REFERENCE MATERIALS

The People, Places, and Things of Making Measurements

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May 2016

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Doctor of Philosophy

Abstract

Reference Materials: The People, Places, and Things of Making Measurement undertakes a series of case studies of standards in the long twentieth-century (1875-2004). The studies include a history of the metric system's standard of mass and the protocols for maintaining the International Prototype Kilogram; the origins of digital image processing as a discipline and the politics of the discipline's test images; the ascendance of atomic time keeping from a simple measurement technique to a global communication and information infrastructure; and the introduction of so-called "standardized patients" into medical education and accreditation. This project interrogates how processes of modeling and comparison are materialized in things, documents, and people. It approaches the work of maintaining standards through the local and provisional protocols for circulating, repairing, maintaining, and sometimes cleaning artifacts like pieces of platinum-iridium, magazine cut-outs, cesium supplies, and human actors.

Reference materials enable commensurability in large-scale systems; they allow for knowledge acquired in one context to be applied to others. These studies interrogate how materials are chosen, maintained, and discarded—processes that take place through deliberate negotiation and philosophical idealism and at other times through haphazard flukes. By considering technology from the point of view of misuse and disrepair, this project enacts an alternative approach to the history of technology. Instead of seeing technologies, standards, and infrastructures as inert things, *Reference Materials* historicizes the social and relational work of animating technology to keep it viable.

Résumé

Ce projet entreprends une série d'études des standards pendant le “long” XXe siècle (1875-2004). Les études sont les suivantes: les origines du standard de masse dans le système métrique et les protocoles qui maintienent “le kilogramme étalon” les origines du traitement des images numériques comme discipline et les dimensions politiques des images test de cette discipline; l’histoire du succès du temps atomique comme infrastructure d’information et de communication globale; et l'introduction de la notion de patients standardizes dans l'éducation et l’accréditation médicale. Ce projet questionne la manière dont les processus de modélisation et de comparaison sont matérialisées dans des choses, des documents, et des personnes. Il traite notamment du travail du maintien des standards au travers des protocoles de circulation, de réparation, et parfois de nettoyage, d’objets tels que les morceaux de platine-iridium, des images tirées de revues, des particules de césium, et des acteurs humains.

Les matériaux de référence permettent la commensurabilité dans les systèmes standardisés de grande échelle ainsi que l’application des connaissances acquises d’un contexte à un autre. Les études de ce projet analysent comment les matériaux sont choisis, conservé et écarté grâce à des processus ayant parfois commencés par des négotiations délibérées et une forme d’idéalisme philosophique, où bien à d'autres moments, par le hasard. En considérant la technologie du point de vue de sa mauvaise utilisation et de son délabrement, ce projet pormulgue une approche alternative à l'histoire de la technologie: au lieu de voir les technologies, les standards, et les infrastructures comme des choses inertes, ce projet historicise le travail social et relationnel qui anime la technologie pour la rendre viable.

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Acknowledgements

It is the irony of the acknowledgements that the people who made this work possible cannot help with this part. I am in debt to my friends, family, teachers, and colleagues for their support.

A special appreciation is owed to the dissertation defense committee who read this work charitably and discovered facets that were hidden to its author. Thank you to Biella Coleman, Tom LaMarre, Andrew Piper, Carrie Rentschler, Jonathan Sterne, and Fred Turner.

There are many people I met while researching, writing, and revising this work that helped me and whose names I do not know. I need to thank the staff at libraries, archives, and institutions who let me in their doors and were always patient with my, admittedly strange, requests. There is no historical work without the people who work to maintain history in these places. Equally, I am thankful for the support staff at McGill for their knowledge, expertise, and consideration.

I am grateful to the financial support of the Social Sciences and Humanities Research Council of Canada, Media@McGill, and the Wolfe Chair in Scientific and Technological Literacy.

Jonathan Sterne has been my mentor, collaborator, and friend since I began at McGill in 2009 and has always known what this project needs. More importantly, he has known what I needed from this project. That is what makes him a gifted advisor. I am privileged to know Jonathan and benefit from his kindness. Carrie Rentschler is the best teacher and reader I have known and I am a better thinker for knowing her. Cait McKinney is a great friend, teammate, and intellect. Cait read more versions of this project than either of us wishes to count and shaped it from the beginning to the end—I am lucky that is the case. I am fortunate that the Department of Art History and Communication Studies attracts good people and I am grateful for the friendship and support of the community there. I am thankful to the Culture and Technology Discussion and Working Group and its curious and astute members for offering feedback on this work and intellectual community.

My parents, Tania Stacey and Robert Mulvin, made it possible for me to be a student for several decades and that is a privilege of this life.

All that I do I do with Alice and Ida, my family. This work, like everything, is dedicated to them.

Figure 1 - Marcel Duchamp, *3 Standard Stoppages* (1914).

Image from the Museum of Modern Art, New York.

It is “a joke about the Meter,” responded Marcel Duchamp when asked in a questionnaire to comment on his artwork *3 Standard Stoppages*.[1] In the work Duchamp measured out three meter-length pieces of string and dropped them from a one-meter height on to a canvas, where their gentle falls produced twisted, sloping shapes. These outlines reshaped the meter and became the templates for three draftsman’s straightedges, the objects on display in *3 Standard Stoppages* (Figure 1). In his *Box of 1914* Duchamp included fragmentary comments about the artwork, describing it as a distortion of standardized measurements:

> ***The Idea of the Fabrication***
>
> –If a straight horizontal thread one meter long falls from a height of one meter onto a horizontal plane distorting itself *as it pleases* and creates a new shape of the measure of length.
>
> –3 patterns obtained in more or less the similar conditions: *considered in their relation to one another* they are an *approximate reconstitution* of the measure of length.
>
> –The 3 *standard stoppages* are the meter diminished.[2]

What Duchamp later called “canned chance,”[3] *3 Standard Stoppages* is representative of

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[1] Sarah Ganz Blythe and Edward D. Powers, *Looking at Dada* (New York, NY: Museum of Modern Art, 2006), 52.

[2] Marcel Duchamp, *The Writings of Marcel Duchamp* (New York, NY: Da Capo Press, 1989), 52. Emphases in original.

a familiar trope from the interwoven history of formal experimentation in the arts, measurement, and standardization. Standardized instruments like the meter stick are created to be usable, reproducible, and communal tools for basic measurement operations. Which is to say, measurement tools make attractive subject matter for artistic experimentation because they embody a simplified formalism, in which representation is reduced to elementary lines, shapes, and colors. In Renaissance painting, artists were trained to use a familiar repertory of stock objects that would allow viewers to gauge how accurately the artist had reproduced a particular perspective: "A painter who left traces of such analysis in his painting was leaving cues his public was well equipped to pick up."[4] These stock objects varied by locality but often relied on knowledge of common sizes of containers: barrels, sacks, and bales.

While Duchamp could turn to the metric system and provoke its arbitrary rigidity with aleatory play, and Renaissance painters could invoke standard objects to cue perspectival awareness, contemporary art is similarly festooned with standard measurement tools. The April 2006 cover of *ArtForum* (figure 2) features the artist Christopher Williams's photograph—a reproduction of a Kodak test image—taken from his collection "For Example: Dix-Huit Leçons Sur La Société Industrielle," while the artist Lucy Raven's contribution to the 2012 Whitney Biennale, titled "Standard Evaluation Materials," included a suite of film projector calibration images and speaker

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[3] Herbert Molderings, *Duchamp and the Aesthetics of Chance: Art as Experiment* (New York, NY: Columbia University Press, 2010), 2.

[4] Michael Baxandall, *Painting and Experience in Fifteenth Century Italy: A Primer in the Social History of Pictorial Style* (Oxford; New York, NY: Oxford University Press, 1988), 86–89.

test tones (see figure 3) and a public lecture about contemporary test films.[5] Raven and Williams are not alone, either: test standards, techniques of representation, and the application of tacit knowledge of commonplace measurement tools are recurrent themes in the history of art and attest to the inseparability of all three.[6] In my own investigations, the use of test materials (beyond just images) as the basis of artistic expression is nothing short of a rite of passage for a test standard. The Lena test image—the focus of two chapters of this dissertation—has not only appeared in an HBO television series (*Silicon Valley)*, but has also been the subject of poems, re-enactments, and video art. Likewise, "Tom's Diner," the Suzanne Vega song used in many tests of what would become the MP3, became material for artworks by Ryan Maguire.[7] Not only do artists frequently return to such standards to distort their apparent simplicity, standards themselves are drawn from an existing world of sensory and bodily commonplaces. Those containers that Renaissance painters were apt to recombine in novel shapes were based on normative estimates of readily available "standards" like the length of person's outstretched arms or the average length of a foot.[8] Standards tell stories about how to represent the world and, in turn, crystallize an abstracted version of the world they set out to represent.

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[5] I attended this lecture and both Raven and her audience fixated on the formal simplicity of test materials.

[6] Genevieve Yue has compiled a long list of recent appropriations of test images in contemporary art. See: Genevieve Yue, "The China Girl on the Margins of Film," *October*, no. 153 (2015); Jonathan Sterne, *MP3: The Meaning of a Format* (Durham, NC: Duke University Press, 2012).

[7] See: Sterne, *MP3: The Meaning of a Format*. Ryan Maguire, "The Ghost in the MP3," http://ryanmaguiremusic.com/theghostinthemp3.html.

[8] Ken Alder, *The Measure of All Things: The Seven-Year Odyssey and Hidden Error That Transformed the World* (New York, NY: Free Press, 2002).

Figure 2 – Cover of ArtForum magazine featuring a reproduction of a Kodak test image (April 2006).

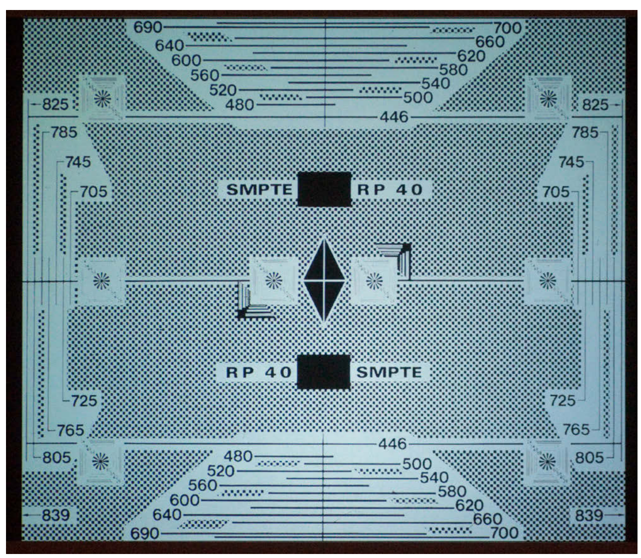

Figure 3 – Slide from Lucy Raven's *Standard Evaluation Materials* (2012)

What kinds of jokes can be told about meters? For one, the International Prototype Meter, the basis of all length measurements in the metric system when Duchamp made his artwork, was by all appearances the opposite of a piece of string dropped "as it pleases." Instead, the meter was a piece of platinum-iridium, forged to be durable and stable—to mutate, in other words, as little as it pleased.[9] Standards are made of things and the exchange of metal for string is a first diminishment of the meter's intended authority: a joke on the meter's rigidity.

3 Standard Stoppages also capitalizes on the arbitrary origins of all standards: though they are made to be precise and maintained in their precision, standards require an initial investment in a single decision about the fixing of points. These "fixed points" then become the hardened basis of a system of measurement and comparison. Standards in this way are arbitrary and (then) precise. As a result, the things that standards comprise—like meter sticks—embody a *conventional materialism:* artifacts that are chosen, used, and shared by agreement and not out of natural necessity. They are, to play off of Duchamp's terminology, "canned decisions" about how to represent the world in a limited fashion. The meter was based on a fraction of the earth's meridian, compiled through seven years of painstaking measurement of French landscape, measured during the peak of post-Revolutionary turmoil. Such measurements were meant to circumvent the arbitrariness of choosing fixed points and were meant to guarantee that the meter was

[9] It is likely not a coincidence that Duchamp, a French citizen, chose the meter as the subject for his joke. The metric system is a product of the French Enlightenment, French colonialism, and French conquest. To this day, the metric system's authority (its bureaucratic offices, its artifacts, its historic locus) is still in Sèvres, France, in the suburbs of Paris.

based on an "invariant of nature"—the size of the planet. Duchamp's second joke is on French Enlightenment idealism: they could have easily saved the trouble and just dropped a piece of string on a canvas.

Standards are crafted and maintained through protocols and rituals and these practices affirm the original decision to choose one set of fixed points over another. The ongoing work to maintain these fixed points continually shores up the material basis of standards so that their legitimacy isn't called into question.[10] *3 Standard Stoppages* turns the process on its head. Instead of choosing a fixed point and establishing a repertoire to maintain it, Duchamp created a small-scale ritual to maintain a random set of points. The joke is on the investment of things with the power to determine standards: there is no need to shore up the legitimacy of a standard if it was never intended to be legitimate in the first place.

Duchamp's last joke concerns the fact that standards work through a system of referentiality to maintain order and create usable systems. The metric system works with very few errors because its standard references are accessible, reproducible, and guaranteed through a network of linkages that trace back to the system's bureaucratic center in France. This dependability of (some) standards is infrastructural. This is to say, standards work as the conditions of operability for other systems (e.g., the thousands of

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[10] As Martha Lampland and Susan Leigh Star write: "A great deal of work is conducted to make the standard possible, and then this must be followed up by agents committed to implementation and oversight." Martha Lampland and Susan Leigh Star, *Standards and Their Stories: How Quantifying, Classifying, and Formalizing Practices Shape Everyday Life* (Ithaca: Cornell University Press, 2009), 14.

standards that make up networked computing allow for applications to work across devices; the standards that make up the highway system allow for any car to use it). Standards fix points so that each subsequent operation built on that standard doesn't need to. If every time someone went to build a house they had to get the architects, engineers, contractors, and inspectors to agree on length standards, building would take a lot longer. This was, in fact, the case, prior to standardized units. In 12th-century cathedral construction, travelling masons would use templates to adjust their tools to each town's civic guidelines using, among other things, pieces of string reminiscent of Duchamp's stoppages:

> A template is a pattern or mold, usually outlined on a thin piece of wood, that a stonemason uses to cut a stone to a particular shape. This small item of representational technology has much of the power of a scientific theory; it manifests the integration of science and technology and theory and practice, and it is a solution to the central problem of how knowledge was transmitted.[11]

The straightedges that are the final product *3 Standard Stoppages* are, likewise, templates: representational technologies that manifest a theory in a physical artifact. Like the standards that the artwork is intended to lampoon, *3 Standard Stoppages* uses a ritual to create tools. Though each tool captures a different moment in the fall of the string onto the canvas, and their differences to one another demonstrate the ridiculousness of the

[11] David Turnbull, "The Ad Hoc Collective Work of Building Gothic Cathedrals with Templates, String, and Geometry," *Science, Technology, & Human Values* 18, no. 3 (1993): 317.

exercise, they nonetheless recapitulate the referential process by which a standard can build a world: begin with a method for fixing points; use those points to create tools; and use those tools to create new objects, systems, and expressions. *3 Standard Stoppages* is a useful way to expose the logic of standards and measurement standards in particular. Among its many jokes, the artwork goads the performative and ritualistic labor that goes into transforming the arbitrariness of standardization into the appearance of objectivity. At the risk of completely ruining the joke through more summary: standards are thought to be durable and rigid, though they are based on arbitrary decisions about where and how to fix points and this tension requires that standards are constantly maintained, repaired, and shored up. To spread across space and to last through time (a condition that makes something a standard) standards must also work within a system of referentiality.

In *Reference Materials: The People, Places, and Things of Making Measurements,* I undertake four case studies drawn from the long 20th century of standardization: from the Meter Convention of 1875 (which created the modern metric system), the standardization of digital test images, the creation of new communication systems relying on cesium's atomic vibrations, and finally, the attempt to standardize care in medical education in the early 2000s. This trajectory demonstrates an increasingly inflated ambit for standardization—an expansion that began with basic units but grew to encompass emotional performance in some of our most sensitive institutional interactions.

This dissertation concerns attempts to simplify and standardize measurement, to track changes in objects, to compress image data, and to train individuals in the simulation of disease. These procedures (standardization, comparison, compression, training, and simulation) are fundamental features of contemporary, complex economies and societies, which rely on a high degree of compatibility and communication across jurisdictions, and the consistency of standards and norms over time. Judicial systems are built around laws, jurisprudence, and ideals of justice. Educational systems are built around ideals and standards of knowledge transmission, performance, and the practical limitations of creating a literate population. Sometimes, however, we build systems that create equivalencies through reference to a shared, material paradigm. In the four cases examined here, an architecture of commensurability is built around a material object or a series of objects. This architecture is meant to guarantee the reproduction of these objects in a traceable, repeatable, and consistent form.

The case studies in this dissertation comprise comparative studies of how reference materials undergird specific practices of commensuration and how each practice addresses the problems of materialization, standardization, and reproducibility. It is perhaps difficult to pick a contemporary term that is more over-interpreted than "materiality." Physics, philosophy, Marxist theory, feminist theory, economics, religious studies, cultural studies, and anthropology all have at least one definition of materialism that operates differently than the others, according to the history of each discipline. "New Materialism(s)" appear at regular intervals. (A cursory search discovers a description of "The New Materialism" in the *Journal of Philosophy* as early as 1922.)[12] In some cases materialism is used to produce distinctions between the physical and the non-physical, the real and the cultural, the basic and the ephemeral, or between primary and secondary

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[12] James Bissett Pratt, "The New Materialism," *The Journal of Philosophy* 19, no. 13 (1922).

qualities. At other times, materialism is a means of breaking down any such distinction. Raymond Williams's cultural materialism was once Marxist theory's New Materialism, appearing as a rejection of the relegation of culture to a superstructural—and by implication *less material*—position vis-à-vis the *more material* production of social life.[13] Myra Hird writes that the words "matter" and "materialism" are so important in various forms of feminist theory that they are used to describe "labor, reproduction, political access, health, education, and intimacy . . . the often mundane, repetitive, and tedious activities of daily life," equally as they are used to describe the "critique, extraction, and engagement" of scientific theories, experiments, and interpretations.[14] Materialism appears across disciplines as a password and a shortcut to make claims on what is "real" and, in short, to declare what matters.

An object can have multiple materializations: a model of car, a kilogram, a magazine photo; and at the same time it can have a material specificity. One aspect of standardization is assuring that the multiple materializations of the same object all resemble and act alike under specific conditions. A television signal is considered to work under ideal conditions only if your TV is tuned correctly, the color is calibrated, the room is dark enough, and you're sitting the right distance from the screen. The standard determines the technical details of the signal; its material specificity includes its infrastructure and its instantiation in a given television set. But it also includes the living

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[13] Raymond Williams, *Marxism and Literature* (Oxford & New York, NY: Oxford University Press, 1977).

[14] Myra J. Hird, "Feminist Engagements with Matter," *Feminist Studies* 35, no. 2 (2009): 329–30.

room, its lighting conditions, the visual apparatus of the viewers, and on and on. Constructing an object is a project for a standards maker and it's a project for the people studying standards. This is not a debate between material vs immaterial—we can stipulate a material existence to standards—but what material properties, affordances, and constraints these standards occupy and compel and what kinds of lines or borders divide one material from other materials.

The histories included in *Reference Materials* serve multiple purposes: they each address a different site and use the artifacts of standardization to see what they can tell us about those sites and the people who work there. They are meant as an addition to a growing literature on standardization and infrastructure, and their relationship to media studies. *Reference Materials* asks what the material underpinnings of standards, and their attendant rituals of crafting, maintenance, and repair, can tell us about the operative media theories and practices of professionals like engineers, scientists, technicians, and bureaucrats. In this way, *Reference Materials* approaches standards as embedded technologies that reach across space, time, and operations at vastly different scales. Yet, despite their geographic and temporal reach, standards are based in hyper-local practices of working with objects and the materials of commensurability.

Why use the word "commensurability"? This project can be summed up simply: when someone needs to compare two things, they almost always make reference to a third element. Sometimes that third element is a concept like decency, common sense, or justice; sometimes that third element is a precedent, like case law; and sometimes that third element is an artifact of some kind. *Reference Materials* concerns the development of artifacts as third elements. Commensuration is the process of comparing and judging artifacts using a shared standard, gauge, or set of criteria. Commensuration assumes that commensurability is already established. Commensurability is a quality of a relationship between things and it is established by the capacity of a relationship to hold together through comparison and measurement.

This project is also a study of the conditions of interoperability.[15] As Laura DeNardis argues, interoperability is the growing concern of systems that are built to efficiently share resources, standardize parts, and exchange information.

> Think of the 19th-century development of a standard gauge interconnecting railroads across the vast expanse of North America or, more than a century later, the standardization that allows us to exchange e-mail across different types of applications and hardware devices.[16]

Instead of viewing this project through the lens of private technological development, where the benefits of interoperability are balanced against the competitive advantage of proprietary systems, I have intentionally chosen case studies of materials that were not

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[15] For some of my objects, however, the term interoperability is anachronistically applied. The OED’s etymology dates the word to 1965, in an article about cooperation between allied armies and the definition of the term retains these origins: “The ability of two or more pieces of equipment esp. military equipment, to operate in conjunction.” Its first appearance: “Aims were ‘to ensure the fullest cooperation and collaboration between all five armies, the highest possible degree of inter-operability through material and non-material standardization, and obtain the greatest possible economy by the use of combined resources and effort.’” "New Zealand in Five Armies Agreement," *Times* November 16, 1965.

[16] Laura DeNardis, "The Social Stakes of Interoperability," *Science* 337, no. 6101 (2012): 1454.

initially developed for profit.[17] In this way, this dissertation aims to be both a pre- and parallel history of interoperability and commercial prototypes: pre- in the sense that the metric system is the first successful, international attempt to standardize the basic materials of measurement; parallel in the sense that the stories of commercial innovation, prototyping, standardization, and competition are already well documented and the stories that are written here will offer a new version of the material underpinnings of standardized systems.

The smooth functioning of an integrated economy and centralized governance relies on the commensurability of people, places, and things, to rank, order, and measure. Standards and norms are by definition exclusive and they often create homogeneity where there was once difference and plurality. They create and enforce categories that become the means of control. Yet, as Geoffrey Bowker and Susan Leigh Star argue, belonging to a category can either be a privilege or an affliction, a condition of possibility, or a means of oppression, or something in between.[18] The two-fold ambivalence of standards and norms can compel the abandonment of radical difference in exchange for the recognition of difference in an institution. Nancy Fraser shows how norms operate by harnessing symbolic and socioeconomic injustice, so that scarce, material resources are distributed in a way that often reflects the distribution of symbolic

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[17] The Lena image is in part an exception. While the image was originally produced for profit, its digitization and transformation into a reference object were not done for profit.

[18] Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out: Classification and Its Consequences* (Cambridge, MA: MIT Press, 1999).

difference.[19] At the same time, as every Whig history of the progress of rights tells us, the recognition of one's difference in a standard or norm is the surest way to economic and political enfranchisement. Thus, while recognition is the only guarantee of institutional representation—and that recognition is itself a struggle—the danger of recognition is that standards are rigid and will fix a form of plastic difference, making it less flexible.

Until the 19th century, conflicts over uniformity and commensurability were usually confined to matters of amounts: of grains, liquids, land, and coinage. But that is no longer the case. *Reference Materials* takes the "long 20th century" as its focus because this is the period where standardization expanded from a local possibility into an operation that could seemingly be applied to any problem. This period, which not only saw the standardization of time, tools, and units, also saw the development of, as Paul Edwards writes, "Standardized techniques for processing, presenting, and storing information (such as filing systems, paper templates, the Dewey decimal system), as well as genre conventions (such as the memorandum and the annual report)."[20] The act of imagination that it took to create a metric system that would unite the world by measuring the earth's dimensions, or the belief that the implementation of time zones would bring about political and economic harmony,[21] are familiar aspirations, even if they were made in a

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[19] Nancy Fraser, *Justice Interruptus: Critical Reflections on the "Postsocialist" Condition* (New York, NY: Routledge, 1997).

[20] Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, MA: MIT Press, 2010), 49. See also: James R. Beniger, *The Control Revolution: Technological and Economic Origins of the Information Society* (Cambridge, MA: Harvard University Press, 1986).

[21] Stephen Kern, *The Culture of Time and Space 1880–1918* (Cambridge, MA: Harvard University Press, 1983).

different register and at a different point in history. As Anna Tsing says, "Capitalism, science, and politics all depend on global connections. Each spreads through aspirations to fulfill *universal* dreams and schemes."[22] Just as these universalizing aspirations run up against the friction of local practices and emergent cultural forms, so too do the attempts at commensuration in *Reference Materials*. As a result of the friction between universalization and localization, there is a constant struggle to maintain the architecture of standards, and to enforce compatibility between jurisdictions. As demands are made of standards that they adapt to some new set of conditions or that they recognize some condition they originally ignored, this architecture is strained. Under the weight of political and economic exigencies, the material bases of standards threaten to give way: hence the imminent end of the artifact-based kilogram discussed in chapter 1 and the still controversial floating of the US dollar, removed from the gold standard. In the case studies included here the straining conditions placed on the material infrastructure of standards appear in many forms: the inevitable fluctuation of mass, the representational politics of image reproduction, the conflicts between physical and astronomical standards of time, and the affective responsibilities of the medical system to its patients and its simulated patients.

The Meaning of Standards

Up until now I have discussed standards as if their definition or meaning were self-evident. It is true that standards can refer to a vast array of objects and phenomena. Not

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[22] Anna Lowenhaupt Tsing, *Friction: An Ethnography of Global Connection* (Princeton, NJ: Princeton University Press, 2005), 1.

just the published, documentary basis of shared systems but also musical standards, standards of decency, or the implicit standards of social life, which are all included under this broad term. In general, I operate with the definition of standards developed by Bowker and Star (and taken up widely in the attendant literature). Standards, they argue, share a number of features:

1. A "standard" is any set of agreed-upon rules for the production of (textual or material) objects….
2. A standard spans more than one community of practice (or site of activity). It has temporal reach as well in that it persists over time….
3. Standards are deployed in making things work together over distance and heterogeneous metrics….
4. Legal bodies often enforce standards, be these mandated by professional organizations, manufacturers' organizations, or the state….
5. There is no natural law that the best standard shall win—QWERTY, Lotus 123, DOS, and VHS are often cited as examples in this context….
6. Standards have significant inertia and can be very difficult and expensive to change.[23]

We can divide Bowker and Star's definition into two parts: those items which address how a standard is a specific kind of technology (list items 1–3) and those items which

[23] Bowker and Star, *Sorting Things Out*, 13–14.

address features of the management and legacies of standards (4–6). In general, we can stipulate that a standard is any technology that people agree to use to create other technologies, objects, or phenomena. They are standards not because they are the best, most efficient, or oldest, but because they are shared. While standards are “agreed-upon rules” their range extends beyond those things enforced by a legal body. Standards can be such because of implicit agreement. In the history of digital image processing, for instance, a *Playboy* centerfold, cropped at the shoulders and renamed the “Lena” test image, became a standard through sheer repetitive use. To omit the image from your battery of compression testing would have made your work more difficult to share. Yet no one ever mandated the use of the Lena image, and no body ever explicitly agreed to its use as a standard. Neither of these facts slowed or hampered its adoption. In fact, one could argue that it was the unofficial status of the Lena image—its ability to signify insider knowledge and know-how—that facilitated its rise to iconic status. Earlier acknowledgement of its use as a standard would likely have produced conflict over its status as a copyrighted image and its origins in *Playboy.*

Standards are a special kind of technology for a couple of reasons. First, standards more than other technologies are primarily intended to make things run smoothly for interested parties by reducing local differences in protocols. There may appear to be exceptions where standards are meant to introduce friction; for instance, proprietary industrial standards that are supposed to make it harder for new entrants to join a market or prevent users from opening the black-boxed content of their media.[24] But even in these cases, we can say that standards are crafted to make them work for certain people in certain ways—to protect the market share of existing operators or to protect the financial benefits of existing copyrights. Studying the proper functioning of a standard then becomes about identifying for whom it works and under what conditions. If we stipulate this premise, and agree that standards are concerned with making things run smoothly, then we can study them as specifically situated and insistently normative statements about how the world *should* operate—statements that unavoidably embody and codify ethical statements about who or what is a priority.[25]

Research questions and conclusions

This dissertation is a historical review of measurement as a relational practice and the investment of certain kinds of materials (some metals, some images, some atoms, some people) with the power to create commensurable testing scenarios. Whether through the large-scale development of a new, fundamental measurement standard like the metric system, or the less grandiose choice of a picture for comparing digital images, the objects of study in this dissertation are seen to possess the capacity to enable measurement and comparison. This dissertation addresses standards as both technologies meant to make things work in complex economies and as crystallizations of culturally conditioned practices of referencing, practices of enunciating visions for the world, and practices of

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[24] Tarleton Gillespie, *Wired Shut: Copyright and the Shape of Digital Culture* (Cambridge, MA: MIT Press, 2007); Laura DeNardis, *Opening Standards: The Global Politics of Interoperability* (Cambridge, MA: MIT Press, 2011).

[25] Lampland and Star, *Standards and Their Stories*.

choosing proxies.[26] If these are the broad, structuring considerations that drive the investigation in *Reference Materials*, the questions that were provoked by my research focus on the closer scrutiny of what actually happens to these materials:

- What is the context in which a materialization of a standard operates?
- How do materials circulate?
- Who is responsible for the materials?
- How do they break down?
- How are they repaired?

Together these broad questions about comparison, commensurability, and materialization and specific questions about contexts and maintenance produced a set of conclusions about creating and maintaining standards in the 20th century.

Standards are mediatic

Reference Materials is a study of the media practices of engineers, scientists, and bureaucrats. This is not simply to argue that standards should be included in the never-ending inventory of things that ought to be considered media. Media, here, refers to the ways that standards work through reference (methods of circulation, citation, canonization), the ways standards crystallize political decision-making (the arbitrary, often contested, and riven-with-power decisions of committees, institute directors, and teachers), and the ways that standards enact measurement operations that are inherently

[26] The materials of standards are here considered as media in the oldest sense of the word, as intermediates.

relational. The purpose is therefore not to simply claim a mediatic status for standards but to use *referencing, the materialization of political decisions, and relational measurement,* as heuristics for understanding the social function that standards perform and the work that makes them possible. I ascribe to Lisa Gitelman's definition, which states that media are:

> Socially realized structures of communication, where structures include both technological forms and their associated protocols, and where communication is a cultural practice, a ritualized collocation of different people on the same mental map, sharing or engaged with popular ontologies of representation.[27]

If media are shared, socially realized and socially maintained structures, where neither their form, content, nor political orientation is guaranteed by technology, technique, or text, then reference materials, as the conditions of commensurability, are one class of media that temporarily structure relationships of comparison and classification by investing certain people, places, or things, with the capacity to compare other people, places, or things.

Standards require imagination

Standards necessarily involve arbitrary decisions about imagining the world in a workable form.[28] These workable, fixed points function as necessary fictions for

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[27] Lisa Gitelman, *Always Already New: Media, History and the Data of Culture* (Cambridge, MA: The MIT Press, 2006), 7.

[28] Madeline Akrich. "The De-Scription of Technical Objects," in *Shaping Technology/Building Society: Studies in Sociotechnical Change*, eds. Wiebe E. Bijker

beginning the work of standardization. Anne Balsamo has defined the "technological imagination" in the following ways:

> A mindset and a creative practice of those who analyze, design, and develop technologies. It is an expressive capacity to use what is at hand and to create something else. This is a quality of mind that grasps the double-nature of technology: as determining and determined, as both autonomous and subservient to human goals.[29]

The technological imagination is fully operational in standards work. Balsamo and others focus on the work of technological "innovation," a process that on first appearance shares a closer relationship with imagination than the work of standardization, which can at times be accused of killing imagination with its implied emphasis on constraint, normalization, and regulation. Yet, as Martha Lampland and Susan Leigh Star explain "the push to standardize presumes the ability to constrain a phenomenon within a particular set of dimensions, as well as the ability to dictate behavior to achieve the narrowly defined dimensions that stipulate its outcome."[30] This ability to constrain a phenomenon should be understood as a creative capacity of the standard maker. The ability to select from amongst many characteristics only those that might be captured and

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and John Law (Cambridge, MA: MIT Press, 1992); Michel Callon. "Society in the Making: The Study of Technology as a Tool for Sociological Analysis," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, eds. Wiebe E. Bijker, Thomas P. Hughes and Trevor Pinch (Cambridge, MA: MIT Press, 1987).

[29] Anne Marie Balsamo, *Designing Culture: The Technological Imagination at Work* (Durham, NC: Duke University Press, 2011), 31.

[30] Lampland and Star, *Standards and Their Stories*, 14.

might stand in for the whole is a kind of observational skill. Most often, constraining a phenomenon entails quantifying it—choosing some feature or features that can stand as representatives for the more complicated and impossible-to-capture whole. A standard then becomes a recipe (in Lawrence Busch's words) for producing and reproducing a narrowly defined phenomenon: a meter stick stands in for a fraction of the earth and is easily reproduced in metal, wood, or string whenever a meter is needed.[31] As a stand-in for the process that created it, the meter stick eliminates the need to re-measure the meridian and protects against the variations in other ready-at-hand standards, like the difference in length of various people's outstretched arms.[32] The presumption that a phenomenon can be constrained materializes in artifacts: tools, documents, and samples of the vast and varied world of phenomena. "Reference materials" are the embodiment of difficult choices about imagining the world "out there" within the testing environment of the lab, the workshop, or the office. They are the materialization of the world, made into small, manageable, usable, workable, exchangeable, and reproducible chunks. These things include the prototypes, working objects, measurement apparatus, lab samples, and test data[33]—but they also include the whole ecology of objects, manuals, and memos for referencing, checking, and maintaining those materials.

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[31] Lawrence Busch, *Standards: Recipes for Reality* (Cambridge, MA: MIT Press, 2011).

[32] Ibid.

[33] Lorraine Daston and Peter Galison, *Objectivity* (New York; Cambridge, MA: Zone Books, 2007); Steven Jackson and David Ribes, "Data Bit Man: The Work of Sustaining a Long-Term Study," in *"Raw Data" Is an Oxymoron*, ed. Lisa Gitelman (Cambridge, MA: MIT Press, 2014); Matthew Fuller, *Media Ecologies: Materialist Energies in Art and Technoculture* (Cambridge, MA: MIT Press, 2005).

To study reference materials is therefore to study the process of materializing the world in usable chunks—to interrogate the choice of some proxies over others—and to investigate the contextual characteristics of maintaining a material apparatus as the basis of a standard. To live with the reality that is created by the original decision to constrain a phenomenon, to fix points, to make necessary but arbitrary decisions about imagining the world, standards are maintained through rituals and protocols. The next three conclusions about standards address these protocols.

Standards are manual

Much of the discussion surrounding standards treats them as a strictly infrastructural problem, meant to grease the process of communication and exchange. A standard is not an inert thing and standards that are based on a set of material references require constant attention. Despite their variations, the standards in *Reference Materials* all required the intervention of human hands and they are fundamentally "manual." In the case of the International Prototype Kilogram, the mass standard is maintained by a strictly choreographed protocol for hand-cleaning. In digital image processing, not only was the Lena test image extracted from the pages of *Playboy* by hand (torn, or folded, descriptions vary) but more importantly, the image spread throughout the image processing community in hand-to-hand exchange on magnetic tape. Personal exchange of a digital artifact underlines the fact that even digital media have manual lives. At times, atomic time standards deviate from astronomical (civic) time standards and to keep them in line a "leap second" must be inserted by manually pausing the timestream. And, finally, in the interface of physician and patient in standardized patient training, the doctor must palpate and manipulate the patient's body, despite the fact that the patient's symptoms are make-believe. These manual aspects to standards complicate any notion that standards are inert, automatic, or that they simply exert an invisible constraint on other systems. Instead, as these examples and others show, they are subject to constant, human attention meant to maintain them and shore up their viability.

Standards are papered (in unpredictable ways)

When the International Prototype Kilogram was ritually entombed—thereby consecrating it as the basis of mass measurements—the sanctioning committee enclosed the object along with the documentation explaining its importance. This was an unnecessary but symbolically rich act that created a closed-loop between the documentary basis of the standard, its material manifestation in the Prototype Kilogram, and the moment of its sanctioning. "Reference materials," as an analytic concept, refers to this entire conjuncture: not just the working object at the basis of the standard, but its documentary support, its ritual entombing, the three keys that were distributed so that no one person could access the Kilogram alone, and the vault—the heavy door of which became increasingly difficult to open, signaling both the manual challenges to maintaining standards and their bodily constraints.

The role of papering in standards is not limited to instructional and ritual functions, either. By "paper" I mean a larger kind of media practice than only the use of pulpy artifacts (consider that a "call for papers" isn't normally a request for anything printed on mushed trees); and I mean something that operates in addition to the category of text or the genre of documents that are, by definition, meant to act as epistemic objects and "evidential structures in the long human history of clues."[34] "Papering," instead, is meant to describe the ways that texts, documents, images, memos, templates, and forms suffuse standards work as a basic form of materiality and a lowest common denominator. Papering is a type of media work that uses things like a stack of symbolically meaningful meeting minutes (in the case of the kilogram) or cropped magazine cutouts (in the case of the "Lena" image), to buttress the provisional and arbitrary decisions made throughout the standardization process. "Reference materials" is in part meant to offer an alternate way of talking about the roles that paper-like materials play in the ritual and official functioning of standards. In addition to the encasing of the Kilogram's documentary ballast, the other case studies in this dissertation similarly hinge on the use of papering.

For instance, when the image engineers at the University of Southern California tired of the same old set of test images and sought to create a new kind of image, they turned to *Playboy* magazine. According to the lore of how image compression is remembered by engineers, they did not choose *Playboy* because of its titillating content, but because the magazine was well regarded for its glossy images and Hugh Hefner's insistence on "using only the best photography and paper stock."[35] (The Lena image was initially digitized for a conference *paper.*)

When the world's authoritative atomic clocks are used to calculate the most precise and accurate time possible, they are weighted according to their accuracy and averaged

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[34] Lisa Gitelman, *Paper Knowledge: Toward a Media History of Documents* (Durham, NC: Duke University Press, 2014), 1.

[35] Peter Nowak, *Sex, Bombs and Burgers: How War, Porn and Fast Food Created Technology as We Know It* (Toronto: Viking Canada, 2010), 173.

together. The final, average time is called a “paper standard” that is distributed back to each laboratory in the form of *Circular T*, a memo that dictates what time *was* the previous month. The memo, the paper standard, and time, are all one, and they are available online, through a web portal at the Bureau International des Poids et Mesures’ FTP server.[36]

When standardized patients are given a patient persona they receive their instruction through the use of a template provided by their employer at a medical education institution. The template provides the intended outcomes of their performance (what, as a patient, they should embody and what, as student physicians, the trainees should elicit). Templates are standard recipes that both constrain and guide authorship. In standardized patient performance, an authentic interaction between patient and physician is the desired outcome. How then, can the template avoid severely restricting the self-determination of the patient’s experience? This, in fact, is a point of contention in the standardized patient community: what voice, if any, should be accorded to the patients’ own reaction to their medical care? The response, not surprisingly, comes in the form of a template: the exit questionnaire caps off a process that is intended to script and calibrate an interaction between patient and physician such that the variability will be limited to a given physician’s skill. It is likely not surprising that the standardized patient process is mediated through the use of questionnaires, scripts, and templates. What is remarkable is that the many kinds of papering involved in other forms of standardization (e.g., basic

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[36] http://www.bipm.org/en/bipm-services/timescales/time-ftp/publication.html#nohref

measurement units, industrial and commercial standards) are so easily extended to the realm of empathy, care, and make-believe performance.

Standards, as a part of infrastructure, require constant concealment

There is a growing body of work at the intersections of standards, infrastructure, media, and technology.[37] Much of this literature is premised on exposing the givenness of standards, infrastructures, norms, platforms, and other technological phenomena. This work depends on a "transparency hypothesis" to argue that these objects of study deserve renewed attention in part because they are taken-for-granted. The most complete articulations of the transparency hypothesis are put forward by Bowker and Star and their various collaborators. Bowker's 1994 introduction of the very popular and useful method of "infrastructural inversion,"[38] which tasked researchers with looking to the embedded infrastructural pre-conditions that make science and technology possible, was followed,

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[37] These include, among others: Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, MD: Johns Hopkins University Press, 1983); Bowker and Star, *Sorting Things Out*; Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999); Alexander R. Galloway, *Protocol: How Control Exists after Decentralization* (Cambridge, MA: MIT Press, 2004); Lawrence Lessig, *Code: Version 2.0* (New York, NY: Basic Books, 2006); Laura DeNardis, *Protocol Politics: The Globalization of Internet Governance* (Cambridge, MA: MIT Press, 2009); Lampland and Star, *Standards and Their Stories*; Busch, *Standards*; DeNardis, *Opening Standards*; Sterne, *MP3*; Jonathan Sterne and Dylan Mulvin, "The Low Acuity for Blue: Perceptual Technics and American Color Television," *Journal of Visual Culture* 13, no. 2 (2014); Nicole Starosielski, *The Undersea Network* (Durham, NC: Duke University Press, 2015); Bernard E. Harcourt, *Exposed: Desire and Disobedience in the Digital Age* (Cambridge, MA: Harvard University Press, 2015); Dylan Mulvin and Jonathan Sterne, "Scenes from an Imaginary Country: Test Images and the American Color Television Standard," *Television and New Media* 17, no. 1 (2016).

[38] Geoffrey C. Bowker, *Science on the Run Information Management and Industrial Geophysics at Schlumberger, 1920–1940* (Cambridge, MA: MIT Press, 1994).

in 1996 by Susan Star and Karen Ruhleder's[39] now-canonical definition of infrastructure, which then became a part of the definition of infrastructure used by many scholars focused on the problematics of infrastructure, and the basis for a new era of "infrastructure studies."[40] Among the most cited features of infrastructure that were articulated by Star and Ruhleder and repeated by those who cite this definition directly or indirectly, is the manner in which infrastructure is embedded, invisible, and only revealed when it breaks down. They write:

- *Embeddedness*. Infrastructure is **"sunk"** into, inside of, other structures, social arrangements and technologies;

- *Transparency*. Infrastructure is **transparent** to use, in the sense that it does not have to be reinvented each time or assembled for each task, but invisibly supports those tasks; […]

- *Learned as part of membership*. The **taken-for-grantedness** of artifacts and organizational arrangements is a *sine qua non* of membership in a community of practice. […]

- *Becomes visible upon breakdown*. **The normally invisible quality of working**

[39] Susan Leigh Star and Karen Ruhleder, "Steps toward an Ecology of Infrastructure: Design and Access for Large Information Spaces," *Information Systems Research Information Systems Research* 7, no. 1 (1996).

[40] Geoffrey C. Bowker et al., "Toward Information Infrastructure Studies: Ways of Knowing in a Networked Environment," in *International Handbook of Internet Research*, ed. Jeremy Hunsinger, Lisbeth Klastrup, and Matthew M. Allen (Dordrecht; London: Springer, 2010); Sterne, *MP3*; Bowker and Star, *Sorting Things Out*; Edwards, *A Vast Machine*.

