a straightforward relationship between the passage of the probe (X-rays) through the patient's body and the resulting image. X-ray beams are differentially attenuated by biological tissues (the bones absorb almost all the rays, while soft tissues as the skin let them pass through), and the rays that make their way through the body directly hit the photographic plate (traditional analogical radiography), or an array of X-ray detectors (digital imaging) letting an imprint of the body (Figure 5.1). Things a quite more complex in the case of other imaging modalities, such as Computed Tomography.

Like radiography, CT technology relies on X-ray attenuation. Unlike radiographs, however, CT scans must be reconstructed by a computer, because the imaging apparatus collects information from a very high number of sections

[48]For an exhaustive discussion of the relationship of non-visual signals into luminosity values see Semczyszyn, 2010.

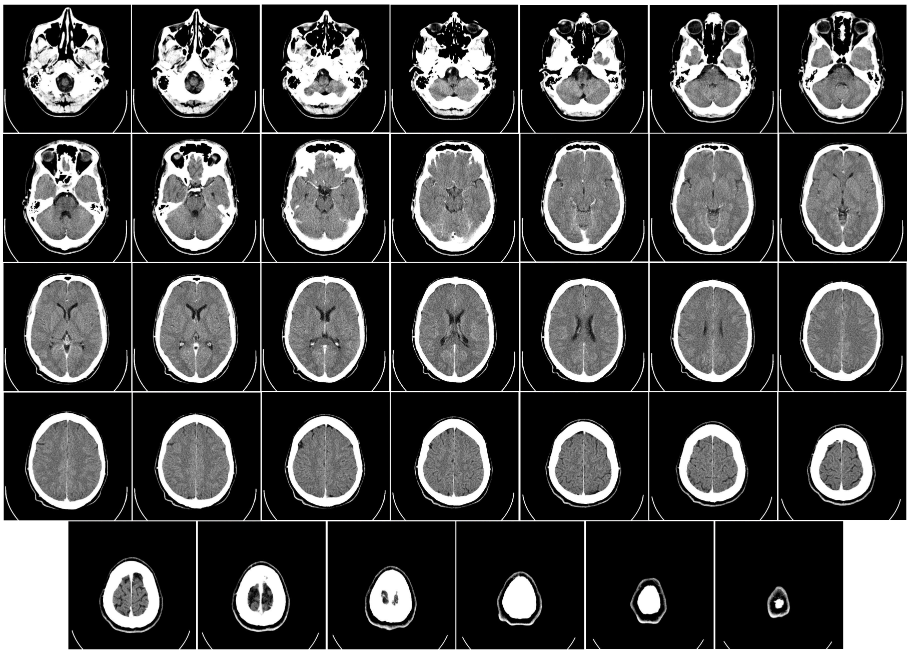

Figure 5.2: Computed tomography scan of the brain, axial view.

(*tomos*) of the body (Figure 5.2), revealing much finer details and allowing for the visualization of organs, such as the brain, that in radiography are almost completely shaded by the bones of the skull. In order to produce a sequence of CT images, a calibrated beam of X-rays is rotated and translated around and along one axis of the slices of the body to be imaged. The attenuated X-rays are captured by crystal receptors, sent to an amplifier, and then to a converter. The final images are subsequently reconstructed by equations that map the intensity of the attenuated beam from each slice of the body in function of its angle. The amount of data embedded in a CT scan is enormous, and the mathematical nature of these images was absolutely clear in early publications. A clinical report published in 1973 in the *British Journal of Radiology* showed a CT scan of the brain. Notably, in this image the data were displayed as a bidimensional array of numbers arranged in the approximative shape of a cerebral section, and the author remarked that physicians could analyze CT scans in the form of images or *quantitative data*.[49] In 1976, medical researchers at Mayo Clinic still wondered if, by opting for images rather than numbers, they were not loosing important information about the tissues they were examining.[50] Already at that time, however, CT numerical data took up a considerable number of sheets of paper, so they were eventually abandoned in favor of images, whose cognitive accessibility is much higher than that of lists of numbers.[51] Nowadays

[49]See Ambrose, 1973. See also Delehanty, 2010.

[50]See Kevles, 1997, 161.

[51]Data visualization is a burgeoning field of research. The fact that visual representations of large amounts of data suit our cognitive apparatus better than lists of numbers is uncon-

the volume of data generated by CT equipments is enormous. These data allow creating very detailed three-dimensional images, and they pose new challenges to radiologists, namely for what concerns their manipulation (data processing), presentation, storage, and interpretation.[52]

Similar considerations can be made for all contemporary medical imaging modalities, because algorithms for image reconstruction play a fundamental role in all of them. In ultrasound imaging, it is necessary to turn into images several pulses of ultrasound beams that are reflected by bodily tissues. In MRI, the images are produced resorting to the spatial coordinates obtained from the magnetic relaxation times of the hydrogen nuclei (protons) of the water molecules which compose our body. In PET, an image of metabolic activity is reconstructed on the basis of the spatial coordinates of the gamma-rays emitted by radioactive molecules previously injected in the patient's blood.[53] This means that when the radiologist looks at a medical image, what he really sees are non-visual signals translated into areas of different luminosity. Of course, he perceives this information in the form of a visual object, and thus uses the depictions to make detections. That is, he relies on the mimetic features of the image to extract non-visual information, namely, information relevant for a medical diagnosis.[54] Being an expert observer, however, the radiologist is aware of the problematic relation between depiction and detection. He knows, for instance, that certain features of the image might refer to artifacts produced by the imaging apparatus, rather than to actual properties of the biological tissue. He also knows that there is no univocal correspondence between what appears in the image and the actual health conditions of the patient.[55] It is also worth noting that the more sophisticated the imaging technology, the higher the possibility of producing artifacts during the imaging process, and thus the greater the expertise required to correctly acquire and interpret the images.

This concise and simplified description of how medical images are produced provides the background for some reflections about their phenomenotechnical nature. First of all, if we focus on the idea that these images are produced "by following and recording, by some means, the progress of suitable probes that are

troversial. What is not always clear is if semi-naturalistic, photograph-like images hold any special advantage compared to other visual formats such as graphs (see Delehanty, 2010). In medical imaging the advantage of highly naturalistic visual displays is quite obvious when one wants to visualize morphological and structural elements, or locate an event (e.g., blood flow rate) in a specific area of the body. The advantage of naturalistic renderings is less clear when imaging is used to quantify metabolic processes, as in the case of PET and functional MRI.

[52]See Pisco, 2009, 33.

[53]See Wolbarst, 1999; Pope, 1999.

[54]See Maynard, 1997, 119-120. I discuss the distinction between depiction and detection in Section 3.2.3.

[55]See Perini, 2012. See also Section 3.2.3.

attempting to pass through a patient's body"[56] we can start to understand them in terms of experimental practice. To produce a diagnostic image is to create an artificial, controlled phenomenon whereby specific signals are elicited from the biological tissues, and subsequently converted into visual outputs. A diagnostic image is really a representation of the body and disease under experimental conditions, for three reasons:

1. An appropriate probe has to be sent into the patient's body in order to emit the desired signal;

2. The patient has to adhere to specific protocols before and during the imaging process to optimize the quality of the output signal (the body is *part of* the imaging apparatus, not just an object of representation);[57]

3. It is possible to properly compare different images only if they are produced with the same imaging modality and following the same operational standards.[58]

Another observation that we can make in relation to the phenomenotechnical nature of radiological images is that they are not conventional images: they are mathematical reconstructions of quantitative data derived from non-visual signals. This unconventional, counterintuitive feature of diagnostic images was already present, although to a lesser degree, in analogical imaging. In fact, although traditional radiography does not depend on a mathematical reconstruction of the original signal (X-ray attenuation), it nevertheless creates an image by exploiting non-visual properties of the biological tissues. It produces a phenomenon (the X-ray image) that can only exist as far as it is technically produced. This character of novelty is one reason why the process of signification of radiographs was complex and involved a combination of technical and cognitive operations that helped create and consolidate new visual skills. Compared to analogical imaging, in digital medical imaging the phenomenotechnical

[56]Wolbarst, 1999, 8.