> **infrastructure becomes visible when it breaks**; the server is down, the bridge washes out, there is a power blackout. Even when there are back-up mechanisms or procedures, their existence further highlights the now-visible infrastructure.[41]

These features of infrastructure are recapitulated in many other places, where infrastructure is said to "exist in the background,"[42] where "science and media become transparent when scientists and society at large forget many of the norms and standards they are heeding,"[43] where platforms are described as "whatever the programmer takes for granted when developing"[44] and where comparisons are made between the relative transparency of infrastructure to other conditions of social life: "software code … is much less visible than law."[45] There are many more examples that make the same point. Like breathing warm air onto a cold window, these authors layer opacity onto ignored, overlooked, and unseen objects. And, by claiming that things like standards, infrastructure, and technology are transparent, participating in the transparency hypothesis extends a special kind of vision, and an epistemic privilege, to the investigator: the ability to see the invisible and to render it legible to others.

This is a powerful gesture and one that accords legitimacy to a nascent,

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[41] Star and Ruhleder, "Steps toward an Ecology of Infrastructure," 113. Emphasis added. Note, as well, that these items are drawn from a longer list of the characteristics of infrastructure.

[42] Bowker et al., "Toward Information Infrastructure Studies."

[43] Gitelman, *Always Already New*, 7.

[44] Nick Montfort and Ian Bogost, *Racing the Beam the Atari Video Computer System* (Cambridge, MA: MIT Press, 2009), 2–3.

[45] Gillespie, *Wired Shut*, 93–94.

interdisciplinary field. The transparency hypothesis is part of a turn towards materiality and a discursive rematerialization of computer technologies and systems that were mistakenly or misleadingly described as immaterial for a generation or more. The transparency hypothesis has taken hold with special force in the study of media conditions. In massive, networked, digital communication systems, where control and resistance are exerted at the level of infrastructure, a realignment of investigatory interests is especially necessary.[46] A new alignment should not, the argument goes, focus on the content of communication technologies and media but on the conditions that make communication technologies and media possible. Such work is conscientious in its unearthing and exposing of standards, infrastructures, and technologies; many of these objects *were* ignored and were, practically speaking, invisible to the kinds of investigations that were normally regarded as legitimate.

Reference Materials arrives in the wake of the transparency hypothesis. Instead of seeking to expose the transparent, the sunken, and the invisible, this project approaches standards and infrastructures as technologies that undergo constant, yet always partial, concealment. Concealment is a repetitive process of repair and maintenance. This is evident, for instance in the ways the Kilogram undergoes cleaning and in the ways standards keepers respond to challenges like feminist and copyright claims against the Lena test image, the need for leap seconds, and the demands of standardized patients to have a say in medical education. If, by definition, infrastructure is invisible—the “infra” pointing to its occupation of a level “below” the readily perceptible—there is perhaps no

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[46] Galloway, *Protocol*; Lessig, *Code: Version 2.0*.

good to be gained from upending a solid etymology. Yet, as Lampland and Star stipulate, “good infrastructure, by definition is invisible,”[47] and here we should pause to not let the word “good” slip by because it is a distinction between what is seen as *good infrastructure* and what is seen as *bad infrastructure* that ought to pique our interest. The experience and appreciation of infrastructure will vary by any number of social-demographic conditions: location, age, ability, and access to alternative forms of infrastructure. For nearly thirty years there has been an “infrastructure crisis” in the United States.[48] If we are in a constant state of crisis about our basic infrastructure, then is any of it good and, by extension, invisible?

Let’s say, for argument’s sake, that good infrastructure is invisible. The next part of the argument goes that infrastructure *only* becomes visible when it breaks down and reveals its workings—when it becomes *infrastructure gone bad*. However, what would happen if, instead of studying infrastructural breakdown and failure, instead of looking to the moments of revelation of infrastructure’s inner workings—we focus on the process of concealing infrastructure?[49] The standards under consideration in *Reference Materials*

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[47] Lampland and Star, *Standards and Their Stories*, 17.

[48] Heywood T. Sanders, "What Infrastructure Crisis?," *Public Interest*, no. 110 (1993).

[49] Living in Montreal for many years one grows accustomed to regular stories about pieces of buildings, bridges, over- and under-passes falling off. There are many culprits who are blamed—politicians, the construction industry, the criminal syndicates that connected politicians with the construction industry, as well as salt and snow. Infrastructural collapse is a reality of daily life in Montreal and any modern city, for that matter. This approach to the study of infrastructure would not examine the infrastructure as it reveals itself when a falling piece of cement crushes a car, but would question what it is that allows anyone to continue driving on those bridges in the first place: what are the layers of paint, scaffolding, and makeshift remediation doing to make the appearance of proper functioning visible enough to not arrest everyone in their homes?

undergo many forms of maintenance, repair, and transformation to allow them to continue functioning in their capacity as the materials of infrastructure. Metal is cleaned, images are cropped, seconds are added to the time standard, standardized patients are sneaked into hospitals to test physicians. These are all creative solutions to the fact that standards and infrastructures aim for invisibility as a condition of being "good."

Chapter outlines

Chapter 1: How to Clean a Kilogram: Data Hygiene and the Maintenance of Standards

The first study in *Reference Materials* is a history of the International Prototype Kilogram (IPK), the last remaining physical artifact used as a standard in the metric system. While there are many popular and scholarly histories of the metric system, standardization, and measurement systems more broadly, this is a very specific analysis of the protocols for keeping the IPK *clean* as a matter of its stability.

"Data hygiene," this chapter argues, is a necessary part of commensuration. Data hygiene is a human practice visible in protocols for database management ("clean data set") and finance ("money laundering"). The IPK comes with precise guidelines for "*nettoyage et lavage*" (cleaning and washing) that are meant to return the kilogram as near as possible to its original state. Cleaning and washing the kilogram are done by hand, with strictly choreographed movements of an ether-soaked chamois cloth. This chapter serves as a template for the following chapters, introducing some key terminology for discussing how standards are composed and maintained: traceability, conventional materialism, necessary fictions, and arbitrary precision. Through a close analysis of how the kilogram was created, ritually stored, contested, and cleaned, chapter one offers a formula for studying the manual protocols subtending standards.

Chaptes 2–3: lena_std.tif v1: Image Processing and the Origins of a New Aesthetic Standard & v2: The Politics of Test Images and the Failures of Representation

In the next two chapters I undertake a history of the most popular digital test image in history, the so-called "Lena" image. These chapters serve two historical purposes: first to tell the untold story of the earliest days of digital image processing and the attempts to get digitally processed and compressed images onto ARPANET; the second purpose is to write the history of the creation, circulation, and canonization of the November 1972 *Playboy* centerfold as a test image. Theoretically, the chapter follows a feminist media studies approach to the history of computing. Methodologically, the chapter draws on an archive of journals, working papers, comparisons of Wikipedia "Talk" pages, masters' theses from the earliest days of digital image engineering, and grey literature—including unofficial reports, documenting the work women engineers did to contest the sexist settings of computer science and engineering throughout the 1980s and 1990s—a period that coincided with the formalization of digital image processing as a distinct discipline.

Chapter 2 examines the origins of digital image processing to understand the environment in which the Lena test image appeared as a solution to the problem of too many boring images. This chapter looks at the work that early image engineers were doing at the University of Southern California on image detection and transmission. The chapter shows how the techniques of circulating images from USC to other laboratories on spools of tape helped build a pedagogy for digital image literacy that canonized images like Lena. It further shows how the "ways of seeing" of engineers were built through the repetitive, tedious work of staring at a set of test images.

Chapter 3 turns to the early 1990s and a time when a graphical, world wide web was on the horizon and digital image processing was finally distinguishing itself from electrical engineering and computer science more broadly. In this moment, the Lena test image appeared more than two-hundred times in the first volume (1992) of the discipline's first journal, *IEEE Transactions on Image Processing*. In the same year *Playboy* challenged the use of the image on copyright grounds. This chapter documents how the image engineering community responded to this challenge and to the claims that the image is sexist. As a discipline, the editorial pages of journals like *Optical Engineering* and *Image Processing* became the grounds for dispute and repair—where editors tried to smooth away the friction created by the Lena image's previously unfettered circulation. Through these histories, these two chapters argue that the methods for "seeing like an engineer" that produced the Lena image—and reproduced it—are a product of institutionalized vision. Techniques for seeing in these ways are re-inscribed in the computer vision models that engineers build.

Chapter 4: The uses of high-resolution time

Based on the fact that the fundamental units of the metric system are undergoing a comprehensive "temporalization," this chapter offers a history of the transformation of time into a fundamental stability around which new communication infrastructures are built. These infrastructures include the Network Time Protocol, GPS, and high frequency trading. This chapter offers terminology through which such changes in the measurement and dissemination of time can be understood: "High-resolution time" refers to the ascendance of atomic timekeeping and its extreme granularity relative to previous time standards; "temporal infrastructures" refer to the systems of time measurement and dissemination which subtend other communication infrastructures at a fundamental level; "arbitrary precision," which was introduced in the first chapter, refers to the more general process by which standards-makers must select and reproduce precise but always-arbitrary fixed points, with the accessibility of atomic timekeeping's precision creating the conditions of possibility for new kinds of infrastructure.

In the case of time measurement, the vibrations of cesium atoms act as a fixed point. But keeping accordance with the cesium-based temporal infrastructures threatens to decouple the calculation of time from the human experience of daylight. Temporal infrastructures, in this sense, not only facilitate and enable communication, they also rework and re-engineer the meaning of time itself. This chapter discusses how a laboratory technique for verifying measurements (atomic counting of time intervals) superseded the measurement standard that it was meant to verify (astronomical time keeping). Further, it intervenes in literature on time and the ongoing debates between speed theory and temporal geography. Instead of approaching time and technicity through velocity and acceleration, I offer *temporal depth* as a means of understanding how the treatment of time affects both massive infrastructural systems and the texture of time in everyday life. This chapter also furthers the discussion of the ways standards are papered and enacted manually and this chapter shows that something as basic, fundamental, and continuous as “what time is it?” is subject to the ongoing, repetitive interventions of hands and documents, necessary to shore up standard time and the constant provision of temporal signatures.

Chapter 5: Living Materials: The Standardized Patient Program

The final chapter of the dissertation is a history of commensuration in which the logic of standardization is extended to include human beings as standardized materials. This section includes a brief history of the standardized patient program, begun at USC in the 1960s and transformed, over forty years into a necessary part of medical accreditation in Canada and the United States. Begun as a bridge between the dissection of cadavers and living anatomy class, the standardized patient program functioned as a “living cadaver” lesson and standardized patients are now a technique for training doctors in diagnosis, and more importantly, in bedside manner—techniques intentionally engineered to help physicians avoid malpractice lawsuits. The chapter considers the work of people acting as reference materials and how standards makers attempted to extend the logic and practice of material commensurability to human performers. Separate from the well-established history of Taylorization and the rationalization of physical labor, the history of standardized patients concerns the provision—by physicians—of a standard kind of empathetic care. The unpredictability of human interaction is both the reason *for* the use of standardized patients (over, say, computer simulations) and the reason that they are an inherently unstable material guarantee. As patients, they act as a gauge; for the evaluators, they act as a shared circumstance that a student navigates with varying success. Yet, standardized patients—unlike magazine images, pieces of platinum, or cesium atoms—are active participants in the standardization effort: they talk, respond, emote, adjust, and evaluate. When commensurability is embodied, bodies also become the tools of measurement. Recent developments in standardized patient programs have seen the actors who perform as patients demand more input in evaluating student physicians. This chapter therefore examines the affective maintenance involved in both training actors and physicians, and in maintaining a standard where the reference materials can talk back. Finally, the dissertation concludes with some methodological remarks that reflect on the preceding chapters and provide some outlines for possible future research.

Chapter 1: How to Clean a Kilogram

Data Hygiene and the Maintenance of Standards

All around the world today, the kilo is the measure
A kilo is one thousand grams, it's easy to remember.

—Ghostface Killah (feat. Raekwon the Chef), "Kilo"

To clean a kilogram you will need the following supplies:

1) A kilogram

For cleaning by hand

2) 1 piece of chamois leather
3) Mixture of equal parts ethanol and ether

For solvent washing

4) 1 L Pyrex flask containing bi-distilled water
5) 1 tube with a 2 mm spout
6) 1 bowl for collecting condensed water
7) 1 tripod that can spin on its vertical axis and extend vertically
8) 1 platinum-iridium disk
9) Filter paper

Time: about 50 minutes

Figure 4 - Cleaning a kilogram by hand

About six days before you want to clean your kilogram, begin soaking the chamois leather in the ether-ethanol mixture for 48 hours. Wring out the leather—this helps remove impurities, and you definitely don't want impurities on your kilogram. Repeat this stage two more times by soaking the chamois leather in a fresh bath of ether and ethanol, wringing it out each time.

When your chamois is finally free of impurities you can begin to clean your kilogram. A kilogram needs to be rubbed with approximately 10 kPa of pressure. If you do not have a Pascal gauge handy to measure kPa, simply rub the kilogram “fairly hard by hand.” Remember, you are trying to return the kilogram to its original luster: “rather handsome, but not specular.”

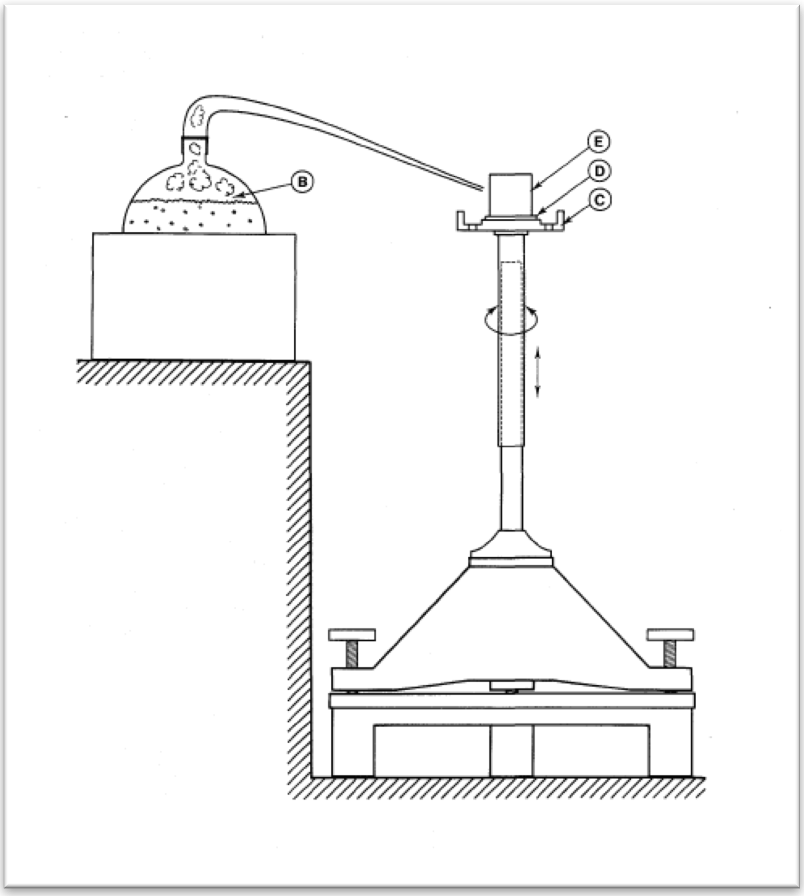

Figure 5 - Solvent cleaning set-up

After the manual rubbing, your kilogram is ready for solvent washing with steam. Figure 5 shows you roughly what your solvent cleaning set-up should look like. Place the kilogram (E) on the platinum-iridium disk (D). The disk should fit comfortably on top of the tripod above the bowl. Fill your Pyrex flask about three-quarters full with doubly distilled water. Run the tube from the flask to the top of the tripod, pointing the orifice of the tube at the kilogram but keeping it about 5 mm from the surface. Heat the water with an electric mantle, operating at 350 W.

As the water boils, steam will start to come out of the tube. It should first be pointed directly at the kilogram’s top and top edge. Rotate the tripod on its vertical axis making sure to steam all 360 degrees of the cylinder. It’s like a vertical rotisserie! Start moving the kilogram upwards while continuing to rotate it. Blast the kilogram with steam for 15 to 20 minutes.

Most of the steam should run off the kilogram and into the bowl. It's normal to have a few drops of condensed steam on the kilogram's surface. For these stragglers, take a corner of the filter paper and absorb each drop individually, using the paper's capillary action. If you don't have filter paper you can also blow the drops away with a jet of clean gas.

Figure 6 - a clean kilogram under its jar

Next, flip the kilogram so you can clean the side that was resting on the disk. Repeat the process of steam cleaning the kilogram—rotating it, raising it—so that the cylindrical surface gets a second cleaning. (Of course, you'll want to make sure the disk under the kilogram was cleaned in advance using the same technique. But you knew that!)

Return the kilogram to its resting place under a glass bell jar. If you are accustomed to using a chemical desiccant to dry the air inside the bell jar, it's really not necessary. Congratulations, your kilogram is clean![1]

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[1] These instructions, including the supplies, estimated times, and figures are based on G. Girard, "The Washing and Cleaning of Kilogram Prototypes at the BIPM," *BIPM internal report* (1990). "Rather handsome, but not specular" is from Richard Davis, "Recalibration of the U.S. National Prototype Kilogram," *Journal of Research of the*

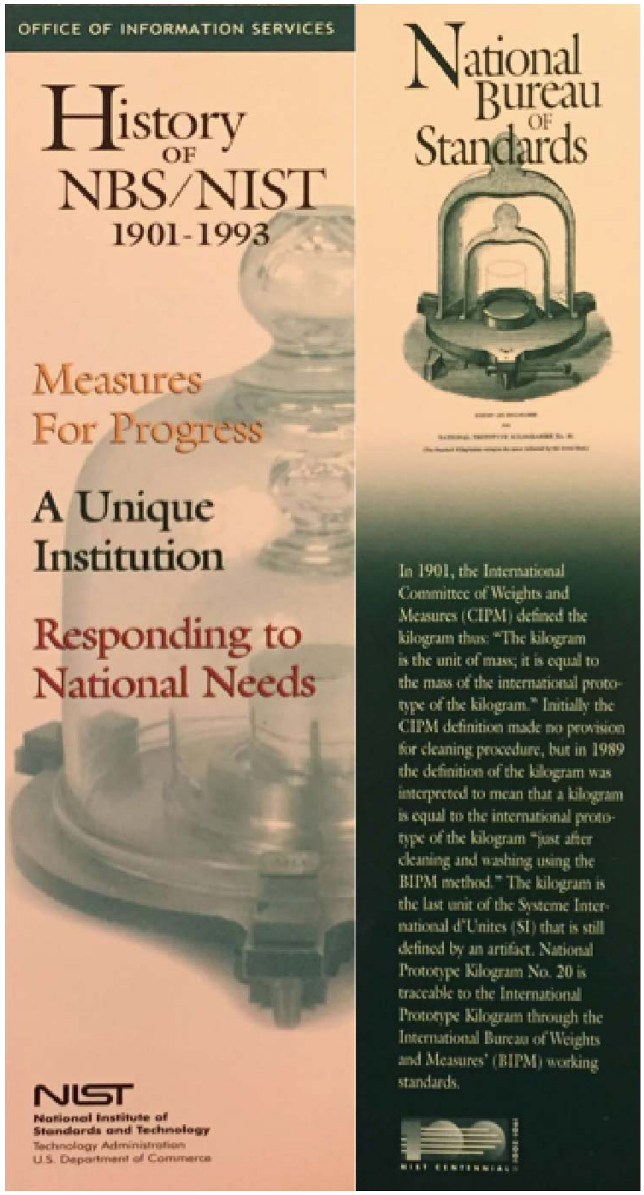

Figure 7 – Bookmark (front and back) from the United States' National Institute of Standards and Technology. Despite America's civic ambivalence towards the metric system, the International Prototype Kilogram has become a favorite symbol of the metrology community. (Author's files)

National Bureau of Standards 90, no. 4 (1985): 265. The author added certain stylistic emphases.

Data Hygiene

In the early 1970s, anyone following the Watergate scandal added a new term to their lexicon when they learned that money could now be *laundered*. Specifically, they learned that President Richard Nixon's ex-Commerce Secretary Maurice Stans, in his new role as finance chairman of the Committee to Re-elect the President (CRP for short, CREEP, for fun), had "laundered" illegal campaign donations through a Mexico City bank—donations that eventually went to bribe the Watergate Burglars, and, among other things, buy Mrs. Nixon a pair of diamond-studded earrings.[1] The term "money laundering" did not appear in a major American paper until 1972, and throughout the Watergate scandal it usually appeared with scare quotes, as in this early appearance in the *New York Times:* "…the President's wish that the C.I.A. ask the Federal Bureau of Investigation not to investigate the 'laundering' of campaign funds through a Mexican bank."[2]

In *All The President's Men*, Carl Bernstein relays how Martin Dardis, the chief investigator for the Dade County, Florida state attorney's office, linked the flow of money from a Mexican bank to Richard Nixon's campaign for re-election.

> "It's called 'laundering,'" Dardis began. "You set up a money chain that makes it impossible to trace the source. The Mafia does it all the time."[3]

Dardis was right and his apparent familiarity with the term indicates the practice's pervasiveness, though the term had yet to penetrate common parlance. Though the

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[1] Bob Woodward and Carl Bernstein, "Funds Laundered," *The Washington Post*, July 11 1974.

[2] "Walters Uncertain of Haldeman Quote," *The New York Times*, May 23 1973.

[3] *All the President's Men* (London: Simon & Schuster, 1974), 46–47.

standard etymology of “money laundering” leads back to Watergate, the term predated the scandal. In his first tell-all memoir, published in 1973, the ex-mobster Vincent Teresa describes how the mafia would pass “dirty” money through legitimate businesses.[4] He writes,

> Hoffa shook his head and asked me if I’d ever heard of a guy named Lou Poller. Poller worked for the Miami National Bank, and his specialty was taking money that had been gotten illegally and “washing” it—cleaning it up and legitimizing it.[5]

Teresa doesn’t employ “laundering” but does extend a similar hygienic metaphor to explain the same process employed by Stans and Nixon. Why would the mob, or a finance committee, or anyone, want to launder, wash, or clean money? In each case the motivation is to wipe money of the traces left by illegitimate sources. Money is fungible, while the records of money’s exchange are not. If you can “clean” money of its history,

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[4] The *Oxford English Dictionary*’s definition of (money) laundering: “To transfer funds of dubious or illegal origin, usu. to a foreign country, and then later to recover them from what seem to be ‘clean’ (i.e. legitimate) sources. The use arose from the Watergate inquiry in the United States in 1973–4.” It should be noted that though etymologies of laundering identify the Watergate scandal as the first appearance, my research shows that the term was not only already in circulation before the scandal, it actually appeared in print in reference to the mafia before it appeared in reference to Watergate. William Safire appears to be one of the only people to recognize earlier uses of laundering. He writes, in his *Political Dictionary,* that prior to laundering, money was considered to be “hot” and needed “cooling” or, sometimes, washing. How temperature related to hygiene is unclear, though the mixing of metaphors isn’t surprising. See: James M. Markham, "Mob-Influenced Businesses Would Fill a List from A to Z, Officials Here Say," *The New York Times*, August 19 1972. William Safire, *Safire's Political Dictionary* (Oxford; New York, NY: Oxford University Press, 2008), 380–81.

[5] Vincent Teresa, *My Life in the Mafia* (New York, NY: Doubleday, 1973), 308.

you can return it to its zero-point as a blank tool of exchange. In the case of ill-gotten or ill-spent money, traceability and cleanliness are at odds.[6]

Anyone working with collections of data, large or small, will recognize the importance of maintaining a "clean" data set. Cleaning in this case involves the removal of extraneous, erroneous, or inconvenient elements from a database to create usable and verifiable data. In financial operations "data scrubbing" or "data cleansing" removes extraneous information from different sources (news reports, official documents, etc.). Sometimes this is as simple as rendering data in the same unit (e.g., gold, silver, or a national currency).[7] In any case, cleaning is a necessary and laborious part of making data commensurable and usable.

In their account of Irving Fisher's attempts to represent economic models, Mary Poovey and Kevin Brine excavate the laboriousness of data cleaning.[8] The practice of bringing disparate data points into relation, of finding common units, and scrubbing extraneous information is a manual, tedious, and repetitive process. Similarly, we can imagine money launderers like Lou Poller or Maurice Stans—who kept the record of Nixon's laundered money—bent over their ledgers, deciding what bare minimum of data was necessary to keep for their own records and what could be effaced. To picture the

[6] Today, money laundering is referred to as both the so-called "Achilles's heel of organized crime" and the Achilles' heel of capitalism. Raymond W. Baker, *Capitalism's Achilles Heel: Dirty Money and How to Renew the Free-Market System* (Hoboken, NJ: John Wiley & Sons, 2005); Michael E. Smith, *International Security: Politics, Policy, Prospects* (Basingstoke, Hampshire; New York, NY: Palgrave Macmillan, 2010), 192.

[7] Mary Poovey and Kevin R. Brine, "From Measuring Desire to Quantifying Expectations: A Late Nineteenth-Century Effort to Marry Economic Theory and Data," in *"Raw Data" Is an Oxymoron*, ed. Lisa Gitelman (Cambridge, MA: MIT Press, 2014).

[8] Ibid.

embodied practices of data cleaning, we can also imagine ourselves staring at a spreadsheet of grades, or ethnographic research, or bibliographic metadata, to carry out the time-consuming practice of moving between "DELETE" and "TAB" and "ENTER."

In the 17th and 18th centuries, European nations regularly faced currency crises related to the value of coinage and its referential relationship to any "true" value. The crises and the debates surrounding them concerned a question of mediation: should coins have intrinsic value and be based on the quantity of a precious metal that they contain; or, should a coin refer, instead, to a set quantity of a precious metal held elsewhere; or should the coin refer to a system in which there were a fixed set of coins? These debates return regularly in crusades for a return to the gold standard—campaigns that generate interest out of a fear that money, as it stands today, is not grounded in any true material value. One British solution to this problem, according to a 19th-century pamphlet, was anointing a standard coin as an ideal type and relieving each individual token of the need to carry intrinsic value:

> The standard should be one **clean piece of metal**, kept under the locks of some of the principal officers of state; and, I think, it should not be accessible to any one, without their personal presence, if not of a certain number of other privy-counsellors. All the use that there need be made of this standard, would be for the adjusting of duplicates or representatives of it, which might be kept in the several offices, as those things called standards are at present.[9]

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[9] John Ramsay McCulloch, Select Collection of Scarce and Valuable Tracts on Money from the Originals of Vaughan, Cotton, Petty, Lowndes, Newton, Prior, Harris, and Others, with a Preface, Notes, and Index, (London: Printed for the Political Economy

Cleanliness, in this case was a part of a larger system for maintaining a stable ground of value, which would only be called into use for rare occasions (the "adjusting of duplicates or representatives"). Cleanliness works in concert with a locked container, the authority of the state, and the network of standards descended from the original, clean piece of metal to establish a system of meaning that is supported by a documentary architecture and common set of protocols.

All of these practices—laundering, cleaning, washing, scrubbing—are a part of "data hygiene," an umbrella term I employ to describe the manual, laborious works of maintenance and repair that are necessary for bringing pieces of data into relation with other pieces of data. These relations of commensuration require that certain features be brought into focus (polished) while others are scrubbed clean off. The different uses of data hygiene—from high-stakes criminal enterprise, to national monetary standards, to the more modest housekeeping aims of data-set management—operate at different scales and with differing motivations. The criminal drive to launder money is an attempt to conceal its origins and its history while data hygiene in an Excel sheet could simply be motivated by a desire to check against human error. In each case, data hygiene is a contextually specific set of practices developed out of the need to reckon with the historicity of data. Whereas Sara Ahmed directs us to consider objects as "sticky"—"what it picks up on its surface 'shows' where it has traveled and what it has come into

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Club, 1856), [Online] Available from http://oll.libertyfund.org/titles/2060; Mary Poovey, *Genres of the Credit Economy Mediating Value in Eighteenth- and Nineteenth-Century Britain* (Chicago, IL: University of Chicago Press, 2008). Emphasis added.

contact with"—a data hygienic perspective is concerned with the ways that people work to conceal those travels and moments of contact.[10]

This chapter concerns a literal practice of data hygiene through a consideration of the International Prototype Kilogram and the protocols for keeping this small piece of metal clean. As the basis of the standard of mass in the metric system, the Prototype Kilogram is a unique object in the current state of measurement standards. Unlike other fundamental units, mass is based on a physical artifact and thereby harkens back to earlier times in the history of standardized units, like the 19th century's solution to debased currency. Since fundamental units are the lowest common denominators of commensuration, the kilogram is a special case: a physical artifact that is meant to serve as the shared and immutable reference point for an entire segment of measurement science. The International Prototype Kilogram (IPK) is an entry for seeing how reference materials are created and maintained. All technologies need cleaning; whether it is the filter in a water jug, the derogatory words in a language, or the heads of a LaserJet printer (see figure 8), cleaning is part of the genre of properly performing technology.

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[10] Sara Ahmed, *Queer Phenomenology: Orientations, Objects, Others* (Durham, NC: Duke University Press, 2006), 40.

Figure 8 - Not only is the printer's self-cleaning page a material representation of data hygiene protocols, it's also a perfect example of phatic communication: an expression that "merely ascertains the existence of the channel."[11] The text at the top of the page reads “This page is generated as a result of selecting the Print Cleaning Page menu item in the control panel. It helps maintain the excellent print quality of your HP LaserJet printer.” The cleaning page also corroborates the multifarious roles of paper in the maintenance of technologies and standards.

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[11] Bernhard Siegert, *Cultural Techniques: Grids, Filters, Doors, and Other Articulations of the Real*, trans. Geoffrey Winthrop-Young (New York, NY: Fordham University Press, 2015), 41.

Reference materials are basic, working objects, meant to be ready-at-hand, easily called into action, used, and unquestioned. In this way, they are compatible with Loraine Daston and Peter Galison's definition of "working objects":

> All sciences must deal with the problem of selecting and constituting "working objects," as opposed to the too plentiful and too various natural objects. Working objects can be atlas images, type specimens, or laboratory processes—any manageable, communal representative of the sector of nature under investigation. No science can do without such standardized working objects, for unrefined natural objects are too quirkily particular to cooperate in generalizations and comparisons. Sometimes these working objects replace natural specimens…[12]

Working objects are a necessity of scientific practice. Reference materials are a pragmatic solution to the need to control experimental conditions and measurement operations by choosing proxies to stand in for other objects. The emphasis here is on "choosing" and "standing in," two processes that are not simple to execute, maintain, or trust. The proxy logic of reference materials follows a classification process of deducing that some objects are of-a-kind. This likeness is a kind of universalization from the particular, where objects surpass their atomized existence.

Like many standards before and after it, the Prototype Kilogram is meant to represent political ideals. The Kilogram, as part of the original metric system, is derived from a scientific endeavor situated in the depths of the Enlightenment and is founded on French Republican ideals of democratic measures that were based on "invariants of

[12] Daston and Galison, *Objectivity*, 21–22.

nature" instead of the arbitrary whims of kings, lords, or merchants. Choosing a proxy object, then, can be as seemingly straightforward as selecting a picture of a cumulous cloud that looks the most cumulous-like, or as high-minded as picking a piece of metal that is the least monarchical.[13] The choice of proxies is a choice of a standard against which subsequent objects will be judged. The choice of a cloud picture can be based on a value of typicality—a representational assessment of one image of one cloud and its relationship to the regular appearance of other clouds. A choice to base a measurement system on the "invariants of nature"—like the earth's circumference or atomic vibrations, or the speed of light—is a search for stability. In each case, the measurement tool is chosen for an ideological reason about how the world is and how it ought to be. By divorcing measurement standards from the whims of kings and their emissaries, the creators of the metric system were declaring that not only should measurements be based in physical constants that weren't under the control of any individual, but the scientific community should be the locus of that decision. "Typical" images, similarly, divorce the decision of what is "ideal" or "normal" from aesthetics and remake it as a decision based in observational expertise about the regular distribution of appearances.

In addition to its origins in a Republican project aimed at creating truly democratic standardization, the Prototype Kilogram is not a normal kind of working object. It is specifically not meant to be ready-at-hand but rather nearly impossible to access. This inaccessibility is what maintains its authority as a ground of value for an

[13] Alder, *The Measure of All Things: The Seven-Year Odyssey and Hidden Error That Transformed the World*; "Revolution to Measure: The Political Economy of the Metric System in France," in *The Values of Precision*, ed. M. Norton Wise (Princeton, N.J.: Princeton University Press, 1995).

entire global system of mass measurement: it is safely kept so that other kilograms can be ready-at-hand as trustworthy representatives of the Prototype Kilogram. Yet, when it is withdrawn from its safe enclosure to be cleaned it becomes a working object; hygiene is what connects the Kilogram's idealism with its realization as a scientific instrument.

Data hygiene is a condition of commensurability. Cleaning, washing, scrubbing, and cleansing data are part of the conventions that make standards feasible. Most often, data hygiene protocols come prior to the work of standards and, by necessity, before operations aimed at producing commensuration. Hygiene protocols are, therefore, best understood as a form of conditional operability. As research objects, hygiene protocols are tricky, since if they are successful, they will be hard to detect. Just as the mob might launder money through legitimate businesses, other data hygiene protocols aim to wipe away their own presence. What is the trace of tracelessness? It becomes the memory of the trace's erasure. For the researcher concerned with data hygiene, the question becomes locating the memories of those traces, the methods of erasure, and the legacies of cleanliness.

In the case of the International Prototype Kilogram, the data hygiene is memorialized in the protocols for washing and cleaning a standard by hand. At the top of this chapter is a rendering of how to wash and clean a kilogram based directly on the officially sanctioned techniques for washing kilograms. The traces of these protocols, if not left on the kilograms themselves, are found in the documentary support for maintaining kilograms, in the metrology journals where scientists debate the best way to clean a kilogram, and in the hands of the kilogram's keepers—hands whose strictly choreographed motions return the IPK to a state of cleanliness.

Sporting the French designation *nettoyage et lavage* (cleaning and washing), the hygiene protocols for the IPK are a response to the object's particular history and its position atop a referential hierarchy. The "lifespan" of the IPK is characterized by a conventional materialism, unique longevity, institutionalized aura, and the environmental contaminants endemic to a scientific milieu. This is to say, the IPK is a privileged case in the history of measurement standards that nonetheless demonstrates many of the basic features that reference materials share. It was selected and agreed upon by committee and convention and it is invested with self-referential importance such that it could not be replaced without rewriting the metric system; and, yet, it is compromised by developments in measurement technology that can now detect the tiny changes in mass that accumulate on any piece of metal—changes that are also specific to a piece of metal housed in a scientific institution. The history of the IPK, then, is both a general history of the manual maintenance of standards and a history specific to the material conditions and constraints of the Kilogram.

At some point in the near future the IPK will be replaced with a new standard, either a more stable physical artifact made of a material like silicon, or a paper standard—a recipe for realizing a kilogram under strict conditions. This is despite the fact that, as the former head of the institution that oversees the metric system argues, "There is no evidence of there ever having been a problem with mass measurement or measurement of any other physical quantity whose unit depends on the kilogram that could be attributed to defects in the system."[14] So until the IPK is replaced, researchers, scientists, and bureaucrats will continue to debate techniques for cleaning it and reasons why its mass may have changed. In recent years, some have turned to trying to deduce the source of deviations between the IPK and its copies. It is suspected that the IPK and other mass standards increase in mass and one explanation includes the presence of atmospheric mercury used in other parts of laboratories.[15] Mercury, which may fall on floors and seep into the ground, eventually vaporizes and resettles in metals like the surface of the platinum-iridium IPK. Cleaning cannot prevent the eventual mass gains from mercury contamination. As Andrew Barry reminds us, in his politics of metallurgy:

> Metals are not the hard, inert objects that they are often thought to be. Metals form part of dynamic, informed assemblages in which the expertise of metallurgists and other material and social scientists have come to play a critical part. They have become "informationally enriched," and part of the driving force for this informational enrichment comes from growing efforts to regulate the properties of the materials and the actions of those who develop and use them.[16]

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[14] Terry Quinn, *From Artefacts to Atoms: The BIPM and the Search for Ultimate Measurement Standards* (Oxford; New York, NY: Oxford University Press, 2012), 341.

[15] Peter Cumpson Peter and Sano Naoko, "Stability of Reference Masses V: Uv/Ozone Treatment of Gold and Platinum Surfaces," *Metrologia* 50, no. 1 (2013); P. J. Cumpson and M. P. Seah, "Stability of Reference Masses I: Evidence for Possible Variations in the Mass of Reference Kilograms Arising from Mercury Contamination," *Metrologia* 31, no. 1 (1994).

[16] Andrew Barry, "Materialist Politics: Metallurgy," in *Political Matter: Technoscience, Democracy, and Public Life*, ed. Bruce Braun and Sarah Whatmore (Minneapolis, MN: University of Minnesota Press, 2010), 90.

The Prototype Kilogram embodies Barry's view of metals: the hard shell of platinum-iridium is shown to be porous and the practices of the Kilogram's handlers are deeply encoded with more than a century's worth of history—an informationally rich protocol drives the need to wipe traces of the environment from the Kilogram. The Kilogram is an artifact of a previous era's understanding of the invariants of nature. Its materiality was meant to guarantee its authority as a ground of value, as a physical anchor for the signifier "kilogram." No signifier is stable and all signifiers undergo maintenance and repair to rebuild and keep up their relationships to their referents. This is the politics of language. In material referents, symbolic maintenance and repair becomes quite literal.

The IPK is defined only with reference to itself—the definition of the kilogram is the mass of the IPK—and, as a result, hygiene protocols for the kilogram are focused on returning it to a stage of most self-likeness. This is a curious and ad hoc process that reveals the haphazard and often flukey ways that standards persist.[17] As the history of the Kilogram indicates, there is a basic discomfort with the provisional nature of data hygiene protocols. They give lie to the claim that test data operate hermetically and objectively by providing access "to the pure technological realm."[18] Yet, paradoxically, data hygiene is a necessary, though not sufficient, condition of commensurability. This chapter charts how standards-keepers came to washing kilograms through the history of

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[17] Turnbull, "The Ad Hoc Collective Work of Building Gothic Cathedrals with Templates, String, and Geometry."

[18] Trevor Pinch, ""Testing - One, Two, Three... Testing!": Toward a Sociology of Testing," *Science, Technology, & Human Values* 18, no. 1: 25-26.

the Kilogram's provenance and the makeshift ways that it maintains its position atop a referential hierarchy.

This chapter introduces a number of terms that are necessary for understanding how standards work; specifically, the International Prototype Kilogram provides an introduction to "traceability," conventional materialism, arbitrary precision, and the material representation of a theory of measurement. The International Prototype Kilogram is a physical artifact and the foundation of the metric system's standard of mass. Because of its artifacticity, the prototype kilogram is subject to an array of manual rituals that keep it viable as the basis of a measurement system. This chapter uses the IPK to illustrate some common features of material reference standards and the protocols and rituals of maintenance and repair that make standards possible.

The International Prototype Kilogram

The International Prototype Kilogram is a 39mm-tall, platinum-iridium cylinder, housed in three nested, vacuum-sealed, glass bell jars and locked in a vault on the outskirts of Paris.[19] Access to the IPK requires three separate keys, kept by three separate individuals.[20] If Hollywood films are to be believed, it is more difficult to access the International Prototype Kilogram (3 keys) than to launch a nuclear missile from a

[19] Quinn, *From Artefacts to Atoms*.

[20] Specifically: "one of these is kept by the Director of the BIPM [Bureau International des Poids et Mesures], one is in the possession of the President of the CIPM [Comité International des Poids et Mesures] and the third is held by the Archives de France." Richard Davis, "The SI Unit of Mass," *Metrologia* 40, no. 6 (2003): 300.

submarine (2 keys).[21] The security is necessary to guarantee that this one piece of metal is safe and, more practically, uncontaminated.[22] The International Prototype Kilogram—represented more elegantly by its symbol 𝔎—is the basis of the unit of mass in the International System of Units. The International System of Units is abbreviated SI and more commonly known as the metric system, though the equation of the two is misleading. When I write 𝔎 please imagine I have written "the International Prototype Kilogram."

𝔎 is afforded its own special symbol because it is a unique object; though it has siblings and descendants, it is special among its kind. Further, 𝔎 gets its own symbol because of its use in mathematical calculations. Like π (pi) or Ω (ohm), 𝔎 is a fixed value used in the calculation of other values. 𝔎, for instance, is used in the calculation of Ω. Unlike π or Ω, however, 𝔎 does not refer to an abstract figure but, instead, to a physical

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[21] In the 1980s, three keys were required to launch a Trident (nuclear) missile from a United States Navy submarine. But in the image below, Captain Marko Aleksandrovich Ramius (Sean Connery), Commanding Officer of the Soviet submarine Red October has ominously acquired the two keys he would require to launch a missile. *The Hunt for Red October*. Directed by John McTiernan (Hollywood, CA: Paramount, 1990). See also: Gerald Marsh, "Skirting Human Error: The Navy's Missile Launch System,' *Bulletin of Atomic Scientists* 43, no. 1 (January 1987): 38.

[22] Davidson Stuart, "A Review of Surface Contamination and the Stability of Standard Masses," *Metrologia,* 40, no. 6.

artifact. The most important aspect of $\mathfrak{K}$ is that all kilograms refer back to it; the most complicated aspect of $\mathfrak{K}$ is that it no longer points back to other objects. Imagine $\mathfrak{K}$ as the beginning of the phone tree. $\mathfrak{K}$ is a ground of value with no ground beneath it.

The referential relationship between $\mathfrak{K}$ and other kilograms is called "traceability." Traceability is a term used in a wide range of disciplines, operations, and practices. Genealogy uses a kind of traceability, so does forensics. In measurement science, metrological traceability refers to

> a property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.[23]

Two things to note: first, metrological traceability deals in a logic of material presence. The unbroken chain of calibration means that each kilogram in the chain of kilograms must have been compared, side-by-side, to a kilogram one level above it in the hierarchy of kilograms. Second, each step away from $\mathfrak{K}$ adds to the uncertainty of each kilogram's precise mass. Traceability is the combination of calibration and citation: an operation that leaves a trace. "To say that a package of butter weighs a pound means that it has been connected by some long and complicated series of comparisons to The Kilogram in Paris, and weighs 0.4539237 times as much."[24] In practice, this means that a local inspector possesses a "working standard" that is checked against, for example, county, state, or

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[23] Joint Committee for Guides in Metrology (JCGM), "International Vocabulary of Metrology (VIM), 3rd Ed," (2008), 241.

[24] David Freedman, Robert Pisani, and Roger Purves, *Statistics* (New York, NY: W.W. Norton, 2007), 98.

national prototypes, so that she can verify a scale in a grocery store—a practical mass measurement instrument—with the knowledge that the standard is traceable to $\mathfrak{K}$. Most national laboratories have prototypes that are traceable to $\mathfrak{K}$ and these are referred to as "secondary standards," which are calibrated through direct comparison with each other or $\mathfrak{K}$, the primary standard. National laboratories, which are government agencies responsible for maintaining scientific, technical, and sometimes consumer standards are responsible for checking their standards against those kept by international bodies. They also disseminate mass standards to lower positions on the hierarchy. This dual role of national laboratories is necessary for their accreditation.

Traceability, understood as calibration + citation, appears to be an anti-hygienic practice; it is the opposite of money laundering as it aims to leave a fully documented history of traceable co-presence. Unlike money laundering, which aims to return money to its fungible state, traceability attempts to quantify, document, and disseminate the difference between individual pieces of metal. Yet, it is also a hygienic operation. Not just any traceable difference will suffice. The kilograms involved in the traceable hierarchy of mass standards need to have as low an uncertainty as possible. For this reason, a system of keeping the mass standards as stable as possible—starting with $\mathfrak{K}$—is necessary for keeping traceability clean.

Figure 9 - Traceability in the wild. In this case, proof that a scale at a New Jersey location of a popular chain of upscale grocery stores was recently inspected. The scale was at a bread counter where goods are not sold by weight. The scale is used, however, for printing out labels for bagged bread. Similar stickers are seen on any scale that an employee operates (deli, butchery, fish, etc.) and on the scales used by cashiers. This interdependent network of inspected scales guarantees that the measurable weight of goods is consistent from the initial point of measurement (the deli counter) to the point of purchase (the cashier).

Like *all* standards, the choice of 𝔎 over other pieces of metal (or glass, or wood, or water) is entirely arbitrary. But unlike *most* standards, 𝔎 was specially planned, designed, and treated in ways that are meant to transcend this arbitrariness. 𝔎 embodies a *conventional materialism*. All standards are conventional and all standards contain material aspects. But objects like 𝔎 embody a conventional materialism when the material specificities (metallic composition, artisanal crafting, ritualized storage) subtend the standard itself. There is no mass standard from 1889 to 2015 (and counting) without worldwide agreement over the material specificities of 𝔎. So although the choice of materials, shapes, sizes, and compositions may be arbitrary, the choices matter and the choices solidify in objects that need maintenance. Cleaning and washing the kilogram is one way that the profane and the transcendent, the arbitrary and the necessary, are mediated in 𝔎. But some background on the metric system is necessary to understand how this mediation works.

If in their most basic form standards are a set of "fixed points" the metric system, despite its Enlightenment bluster, is no different.[25] Fixed points are an extension of the logic subtending standards. As discussed in the introduction, standards rely on "arbitrary precision," which is to say they are *first* arbitrary*, and then* precise. In American football, referees place the ball on a line at the end of each play by basing the measurement on their split-second judgment of a tackle and determining exactly where the football stopped moving forward. This location becomes the fixed starting point of the next play. In some instances, a set of ten-yard chains is brought on to the field to measure the ball's

[25] Chang, *Inventing Temperature*.

progress.[26] Why employ a precise measurement instrument when the first judgment was so imprecise? This is the logic of arbitrary precision: decisions must be made to situate fixed points in certain positions and use those fixed, certain positions to make further judgments. Protocols like the referee's locating of the football are part of the rituals that go into making standards appear objective. In another sense, fixed points work as "necessary fictions": standards need any kind of starting points to begin the work of standards-making. This dissertation is, above all else, fixated on the material specificities of those fictions and the fictionalizing work of scientists, bureaucrats, and engineers.

The metric system is, by almost any measure, the most wide-reaching set of measurement standards in history—it is, in other words, the most comprehensive set of fixed points in existence. Among modern standards, it is also one of the longest lasting, having been in force in some form since 1799. And many of the protocols surrounding the metric system established the means through which international standardization efforts could take place. Tellingly, the 1798–99 "Congress on Definitive Metric Standards", organized by the French government, was the first international scientific conference of any kind.[27] In many cases, the fixing of points is a highly complex and contentious affair. At other times, a standard is simply imposed for the sake of having any kind of shared reference parameters. For example, prior to the creation of the metric system, the pre-Republican, French Ancien Régime believed that the flourishing of the British economy was due to their standard measurement system and that the French lack

[26] This particular thought problem comes from a discussion with Jonathan Sterne.

[27] Maurice Crosland, "The Congress on Definitive Metric Standards, 1798–1799: The First International Scientific Conference?," *Isis* 60, no. 2 (1969).

of any such system prevented them from participating in the kind of frictionless trade possible in Britain.[28] A uniform system of measurement, the monarchy's chief minister of the nation believed, could solve the national food crisis, and so he recommended declaring the local Parisian set of measurements the new national standards. "A modern nation needed a standard, any standard, and the surest course of action would be to declare the units used in Paris the national units."[29] Instead, the metric system's development coincided with the revolution and became a symbol of the egalitarian possibilities of non-authoritarian rule. Instead of declaring the monarch's measurements as the standard, the Academy of Science wanted a universal measurement based on the "invariants of nature." Hence, the meter was based on a fraction of the Earth's quarter-meridian: "They vowed to choose a set of measures which would 'encompass nothing that was arbitrary, nor to the particular advantages of any people on the planet;'" a set of measures that could establish "a uniform language for the objects of daily economic life."[30] In the metric system, choosing a necessary fiction as the starting point of a new measurement system encompassed the social, political, and economic possibilities of a nation on the brink of revolution and the very capacity of citizens and the state to share information.

The early years of the metric system were tumultuous, since they were an extension of the political upheavals of post-Revolutionary France. In these early years, a prototype meter and kilogram were produced using provisional measurements of the

[28] Alder, *The Measure of All Things*.

[29] Ibid., 21.

[30] Ibid., 19; Alder, "Revolution to Measure," 41.

meridian. Once the meridional measurements were complete "Le Mètre des Archives" and the "Kilogramme des Archives"—the provisional prototypes—turned out to be inaccurate derivations of the meridian. Yet, this imprecision was ignored in the same way a referee might ignore the imprecise placement of the football.

For nearly a hundred years the metric system ebbed and flowed in its popularity and enforceability. Despite being illegal in England (it was legalized in 1896) and the United States (1866) for much of the 19th century, the metric system grew into a singularly powerful standard through industrial adoption and military imperialism. Three factors, in particular, led to the metric system's ascendance:

> First, the growth of market exchange encouraged uniformity in measures. Second, both popular sentiment and Enlightenment philosophy favored a single standard throughout France. Finally, the Revolution and especially Napoleonic state building actually enforced the metric system in France and the empire.[31]

While Napoleonic conquest is often credited with the metric system's success, recent research has highlighted the role of industrial standardization. Beyond mere "market exchange," international expositions became major trading sites and stages for the benefits of standardization.[32]

The metric system's next leap came in 1875 with the signing of the Metre Convention. The Metre Convention took place in Quai d'Orsay and lasted from March 1

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[31] James C. Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven, CT: Yale University Press, 1998), 30.

[32] Robert P. Crease, *World in the Balance: The Historic Quest for an Absolute System of Measurement* (New York, NY: W.W. Norton, 2011).

until May 20 of that year. Over those seven weeks, attendees planned the creation and maintenance of new reference standards for the meter and the kilogram.[33] This meant deciding on the design and selection of new physical artifacts as well as the establishment of a new bureaucracy to oversee the system. As to the latter, the convention established three institutions: the Conférence Générale des Poids et Mesures, the CGPM, which acts as the general assembly of all signatories to the Convention and meets every four years; the Comité International des Poids et Mesures, the CIPM, which is a kind of security council to the CGPM, meeting every year and guiding decisions about measurement standards; and the Bureau International des Poids et Mesures, the BIPM, which is the physical manifestation of the convention, a set of laboratories and offices in the suburbs of Paris, in Sèvres. Together, these institutions are responsible for guiding changes to the future of metrology and providing commensuration protocols: methods for establishing equivalences between national measurement standards.

Until 1921, the metric system was synonymous with the standard units for mass and length. The 1875 Metre Convention approached the open question of whether or not the Mètre des Archives and Kilogramme des Archives would serve the bases of the new standards, as the intervening decades had shown these standards to be far from true derivations of the invariants of nature on which they were supposedly based. Yet, the attendees decided to use the Archives units and to produce new prototype meters and kilograms as facsimiles. When it came time to compare the new kilograms with the

[33] Quinn, *From Artefacts to Atoms*.

Kilogramme des Archives, the measurements were carried out in the grand hall of the Paris Observatory, through which the meridian passes.[34]

A British assayer and refiner, Johnson & Matthey Company, was chosen by the CIPM to produce thirty prototype meters and forty prototype kilograms to serve as national reference standards for signatories of the convention.[35] The first three kilogram prototypes were produced together and, as such, 𝔎 is one of three "identical" artifacts, chosen for having the smallest measurable difference to the Kilogramme des Archives. "Identical" is tentatively used here since 𝔎 is vested with its position atop the hierarchy of mass measurements precisely because it is not identical to any other object. Yet, likeness is the goal of the kilogram system—the purpose being to create more objects that are *like* 𝔎—and, as a result, 𝔎 is surrounded by objects with similar biographies. This is key, because material specificity should not be considered as a mere accounting of properties. The history of objects also constitutes their composition, including where they were made and their situatedness in particular settings (open or closed doors, the humidity of the air, the ways they've been handled). To access 𝔎 is not just to measure the object and compare its mass to other kilograms; accessing its material specificity requires knowledge and testimony of its history. To this end 𝔎 is joined in its Parisian vault by six other "check-standard" kilograms, called *témoins* (witnesses). The wording here is important. The meaning of *témoin* or *témoinage* (witnessing) in French is comparable to the English. The witnessing kilograms are meant to attest to changes in 𝔎.

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[34] Ibid.

[35] Johnson & Matthey was the Assayer and Refiner of the Bank of England. Davis, "Recalibration of the U.S. National Prototype Kilogram."

They do not do this through eyewitness accounts or oral testimony, but rather they attest to changes in 𝔎 by being brought into measurable comparison. The only knowledge we have of 𝔎's absolute mass comes from comparisons conducted with a mass comparator. A mass comparator is like a kind of scale that *only* measures differences between two objects. The witnesses' bona fides are established through a shared history and through their identity as kilograms: they were produced from the same metallic alloy, from the same refining company, some at the same time as 𝔎 and some in the years after, and they are housed in the same environment, the same vault, with the same air, and the same exposure to light. According to the BIPM, any factor that is shared by 𝔎 and its witnesses can be ruled out as a factor contributing to changes in 𝔎.[36] 𝔎 is afforded more care and attention than most measurement tools but the use of *témoins* and the attempt to control for 𝔎's historical specificity—to identify what is special to it that might explain some change in mass—highlight a facet of commensuration in all measurement operations: measurement is a process of developing conditions for identifying difference.

In 1889, fourteen years after the Metre Convention, it came time to vest the prototypes and the *témoins* with the imprimatur of the institution at the first Conférence Génèrale des Poids et Mesures (First General Conference on Weights and Measures). During the "troisième séance" (third session) of the Conférence Génèrale, the attendees entombed 𝔎 along with 𝔐, the prototype meter. The two would serve as the basis of the Metric System but needed to be sanctioned by the attendees of the Convention.

[36] From the BIPM's Frequently asked questions about the international prototype of the kilogram http://www.bipm.org/en/bipm/mass/faqs_mass.html

In the early afternoon of September 28, 1889 the attendees of the Conférence gathered to enclose the new prototype meter and kilogram. The minutes from the session describe the process as "*enfermer*," which translates in a number of ways: to enclose, lock up, or sequester. Peter Galison translates this act as "burial" and "interment," which exaggerates the inaccessibility of the prototypes to future access, while simultaneously highlighting the ritual nature of the event. Eight objects were enclosed that day: 𝔎 and 𝔐 were joined by two *témoins* each, as well as a thermometer, and a copy of the report describing the ritual. The system of objects created a circuit of referentiality, with each piece pointing back to another: the report signifying the consecration of the objects, the thermometer attesting to the fact that the objects are kept at a stable temperature (that of melting ice), the *témoins* as corroborators of the prototypes, and the prototypes as embodiments of the measurement system's authority.[37] The entire vault was locked by three keys, behind an outer door locked by an additional two keys, and the keys were distributed to three separate officials.[38] Like Jacques Derrida's teasing of the Declaration of Independence, where he states that "The signature invents the signer," the Prototype Meter and Kilogram had no authority *until* they were hidden from view, locked in the dark with the document declaring their power. [39] This process, of burying objects with

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[37] "Comptes Rendus Des Séances De La Première Conférence Générale Des Poids Et Mesures", (1889); Peter Galison, *Einstein's Clocks and Poincaré's Maps: Empires of Time* (New York, NY: W.W. Norton, 2003).

[38] There was debate over which French governmental office was worthy of the key. "Comptes Rendus Des Séances De La Première Conférence Générale Des Poids Et Mesures."

[39] Jacques Derrida, "Declarations of Independence," *New Political Science* 7, no. 1 (1986).

reports, of locking those things away with keys to make them transcend their profane origins in a British foundry or a committee meeting, attests to the ritual, manual, and documentary conditions that enable, create, and maintain standards.

Kilogram hygiene

The ritual sequestration of $\mathfrak{K}$ and $\mathfrak{M}$ began a new era in the metric system. There was now widespread international agreement among a plurality of nations to assign foreign (Parisian) artifacts as the basis of their measurement systems. Even in the United States—a country famous for its refusal to use the metric system in civic measurements—the Metre Convention changed the meaning of standard units. America was an original signatory to the convention and in 1893 changed the definition of its customary units (feet, inches, pounds, ounces) to be based on fractions of the metric system. The lure of international commensuration was too powerful to resist. But the 1889 ritual enclosing gets short shrift in the history and philosophy of measurement. Focus, instead, tends to fall on the definitions of the meter and kilogram that followed after those artifacts were sealed into the vault. At the third Conférence Générale in 1901, the mass standard was defined explicitly:

> The kilogram is the unit of mass; it is equal to the mass of the international prototype kilogram.[40]

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[40] Bureau International des Poids et Mesures, *SI Brochure: The International System of Units (SI)*, 8th ed. (Paris, France: Stedi Media, 2006), 112.

This declaration meant that the kilogram, as a unit, is only ever the mass of 𝔎 and the mass of 𝔎 is always equal to one kilogram. By this definition, 𝔎 cannot produce a measurement error, as it contains no uncertainty.[41] This is the only way that it can serve as a stable ground for determining difference in other prototypes.[42]

This assertion of 𝔎's lack of inherent error is strictly conventional—a fact created by fiat. A "kilogram" has no natural meaning except that which is assigned by decree to one particular piece of platinum-iridium. Remember, for instance, that the original Kilogramme des Archives, a product of Enlightenment ideals and French Revolutionary politics, was based on both the measurement of the meter and the density of water. The meter, in turn, was based on a fraction of painstaking measurements of the earth's meridian. When later calculations showed that both the calculation of the meridian and the density of water were mistaken it had no effect on the future definitions of mass and length standards in the metric system. Path dependency, even in Enlightenment projects based on the so-called invariants of nature, can force a choice that crystallizes another form of knowledge—the organization and negotiation of bureaucratic decision-making. Path dependency is the fact that certain well-established standards "make it costly (in terms of money, skill, organization, and social networks) to shift to an

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[41] There is some equivocating on "uncertainty" in 𝔎. In one sense, the problems associated with the use of the Prototype Kilogram as a physical artifact are a result of the fact that the uncertainty in its absolute mass cannot be known. Quinn, *From Artefacts to Atoms*.

[42] Georges Canguilhem notes that in France in the 1930s, "normalization" was used in place of "standardization" as if the two had always been interchangeable. The IPK puts this elision into practice by making all non-prototype kilograms inherent deviations. Georges Canguilhem, *The Normal and the Pathological* (Brooklyn, NY: Zone Books, 1989), 247.

alternative development path since future actions are contingent on those taken in the past."[43] Objects seal in provisional, mistaken, hurried knowledge and assumptions about nature, behavior, and political process. The mass standard is more an index of political process (the conduct of international conventions, committee compromises, and local protocols) and a canned decision than it is an index of any natural quality of the earth.

The circular definitions of the mass and length standards, as based on the Prototype Kilogram and Meter, have produced no shortage of philosophical consideration.[44] Ludwig Wittgenstein turned to the International Prototype Metre to prove a point about the conventionality of paradigmatic thinking. He writes by way of example in *Philosophical Investigations* § 50*: "*There is one thing of which one can say neither that it is one metre long, nor that it is not one metre long, and that is the standard metre in Paris."[45] What Wittgenstein is arguing is that there are certain concepts or, in this case, objects that are paradigmatic and self-sufficient such that they create the standard by which other objects of that kind will be understood, measured, classified, and otherwise ordered. It would be easy to dismiss Wittgenstein as fundamentally misunderstanding or misstating the function of measurement—as some have done—but Wittgenstein and likeminded philosophers accurately expose both the conventionality of measurement and an aporia at the center of measurement standards.[46]

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[43] Busch, *Standards*, 61.

[44] Prior to its redefinition in 1960, the meter was based on the Prototype Meter. It is now based on the length of light travelling in a vacuum in a certain fraction of a second.

[45] Ludwig Wittgenstein, *Philosophical Investigations* (Oxford: B. Blackwell, 1953).

[46] Nathan Salmon, "How to Measure the Standard Metre," *Proceedings of the Aristotelian Society* 88 (1987). Why these philosophers usually choose the length over the mass

Comparison is a relational activity and commensuration is an act that builds on the basis of comparison to bring things into equivalence. This much is obvious. But beyond this redundancy, what can we say about the conditions of the relation between two things? How, for instance, can we say that two things are even separate things? We have methods for delineating such divisions—historical analysis, mechanical separation, measurement classification, etc. These are all conditions for creating comparisons. The Prototype Kilogram of 1889 is, in a sense, a different object than the prototype Kilogram of 2014. But an object cannot be compared with itself—we need methods for separating objects from each other *or* from themselves. As Natalie Melas argues, comparison implies both a *comparator* and a *perspective,* as all comparison is situated by who or what is doing the comparison and from what position in space-time. In comparative literature, the Western canon provided the background against which other literatures could be compared. In mass metrology, the kilogram serves that purpose.[47]

As Karen Barad writes, "there is something fundamental about the nature of measurement interactions such that, given a particular measuring apparatus, certain

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standards is not for me to say but Charles Peirce also turned to reference standards in explicating his science of signs: "A yard-stick might seem, at first sight, to be an icon of a yard; and so it would be, if it were merely intended to show a yard as near as it can be seen and estimated to be a yard. But the very purpose of a yard-stick is to show a yard nearer than it can be estimated by its appearance. This it does in consequence of an accurate mechanical comparison made with the bar in London called the yard. Thus it is a real connection which gives the yard-stick its value as a representamen; and thus it is an *index*, not a mere *icon.* Charles S. Peirce, *Philosophical Writings of Peirce*, ed. Justus Buchler (New York, NY: Dover Publications, 1955), 109.

[47] Natalie Melas, *All the Difference in the World: Postcoloniality and the Ends of Comparison* (Stanford, CA: Stanford University Press, 2007).

properties *become determinate*, while others are specifically excluded." [48] In the case of mass measurements in the metric system, 𝔎 appears to create the possibility for a determinate mass property in its traceable descendants; through traceability to 𝔎, other kilograms are leant the property of being kilograms. But with no ground of its own, 𝔎 cannot resort to traceability for its own determination. As Barad continues, she makes it clear that determinate properties are not grantable by fiat. Instead, she writes, "Which properties become determinate is not governed by the desires or will of the experimenter but rather by the specificity of the experimental apparatus."[49] 𝔎 gains its status as kilogram through a piece of circular logic, embedded in the written documentation for the metric system. 𝔎's statutory status as a self-sufficient measurement standard provokes a couple of uncomfortable questions: Can a decree be the grounds for determining a measurable property? Is the decree, in other words, part *or* parcel of a measuring apparatus? Changes that the BIPM made to the definition of the kilogram in subsequent years, short of answering these questions, show how the metrology community has, at least, struggled with their answers.

In its 1921 definition for the kilogram, the BIPM tried to obviate the need to determine the Prototype's mass through measurement and comparison. The self-sufficient definition vested the act of determining the kilogram's mass in the institutions of the metric system—in its conventions, practices, protocols, but also its vaults, bell jars, and keys. But the need to compare 𝔎 to its *témoins* created friction. By middle of the 20th

[48] Karen Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Durham, NC: Duke University Press, 2007), 19.
[49] Ibid.

century, BIPM officials were aware of the mounting problem of the Prototype's poor hygiene. Earlier I stated that the prototype kilogram, by definition, cannot contain uncertainty: it is, at all times, equal to one kilogram. This is, in practice, true. However, the kilogram does have an absolute uncertainty—a rate or amount by which its mass is increasing or decreasing—which could, in theory, be estimated through comparison to its *témoin*s though never determined with absolute certainty (simpler: we cannot be certain about its uncertainty). However, there is a more fundamental uncertainty that prevents this from occurring—an uncertainty that results from an untimely act of cleaning.

When Johnson & Matthey manufactured 𝔎 and the other forty original kilograms, the committee responsible for overseeing the production and the calibration by the artisan A. Collot, specified at which stages and in what ways the pieces of platinum-iridium were to be washed and cleaned.[50] At times this meant cleaning with some combination of steam, alcohol, or pure water. The final step, when manufacture was complete, was a steam bath.[51] (The apparatus used to clean kilograms from 1882 to 1889 is visible in figure 10). The kilograms were then left to dry out under a bell jar in the presence of the desiccant anhydrous potassium hydroxide. Great care and specification was put into the directions for precise hygienic treatment of the kilogram prototypes, yet no directions were provided for the upkeep, maintenance, and ongoing hygiene of the prototypes *after* manufacture. It is important to remember that in the mid-to-late 19th century, the possibility of a truly functional metric system was an unprecedentedly large

[50] Comité International des Poids et Mesures (CIPM), *Procès-Verbaux Des Séances De 1882* (Paris: Gauthier-Villars, 1883); Quinn, *From Artefacts to Atoms*.

[51] Quinn, *From Artefacts to Atoms*.

standardization project. Though most countries, municipalities, and merchants had experience with their own reference standards, little thought had ever been paid to how a reference material would be maintained for a longer period and in a verifiable way.

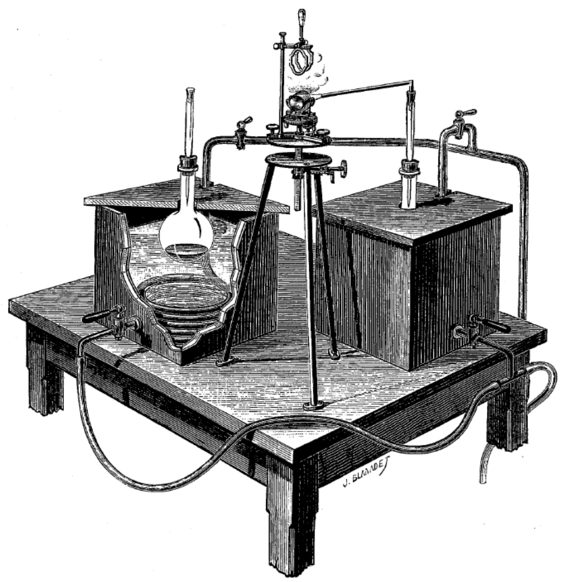

Figure 10 - Apparatus for cleaning prototype kilograms from 1882–1889. Steam and alcohol vapor were directed alternately at the kilogram.[52]

Hence, there was no mention of cleaning kilograms again until 1939. At this point Albert Bonhoure investigated the effect of cleaning on the mass of platinum-iridium kilograms. He used a chamois leather cloth, soaked in ethanol and then in redistilled petrol, and rubbed all surfaces of the cylinder. While World War II interrupted his investigations, in 1946 Bonhoure cleaned $\mathfrak{K}$ and its témoins. However: Bonhoure cleaned the kilograms before noting their masses and how each compared to the other. This

[52] Girard, "The Washing and Cleaning of Kilogram Prototypes at the BIPM."

untimely act of *nettoyage* wiped the traceable history of measureable contamination off of the Prototype and its official copies. This decision of Bonhoure to clean before measurement fundamentally changed the capacity to quantify the uncertain relationship between 𝔎 and its descendent kilograms.[53] Data hygiene, in other words, is a set of manual protocols for maintaining the authority of data, for hiding its traces, or for eliminating errors, but there is also a temporality to these protocols. Once 𝔎 was cleaned, cleanliness became a part of its history, a pivotal moment that altered its commensurability with other objects. The history of its hygiene then became a crucial part of accounting for its materiality. But by mistiming the act of cleaning—by wiping, then measuring—Bonhoure left a gap in the documentary regime that maintains 𝔎's authority as a ground of value.

Despite this untimeliness the BIPM extended Bonhoure's new cleaning protocols to all kilograms that were sent to the BIPM for verification; the only provisional remedy to the erasure of 𝔎's history was to scrub the objects it was compared with. There have now been three "periodic verifications" of 𝔎 and the national standards that are descended from it. These verification periods last many years (the first lasted from 1899–1911, the second from 1947–1954, and the third from 1988–1992). During these verifications members of the Metre Convention are invited to send their national prototypes to be verified by the BIPM against 𝔎 and the BIPM's other working standards. By means of rotating comparison, BIPM scientists can deduce changes of mass in national prototypes and these changes can be registered in measurements going

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[53] Ibid.; Quinn, *From Artefacts to Atoms*.

forward as innate errors in those prototypes. The verifications also allow for the possibility—with no absolute certainty—of deducing estimated mass changes in 𝔎.

The third periodic verification allowed for the greatest comparison between secondary standards, 𝔎, and its *témoins*, and it became a staging ground for developing a more complete standard for cleaning and washing kilograms. The comprehensiveness of the third verification was enabled by (among other things) the ease of overseas travel. Previously, circulation was a major hindrance to comparison as the travel threatened to contaminate the standards. Objects in comparison can only be compared if they can be made present together. And easy co-presence for a measurement standard that is dispersed around the world is only a possibility of the past couple of generations. In fact, circulation began as a condition of commensurability but transformed into a non-negligible factor in the measurement apparatus: new techniques for holding kilograms are added to techniques for cleaning kilograms and the effect of transportation on mass is now quantifiable.[54]

Above all else, the third verification allowed for the issue of cleaning and washing to be "addressed in a more searching way than had been done previously."[55] The technique developed by Girard, through the third verification, is described in the opening pages of this chapter and describes a method for *nettoyage et lavage* that cleanses the surface of the kilogram while doing no damage to the prototype. In 1989, cleaning shifted

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[54] Davis, "The SI Unit of Mass." Transportation is also considered in the ways that mass standards are handled, so as not to create too much air turbulence. "Recalibration of the U.S. National Prototype Kilogram."

[55] "The SI Unit of Mass," 303.

from a supportive protocol in the maintenance of mass standards to become a constitutive part of the kilogram's definition. Henceforth, the kilogram would be defined by reference to 𝔎 *immediately after cleaning.* The full definition reads as follows:

> ***The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.***
>
> *It follows that the mass of the international prototype of the kilogram is always 1 kilogram exactly, m(𝔎) = 1 kg. However, due to the inevitable accumulation of contaminants on surfaces, the international prototype is subject to reversible surface contamination that approaches 1* **μ***g per year in mass. For this reason, the CIPM declared that, pending further research, the reference mass of the international prototype is that immediately after cleaning and washing by a specified method.*
>
> *The reference mass thus defined is used to calibrate national standards of platinum-iridium alloy.*[56]

The standard is therefore not defined by reference to its Enlightenment ideals—the transcendence of nature's invariants—but rather in reference to 𝔎's own history and the makeshift methods for mediating between its environment (contaminants) and its original alloy (platinum-iridium). In this formulation the CIPM appears to understand and incorporate (though mildly) Barad's statement against the whim's of the scientist. The documentary history of the mass standard shows a growing awareness that 𝔎'ʻs milieu

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[56] Bureau International des Poids et Mesures, *SI Brochure: The International System of Units (SI)*, 112.

and the manual protocols for maintenance are as much a part of the object as its finely tuned crafting and ritual encasing.

Data hygiene, as an analytic term, is meant to illuminate the work of maintaining standards: of choosing some features to polish and focus on, while scrubbing and concealing others. If, as Martha Lampland and Susan Star write, standards presume the "ability to constrain a phenomenon within a particular set of dimensions," then hygiene is a method for maintaining those constraints and responding to new dimensions as they develop. If initial considerations of 𝔎's material specificity concerned its metallic alloy, the reputation of its makers, and the security of its enclosure, then current concerns have turned to the contaminants of its environments, its circulation, and the potential (or lack of potential) to account for its history when it is compared to its sibling kilograms.

Consider its most recent change: 𝔎 has moved homes to a new vault. In 1889 the Prototype Kilogram and Meter were buried together in the same safe, an act that compelled a "cascade of rituals" that included the redefinition of the kilogram to incorporate a manual, hygienic practice.[57] From 1889 to 2002 the standards were kept in that same safe. In 2002, the "safe was replaced by a new modern one because the old one was becoming increasingly difficult to open."[58] "There is a problem with doors," Bruno Latour reminds us. The problem of doors, the "hole-wall dilemma," animates the negotiated treaties between people and technologies.[59] Such a treaty is on display in

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[57] Jackson and Ribes, "Data Bit Man: The Work of Sustaining a Long-Term Study."

[58] Quinn, *From Artefacts to Atoms*, 173 (plate 31).

[59] Jim Johnson [Bruno Latour], "Mixing Humans and Nonhumans Together: The Sociology of a Door-Closer," *Social Problems* 35, no. 3 (1988).

Sèvres, where maintaining standards is conditioned by the physical abilities of scientists. In this case keeping pace with an increasingly creaky and difficult door required the displacement of the kilogram. And since the kilogram's milieu in fact changes its measurable mass and composition, this particular door problem will have a material effect on the mass standard. In other words, it is a given that the kilogram will change in mass. How it changes and with what intensity will always depend on where it is kept. Decisions about where to keep it will not determine whether or not it changes but will have material effects on how it changes. In this case, however, the decision was based on bodily accessibility and the implications for the kilogram are not yet known.

Figure 11 - The International Prototype Kilogram, its six official copies, and the previous physical artifact standard of the meter in its old safe.[60]

[60] Quinn, *From Artefacts to Atoms,* plate 31

A trip to Canada

In the 19th century, the United States possessed two yard sticks that it used as standard references for length in its system of customary units: Bronze no. 11 and Bronze no. 57. The yards were presented to the American Office of Weights and Measures (OWM) by the Astronomer Royal of the United Kingdom after the original British standards were destroyed in the parliamentary fire of 1834. Throughout this period the measurement of length and space in the United States was meant to be traceable to the reference standards housed at the OWM, which were in turn traceable to the prototype standards in London.[61]

Bronze no. 11 was the standard yard for the United States from 1857 to 1893 (when it signed on to the metric system) and no. 57 was its check-standard, a sibling yard used to gauge how standard yard no. 11 changed in shape over time. When the Astronomer Royal furnished the yards, he noted that the two differed by 0.00026 inches.[62] This difference was recognized as the fundamental divergence between the two yards, against which further divergences could be measured. But the two yards were not re-measured again until 1876–1877, at which point the OWM faced a harsh reality: they didn't know how the yards had changed. "The comparisons of 1876-77 establishing beyond doubt the fact and the amount of the change in their relation, it became important to ascertain which one had changed length or whether the change was partly in both."

[61] Bureau of Weights and Measures US Coast Survey, "Comparison of Standard Well Yeards Bronze No. 11, Bronze No. 16 and Dominion Standard A. Ottawa, Canada. May and June 1877," (1877). From National Archives II, Records of the Office of Standard Weights and Measures 1830–1901.

[62] Ibid.

Was the difference in the standard yard, no. 11, or in its sibling, no. 57? Or had they both changed?

The American Bronze yards were representations of British originals and their presence in the United States established a traceable linkage to British Imperial units and the ultimate authority of British standard yards. But the failure to monitor the American yards over a twenty-year period disrupted the linkage between the United States and Britain, leaving the American yards adrift, across the Atlantic Ocean, without a ground for establishing their value. Moreover, travelling to the United Kingdom was not a viable option for either the yards or their keepers as changes in temperature and atmosphere on the ocean threatened to mutate the yards even further. Instead, the American standards' keepers organized a trip to Upper Canada, to visit the Canadian standard yard, "Dominion Standard A." The next best emissary to actually visiting the United Kingdom was visiting a colony, as measurement hierarchies tend to reflect political cartographies.

For six days from May 26 to June 1, 1877, the Canadians and Americans compared their sticks in the basement of the Parliament Building. Here is a detailed account of the measurement conditions:

> The illumination was obtained sometimes by daylight, sometimes by the use of illuminating lamps. The manner of illuminating appears to have no marked effect upon the results and though generally noted is not regarded.

> The temperature was very uniform throughout the observations. The bars being all of the same material, shape and size, the variations of temperature, though recorded, are not taken into account in the reductions.[63]

Here is the documentary support for making objects commensurable. They note the factors that are observable and measureable (light, temperature) while rejecting them as factors since the objects themselves are so close in material that they must share in the effects of the atmosphere. However, they note, on the first day, May 26, the observations had to be rejected:

> The sun having shone upon the apparatus for some time in the early morning and the observations being intended as experimental and for practice.[64]

The apparatus, unfortunately, was swollen from exposure to the contaminating sun. *These are the dangers of enlightenment.* But notice, also, the embedded statement in this excuse, that these observations were intended "for practice." The account records the embodied rehearsal of measurement. Bodies too are a part of the experimental apparatus and must be trained in the manual processes of registering observations.

This is a story about the material specificity of making measurements. The story of American standard measurements is hemmed by the geographic contingencies of the 19th century. But it is also propelled by the need to create meaning from the standard yardstick through comparison. The capacity of prototypical reference materials to be primary referents in measurement systems is determined by the conditions for bringing

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[63] Ibid., 3–4.
[64] Ibid., 4.

them into relation with other like-objects. Material reference standards are unknowable in and of themselves. Yet bringing them into relation is not a simple matter; these objects are marked by their journeys to remote sites, the repetition of routine comparisons, and the dangers of atmospheric contamination (including sunlight). Indeed, reference materials only emerge as knowable when the conditions of comparison are stable enough to produce the object as a representation of an ideal standard.

The instability of physical artifacts as reference materials produces a demand. Either these physical artifacts are, by conventional decree, too instable and need to be replaced with a more contemporaneous form of invariance: "standards are not static, never definitions, but representations of something infinite, merely provisional drafts certain to be corrected, stand-ins for better ones to come."[65] If not replaced, then physical artifacts—reference materials—require supportive practices to keep them viable. Reference materials, even those erected on a scaffolding of the French Revolution's most idealistic promises, are in constant need of repair. In order to salve the wound of the mass standard, created by the instability of its tautological definition, the metrological community offers new paper standards (new definitions in documentary statutes) and maintenance standards (repair by hand).

𝔎 was born in ritual and has returned to ritual throughout its existence. Ritual, in this instance, is best understood as a way of construing a protocol or a repetitive act so as to invest it with importance. Rituals are needed to separate 𝔎 from other kilograms. The protocols that keep 𝔎 viable carry over many stages of its existence: its crafting, its

[65] Crease, *World in the Balance*.

endowment as the prototype kilogram, and its maintenance as a ground of value. Protocols for creating, storing, cleaning, and comparing reference standards are part of what make up the experimental apparatus through which measurement operations become possible.

Rituals make standards appear objective. Whether it's the conspicuous measuring performance used to judge a first down in football, or the trained hands of scientists rubbing a kilogram with a piece of chamois leather, rituals bolster the significance of materials that make standards possible. These are not only acts meant to protect against scrutiny, they are also internal acts that signal to professionals that the work they are doing is meaningful. Standards, even when based on contemporary notions of the invariants of nature, must mitigate the dangers of appearing too arbitrary. In commercial standards path dependence will often compel accordance with a standard because of the power of history, economics, and learned behavior. In the actual crafting of a standard and in its maintenance, rituals can serve a similar function, by helping to conceal the fissures of arbitrariness. By developing protocols for keeping kilograms clean, officials at the BIPM invested a kind of performance—an embodied practice of cleaning—with the endorsement of scientific necessity. These cleaning protocols are manual and practiced and they mediate between the kilogram as a piece of scientific hardware and the reality of its being a piece of metal in the care of people.

Chapter 2:

lena_std.tif v1

Image Processing and the Origins of a New Aesthetic Standard

(Or: How to Clean a Dirty Picture)

Figure 12 - The "Lena image" in its test image form. This image is called lena_std.tif and was obtained from the Signal and Image Processing Institute's test image database.

The centerfold image in the November 1972 issue of *Playboy* features a young Swedish woman in a hat and scarf. It appears she is in an attic: a wicker bassinet containing a doll is visible in the background and a kerosene lamp sits above her shoulders. One of the woman's breasts is exposed and reflected in a mirror on the right-hand side of the image. She is naked but for the hat, the scarf, and a pair of boots, and stares directly into the camera. *Playboy* says her name is Lenna Sjööblom, though we now know her real name is Lena Söderberg. The centerfold appears in what happens to be the highest selling issue of *Playboy* ever.[1] Other than this bit of trivia, the centerfold would be an unremarkable footnote in the history of visual culture, photography, softcore pornography, and magazine publishing, were it not for the fact that in 1973 someone at the University of Southern California's Signal and Image Processing Institute (SIPI) scanned the image to

[1] See: http://www.playboyenterprises.com/about/history/

test new compression algorithms for use on ARPANET.[2] Between the moment it was created in 1973 and today this particular image transformed into the "Lena image," an industry standard and the most popular digital test image of all time.

There are differing accounts of how the November 1972 *Playboy* centerfold wound up on ARPANET. The accounts agree that it took place in mid-1973 and that a SIPI engineer named Alexander Sawchuck and/or his graduate assistant W. Scott Johnson performed the digitization. The precise details diverge, however. One version describes a deliberate choice to send someone out to buy the magazine, which was singled out because of its material qualities:

> One team member ran out to the nearest magazine store and picked up the latest *Playboy*, the fateful Lena issue. The magazine was chosen because it was one of the few publications that had full-colour, high-quality glossy photos—Hugh Hefner insisted on using only the best photography and paper stock to avoid having his product considered a low-end skin rag—and its centrefold was ideal because it was the right size. Photos were wrapped around the scanner's cylindrical drum, which measured thirteen centimetres by thirteen centimetres. Folded to hide the "naughty bits," the top third of the centerfold fit perfectly.[3]

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[2] ARPANET was the predecessor of the internet and a project that was funded by the Department of Defense's Advanced Research Projects Agency.

[3] Nowak, *Sex, Bombs and Burgers*, 173. I should note here that though Nowak's book is a popular history of technology and does not conform to the generic and review standards of an academic text, his research is evidently based on interviews with SIPI engineers. Likewise, subsequent versions of this story are gleaned from interviews. The point is not to say, once-and-for-all, that the Lena image was digitized in one particular way, but to highlight the ways this history gets re-told, in authoritative or less authoritative venues.

In this version, the image was specifically chosen with foresight out of a desire for a high quality image on good paper stock—an attempt, as it is remembered, to capture the material qualities of *Playboy*. Though someone is said to run out to a store, the scene is relatively calm and deliberate and it's remarked upon that the object (the centerfold) and the instrument (the scanner) fit perfectly together, just the right size to crop the image of its controversial subject matter, Lena's breasts. The image, in this version, was simply "folded" in a primary act of *nettoyage* and image data hygiene.

In another version of this story, published in the *IEEE Professional Communication Society Newsletter*, the scene is much more frenzied.

> Sawchuk estimates that it was in June or July of 1973 when he . . . along with a graduate student and the SIPI lab manager, was hurriedly searching the lab for a good image to scan for a colleague's conference paper. They had tired of their stock of usual test images, dull stuff dating back to television standards work in the early 1960s. They wanted something glossy to ensure good output dynamic range, and they wanted a human face. Just then, somebody happened to walk in with a recent issue of *Playboy*. The engineers tore away the top third of the centerfold so they could wrap it around the drum of their Muirhead wirephoto scanner, which they had outfitted with analog-to-digital converters (one each for the red, green, and blue channels) and a Hewlett Packard 2100 minicomputer. The Muirhead had a fixed resolution of 100 lines per inch and the engineers wanted a

> 512 x 512 image, so they limited the scan to the top 5.12 inches of the picture, effectively cropping it at the subject's shoulders.[4]

In this version Sawchuk, his assistant, and the lab director use the magazine both out of necessity and a felt desire for a novel image. Instead of folding the image "the engineers tore away the top third." This is the way technological innovation is often remembered in both popular culture and in the ways technical disciplines assert their own narratives; moments of boredom are interrupted in frenzied spasms of improvised ingenuity. Often an engineer or computer scientist can't help but start writing on an unconventional writing surface (a window, a mirror, or whatever is ready-at-hand). The Lena image's digitization is no different. Instead of a writing surface, this hurried scene is characterized by the hectic pace of intense and virtuosic labor and the scanner, limited by its resolution, does the hard work of cleaning the image of its "not safe for work" content. The irony, of course, is that by using the *Playboy* image, the engineers had already revealed that for their workplace the image was "safe."

There is one obvious discrepancy between the two versions of the image's digitization. In the first version, a team member "ran out to the nearest magazine store" to buy the magazine. In the second version, at the moment of need, "somebody happened to walk in with a recent issue of *Playboy*." We can probably dismiss the first version's explanation, since the image is from the November 1972 issue and therefore wouldn't be on the shelves of a nearby magazine store in "June or July of 1973." In each version,

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[4] Jamie Hutchinson, "Culture, Communication, and an Information Age Madonna," *IEEE Profesional Communication Society Newsletter* 45, no. 3 (May/June 2001): 1.

agency for acquiring and possessing the magazine is redistributed and these stories of the Lena image's origins work to retrospectively narrate a single moment in a nearly all-male lab where a group of men digitized a pornographic image in order to transform it into a tool of commensuration. The stories recall Eve Sedgwick's explorations of "male homosocial desire" and the (non-sexual) ways that men mediate their relationships with other men through objects of desire.[5] The Lena image in its original context was not just any kind of private image but a *Playboy* centerfold, the archetypal artifact of what Lauren Berlant calls the "'zone of privacy' or national heterosexuality 'adult' Americans generally seek to inhabit."[6]

Objects—like softcore pornographic magazines—are never just lying around and do not happen to appear in a lab at just the right moment. Objects, as Sara Ahmed writes, do not "make an appearance"; an arrival takes time. Objects, Ahmed continues, "could even be described as the transformation of time into form."[7] To study the appearance of objects is to try to understand how the conditions of arrival determine *what* it is that arrives. This is to say: we cannot understand how the Lena image came to arrive on ARPANET in the early 1970s without understanding that the November 1972 issue of *Playboy* did not simply appear in the SIPI offices. The conditions for the arrival of the Lena image included the practiced surveillance of a woman's body by the trained eyes of engineers, who themselves were devoted to training computers in the surveillance of

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[5] Eve Kosofsky Sedgwick, *Between Men: English Literature and Male Homosocial Desire* (New York, NY: Columbia University Press, 1985).

[6] Lauren Berlant, *The Queen of America Goes to Washington City: Essays on Sex and Citizenship* (Durham, NC: Duke University Press, 1997), 59.

[7] Ahmed, *Queer Phenomenology*, 40.

images. To investigate the history of a standard test image is not only to plumb the standards of visual culture but also to reckon with the visual culture of engineers.

This chapter investigates a history of aesthetic commensurability by documenting the technical and institutional environment in which the Lena image appeared in the earliest days of network computing. By "aesthetic commensurability" I mean simply the ability to compare two images and, with professional authority, declare that one looks better than the other. This chapter tunnels into the history of communication and aesthetic commensurability through an image standard. By reconstructing the media practices of computer scientists in the early and adolescent periods of the internet, this chapter is based on the norms and controversies of image reproduction in the image processing community. I focus on two periods in this chapter and the subsequent one: the genesis of image processing in the 1960s and 1970s and its maturation in the early-to-mid 1990s. These periods are marked by the appearance of the Lena image, its incorporation as an instrument of commensuration in the early days of ARPANET, and the canonization of the image in the pages of professional journals.