[57]Depending on the technology employed, a patient might be asked not to eat previously to the examination, to drink a contrast liquid, or to undergo other forms of bodily preparations. During the imaging process, one will be typically asked to stand still, to hold one's breath, to breath deeply, and so forth.

[58]In order to elaborate a diagnosis it can be useful to combine different imaging modalities (e.g., ultrasound and MRI) because they allow to collect different information. However, to study the evolution of a disease in a single patient, or to compare the radiological presentation of the same disease in different patients, one has to compare images of the same modality produced under the same conditions (e.g., instruments with identical, or very similar, technical characteristics, same time of exposure, same physical preparation of the patient, and so on). For the relevance of operational standards to the creation of scientific objectivity see Section 3.2.2.

nature of images is taken to a more sophisticated and accomplished level.[59] The reconfiguration of quantitative data into images is performed by mathematical algorithms that embody a specific epistemic context: the pre-existing knowledge about the object under study; the questions that need to be answered (the diagnostic problem); the working hypothesis; the expected outcomes; and so forth. We could say that contemporary medical images entail the materialization of mathematical noumena. This does not mean that medical images are mathematical inventions, because there is a counterfactual causal chain that links biological indicators, probes, and images (if the tissue were different, the signal emitted would be different, and therefore the image would be different). Yet, diagnostic images are not copies of the human body. They are rather *simulations* of the real object, because they can be manipulated in order to increase the visibility of specific aspects of the body or of the disease, and to erase those elements that are irrelevant to the diagnosis and would provide only visual noise.

For instance, in MRI, by selecting specific sequences of radio frequency pulse in the phase of image acquisition, it is possible to selectively enhance the brightness of soft tissues (e.g., fat or brain matter), and neglect watery tissues (diseased areas) or liquids (e.g., urine or cerebrospinal fluid). Similarly, in the phase of image reconstruction, the selection of specific parameters allows to better visualize certain areas rather than others. Moreover, the final user (the radiologist who interprets the scan) can manipulate several parameters, such as color, while looking at the image.[60] The mathematical substructure of these images allows for an increased representational plasticity, and thus enhances their cognitive effectiveness. In this respect it is important to stress that the selection of parameters in the phase of image acquisition determines the kind of information that can be extracted from the final output. For example, if an MRI image was acquired according to parameters that neglect watery tissues, it will not be possible to retrieve information about such tissues from the final image, no matter how many software-based manipulations one performs on it. These manipulations only affect the way the information gathered during image acquisition is presented to the observer.

Blurred boundaries As the great majority of contemporary scientific images, todays' diagnostic images are image-data, that is, they are lists of numbers cor-

[59]This is not, of course, an instance of teleological progress, but rather the result of scientific and technological development. I use the adjective "accomplished" to point out that new diagnostic images are better suited to carry out the task of medical imaging, which is to extract information from the patient's body by reconfiguring its visibility.

[60]For an informative study on software-based interaction between radiologists and images see Friedrich, 2010.

responding to physical quantities which are displayed in the form of a bidimensional visual object.[61] They are hybrid objects that blur the boundaries between quantitative data and qualitative representation: we use quantitative data to produce the image, and we resort to the qualitative features of the image to interpret the data. As all mechanical images of invisible referents, contemporary diagnostic images also blur the difference between the indexical and symbolic modes of signification. We are justified in trusting the indexical nature of these images as far as they have been produced according to well defined operational conventions, because these protocols assure the stability of both the causal and counterfactual relationship between the referent and its image. In turn, the application of the operational standards lays the foundations for the symbolic mode of signification of the images (it creates the material preconditions to define the rules according to which the image must be interpreted).[62] In digital imaging, however, an important role in the process of image making is played by the iconic mode of signification, too. Icons are signs that signify by virtue of similarity, by sharing some quality with the referent.[63] In morphological medical imaging, the mathematical algorithms for image reconstruction have precisely the aim to create images that *resemble* the original object by preserving its geometry. In the same way, in functional imaging the original signal is processed so as that the intensity of the physiological phenomenon under study is visually rendered in terms of intensity of the luminosity of a specific area of the image. The preservation of a resemblance between the image and its referent is thus a principle built into the mathematical equations that determine the aspect of the image. This means that the interpretation of the original data (the non visual signal) begins during the very production of the image, on the basis of the knowledge used to design the algorithms for image reconstruction.

5.1.3 Diagnostic images as reified knowledge

Bachelard claimed that instruments, in modern science, are "reified theorems"[64] and that the phenomena produced by scientific instruments "bear the stamp of theory throughout."[65] For him, Millikan's oil drop experiment or Stern and Garlach's space quantization experiment were "conceived directly as a function of the electron or the atom."[66] That is, they were specifically designed to test a well defined theory, they materialized the theory. A common interpretation

[61] See Prasad, 2005; Israel-Jost, 2011.
[62] See Section 3.2.2.
[63] See Peirce, CP 2.247. See also Section 2.2.
[64] Bachelard, 1971, 137; 1949, 103; 1934, 13.
[65] Bachelard, 1934, 13.
[66] Bachelard, 1971, 137.

of these statements is that they point to the self-referentiality of theory, thus, to the theory-ladenness of observation and the underdetermination of scientific theories.[67] However, considering the importance attributed by Bachelard to experiment, and taking into account that he saw science application as a constitutive element in the creation of scientific concepts, we can regard his claims on instruments as reified theorems as a general statement concerning the fact that scientific instruments materialize a large body of pre-existing knowledge, and that they help produce the object under study as a technophenomenon.[68]

If instruments materialize different bodies of knowledge (not only well defined theories about the object of study), and if they help recreate the object of interest as a technophenomenon, then we can really think of technology not as a mere application of science, but as an active constituent of it. Accordingly, we can understand medical imaging not simply as the application to medicine of technologies based on physical theories, but as the reification of knowledge (both theoretical and practical) developed in different domains, such as, physics, chemistry, pharmacology, biology, physiology, pathology, and so forth. This implies that medical imaging technologies embody and blend together theories, concepts, hypotheses and practices concerning the machinery that produces the image as well as the human body that through those images is examined. By reconfiguring natural objects and by creating totally new phenomena, imaging technologies extend the scope of our sensory experience, and at the same time they extend the domain of what can be thought and how it can be thought. They extend the scientific mind.[69] Conversely, for a technology to become part of a given scientific domain it must accommodate the pre-existing knowledge of that domain, or at least part of it.

In the specific case of medical imaging, I have shown in Chapter 1 that physicians could be receptive to the possibilities open by radiography because they conceptualized disease in terms of organic lesions. However, the creation and stabilization of proper clinical knowledge based on radiographs was a long and complex process. It entailed:

[67]See Galison, 1997, 18.

[68]See Rheinberger, 2005, 320. Bachelard wrote: "The instrument is the necessary intermediary in the study of a definitely instrumented phenomenon [*un phénomène vraiment instrumenté*] that has been designed as an object of a phenomenotechnique." Bachelard, 1949, 2-3, my translation.

[69]Castelao-Lawless makes a similar point when she says that Bachelard's claim that instruments are reified theories refers to the fact that, for him, both mathematical models and scientific instruments were extensions of the scientific mind. See Castelao-Lawless, 1995, 50. In *La formation de l'esprit scientifique* Bachelard wrote: "A measuring instrument always ends up as a theory: the microscope has to be understood as extending the mind rather than the eye." Bachelard, 1938, 240.

1. Technology control and stabilization (an operation that brought together physicians, physicists, engineers, photographers, and other professionals).

2. The matching of what was shown by radiographic images and what could be directly observed in the cadaver (an operation that led to the revision of some well entrenched assumption about human anatomy based on autopsic observations).

3. The comparison of the information provided by radiographs and information collected through other diagnostic techniques (an operation that required the development not only of new visual skills, but also of a new language).

4. The comparison of different images among them (an operation whereby images were turned into a *medium* of the patient's body).[70]

Indeed, the history of the discovery of X-rays and their subsequent introduction in medicine shows that instruments are less a direct reification of a single, well-defined theory, than the embodiment of complex dynamics of practices, theories, hypotheses and concepts. Roentgen discovered X-rays by chance. While exploring the properties of cathode rays, he inadvertently set the conditions for the appearance of a new phenomenon that seemed anomalous in the context of what he knew about the electromagnetic waves. It took several years to develop a proper physical theory of X-rays, but this did not prevent the development of a more efficient radiographic technology for medical purposes. Such improvement was brought about on empirical bases, not as the direct application of better theories. In turn, the refinement of the technology for X-rays production and manipulation contributed to the growth of theoretical knowledge about radiation, as well as about human anatomy and disease. At each step of their development X-ray machines and the related practices of image making were the materialization of a heterogeneous body of knowledge distributed among different professionals. This included, for example, theoretical and empirical knowledge about X-rays production, image fixation, use of contrast agents, tissues' densities in healthy and diseased tissues, and so forth. The imaging apparatus emerged at the intersection of different domains of knowledge.

An exemplary case of knowledge crossing The intersection of knowledge coming from different disciplinary fields is particularly marked in positron emission tomography. While X-ray, ultrasound, and magnetic resonance imaging

[70]See Sections 3.4.5, 3.4.6, and 4.2.2.

provide morphological information, PET allows visualizing the physiological activity of the inner tissues, by showing the variation of concentration of certain molecules in specific areas of the body over a given amount of time. It has several applications: it helps diagnosing cancer and monitoring possible metastases by detecting the elevation of glucose uptake by cells in rapid division; it allows tracking the levels of oxygenation of different areas of the heart or the brain; and it can be used to measure the activity of specific neural receptors. This kind of imaging is possible thanks to so called radiotracers or radiopharmaceuticals. These are molecules in which an atom of carbon, oxygen, nitrogen or fluorine has been replaced by a correspondent radioactive isotope. To produce a PET image, the radiotracer, selected according to the physiological process that one wants to monitor, has to be injected into the patient's blood. At this point it flows through the body as a normal molecule, but after a precise span of time (the isotope half life)[71] it emits radioactivity in the form of a positron that, after colliding with an electron, produces two γ-rays that shoot off the body almost 180º apart. These two γ-rays are the signal detected by the imaging apparatus, and they are used to map the flow rate of the labelled molecule. As in the case of CT scans, the machinery delivers a set of images corresponding to the slices in which the original volume (the human body) has been divided. And as in the case of CT, the production of the images entails complex mathematical operations which require considerable computing power.

This means that for PET technology to be possible, many branches of knowledge have to converge: physiology, medicine, biochemistry, nuclear chemistry, physics, electronic engineering, and mathematics. PET as a technology, and PET images as the material output of such technology materialize knowledge about normal and pathological physiology, physiological modeling, tracers kinetics, radioactivity production and detection, image processing, image reconstruction, and so forth. Indeed, PET images are particularly complex for what concerns both their production and interpretation. The information they present is both quantitative (they are meant to literally measure biological activity) and qualitative (they show the spatial distribution of the phenomenon under study). Consequently they demand complex physiological modeling. Moreover, to be medically relevant, they have to be processed in terms of relationships between molecular circulation in the organism, radioactive decay, and specific properties of the physiological process under examination (e.g., the relationship between glucose concentration in the cells, cells' proliferation, and tumor malignity).[72]

[71] The half life is the length of time required for half of any given amount of an element to decay into another element. It is specific for each isotope.

[72] See Dumit, 2004, 30.

In his study on the role of PET imaging in neuropsychiatry, the anthropologist of science Joseph Dumit has shown that the different researchers that contributed to the invention of PET conceptualized this technology in different terms. For one of them, the physicist Michel M. Ter-Pogossian, PET was not exactly an invention, it was rather a "recognition."[73] That is, it was the result of noting that certain positron emitting radionuclides have physiological properties and thus can be used to image biological processes. Once the imaging potential of these molecules was realized, it was just a matter of finding a way to take advantage of them. This was possible thanks to the insights and instruments produced by the researchers in the area of CT scanning. For Ter-Pogossian, designing the first PET machine was essentially a matter of putting together "different building blocks"[74] from different scientific areas. The building blocks to which Ter-Pogossian refers are both ideas (theories, hypothesis, kinetic models, and so on) and material objects (such as the cyclotron for the production of radioisotopes, the imaging apparatus, and the radiopharmaceuticals). All these elements converge in the technology that goes under the name of positron emission tomography. Ter-Pogossian's account of the invention of PET points in the direction of a conceptualization of technology as materialization of different strands of knowledge, yet it provides a picture of medical imaging as an application of technology to medicine. In his account, first came the realization that specific radiotracers could be used to monitor physiological activity, then it was developed into an apparatus that could take advantage of these molecules, and finally physicians embraced the new technology for diagnostic and research purposes.

The physician Henry N. Wagner, another contributor to the invention of PET,[75] offers a different perspective. For him, the development of PET "was a chain of events"[76] that started in the nineteenth century with Claude Bernard's conceptualization of disease in physiological terms.[77] The other fundamental events in the chain were Georg von Hevesy's success in using radioactive isotopes to study metabolic processes, in 1923, and the medical measurements of thyroid activity by scintigraphy, the first technology for functional imaging, developed some twenty years before PET. For Wagner, "thyroid scanning started because

[73]Dumit, 2004, 43.

[74]Ter-Pogossian in an interview with Dumit. Dumit, 2004, 45.

[75]The attribution of an invention is a classical problem for history of science. Given the multidisciplinary nature of PET, it is consensual that many people contributed to its invention. Ter-Pogossian himself claims that "there are masses of fathers of PET." Dumit, 2004, 40.

[76]Wagner, in an interview with Dumit. Dumit, 2004, 47.

[77]Note that the idea that the preconditions for functional imaging were set by Bernard's conceptualization of body and disease in terms of physiological functions is specular to the idea that clinical anatomy set the preconditions for morphological imaging.

of nodules in the thyroid,"[78] not because there was a technology that made functional scanning possible. This shift of perspective is important, because it highlights the fact that medical technologies embody the need to solve medical problems, medical questions. Physicians needed to know whether the nodules in the thyroid were functional or not. They needed to measure blood flow and to associate it to a variety of problems, from the effects of anesthesia to the diagnosis of schizophrenia. To solve these problems they did what they could with the tracers and detectors they had at their disposal at any given time. The diagnostic questions and problems were not simply an external force that provided the practical goal which demanded the development of a technology. Rather, they were the core around which successive technologies acquired their specific form, within a number of constraints posed by all the other factors at stake (tracers, detectors, image reconstruction models, and so on). But there is more than this.

By integrating the medical problem, the technology can reshape the way the problem itself is posed. Wagner gives the example of the development of single photon emission radiopharmaceuticals that simulate somatostatin, a peptide with a wide range of inhibiting effects on various organs. Single photon emission tracers are akin to those used in PET, and they started to be used in the 1980s to study and diagnose neuroendocrine tumors through single photon emission computed tomography (SPECT).[79] Such studies showed that in certain tumors there are specific metabolic alterations, a discovery that played an important role in directing cancer research towards a molecular approach. SPECT and single photon emission tracers were part of the solution to the problem of diagnosing cancer, in turn they helped rethinking cancer in terms of cellular growth and communication, and this led to the development of new molecular approaches and technologies in oncological research.[80] A medical imaging technology materializes the techniques, practices, problems, hypotheses, concepts and theories of different domains, and that by changing the kind of information available, it can redirect the approach to the medical questions it addresses.