Lena/"Lena"/Lenna

There are at least three different, overlapping figures to consider in the Lena image. There is Lena Söderberg, a Swedish model; there is Lenna Sjööblom, *Playboy*'s Americanized spelling of Lena's name, and the subject of the magazine's centerfold; and there is the Lenna/Lena image, a cropped, scanned, and digitized copy of the Lena centerfold, whose varied spelling in the digital imaging literature indicates the awkward liminality of the digital image. Maybe we should be uncomfortable separating these three figures, as doing so threatens to undercut the humanity of the model whose body and labor are on display. However, to understand how the Lena image operates as an instrument and came to act as a token of insider knowledge, it is necessary to understand how "Lena" and "Lenna" are separated—how, in other words, a person is functionally separated from her image and how an image is separated from its original context. For instance, both the digital image and the model have separate Wikipedia pages. The pages for Lena and Lenna include entirely different sets of information. Looking at the upper right-hand panel of the page, a section normally reserved for basic information on Wikipedia (a country's population and capital; a celebrity's age and location of birth, etc.) we get two different perspectives on the same image.

On the page for the test image "Lenna," we see the image in its normal, cropped form (figure 13). Some additional parenthetical information tells us about the standard pixel count and where to access the test version. On the page for the Swedish model Lena Söderberg, the image is missing (figure 14). Instead, we see a Wikipedia template for Playboy models, filled in with Lena's measurements, her age, and her position in the chronology of centerfolds. Both entries feature measurement information: the image's pixel ratio and the model's bust, waist, and hip size. Searching the "History" (a complete record of a page's versions and edits) and "Talk" (a backstage area of Wikipedia where editors and contributors can debate the edits to a page) sections for both entries reveals several conflicts over the difference between the image and the model. For instance, some balk when the "Pornography wiki-project" tag was added to the test image and they subsequently had it removed. There is also a dismissal of the idea of merging the model's page and the image's page. User DavidWBrooks writes, "I think the Lenna article is sufficiently established in the geek world that this article is justified going into more detail than would be right on an article about the playmate herself."[8] At one point the test image appeared on the model's page under a fair use claim, but it was removed since it didn't, the editors say, meet Wikipedia's standards for using copyrighted images.[9] Hence, on the web, model and image are treated as separate entities with separate histories and separate privileges.

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[8] http://en.wikipedia.org/wiki/Talk:Lenna

[9] http://en.wikipedia.org/wiki/Talk:Lena_Söderberg

Image of Lena Söderberg used in many image processing experiments. *(Click on the image to access the actual 512x512px standard test version.)*

Figure 13 – Information panel from the Wikipedia page for the "Lenna" (sic) test image

Lena Söderberg	
Playboy centerfold appearance	
November 1972	
Preceded by	Sharon Johansen
Succeeded by	Mercy Rooney
Personal details	
Born	31 March 1951 (age 63) Sweden
Measurements	Bust: 34",86.4 cm Waist: 26", 66 cm Hips: 36", 91.4 cm
Height	5 ft 6 in (1.68 m)
Weight	110 lb (50 kg; 7.9 st)

Figure 14 - Information panel from the Wikipedia page for the model "Lena Söderberg"

What really separates the Lena image from the Lenna centerfold is a massive act of erasure and a concerted effort at data hygiene: cropped just above her bare breasts, the image elides the illicit content of the original, leaving only her face, and the reflection in the mirror beside her. The act of concealment that turned the image from lurid centerfold into a decontextualized headshot can only ever be partial and the image is still marked by the soft-focus styling of magazine representations of women. This decontextualization also transformed the Lena image into a working object—or *workable object.* The Prototype Kilogram needs to be rubbed with a chamois cloth and an ether solution to bring it as near to a zero point as possible but the act of cropping (tearing or folding) the Lena image above the bare breasts cleaned it of its context and moved it from a private image into a testable one. It is safe to say that the cropping did not harm its publicity and the *nettoyage* neutralized the image's unworkability, with unworkability here refering to the image's status as pornography and as the property of Playboy Enterprises (signified in the uncropped version by the words "November: Playmate of the Month"). Like with the kilogram, the Lena image undergoes a process of environmental decontamination. The IPK needs to be washed and cleaned because the ambient atmosphere of its subterranean Parisian home does not adequately protect it from detectable changes in mass. The Lena image needs to be cropped because it was leaving the private sphere of heterosexual desire. It too needs to be stripped of the signs of its environment.

The Lena image is a gateway to talking about the gendered history of test images, the power to choose the conditions of testing and measuring difference, and the materialization of culturally embedded vision of the world. There are thousands of test images in the world, and each one has a history that could tell us something about the roles test objects play in scientific and technical research. But the Lena image is a privileged case. Not only is it the most frequently used test image, it stands out from other test images and test objects because of its longevity, the sentimental affection espoused by engineers towards the image and the woman it portrays, and the fact that it is taken from a pornographic magazine owned by a privately held company.[10]

Computer science grew up with the Department of Defense's surge of funding in the late 1960s. By the 1970s and the burgeoning of ARPANET, it had transformed into a discipline distinct from electrical engineering. In the late 1980s and early 1990s, as the internet grew and participating institutions added new interfaces like the world wide web, computer science became the technical domain of a new public-private communication infrastructure and media environment. The Lena test image was present throughout this history, operating at times as the basis of standards in a new, graphic medium and at other times provoking new definitions and delineations of public and private, decent and indecent, sexist and inclusive.

Test Images

Like crash dummies, test images are objects for working upon, for taking apart, and for rebuilding.[11] Among the ways that test images are worked upon, they are transformed, compressed, warped, masked, decompiled, and recompiled. A test image is a known quantity, a fixed point, and a functional invariable for testing variables. What ever is done

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[10] Shuyu Yang and Sunanda Mitra, "Content Based Vector Coder for Efficient Information Retrieval," in *Enhancing the Power of the Internet*, ed. Masoud Nikravesh, et al., Studies in Fuzziness and Soft Computing (Berlin; Heidelberg: Springer, 2004), 300.

[11] Mulvin and Sterne, "Scenes from an Imaginary Country."

to a test image, like a crash test dummy, has to be measurable.[12] Does it look better or worse? How much worse? In the parlance of digital image processing, test images are considered "data." The textbook explanation for test images states plainly:

> Testing different methods on the same data makes it possible to compare their performance both in compression efficiency and in speed. . . . The need for standard test data has also been felt in the field of image compression, and there currently exist collections of still images commonly used by researchers and implementers in this field.[13]

Test images constitute a standard set of data when testing a new image compression or transmission technique. Test images enable a process of techno-aesthetic benchmarking. Benchmarking is already a term in computer science, used to describe the process of measuring and comparing processor speed. But by using the term benchmarking I want to allude to its origins in the 19th century as a noun: "*Bench marks*: in surveying, fixed points left on a line of survey for reference at a future time, consisting of cuts in trees, pegs driven into the ground, etc."[14] This earlier definition is especially apt because it captures the make-shift materiality of benchmarking: cuts, pegs, and lines drawn in stone

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[12] Greg Siegel, *Forensic Media: Reconstructing Accidents in Accelerated Modernity* (Durham, NC: Duke University Press, 2014).

[13] David Salomon, *Data Compression: The Complete Reference* (London: Springer, 2007), 517.

[14] From George William Francis, *The dictionary of the arts, sciences, and manufactures*, 1842. Oxford English Dictionary, *"Bench-Mark, n."* (Oxford University Press).

are all physical traces left with the faith that such material marks are communal, and another surveyor will need them one day.

It is critical that test images react predictably to the same kinds of transformation, that their use is consistent, and that their individual facets are identifiable. These features are what make test images a known quantity. Test images are canvases for difference. More importantly, they are canvases for crafting, marking, and capturing difference. If we are going to compress an image we have to be able to tell if the compressed version looks "good enough" compared to the original. As such, test images often (but not always) feature inconspicuous subject matter, clear divisions of space, as well as a variety of pictorial features (to test as many variables as possible). Compression techniques rely on models of human vision and test images model the world that is to be compressed or analyzed. The thinking goes that if a compression technique works well on a test image, or series of test images, then it is likely to work well on future, yet-unknown images.

Test images are used at various stages in the creation and calibration of media technologies. Lorna Roth, Genevieve Yue, Mary Ann Doane, Jonathan Sterne and myself have written about some of the most conspicuous test images of the twentieth and twenty-first centuries.[15] Yue and Doane have each written about so-called "China Girls" (see figure 15). China Girls are short filmstrips, excepted from a young woman's screen test and stitched to the beginning of freshly developed film reels as "leaders." The strips are

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[15] Lorna Roth, "Looking at Shirley, the Ultimate Norm: Colour Balance, Image Technologies, and Cognitive Equity," *Canadian Journal of Communication* 34, no. 1 (2009); Mary Ann Doane, "Screening the Avant-Garde Face," in *The Question of Gender: Joan W. Scott's Critical Feminism*, ed. Judith Butler and Elizabeth Weed (Bloomington: Indiana University Press, 2011); Yue, "The China Girl on the Margins of Film."; Mulvin and Sterne, "Scenes from an Imaginary Country."

played before the newly processed film and through these side-by-side comparisons technicians assure the film was developed correctly. In this way, China Girls work as a failsafe check against error. Yue notes that there is no clear account of the origins of the term “China Girl” and that its vernacular use far pre-dates any appearance in print. This is consistent with the history of other test images; their histories are not often recorded in the places that we would normally look, like journals, books, glossaries, or patent applications. Instead, their traces are only visible in grey literature, oral histories, and the collected miscellany that accumulates around any profession. Despite the difficulties in precisely locating the origins of the term China Girl, the orientalist emphases of the term privileges, as Yue writes, “a woman’s subordinate, submissive behavior, qualities that would be consistent with the technological function the image serves.”[16] These desired qualities are corroborated by other long-standing uses of images of women as test objects, in which whiteness, skin tone, and remediated representational norms are used to set the conditions of new media and maintain their default settings.

For instance, "Shirley images" (see figures 16, 19) serve a similar function to China Girls but are used in color calibration in still photography. Named for an early test-card model, Shirley cards act like color bars for flesh tones.

> “Skin-colour balance” in still photography printing refers historically to a process in which a norm reference card showing a “Caucasian” woman wearing a

[16] Yue, "The China Girl on the Margins of Film," 99.

> colourful, high-contrast dress is used as a basis for measuring and calibrating the skin tones on the photograph being printed.[17]

The Shirley cards and China Girls are striking in the ways that they try to suture together a technical apparatus (color bars, or primary-color accouterments) and a woman's face and body—at once attempting to elevate the test object to the level of an object of beauty and render the person's body as an instrument of normalization. Figure 16 shows a typical Kodak Shirley card, a woman in upper class garb surrounded by pillows in primary colors. Against the stark contrast of her monochrome clothing, the image provides clearly delineated color swaths that can be tested and compared with other images. Figure 17, on the other hand, is a "pixl" test image produced by a Russian ink supplier and used for color calibration of photo printers, acting like an unofficial Shirley card. The image features many women's faces, a pile of meat, a luxury car and watch, and a naked bum. These images circulate on message boards as makeshift calibration tools and though the assemblage sometimes changes (the car is updated, for instance) the women's faces and the bum stay constant.

In color television, the National Television System Committee (NTSC) developed two television standards for the United States, one color and one monochrome. The color standard was adopted by many other countries and was used for an inordinately long time, and was phased out of use only in the past decade. To build this standard, the NTSC used twenty-seven test slides and a single filmstrip, using mostly still images to build the most pervasive moving image standard of the twentieth century (see figure 18). The

[17] Roth, "Looking at Shirley, the Ultimate Norm," 112.

NTSC slides feature scenes from an idyllic, pastoral life, while portraying exclusively white skin and continue the pattern seen in China Girls and Shirley cards by often highlighting the bodies and faces of young white women (The history of Shirley cards is traceable to the Kodak corporation and the NTSC images, too, were produced by Kodak).[18] By tuning photographic standards to light-colored skin, still and moving-image photography and television have historically failed to reproduce darker-colored skin in legible ways. By limiting their sample of the outside world to a circumscribed racial representation these failures of imagination are embedded in technologies that are developed and calibrated according to a strictly limited cultural viewpoint.

As these failings of representational technologies became clear, companies like Kodak sought to remedy the problem by designing film standards that could accommodate a wider range of skin tones. As part of this effort they had to produce new “multiracial” Shirley cards that would capture a wider (though still thoroughly limited) range of skin tones. Figure 19 displays one attempt at a “multiracial” Shirley card I obtained from the Boise Camera Club’s website. Here, however, the contrast of skin tones has brought with it an essentializing of ethnic stereotypes. The image replaces the finery of upper-class leisure visible in many China Girl and Shirley images with a set of musical instruments and “traditional” dress codes. Though they all hold stringed instruments and all have a headdress of some sort, the image attempts to create another kind of striking delineation. Like the stark opposition of white, black, and primary colors

[18] Mulvin and Sterne, "Scenes from an Imaginary Country."

in figure 16, here the accessorization of the models separates them into ethnic categories based on an equation of skin tone with culturally pre-determined modes of dress.

The images discussed here are used at different phases of the media development process. The NTSC images, for instance, were used to test the color television standard before it was created and to gauge the costs of bandwidth against the aesthetic satisfaction of an image. Shirley cards and china girls are used to check that a standard is being used properly and images like the sRGB pixl card or the database of images supplied by the Boise Camera Club help calibrate a set of tools (cameras, monitors, printers) to the original intents of the makers of a technology or standard. The fact that women's bodies and faces—and white skin, in particular—are used *throughout* the process of creating and maintaining a standard is noteworthy. It demonstrates that test instruments are not only used as a way of modeling the world "out there" in the laboratory setting but, moreover, that they are used to conform technologies to the world imagined in the laboratory. This imagined world, as is evident, is most often articulated through the instrumental use of women as test objects.

Figure 15 - A "China Girl" image[19]

Figure 16 – Kodak Shirley card[20]

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[19] This image was reproduced in the *Harvard Gazette* in an article about an exhibition of test images, mostly "China Girls" at Harvard's Carpenter Center. The show put these images on display in yet another example of the artistic appropriation of test materials described in the introduction. http://news.harvard.edu/gazette/2005/07.21/00-girls.html

Figure 17 - The Pixl test image for 2009. Used for sRGB calibration[21]

Figure 18 - NTSC image, "Boat-Ashore Pair"[22]

[20]Downloaded from: http://www.npr.org/2014/11/13/363517842/for-decades-kodak-s-shirley-cards-set-photography-s-skin-tone-standard

[21] Downloaded from: http://wwm.ua/news/5600/

[22] Donald G. Fink and NTSC, *Color Television Standards; Selected Papers and Records* (New York, NY: McGraw-Hill, 1955).

Figure 19 – A multiracial Kodak "Shirley" card[23]

Test images are not stand-alone objects, they are relational instruments made to participate in larger processes. For a test image to be a test image, something must be tested on it. It's a tool for measuring psychophysical outcomes (i.e., does the image look good enough for the bandwidth or storage limitations?). Without it, difference isn't measurable. In fact, there are images called "difference images" (figure 20) that manifest difference in visual form by subtracting the pixel value of one image from another image. Following a reversal of the logic first practiced by Francis Galton in his composite photography, difference images quantify and visualize compression through subtraction.

[23] Downloaded from: http://www.boisecameraclub.org/monitor-calibration.html

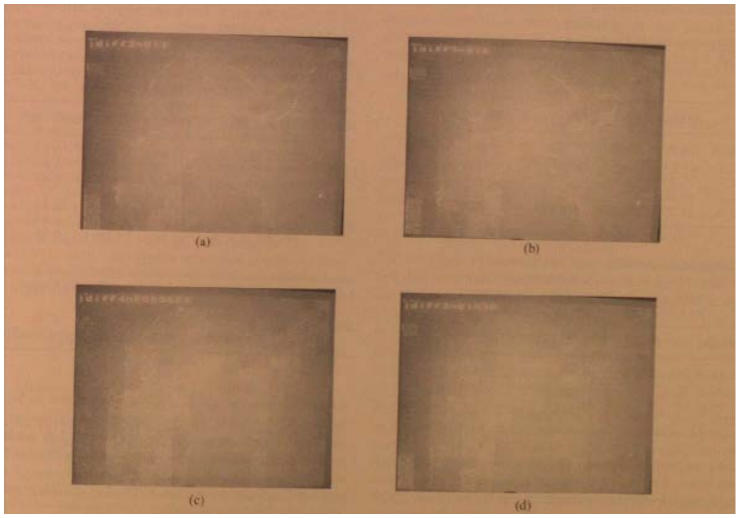

Figure 20 - Difference images for a transformation of the Lena image[24]

Test images visualize differences in ways of transforming images, whether through compression, coding, photochemical development, printing, projection, or any other form of transmission or remediation. Technically speaking, this isn't very complicated. But test images also work—as a part of a larger set of tools and practices that make up reference materials—to coalesce disciplines around a shared set of references and representational values. As a discipline, digital image processing is maintained by its practitioners through reiteration in things professional groups, journals, conferences, archives, canons, and practices of citation. While the Lena image is a rare example of a canonized test image, the larger grouping of digital test images acts as an archive, in the Foucauldian sense, as the "first the law of what can be said."[25] In this way

[24] M. Das and N. K. Loh, "New Studies on Adaptive Predictive Coding of Images Using Multiplicative Autoregressive Models," *IEEE Transactions on Image Processing* 1, no. 1 (1992): 108.

[25] Michel Foucault, *Archaeology of Knowledge* (London; New York, NY: Routledge, 2002), 128–30.

the archive is both a precedent for the possibility of "statements" and the organizing principle of statements. "The archive defines a particular level: that of a practice that causes a multiplicity of statements to emerge as so many regular events, as so many things to be dealt with and manipulated."[26] In this way, the bank of test images in digital image processing functions as the discipline's archive: they are the grounds on which statements (in this case, discrete coding events) make sense. And since the archive persists, the statements are ordered in time. Thus, test images contribute to an archive that conditions what can be done in a given visual discipline.

A new way of sending pictures

The *Playboy* image that ended up on the analogue-to-digital converter was not a random excerpt from the world of pop culture. The Lena centerfold was rather a conspicuous sample of the SIPI engineers' milieu. This milieu was characterized by the kinds of work already happening in image compression and transmission at the University of Southern California, the precedents of test image use, and the desire to create a new kind of test image that reflected the cultural vision of the SIPI engineers. The remainder of this chapter describes the SIPI milieu through several paths: a history of image compression as it led to SIPI, a history of the US Department of Defense's funding of computer science research and how image processing fit within that project, and the acts of conversion that transformed a paper-based photo in *Playboy* into a pixelated image stored on tape and transmitted over a computer network.

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[26] Ibid.

According to the Institute's own history "SIPI was one of the first research organizations in the world dedicated to image processing."[27] SIPI was established between 1971 and 1972 as the Image Processing Institute (IPI), using funding provided by the United States Military as part of its ARPANET project. Prior to its foundation as the IPI, the Department of Electrical Engineering worked with several branches of the military, conducting image-processing work contracted by the Air Force's Cambridge Research Laboratories and its Office of Aerospace Research, the Army Research Office, and NASA's Jet Propulsion Laboratory. Initial work began "on a very modest scale, but the program increased in size and scope with the attendant international interest in the field."[28] The institute was funded by a contract from the Department of Defense's Advanded Research Projects Agency (ARPA) and its Information Processing Techniques Office.[29] The IPTO had been founded in 1962, at which point ARPA became a prime funder of computer science in the United States.[30] The IPTO helped establish computer science as a discipline, and, as is well documented, drove the research and funding of what would become the internet in its precursory form as ARPANET.[31]

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[27] http://sipi.usc.edu/about/ "Signal and Image Processing Institute: About"

[28] William K. Pratt, *Digital Image Processing: PIKS Scientific Inside* (Hoboken, NJ: Wiley-Interscience, 2007), xvii.

[29] SIPI, then called "USC-IPI," was funded by Contract No. F08606–72–C-0008, Order number 1706 with the Advanced Research Projects Agency, Information Processing Techniques Office.

[30] Janet Abbate, *Inventing the Internet* (Cambridge, MA: MIT Press, 1999), 36.

[31] Ibid.; Gitelman, *Always Already New*; Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago, IL: University of Chicago Press, 2006).

The history of SIPI runs parallel with both the rise of computer science and the establishment of the IPTO. In ARPANET's formative years, the IPTO was run by Lawrence G. Roberts, whose electrical engineering background included work in digital image processing. In his Master’s thesis, Roberts used several attributed (and cropped) *Playboy* images of the model Teddi Smith, who it was later revealed, was sixteen when she posed for her nude photos (figure 21). [32] Despite this revelation, no attempt to redact Roberts’s thesis—an important document in the earliest days of the discipline—was ever made. An article version of this research ran in the *IRE Transactions of Information Theory* in 1962 and William Pratt, the founding Director of SIPI, cites it in “A Bibliography on Television Bandwidth Reduction Studies,” which was also published in *Information Theory* in 1967.[33] Additionally, Lawrence Roberts’s doctoral work "Machine Perception of Three-Dimensional Solids” is widely cited by the engineers at SIPI and beyond.[34] The terms “Roberts gradient” or “Roberts Cross” are derived from his work and are key concepts in computer vision and digital image processing. As Roberts noted in an oral history interview many years later, however, research in this early era of computer science had to conceal the computer as an object of research:

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[32] Lawrence G. Roberts, "Picture Coding Using Pseudo-Random Noise," *IEEE Transactions on Information Theory* 8, no. 2 (1962).

[33] William K. Pratt, "A Bibliography on Television Bandwidth Reduction Studies," ibid.13, no. 1 (1967).

[34] Lawrence G. Roberts, *Machine Perception of Three-Dimensional Solids* (New York, NY: Garland Publishing, 1980).

> People have changed, and now computers are recognized as an item. But this thesis had to be founded in psychology and math, and be a sound thesis on those principles as well.[35]

Test images function through a similar interdisciplinary convergence of perceptual technics with computer science and psychology. Image compression uses perceptual technics to code the minimally necessary information in a signal. Perceptual technics, in turn, employs a model of the human perceptual apparatus and how it responds to different stimuli. Test images are the source of a constant stimulus, meant to stand in for the world of visual stimuli. In the case of the Lena image and Roberts's use of Teddi Smith's photos, "stimulation" takes on new valences as it assumes a pre-given homosociality in which male engineers regularly use *Playboy* images to prove their hypotheses. Lawrence Roberts was instrumental in creating ARPANET as well as the field of digital image processing. His use of the Teddi Smith pictorial (and Pratt's canonization of it in an early bibliography) established another important feature of the discipline: that it would continue the pattern established in other image engineering fields by using images of women as test objects.

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[35] Roberts, Lawrence G. "Oral History Interview with Lawrence G. Roberts." (1989).

Figure 21 - Teddi Smith in *Playboy* as she appeared in Lawrence Roberts's image dithering research.[36]

[36] Roberts, "Picture Coding Using Pseudo-Random Noise," 152.

Figure 22 - Typical test images from SIPI: a tank, “Girl,” and an aerial surveillance image.[37]

[37] William K. Pratt, "USCIPI Report #660: Semiannual Technical Report Covering Research Activity During the Period 1 September 1975 to 31 March 1976," (Los Angeles, CA: Signal and Image Processing Institute, March 1976), 51.

The test images used at USC from its earliest years speak to the interests of their government and military funders. Frequently, tanks, human faces, and aerial surveillance images appear next to other banal subject matter (see figure 22). The “Girl” image is actually a frame from an earlier (1966) test film produced by the SMPTE (The Society of Motion Picture and Television Engineers). Frames from the SMPTE’s test film appear throughout SIPI’s tests, including other images of the same woman, as well as a "Man" image.[38] The "Girl" image even appears in the latest edition (2007) of William Pratt’s *Digital Image Processing* and a more recent textbook of his (2014) *Introduction to Digital Image Processing.*[39] The remediation of test materials meant for film and television tells us that the investigators at SIPI were searching for appropriate test materials for digital image testing; and it confirms that television was a functional horizon of compression studies. This is further confirmed as NTSC color is often used as the model for human vision in digital image compression tests from this period and into the 1980s.

In addition to the remediated use of film slides, SIPI’s test images highlight their military purpose. Ivan Sutherland (an influential computer scientist and pioneer of computer graphics) was an early director of IPTO and remembers some image processing work that was attached to artificial intelligence:

> There is always the hope that computers will do something that is really hard. Even when I was in ARPA, the Army had **this set of tank and non-tank images**,

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[38] Note that it is not referred to as the “Boy” image.

[39] Pratt, *Digital Image Processing: PIKS Scientific Inside*; *Introduction to Digital Image Processing* (Boca Raton, FL: Taylor & Francis, 2014).

> and one of the problems was, could you recognize tanks in aerial photographs? There was this wonderful set of tank and non-tank images - I think there were a hundred images. Some of the tanks were half under a tree, and some of them were recognizable mostly because of the tracks, the trail that they leave behind. For 20 or 25 years there has been the hope that some artificial intelligence program or vision program would be able to recognize tanks reliably.[40]

Sutherland's comments are revealing for two reasons: they indicate some of the test images that SIPI engineers would be expected to use (tank images certainly do reappear with regularity in their reports) and to the larger goals of image transmission and image recognition in this period. Much of the earliest digital image processing began as an attempt at character recognition—the idea of processing images to be automatically read was always a focus of research. It wasn't just about processing images to have a digital copy, but about trying to build some kind of interpretative act into the system.[41] The potential of digital image processing as an *interpretative* technique and its potential as a *transmission* technique sometimes run up against each other. Transmission focuses on compression, while interpretation focuses on symbolic recognition. They work at different scales, in different timeframes, and at different stages in the communication process. Moreover, each implies a different relationship to networked communication. If you are trying to detect a tank from an airplane flying above a jungle or trying to disaggregate an image into manageable packets, your approach to computer vision and

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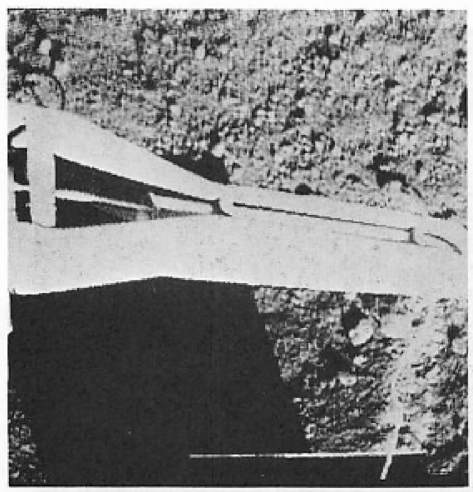
[40] Ivan Edward Sutherland, 1989. Emphasis added.

[41] http://museum.nist.gov/panels/seac/earliest.htm

image fidelity are going to be quite different. Finally, if you are tasked with testing the viability of developing "meaningful quantitative characterizations of an image" but you are not certain how this technique is going to be used, what are your test objects?

In addition to "tank" and "non-tank" images, research from the late 1960s was often concerned with the processing and coding of lunar surveyor images.[42] Test images of the moon's surface, with a slab of a lunar surveyor, are scattered throughout these early reports (see figure 23).



a) Original

Figure 23 - Original test image of Surveyor spacecraft boom[43]

[42] Julius Kane, Harry C. Andrews, and William K. Pratt, "Orthogonal Decomposition and Seismic Arrays," (Signal and Image Processing Institute, University of Southern California, November 1969). William K. Pratt and Harry C. Andrews, "Transform Processing and Coding of Images," (Signal and Image Processing Institute, University of Southern California, March 1969).

[43] Pratt and Andrews, "Transform Processing and Coding of Images," 6.

NASA ran seven Surveyor missions from 1966 to 1968 as part of its lead-up to the Apollo missions and the Surveyors (only five survived) sent back 87, 674 images of the moon's surface via telemetered video signals taken by television cameras.[44] The process of transmitting images from the moon was complex and laborious as the time lag meant that images would vanish from screens before they were finished transmitting. Technicians eventually coated monitors with a long persistency phosphor to burn the images into the screen long enough that they could be captured.[45] In other words, to reproduce images, NASA employed an intentionally laggy television system in which the normally quick-refreshing lines of the television signal were engineered to linger on the screen as an intermediary storage medium between outer space and videotape (another nascent technology).[46] Digital image processing and the possibility of compressing images before transmission and reconstitute them as stored files appeared, then, as a potential solution to the arduous task of sending images through space.

Engineers at USC conducted pioneering research into image processing in the late 1960s. According to SIPI's current director, Richard Leahy, "Much of the early work at SIPI was on transform coding, now the basis of the JPEG and MPEG standards for still and video image compression and transmission over the internet."[47] The reports from the

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[44] "Surveyor Program Results," (Washington, DC: Office of Technology Utilization: National Aeronautics and Space Administration, 1969).

[45] http://nssdc.gsfc.nasa.gov/nmc/experimentDisplay.do?id=1967-035A-01]

[46] Cathode ray tubes have functioned as storage media at different times in history and televisions always "store" images for some amount of time, if even for an imperceptibly short period. Matthew G. Kirschenbaum, *Mechanisms: New Media and the Forensic Imagination* (Cambridge, MA: MIT Press, 2008), 25.

[47] http://ee.usc.edu/research/research_centers_and_institutes/sipi.htm

1960s attest to Leahy's claim. They include military funded research into transform coding and a dissertation on the Fourier transform of images. In a representative report by William Pratt and Harry Andrews they describe the "classic problem" of digital image coding as "the search for a coding method which will minimize the number of code symbols required to describe an image."[48] To this end, SIPI engineers developed what they describe as a novel means of image communication: "whereby the two dimensional Fourier transform of an image is transmitted over a channel rather than the image itself." When Pratt and Andrews refer to "the image itself" they are referring to a situation like the Surveyor missions (this report was part of a larger project for NASA's Jet Propulsion Laboratory, after all), where a television image had to be transmitted and received *as a* television image. Transform coding, by contrast, samples the image, coding it as a digital representation in the form of data. This data is then used to reverse the process by decoding it and reconstructing the image at a new location. Though this process is so common sense today that even its description sounds pedestrian, in the 1960s Pratt, Andrews, and their contemporaries needed to make the case for transform coding over other forms of image processing.

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[48] Pratt and Andrews, "Transform Processing and Coding of Images," 1.

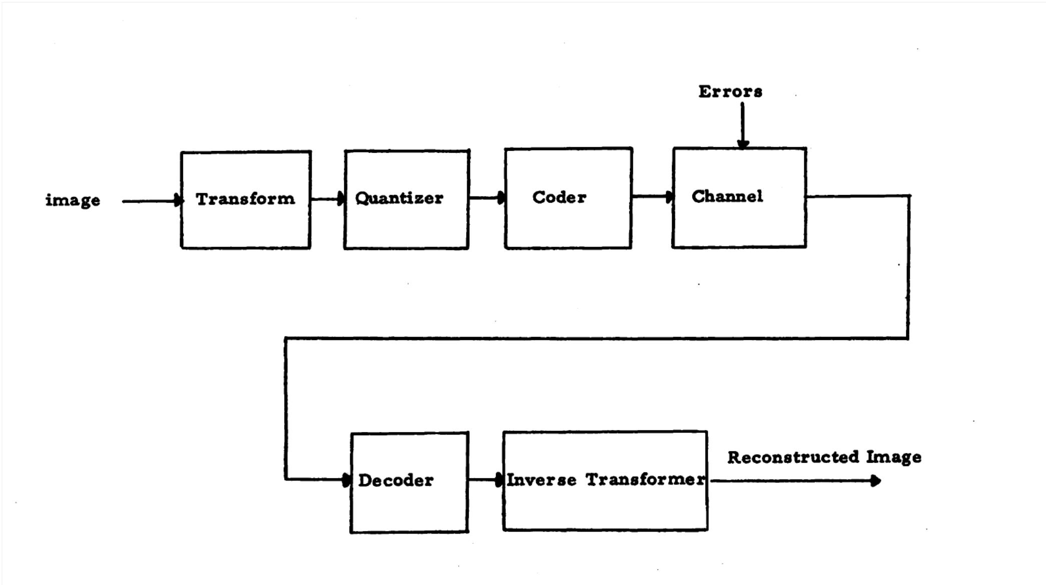

Figure 24 - Block diagram for "Image transform coding system"[49]

This block diagram in figure 24 from Pratt and Andrews's report shows a generalized version of their image digitization process. In this diagram both the "initial image" and the "reconstructed image" are labeled as uncomplicated inputs and outputs. The block diagram follows the familiar shape of the transmission model of communication—unsurprising for a paper offering a new way of sending images from the moon. But tucked in that upper left-hand corner, so neglected that someone forgot to even capitalize the "i" is another story about the "image." It's a story of fellowship in a scientific discipline designed to establish new norms of visual reproduction. In the image processing discipline test images produce a stable visual referent, whereas the remainder of the digitization process is comprised of variables. Test images function as a stable set

[49] Ibid., 3.

of pre-given data for image engineers to use to demonstrate their aptitude and skill. In addition to being a pre-given set of data, test images are the basis of commonality and community; they embody sameness at the same time that they enable difference. Whether or not they are always stable, whether or not they should be always pre-given, and whether or not their data are neutral is open for debate. What is clear is that they are functionally stable instruments in digital image processing's experimental designs.

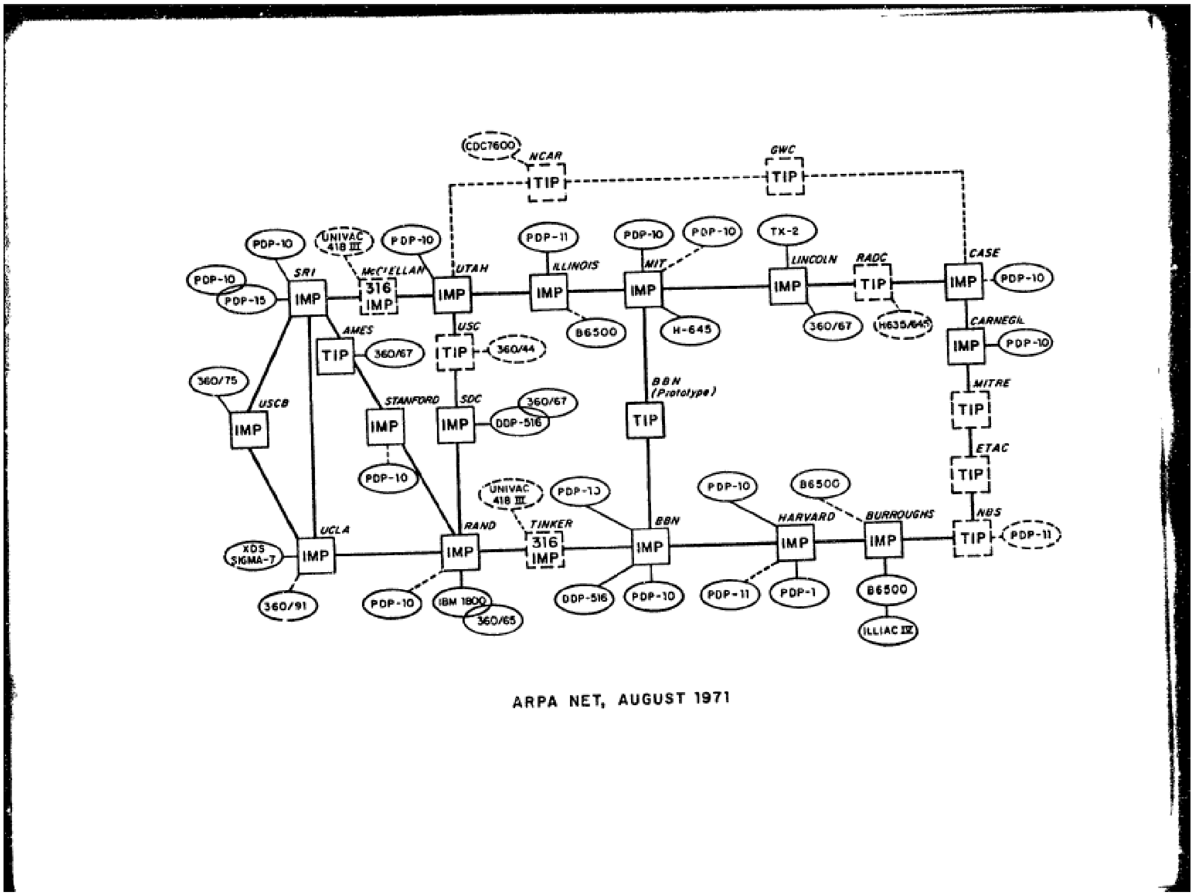

Figure 25 – ARPANET map, August 1971. USC is located on the far left-hand side of the map, marked by the position of its Interface Message Processor (IMP) to others. IMPs were the basic packet-switching nodes that made up ARPANET.[50] This image is meant to both illustrate a technical fact about networked computing and to serve as a piece of historical context but also as an example of the visual culture that surrounded image processing. As Bradley Fidler and Morgan Currie have argued, however, these maps are both diagrammatic and discursive. Though they originally served a specific purpose as diagrams for packet switching they have gone on to symbolize a prelapsarian, non-hierarchical network in the ways that the internet's pre-history is mythologized.[51]

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[50] Sidney G. Reed, Richard H. Van Atta, and Seymour J. Deitchman, "Darpa Technical Accomplishments: An Historical Review of Selevted Darpa Projects, Volume 1," (Alexandria, VA: Institute for Defense Analysis (Prepared for Defense Advanced Research Projects Agency), February 1990), no page.

[51] Bradley Fidler and Morgan Currie, "The Production and Interpretation of ARPANET Maps," *IEEE Annals of the History of Computing* 37, no. 1 (2015).

Reference Materiel: images for military use

USC joined ARPANET in 1971, the same year that SIPI was founded. USC's ARPA funding focused precisely on some of the research priorities identified by the DoD in 1967: surveillance, navigation, information processing, and military-vehicle technology. We have some indication of the work going on at USC (the Information Sciences Institute was also established there in 1972, and produced the Domain Name System) but much of this history is concealed by a lack of publicity about the IPTO. Lisa Gitelman describes how few published materials from ARPANET are accessible to researchers and historians:

> In the popular press, for example, the New York Times only mentioned the Internet once before 1988; then too, there was little relevant trade literature to speak of, and scholarly publication in the nascent field of computer science was only beginning to gain momentum. . . . As an agency within the U.S. Department of Defense, ARPA and its Information Processing Techniques Office (IPTO) didn't publicize its activities. Even the IPTO's contract bidding process was—an oxymoron—selectively public.[52]

This reflects my own experience with this era as well. I know, for instance, which contract number funded the image processing research at USC, but I have very limited information about what that contract means. Janet Abbate's history of the Internet is a valuable resource but doesn't mention SIPI.[53] The piecemeal documentation of early

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[52] Gitelman, *Always Already New*, 97.

[53] Abbate, *Inventing the Internet*.

ARPANET work makes it difficult to understand this period outside of the dominant narratives provided by its chief architects in interviews and existing histories. Those narratives are characterized by the frequent claim that a series of high-risk decisions about packet switching, time sharing, and distributed and open networks created the internet as we know it. It is difficult to test these claims with a limited set of documentary evidence from ARPA, the IPTO, and other involved institutions. The funding of individual sub-projects is an especially opaque area. One small hint comes from a call for proposals for Themis funding—part of the Department of Defense's attempt to spur new military research in universities—that were meant to address one of a few priority areas:

> The research areas in which investigations are desired involve the physical, engineering, environmental, medical, social, and behavioral sciences. Some specific problems—such as surveillance, navigation and control, information processing, and military-vehicle technology—have been singled out for each of the research areas mentioned.[54]

Project Themis funded fifty programs in its first year but by 1970 funding was slashed in response to protests against Department of Defense spending on campuses during the Vietnam War.[55] The American Association of University Professors had passed a resolution opposing DoD funding on campuses in 1967 and groups across the United States organized to protest their schools' involvement in the war. As John Walsh wrote at

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[54] Luther J. Carter, "Project Themis: More Research Dollars for the Have-Nots," *Science* 155, no. 3762 (1967): 548.

[55] Joy Rohde, *Armed with Expertise: The Militarization of American Social Research During the Cold War* (Ithaca, NY: Cornell University Press, 2013).

the time, these actions latched on to Themis as a manifestation of university complicity in the war, though such responses were ultimately ironic: Themis was the DoD's first attempt to be candid about its university funding and the protests pushed the research and the funding back underground. By 1970, projects that had been funded under Themis were moved to other budget headings and tracking these changes was "a virtually impossible task."[56] ARPA and the IPTO seem to have learned a lesson from Project Themis. Abbate writes that

> One potential source of tension that does not seem to have arisen within the ARPANET community was the involvement of university researchers—many of them students—in a military project during the height of the Vietnam War. It helped that the network technology was not inherently destructive and had no immediate defense application.[57]

This seems highly implausible on two levels. First, as Bob Kahn (one of IPTO's directors in this period) says, the IPTO's budget was suppressed in the mid-1970s due to the "Vietnam Syndrome."[58] If the IPTO's budget was affected by a backlash against DoD funding in higher education, it seems likely that there were internal conflicts too. Secondly, to argue that "the network technology was not inherently destructive" is to take an extremely narrow view of "the network technology." For starters, multiple members of the IPTO research team point to the IPTO's involvement in crafting command-and-

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[56] John Walsh, "Project Themis: Budget Cuts, Critics Cause Phase Out," *Science* 169, no. 3947 (1970): 749.

[57] Abbate, *Inventing the Internet*, 74–75.

[58] Robert E. Kahn, "Oral History Interview with Robert E. Kahn," 1989.

control technologies.[59] And the case of image processing makes clear that some parties involved in ARPANET were working directly on "destructive" applications, including the attempt to automate the detection of military targets. Ever since the First World War, a cycle of camouflage techniques (image concealment) and surveillance techniques (image interpretation) have battled to best the other[60] and in the Cold War period image processing became the newest technique of enemy detection.[61]

In the earliest reports from SIPI, they explicate the work they are meant to be doing for ARPA. An early abstract reads:

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[59] As Abbate herself notes, IPTO leadership was very adept at construing a military justification for their work by often dissembling about what was "research" and what was "development," depending on what they thought Congress wanted to hear. Abbate, *Inventing the Internet*.

[60] Hanna Rose Shell, *Hide and Seek: Camouflage, Photography, and the Media of Reconnaissance* (New York, NY: Zone Books, 2012).

[61] When Bob Kahn began at the IPTO in 1972 it was the first full year that SIPI was on ARPANET. He was later director of the IPTO and co-inventor of TCP/IP. In an interview from 1989, Kahn talks about IPTO project growth from the late 1960s to mid-70s. Kahn says that funding for the IPTO fluctuated from $10 to $20 million in the mid-1960s to $40 million in 1974, after which it dropped due to the (aforementioned) "Vietnam syndrome." When Kahn left the IPTO in 1985 its budget was "around a quarter billion dollars."[61] When asked about early-70s projects associated with the IPTO, Kahn lists a handful of the ones he can remember before, at the end, remembering one more.

> That's my recollection of what the program was like at that time. Oh, there may have been a program on computer graphics. Oh, no, there was one more — image processing. It was not quite image understanding, which started up a few years later, but it had to do with the ability to use computers to process images to enhance them, deblur them, and shape and shadow them — things like that.

Kahn, "Oral History Interview with Robert E. Kahn," 26.