Transparent and visible theories The interweaving between medical theories, instruments, and images can be more or less complex. It depends on what must be visualized (it is easier to visualize a structure than a process);

[78] Wagner, in an interview with Dumit. Dumit, 2004, 47.

[79] SPECT is an imaging technology akin to PET, but it uses a different family of tracers (single photon emission rather than positron emission radionuclides), and a different scanner. Its spatial resolution is significantly lower than that of PET's, but it is considerably less expensive.

[80] See Dumit, 2004, 48; Pepe *et al.*, 2012.

how it is visualized (some technologies are more theory-loaded than others); and for what specific reason (some diseases are better understood than others). As discussed in Chapter 3, the visualization of teeth and broken bones by X-ray imaging was uncontroversial and relatively straightforward, while the same technology demanded a much more complex process of image signification in order to acquire meaning in clinical medicine.[81] In the case of tuberculosis, such process implied, among other things, the construction of a semiotic network that bounded radiological images with already established diagnostic techniques.[82] Contemporary imaging offers even more compelling examples of how theories and images influence each other. It also shows that the theory embedded in an imaging apparatus and in the interpretation of the images it produces becomes *transparent* when the approach to the problem at stake is consensual. On the contrary, in contested domains, where the conceptualization of a medical problem is not settled, the theory beyond images production and interpretation becomes *visible* because controversial. PET images provide a good example of both situations.

The use of PET scanning to monitor cancer, to verify cardiac perfusion, or to evaluate brain disorders such as Alzheimer's disease and epileptic seizures, is uncontroversial. Our medical understanding and conceptualization of these conditions, although not static, is sufficiently settled to render unproblematic the idea that we can visualize information about them by means of PET. This signifies that, although there might be doubts whether in specific cases PET is the best option compared to other diagnostic modalities, there is no disagreement upon the fact that PET images provide information actually related to the disease under study. In this case the theory (or theories) that binds patient, apparatus and images is transparent in virtue of being well corroborated and generally accepted, it becomes implicit and thus almost invisible.

This is not the case when PET is used to study and diagnose psychiatric disorders.[83] At present, in spite of the great amount of studies carried out in this field, there are no validated brain imaging techniques to diagnose psychiatric diseases. This is so not only because of technical reasons,[84] but also because there is no agreement upon whether what we can visualize through cerebral PET (the relative oxygenation or the metabolic rate of glucose in different areas of the brain) does correlate to specific psychiatric conditions.[85] Hence, if a psychiatrist

[81]See Section 3.4.

[82]See Section 4.2.2.

[83]Together with PET, the other brain imaging technologies used to study and diagnose psychiatric conditions are SPECT and functional MRI (fMRI).

[84]See Farah and Gillihan, 2012.

[85]The discussion over the neural correlates of psychiatric disorders occurs at two levels. On the one hand, the very existence of such correlates is contested, especially by scholars

resorts to brain imaging to study such conditions, he is explicitly endorsing a specific theory of the mind, of psychiatric illness, and of psychiatric illnesses' classification. These theories motivate and justify the choice of the imaging apparatus, which is supposed to allow to see a putative diagnostic indicator in the image in question. Since the theory is contested, it becomes *visible* through the technology and through the image.

5.1.4 Diagnostic images and the "phenomenotechnique of the observer"

Independently from the fact that the theory about the phenomenon under study is transparent or visible, diagnostic images are always "belief-opaque."[86] In the definition of the philosopher and cognitive scientist Adina Roskies, an imaging technique is belief-transparent "if it is possible to appropriately interpret the image it produces with information contained in the image," and it is belief-opaque "when the information needed for the interpretation is not present in the resultant image."[87] Typically, a photograph of a visible object is belief-transparent, because we have a previous knowledge of how the thing represented in the picture looks like. It has a visible referent and thus we can rely on our intuition, that is, on the visual habits produced by everyday experience to interpret the image (of course, this does not mean that our interpretation is always correct). When the referent is invisible, however, not only we lack such intuitive knowledge, but relying on commonsense visual habits might lead to gross mistakes in the interpretation of the image. For instance, a non-expert viewer who looks at the PET scan of an oncological patient will probably think that all the "spots" on the image are an indication of active disease, and that one can easily *see* the disease in the image. The expert viewer, on the contrary, knows that the image must be *interpreted* in the light of a wider set of knowledge, because noncancerous conditions such as chronic or acute inflammations have the same appearance of cancer on PET images, while many types of tumors do not show up. The gaze of the experienced observer incorporates a wider set of knowledge that is not directly available in the image and that allows

from philosophy and from the human and social sciences. On the other hand, within the neuroscientific community who endorses this approach to mental illness, the debate revolves around the use of brain imaging in the actual identification of neurocorrelates. For a review of the two debates see Vidal and Ortega, 2012. The debate over the neural correlates of psychiatric diseases can be seen as part of a larger debate over brain modularity and the use of neuroimaging in cognitive studies. For an epistemological analysis of the use of neuroimaging in cognitive science see Roskies, 2007. For an epistemological critique of the localizationist and modularity approach in neuroscience see Hardcastle and Stewart, 2002.

[86] Roskies, 2007, 868.

[87] Roskies, 2007, 868.

making such distinctions. The expert viewer knows the rules, both implicit and explicit, necessary to make sense of the extended sensory domain produced by the phenomenotechnique. This is to say that, although visual experience is fundamental for the radiologist to deal with the data generated by imaging technologies, his visual experience is of a different order compared to primary, everyday life visual experience. It is a peculiar form of perception that requires a *phenomenotechnique of the observer*.[88]

A fundamental element of the divide between naïve perception and educated perception is the comprehension of the complex nature of the causal and counterfactual relation between an image and the object of study. The untrained viewer is not aware of the complexity of the causal chain of events that links the original phenomenon to its image, and consequently has no awareness of the number of variables at stake (for instance, the production of artifacts). He has an equally simplified understanding of the counterfactual relation, that is, he does not know that different phenomena (e.g., benign rather than malignant tumor) could result in the same image. The expert viewer, on the contrary, not only is aware of such problems, but is also in command of the theoretical knowledge and practical skills necessary to deal with them. In other words, the naïve viewer engages in an intuitive process of signification that is misleading, he takes a complex sign for a simple index, or an icon.

In Chapter 3 I argued that we are warranted in inferring properties of invisible objects and phenomena from mechanical images because such images are indices. I also argued that the indexical mode of signification is not enough, because it does not allow to endow an image with meaning and to directly distinguish the properties of the object from the artifacts created by the imaging process. To tackle this problem, scientists resort to three strategies: (1) they put in place a symbolic mode of signification based on the creation of operational standards for image production;[89] (2) they inscribe the image into a specific

[88]I use the term "phenomenotechnique" rather than simply "technique" of the observer for two reasons. First, because by maintaining a homogeneous terminology along the description of technologies, images and observers I stress the entanglement of the processes of image production and image signification, the continuum that binds the production of an image to its interpretation. Second, I want to mark a conceptual distance from the expression "technique of the observer" as used by Jonathan Crary. In the book *Techniques of the Observer* (1990), Crary explores the dynamics of embodiment and disembodiment of the act of vision brought about by different optical devices, and he analyzes such devices as part of a larger assemblage of historical events and powers. By talking of phenomenotechnique of the observer, I frame my analysis in a different domain. I am not interested in the embodied act of seen, nor in the relations of power in which optical devices are embedded. I rather focus on how scientific vision is constructed as an explicitly and necessarily artificial form of perception, and as a distributed process.

[89]See Section 3.2.

theoretical framework that defines what can be seen;[90] (3) they manipulate the object under study performing different sorts of experiments in order to gather additional information to combine with that obtained through the image.[91] I consider all these activities, both practical and intellectual, a phenomenotechnique of the observer, because they put the viewer at the centre of an epistemic network that makes possible the emergence of a perception removed from that which is granted by everyday experience.

This way of understanding the process whereby scientific perception is produced is quite different from Bachelard’s idea of psychoanalysis of the scientific spirit.[92] To Bachelard, science is continuously getting rid of conventions and mental habits so that new forms of rationality can emerge. It aims to a surrationality that constantly breaks with the past and will necessarily change in the future. The phenomenotechnique of the observer I have just described works at a different level. It has a pragmatic value, in the sense that its aim is to make possible actual scientific observations in the present, rather than to break with the past. It produces and stabilizes perceptual habits that are different from those of commonsense experience, but they are habits nevertheless. It leads to the creation of conventions for image production and interpretation. These conventions are responsive to conceptual change, because they rely on the practical and theoretical knowledge of a given scientific domain, but they do not necessarily emerge in polemic with past knowledge. Finally, what is demanded of the observer is not the ability to dissolve reality into pure rationality. Rather, it is demanded that he learns to deal with the materiality of the instruments and of the objects that through the instruments are made visible and examined (the human bodies).

The phenomenotechnique of the observer entails the training of the scientists in relation to the strategies of image signification mentioned above: operational conventions, theoretical frameworks, experimental practices. This means that medical images acquire meaning within a distributed process that goes well beyond the act of watching. It is an educated act of perception that is possible because there are standards for image making; semiotic networks created and distributed on the pages of journals, books and atlases; practices of samples preparation and manipulation. Since early medical photography, the meaning of diagnostic images has emerged from a combination of all these factors, and the process has been further enriched and complicated by the introduction of digital imaging, with its mathematical models for image reconstruction. Through this

[90] Section 3.3. See also Section 2.4

[91] See Sections 3.2.3 and 4.2.3.

[92] See Bachelard, 1938.

multilayered process the act of *seeing* is deeply transformed. It moves away from intuitive natural perception and acquires a scientific character.

Conclusions

In this dissertation I attempted to develop an epistemology of medical imaging that took into account the fact that diagnostic images are simultaneously diagnostic instruments *and* scientific images. It was thus necessary to highlight distinct epistemological problems concerning, respectively, medical diagnostics and the cognitive statute of instrument-mediated images.

Although, as a whole, my study is mainly focused on the problems posed by diagnostic images *qua* images, in the first chapter I proposed an account of the historical and conceptual conditions of possibility of diagnostic images *qua* diagnostic instruments. I did so by going back to the birth of clinical anatomy, when diagnosis became a matter of scrutinizing the inner body, and medicine started to establish itself as an empirical science capable of producing a clear and precise visibility of illness. My basic intuition was that one can diagnose a disease by means of an image of the inner body only if illness is understood in visual and spatial terms. Drawing on Foucault's *The Birth of the Clinic* and on historical medical literature, I argued that the conceptual roots of medical imaging as a diagnostic technique go back to the understanding of body and disease defined by clinical anatomy at the end of the eighteenth century, and that diagnostic images are to be understood first and foremost as instruments that help turning diseases into an objective, visual entity. The clinical paradigm that emerged from clinical anatomy commanded specific forms of objectivation of the human body: to make a diagnosis, the physician could no longer rely exclusively on the symptoms related by the patient, he had to actively elicit or even fabricate the signs that pointed to the disease, which was conceptualized in terms of organic lesion. In this context it became necessary to develop diagnostic instruments that could produce a specific expressivity of the human body.[1] By turning the inside out, such instruments transformed invisible structures and processes into visible indices of health or disease.

By analyzing the wide range of diagnostic modalities developed in the nineteenth century, I tracked down the clinical tradition wherein medical imaging can be inscribed, and highlighted the entanglement between the development of

[1]See Section 1.1.

the new instruments and the transformations in the understanding of anatomy, physiology and of the nature of disease.[2] From this part of the research it was possible to conclude that although the invention of radiography has been often described as a revolution in medicine and in medical visual culture,[3] it should be understood less as an epistemological than as a technological and cultural transformation. On the one hand, the conceptual bases for medical imaging are rooted in the conceptualization of disease put forward by clinical anatomy; on the other hand, the vast array of diagnostic instruments developed during the nineteenth century posed some epistemological questions that were subsequently inherited by radiology. In particular, the replacement of subjective sensations of both patients and physicians with objective (or at least inter-subjective) mechanical indices of health and disease; the production of visual records of the interior of the body that could be filed, retrieved and shared by several observers; the need to develop a specialized language that allowed to describe and discuss such visual data; the introduction of a mediation between the observer (the physician) and the object (the patient), which generated different forms of instrument-mediated perception.

Subsequently I turned my attention to the image-related problems posed by medical imaging. Through the analysis of early photography, I explored the role played by this groundbreaking optic media in reshaping the visibility of both the human body and disease.[4] More precisely, I tried to understand how medical photography contributed to the reconfiguration of a natural object (the human body and its ailments) into a scientific object. Following Peirce's semiotics, more precisely his organization of signs in indices, icons and symbols, I argued that although nineteenth-century theorization of photography revolved essentially around the idea of photographs as perfect records of reality (iconic mode of signification), predicated on the mechanical nature of the photographic process (indexical mode of signification),[5] the symbolic mode of signification played a fundamental role in establishing specific forms of visibility of disease in such diverse fields such as psychiatry, dermatology and neurology. In fact, what the physician-photographers struggled to see in their pictures were less the visible signs of illness in a specific patient, than the *facies* of the disease, that is, its general yet characteristic appearance. On the one hand, photographs were used to keep records of individual patients and monitor the evolution of their condition. In this case each picture was an index, in the sense that it identi-

[2]Sections 1.2 to 1.5.

[3]See, for instance, Reiser, 1978; Cartwright, 1995.

[4]See Chapter 2.

[5]It should be noted that our commonsensical intuition about photography and its epistemic reliability has not changed since the nineteenth century.

fied in a strict one-to-one relation the individual patient affected by a specific manifestation of the disease. On the other hand, photographic collections were used to make abstraction of the specific circumstances of a patient and generate a universal image of the disease. These collections were nomological machines, they worked according to the symbolic mode of signification and were meant to reveal the laws of nature that govern the appearing of a disease.

The analysis of medical photography was further enriched by taking into consideration Benjamin's reflections on the photographic series (mechanical production and reproduction of an image and of the body it represents), and on the intrinsic analytic and dissecting potential of photography (the photographer as a surgeon). Looking at the works of the early physician-photographers in the light of Benjamin's ideas, I reached the conclusion that the photographic series collected in medical journals, manuals, and hospital archives produced a clinical gaze in the Foucauldian sense. That is, they created a neutral visual space similar to that of the hospital wards, where each body was open to medical observation and could be put in relation with other bodies, so that the pathological could emerge as a stable pattern from the heterogeneous variability of the individual instances. The photographic collection recreated on paper the sensorial and cognitive domain of the clinic. Moreover, in the new regime of mechanical visibility and reproducibility created by the photographic camera, the body became not only an object of scientific analysis, it was also directly embedded into a complex apparatus for visualization and experimentation (an emblematic case is that of the electrophysiologic portraits by Duchenne de Boulogne), which enhanced and transformed the visibility of the body.