The research program, entitled, "Image Processing Research," has as its primary purpose the analysis and development of techniques and systems for efficiently generating, processing, transmitting, and displaying visual images and two dimensional data arrays. Research is oriented toward digital processing and transmission systems. Four task areas are reported on: (1) Image Analysis Projects, the development of quantitative measures of image quality; (2) Image Coding Projects, the investigation of digital bandwidth reduction coding methods; (3) Image Enhancement and Restoration Projects: the improvement of image fidelity and presentation format; (4) Image Processing Support Projects, a description of the USC image processing facilities and support projects.[62]

Later, SIPI reports are more specific:

The image analysis project comprises the background research effort into the basic structure of images in order to develop meaningful quantitative characterizations of an image. In image coding the orientation of the research is toward the development of digital image coding systems that represent monochrome and color images with a minimal number of code bits. Image restoration is the task of improving the fidelity of an image in the sense of compensating for image degradations. In image enhancement, picture manipulation processes are performed to provide a more subjectively pleasing

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[62] William K. Pratt, "USCEE Report #411: Semiannual Technical Report Covering Research Activity During the Period 3 August 1971 to 29 February 1972," (Los Angeles, CA: Signal and Image Processing Institute, February 1972), i.

image or to convert the image to a form more amenable to human or machine analysis. The objective of the image detection projects is the recognition, classification, and identification of objects within pictures. Finally, the image research projects include research on image processing computer languages and the development of experimental equipment for the sensing, processing, and display of images. [63]

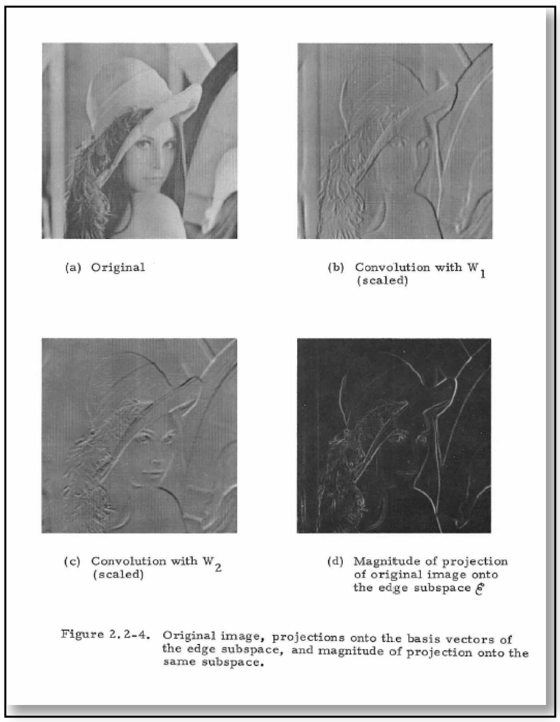

Figure 26 - The first appearance of the Lena image in print

The Lena image entered this process of developing new image analysis techniques as the grist for the image processing system. Though it was scanned in 1973, the image did not appear in a published SIPI report until 1975–1976. The first reports to

[63] Ibid., 1.

use the image are typical for SIPI research in this period. The semiannual report where the image first appears concerns progress at the Institute in three areas: image understanding projects; image processing projects; and smart sensors projects. These projects are concerned with: "developing generalized processing systems capable of analyzing images and extracting salient information" (image understanding); image coding, restoration, and vision modeling (image processing); and a project for integrating low level image enhancement within an optical sensor (smart sensors).[64] In short, the work continues the project of combining image coding with "artificial intelligence" and the hope that symbolic extraction and feature detection will lead to a system that can automatically detect and identify picture content (like tanks!). Though there is no way of knowing which work used the Lena image first, the first study it appears in is titled "A New class of Edge and Feature Detection Operators" by Werner Frei and Chung-Ching Chen (see figure 26) and a second article in the same volume, a study on color detection, uses the Lena image extensively. As the title of Frei and Chen's article indicates, they describe a transform coding process for extracting the salient edges and features of an image.[65] The first appearance of the Lena image demonstrates some of their results. This is the beginning of what would become a forty-year-tradition of "extracting" the salient features of the Lena image's face. Which is to say that engineers were working with a stockpile of images dictated by military research goals (tank images, aerial surveillance images, etc.) and recycled from film and television standards testing but chose to create

[64] Pratt, "USCIPI Report #660: Semiannual Technical Report Covering Research Activity During the Period 1 September 1975 to 31 March 1976," 1.

[65] Frei and Chen, "A New Class of Edge and Feature Detection Operators."

(and re-use) a new standard image based on the extraction of a *Playboy* model's features. Lawrence Roberts had already shown *Playboy* to be a suitable source of test material and existing image standards like China Girls and Shirley Cards echoed the notion that images of women could be useful instruments. In essence, choosing an image from which to extract features requires a familiarity with the features one wishes to extract. The Lena image is not a haphazard fluke of engineering: it's the result of a concerted effort to crystallize the existing and familiar standard of pornography's pictorial representation in a new technology.

Conversions

When SIPI engineers converted the Lena image from a centerfold into a digital image, they said they were responding to their work environment and the kinds of image tasks that they were required to do. Part of this environment was based on boredom and the fact that the engineers were "desperate for a new test image"[66] and were "tired of their stock of usual test images, dull stuff dating back to television standards work in the early 1960s."[67] As was discussed above, their existing images were either recycled from previous standards or dictated by their research goals. The political and economic contexts of image processing at SIPI, then, were first and foremost a military funded campaign in the middle of the Vietnam war and a mostly fruitless attempt to automate the detection of tanks. As a matter of labor, the engineers responded with sheer boredom to the repetitive use of their existing set of images.

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[66] Nowak, *Sex, Bombs and Burgers*, 173.

[67] Hutchinson, "Culture, Communication, and an Information Age Madonna," 1.

The Lena image appeared as potential answer to boredom. A break from things like tank and surveyor images, it was a chance to make a new kind of test image. To transform into "the Lena image," the centerfold underwent three kinds of conversion: from paper to pixels, analogue to digital, (softcore pornographic) magazine standard to image standard. The Lena image is often lauded for its formal features. In the Jargon file (a glossary of computing terms first compiled and hosted on ARPANET in 1975) the image is described as having "interesting properties—its complex feathers, shadows, smooth (but not flat) surfaces" and these properties are regularly cited in accounts of the image's digitization and in justifications for its use today.[68] The argument goes: it is not that the Lena image was simply a centerfold; it was also a particularly testable image that gave engineers a set of problems to solve, including complex surfaces, reflections, and overlapping textures. This logic is repeated as new image techniques, even today, are demonstrated through the use of the Lena image, even when those techniques were developed using a much larger set of test images.[69]

In the descriptions of why *Playboy* was chosen over other potential sources for a new digital image, the conversion of the Lena image from paper to pixel is described as an attempt to capture the material quality of *Playboy's* image and paper stock in a digital format. This is a very straightforward act of re-mediation—of transporting an existing

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[68] The full entry is located at: http://www.catb.org/jargon/html/L/lenna.html

[69] For instance, in 2012, researchers in Singapore received widespread attention for printing a copy of the Lena image that measured only fifty micrometers across, the smallest image ever printed. "Playboy centrefold photo shrunk to width of human hair" http://www.bbc.com/news/technology-19260550

image standard into a new medium.[70] And, if we recall that the model of color vision that the engineers were using was imported from NTSC color television, it's actually possible to describe these early digital images as the attempt to see glossy magazine photos through the visual capacities of analogue television. Furthermore, it's appropriate that the Lena image, crafted to be a tool of image compression should come from a centerfold. The centerfold was already an analogue compression technology that used the compression technique of "folding" to fit three times as much nude woman into the bandwidth limitations of the standard magazine page.

It is a commonplace of the history of media that with each new medium its creators will try to capture and reproduce surrounding and existing codes and styles of representation. This is the case with the engineers using NTSC color as a reference point in their digital compression tests equally as it is true of electric light being made to imitate gaslight.[71] It is also why, at the advent of ARPANET—SIPI engineers chose to encode *Playboy*'s aesthetic template into their new medium. In addition to being a seemingly testable image, printed on glossy, high-quality paper (the material qualities that supposedly set it apart), it was the most conspicuous section of an iconic pornographic magazine at the peak of the mainstreaming of pornography. Not only does the Lena image appear in the highest selling issue of *Playboy* ever, that issue appeared only a few months after the release of *Deep Throat*, one of the first hardcore

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[70] Jay Bolter and Richard Grusin, *Remediation* (Cambridge, MA: MIT Press, 1999).

[71] Wolfgang Schivelbusch, *Disenchanted Night: The Industrialization of Light in the Nineteenth Century*, trans. Angela Davies (Berkeley; Los Angeles: University of California Press, 1988).

pornographic films to be seen by a large portion of American public.[72] A year later, in 1973 (the same year that the Lena image was digitized) the US Supreme Court delivered a decision in *Miller v. California* that redefined pornography. The court said that while pornography had been defined as something “utterly without socially redeeming value” it would henceforth be defined as anything lacking "serious literary, artistic, political, or scientific value.”[73] This was actually a broadening of the definition of pornography meant to widen the number of things that could be called obscene (and therefore illegal) and rein in the mainstreaming of pornography. The implications of this timing are significant: in the year of *Miller* the engineers at SIPI inadvertently helped *Playboy* overcome the new standard for obscenity by sanctioning the use of a centerfold through a demonstration of its potential scientific value. By inscribing *Playboy's* aesthetic standard into the prototype of the internet, SIPI engineers not only demonstrated its scientific worth, the new image standard converted their ability to read pornographic images and their trained, subjective capacity for the feature extraction of a woman’s body, into a new digital standard of aesthetic commensurability.

Playboy did not simply appear in the SIPI lab. Instead, the image’s presence is a symptom of a moment in the history of American media consumption (a new era of publicity for pornography), a moment when the aesthetic and material standards of *Playboy* were self-evidently valuable (glossy, good paper stock), and in a setting where

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[72] Linda Williams, *Hard Core: Power, Pleasure, and the "Frenzy of the Visible"* (Berkeley: University of California Press, 1989).

[73] Supreme Court of the United States, "Miller V. California, 413 U.S. 15," (June 21, 1973).

control over the selection of test materials was accorded to a small group of men. The history of image processing from film, photography, television, and through digital image processing shows that the thorough instrumentalization of women's bodies is part and parcel of creating a new image standard and the Lena image corroborates this fact. In the next chapter, as we follow how the Lena image circulated outside of USC, the image's history traces the contours of a new discipline. The Lena image was exchanged, cited, lauded, canonized, challenged, and redeemed, as its circulation continued to index who had the power to choose test materials, how those materials were used, and what context those images sought to represent. Image engineers at SIPI were training computers to compress, transmit, and understand a new kind of picture. Tasked with this assignment, they chose to create a new kind of image that reflected the kinds of representation that they were comfortable decoding.

Chapter 3:

lena_std.tif v2

The Politics of Test Images and the Failures of Representation

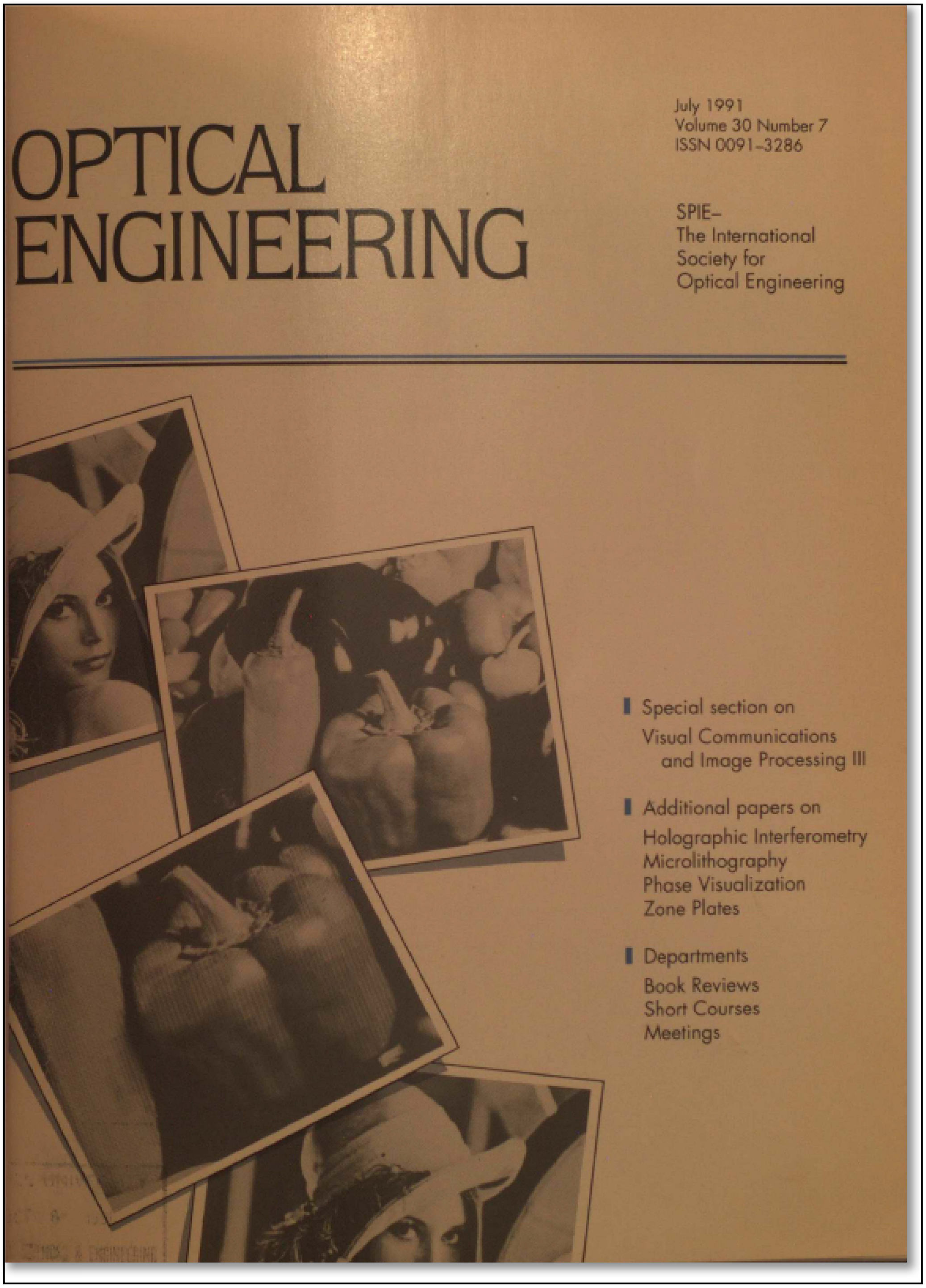

Figure 27 – Cover of July 1991 *Optical Engineering* featuring the Lena image

Optical Engineering is the flagship journal of the International Society for Optics and Photonics (SPIE). The July 1991 issue of the journal features the Lena image in two articles and the image appears on the cover, advertising a special section devoted to "visual communications and image processing." *Optical Engineering* was not, before 1991, a journal that regularly concerned itself with digital image processing and the special section was a clear departure.[1] This is significant because a few months later Playboy Enterprises sent an admonishing letter to *Optical Engineering* and the journal's editor, Brian Thompson, had to deliver a somber message about the meaning of copyright. *Playboy's* letter reads (*sic*):

> It has come to our attention that you have used a portion of the centerfold photograph of our November 1972 PLAYBOY PLAYMATE OF THE MONTH Lenna Sjööblom, in your July 1991 issue of *Optical Engineering* magazine. . . . Playboy Enterprises, Inc., the publisher of PLAYBOY magazine, owns the copyright in and to this photograph.
>
> As fellow publishers, we're sure you understand the need for us to protect our proprietary rights. We assume you did not intentionally make unauthorized use of our material and we ask that you contact us for authorization before using any of our copyrighted material in the future.[2]

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[1] The July 1991 issue is also, as far as I have ascertained, the first time the Lena image appeared in the pages of the journal.

[2] Brian J. Thompson, "Editorial: Copyright Problems," *Optical Engineering* 31, no. 1 (1992): 5.

In Thompson's response he is clearly contrite but makes it clear that though this letter was sent to *Optical Engineering* this is a problem for digital image processing to address. He writes:

> The image in question is used a great deal by workers in image processing and is often referred to as the "Lena" image. As SPIE noted in its response to Playboy Enterprises, "The image is widely used in the worldwide optics and electronics community. It is digitized and its common use permits comparison of different image processing techniques and algorithms coming out of different research laboratories."[3]

Thus, in its appeal for leniency, *Optical Engineering* made a case for the Lena image on the grounds that its popularity provided the conditions of commensurability for digital image processing. The Lena image was not alone, either. There was another article from the November 1991 issue that used the *Playboy* logo. In this case, the authors had obtained permission to use the image.

[3] Ibid.

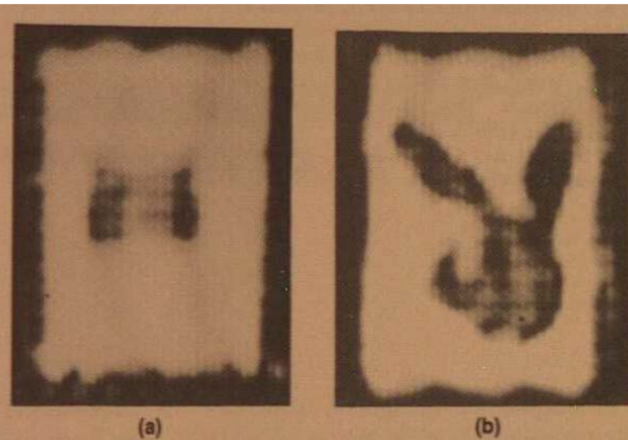

Fig. 9. Example images: (a) opaque rectangle and (b) rabbit head design. (Rabbit head design is a trademark of and used with permission of Playboy Enterprises, Inc.)

Figure 28 – Sanctioned appearance of *Playboy* logo in *Optical Engineering*[4]

Ultimately, Thompson put the onus on researchers (emphasis in original):

> "With regard to the "Lena" image, we reached an understanding with Playboy and appreciate their cooperation. However, because publishers do not know whether or not material is borrowed, adapted, etc., from other sources, be advised that **it is each author's responsibility to make sure that materials in their articles are either free of copyright or that permission from the copyright holder has been obtained.**[5]

Individual responsibility took the place of collective responsibility to control and manage the selection of test materials. It is a telling indication of Thompson's distance from

[4] Jeffrey S. Sanders et al., "Imaging with Frequency-Modulated Reticles," *Optical Engineering* 30, no. 11 (1991).

[5] Brian J. Thompson, "Editorial: Copyright Problems," *Optical Engineering* 31, no. 1 (1992).

digital image processing that he does not see fit to address the implications of using a copyrighted image or an image taken from *Playboy*. Instead, he leaves it as a matter for individuals to negotiate consent for the use of their images. Furthermore, Thompson does not suggest that Playboy Enterprises could be wrong. By all appearance, use of the Lena image *without* permission is legitimate under fair use provisions in the United States and fair dealing in Canada. The Lena image is cropped and does not reproduce the entire centerfold, which conforms to the protection of the use of excerpts. It was also only ever used for research and scholarly purposes, again conforming to a use that is (in theory) protected. Thompson does not give any details about the agreement he reached with *Playboy* and he stops short of telling *Optical Engineering* authors to cease using the image. *Playboy,* for their part, later claimed that the agreement grew out of their opportunism and they worked with the Society for Imaging Science in Technology to track down Lena Söderberg and bring her to the 50th annual conference of the society, in 1997. *Playboy'*s VP of new media said, "We decided we should exploit this, because it is a phenomenon."[6]

Playboy Enterprise's letter to *Optical Engineering* was the first challenge to the viability of the Lena image as an industry standard. This controversy erupted because the Lena image had circulated unobstructed in digital image processing for nearly twenty years, which brought it to the cover of a journal not even fully a part of its discipline, without anyone ever stopping to ask permission from *Playboy* or questioning its use.

[6] Janelle Brown. "Playmate Meets Geeks Who Made Her a Net Star." *Wired* (May 1997). http://archive.wired.com/culture/lifestyle/news/1997/05/4000

Instead the initial challenge to the image's free circulation came in the form of an assertion, by Playboy Enterprises, that the image was their property.

A second challenge came a few years later, in 1996, and again it emerged on the editorial page of a professional journal, the *IEEE Transactions on Image Processing*, where the editor responded to accusations that the Lena image's origins in a softcore porn magazine should preclude it from use on sexist grounds.[7] *Transactions on Image Processing* was established in 1992, when it splintered off from *Transactions on Signal Processing* because that journal's backlog of paper submissions grew too large and the digital image processing community feared "the exodus of image processing expertise from our society to other professional groups."[8] This is a key moment since it signals a two-fold attempt to distinguish digital image processing as a discipline: its separation from a larger and older discipline (signal processing) and an attempt to keep members within its specialization. It is noteworthy, then, that at this important point in the discipline's development the Lena image appears 205 times in the first volume (the first four issues) of the journal.[9]

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[7] David C. Munson, "A Note on Lena," *IEEE Transactions On Image Processing* 5, no. 1 (1996).

[8] Ibid., 1.

[9] I counted total reproductions: so if there was a sequence of four images showing four different steps of a process or contrasting different processes, that counted as four reproductions. I wasn't trying to count discrete tasks that used the Lena image but to do a rough accounting of the image's dominance of the population of images in this one important journal.

IEEE Transactions on Image Processing	Appearances of the Lena image
Issue 1	62
Issue 2	61
Issue 3	45
Issue 4	37

For context, while other common test images appear, the Lena image is by far the most used. There are, in the same volume, six reproductions of an image of Walter Cronkite and one image of Ronald Reagan. There are no virtually no traces of a person of color: even by the early 1990s digital image processing operated through a visual culture of white supremacy. Here "white supremacy" refers to the long-standing use of virtually uniform white models in the testing and calibration images for image technologies, from film, to television, to digital image processing. As these engineers worked towards the virtuosic manipulation and transformation of images, they did so through tools that were calibrated to white skin. This equated mastery over the tools of representation and reproduction with a visual culture where the default setting was white. Representational equity was clearly not on the minds of engineers, even while the Lena image is used to fulfill other representational desires. As Hutchinson crowed in 2001, "if the criterion is frequency of Lena, then the *IEEE Transactions on Image Processing* is by far the sexiest journal out there."[10] A process that began in the 1970s with extracting the salient features of the Lena image's face is canonized in the first volume of *Image Processing.*

[10] Hutchinson, "Culture, Communication, and an Information Age Madonna," 5.

Citation patterns can expose an unspoken politics for narrating a discipline.[11] At moments of genesis, like the first volume of *Image Processing*, citation was a way of establishing a shared set of referential materials that would cohere a newly formed field. In some ways, to be a reader of the IEEE's *Transactions on Image Processing* in the 1990s was equivalent to witnessing how different people transformed the Lena image and technical scrutiny of the Lena test image in digital image engineering became an occupational obligation. To be literate in image engineering in this period was to be conversant in the transformations of the Lena image. As repair work is repetitive, necessarily local, and almost always manual, citation becomes its own kind of disciplinary repair. Citation sutures together a discipline: it builds canons and defines boundaries of insider and outsider. Citation confers legitimacy on the citation and, through repeated use, legitimacy on those doing the citing. As the story of the Lena image demonstrates, reference materials don't just form the foundation of a discipline but are also themselves in need of repair and susceptible to contestation. To stay legible and usable someone had to crop the Lena image to clean it of its soft-core origins, someone had to circulate the image to turn it into a commonplace object, and someone (many someones) had to cite it. In standards making cropping, circulation, and citation all become kinds of repair and maintenance. These social acts are among the most common and most powerful ways that reference materials gain and retain legitimacy. In the case of *Image Processing*, the source of damage and repair were both located in the use of the

[11] Clare Hemmings, *Why Stories Matter: The Political Grammar of Feminist Theory* (Durham, NC: Duke University Press, 2011).

Lena image, as challenges to its legitimacy came in the form of copyright assertions and claims that the image epitomized the sexist environments of computer science.

Just as there was a cost to *Playboy* learning of the unpermitted use of the Lena image, there was a cost to the repetitive use of women as test objects and the regular presence of pornography in computer science environments. In the late 1980s women scientists, computer scientists, and engineers started publishing accounts of their experiences of gendered abuse, isolation, and mistreatment in their laboratories, offices, and classrooms. These accounts took the form of official and unofficial reports, published by universities or circulated online, between women, and through backchannels. The objections that they voiced went directly to the cause of the Lena image's use: the Lena image would not have made its way on to ARPANET if the November 1972 issue of *Playboy* hadn't made its way into the USC lab. As these issues came into contact with the growing cultural power of computer science, a shift to digital and networked methods of visual representation, and a drop-off in women's enrollment in computer science undergraduate programs, the Lena image came in for public criticism as an emblem of a history of sexist exclusion and misrepresentation.

The origins of digital image processing were not inevitable.[12] While the Lena image ascended as the constant against which the variability of different image compression techniques were tested it was always superseded by a more forceful constant: a model of vision conditioned by western, male, heterosexual desire. Work at SIPI began, after all, with the search for tanks. But the testing scenario shifted, almost

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[12] Williams, *Hard Core*, 56.

immediately, to the well established perspective of using women and women's bodies as test instruments. To see from this perspective, "is not to see woman at all but to see only…the one and the same of man against the more or the less of woman."[13] The demand put forward, therefore, by the feminist rebuttals to the environments of image processing work, was a demand for better test images and better representations of human subjects. It was, above all else, a demand for better models of vision.

This chapter addresses both forms of conflict surrounding the Lena image: those that centered on its copyright status and those that focused on its origins and its representation of a larger set of sexist practices in computer engineering labs and classrooms. Pornography is often credited with key, vanguard decisions about how new media and technologies will be used, adopted, appropriated, and controlled. The production, circulation, and consumption of pornography helped shape the ways that both regulation and commerce took form on the internet and the legal framework for the internet's infrastructure in the United States and beyond.[14]

> The Internet's privatization paved the way for cyberporn to the extent that it made digital pornography a hyper visible threat/phenomenon, and cyberporn paved the way for the ''Information Superhighway'' to the extent that it initiated the Internet gold rush and caused media,

[13] Ibid.

[14] Wendy Hui Kyong Chun, *Control and Freedom: Power and Paranoia in the Age of Fiber Optics* (Cambridge, MA: MIT Press, 2006).

> government, and commercial companies to debate seriously and publicly the status of the Internet as a mass medium.[15]

The Lena image is part of this phenomenon but is not merely another example pornography's vanguard role. First, its pornographic content had been cleaned from the test image and so its history had to be recovered through a reconstruction of its origins; second, as a tool of commensuration used in the preconditioning of visual standards, it bridges the visual culture of engineers with the capacities for visual representation that they were shaping. It is not, in other words, a mere token pornographic commodity that is fought over by stakeholders in the technological development, but a tool used in the labor of building the internet and determining which images would look *good enough*.

Circulations

If the use of the Lena image came to *Playboy's* attention only after twenty years it was not because the image was hidden away. Though signs of the image's use are easier to track in the 1990s, there are evident traces of its movement, storage, and transmission, as early as the mid-1970s. According to SIPI engineers, in the early 70s the Institute distributed batches of test images to other research centers using magnetic tape. Alexander Sawchuk recalls "Visitors asked us for copies, and we gave it to them so they could compare their image processing and compression algorithms with ours on the same test image."[16] The social media of digital image processing, in other words, began with

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[15] Ibid., 79.

[16] Hutchinson, "Culture, Communication, and an Information Age Madonna," 1.

the circulation of privately collected images that were exchanged by hand. A similar story is told about the origins of the Computerized Bulletin Board System (BBS) in 1978. The architects of BBS, Ward Christensen and Randy Suess, had exchanged programs with each other by recording them to cassettes and then mailing them. When a snowstorm stranded the two men at home, as Christensen recalls, BBS was born, "of the necessity of transferring files mostly between Randy and myself, at some means faster than mailing cassettes (if we'd lived less than the 30 miles apart we did, XMODEM might not have been born)."[17] These stories of manual exchange that follow personal networks and precede digital ones, captures two common aspects in the history of standards and reference materials: at key moments, the work of building and maintaining a standard is done by hand; and the tools of standards work are assembled ad hoc, but always with the aim of establishing conditions of commensurability across space and time between like-minded researchers and workers.

In 1975, the same year the Lena image first appeared in the Institute's reports, SIPI engineers transmitted test images over ARPANET.[18] While the multiple appearances of the Lena image in SIPI documents from this period is evidence of its wider use at the Institute, the image was concurrently spreading through the larger community of image engineers through their existing research networks. SIPI had established a growing database of images, which was functioning as a storehouse of

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[17] Quoted in Howard Rheingold, *The Virtual Community: Homesteading on the Electronic Frontier* (Cambridge, MA: MIT Press, 2000), 136.

[18] Hutchinson, "Culture, Communication, and an Information Age Madonna."; Nowak, *Sex, Bombs and Burgers*.

potential commensurability. The value of this database was in its ability to be shared, re-used, and referenced. As such, the first appearances of the Lena image do not only announce its use, they also index an early stage of canonization. After years of manual distribution, the image could now be valued as a shared referent. By the mid-1980s the Lena image was tagged as "Lena" or "Lenna" in articles outside of USC. One of the earliest articles I have located where the image is tagged with the name "Lena" concerns a technique for improving the quality of satellite television's NTSC-coded images. Closing a loop where NTSC images and the color TV model of vision were used to build early digital image standards, the Lena image was now used to improve techniques for sending TV signals.[19] It was still rare for the image to be consistently tagged in this period and there is no firm chronology for the use of "Lena/Lenna" over other more generic appellations. It sometimes appeared, as with other images of women's faces, tagged as "Girl" or "woman in hat." Though signs of its circulation are everywhere accounts of its circulation are scarce and were only made visible with the controversies and conflicts surrounding the Lena image in the 1990s.

The first controversy, as discussed above, concerns the image's copyright status and the threat to its workability if it could not circulate freely. In his *Optical Engineering* editorial, Thompson makes it clear that he negotiated limited permissions for the use of the Lena image. Individuals were now responsible for securing usage rights but *Playboy* was not asking for an outright ban on the use of the image. It's evident from my research

[19] In the article, the Lena image is only tagged parenthetically. It is described as "the woman in the hat (Lena)." Kerns H. Powers, "Techniques for Increasing the Picture Quality of NTSC Transmissions in Direct Satellite Broadcasting," *IEEE Journal on Selected Areas in Communications* 3, no. 1 (1985): 61.

that *Playboy* didn't enforce its copyright claim on journal articles following 1992 and the image appears in books regularly. On SIPI's current image database they refer to images by their catalogue number instead of proper names like "Lena image." SIPI still only passively notes that Lena, among some other images, is copyright protected by the original magazine publishers.[20] Two other images in their database, "Numbers" and "testpat," incorporate the Lena image, and as the SIPI copyright guidelines note, "may have same copyright issues as with that image," referring back to the original Lena image.[21]

Playboy Enterprises is infamous for enforcing its copyright in all circumstances, going to great lengths to sue violators. In the 1990s, several landmark legal decisions followed from web and pre-web online companies hosting *Playboy* content. For instance, *Playboy Enterprises, Inc. v. Russ Hardenburgh* (1997), *Playboy Enterprises v. Webbworld Inc* (1997), *Playboy Enterprises, Inc. v. Netscape Communications Corp.* (Which went all the way to Ninth Circuit Court of Appeals), and *Playboy v. Frena* (1993). Both *Hardenburgh* and *Webbworld* are still cited by the Recording Industry Association of America on their website's section on copyright infringement with regards to digital images.[22] In both *Hardenburgh* and *Webbworld*, *Playboy* sued because online aggregators had reproduced *Playboy*'s copyrighted images in a non-passive way (a server that acts as a "conduit" has a much easier defense than one that undertakes any kind of curation or control over the selection of images). In *Webbworld*, the defendants argued

[20] http://sipi.usc.edu/database/copyright.php

[21] Ibid.

[22] www.riaa.com/physicalpiracy.php?content_selector=piracy_online_the_law

that they didn't know what their users were doing and couldn't be held liable if they were uploading copyrighted images. The court found that it was not an acceptable defense in this case of copyright infringement as *Webbworld* had targeted adult websites and concertedly built what amounted to a store of second-hand images.[23]

Hardenburgh offers a more intricate case to consider the kinds of infrastructural and cultural labor that shape technologies and standards—including legal ones. The BBS in *Hardenburgh*, "Rusty-N-Edie's" (RNE), issued download credits to users for uploading photographs. Of the 50,000 images on RNE, an estimated 40,000 were "adult," a portion of which were proved to be Playboy Enterprise's property. The FBI raided RNE's servers in 1993, which were in the Ohio home of Rusty and Edie Hardenburgh, and seized hundreds of computers. The case became a cause célèbre for the American Civil Liberties Union but the judge in the case used *Playboy's* display rights to find in the magazine's favor—deciding, ultimately, that hyperlinking infringed on those rights.

In building their case against Rusty-N-Edie's BBS *Playboy* paid an employee, a woman named Anne Steinfeldt, who joined the BBS and spent her day downloading images from the server, finding and tagging images that were owned by *Playboy.* The judge, Sam Bell, describes the manual process of finding, tagging, downloading, and examining the pictures at length:

> PEI [Playboy Enterprises, Inc.] is understandably concerned that on-line systems can be used to transmit copies of its copyrighted photographs to people who have

[23] This was prior to the Digital Millennium Copyright Act (1998), which did provide some safe harbor rights to websites that host third-party content (not much, but more than *Webbworld* could claim in 1997).

> not themselves purchased Playboy Magazine. In the early 1990s, PEI employee Anne Steinfeldt was given the job of scanning on-line systems to determine whether such photographs were available to subscribers via their home computers. In November of 1992, Ms. Steinfeldt subscribed to Rusty-N-Edie's BBS under the pseudonym "Bob Campbell." She conducted key word searches in the files available on the BBS, and claims to have downloaded approximately 100 GIFs from the BBS which contained reproductions of PEI's photographs. She transferred these files to floppy disks, and then delivered the disks to PEI photo-librarian Timothy Hawkins. Mr. Hawkins states that he examined the files by displaying the images on his computer monitor and comparing those images with photographs from Playboy Magazine.[24]

The work that Anne Steinfeldt performed on behalf of Playboy Enterprises is infrastructural labor. Just as thousands of people are now employed to moderate content on commercial social media platforms like Facebook and Instagram and to check that images uploaded to the platform meet standards of decency (including that the image are not sexually explicit), *Playboy* contracted an employee to scan the depths of a BBS to locate its private property.[25] Content moderators perform this labor today because it is both cheaper and more reliable to sort images online by hand then to automate censorship. Anne Steinfeldt was already performing that same labor, prior to the existence of the world wide web. Steinfeldt went an extra step by downloading images,

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[24] United States District Court Northern District of Ohio (Eastern Division), "Playboy Enterprises Inc. V. Russ Hardenburgh, Inc., 982 F. Supp. 503," (November 25, 1997).

[25] Adrian Chen, "Unseen," *Wired*, November 2014.

copying them to disk, and providing them to a librarian. The librarian, in turn, performs a final act of commensuration by comparing the images side-by-side with *Playboy*'s archive of images. This work, all performed without the help of automation, became the basis of a precedent-setting legal decision regarding the knowing curation of images. While the legal precedents shape which contexts images can legally appear and circulate over the internet, it is possible to ignore the actual labor that it takes to create a testable batch of possibly copyright-infringing images. The work of Steinfeldt and Hawkins is just such an example of infrastructural labor.

Unfortunately, it is impossible to know if the November 1972 *Playboy* centerfold was among the images Anne Steinfeldt found on Rusty-N-Edie's on behalf of *Plaboy* (the company identified ninety-nine images and submitted ten to the court, though these are kept sealed in an Akron courthouse). Nonetheless, it is in this context of sounding out the limits of free expression and free circulation in networked communication that *Playboy* became aware of the Lena image's use in the image processing community. However, the very techniques that were used to digitize, compress, and transmit the images on RNE and used by Playboy Enterprises to build its case were built in the same laboratories that used the Lena image as the basis of commensuration.

The Lena image is yet another case where pornography played a conditioning role in how the internet was formed as a communication medium. In its original digitization, the *nettoyage* of *Playboy*'s trademark cleaned it of its visible copyright status, and in the negotiated agreement with *Playboy* in 1992, the image was once again repaired, saving it from illegitimacy as a piece of the material of commensurability. The self-policing that image engineers tacitly agreed to was meant to secure the consent of *Playboy* (and not of, say, Lena Söderberg) and that consent concerned only the status of the image as *property*. Amy Hasinoff has shown how property rights became the only legitimate way to prevent the unwanted circulation of images.[26] Hasinoff addresses the popular claim that it is impossible to curtail the spread of personal information while simultaneously regulating and stanching the flow of commercial texts. The belief that personal information will always circulate freely grew out of the computing communities of the early 1990s, in which nude images, and in particular *Playboy* had a significant role. Hasinoff writes,

> In the heady rhetoric of the early 1990s, the internet is naturally democratic, anticensorship, and virtually impossible to regulate. As Willis points out, metaphors positioning the early internet as a "wild west" frontier space justified the idea that it was an unsafe place that women should avoid. The key idea is that the internet could not (and should not) be governed.[27]

As we have seen throughout the history of the Lena image, censorship is always treated as a last resort and was never fully embraced by any of the male authorities who could have enforced it. The only authority that found quarter with the engineering community was the legal claim by *Playboy*. Like others working at the beginning of the ARPA-

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[26] Amy Adele Hasinoff, *Sexting Panic: Rethinking Criminalization, Privacy, and Consent* (Urbana, IL: University of Illinois Press, 2015).

[27] Ibid., 130.

funded computer projects of the Cold War period the engineers at SIPI couldn't have predicted the outcome of digitizing any one particular image in the 1970s.[28]

Nonetheless, we now know that the non-consensual circulation of pornography is a major endeavor on the internet. As a commercial sector, it has risen to enough prominence that there is an identifiable political economy for the acquisition and distribution of private images as well as a growing assemblage of laws designed to criminalize the specific ways that the public circulation of private images is conducted using contemporary technology.[29] Hasinoff's analysis deals with a different kind of consent in a different domain of copyright law. Whereas Hasinoff addresses the conflicts created when individuals lose control over private images against their consent, the Lena image is a more conventional case where a copyrighted image was used without the consent of its owner. Yet, given the constitutive role that *Playboy* played in the development of copyright policy and jurisprudence for the internet, the different uses of "consent" can be illustrative. As a private actor, *Playboy* enjoys much more authority than an individual would in its capacity to control the circulation of its property. No surprise then that copyright emerges as an obvious and deeply flawed solution to restricting the use of one's own private images.

It's commonplace to note the originary role that pornography plays in new media technology and the development of new markets for new technology. In the case of image processing, this role can be traced to the setting of the laboratory and not just the

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[28] Turner, *From Counterculture to Cyberculture.*

[29] Hasinoff, *Sexting Panic*.

early presence of pornography on the internet and the world wide web. But how could it have been different? We can imagine another history in which image engineers voluntarily quit using the image before or immediately after *Playboy's* copyright claim. This was the moment that they could no longer claim ignorance about its origins. It would then stand as a powerful counterexample to the uncontrolled distribution of pornographic images on the internet, instead of the original model of the form. Instead, the image only grew in celebrity, while image engineers were given special dispensation from *Playboy* to keep using it.

As Judith Butler argues, gender has to be iterable to persist: "…the historicity of norms (the "chains" of iteration invoked and dissimulated in the imperative utterance) constitute the power of discourse to enact what it names."[30] The use of test images as instruments is a powerful means of reiterating a gendered and heterosexist norm. Standards too work as a powerful norming influence in media infrastructures. Since the Lena image is both its own industry standard and a tool for constructing other standards, it is doubly important in perpetuating the chains of iteration that constrain the potential for utterable difference. But just as norms have to reiterate to persist, breaking the chain of iteration can break the norm. This is the political potential of refusal. No one mandated the use of the Lena image and anyone could stop using it at any time. For instance, other than its copyright status, a person could refuse to use the Lena image because: they think the image is sexist; the use of the image seems overly arbitrary; the image is formally insufficient (despite what some have insisted); there isn't enough information about the

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[30] Judith Butler, *Bodies That Matter: On the Discursive Limits of "Sex"* (New York, NY: Routledge, 1993), 139.

image's production to make it a truly useful reference image; the image is too old; or the image is not a "born-digital image." Any of these would suffice as a reason to stop using it or to even ban its use.

Instead, in a final twist to this story, one engineer, concerned that *Playboy* may one day quit permitting academic uses of its image, had his wife pose for a new version of the Lena image, calling it the *iLena* image. The image is licensed Creative Commons Attribution-Share Alike.

Figure 29 - The "iLena" image[31]

He was not the first or the last image engineer to invoke his wife's appearance. William Pratt, the first and long-time director of SIPI has released four editions of his *Digital Image Processing* textbook over a forty-year period. Each one begins with the same dedication:

[31] "Lena e iLena" http://blog.ricbit.com/2009/11/lena-e-ilena.html

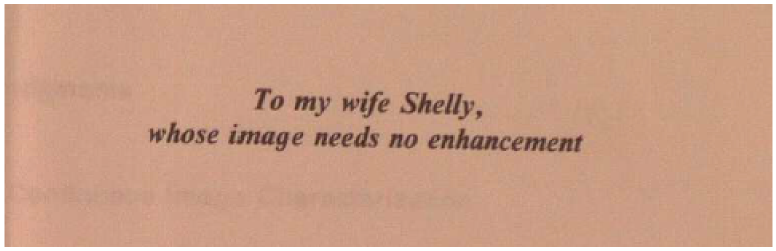
To my wife Shelly,
whose image needs no enhancement

Figure 30 - William Pratt's dedication for *Digital Image Processing*[32]

This constant enfolding of heterosexual, male engineers' wives into the image production system underscores the constant reiteration of women's images as tools of masculine mastery. While Pratt's dedication draws a distinction between the images of women he works on professionally (those "needing" enhancement) and his wife, the *iLena* image exposes another flawed argument: that simply by removing the Lena image's status as a copyrighted image any danger that it poses to the coherence of the discipline will be repaired. Yes, better and different test images would make better standards. But, more importantly, better contexts for standards work would make different images appear and would change who has the power to select the material referents for testing.

Conflicts

In 1996 *Image Processing*'s first editor was set to resign after four years in the position. Volume 5, issue 1 contains a normal editorial in which David Munson reflects on the journal's first four years and its future. On the subsequent page, there is a second editorial message, "A Note on Lena." David Munson, the editor, begins:

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[32] Pratt, *Digital Image Processing: PIKS Scientific Inside*.

> During my term as Editor-in-Chief, I was approached a number of times with the suggestion that the *IEEE Transactions on Image Processing* should consider banning the use of the image of Lena.