From the scrutiny of early medical photography and of its role as a predecessor of radiology, I zoomed out, so to speak, to a problem that concerns not only medical imaging, but scientific imaging in general. Namely, the problem of the visualization of the invisible and of the validation of instrument-mediated images that are meant to show invisible referents. Taking into account specific examples from microphotography, chronophotography and early radiography, I defended the idea that the process of signification of the images of invisible referents entails a complex interplay of indexical, iconic and symbolic semiosis. In these cases, the creation of operational conventions for image production and the definition of theoretical frameworks for image interpretation play a fundamental role in securing the epistemic authority of the image. My argumentation, built in opposition to Daston and Galison's idea of mechanical objectivity as suppression of the subjectivity of the image maker and of the observer, was organized in three moments. Firstly, I stressed that in the case of microphotography the acceptance of the truthfulness of an image and of its scientific value largely depended on the definition of experimental standards for samples' preparation, observation and imaging. These standards provided operational conventions that grounded a symbolic mode of signification. That is, the microscopists believed that two microphotographs showed the same thing, and that what they showed was the actual specimen and not an artifact produced by a specific apparatus, when the pictures had been produced under the same conditions. The microphotograph was considered the result of a complex experimental process, not the direct and transparent imprint of nature. Accordingly, their idea of objectivity was grounded in inter-subjectivity, not in the suppression of the subjectivity of the individual researcher.[6]

In a second step, through the analysis of the chronophotographic method developed in the 1880s by the French physiologist Etienne-Jules Marey to study animal locomotion, I argued that Daston and Galison's notion of mechanical objectivity should be replaced by that of "mechanical sensibility,"[7] a concept strictly related to Benjamin's idea of optical unconscious. The aim of chronophotography, in fact, was not that of suppressing the subjectivity of the observer, but rather to extend his sensorial domain. As theorized by Benjamin, imaging devices can be considered sensorial prosthesis, because they grant us access to the optical unconscious, that is, to a perceptual domain that lies beyond our senses. This sensorial enhancement, however, cannot be passive. The fragmentation of motion produced by high-speed cameras does not pertain to natural perception. As a consequence, in order to make sense of this new world of images, vision has to be complemented by imagination, and the indexical and iconic modes of signification must leave space to symbolic semiosis. This means that when we deal with pictures of invisible objects and phenomena, the notion of image objectivity and truthfulness must be separated from that of photographic realism and visual likeness.[8]

Finally, I delved into the different phases of the process of signification of radiographs. This process, that spanned over several years, entailed the standardization of instruments and procedures (as in the case of microscopy); the validation of the visual content of radiographs by comparing them with real organs; the comparison of X-ray images with other diagnostic techniques, in order to validate the diagnostic value of the images; and the comparison of images of different patients or of the same patient in different moments, in order to check the internal coherence of a system of images and turn radiographs into relatively autonomous instruments for diagnosis. As a whole, the questions I

[6]See Section 3.2.
[7]Snyder, 1998, 393.
[8]See Section 3.3.

dealt with in this discussion suggested that scientific images show their objects through several layers of mediation, which are related to the preparation of the object to be imaged (e.g., the treatment of a sample for microscopy analysis); to the imaging process proper (the functioning and the conditions of operation of the imaging device); and to the theoretical framework wherein the image has to acquire a meaning.[9]

From these considerations emerged the need to further explore the statute of scientific images as epistemic tools, and to shed more light on the processes of signification of diagnostic images, considered as a specific case of scientific images. For what concerns the first point, I argued in favor of an epistemology of images grounded in a *poietic* rather than *mimetic* conception of visual representation. Drawing on both historical and theoretical arguments, I emphasized the embodied dimension of image production and fruition, and suggested that scientific images should be considered cognitive tools in a strong, non metaphorical sense.[10] To clarify this idea I examined three cases of clinicians and scientists working with images.[11] First, I developed the concept of semiotic network through the analysis of a radiology article published in 1903. I observed that in such article text, diagrams, and tables of numbers were combined into a nexus of interrelated signs, in order to prove that X-ray images can be effectively used to diagnose different pathologies of the heart and the lung. Subsequently, drawing on a classical study in laboratory ethnography carried out by Karin Knorr-Cetina and Klaus Amann,[12] I stressed the relevance of the experiential and collective dimension of image interpretation in a discipline, such as molecular biology, that deals with forms of visualization and invisibility quite different from those of radiography. Finally, following Ian Hacking's theory of scientific observation and his discussion of microscopy images,[13] I pointed out that, in order to learn something about invisible entities from instrument-mediated images, watching is not enough.[14] One has to perform a range of activities, such as using imaging equipments that work according to different physical principles, and preparing the sample in different ways. Also, one has to complement visual observations with the results from other sciences (in the case examined by Hacking, microscopy observations are complemented by biochemical and crystallographic data, in the case of medical imaging, additional information can be collected using a variety of diagnostic methods).

[9]See Section 3.4.

[10]See Section 4.1.

[11]See Section 4.2.

[12]See Knorr-Cetina and Amann, 1990.

[13]See Hacking, 1983, Ch. 11.

[14]Hacking refers to this methodological imperative with the catchphrase "Don't just peer: interfere." Hacking, 1983, 189.

What became apparent from this analysis is that the process of signification of scientific images has a distributed character. It is not simply a matter of interpreting a ready-made image released by a mechanical or electronic apparatus. It rather requires a complex set of operations, both material and cognitive, that might involve different people at different moments and the use of a variety of instruments. Scientific images can be considered experimental tools, in the sense that scientists and physicians handle them in several forms in order to explore different aspects of their object of study. More importantly, these images are to be understood as controlled, artificial phenomena produced with the aim of redefining the visibility of natural objects.

The need to elaborate more on this latter idea drew me to Bachelard's concept of phenomenotechnique. Although I could not directly apply this concept to medical imaging, for the reasons explained in Chapter 5,[15] it proved useful and inspiring for summarizing and reorganizing the ideas and arguments developed in the dissertation, as well as to analyze some specific features of contemporary medical imaging, characterized by a high level of mathematization. A central point I retained from Bachelard's idea of phenomenotechnique is that science has to create its own objects.[16] Scientific instruments – that for Bachelard are reified theories – produce scientific objects by isolating and dissecting natural objects into partial components that can be reassembled and observed under stable and reproducible conditions. Although we cannot say that medical imaging *creates* the human body or its diseases, we can reasonably say that it creates artificial objects (images) that in turn produce a specific visibility, and thus intelligibility, of both the body and disease. This visibility sums up to the reconfiguration of the natural phenomenon under controlled, experimental conditions. By analyzing medical imaging through the lens of phenomenotechnique, I reached four conclusions that summarize and refine the arguments and considerations developed in the course of the dissertation: (1) diagnostic images should be considered *simulations* of the patient's body, rather than mimetic representations; (2) diagnostic images are an example of materialized knowledge; (3) diagnostic images are a *medium* of the human body and of the individual experience of illness; (4) a phenomenotechnique of the observer is needed in order to make sense of diagnostic images.

For what concerns the first consideration (diagnostic images as simulations), it emerged from the observation that diagnostic images can be conceived of as artificial, technical entities generated by an apparatus that extracts information from the patient's body and displays it in a visual form. If we actually examine

[15]See Section 5.1.
[16]See Bachelard, 1938, 221.

the technologies for medical images production, we understand that the imaging apparatus elicits the emission of biochemical and biophysical signals from the inner organs (quantitative data), and transforms such signals into images. It is thus possible to say that medical imaging creates images by probing non-visual properties of the biological tissues (e.g., X-ray attenuation in the case of radiography, ultrasounds reflection in the case of ultrasound imaging). In contemporary digital imaging the detection and elaboration of the original signal relies on advanced physics and complex mathematical algorithms for image acquisition and reconstruction. The image that results from these processes has an enhanced plasticity for two reasons. On the one hand, during the phase of data acquisition it is possible to fine tune the kind of biochemical and biophysical signals we want to collect (e.g., signals corresponding to high metabolical activity in specific areas of the body); on the other hand, in the phase of image reconstruction the selected algorithms will further refine the information to be retained (e.g., fat tissue or liquids could be phased out). Finally, during the phase of analysis and interpretation the observer can manipulate the image in several ways, for instance rotating it or changing the color scale. This is why diagnostic images are akin to computer simulations: they are virtual objects on which one can perform a number of operations that would be impossible or very difficult on the natural object. These virtual objects, however, are more than the assembling of millions of bits of mathematical data, they are the technical (or electronic) reconfiguration of real bodies. That is to say that the image, as an artificial object created by making visible non-visual data, gives a new sensible form to the human body. It brings into presence an artificial figure whereby the observer can see the inner body. The diagnostic image is not a mirror, it does not work by *mimesis*, it is rather a dissecting device that makes visible that which the body by transforming disease into a visual entity.