Munson establishes a vague controversy but makes it clear this has been an issue throughout his tenure as editor.[33] He continues:

> I think it is safe to assume that the Lena image became a standard in our "industry" for two reasons. First, the image contains a nice mixture of detail, flat regions, shading, and texture that do a good job of testing various image processing algorithms. It is a good test image! Second, the Lena image is a picture of an attractive woman. It is not surprising that the (mostly male) image processing research community gravitated toward an image that they found attractive.[34]

This is the first time anyone acknowledges that the image is popular for reasons beyond the fact that it is a particular "good" test image and (tautologically) because it is used by everyone else in the industry. With this stipulated, Munson details the controversy. He summarizes the earlier conflict between *Playboy* and *Optical Engineering* but notes that it is essentially resolved. Munson writes,

> So what is the problem? Well, quite understandably, some members of our community are unhappy with the source of the Lena image. I am sympathetic to their argument, which states that we should not use material from any publication

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[33] Munson, "A Note on Lena," 3.
[34] Ibid.

that is seen (by some) as being degrading to women. I must tell you, though, that within any single segment of our community (e.g., men, women, feminists), there is a complete diversity of opinion on the Lena issue. You may be surprised to know that most persons who have approached me on this issue are male. On the other hand, some informal polling on my part suggests that most males are not even aware of the origin of the Lena image! I have heard feminists argue that the image should be retired. However, I just recently corresponded with a feminist who had a different point of view. She was familiar with the Lena image, but she had not imagined that there could be any controversy. When I offered an explanation of why some persons are offended by the use of the image. She responded tartly. A watered-down version of her reply is, "There isn't much of Lena showing in the Lena image. This political correctness stuff infuriates me![35]

Munson is perhaps receptive to the complaints of some people but is at pains to make it clear that the issue is more complicated than some may think. His anecdote about a woman with anti-PC views is an attempt to muddy the waters and disarticulate the notion that a demand for different test images is not simply a feminist demand but one from a particular brand of censorious feminist. It appears that Munson is setting the stage for an equanimous decision; he thinks that an issue without clear gender-ideology delineations calls for a decision that is similarly compromised:

As Editor-in-Chief, I did not feel that this issue warranted the imposition of censorship, which, in my view, should be applied in only the most extreme

[35] Ibid.

> circumstances. In addition, in establishing the precedent, I was not sure where this might lead. Should we ban the Cheerleader video sequence? Should we establish an oversight panel to rule on acceptable imagery? Instead, I opted to wait and see how the situation might develop. I suspected that the use of Lena would decline naturally, as diverse imagery became more widely available and as the field of image processing broadened in scope.[36]

Munson was right in one regard: the use of the image did decline after the run-in with *Playboy*, but it was still present in 1996 and is still used today to demonstrate novel image processing techniques. The image appears in multiple papers in the same issue where "A Note on Lena" appears and throughout the fifth volume of *Image Processing*. Moreover, as its fame spread in the early aughts, its symbolic meaning only increased. Munson's concluding suggestions, though, come down on the side of the complainants, if only passively.

> In cases where another image will serve your purpose equally well, why not use that other image? After all, why needlessly upset colleagues? And who knows? **We may even devise image compression schemes that work well across a broader class of images, instead of being tuned to Lena!**[37]

Munson's final response is not to censor the image but plead rather weakly (why are all his statements phrased as questions?) that engineers ought to be more considerate. It's the final sentence, however, that makes the use of the Lena image seem inescapable. There is

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[36] Ibid.

[37] Ibid. Emphasis added

a hint of sarcasm, but the notion that existing image compression schemes are "tuned to Lena!" is a clear indication of the image's power as a commensuration tool and an object that binds the community of digital image engineers. And here precisely is the problem. Munson is drawing attention to the fact that the *work* of doing image processing is already calibrated (tuned) to this one particular image. But there is also an elision. It is not just "compression schemes" that are tuned to the Lena image, it's also the people doing the compression, through the repetitive, ongoing, and tedious use of the same images.

This feeling is echoed in 2001, by a Carnegie Mellon University engineer who says, "many researchers know the Lena image so well that they can easily evaluate any algorithm run on her."[38] These statements confirm the observation that to participate in the image engineering community of the early 1990s was to put the Lena image under scrutiny as a matter of professional obligation. But they go further than that by claiming that the inseparability of the engineers' professional identification and practice and the Lena image has actually affected the perceptual experience of doing image engineering.

We now have two interventions in the smooth circulation and use of the Lena image: the copyright claim by *Playboy* and the acknowledgement of the image's sexist provenance. Both conflicts come to the foreground in image engineering journals. Journals are a centripetal force where participants perform the work of repairing the discipline to keep it stable. Maintaining the legibility and coherence of the Lena image is

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[38] Rosenberg as quoted in Hutchinson, "Culture, Communication, and an Information Age Madonna," 6.

one way the image engineering disciplining performed this centripetal work. Circulating the image, citing it, putting it in published research, and defending it against copyright claims and claims of injustice are other ways that the image is maintained. But journals are on an untimely lag and scientific journals, in particular, provide little space to explicitly address the cultural and political dimensions of a discipline's canon. By canon here I mean a version of John Guillory's definition, via Bourdieu, where canon is "best understood as a problem in the constitution and distribution of cultural capital, or more specifically, a problem of access to the means of literary production and consumption."[39] Replace "literary" with "techno-aesthetic," and we have a good description of the ways that devotion to the Lena image has strictly limited who has access to the imaginative capabilities of digital image engineering, which is, among other things, a profession of creative and imaginative image transformation. Which is all to say that journals are an important site of disciplinary maintenance and repair. They are also the site of change and critique and the conflicts surrounding the Lena image were symptomatic of changes that women were seeking to the many professions associated with computer science in the 1980s and 1990s—issues that persist today.

Rebuttals

In the early-to-mid 1990s, enrollment in STEM programs in Canadian and American universities was dominated by men and trending away from a period of increasing gender parity. Many women who did find themselves in these programs often found them

[39] John Guillory, *Cultural Capital: The Problem of Literary Canon Formation* (Chicago, IL: University of Chicago Press, 1993), ix.

alienating, inhospitable, and abusive. In 1989, a gunman shot and killed fourteen women and injured another thirteen people at the University of Montreal's École Polytechnique. The gunman's motivations were explicitly political and misogynist. He is quoted as telling his victims "You're women, you're going to be engineers. You're all a bunch of fucking feminists. I hate feminists."[40] The Montreal Massacre irrevocably changed the context for women in engineering and forced a confrontation with the misogynistic surroundings of engineering programs. Computer science, which had only established itself as a discipline in the preceding two decades, featured the same inhospitable environment as other engineering disciplines. A series of reports were published in this period that documented the difficulties women were experiencing on campuses. These include the Spertus Report from MIT (1991), The Cottrell Report from the University of Vermont (1992), and the Winslett Report from the University of Illinois at Urbana-Champaign (1993), as well as a cover story in the *Communications of the ACM* by Karen Frenkel (1990). There were other related reports as well, including the Harvard report on Women in the Sciences (1991) and a second MIT report on Family and Work (1990).[41] Many universities produced similar reports throughout the 1990s and

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[40] Donna Riley and Gina L. Sciarra, ""You're All a Bunch of Fucking Feminists:" Addressing the Perceived Conflict between Gender and Professional Identities Using the Montreal Massacre," *Proceedings: 36th ASEE/IEEE Frontiers in Education Conference* (2006): 19.

[41] Karen A. Frenkel, "Women and Computing," *Communications of the ACM* 33, no. 11 (1990); Ellen Spertus, "Why Are There So Few Female Computer Scientists?," (MIT Artificial Intelligence Laboratory, 1991); Janet Cottrell, "I'm a Stranger Here Myself: A Consideration of Women in Computing," *ACM SIGUCCS User Services Conference* 20 (1992); "Final Report of the Committee on the Status of Women Graduate Students and Faculty in the College of Engineering," (University of Illinois at Urbana-Champaign, 1993).

early aughts. There is also a collection of grey literature that includes reports that are cited but not published (I have, in a couple of cases, asked the authors of these if they still have this literature but so far have had no luck). These reports, and their supporting literature, circulated on message boards and the world wide web's predecessors. They offered support for young academics and engineers looking to address the institutionalized sexism and gendered inequalities of the science fields in which they worked.

One of the most widely cited reports came from Ellen Spertus, titled "Why are There So Few Female Computer Scientists?" She notes that in 1990, only 13% of computer science PhDs went to women, only 7.8% of computer science faculty were women and only 2.7% of tenured faculty were women.[42] Spertus, then a student at MIT, assembled a wide ranging report on all of the possible factors that could contribute to the lack of women computer scientists, including: social factors like stereotyping, subtle biases, the masculine environment, gendered language, and the tyranny of low expectations. Among Spertus's most impressive accomplishments is an exhaustive bibliography, which later circulated on message boards, was added to, and became a hyperlinked web resource.

These reports describe computer science departments as both hostile work places and classrooms. Among the many discriminatory aspects they describe, they include the regular presence of pornography. "Some computer science graduate students and staff at Carnegie Mellon were sufficiently disturbed by the display of nude pictures as

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[42] Spertus, "Why Are There So Few Female Computer Scientists?," 1.

backgrounds on computer terminals that they got together and tried to change the situation by publicly appealing to the community."[43] Spertus draws on an unpublished report written by CMU students and staff, "Dealing With Pornography in Academia: Report on a Grassroots Action." The published/unpublished divide demonstrates the restrictions on willful speech. After challenging the presence of pornography in computer labs and appealing for a change, the students and staff were met with outrage. Spertus writes,

> The appeal closed by making clear that they were not advocating banning such displays but were requesting that people voluntarily remove them out of sensitivity to others. Responses about the appropriateness of the displays and of the appeal were mixed and are categorized in the report. Negative reactions included the position that the writers were advocating censorship "like the Nazis or the Ayatollah Khomeini," that people should not be asked to change their behavior merely because of what others might think, and that a public appeal was inappropriate but instead should have been made by individuals to individuals. Of those agreeing, the majority of responses said that the request was reasonable and not an attempt at censorship, that it prevented people from unintentionally giving offense, and that it was effective at raising consciousness. In response to the criticism that individuals should complain personally, several women wrote that

[43] Ibid., 24

"[w]omen asking for changes in behavior individually are exposed to ridicule and abuse."[44]

The Illinois report, drawing on many of the same materials, includes several recommendations in the form of instructive "DOs" and "DON'Ts" for classrooms and laboratories. This includes a statement related to the display of pornography:

> **DO** display pictures or computer screens that convey the beauty and excitement of your work. Other office displays that make a positive first impression and stimulate students' interests might include pictures of personal heroes (Gandhi, Einstein, Bill Gates, Chris Evert, Beethoven etc.) or a personal hobby such as mountain climbing.
>
> **DON'T** display pictures or computer screens that depict explicitly sexual images.[45]

Similar anecdotes emerge from the private sector as well. In an article on the Stanford graduating class of 1994, Jodi Kantor relays this story of the early days of PayPal, in Silicon Valley:

> Litauri Schultheis said that when she interviewed to be PayPal's office manager, and its first female employee — before even Mr. Sacks arrived — an engineer asked her, "Does this mean I have to stop looking at porn?"[46]

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[44] Ibid., Carnegie Mellon University report quoted in Spertus, 25-26.

[45] "Final Report of the Committee on the Status of Women Graduate Students and Faculty in the College of Engineering," no page. Emphasis added.

[46] Jodi Kantor, "A Gender Gap More Powerful Than the Internet," *The New York Times*, Dec. 23, 2014.

Between the late 1980s and the mid-1990s the major shift in attitudes appears to be a mild awareness that in certain, contingent circumstances, the presence of pornography in the workplace isn't appropriate. The comparisons to the Ayatollah Khomeini give way to a grudging compromise like Munson's: "In cases where another image will serve your purpose equally well, why not use that other image?" There was not a culture change so much as a finer calibration of when, if ever, it was okay to look at pornography in the workplace.

In Karen Frenkel's 1990 cover article for *Communications of the ACM*, titled "Women and Computing" she includes anonymous quotes gathered from women computer scientists around the United States. The quotes detail experiences of harassment, abuse, and alienation. In one passage, a woman details her experience choosing test materials at MIT's Media Lab (Screenshot here to retain its original appearance):[47]

> In "The Garden [at MIT's Media Lab] . . . some faculty, students, and staff [chose] a test sequence from a film clip of the TV program 'Moonlighting'. They were looking for a sequence of a few frames that had a variety of colors, textures, and camera motions, and that probably had human figures on it. On these strictly technical considerations, they chose a sequence in which, at the beginning, the camera focuses closely on the legs of Cybil Shepherd as she walks away from the camera in a torn skirt. Subsequent frames show her walking flirtatiously past Bruce Willis, pretending to be angry at him but with a small, triumphant smile on her face . . . Women must deal with these pictures of women as test objects, as pictures to be used over and over again, long after their anger has worn off."

It is remarkable how perfectly this person's description echoes Munson's description of the Lena image from six years later and Alexander Sawchuk's description of his boredom with existing test images before the Lena image's initial digitization. It appears from these accounts that the search for a formally complex image inevitably leads to men selecting a woman's body parts to act as a testing instrument. The correspondent's

[47] Frenkel, "Women and Computing," 36.

description of her work in the Media Lab describes the anger of being forced to select a clip for sexist reasons. But it also describes the routinized violence of using the clip repeatedly as a necessary and assumed practice of the job.

The neglect of object B

Beginning in the 1970s, without the working concept of the internet, computer scientists and image engineers were hard at work perfecting the most efficient and dependable ways of sending a now-cleaned but formerly pornographic image over a computer network. Artifacts have politics but they do not all have politics in the same ways. To talk about the politics of the Lena image is to, by extension, talk about the image standards like JPEG and MPEG that it helped test. The politics of test images compel us to question "Who is seeing?" "Whom is this a representation of?" "Who is it for?" and "Who gets to use it?" Image standards are shaped by their testing regimes, which are, in turn, shaped by the cultural milieus where those tests take place. The Lena image is unique in that it spans so many milieus and so many standards, that it became a standard of its own. Thorstein Veblen suggested the term "trained incapacities" for the kinds of failings that follow from proper professional training and execution.[48] Kenneth Burke and Robert Merton both took up the concept of trained incapacities and developed it. Burke writes that "One adopts measures in keeping with his past training—and the very soundness of this training may lead him to adopt the wrong measures."[49] In other words, trained

[48] Thorstein Veblen, *The Instinct of Workmanship, and the State of the Industrial Arts* (New York, NY: The Macmillan Company, 1914).

[49] Kenneth Burke, *Permanence and Change: An Anatomy of Purpose* (Los Altos, CA: Hermes Publications, 1954), 18.

incapacity is not an unwanted side effect of proper training; it is a way of understanding properly trained actions from a different perspective. Trained incapacity is a term "which helps us to observe in the medium of communication simultaneously both the defects of its qualities and the qualities of its defects."[50] The routines of professionalization required image engineers to choose particular pictures, to potentially favor certain kind of images, and to reproduce those images with as much regularity as possible—building up the known catalog of possible image transformations. Constant reproduction guarantees the legibility of the image as an instrument and as a test subject. Understanding this repetitive labor as a manifestation of trained incapacity is one way of accounting for the selection and maintenance of the Lena image if we wed it to the descriptions of functional misogyny that suffused lab environments.

As Burke writes, in an appropriately visual metaphor, "A way of seeing is also a way of not seeing—a focus upon object A involves a neglect of object B."[51] This is precisely the problem David Munson diagnosed in 1996 when he wrote, "We may even devise image compression schemes that work well across a broader class of images, instead of being tuned to Lena!" The Lena image was a tuning instrument that permanently affected the ways that engineers experienced their profession. But the experience of engineers only matters insofar as we care about the shaping of technology. The other story here is one of historical exclusion, a story where women were limited in their capacity to shape computer science as a discipline, were limited in shaping the

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[50] Ibid., 70.

[51] Ibid.

media environment of their workplaces and classrooms, and were excluded when men repaired the instrumental value of the Lena centerfold. The Lena image was what Luce Irigaray calls the "*target, object,* and *stake*" of a masculine discourse.[52] If we acknowledge that the work of digital image processing was inseparable from the work of transforming the Lena image and the problem of unlocking its "compressibility," then the Lena image was a riddle to be solved, an object to study, a target of processes, and it encapsulated the stakes of the discipline.

Wittingly or not, David Munson pinpointed the problem with the dominant use of the Lena image. The subjects who exposed the sexist contexts computer science and engineering were responding to the notion that fundamental image technologies of the late twentieth century are tuned to a norm of hetero desire. To look at a digital image is to look at an image in the way a computer scientist or image engineer would prefer to look at the Lena centerfold. The rebuttals to this labor did not just demand new images and a break from the repetitive use of women's bodies as tools of commensuration. It was a knowing demand that to change the work of doing image engineering would mean changing who has the power—within classrooms, labs, and offices—to choose the tools and materials of representation.

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[52] Luce Irigaray, *Speculum of the Other Woman* (Ithaca, NY: Cornell University Press, 1985), 13 (emphasis in original).

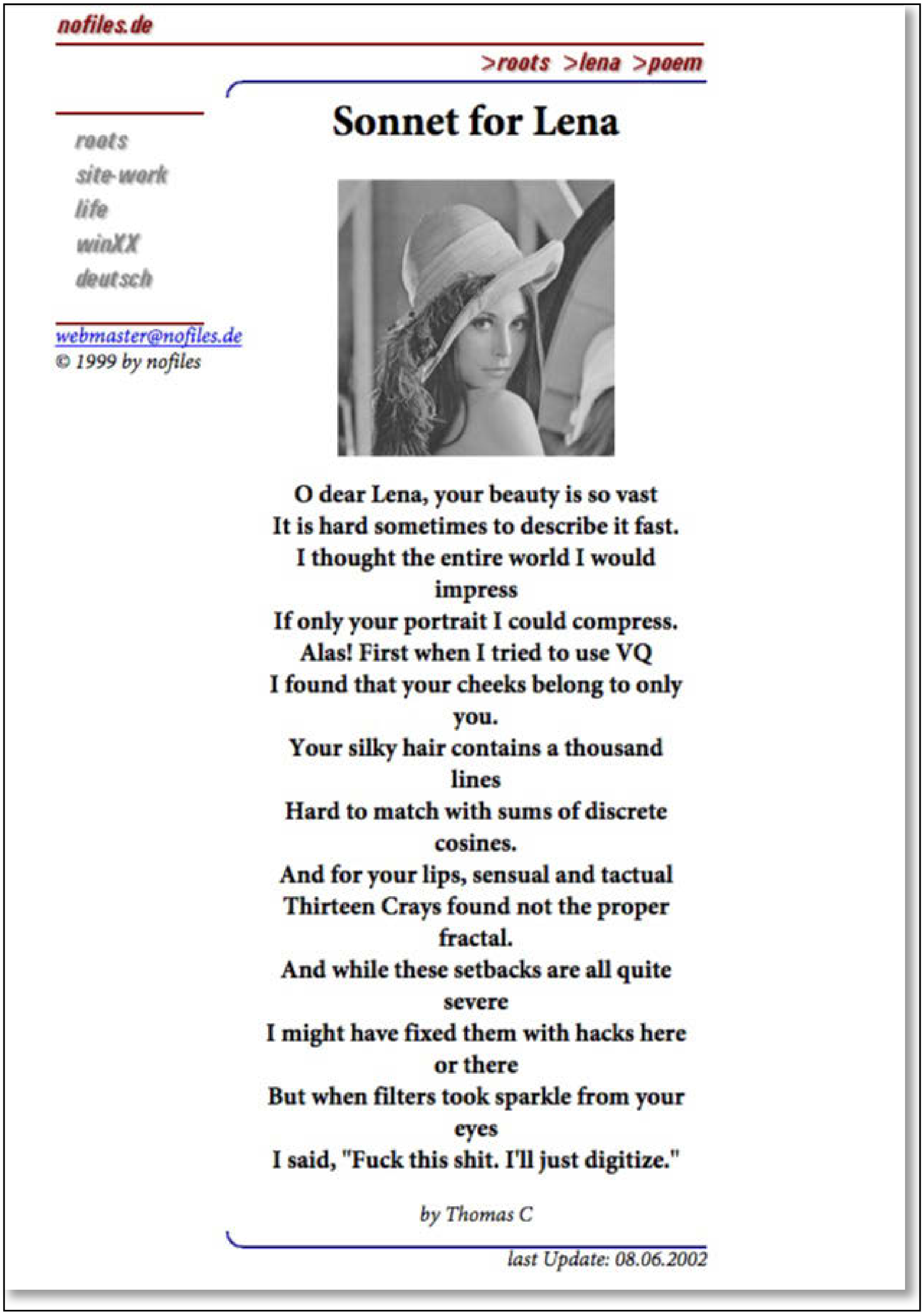

Figure 31– An sonnet written to Lena and published online in the late 1990s. The image is appropriated in many places. In this case, the poem satirizes the labor of trying to transform and manipulate the image efficiently.

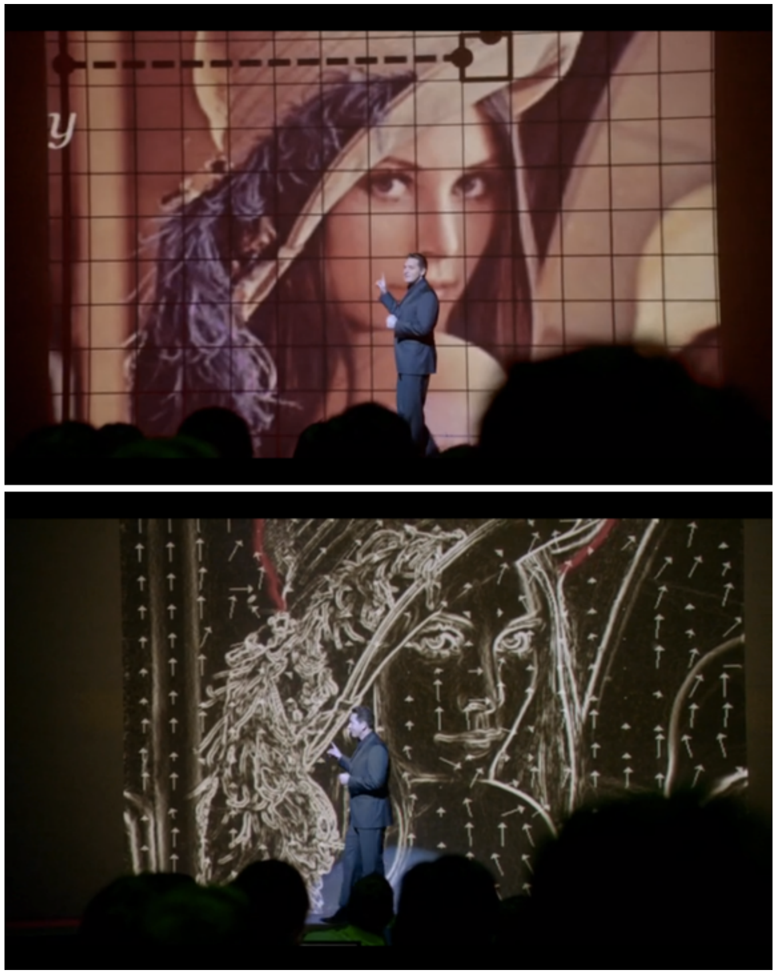

Figure 32 – *Silicon Valley:* Hooli CEO demonstrates compression on Lena image

Figure 33 – *Silicon Valley:* Rusty at his desk, Lena watching over him

Afterlives

In the summer of 2014 the HBO comedy *Silicon Valley* is finishing its first season. In the season finale, the series' protagonists, a start-up with an enviable compression algorithm, compete against their main antagonists "Hooli," a powerful Silicon Valley firm standing in as the show's Google. Hooli has both bottomless funds and an abiding grudge against the startup. The two sides meet in the finals of a Valley competition, pitting their compression algorithms against one another. Hooli's C.E.O. stands in front of the crowd and in the familiar bravado of the Valley's product showcases, proceeds to compress an image more efficiently than an image has ever been compressed (figure 32). The image is the Lena image (probably lena_std.tif).

Earlier in the series, the start-up's leader sits at his desk, trying to think his way out of a stymying compression problem. Deep in thought his head is framed facing a now-familiar figure, the Lena image is pinned to the wall next to his desk (figure 33). This is a little curious because we normally don't see Lena printed out. But the point is clear. The fact that the Lena image appears at these two moments in *Silicon Valley* is not at all surprising. The image is there when the young, aspiring compression engineer needs inspiration, and the image is present when the behemoth corporation needs to assert its nonpareil mastery: in the visual culture of Silicon Valley (and *Silicon Valley)* the Lena image is both muse and model.

Use of the Lena image may finally be waning. But of its many legacies, its status as an icon of image engineering, and "compression" more broadly, has profession has prompted a range of responses. In addition to appearing regularly on *Silicon Valley* and in poetry (figure 31), the image appears in art works, the aforementioned creative-commons re-enactment, 3D renders, throughout the stock images used on the Apple app store, and in video art pieces.[53] This is not surprising. As recurs throughout the history of standard test materials, people will often find and repurpose test tools as the basis of artistic creation.

A video art work by Jamie Allen called (unfortunately) "Killing Lena" shows the image undergoing repeated compression. Like a photocopy of a photocopy the image slowly disappears in a cloud of pixelated noise while a Roberta Flack song plays underneath.[54] This is not the story of the Lena image. Repeated reproduction did not kill the Lena image, it strengthened and hardened it and, more importantly, reproduction gathered a discipline around the image.

Test images forecast what we think our publics and our machines will see. They imagine *how* we will see—whether it's the automated detection of tanks or centerfolds, or it's through a gun sight, test images *foresee* one version of things to come. Our media technologies are built on standards and our standards, in turn, are built through the materials that standards makers use. The history of test materials, like the Lena image, however, tells us that our standards are made to work in the world but they are made to work for only some people in some ways.

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[53] A recent exhibit at the Vancouver Art Gallery, which the gallery claims is their biggest ever, called "Mashup: The Birth of Modern Culture" features the Lena image on the first floor in an artwork by Amber Frid-Jimenez. In the piece, "This is not a test" (2016) The full centerfold appears wrapped around a three-dimensional triangular sculpture, and is overlaid with quotes from feminist authors.

[54] The video is viewable on the artist's website: http://www.jamieallen.com/killinglena/

Chapter 4:
The Uses of High-Resolution Time

Temporal Infrastructures

"Next to the inconveniency of speaking different languages, is that of using different and arbitrary weights and measures," writes future American President James Madison to another future American President, James Monroe, in a letter dated April 28, 1785. "Do not Congress think of a remedy for these evils?"[1]

Madison had his own solution: use a clock beating regular seconds; measure the length of a pendulum that beats seconds or half-seconds; and create a standard measure of length based on that fixed value of seconds. In turn, a standard measure of length could establish a standard of mass and even a standard coinage. Madison thought, in other words, that the solution to the problem of non-standardized measurements was basing all units on time.

The so-called "seconds pendulum" is one of several predecessors to the contemporary age, in which all basic measurements are undergoing a process of temporalization. In this chapter, I argue that the temporalization of measurement has had profound consequences for media and communication infrastructures. Specifically, the expansion of temporal infrastructures based on what I call "high-resolution time" has created unprecedented resources for the management of information, the derivation of difference, and the extraction of value.

In the budding American republic, senior government officials often made standardized measurement their bailiwick. In 1790, Thomas Jefferson proposed a new

[1] James Madison, *Letters and Other Writings of James Madison: Fourth President of the United States* (Philadelphia: J.B. Lippincott & Co., 1865), 152–53.

decimal system of measurement based on the swinging pendulum but stalls in Congress and war in the Northwest Territory delayed the approval of a clock-based length standard.[2] John Quincy Adams, then Secretary of State, took up the subject of standardized measures in 1817. His ambivalent analysis, one of the most erudite studies on the subject of standardization for its time, ultimately concludes that standardization is futile, if only because common people will resort to referring measurements back to the human body—the most accessible of reference points. Adams marks a significant chapter in the long history of American measurement and its divergence from international norming.[3]

Measurement standardization followed a bloodier path in France, where the French Revolution interrupted similar proposals to use the pendulum as the standard of length. At one hopeful moment it appeared likely that the United States, Great Britain, and France would all share a measurement system based on the swinging seconds pendulum. However, a disagreement on *where* to measure the pendulum's movement postponed the plan.[4] Since differences in latitude affect a pendulum's swing, the parties needed to agree on the measurement's location. Would the observations be done in Paris, London, Monticello, or some neutral location? Before an agreement was reached, the French Commission of Weights and Measures retreated, worried that the units of time

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[2] C. Doris Hellman, "Jefferson's Efforts Towards the Decimalization of United States Weights and Measures," *Isis* 16, no. 2 (1931); Thomas Jefferson, *The Papers of Thomas Jefferson*, ed. Julian P. Boyd, vol. 16, 30 November 1789 to 4 July 1790 (Princeton, NJ: Princeton University Press, 1950).

[3] John Quincy Adams, *Report of the Secretary of State, Upon Weights and Measures* (Washington: Gales & Seaton, 1821).

[4] Alder, *The Measure of All Things.*

were not themselves stable enough. Instead, as is well established in the history of the kilogram, the French based their Metric System on a measurement of the circumference of the earth, the supposedly infallible "invariant of nature."[5]

Time standards have historically involved the attempt to locate a consensual invariant of nature and to ratify that invariant at national and international levels. The politics of time measurement are at work in the debates, contestations, and compromises over how we measure time—all of which have transformed drastically in the past fifty years. Among the many negotiations and contestations, there are disagreements over whether our temporal standards ought to be based on physical measurements or astronomical ones, how we schedule daylight, and how much authority we accord the measurement of time as its own invariant of nature. Just as 19th century states struggled to agree on a locale for observing a swinging pendulum, the politics of time measurement are evident in the 1949 erasure of separate time zones in China and the subsequent implementation of a single, national time zone known as "Beijing Time."[6] More recently, the politics of time measurement are evident in the shift from astronomical timekeeping to atomic clocks, a shift that threatens to decouple daylight from how we schedule civil time.

Long before atomic time, Lewis Mumford wrote,

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[5] Ibid.

[6] Jonathan Hassid and Bartholomew C Watson, "State of Mind: Power, Time Zones and Symbolic State Centralization," *Time & Society* 23, no. 2 (2014).

> The clock, not the steam-engine, is the key-machine of the modern industrial age. . . . The clock, moreover, is a piece of power-machinery whose "product" is seconds and minutes: by its essential nature it dissociated time from human events and helped create the belief in an independent world of mathematically measureable sequences: the special world of science.[7]

Mumford's description of the *productivity* of the clock is perhaps more apt now than it was when he first wrote it. Today, the clock's products—its seconds and fractions of seconds—are more precise, accurate, and stable then ever before. They thereby offer greater resources for systems that run on precision and differentiation. Whereas time discipline and time consciousness are both commonly used in social theory to account for the clock as a life- and work-structuring device, very little attention in media and communication studies is paid to the actual mechanics of time: the seconds, minutes, and hours that are the results of large- and atomic-scale stratifications of technique and technology.

Zygmunt Bauman, Paul Virilio, and Jonathan Crary, among others, claim to reveal the world as increasingly accelerated and taking place in an unremitting "present."[8] At the same time, there is renewed focus on felt and lived temporalities in the areas of "time consciousness" and "time geography." These latter works turn away from

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[7] Lewis Mumford, *Technics and Civilization* (Chicago, IL: University of Chicago Press, 2010 [1934]), 14–15.

[8] Zygmunt Bauman, *Globalization: The Human Consequences* (New York, NY: Columbia University Press, 1998); Paul Virilio, *Speed and Politics: An Essay on Dromology* (New York, NY: Columbia University, 1986); Jonathan Crary, *24/7: Late Capitalism and the Ends of Sleep* (London; New York, NY: Verso, 2013).

the technical history of an apparently increased synchronicity to understand the stratifications of time and power in everyday life.[9] The debate between “accelerationism” and “time consciousness” is a debate over scale: over large-scale changes in the speed of business and communication versus the life experiences of workers in precarious economies. In both of these approaches, however, very little attention is paid to the problems of measurement subtending temporal infrastructures. Today, the production of time is a process of measurement built on regular frequencies of the cesium atom. Understanding time through its transformations and mediations exposes the precise and arbitrary nature of measurement at the root of our most important infrastructures. The replacement of astronomical timekeeping by physical, atomic timekeeping did not lead to a greater speeding up of society. Instead, atomic time led to high-resolution time, which became the basis for multiple relationships of work, and communication, temporality. High-resolution time and a focus on the technics of time, I argue, accommodate different scales of speed and temporality, and can offer a way out of the debate between accelerationism and time consciousness.

This chapter is concerned with the ascendance of atomic clocks as a uniquely powerful fixed point in the construction of information systems and, in particular, the materials that make up atomic time: the atoms, the servomechanisms, the memos, and the

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[9] Nigel Thrift, "Time and Theory in Human Geography: Part I," *Progress in Human Geography* 1, no. 1 (1977); Thrift Nigel, "Time and Theory in Human Geography: Part II," *Progress in Human Geography* 1, no. 3; Mark M. Smith, *Mastered by the Clock: Time, Slavery, and Freedom in the American South* (Chapel Hill: University of North Carolina Press, 1997); Sarah Sharma, *In the Meantime: Temporality and Cultural Politics* (Durham, NC: Duke University Press, 2014).

hands that switch time servers on and off. In the latter part of the twentieth century, the atomic-based definition of the second became an unassailable ground of measurement and difference. In the near future, the fixed measurement of high-resolution time will become the new basis of the metric system and a "temporal infrastructure" based on atomic timekeeping already subtends nearly all of our communication infrastructures. Temporal infrastructures—which act as an "infrastructure of infrastructures"—are possible because the measurement of time is easily produced, stable, and hyper-relational. Like all standards work, timekeeping is political; it necessarily involves debates over norms and protocols. The standards of atomic timekeeping enable practices based on the increased density of high-resolution time, which in turn becomes the condition of possibility for new practices, standards, and infrastructures. The result is a tiered assemblage: a measurement practice that creates an easily reproduced temporal infrastructure, which undergirds larger communication networks. All of this, ultimately, must be balanced against concerns that atomic measurements sever the connection between time and terrestrial movements.

Figure 34 - Time signals are a fundamental component of media systems and their infrastructural role far pre-dates the use of atomic time, network time, and satellite-based synchronicity. This advertisement for Bell Telephone celebrates the minute measurement of time for the determination of color. From *Scientific American*, April 1954: 11.

9, 192, 631, 770

There are four basic quantities in most physical measurement operations: length, mass, temperature, and time. Time is special for a number of reasons. First, time is the only one of these quantities that is always necessarily mediated by a measurement technology. We can feel time by its effects: the shifting of shadows, the progress of dawn to dusk, seasons, and wrinkles. But unlike a meter stick or a kilogram weight, there are no seconds ready at hand.[10] Second, time only "moves" in one direction. This means that the tools for measuring time require continuous calibration. If we weigh something with a scale, we can know its mass, whereas a clock is, in essence, always asking "What time is it now?"

The second is a measure of duration. Contemporary time systems are based on the transduction of atomic vibrations into stable signals we call seconds, which then compose a calculated time. To refer to something as a temporal infrastructure is in fact to refer to two processes: the measurement of seconds as a duration, and the broadcast of a time standard as a stable frequency; beginning in 1967, atomic clocks married the measurement of time and the broadcast of time in large, centralized timeservers. This marriage was made possible by the stability of cesium 133 atoms, which, under strict conditions, vibrates at 9, 192, 631, 770 Hz per second. The vibrations of cesium 133—what is called its "resonance"—are treated as an invariant of nature. And since fixed

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[10] James Jespersen et al., *From Sundials to Atomic Clocks: Understanding Time and Frequency* (Washington, DC: U.S. Dept. of Commerce, Technology Administration, National Institute of Standards and Technology, 1999).

points and known quantities are the fundamental features of a measurement system, by building clocks that constantly broadcast the invariance of cesium's resonance, we now have a time standard that is always ready at hand as both a fixed point and a known quantity.

Atomic clocks are so stable, in fact, that of the seven base units of measurement in the International System of units, the definition of the atomic-based second is a benchmark for all but the kilogram and the kelvin. In recently proposed SI redefinitions, the second is also incorporated in the definition of these units.[11] As such, the second is poised to become nothing less than the primary unit for all other units. This is because, relative to other measurement standards, time and frequency are the most accurate and cheapest measurements to produce. Just as scientists and statesmen in the 18th and 19th century saw the seconds pendulum as the potential basis for a length standard, clocks are once again the preferred sources of consistent frequencies. As Tony Jones argues, "If you want to measure something accurately, try turning it into a time or a frequency."[12] Jones specifies —and if anything, his figures are conservative— that "[t]ime can be measured a thousand times more accurately than mass and, for the same levels of accuracy, at less than 1 percent of the cost of measuring either."[13]

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[11] Approved in 2011, Resolution 1 of the Bureau International des Poids et Mesures (one of the bodies responsible for the International System of Units) describes the redefinitions of the base units in terms of the "invariants of nature," among which the second, and by extension the resonance of the cesium 133 atom, will be most primary. Resolution is available at http://www.bipm.org/en/si/new_si/what.html

[12] Tony Jones, *Splitting the Second: The Story of Atomic Time* (Bristol; Philadelphia: Institute of Physics, 2000), 141.

[13] Ibid.

An atomic clock works much like a wristwatch (see figure 35 for a simplified diagram). At the atomic clock's core is a quartz crystal and the purpose of the atomic clock is to create vibrations in that crystal. These vibrations produce the seconds used in time signals just as the quartz crystal in a wristwatch signals a second hand to move. But, unlike a wristwatch, the constant vibrations of the quartz crystal are also repurposed in the maintenance of a near-perfect cybernetic technology. The crystal, if powered correctly, maintains a microwave resonator at a constant frequency of 9 192 631 770 Hz. To assure that the quartz does both these things, it is linked to a servomechanism that automatically adjusts the electrical input to the quartz crystal controlling the vibrations. The remainder of the clock is engineered to communicate with the servomechanism to create feedback and control. Thus the atomic clock is made up of two basic pieces: a vibrating mechanism that produces the pulses of "seconds" and a feedback-and-control mechanism that calibrates the vibrating mechanism.[14]

In the atomic clock, the cesium atom enters the process as the grist for the feedback mechanism. Cesium 133 shifts its energy states in an almost perfectly predictable manner. Harnessing this predictability was an improvement over mechanical clocks that depended on precisely measured pendulums or finely cut crystals.[15] Instead the resonance of cesium, by contrast, was naturally invariant. Economically, cesium is also abundant and relatively easy to manipulate, which makes it an attractive form of fuel. Though rare, the largest deposit of cesium in the world is in Canada, produced from

[14] There are many kinds of atomic clock available today. This description is a simplification of the original atomic clocks developed in the 1950s and 60s.

[15] Jespersen et al., *From Sundials to Atomic Clocks*.

the Tanco Mine at Bernic Lake in Manitoba, and Canada is by far the world's largest producer of the element. At current rates of mining production (anywhere from 5, 000 and 10, 000 kg per year), worldwide reserves of cesium would last thousands of years. One form of cesium, a reactor by-product, is considered a potential ingredient in so-called "dirty bombs" and though pure cesium is hazardous, the United States Geological Survey considers most of its compounds to be "innocuous." Politically, the same report says, "Because the potential supply is vast compared with foreseen demand and most of it is located in a politically stable environment, no supply disruptions seem likely."[16] Hence, cesium, as the material basis of the most stable measurement standard available, is doubly lauded because the socio-political context of its mining in Canada is also seen as a long-term stable prospect.

[16] William C. Butterman, William E. Brooks, and Robert G. Reese, "Cesium," in *Mineral Commodity Profiles* (U.S. Geological Survey, 2005), 8.

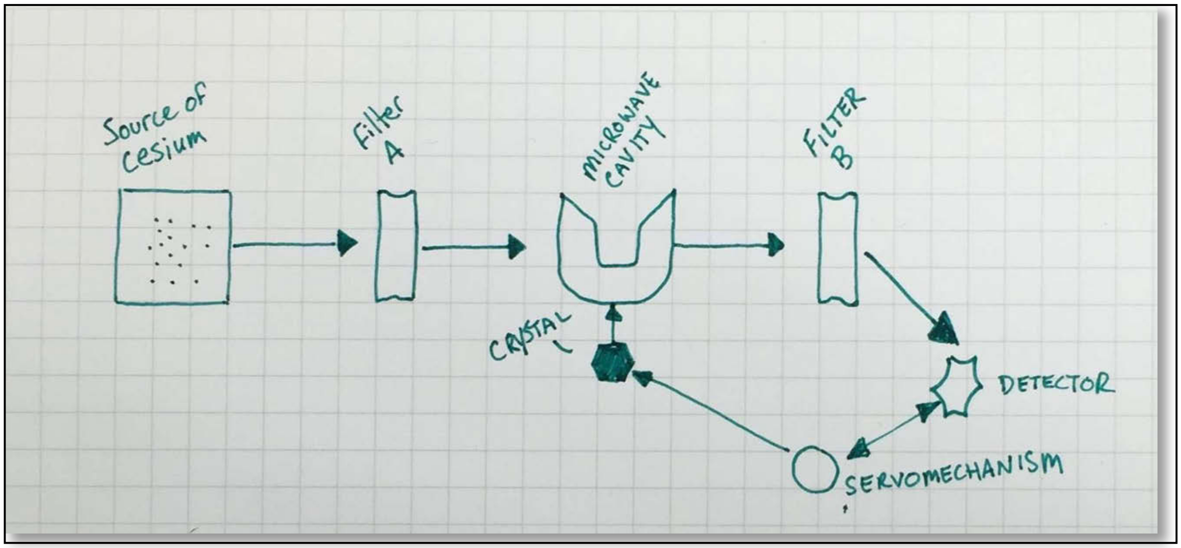

Figure 35 – A simplified diagram of an atomic clock showing the closed loop between microwave cavity, the servomechanism, and the quartz crystal. The cesium, as is visible in this diagram, is simply a stable fuel for powering a perfectly closed system. Diagram by author.

Cesium atoms have no natural alliance with temporal measurements. They are, instead, a stable variable, perfect for being the basis of a standard. As James Madison knew, a coordinated system requires a fixed point—*any fixed point.* Fixed points allow for precise measurements and create the conditions of commensurability. This process (as discussed in previous chapters) is characterized by an "arbitrary precision," which creates the possibility for the production of stabilities, like the time of day. Stabilities, in turn, create the possibility for infrastructures based on a constant signal or system of signals. While *imprecision* and *instability* are liable to intervene in this process at any stage, the maintenance of fixed points and the production of stabilities largely guarantees that our buildings don't fall down and our planes don't crash. Time, based on the production of seconds as a stability and atomic vibrations as a fixed point, is now the most important form of measurement in our infrastructure.

The functioning of the atomic clock is described in the familiar terms of a media technology—in terms of frequencies, vibrations, tuning. These terms are a part of the technical language used to describe the clocks but they also demonstrate the ways conceptual understandings of standards as communication technologies undergird even the most fundamental measurements of contemporary life and science. In 1979, Jespersen and Fitz-Randolph describe the atomic clock in terms of one such communication metaphor:

> This whole *feedback* system operates in a continuous cycle, automatically. The process is much like carefully tuning in a radio so that the listener hears the loudest and clearest signal. When this happens, the receiver is exactly "on frequency" with the signal that is sent. In the case of the atomic clock, the cesium atoms thus provide the broadcast signal and maintain the frequency at 9, 192, 631, 770 Hz.[17]

All standards require calibration as part of their crafting and ongoing maintenance. Data hygiene is one form of calibration. "Tuning" is another. In the preceding history of digital image compression, the final response to the claims that the Lena image should be abandoned was met with a limited endorsement from the editor of the *IEEE Transactions on Image Processing*. David Munson concluded, ultimately, that perhaps image engineers

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[17] James Jespersen and Jane Fitz-Randolph, *Time & Clocks for the Space Age* (New York, NY: Atheneum, 1979), 52.

would one day develop image compression methods that worked well across a wide range of images "instead of being tuned to Lena!"[18] While Munson's comment is in part tongue-in-cheek, both the Lena image and the frequency of cesium's vibrations tell us something important about the work of creating and maintaining standards: fixed points like test images and stable signals like atomic vibrations create conditions of "normalcy" that must be constantly adhered to. These arbitrary choices about what will form the backdrop for commensurability become lodestars that engineers, technicians, and other workers in standards must train their bodies and tools to follow.

What I call "infrastructural time" is now based in processes of transduction, calibrated and mediated through atomic resonance, microwave tuning, and vibrational and oscillatory frequency. As such, the ways in which time is produced through measurement standards and reproduced as a coordinated resource in civil, financial, military, and scientific operations, remake time as an infrastructural problem steeped in a politics of atomic frequency and grounded in a transduction of resonance.

The history of atomic clocks illustrates how the easy reproducibility and cost-effective precision of cesium 133 has transformed it into an unimpeachable and irresistibly plastic measurement device. The predictable resonance of cesium 133 also created new practices of transduction and transformation, as formerly non-temporal forms of measurement were *turned into* times and frequencies. This transformation highlights the mediating role that time and frequency play in building knowledge infrastructures and evidences the stakes involved in maintaining temporal standards.

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[18] Munson, "A Note on Lena," 3.

Infrastructures exist as sets of protocols, conditions, and forms for enabling other kinds of activities and, as such, all infrastructures are relational.[19] Time measurement and time broadcast simply tend to hold more relations together than other forms of enabling infrastructure. And as the stability of time is further embedded as a fundamental infrastructure, intervention in temporal standards threatens to dislodge an entire array of entwined systems.

Rationalizing Synchronicity

Although the calendar might appear immutable and obvious now, the standardization of time was marked by violence and fierce political opposition, with disagreements ranging from the refusal of England to adopt the Gregorian calendar until the 18th century, 19th century religious opposition to the system of time zones, and recent debates over the George W. Bush administration's alterations to Daylight Saving Time. At the core of such histories is an encounter with how time standards have impacted the conceptualization and control of space.[20] Between the Industrial Revolution and the

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[19] Star and Ruhleder, "Steps toward an Ecology of Infrastructure."

[20] Anthony F. Aveni, *Empires of Time: Calendars, Clocks, and Cultures* (New York, NY: Basic Books, 1989), 98–100; Jo Ellen Barnett, *Time's Pendulum: The Quest to Capture Time--from Sundials to Atomic Clocks* (New York, NY: Plenum Trade, 1998); Ian R. Bartky, *Selling the True Time: Nineteenth-Century Timekeeping in America* (Stanford, CA: Stanford University Press, 2000), 101–02; James W. Carey, *Communication as Culture: Essays on Media and Society*, 2nd ed. (New York, NY: Routledge, 2009[1989]), 162–75; Norbert Elias, *Time: An Essay*, trans. Edmund Jephcott (Oxford: Blackwell, 1992); Kern, *The Culture of Time and Space 1880–1918*, 10–35; Adrian Mackenzie, "The Technicity of Time: From 1.00 Oscillations/Sec to 9,192,631,770 Hz," *Time & Society* 10, no. 2–3 (2001); Mumford, *Technics and Civilization*, 9–17; Marita Sturken, "Mobilities of Time and Space: Technologies of the Modern and the Postmodern," in *Technological Visions: The Hopes and Fears That Shape New Technologies*, ed. Marita

Second World War, the imperatives for new, coordinated standards developed within the confluence of a wide range of rationalizing processes. These processes were established between actors in state, industrial, laboratory, factory, plantation, religious, financial, military, and artistic institutions. The objects of study in such histories include public clocks, factory clocks, telegraphs, the longitudes, the system of time zones, and powered quartz clocks, or more generally include the establishment and standardization of the calendar, the year, the day, and Daylight Saving Time (DST).

In *Communication as Culture,* James Carey memorably writes, “The control of time allows for the coordination of activity and, therefore, effective social control;”[21] Time, for Carey, was colonized by the “tentacles of commerce and politics.”[22] In the late 19th century, the telegraph and the system of time zones were technologies of industrialization and social control. Temporal structures for theorists like Carey bear ontological weight, as the structures seep into consciousness, disciplining mind and body to the patterns of time management. But time was no longer time, Carey argues, it was “a continuation of space in another dimension.”[23] Yet synchronicity and simultaneity are not equal terms, and each has different implications for understanding how technology configures space and time. Stephen Kern argues that “simultaneity extended the present spatially” but that control was not the only ideal attached to the unification of time

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Sturken, Douglas Thomas, and Sandra Ball-Rokeach (Philadelphia: Temple University Press, 2004), 75–76; E. P. Thompson, "Time, Work-Discipline, and Industrial Capitalism," *Past and Present*, no. 38 (1967).

[21] Carey, *Communication as Culture: Essays on Media and Society*, 173.

[22] Ibid., 172.

[23] Ibid., 175.

standards in the 19th century.[24] Just as GPS guides military operations today, military strategists in the 19th century desired a standard time for the coordinated movement of troops; yet, contemporaneously, Sandford Fleming imagined that a unified time system would actually bring about harmony among nations, by realizing simultaneity: familiar echoes of twentieth century champions of simultaneous media, who saw the internet and satellite television broadcasting as the coming of a peaceful, global village.[25]

When standardized time is used to control geopolitical space, the consequences are unpredictable. At the peak of its empire, the 0° meridian located in Greenwich placed Britain at the center of a global time system. But by placing the International Date Line in the far-away Pacific Ocean, the British Empire paved the way for East Asian stock markets to exert greater influence on financial events in the late 20th century, since they are the first markets to open each morning.[26] As atomic timekeeping replaces previous time systems, the centrality of the US Naval Observatory overtakes the historical home of astronomical timekeeping in Greenwich—wiping away another residual artifact of British Imperial control over space and time. Time management charts shifts in global political and financial power and evinces the political and spatial dynamics of choices and debates about time standards. As Carey, Kern, and Sturken show, the relationship between space and time inspires descriptions of the relations underlying social life. As the process of

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[24] Kern, *The Culture of Time and Space: 1880–1918*, 12–13.

[25] For the utopian claims made about satellite broadcasting, see Lisa Parks' discussion of the "Our World" broadcast. Lisa Parks, *Cultures in Orbit: Satellites and the Televisual* (Durham, NC: Duke University Press, 2005), 21–45. See also: Marshall McLuhan, *The Gutenberg Galaxy: The Making of Typographic Man* (Toronto: University of Toronto Press, 1962).

[26] Sturken, "Mobilities of Time and Space," 75–76.

decoupling space from transportation spread in the 19^{th} century, time became a problem of communication. Indeed, in terms of time, the nineteenth century is perhaps best thought of as the century of *synchronization* or *simultaneity,* as the telegraph, standardized time, time zones, and broadcast time all introduced new conceptualizations of bounded space.[27]

At its most basic level, pure sensory simultaneity is now understood to be an impossible achievement— because of communication lags, certainly, but more to the point, because of the Special Theory of Relativity. In "On the Electrodynamics of Moving Bodies" Einstein defines simultaneous events in terms of everyday life:

> If, for instance, I say, "That train arrives here at 7 o'clock," I mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events."[28]

Simultaneity is, in other words, felt but always illusory. With simultaneity, we are always dealing with a social construction of a sense of timeliness, which may be a useful concept for theories of modernity but is shaky ground on which to build our understanding of time and infrastructure. Temporal infrastructures have embraced this uncertainty by constructing systems based on *artificial synchronicity*, systems that are very good at

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[27] Harold Innis too describes space-bias media such as the telegraph as naturally compatible with the machinations of empire and the maintenance of control over space. See: Harold Adams Innis, *The Bias of Communication* (Toronto: University of Toronto Press, 1951).

[28] Albert Einstein, "On the Electrodynamics of Moving Bodies," in *The Principle of Relativity: A Collection of Original Memoirs on the Special and General Theory of Relativity* (New York, NY: Dover, 1952), 39.

counting and coordinating their counting by correcting for entropy, gravity, and movement.

Artificial synchronicity refers to events and operations that use an agreed-upon time scale. More importantly, synchronicity makes its own arbitrariness obvious: the epochs, nodes, and standards of measurement necessary-but-not-natural to a synchronous system are the products of human choices, protocols, institutions, and programs. Therefore, what is frequently called “simultaneity” is a conventional fiction of time standardization. This convention functions out of convenience or by a lack of scrutiny of the material means of time measurement and coordination. As Adrian Mackenzie writes, “Clocktime neither stands apart from collectives nor is it completely coded in their social functions or purposes. Its mutability stems from the structural incompleteness of collectives themselves.”[29] Atomic clocks, then, become one way (and for the time being, the best way) to account for the appearance of time as a stable measurement that structures social relations. The definition of the second is a mediatic recording protocol for transforming constant energy into stable ticks; broadcast time standards like Coordinated Universal Time are, accordingly, media transmission standards for translating measurement into information. Theorizing measurements and protocols as communication problems opens them up to being de-naturalized and potentially revised.

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[29] Mackenzie, "The Technicity of Time," 253–54.

Atomic Time in Practice

When atomic clocks first appeared, they were the latest in a series of instruments used to verify the complicated measurement of seconds. Prior to atomic timekeeping, seconds were based on knowledge gleaned from an ephemeris, a catalogue of calculated celestial events. Time was based either on the earth's rotation or on the regular occurrence of other celestial events: the earth's orbital motion around the sun and the moon's orbital motion around the earth. As astronomers measured these movements they would compare their observations and calculations against an atomic clock, which up to this point was simply a very accurate check on their manual calculations. But the tool's usefulness exposed that the measurement of time was swifter, easier, and more consistent when based on atomic vibrations. Atomic clocks had the added bonus of excluding the subjective errors of observation and calculation.

By 1967, atomic clocks had proved so accurate that the definition of the second changed from one based on the ephemeris to one based on cesium 133. In other words, the means of verification usurped the measurement it was created to verify. Moreover, since atomic clocks were developed as checks on calculations of the ephemeris, the seconds they calculated were meant to perfectly model an ephemeris second. But the models of ephemeris seconds produced by atomic clocks were so perfect that the manual calculations couldn't withstand the scrutiny. Thus, when atomic clocks replaced ephemerides, the tool of measurement replaced the process it was meant to scrutinize. This transition is often lamented as the exchange of the celestial for the profane.

The coordinated measurement of seconds already undergirds our global mapping systems, financial transactions, and every single networked computer interaction. The fundamental stability of time in the past fifty years is nothing short of the basic condition for the building of our contemporary information infrastructures. A politics of frequency—the frequency of vibrations, of oscillations, of intervals—continues to pervade debates over how time should be measured. But as the importance of temporal infrastructures becomes entrenched, the stakes of timekeeping grow too.

Two problems have plagued those who have tried to keep a long-term record of time: the earth is an unpredictable timekeeper, and every clock eventually becomes less accurate.[30] To mitigate the effects of these facts, governments, scientists, and private enterprises have provided larger groups of people with clocks and networks that lose time less frequently; and they have promoted the replacement of the earth as a timekeeping device. The result is that many atomic clocks in operation today lose a second once in every thirty million years. Our most stable clocks are, in other words, accurate beyond any scale of humanity's past or future.

The clock on my computer's desktop reads 1:35:16. If I disconnected it from the internet, it might lose one or two seconds today and ten to thirty seconds by the end of the week. This will probably not gravely affect my life. When David Mills first introduced the NTP, he made it clear that such protocols are not designed merely for everyday use. He recognized then that, "Accurate, reliable time is necessary for financial and legal transactions, transportation and distribution systems and many other applications

[30] "Accuracy," is how closely a clock is aligned to time standards, while "precision" is how granular the time reading is, and "stability" is how well a specific clock can maintain its accuracy.

involving widely distributed resources."[31] Mills knew that two, interwoven questions could encapsulate the late 20th-century concerns about synchronized time. So he asked:

> How do hosts in a large, dispersed networking community know what time it is?
>
> How accurate are their clocks?[32]

The NTP was one of the first Internet Protocols, and Milles's own answer to his question "How accurate are their clocks?" illustrates the lack of concern for synchronous timekeeping at the time. In a survey of the internet's 94 260 servers in the late 1980s, he found, "About half of the replies had errors greater than 2 [minutes], while 10% had errors greater than 4 [hours]. A few had errors over two weeks."[33] While Milles's questions persist, hosts in a networking community now "know" what time it is because of protocols like Milles's NTP, and their clocks are accurate beyond any scale that fits our most optimistic projections of humanity's time on earth. The new question for time standards and time synchronization is what we do now that a nearly unimpeachable authority has accreted to timekeeping as the most stable and accessible form of measurement.

The connection between atomic timekeeping and the network timekeeping exemplifies the union of the measurement of time and the administration of time. This union animates the history of civil timekeeping, with everything from the system of

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[31] David. L. Mills, "Internet Time Synchronization: The Network Time Protocol," *IEEE Transactions on Communications* 39, no. 10 (1991): 1482.

[32] Ibid.

[33] Ibid.

longitudes, time zones, the telegraph, and the railway system entwined in a struggle over how to measure time and how to tell a population what time it is. Since the beginning of synchronized time in the 19th century, bureaucracy and infrastructure have appeared at risk of non-synchronicity. While pitching his system of standardized time zones—”Cosmic Time” as he called it—the Canadian engineer Sandford Fleming argued that unsynchronized time posed an increasing risk to social and bureaucratic life:

> our present system of notation . . . produces a degree of ambiguity which, as railways and telegraphs become greatly multiplied, will lead to complications in social and commercial affairs, to errors in chronology, to litigation in connection with succession to property, insurance, contracts, and other matters; and, in view of individual and general relationships, it will undoubtedly act as a clog to the business of life and prove an increasing hindrance to human intercourse.[34]

Fleming and other standard time advocates were eventually heeded and along with Universal Time, an international system of time zones and daylight-saving time were all adopted as solutions to the obstacles of communicating, moving, measuring, and controlling energy use in the industrial economies following the First World War.

In the years since David Mills created his Network Time Protocol, the list of systems, industries, and occupations that rely on networked, coordinated time has expanded exponentially. Protocols like the NTP made this possible by creating highly precise conditions of synchronicity. But these systems also rely on high-resolution time.

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[34] Sandford Fleming, "Time-Reckoning for the Twentieth Century," in *Smithsonian Institution* (Washington, DC: 1889), 348.

A clock's depth of granularity is referred to as its "resolution." Resolution is equal to the smallest increment that a given model can count. A manual wristwatch usually has a resolution of one second. A word-a-day calendar has a resolution of one day. The GPS has a resolution of one nanosecond. The high resolution of atomic clocks and the synchronicity of their time measurements (their epochs) are the two features underlying contemporary, sophisticated communication infrastructures.

Take the GPS system as an example of the embeddedness of high-resolution time. In the GPS the synchronization of satellite-mounted atomic clocks calculates physical location, and a miscalculation of a nanosecond (one billionth of one second) is equivalent to at least twelve inches in mapped space. The loss or gain of a full second, then, is equivalent to a mis-location of at least a billion feet, or 7.6 times the circumference of the earth, or eighty-percent of the distance to the moon. If you are planning a road trip or trying to shoot a missile, a lost second in the GPS could severely hamper your plans.[35]

Finance capital is equally reliant on the measurement of miniscule amounts of time and hinges on a network suffused with temporal contingency. Automated arbitrage is nearing the speed of light, with thousands of electronic trades occurring each second. In finance capital, the frequency of trading dictates the potential for gains in profit. As the Chief Information Officer for the New York Stock Exchange identifies, "There's a perception that any slight increase in speed can result in a huge financial advantage."[36] In

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[35] Tom Logsdon, *Understanding the Navstar: GPS, GIS, and IVHS*, 2nd ed. (New York, NY: Van Nostrand Reinhold, 1995).

[36] L. D. Paulson, "Some Users Find the Speed of Light Too Slow for Their Networks," *Computer* 44, no. 4 (2011): 18.

automated arbitrage, buying and selling financial products in tiny fractions of a second accumulates value; profits come about through additions of many fractions of a cent instead of larger, long-term gains in the value of a single investment. While trades regularly occur in microseconds, one latency management group predicts future trades could occur in picoseconds (one trillionth of a second), as the management of latency is reduced to controlling the processing of light in fiber optic systems as quickly as possible: "In high-frequency trading, light propagation delays are, in many cases, the largest limiting factor preventing traders from immediately exploiting arbitrage opportunities."[37] Value cannot be created in financial trading without the measurement of difference in the prices of commodities over time or space; accordingly, there is a greater potential for value extraction where finer temporal resolution exists. Time standards can provide that resolution by coordinating epochs with greater precision and accuracy. As Donald MacKenzie shows in his study of the material sociology of arbitrage, high frequency trading depends on a complex material apparatus that extends from the location of bodies, to terminals, to buildings, and to fiber optic nodes.[38] Each morning, however, the entire system is re-synchronized to atomic clocks.[39] Atomic synchronicity, in other words, subtends the entire assemblage of high frequency trading.

We have inherited the truism, from Marx, that the duration of a transaction—the process of transforming commodities into money—was a primary source of loss: "Quite

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[37] Ibid., 19.

[38] Donald MacKenzie, *Material Markets: How Economic Agents Are Constructed* (Oxford: Oxford University Press, 2008).

[39] Ibid.

different is the time which generally passes before the commodity makes its transition into money; or the time during which it remains a *commodity,* only a potential but not a real value. This is pure loss."[40] The physical conditions of transforming commodities into money have changed but this characteristic has not. The speed of light is merely the newest obstacle for reducing the "pure loss" of monetization. What Marx described as pure loss, we now refer to as "latency," the realm of untapped potentials. Light replaced time as the constraint on monetization—as the problem of latency management—only when it became given that the precise measurement of microseconds was a stable component in the infrastructures of finance. James Carey saw the creation of new futures markets as a direct result of the building of the American telegraph network and the coordination of temporal epochs. For Carey, the telegraph decoupled space from time in the coordination of human affairs. Carey writes, "In a certain sense the telegraph invented the future as a new zone of uncertainty and a new region of practical action."[41] Telegraph-coordinated time created the possibility for space-independent trading in the 19th century. If global information networks and free trade agreements have collapsed spatial differences—and the potential to exploit spatial distances in trading—then time once again becomes the territory of financial gain. The expansion of coordinated time and the greater resolution of new time systems have further expanded the possibilities of mining value from temporal difference. But the speed of trading is also a liability. Speedy, high frequency trading exacerbated the so-called "Flash Crash" of 2010. When,

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[40] Karl Marx, *Grundrisse*, trans. Martin Nicolaus (London: Penguin, 1973[1939]), 534–35. Emphasis in original.

[41] Carey, *Communication as Culture,* 168–71.

on May 6, overall stock prices fell %5 and prices fluctuated wildly, it was evident that high frequency trading surpassed human capacities to observe market fluctuations. The Flash Crash helped uncover the fragility and limits of the temporal infrastructure underlying the production of value.

Atomic time, in a short period, ascended from a secondary check on astronomical time to the primary condition of possibility and commensurability for the Network Time Protocol, the Global Positioning System, and microsecond financial transactions, among many other infrastructural achievements that unite the science and administration of time. These practices are systems, networks, and protocols that coordinate the timing of epochs for the exchange of information. The exact epochs that are used in these systems are arbitrary, precise, and necessary. In other words, epochs are fixed points—a known quantity—and while the initial choice of one epoch over another is open for debate, it becomes increasingly difficult and sometimes dangerous to try to change it once the point is fixed.

36 seconds

The second is only one part of a complicated set of agreements that determine official time. Time administration is structured at three levels: unit definitions, synchronizations, and dates. Calendars, national, and international policies determine our dates. Communication technologies create a working sense of synchronicity. And the International System of Units determines the definition of the second. Time scales work to unite these three levels within a single regime of timekeeping.

There are many time scales in use in different kinds of operations. Two "broadcast time" scales are used in most civil operations: International Atomic Time or GPS time and Coordinated Universal Time (UTC). The two are identical except for an exact deviation of thirty-six seconds: Universal time runs thirty-six seconds ahead of GPS time because of the differences in frequency between the earth as a timekeeping device and atomic clocks as providers of constant information. To understand this difference we must understand how time scales are themselves realizations of "time ideals."

Both GPS time and UTC are "paper" clocks, meaning that they do not originate from a single device. Instead, they are calculated through a weighted synthesis of over three hundred atomic clocks in laboratories worldwide. This process of weighting is at the heart of universal timekeeping. In fact, the time provided by our computers, telephones, and GPS systems is itself an approximation, which is later adjusted using a document called *Circular T*. Every month, *Circular T* retrospectively provides laboratories with the true times of the previous month. To simplify this: even the most precise clock readings available to everyday civil operations are, in the final measure, susceptible to revision by a memo. The memo is, as John Guillory has argued, the "quintessential information genre" and it confirms this status as the ultimate authority on the calculation of time.[42]

[42] John Guillory, "The Memo and Modernity," *Critical Inquiry* 31, no. 1 (2004): 112.

CIRCULAR T 335 ISSN 1143-1393
2015 DECEMBER 10, 11h UTC

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1 - Coordinated Universal Time UTC and its local realizations UTC(k). Computed values of [UTC-UTC(k)]
and uncertainties valid for the period of this Circular.
From 2015 July 1, 0h UTC, TAI-UTC = 36 s.

Date 2015 0h UTC	OCT 29	NOV 3	NOV 8	NOV 13	NOV 18	NOV 23	NOV 28	Uncertainty/ns			Notes
MJD	57324	57329	57334	57339	57344	57349	57354	uA	uB	u	
Laboratory k				[UTC-UTC(k)]/ns							
AOS (Borowiec)	-2.4	-2.9	-2.1	-0.6	-0.7	-1.1	-2.3	0.3	5.1	5.1	
APL (Laurel)	1.8	3.0	2.9	2.9	1.6	2.5	2.6	0.3	4.9	4.9	
AUS (Sydney)	-444.1	-425.7	-408.3	-385.0	-363.8	-352.8	-328.6	0.3	5.1	5.1	
BEV (Wien)	24.0	31.3	40.3	34.5	33.9	37.0	32.5	0.3	3.1	3.1	
BIM (Sofiya)	2946.0	2951.5	2971.7	2988.2	3012.9	3021.0	3050.9	1.5	7.0	7.2	
BIRM (Beijing)	-204.0	-219.8	-218.8	-226.0	-234.8	-252.6	-263.4	1.5	20.0	20.1	
BY (Minsk)	4.7	1.2	-3.0	-7.2	-5.9	-7.4	-4.5	1.5	7.0	7.2	
CAO (Cagliari)	-8820.8	-8915.6	-9016.5	-9131.2	-9232.1	-9336.1	-9444.9	8.0	7.0	10.7	
CH (Bern-Wabern)	5.2	4.1	3.8	4.3	4.5	3.1	1.5	0.3	1.2	1.3	
CNM (Queretaro)	4.2	4.6	-2.7	-7.7	-4.2	-4.5	-2.4	3.0	5.0	5.8	
CNMP (Panama)	-12.7	-0.3	-3.9	8.6	14.2	14.9	24.2	3.5	5.1	6.1	
DFNT (Tunis)	15123.3	15287.8	15495.8	15680.3	15860.1	16038.2	16231.3	0.3	20.0	20.0	
DMDM (Belgrade)	-24.1	-24.8	-28.0	-22.2	-26.4	-39.5	-25.3	1.5	7.0	7.2	
DTAG (Frankfurt/M)	93.6	102.3	102.8	107.3	159.4	168.8	178.1	0.3	10.0	10.0	(1)
EIM (Thessaloniki)	17.4	1.8	8.2	13.3	14.0	9.4	8.0	7.5	5.1	9.0	
ESTC (Noordwijk)	6.7	6.3	4.6	4.4	2.2	2.2	1.0	0.4	5.0	5.1	
HKO (Hong Kong)	15.1	15.4	17.4	18.1	22.9	29.1	33.8	0.3	5.0	5.1	
IFAG (Wettzell)	-850.5	-840.4	-841.6	-844.4	-851.6	-856.3	-861.3	0.3	5.0	5.0	
IGNA (Buenos Aires)	-	-	-	-	-	-	-				
IMBH (Sarajevo)	476.6	464.8	449.1	427.6	413.9	397.0	379.8	0.3	7.0	7.0	
INPL (Jerusalem)	102.4	104.2	110.5	111.3	118.6	129.5	136.8	0.5	7.0	7.0	
INTI (Buenos Aires)	-51.0	-59.9	-58.9	-50.8	-56.6	-54.4	-57.4	2.5	20.0	20.2	
INXE (Rio de Janeiro)	-7.0	-11.9	-14.2	-13.4	-14.2	-21.5	-24.4	0.3	20.0	20.0	
IT (Torino)	0.8	1.2	1.1	2.4	2.5	2.0	1.6	0.3	1.2	1.2	
JATC (Lintong)	5.6	7.1	5.9	10.0	8.9	7.9	2.4	0.4	4.9	4.9	
JV (Kjeller)	-30.0	-34.7	-39.9	-42.3	-42.1	-38.0	-40.3	0.3	20.0	20.0	
KEBS (Nairobi)	-	-37.1	-325.1	-	-	58.9	258.6	1.5	20.0	20.1	
KIM (Serpong-Tangerang)	923.6	915.3	913.1	923.0	925.7	934.6	958.7	2.0	20.0	20.1	
KRIS (Daejeon)	-3.8	-4.1	-4.2	-3.7	-3.5	-3.1	-2.6	0.3	5.0	5.0	
KZ (Astana)	-591.9	-578.4	-559.4	-553.1	-548.2	-542.9	-527.9	1.5	7.0	7.2	

Figure 36 – An excerpt from *Circular T for December 2015.* These figures show the local realizations of Coordinated Universal Time (UTC). Note that the document includes the standard features of the memo: a header, date (including time in UTC: how recursive!), and contact information for the BIPM. It also includes an ISSN and a note that specifies that since July 2015 Universal Time and Atomic Time diverge by thirty-six seconds. This figure has risen incrementally and the most recent second was added in July 2015.

Up until the 1960s, astronomers still produced time standards that were derived from the earth's movements, and older time standards tried to mitigate the divergence by using an average year instead of constant measurements. The ephemeris second was their last, best attempt to develop a second that could include all the errors embedded in using the earth as a timekeeper. However, the ephemeris second only lasted seven years. Atomic clocks were proven possible in 1955 and by 1967 were precise and stable enough to replace ephemeris measurements in the production of seconds and standard time scales. What the cesium second lacked, however, was any ongoing indexical relationship to another frequency; whereas the ephemeris second could be checked against the earth's orbital frequencies, the cesium second was simply good at *ticking*. The second has been defined since 1967 as the radiation required or emitted by a cesium atom when it shifts between its high-energy and low-energy states. These 9 billion-odd oscillations of radiation took exactly one ephemeris second in 1967. Prior to its ratification in 1967, the cesium second was checked against lunar observations from 1956 to 1965. The atomic-based second adopted in 1967 and used to the present day is consequently something like a "paper second," an index of lunar movement from the 1950s and 1960s.

When my desktop clock flashes 1:35:16, it does not communicate the flow of seconds from a time reservoir. Instead, this time is correct only as a negative: it communicates that hundreds of resonance-measurement systems in the hundreds of clocks around the world have not all failed at the same moment. The clock says, "The feedback system is not broken." It is a mistake to say that cesium is, by dint of its natural properties, the basis of stable measurement: it is the *process* of transforming cesium into a stability that our infrastructures cannot do without.

What happens, then, if we choose to force instability into our perfectly ticking clocks? Once every few years the earth's movements have changed such that our broadcast "time" will be a second removed from the mean solar day. UTC and GPS times diverge because the earth does not conform to the perfect stability of atomic timekeeping. To bring civil time back in line with solar time—with noon as the middle of the day—a new second is inserted into the time stream. These seconds are "leap seconds" and they have occurred twenty-five times since 1972.[43] Between the original ten-second deviation and the twenty-five leap seconds, the two times now diverge by thirty-six seconds.

In practice, inserting a leap second requires a manual (literally, by hand) switching of the national timeservers around the globe. These insertions are now extremely controversial and may be eliminated in the near future, at which point civil time will be completely disarticulated from the sun. In theory, the steady divergence of civil and solar time would mean that noon would eventually be pitch black. The risks of keeping the leap seconds are also stark: manual intervention in the time service could have unpredictable results, as an increasing number of networks are tied into services like the Network Time Protocol and programming computers to deal with leap seconds is complex. For instance, the entire nuclear deterrent system in the United States is supposedly turned to a "special mode" for one hour before and after each leap second, which costs in the "two-digit million dollars."[44] Consequently, the cost of reprogramming computers and networks and the threatening cost of unforeseen physical, financial, or military disaster make leap seconds an increasingly untenable practice.

Leap seconds, like *Circular T*, are a part of the necessary data hygiene that time standards undergo. *Circular T* is a centralized paper standard that, once distributed, helps smooth over the local deviations from an averaged time. In this way, the circular acts as a cleaning tool in maintaining the quality control of universal time. Leap seconds too are

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[43] Dennis. D. McCarthy and P. Kenneth Seidelmann, *Time: From Earth Rotation to Atomic Physics* (Wiley-VCH, 2009), 223–33.

[44] Poul-Henning Kamp, "The One-Second War," *Communication of the ACM* 54, no. 5 (May 2011): 47.

used as hygienic instruments. The deviation of atomic and universal time is not tenable for those who think that civil time standards should accord with daylight. The mess created by the shift from astronomical calculations to the stabilities produced through the use of cesium has to be cleaned manually. Data hygiene usually requires something be removed—like erroneous information from a data set or the excess mass from a kilogram—but leap seconds show that sometimes *adding* data can also serve the purposes of hygiene and cleanliness.

High Noon

When NASA launched the *Voyager 1* spacecraft, it was intended to be the first object that was purposefully sent to leave the solar system. It was equipped, famously, with sounds and images from Earth, curated specifically to represent human civilization to any intelligent life form that might intercept it. The "golden record" it carried on board was programmed to play back at 3.6 seconds per rotation. This rate was expressed in 0.7 billionths of a second—the rate of a hydrogen atom's fundamental transition. Atomic resonance—clearly—is such a powerful known quantity, that we can suppose it to be universally decipherable. Our media standards, from the mundane to the galactic, are tuned to temporal frequencies.

Time standards are media standards that provide guidelines for the translation of material measurements into information and back into material structures. These standards are created through transductions in which resonances are made into stable pulses, which in turn create time signals. These signals are re-interpreted in bureaucracies and networked infrastructures as information: either as purely epochal readings or as the baseline for differentiation and coordination. Time is provided as a base resource for a multitude of measurements and coordinates. It is maintained through political bodies and associations, including the International Telecommunication Union, the International Earth Rotation Service, The International Astronomical Union, and the International Bureau of Weights and Measures. The measurement of the second has historically been tied to the duration of the day. Debates about how long a terrestrial day is, on average, have had direct impacts on how the second is defined. The capacity to measure the length of the average day and to compare it to some more stable standard, whether a pendulum, electric-quartz, or atomic clock, has also limited the precision of ephemeris measurement.

The problem of leap seconds and the conversion of all base units to standards of time expose the fact that the stabilization of the second has directly affected the administration of both synchronicity and measurement. In each, the second has hardened and become less apparently susceptible to revision. This has consequences for how we conceive of physical infrastructures, as they too begin to take on a hardened appearance. Leap seconds make this clear in the way they threaten the stability of coordinated time and, more importantly, how they are figured as threats to the very operation of social and physical order.

The number of different things with clocks within them has increased exponentially but the number of times has decreased to nearly one. Phones, computers, televisions, cars, and a growing number of “connected” objects now share a networked time. This suturing together of the physical world through a technical monochronic sameness isn’t the same thing as saying that temporality is flattened out. It does mean, however, that time, more than ever, is a shared, fixed point across a larger jurisdiction of people, institutions, and things.

The definition of the second and civil time scales are necessary conditions of industrial and postindustrial life, yet they are always constituted through political struggles over the use and understanding of temporal frequency. The definition of the second, disarticulated from the earth's movements, challenges engineers, astronomers, and states to consider a new civil time that may not be based in an already imaginary "high noon" sun. As an infrastructure of infrastructures, the measurement and broadcast of time is uniquely powerful in the derivation of difference. It would be a mistake, however, to take the measurement of time for granted or as the mere transduction of a natural invariant. Instead, to understand contemporary temporal infrastructures and the politics of synchronicity they entail, it is necessary to consider the material and social protocols that make synchronicity possible: the atoms, the clocks, the memos, and the hands that insert leap seconds into the time stream. The future of Coordinated Universal Time forces a question: ought time, as we understand it, be tied to the frequency of the sun? Or, does the vulnerability of time-based infrastructure trump an attachment to a predictable noon? We will have an answer to this question soon. But the answer will not emerge from an atom or an ephemeris; it will be decided by the votes of a subcommittee in the International Telecommunications Union.

Chapter 5:

Living Materials

The Standardized Patient Program

INT. MEDICAL EXAMINATION ROOM, MT. SINAI HOSPITAL.

KRAMER IS ON THE EXAM TABLE SURROUNDED BY MEDICAL STUDENTS

STUDENT #1
And are you experiencing any discomfort?

KRAMER
Just a little burning during urination.

STUDENT #1
Okay, any other pain?

KRAMER
The haunting memories of lost love. May I? Lights?

(Mickey turns down the lights)
(Kramer lights a cigar)

Our eyes met across the crowded hat store. I, a customer, and she a coquettish haberdasher. Oh, I pursued and she withdrew, then she pursued and I withdrew, and so we danced. I burned for her, much like the burning during urination that I would experience soon afterwards.

STUDENT #1
Gonorrhea?!

KRAMER
Gonorrhea!

(The lab breaks out in spontaneous applause as Mickey turns up the lights and Kramer takes a bow.)[1]

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[1] Standardized patients regularly crop up in popular culture as part of the artistic appropriation of test materials. In this classic scene from the final season of the NBC sitcom *Seinfeld*, Kramer and his friend Mickey compete for the best roles as standardized patients. Kramer is precisely the kind of part-time actor and gig-worker who is described in the standardized patient literature as best suited to the work. Mt. Sinai Hospital in New York City, where this scene takes place, was an early adopter of the standardized patient

The standardized patient program uses actors to simulate illness and disease. Once given an assignment, the patients are interviewed and examined by medical students who try to diagnose the performers. The entire process is monitored and the students are evaluated on the accuracy of their diagnosis as well as the affective care they demonstrate through their interactions with the standardized patient (SP, for short). The SP program is a part of a shift in medical training towards the clinical performance of care. Every physician, whether trained nationally or internationally, must now complete an exam called an Objective Structured Clinical Examination (OSCE) based on SP interactions in Canada (since 1993) and the United States (since 2004).[2] In other words, the possibility of standardized medical care today hinges on a bureaucratically administered system for training actors to simulate disease, perform as disabled, and occupy scripted affective roles.

The history of standards is often characterized by a search for the "invariants of nature" as an ultimate ground of value and invariance is an unsurpassed virtue in

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program and runs one of the largest programs in the United States. *Seinfeld*. Episode no. 172, "The Burning," first broadcast March 19, 1998 by NBC. Directed by Andy Ackerman and written by Jennifer Crittenden.

[2] The first physicians who were required to pass the SP test were foreign-trained physicians trying to practice in Canada and the United States. Thus, before it seemed necessary or acceptable to require nationally trained physicians to pass a test using SPs, it was acceptable to require this level of standardization in the affective care of foreign-trained physicians. Standardization undergoes many stages of testing. Here, standardized affect—as a licensing requirement—was field-tested on "outsiders" to the Canadian and American medical systems before it was tested on insiders.

Roy Porter, "The Patient's View: Doing Medical History from Below," *Theory and Society* 14, no. 2 (1985). L. Stephen Jacyna and Stephen T. Casper, *The Neurological Patient in History* (Rochester, NY: University of Rochester Press, 2012); Brian David Hodges and Nancy McNaughton, "Who Should Be an OSCE Examiner?," *Academic Psychiatry* 33, no. 4 (2009).

reference materials. But what happens when invariance meets human bodies, which are by nature, variant? The task becomes training people in the occupation of invariance. Standardized patients are both performers and test materials. They perform *trained invariance* that operates at the fulcrum of diagnostic medicine, pathology, and clinical care. If there is any doubt that standardized patients are "test materials" or treated as such Janelle Taylor quotes a (typical) speaker at a standardized patient education conference and how they explicate patients' instrumental role: ''this is a technology from my perspective. Whether you're using a person, or a computer program or a mannequin, it's all part of the continuum of simulation.''[3]

Between the 1970s and 2000s, medical educators in Canada, the United States, and Great Britain adopted a greater "performance-based" framework in training and accrediting physicians, and the SP program is perhaps the signal example of this transition. This period was also characterized by the influence of medical educators trained in psychometrics, which led to more emphasis on "standardization, reliability, and validity in assessment."[4] This shift in emphasis, to standardization and reliability, was also compelled by the rise in malpractice lawsuits filed against American physicians, a perceived increase in medical error, and a decrease in patient satisfaction with care.[5] In the United States, OSCE testing is centralized in five cities, where exams are run every

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[3] Janelle S. Taylor, "The Moral Aesthetics of Simulated Suffering in Standardized Patient Performances," *Culture, Medicine and Psychiatry* 35, no. 2 (2011): 138.

[4] Hodges and McNaughton, "Who Should Be an OSCE Examiner?," 282.

[5] Adam I. Levine and Mark H. Swartz, "Standardized Patients: The "Other" Simulation," *Journal of Critical Care* 23, no. 2 (2008).

workday.[6] This new licensing requirement emerged out of a belief that it was financially and ethically necessary to supervise the affective care of physicians and SPs were chosen as the best way to standardize that care.

The use of standardized patients dates to 1963, when a physician and a star medical education researcher at the University of Southern California were looking for a solution to the problems inherent in trying to train and compare third-year medical students (on the same campus where, precisely a decade later, the Lena image was first digitized). Howard Barrows, the SP program designer, remembers faculty trying to conduct clinical evaluations prior to the use of standardized patients (as told to Peggy Wallace):

> "Let me look at that student's picture....Well, I think I remember him." Typically, according to Barrows, most clerks received satisfactory or better evaluations. "And I knew it was because of the way they combed their hair or how neatly they dressed or if they said 'Yes sir' and 'No sir.' Almost never was there a student whose clinical skills were evaluated as unsatisfactory because the faculty almost never directly observed a student with patients." [7]

Howard Barrows was a young physician in USC's Department of Neurology and his collaborator, Stephen Abrahamson, was the school's Director of the Division of Research in Medical Education. They published their first paper on the use of standardized patients

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[6] Physicians proceed through twelve examinations, with an interview and physical examination of a patient that lasts fifteen minutes and a ten-minute station where the examinee writes a record of the SP's history and physical findings.

[7] Peggy Wallace, "Following the Threads of an Innovation: The History of Standardized Patients in Medical Education," *Caduceus* 13, no. 2 (1997): 7.

in 1964 under the title “The Programmed Patient: A Technique for Appraising Student Performance in Clinical Neurology.” Over the years the program transformed from using the term “programmed patients” to “simulated patients” to, finally, “standardized patients.”[8] The change in names does not indicate a drastic change in what these actors do for a job. However, the use of these three words—programmed, simulated, standardized—actually says something important about reference materials: they are *programmed* objects meant to *simulate* an event for the purpose of *standardization*. By calling them standardized patients, however, it actually reverses the process: they are *standardized* instruments meant to *program* medical students in proper behavior through *simulation*.[9]

In 1964, American medical board exams did away with a bedside manner test when it was revealed that the evaluations were as random as chance.[10] Early adopters of Barrows’s SP program who used it as a supplement to their gross anatomy classes said

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[8] Standardized patients have been called many other things as well: patient instructor, patient educator, professional patient, surrogate patient, and teaching associate. The three most popular names, and those that mark three stages in the development of the program, are “programmed,” “simulated,” and “standardized.” Howard S. Barrows, "Simulated Patients in Medical Training," *Canadian Medical Association Journal* 98 (1968); *Simulated Patients (Programmed Patients): The Development and Use of a New Technique in Medical Education* (Springfield, IL: Charles C. Thomas, 1971); Wallace, "Following the Threads of an Innovation."

[9] The Canadian psychometrician, Geoffrey Norman, who coined the term “standardized patient,” did so for this exact reason. He wanted a term that captured the “technique’s strongest features, the fact that the patient challenge to each student remains the same.” Wallace, "Following the Threads of an Innovation," 6.

[10] Donald E. Melnick, Gerard F. Dillon, and David B. Swanson, "Medical Licensing Examinations in the United States," *Journal of Dental Education* 66, no. 5 (2002).

that they viewed the standardized patients as "'bridging the gap' between cadaver anatomy and the anatomy of the living human being."[11]

To generate the SP scenario, medical educators first develop a profile using a template and then distribute patient scripts to SPs. Standardized patients, too, are often expected to provide feedback on their experiences using another kind of template, a checklist. Templates are an ur-form of standardization tool—a basic document like a checklist, a simple outline on a piece of paper, or a piece of string that translates one set of measurements into another. In this way, templates generate and shape information according to a basic formula.[12] For the medical educator the template takes the form of a lengthy document that covers everything from demographic descriptors of the SP like age, gender, race, and physical description, to a detailed account of the SP's complaint, wardrobe, background, and affect.[13] For the patient, the script can vary in its detail. The example in figure 37 is an excerpt from the "Patient Behavior" section of an SP template, which provides a limited range for the dimensions of the SP's emotional state and how that state should manifest in bodily and facial expressions The template is meant to

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[11] Howard S. Barrows, Paul R. Patek, and Stephen Abrahamson, "Introduction of the Living Human Body in Freshman Gross Anatomy," *British Journal of Medical Education* 2, no. 1 (1968).

[12] Templates—which appear throughout *Reference Materials*—work much the way "algorithms" are said to work in computer science. The OED, for instance, defines an algorithm as "A procedure or set of rules used in calculation and problem-solving; A precisely defined set of mathematical or logical operations for the performance of a particular task." Lisa Gitelman describes blank books (like checkbooks) in a similar way, as "meta-microgenres, one might say, documents establishing the parameters or the rules for entries." Oxford English Dictionary, *"Algorithm, n."* (Oxford University Press). Gitelman, *Paper Knowledge: Toward a Media History of Documents*, 23.

[13] University of Texas Medical Branch, "Template for Standardized Patient Script," Available at: http://www.utmb.edu/ocs/FacDevTools/script-template.asp.

program, as much as possible, the basic contours of the interaction such that the responses of the physician-in-training can be judged both qualitatively and quantitatively and, moreover, so that the scenario can be re-used.

Patient Behavior:

Affect: (check all that apply)

[ ] relaxed	[ ] cooperative	[ ] pleasant	[ ] confident
[ ] uncooperative	[ ] hostile	[ ] demanding	[ ] preoccupied
[ ] anxious	[ ] fearful	[ ] apprehensive	[ ] sad
[ ] listless	[ ] sad	[ ] withdrawn	[ ] other__________

Body Language:

[ ] relaxed	[ ] withdrawn	[ ] defensive	[ ] uncomfortable
[ ] anxious	[ ] fearful	[ ] nervous	[ ] other __________

Facial Expression

[ ] relaxed	[ ] tense	[ ] worried	[ ] irritated
[ ] other ________________________			

Eye contact:

[ ] normal eye contact	[ ] looks away frequently	[ ] no eye contact

Figure 37 - Template excerpt from the "Patient Behavior" section of a Standardized Patient Script Template, from the University of Texas Medical Branch's resources for medical educators. The full document is twenty-two pages long.