The formulation of the second conclusion (diagnostic images as materialized knowledge) owes much to Bachelard's claims about instruments as reified theories and to the fact that the concept of phenomenotechnique implies that scientific instruments and technologies are not a secondary product of scientific development, but an intrinsic facet of the scientific process. By analyzing in the light of these ideas the history of the invention of positron emission tomography, it became clear to me that a medical imaging as a technology, and diagnostic images as the product of such technology, can be seen as the materialization of a wide set of knowledge. They embody theories, concepts, problems and practices pertaining to different scientific areas, not only medicine, but also physics, chemistry, biology, engineering, and so on. Medical imaging reconfigures the visibility of the natural objects (the human body and its ailments), and in doing so it extends the domain not only of what can be perceived (mechanical sensibility and the optical unconscious), but also of what can be thought and how it can be thought. Indeed, to think of technology as the reification of various strands of knowledge and, at the same time, as an active constituent of scientific concepts (thus also medical concepts) helps to better understand why radiology – which according to my analysis was grounded in the conceptualization of disease put forward by clinical anatomy at the end of the eighteenth century – not only accompanied the transformation of medical theories during the twentieth century, but also exerted a very strong impact on the theoretical and practical development of different areas of medicine (from oncology to obstetrics).

The concept of phenomenotechnique also helped clarify the idea that diagnostic images are a *medium* of the patient's body. Discussing the introduction of radiography in clinical medicine and its relation with clinical anatomy, in Chapter 3 I argued that X-ray images can be considered a *medium* of the patient's body for different reasons: because they physically mediate the sensorial access of the physician to the interior of the body of the diseased person; because they replace (or displace) human vision creating an extra-sensory form of perception; because they are a material support that shows outside and away from the real body that which the actual body normally conceals; because they mediate the first-person experience of illness, by virtually allowing the physicians to recognize signs of disease well before they manifest themselves through symptoms that can be perceived by the patient.[17] Now, if we consider the radiographic image as the product of a phenomenotechnique, we can say that it works as a *medium* because it is an artificial, technical entity that replaces a natural object, namely the human body, and in so doing it grants sensorial and cognitive access to anatomical structures and physiological processes that under normal conditions are screened by the flesh and the skin. Medical imaging is thus one of the instruments developed by medicine to transform disease into a scientific, although not mathematical, object. Through medical imaging disease acquires a novel visual dimension, but the meaning of such visibility is discernible only in the context of a wider set of knowledge.

This latter point is related with the idea that medical imaging does not just entail the creation of artificial phenomena that objectify the human body. It necessarily implies a transformation of the perceptual habits of the observer, and of his modes of image signification. I coined the expression "phenomenotechnique of the observer" to emphasize the fact that scientific instruments do not only produce specific objects, they also mold specific observers. I used this phrasing, instead of simply talking of techniques of interpretation, because I wanted to

[17] See Section 3.4.6.

maintain a linguistic unity that underlined the continuity and interrelatedness of the processes of image production and signification. In the case of medical imaging technologies, the observer can make sense of the new entities (a variety of complex images of the inner body) only if he has gone through a cycle of instruction and education that allows to resort to the sophisticated modes of image signification examined above (combination of indexical, iconic and symbolic semiosis related to operational conventions, theoretical frameworks and experimental practices). The proposed notion of phenomenotechnique of the observer is akin to Bachelard's idea of formation of the scientific spirit in that it stresses the importance of education and scientific training,[18] and the ongoing character of the formative process[19] (potentially, each new instrument opens new possibilities for experimenting and thinking). Unlike Bachelard's formation of the scientific spirit, however, the idea of phenomenotechnique of the observer does not focus on the systematic abandonment of pre-existing mental habits and forms of rationality. It rather tries to account for the process whereby one learns to make sense of a continuously enhanced sensorial domain. In this it is akin to the idea defended by Benjamin and other theorists of photography, such as Moholy-Nagy and Balász, according to whom the new optical fields open by photography forced a training of the eye and led to a reorganization and evolution of our senses.[20] However, while the training of the eye envisaged by these authors was related to the idea of optical unconscious and "unbiased optical vision,"[21] thus emphasized the autonomy of the imaging apparatus in relation to the sensorial capabilities and cognitive intentions of the viewer, the idea of phenomenotechnique of the observer stresses not only the intentional nature of the training of visual perception, but also its constructed and social dimension (the education of the eye occurs within the scientific community and through the composite, distributed process of image signification described in Chapters 3 and 4). In other words, the notion of phenomenotechnique of the observer refers to the fact that the creation of a new perceptual domain must be accompanied by a specific education of the observer if it is to have scientific (or medical) import. It is a platitude to say that an image has to be interpreted in order to acquire a meaning. Still, it is interesting to remark how wide the

[18]In French, as in Italian and Portuguese, but also German, the word formation (*formazione*, *formação*, *Bildung*) also means teaching and training. Indeed, the discussion of school teaching is pursued by Bachelard throughout *La formation de l'esprit scientifique*, alongside the consideration of epistemic obstacles, and in the last page of the book he wrote: "The principle of *continued culture* is [...] at the root of modem scientific culture. [...] There is science only if schooling is permanent." Bachelard, 1938, 249, italics in the original.

[19]"The mind must be formed by being reformed." Bachelard, 1938, 33.

[20]See Benjamin, 1936; Moholy-Nagy, 1925. See Section 2.3.

[21]Moholy-Nagy, 1925, 5.

range of significations attributed to diagnostic images can be, and how equally wide can be the divide between naïve and expert perception. In this regard a telling example is provided by fetal ultrasound. The hyper-real images of the unborn are nowadays part of popular visual culture. They enter the family album and the social media as the baby's first picture. In the eye of the lay observer they are portraits and are treated as such, both at the emotional and rhetorical level. In the eye of the expert viewer, the medical operator who went through the necessary process of training and education, they are diagnostic tools and can be used to take therapeutical decisions, often resorting to complex probabilistic reasoning, rather than to some indisputable evidence displayed by the image.[22] Medical imaging technologies do not only redefine the visibility of the human body and of disease, they also impose a reshaping of the perception of the radiographer.

By producing new optical domains, medical imaging has deeply transformed doctor's perception of the human body. Through medical imaging the dark, dense and amorphous visceral body has been turned into a seemingly transparent volume, wherein overlapping shadows or neat sectional images reveal the geography of an orderly anatomy and the marks of disease. Together with the other diagnostic techniques developed by Western medicine over the last two centuries, medical imaging has contributed to transform both the lived body and its ailments into scientific objects. Reconfigured into a vast array of images, the natural object has been cleared of the redundant features of its materiality and of the sensations it produces, and thus made amenable to scientific analysis. The body reconstructed through the imaging apparatus can be observed at will, phasing out irrelevant aspects and enhancing others, it can be measured, compared, filed, retrieved, manipulated in unprecedented ways.