Figure 38 demonstrates how the template produces a script for SPs to follow. This “Back Pain Script” includes basic demographic information, with added identifying information including education, employment background, and possible stressors, like feeling overworked. The bottom section of the script, the “patient profile” is written in the second person, describing exactly how the performance should unfold from the perspective of the performer. SPs are given a list of questions they should expect to hear and the answers they give to each. These questions range from specific questions about the pain, “Q: Where is the pain? A: Lower back, especially left side and left leg,” to questions about the person's history, "Q: Alcohol? A: Socially, one or two glasses of wine a week."[14] Patients are subsequently coached in how to interpret these scripts through bodily comportment and their reactions to physical examination.

Back Pain Script

(Nancy Owens, Age 44)

Chief Complaint: "I've had some back and leg pain and want help for it."

Identifying Data: College-educated accountant; workload stressful at times; married, one child, good home life.

Scenario: Your low back/left leg pain began about three months ago. You had a similar problem during the last few months of your pregnancy (your child was born seven years ago), but then none until three months ago. You consider yourself an athlete and can't run due to pain and intermittent numbness and tingling (pins and needles feeling) in left leg.

Patient Profile: Concerned/anxious about this problem. You are in pain during the interview, but it is tolerable. Sitting is very uncomfortable, so shift around after several minutes. Bend forward slightly when sitting (put hands under knees—having knees higher than pelvis feels better). When walking, do so slowly with pelvis tilted forward. You have slow movements with some stiffness in your back. Standing tolerance is 10-15 minutes. You bend over and rotate slowly. If asked to lie down: bring your knees up and flatten your back for comfort.

Figure 38 - The beginning of an SP brief from the Baylor College of Medicine.

In Barrows and Abrahamson's first published description of the program they wrote:

> The concept of the "programmed patient" involves the simulation of disease by a normal person who is trained to assume and present, on examination, the history and neurological findings of an actual patient in the manner of an actual patient. This person is then used as the subject for clinical testing of student performance.[15]

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[14] Baylor College of Medicine, "Standardized Patient Script Example: Back Pain Script," https://www.bcm.edu/education/schools/medical-school/programs/standardized-patient-program/become-a-standardized-patient/script-example.

[15] Howard S. Barrows and Stephen Abrahamson, "The Programmed Patient: A Technique for Appraising Student Performance in Clinical Neurology," *Journal of Medical Education* 39 (1964): 803.

Barrows and Abrahamson make a number of assertions about the feasibility of standardizing human performances and their affective states. First is the notion that a person could be "programmed." Barrows and Abrahamson were developing their program in the middle of a boom in cybernetic thinking about human beings and such ideas about the programmed use of humans in complex systems were gaining widespread currency.[16]

Second, the simple declaration that the programmed patient would be a "normal person" trained to assume and present the characteristics of an "actual patient" delineates a presupposition that there are "normal" and "diseased" people and that the former can learn to be like the latter with enough coaching. In *Stigma*, Erving Goffman describes "We and those who do not depart negatively from the particular expectations at issue" as "the normals."[17] The standardized patient program appears to uphold such a distinction and to take Goffman's typology one step further. Whereas "we normals" are those who can pass without stigma, the standardized patient program uses this normalcy as the basis for creating a dependable and reproducible appearance of illness. As is further discussed below, using actual patients—those living with the actual diseases or illnesses they describe—would hamper the possibilities of standardization.

Third, is the suspension of disbelief that this work makes necessary: suspension on the part of the actor and the physician-in-training. Barrows and Abrahamson address this suspension head-on: "The student is informed that this is a simulation but that he is

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[16] Turner, *From Counterculture to Cyberculture.*

[17] Erving Goffman, *Stigma: Notes on the Management of Spoiled Identity* (Englewood Cliffs, NJ: Prentice Hall, 1962), 5.

expected to treat the subject as he would a patient."[18] The artifice of the scenario must be concealed for the genre of the performance to succeed—in this case the genre of "clinical encounter."

In her essay, "The Empathy Exams," which is in part a meditation on her experience as a standardized patient, Leslie Jamison describes the kinds of maintenance and *nettoyage* that she and her fellow actors undertake between simulated examinations.

> Between encounters, we are given water, fruit, granola bars, and an endless supply of mints. We aren't supposed to exhaust the students with our bad breath and growling stomachs, the side effects of our actual bodies.[19]

Standardized patients use these practices of bodily upkeep to conceal and mask the parts of their bodies that would interfere with the encounter. This is a textbook way of controlling the variables in a testing scenario—of highlighting only the parts of the body and the emotional exchange that are supposed to be examined. It is yet another example of the manual, embodied, and routine forms of data hygiene that standards workers use to maintain their test materials. Instead of an ether-alcohol solution, or a cropped image, or a leap second, the "data set" for a standardized patient is an organic, living person. And while Jamison notes that they are given water, food, and mints, they are responsible for the maintenance of their own bodies.

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[18] Barrows and Abrahamson, "The Programmed Patient," 803.

[19] Granola bars and mints are also the things I carried with me while interviewing for jobs. It is possible that they are a standard part of the equipment that many people use to maintain their bodies and minimize the discomfort that those bodies might compel in other people. Leslie Jamison, *The Empathy Exams* (Minneapolis, MN: Graywolf Press, 2014), 3.

Repetition can help the physicians-in-training conceal the artificial nature of the encounter. Louise Aronson, a physician and educator says, she has "often heard from students that the greatest challenge of standardized patient exercises was the suspension of disbelief. The most vociferous complained that circumstances so contrived couldn't possibly test them on actual practice skills."[20] As Aronson concludes however, immersion in the scenario is possible for her—as an experienced physician—through the practiced execution of labor she is accustomed to performing.

> As my own encounter began, I could see their point. Yet soon thereafter, with patient and student fully immersed in their roles, I couldn't help but behave—and respond—much as I would in so-called real life. There was artifice but also familiar work to be done.[21]

The unpredictability of human interaction is both the reason *for* the use of SPs *and* the reason that they are an inherently unstable material guarantee. Critics of standardized patients claim that too much emphasis is put on simulation in medical education, at the cost of experience with "actual patients," which threatens to make "simulation doctors" instead of actual ones;[22] and advocates of SPs claim that actual patients are too idiosyncratic and computer simulations too inert.[23] Thus, the implication is that SPs exist in a hierarchy of experiential value, somewhere below "real" patients and above

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[20] Louise Aronson, "Examining Empathy," *The Lancet* 384, no. 9937 (2014): 16.

[21] Ibid.

[22] Taylor, "The Moral Aesthetics of Simulated Suffering in Standardized Patient Performances."

[23] Christopher Pearce and Steve Trumble, "Computers Can't Listen: Algorithmic Logic Meets Patient Centredness," *Australian Family Physician* 35, no. 6 (2006).

computer simulations. For standardization purposes, however, the hierarchy is reversed: computer simulations would give the greatest amount of reproducibility across student encounters and real patients the least. SPs are therefore a compromise between the burdens of representation and communalism that all test materials must negotiate.

To be effective simulations must be both typical and realistic. Typicality is necessary because they have to accord with situations that physicians-in-training can expect to encounter. Realism, on the other hand, is a genre of performance for both the patient and the physician. Realism helps to keep the simulation coherent and to maintain the valence that each person's actions have real consequences. In SP scenarios realism also relies on the suspension of disbelief about the actual medical stakes of the scenario. Yes, both patient and physician-in-training know that no one's life is in danger. Yet, the suspension of disbelief is maintained through a mutual recognition of the stakes for each party's potential for employment. For the medical student the SP interaction is a necessary part of their professionalization; participation in the fantasy of the interaction is a requirement of the testing scenario. For the SP, the medical school or the licensing body is paying their wage, and participation in the fantasy is a condition of future employment. The testing scenario—and, with it, the possibilities of commensuration—is mediated through a suspension of disbelief that is established through the precarity of two different kinds of employment.

A suspension of disbelief would not be necessary, however, if students interacted with people who were actually experiencing the diseases they described. Yet, while patient interaction is a crucial part of a physician's training, it is not a viable means of *comparing* students. In standardized patient scenarios, the embodiment of a simulated disease is a trained technique and a method for controlling for affect. Simulation is a means of testing and modeling behavior that always serves two purposes: to train individuals and groups in the embodied experience of doing something like the actual thing and providing officials with information and observations from a controlled test. Standardization works by "scaling-up" from a controlled test into an actual implementation. According to Barrows's original justifications for the SP program, standardized patients offered many advantages over actual sick people and cadavers, the only two alternatives that were suggested at that time (Paraphrased except where quoted). Standardized patients are preferable because:

- They save embarrassment
- The patient does not fatigue
- "All necessary aspects of disease complications and prognosis can be freely discussed in front of the simulated patients without concern for their reaction to such information."
- The diagnosis is invented by the examiners before the examination can begin, so a controlled evaluation of the student is possible.
- The same clinical problem can be repeated to many examinees.
- The trained SP can report "objectively on the student physician's skills."[24]

These advantages are split between concerns for the affective state of real patients and the potentials of standardization as a means of commensuration. Simply put, the use of actual patients would be neither ethical nor reliable and reproducible. There is an ambiguity

[24] Barrows, "Simulated Patients in Medical Training."; Barrows, Patek, and Abrahamson, "Introduction of the Living Human Body in Freshman Gross Anatomy."

here about which concern actually weighs more heavily. Certainly, as a means of testing physicians, interactions with actual patients would be more instructive, though the ethical concerns for the patients preclude this as a reliable training method. But to create a standard requires reproducibility and here ethics do not figure as centrally. Instead, *if* SP performances are made reproducible they can become a tool of standardization (and not the other way around). Saving embarrassment and a lack of concern for the "reactions" of standardized patients are frequently credited as a reason for using SPs. Yet, the benefits of simulation also undercut any notion that the SP interaction is especially "realistic" or "typical." It is remarkable, in other words, that in a scenario that is crafted to be a test of a student's affective care of a patient the scenario is lauded because it does not threaten to embarrass the patient. As Taylor notes, this is the authority of "presence" that the SP achieves by being both "real" and a "simulation":

> Simulation generally is distinguished by the premise that suffering is not present—it may be *there*, or *then*, but it is *not here-and-now*, and that is what makes the SP performance a ''safe'' learning environment for the student. At the same time, however, everyone I have spoken with agrees that the presence of the SP as an *actual person* is crucial to these performances, and is what distinguishes them from other forms of ''mere'' simulation.[25]

These are the paradoxes of test materials that are at once meant to stand in as proxies for "real world" situations and yet still be usable: actual embarrassment or actual pain would make the simulation untestable or unreproducbile but what is being tested, in some ways,

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[25] Taylor, "The Moral Aesthetics of Simulated Suffering in Standardized Patient Performances," 155. Emphasis in original.

is the ability of a physician-in-training to manage the patient's emotional response to a diagnosis. Hence, SPs must be trained to react in ways that would imply the possibility of feelings like embarrassment, shock, or shame, while guaranteeing that those feelings will only ever be performances.

Model patients

Howard Barrows's first standardized patient was a twenty-two-year-old woman named Rose McWilliams, who he met through USC's Art Department, where McWilliams worked as an artist's model. McWilliams was soon joined by a second standardized patient, Lynn Taylor, another artist's model from the same department. Response to the SP program was harsh and few physicians outside of USC thought that the project was viable. The project was maligned for its association with Hollywood, with performance, and for the artifice of simulating disease.[26] This criticism was articulated to the women working as patients. In 1965, in the early stages of the program, the Associated Press learned of Barrows and Abrahamson's work and syndicated a story to several papers. In the *San Francisco Chronicle* the headline read "Models Who Imitate Patients: Paradise for Medical Students" (see figure 40), in the *Los Angeles Herald Examiner,* "Hollywood Invades USC Medical School," and in *Newsday*, simply, "Model Patients" (figure 41). The story, as it was rewritten from the wire report, begins the same. The article in the *Chronicle* begins, "Scantily clad models are making life a little more interesting for University of Southern California medical students," then goes on to describe Taylor as

[26] Wallace, "Following the Threads of an Innovation."

"a shapely brunette" and McWilliams as "the blonde."[27] Standardized patients continue, therefore, the pattern that the history of test images set forth: the practiced use of women's bodies as test instruments at the genesis of new standards.

The novelty of using actors to simulate disease was understood like many stories of innovation: as a feature of a special workplace benefit. Like the *Playboy* that was a convenient tool in the Signal and Image Processing Institute, ingenuity is understood through the instrumentalization of a (female) model's body. Which is to say that these accounts of the origins of standardized patients using the bodies of models echo the accounts of creating a test image using a *Playboy* centerfold. The origins of the Lena image are recounted (see chapter 2) as the confluence of boredom, innovation, and happenstance. This is repeated in the account of SPs and the ways that having models ready-at-hand at USC (on a campus famous for its ties to the entertainment industry) was a fortunate coincidence. In neither case do the makers of these standards take credit for seeking out women's bodies as the templates for a new kind of material commensurability.

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[27] "Models Who Imitate Patients: Paradise for Medical Students," *San Francisco Chronicle*, September 28, 1965.

Figure 39 -This is a painting of Lynn Taylor, one of the first standardized patients. It was painted by Phyllis Barrows, Howard's wife, without knowing that Taylor was one of her husband's SPs. What's remarkable is that the painting was reprinted by Howard in a special issue (1997) of the medical journal *Caduceus*, on the topic "Simulation in Medical Education." A recurrent theme in this project is the continuous loop between test objects as technical instruments and as artistic subject matter. Standardized patients are a popular topic in television, film, and journalistic writing, but as this painting shows, standards makers are also keen to re-appropriate their own reference materials.

Models Who Imitate Patients

Paradise for Medical Students

THE EASY WAY TO LEARN MEDICINE
Rose McWilliams, Professor Howard Barrows and student John Goodman

Figure 40 – Headline, image and caption from *San Francisco Chronicle* article, September 28, 1965. The caption reads "The Easy Way to Learn Medicine."

UPI Telephoto

METHOD MEDICINE. Rose McWilliams, actress and model, performs as a patient with neurological troubles during a checkup by medical student John Goodman, left. Dr. Howard S. Barrows, associate professor of neurology in the University of California School of Medicine, is observer.

Figure 41 – Image and caption from *Newsday* article about standardized patients, September 28, 1965, p. 73.

By all evidence, however, the AP's telling was not the story Barrows sought to tell about his new program. Instead, Barrows saw the use of the art department as a canny strategy to appropriate existing university resources. In a handbook that he produced for interested educators in 1971, Barrows reaffirms his commitment to this method:

> If I were to start a program elsewhere, my first move would be to inquire at the local drama department or a local amateur or professional acting society as to whether or not there would be potential interest.[28]

Barrows is quick to deny the claim that his program is unduly indebted to its proximity to Hollywood. He says that during a sabbatical year at McMaster University, in the "Steel Mill Capital of Canada," he relied on an actor, "a housewife," who "became one of the most effective and versatile simulators with whom I have worked."[29] His ultimate advice is to seek out facility for SP work wherever it can be located, "Do not ever ignore interested technicians, secretaries, housewives, and so on. Motivation is the real key."[30] SP work lends itself to a wide array of potential actors: physicians need training across a broad range of bodies, demographic attributes, and personality types. But the labor of being a standardized patient is also potentially amenable to a worker with precarious employment or intermittent work. *Who can be a standard* is in part determined by who has the time and needs the money to learn the techniques of embodied illness and disease. Theatre departments and local troupes are a ready resource of acting ability, but as

[28] Barrows, *Simulated Patients (Programmed Patients)*, 15.
[29] Ibid., 14.
[30] Ibid., 15.

Barrows's list of other possible actors—"technicians, scientists, housewives"—indicates, financial need is also a good motivation and flexible working hours are an added bonus.

What Barrows foresaw was that SP jobs could be a part of a person's pool of possible "gig work" assignments. The so-called "gig economy" is often ascribed to the twenty-first century and de-industrializing labor forces, in which an increasing number of people cobble together a living through many part-time, non-permanent positions and full-time employment (along with benefits like a pension, disability and parental leave, or sick time) becomes a rarity. SP work in the 1960s and 1970s was already imagined as part of such a gig assemblage and SPs are drawn from pools of people just making-do. For actors, SP work is a supplement to intermittent acting work and often described as a way of honing and sharpening performance skills (much the same way restaurant work fills an income void).[31] For everyone else, SP work is a way of instrumentalizing something everyone has: a body that is always ready to be medicalized.

Many of the preceding studies in *Reference Materials* have sought to further understand the labor of standards and infrastructure through the practices of engineers, technicians, bureaucrats, and lawyers. Actors, doctors, and medical licensing boards also work in concert to maintain standards and each are involved in an aspect of

[31] This was precisely the context in which Kramer and his colleague Mickey became standardized patients in *Seinfeld* (see the epigraph to this chapter). Kramer was a quintessential gig worker and actor. The joke in the Seinfeld episode involves Kramer and Mickey escalating their SP performances to the point of absurdity and competing for the best diseases to perform.

Barrows, *Simulated Patients (Programmed Patients)*; Emily Cegielski, "For Actors, Pretending to Be Sick Can Pay Off," Backstage.com, http://www.backstage.com/news/for-actors-pretending-to-be-sick-can-pay-off/.

infrastructural labor. To understand what it means to perform infrastructural labor as a standardized patient is to understand the ways that the work is rewarded, how it is regarded as a form of employment, and its relationship (if any) to notions of professionalization and expertise.

Rose McWilliams and Lynn Taylor, the first standardized patients, were paid $45-an-hour in 1965 (approximately $340-an-hour in 2015), the fee that they normally charged for modeling work.[32] This pay treated their professional skills as models as transferrable to their work as patients and as equally worthy of remuneration. Today, SPs make an average of $15-an-hour, though they can earn as little as $8 and as much as $25.[33] In general, more experience does not earn more pay. However, invasive exams do earn more—on average $40-an-hour—though one report notes that working as an SP for breast and vaginal exams can earn as much as $55-an-hour because these patients "are also instructing students how to perform them."[34] Here, more invasive examination is accorded more pay not because of its effect on the SP's body but because of the expertise that this invasiveness elicits. Regular SPs are coached to not give physicians-in-training any advice since it's beyond the scope of their assignment and any advice they gave would taint the exam results. But SPs who opt for invasive examination *are* expected to coach physicians in training scenarios, if not in exams, because only the patient can be

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[32] "Models Who Imitate Patients."

[33] Lisa D. Howley et al., "Standardized Patient Practices: Initial Report on the Survey of US and Canadian Medical Schools," *Medical Education Online* 14 (2009).

[34] Lena H. Sun, "Demand Is High for Pretend Patients," *The Washington Post*, October 14, 2011.

sure if invasive procedures “feel right.” Expertise and bodily sovereignty are aligned in this case, which only emphasizes how much they are denied in the case of regular SPs.

A report that notes that SP work is popular in the Washington, DC area claims that it is suitable for “Retired engineers and lawyers, [who] are good candidates because they can remember a wealth of information.”[35] Against claims that SP work can serve as full-time employment, Temple University’s guide for SPs notes that most of their SPs earn less than $2000 per year.[36] In the process of legitimating SP work, therefore, the labor of simulating disease has transformed from a skill regarded as commensurate with professional modeling to a low-wage, part-time job with little-to-no prospect for a raise, in which a person’s value as a resource is tied to their body and trainability as a performer. There is greater need for SPs (and need for variety among them) but less of a demand for the trained skills of McWilliams and Taylor.

By treating standardized patients as amateurs, the process also minimizes their role in evaluating physicians. When McWilliams and Taylor first began as SPs, Barrows gave them the responsibility of recording what transpired with the student. As SP education expanded and gained legitimacy, it did so by being regarded as reliable, verifiable, and reproducible—which meant that SPs could only be one node in the evaluation system. While SPs still complete questionnaires (see figure 42), the weight of the evaluations falls with educators. In recent years, some SPs have claimed that they

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[35] Ibid.

[36] Temple University School of Medicine, "Standardized Patient Program: Questions and Answers About Working as a Standardized Patient for Temple University School of Medicine," (2013).

should have a greater say in evaluating physicians.[37] Meanwhile, SP program coordinators must intervene when SPs appear to overstep their roles by, for instance, "providing feedback that seems to tread into the domain of medical expertise."[38] When commensurability is embodied, bodies also become the tools of measurement. The SPs who make the demand for more authority are negotiating for greater power over their own representation in a standardization process. When bodies are treated as tools of affective measurement, standardization will necessarily require a political negotiation over who has the power to access and describe those measurements.

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[37] Taylor, "The Moral Aesthetics of Simulated Suffering in Standardized Patient Performances."

[38] Ibid., 156.

Table 1

Standardized Patient Questionnaire

HISTORY: Did the resident ask?	Yes	No
1. Any family history of chief complaint		
2. Any sexual history		
3. If you take any prescription or OTC medication		
4. If you smoke		
5. If you drink alcohol		
6. If you take any illegal drugs		
7. If you have any allergies		
8. About any aches and pains you are having		
9. About the source of your unhappiness		
10. About family history of emotional disorders		
11. About weight change		
12. About change in appetite		
13. Changes in sleep patterns		
14. How long you have felt low or sad		
15. Whether you have had any thoughts of suicide		
16. If you have had any hallucinations or delusions		
17. Specific questions about anemia or bleeding		
18. Specific questions about possible thyroid problems		
PHYSICAL EXAM: Did the resident:	Yes	No
19. Check inside lower eyelid		
20. Look in throat		
21. Palpate thyroid		
22. Feel lymph nodes		
23. Listen to heart and lungs		
24. Palpate abdomen		

INFORMATION SHARING: Did the resident?	Yes	No	
25. Address what might be going on			
26. Indicate need for counseling			
27. Suggest antidepressant medication			
PATIENT/PHYSICIAN INTERACTION: Did the resident?	Yes	No	
28. Introduce him/herself (Must give last name)			
29. Wash his/her hands before the physical			
SATISFACTION: 30. I was satisfied with this encounter	Yes	No	
COMMUNICATION: 0=Poor to 2=Excellent How was the resident you saw at:	0	1	2
31. Demonstrating sensitivity and empathy regarding the concern			
32. Behaving warmly and professionally throughout the encounter			
33. Using words easily understood when discussing the problem			
34. Encouraging questions and never avoiding giving answer			

OTC—over the counter

Figure 42 - SP questionnaire used to evaluate the potential for using SPs in family medicine training[39]

[39] Richard Terry, Erik Hiester, and Gary D James, "The Use of Standardized Patients to Evaluate Family Medicine Resident Decision Making," *Family Medicine* 39, no. 4 (2007): 263.

The Standardized Heart

In Arlie Russell Hochschild's landmark study of work and affect, *The Managed Heart*, she describes three characteristics of jobs that require "emotional labor."[40] Hochschild writes:

> First, they require face-to-face or voice-to-voice contact with the public. Second, they require the worker to produce an emotional state in another person—gratitude or fear, for example. Third, they allow the employer, through training and supervision, to exercise a degree of control over the emotional activities of employees.[41]

These criteria are useful because they expose facets of labor that are often under-valued (in the marketplace), difficult to describe (as they involve at least two persons' internal emotional states), and awkward to enforce (one person's politeness is another person's insincerity). They are also useful because they let Hochschild make an important distinction between work that *requires* emotional labor as a crucial aspect of its execution and work that involves occasional or intermittent emotional labor or emotional labor that goes unsupervised. As Hochschild concludes, while jobs like social worker, day care

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[40] Hochschild coined "emotional labor" for this study though the term is now widely used in a range of disciplines and denotes a much wider set of practices than Hochschild's originally restrained scope. Arlie Russell Hochschild, *The Managed Heart: Commercialization of Human Feeling.*, Second ed. (Berkeley: University of California Press, 2012).

[41] Ibid., 147.

worker, lawyer, and doctor all involve face-to-face interaction and affective attentiveness, they are all excludable from the category of strictly emotional labor.[42]

Hochschild describes the emotional management and affective care that are required by a physician who must interact with a person in an intimate setting, on the topic of their body and their health, and with often surprising, disappointing, or frightening information.

> Doctors, in treating bodies, also treat feelings about bodies, and even patients who are used to impersonal treatment often feel disappointed if the doctor doesn't seem to care enough. It is sometimes the doctor's job to present alarming information to the patient and to help the patient manage feelings about that. In general, the doctor is trained to show a kindly, trusting concern for the patient.[43]

By citing Hochschild's strict criteria here I do not intend to litigate the category of emotional labor. Instead, the purpose is to better understand how the emotional labor of doctors has undergone a process of standardization and the greater attempt to account and control this emotional labor. Hochschild excluded physicians from those involved in strictly emotional labor because, despite the inextricability of patient care with affective communication and management, they do not have a supervisor exercising control over

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[42] It makes sense that Hochschild would limit the number of things that could be called strictly emotional labor in her original study on the subject. By marking out new territory at the intersection of affect and work Hochschild made a new kind of sociology of labor possible. If her criteria had been too broad it could have threatened the viability of her study ("What's *not* emotional labor?").

[43] Ibid., 151.

their emotional activities.[44] *The Managed Heart* was first published in 1979 and Hochschild's depiction of the limited enforceability of a physician's emotional labor was apt for its time. In the intervening years, however, the emotional work of medical students has come under greater scrutiny by medical schools, accreditation boards, and insurance firms who underwrite physicians. While some clinical physicians do not experience direct supervision in their workplace, and Hochschild could not have imagined how standardized patients would reform medical education and accreditation, SPs are nonetheless used to hone the emotional labor of doctors as a means of professional disciplining.

The notion that the human body is, could be, or ought to be standardized is, obviously, controversial.[45] In the mid-nineteenth century, a crisis emerged in the classification and identification of human bodies. In histories of this crisis of "governability," the crisis is often understood to have propelled the development of eugenic policies, sciences, and normalization efforts to police bodies and reproduction.[46] It also coincided with the attempt to standardize clothing production through the anticipation of future sales to middle-class consumers. In the United States, standardization of clothing accelerated with the Civil War as metrics of "normal" body

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[44] Hochschild, *The Managed Heart*.

[45] Lennard J. Davis, *Enforcing Normalcy: Disability, Deafness, and the Body* (London; New York, NY: Verso, 1995); Ellen Samuels, *Fantasies of Identification: Disability, Gender, Race* (New York, NY: New York University Press, 2014); Michel Foucault, *The History of Sexuality Volume I: An Introduction*, trans. Robert Hurley (New York, NY: Vintage Books, 1978).

[46] Samuels, *Fantasies of Identification*.

measurements allowed the mass production of uniforms.[47] Standardization, not coincidentally, is often equated with violence and the attempt to eradicate difference.[48] Medical science is often the instrument of this violence, either operating as the institution that enforces a code of normalcy or providing a scientific and moral justification. In either case, recognition by a medical institution (a hospital, a professional group like the American Psychological Association, a classification scheme like the International Classification of Diseases, or an insurance policy) carries the double-edged promise and threat of recognition, as it enables access to institutions but threatens to reduce a person to a governable category.

Standardized medical care can potentially mitigate the oppressive effects of classification. The SP program is, in one way, a technique for helping train doctors in seeing patients as more than the embodiment of a history of symptoms and to engage them as agents of their own care. Standards operate through normative conceptions of how the world ought to operate. The fantasy of more humane medical care, of a more empathetic interface with medical professionals, is an optimistic norm but carries the potential to significantly reform medicine as the fantasy is incorporated into licensing procedures and the insurance system.

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[47] Joyce N. Chinen, "Women in the Garment Industry," in *Women and Work: A Handbook*, ed. Sonia Carreon, et al. (New York, NY: Routledge, 1996).

[48] As Lennard Davis has written, fingerprinting was a crucial step in developing the idea that the human body is already standardized in certain ways. Davis, *Enforcing Normalcy*.

Imagining normal

In a training video produced by Howard Barrows in 1988, he demonstrates the steps involved in developing an SP encounter. The video, titled "Acute paralysis of both legs in a young woman," shows how a physician should take a patient's history and conduct a physical exam.[49] For the performer, Barrows describes the development of the case, the dress rehearsal, and the final encounter. He instructs the young woman in how to simulate paralysis. When he pokes her leg with a sharp pin and asks her, "Do you feel that?" she is expected to say "Feel what?" instead of "No." The "No" would give lie to the scenario—an indication that she is suppressing her actual sensation for the purpose of simulation. Instead, verisimilitude is achieved through a total denial of sensation. It is telling that Barrows would use paralysis as a template for training SPs as it clearly demonstrates the bifurcated identities that SPs must occupy when their bodies are both scripted and lived in.

At the end of his interaction with the actor, Barrows, in testing the patient's readiness, simply asks, "Can you conceive of all of this happening to you?"[50] Barrows's question is a final attempt to make sure that the act of imagination that the SP participates in—the same act that that medical educators use as a standardizing instrument—will accord with reality. All standards involve practices of imagination, acts of temporary

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[49] Howard S. Barrows, *Simulated Patient Training: Acute Paralysis of Both Legs in a Young Woman* [Video] (Chapel Hill, NC: Health Sciences Consortium, 1988).

[50] Barrows's original simulation, a patient he gave the name "Patty Dugger" was also paraplegic and in an early newspaper article about programmed patients, it mentions that Barrows's first patients were trained to simulate (presumably among other things) paralysis, loss of sensation, blindness, and abnormal reflexes. Wallace, "Following the Threads of an Innovation." "Models Who Imitate Patients."

make-believe that allow a phenomenon to be constrained, tested, measured, and reproduced. These acts of imagination are vested in the testing tools and scenarios that standards makers develop, endorse, and share. This is how standards work: by asserting a separation between the world "out there" (the vast and varied world of ongoing phenomena) and the world "in here" (the internal, apparently controllable setting of technological development). By breaking the world up into manageable chunks, standards makers must make certain decisions about how best to represent the world. "Best" here, however, can refer to any number of factors: most efficient, most cost-effective, most stable over time or across settings, most just, most typical, etc. These choices about the best way to represent the world for the given task take the form of reference materials, which are used to build and maintain standards and have real effects on the representational and distributive capacities of standards.

Standardized patients have the potential to irritate the smooth production of standards on the very terms of this proxy logic. A person cannot be a simple, manageable chunk of the world and standardized patient encounters are highly scripted because their manageability is threatened by the possibilities of improvisation and extemporaneity. Moreover, standardized patients give lie to the always-performative separation of the world "out there" and the world "in here." While they are employed as "we normals" play-acting as ill, standardized patients also have their own, unique, leaky bodies that breach the membrane between testing scenario and outside world. In the history of reference materials, the viability of standards is endangered when their representational capacities are called into question, which threatens this functional separation of inside and outside. Standardized patients are special because they only work through their capacity to bridge *both* inside and outside by being both human, and knowing what it is to be sick, but not actually *being sick*. Like all standards, though, this is only possible through the belief that the proxies used in testing scenarios can capture the measurable qualities of the world.

Conclusion

Unlike other standards examined in *Reference Materials*, which manifest in things like pieces of metal, paper, and cesium, standardized patients are maintained not only *through* the bodies of workers but *in* them. Standardized patients expose the limits of standardization, as they chafe the ability to create predictable and reproducible testing scenarios and show how messy standardization can be. But all standards are messy and though *Reference Materials* often returns to apparently inert materials, each of their histories includes contingent, makeshift, and ritualized forms of labor that standards workers use to justify and maintain the use of certain materials over others. This labor, as I have argued, is aimed at concealing and suppressing the arbitrary nature of decision-making in standards. The messiness of standardized patients simply brings these issues to the foreground. The task of masking the Lena image's origins—as *Playboy* image, as centerfold, as private property—is no small task, but it appears easy when compared to the difficulty of concealing a person's "actual body" when employed as a standardized patient.

In a posthumously published essay, *On Truth and Lie in an Extra-Moral Sense,* Friedrich Nietzsche turns to a kind of data hygiene involved with coinage—a very loose version of money laundering—to explicate his understanding of truth. "Truths are illusions," he writes, "about which one has forgotten that this is what they are; metaphors which are worn out and without sensuous power; coins which have lost their pictures and now matter only as metal, no longer as coins."[1] Nietzsche's analogy contrasts elegantly with the history of standardization. Whereas nineteenth century economic reformers believed that monetary security could be aided by a standard, "clean" coin kept under lock-and-key, Nietzsche sees truth as a conventional artifact, where the traces of its arbitrary rules have been scrubbed away and forgotten. Standards makers do not claim that standards are truth. Instead, standards are explicitly arbitrary: they are coins where the pictures are scrupulously maintained. If standards function it is not by mere dint of illusion but through the power to set the terms of normativity. As *Reference Materials* has shown, the source of this power is not pre-determined. Some standards function because they achieved commercial priority and benefit from the effects of path dependence, while others work by international agreement, legal enforcement, or through the entrenched power relations of gender, sexuality, race, ability and other strata of difference that condition the selection of some standards over others.

Reference Materials is structured by the histories of individual standards from disparate—though not unconnected—arenas. As standards makers expanded the ambit of phenomena that might be standardized they were both driven by and accompanied by a widening scope of things that seemed measurable. Thus, this project traces a filament of standardization in the long twentieth century, from basic measurement standards of mass and time, to the measurement of whether an image looks "good enough" after compression or for the demands of computer vision, to, finally, the attempt to standardize medical care through the use of (also standardized) human actors employed as test

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[1] Friedrich Nietzsche, *The Portable Nietzsche*, trans. Walter Kaufmann (1982), 47.

objects. These histories are meant to both add to an understanding of how standards developed and a better understanding of who works to make standards possible. In particular, though, these case studies were chosen because they left a body of evidence that tells us something about how standards are maintained through the routines and rituals of scientific and technical labor.

Reference Materials contributes to a number of fields and areas of inquiry, including media and communication studies, infrastructure studies, the history of standards and measurement, and the philosophy of technology. With a focus on protocols for working with measurement and testing tools, this project intervenes in these fields by expanding the understanding of who is a worker in the creation of standards. It is an attempt to uncover and account for the media theories and media practices of standards workers including engineers, secretaries, scientists, technicians, bureaucrats, doctors, teachers, and lawyers. "Reference materials" is the name I gave to the body of objects and practices that these people use to make and maintain standards. By according certain materials the authority of a standardization tool, they invoke a well-tested and practiced method for producing meaning. The production of meaning in standards—the process enabled through the selection and maintenance of reference materials—is the creation, maintenance, and reproduction of the conditions of commensurability. Ultimately, this is what is at stake in the history of reference materials: what do standards makers choose to use when they need to bring things into measurable relationships. The long tail of these choices, as the preceding chapters show, have wide reaching and unpredictable results. If potential future research might incorporate the conclusions of *Reference Materials* these conclusions may include: that standards are papered, repaired, and made possible by acts of imagination; that hygiene is a necessary part of any attempt to manage data but that the protocols for cleaning data are a constitutive part of that management; and that any functional concept of commensuration—such as it exists in modern standards—is materialized in the tools and practices of standards makers. Since standardized commensuration is a condition of making and measuring difference, attention to the materials of standardization is a means of understanding and historicizing the production of difference.

As a historical project, the methodological preoccupations of this project seek out the traces that reference materials leave in sundry archives, both formal and informal. Early in *Reference Materials* I asked, "What is the trace of tracelessness?" as I tried to reckon with studying data hygiene as a common practice across standards labor. The answer, in the discussion of the International Prototype Kilogram and the protocols for cleaning it, was "the memory of the trace's erasure." The only way to know that the Kilogram was cleaned is to find the instructions for cleaning it or the tabulation of its measurements before and after cleaning. The range of objects, practices, and standards studied in *Reference Materials* required a suitably wide range of methods to find the traces of their histories. I spent several months in Washington, DC, at the Library of Congress, the National Archives, the National Library of Medicine, and the National Institute of Standards and Technology (NIST). While some of this research is directly cited in this dissertation, these archives, more importantly, introduced me to the record keeping systems for standards. I learned how an organization like the NIST treats its test materials, how it writes its own history, and how it exposes and conceals its own maintenance protocols. This was both a conventional, archival research trip and an immersion in the paperwork of standards.

Yet this particular perspective on record keeping and paperwork only applied to the most conventional forms of standardization: measurement standards maintained by national regulatory and scientific institutions. To study something like the origins and legacies of a test image required a very different approach. It began with obtaining any published report I could find from the Signal and Image Processing Institute, to create my own chronology of that institute's use of test images. This chronology then allowed me to pinpoint the moment when the Lena image first appeared, its uses in comparison to other images, and its accordance with the Institute's military-funded mandates. These reports also opened up a second research path, into the history of digital image compression and its development as a solution to the transmission and analysis of images, a paper trail that led to the history of lunar surveyor missions and the earliest attempts at automated computer vision algorithms used in the detection of enemies in war. Perhaps many research questions would lead down both of these paths, but the ethos of *Reference Materials* is hopefully especially attuned to following the political networks of actors who choose, use, and share tools of commensuration.

What happens when the trail runs cold? Following the Lena image through the 1980s was difficult as the image was rarely tagged with any easily identifying appellation. While I located a few traces of its use, I had to wait until image engineering journals in the 1990s were called to task for its usage to start the history anew. The fact of the Lena image's tracelessness in the 1980s led to a conclusion about standardized test images: they should be tagged in predictable ways that allow for cross-referencing. If test images had standardized names and methods for citing them it would: first, allow for a more comprehensive comparison of test results; second, permit an accounting of which images are used more frequently; and third, from this accounting there could be an audit of test image use when problems like copyright infringement or sexist (mis)representation crop up. This is not a solution to the oppressive environments of computer science and image engineering, but it is a partial solution to the tacit canonization of certain test images and the material consequences that those images have for the representational capacities of media technologies.

Beyond the world of official standards, journals, reports, and databases, the trail of traces becomes much messier. In researching the afterlives of test images I often found myself on message boards where hobbyists and amateurs exchanged recycled test and calibration tools. The crude image provided by the Russian ink supplier was found on one such message board, while the "multiracial Shirley" card was found on the website of the Boise Camera Club. The club's website supplies a set of monitor calibration images that help its members control their digital photo process (a monitor must be calibrated to the same settings as the printer to guarantee that an image on a screen will look like an image on photo paper). The images are all pulled from other sources and combined in an assemblage of ad hoc testing instruments. The image (figure 19) I included in chapter two was originally supplied by Kodak to commercial photography printers but is evidently taken from an Australian photo printing company—the traces of which are left in the bottom right-hand corner where the template fields "Printed on" and "Date" still remain. Many of the images I have collected were obtained through a process of reverse-image-searching, a painfully contemporary form of re-tracing. I located an image, used it as the basis of a new search, and followed the places it went. This process exposed some of the unpredictable paths that test instruments take. The conclusion is that some test instruments work in highly controlled setting while others operate in the world in uncontrolled and unscripted ways.

The history of standardized patients followed a hybrid path, moving between official sources and the online repositories of quasi-official documentation. At the National Library of Medicine I was able to consult Howard Barrows's original publications on, what he called then, "programmed patients" and watch videos of Barrows and others training performers in the embodiment of disease. These videos were sometimes on formats that would be extremely arduous to watch outside of an official archive. I supplemented these recordings with dozens of the thousands of SP encounters that users have uploaded to YouTube. But, as with much research online, there is a contemporaneity bias to these latter videos. In addition to the video research, I read medical journals from the 1960s to the present to follow how standardized patients became a legitimate pedagogical tool and method of standardization. I also copied as many templates and scripts I could find online for training SPs and FAQ pages for people looking to take up SP work to supplement their income. These sources provided a range of perspectives to the process of standardizing the performance of disease: its historical background, institutional mainstreaming, the micro-protocols for maintaining the program, and the labor dynamics of recruiting and paying people to do the work. Our research questions are always idiosyncratic and anyone choosing to do their own project on reference materials surely would have followed a very different methodological path. If this history has a preoccupation it is with the labor conditions of doing standards work.

There is a high contrast—as there ought to be—between the work that it takes to clean a piece of platinum-iridium and the work that it takes to hide stale breath but both appear necessary in the maintenance of standards and both are grasped here as a larger set of hygienic practices. Similarly, there is a high contrast between the roles that "paper"—as a figure of materiality—plays in the development of standards. Time is maintained through a "paper standard" in the form of *Circular T*, while engineers sought to capture *Playboy* magazine's paper stock quality in the standards of digital image compression. Every standard is processed through various forms, genres, and instances of paper but each uses paper differently; and this is the project at hand: to understand how common practices of manual labor, maintenance, hygiene, and repair are interpreted differently in standardization efforts.

The search for "invariants of nature" is a search for reproducible universals. In other words, it is a search for reproducible non-difference.[2] Yet, despite the seeming simplicity of using elements like cesium to build new clocks, there are no invariants ready-at-hand. Standardized patients are aimed towards a trained invariance (as discussed above) but the work of making standards appear invariant is present in all of the cases in *Reference Materials.* This project began and finished during the twilight of the International Prototype Kilogram and the impending end of an artifactual basis of measurement in the metric system. It seemed appropriate for a project fixated on the material basis of standards that it should begin with the world's largest standards organization dissociating itself from material guarantees. Of course the process of

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[2] Joseph O'Connell, "Metrology: The Creation of Universality by the Circulation of Particulars," *Social Studies of Science* 23, no. 1 (1993).

redefining the kilogram is not easy and the search for a more stable standard always invokes the possibility that the new standard may not be stable enough. The fact is that what appears as an "invariant of nature" today will one day appear too variable for use. Every unit in the metric system has changed, except for the kilogram, despite basing those units on a seemingly inviolable effort to measure the earth's circumference. Instead of obsessing over what is and is not invariant, *Reference Materials* is concerned with the process of creating temporary, functional invariance. Functional invariance is equally visible in the protocols for cleaning the International Prototype Kilogram as it is in the patient templates SPs use to prepare their personas; the process of crafting, embodying (in metal, in flesh), maintaining, and repairing standards is the process of shoring up functional invariance to create scenarios that are testable, measurable, and reproducible.

Standards break down. Not just in the large-scale, public disasters of bridge collapses and airplane explosions—the failures of planning, execution, and funding that compel calls to fix an "infrastructure crisis." Standards break down in smaller ways that can equally call their viability into question. These ongoing failures require the intervention of standards keepers at the level of reference materials. The International Prototype Kilogram puts on mass (or does it?) and requires regular repair. The Lena image is called out as part and parcel of a sexist history of computer science and image engineering and journal editors are required to speak on behalf of the discipline in an attempt to repair the damage to the system of commensurability. Atomic time signals depart from astronomical timescales and threaten a divorce of time from human schedules of day and night. Leap seconds patch the system but are also a threat to the security of communications infrastructures built on the exchange of precise temporal epochs. And standardized patients don't just have bad breath and growling stomachs, they have demands for greater representation in the evaluation of physicians-in-training. As a fairly recent standard, a full reckoning with standardized patients is still on the horizon. What happens, for instance, when SPs don't just decide they want a greater voice, but when they want greater pay, guaranteed hours, seniority, or a union?

When issues appear with reference materials it is not in the form of some sudden, catastrophic failure; instead, these problems with the tools of standardization were problems that existed from the moment of their creation. The arbitrariness of picking one reference material over another only becomes problematic when there is some other, contested issue: the instability of platinum-iridium; sexism and copyright ownership; the triumph of physics over astronomy; or the power to speak for one's body. The resolution to these problems will not simply arrive in a new and better material guarantee for the basis of standards. These are not merely struggles over the arbitrariness of picking one fixed point over another, these are struggles over the power to pick *any* fixed point, over the ability to contest the circumstances of one's work, and over the very possibilities of standardization. The possibility of standardization hinges on creating conditions of commensurability: scenarios where people, places, and things, can be brought into measurable comparison. The power to determine standardization, therefore, is nothing less than the power to determine difference. Who makes that difference, ultimately, is always open to debate.

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