Radiology, and the perceptual domain it produces, acquired diagnostic significance within the conceptualization of body and disease put forward by clinical medicine. It subsequently evolved through technological innovations and, more importantly, through the integration of physiological and molecular theories. Functional imaging has been in use since the 1950s to monitor physiological and metabolic processes, and molecular imaging (also called quantitative imaging) is emerging as a diagnostic and research instrument in the context of so-called

[22] Fetal ultrasound scans render a clinical and emotional message at the same time. This ambiguity is unproblematic when the fetus appears to be healthy. However, when the image shows indications of potential malformations or syndromes, prospective parents are asked to suspend the iconic mode of signification (the idea that the sonographic image is a photographic portrait of their baby), and to focus on the clinical meaning of the ultrasound examination. This passage can be extremely difficult not only for psychological reasons, but also because most parents do not posses the knowledge required to assess an image in diagnostic terms.

personalized medicine.[23] By producing new phenomena, each innovation in medical imaging brings with it a reconfiguration of the human body and disease into different scientific objects organized around morphology, physiology, cellular metabolism or genetic expression. At each reorganization of the scientific object corresponds a reorganization of the perception of medical researchers and practitioners. Old and new objects and modes of perception are not mutually exclusive, they rather coexist in quite complex dynamics, and in some cases tend towards integration.[24] For instance, in oncology the physical examination of the patient is still part of the assessment of the disease. The physician inspects by touch and auscultation the body of the patient and listens to his or her description of symptoms. On occasions he might also pay attention to the patient's emotional distress or practical daily difficulties. In the clinician's office, cancer is still perceived and conceptualized in clinical terms. But the construction of the scientific objects corresponding to "cancer X" and "patient with cancer X" relies on a variety of additional elements gathered through radiological, pathological, and molecular examinations. These are the phenomenotechniques whereby the scientific objects are brought into being, that is, these are the prisms through which the physician operatively perceives the patient and the disease.

One of the main struggles of this study was to keep the focus on image epistemology, resisting the temptation to follow the endless threads of research that appeared along the way. For instance, I could not fully engage in a discussion of the ontology of disease, a fundamental topic in philosophy of medicine, and I could only couch the complexity of the process of medical diagnosis. Another important and fascinating topic that was merely alluded to is the relationship between scientific images and specialized language. A question that has relevant practical implications when it comes to define standardized lexicons to improve communication among health practitioners and researchers, and to allow data retrieval for both clinical and research purposes. Also, much remains to be said about the paradoxical statute of diagnostic images as images of a specific individual. Unlike other scientific images, in fact, the function of diagnostic images is not that of leading from the particular (the contingent phenomenon captured in the image) to the general (the scientific model or law that accounts for all the contingent manifestations of that phenomenon), but rather to provide informa-

[23] There is no univocal definition of what personalized medicine (PM) is, or might be. The concept of PM was born in 2003 with in the sequence of the completion of the Human Genome Project. Put in a nutshell, PM devises a different treatment for each patient, tailored on his or her genetic makeup. In recent years, however, there have been many attempts to redefine PM in more realistic and operative terms, in order to encompass factors that go beyond genetics.

[24] For an insightful description of how the same disease can be conceptualized and made the object of actual medical practice by different specialists, see Annemarie Moll's ethnographic study on atherosclerosis. Moll, 2002.

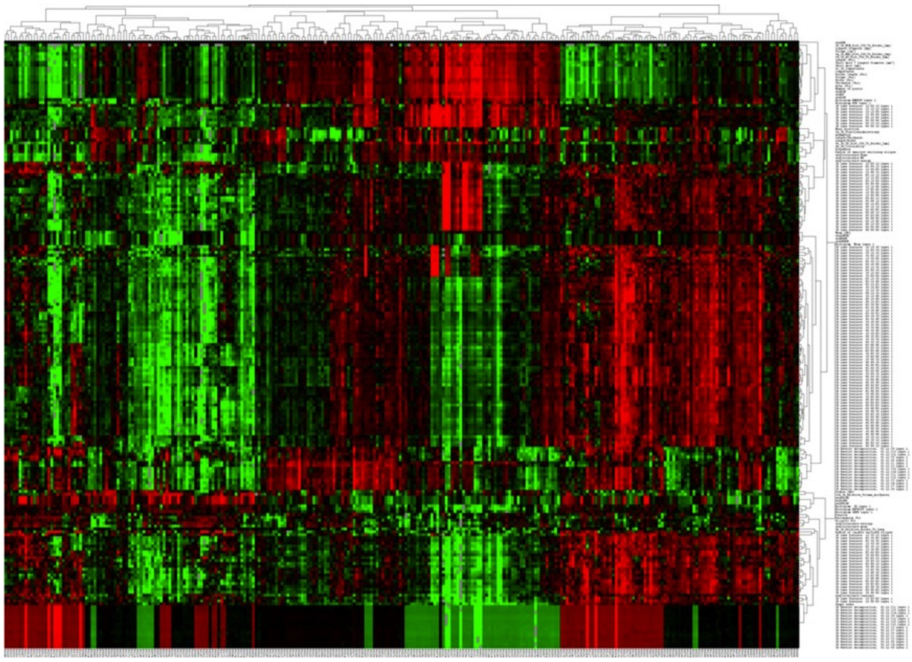

Figure 5.1: Cluster heat map of lung tumor image features extracted from CT images from 276 patients. Biomarkers such as tumor volume, shape and texture were represented. Each row of the heat map represents a specific imaging feature across patients, and each column represents all features for a patient's lung tumor from CT. From Kumar *et. al.*, 2012.

tion about an idiosyncratic subject. Through diagnostic images the physician does not want to grasp a general picture of a disease, he wants to understand the exact features with which the disease manifests itself in a specific patient. Diagnostic images have the individualizing nature of the portrait. For the physician, however, they are not the portrait of the patient. They are the portrait of a specific instance of a disease, not of a person. This is why Méheux's photographs of dermatological patients were deemed art, not science.[25] They told the private story of a human being, more than they displayed the features of the disease (Figure 2.10). Important insights about the individual, distinctively humane dimension of diagnostic images might come from the study of artworks that rely directly or indirectly on medical imaging technologies. In the article "Inside the body: medical imaging and visual arts,"[26] I analyzed a variety of artworks, ranging from John Heartfield's photomontages to Mona Hatoum's endoscopic installations, providing an overview of the multiple perspectives whereby visual artists assimilate medical imaging into their works. On this topic, however, much work remains to be done.[27]

[25]See Section 2.6.
[26]Di Marco, 2012.
[27]To my best knowledge there are not many works published on this subject. See Kevles, 1997, Ch. 11; Slatman, 2004; van de Vall, 2008, Ch. 3; Casini, 2010, 2011; Laryionava, 2012.

Diagnostic images are by their own nature multidisciplinary objects that call into question problems of philosophy of science and technology, philosophy of medicine, image theory, aesthetics, media theory, and anthropology, to name just a few. Consequently, they provide a virtually endless field of research, because one can always approach them from a different perspective. Moreover, the emerging field of radiomics, which relies on advanced image analysis to infer genomic and proteomic patterns from image data,[28] promises to blur more and more the boundaries between quantitative and qualitative information, to reshape the visual landscape of clinical medical imaging (Figure 5.1), and to redefine the theory and practice of diagnostic images' interpretation. Hence, future research in the philosophy of medical imaging will necessarily come across the methodological and philosophical problems posed by so-called Big Data,[29] as well as with the conceptual and ethical issues posed by personalized medicine. Hopefully, the epistemological work developed in this dissertation will serve as a point of departure and conceptual basis for further investigations.

[28]See Gillies *et al.*, 2010; Lambin *et al.*, 2012; Kumar *et al.*, 2012.

[29]This term is used to refer to any collection of data sets too large and complex to be properly processed using traditional computational methods. Among the problems posed by Big Data we can count data collection, analysis, visualization, mining, sharing, storage, transfer, and privacy protection.

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