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A Voice of Process: Re-Presencing the Gendered Labor of Apollo Innovation

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From Ada Lovelace to Margaret Hamilton, retelling the stories of previously unrecognized women can broaden histories of technology and challenge the dominant imaginary of innovation today. These figures remind us that women can be(and always have been)part of computing. Yet, their significant accomplishments represent a small fraction of women's contributions to technology. Women, and especially working class women of color, have consistently done the work just below the surface of discovery. However, the data comprising their experiences remains thin, keeping those figures on the scientific margins. This essay explores how communication studies can integrate expanded methods of media archeology to address issues of representation in the absence of remarkable personal narratives. We present the case study the Apollo Guidance Computer's woven core memory, a history that is "re-presenced" through a participatory workshop that engages participants in collaborative acts of weaving. In an appeal to the tactics of design, this recuperation opens an indeterminate past to illuminate the networks of labor called into being by technological artifacts. We argue that integrating these methods can produce new, feminist histories of material practices(bringing people and places into the present along with their associated artifacts.

Keywords: Media archeology, core memory, Apollo Guidance Computer, gendered labor, history of technology

Introduction

You can't be what you can't see[1]. For communication scholars concerned with issues of media representation, this is a familiar dictum. Stories and figures give shape to our dreams and, at their best, help us reimagine our place in the social world. Media representation has been a primary focus of recent initiatives attempting to address the persistent gender imbalance in science and technology fields[2]. Beyond creating more fictional portrayals of women scientists, advocates have turned to historical representations to challenge entrenched gendered biases about technological work. From Ada Lovelace[3] to Katherine Johnson[4] these stories attempt to encourage women to participate in technology by reminding them they can be—and always have been—part of science.

Historical retellings require recorded information about individuals—the material that transforms moments into narratives and women into "worthy" significant figures[5]. Yet, historical data is thin about people on the scientific margins. How might communication studies address issues of historical representation when historical records fail? What methods of connection exist when the story isn't one of invention or original insight, when the people might not even have names? This essay explores the capacity of media archeology scholarship to remake technology histories when individual narratives are lost and unrecoverable.

The software code for the Apollo moon missions was stored in woven memory, handmade by a team of women in a Raytheon facility outside of Boston[6]. This technology—called "core rope memory"—was constructed using a process extraordinarily similar to weaving. They called it the "LOL method" for the Little

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[1] Sally Ride, the first American woman in space, was especially fond of this saying. See: Sally Ride, Harvard Business Review, interview by Alison Beard, September 1, 2012, https://hbr.org/2012/09/sally-ride.

[2] Jo Handlesman, Megan Smith, and Knatokie Ford, "Shining a Light on Untold Stories in STEM" (Washington D.C.: The White House, March 31, 2016), https://www.whitehouse.gov/blog/2016/03/31/shining-light-untold-stories-stem.

[3] Walter Isaacson, *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution*, 1st ed. (New York, NY: Simon & Schuster Paperbacks, 2015); Steven Johnson, *How We Got to Now: Six Innovations That Made the Modern World* (New York, NY: Riverhead Books, 2014).

[4] Margot Lee Shetterly, *Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race* (New York, NY: Harper, 2016).

[5] Sandra G. Harding, *Whose Science? Whose Knowledge? Thinking from Women's Lives* (Ithaca, NY: Cornell University Press, 1991).

[6] David A. Mindell, *Digital Apollo: Human and Machine in Spaceflight*, (Cambridge, MA: MIT Press, 2008).

Old Ladies who did the work[7]. The Apollo project is one of the most significant engineering accomplishments in modern history. There are countless biographies and scholarly books detailing the accomplishments of astronauts and engineers[8]. Yet, there don't seem to be any first-person accounts of the women whose careful handwork transformed software into hardware. Because we neglected to collect their stories in the past, we fail to know them in the present. The absence of their accounts re-inscribes our contemporary understanding of what innovation looks like and, in turn, shapes possibilities for building technology otherwise.

In light of this historical absence, this article describes a participatory workshop titled *Making Core Memory* that we developed with collaborators across 2016-2018. Here, participants weave a core memory quilt—engaging in the media archeology practice Vivian Sobchack calls "re-presencing"[9]. Unlike representation, re-presencing is a method that resists the desire to "fill the absence of the past with coherent narratives that substitute for their loss"[10]. Drawing on this approach, we explore the embodied experiences of the weavers as they become "activated" by the participants[11] to develop new understandings that are entwined with the gendered histories of craftwork and labor. *Making Core Memory* integrates communication and media archeology scholarship to motivate feminist histories of material practices—building new types of inquiry into historical moments and media technologies beyond the individual.

In what follows, we give a brief account of the troubles of representation and gendered labor within engineering histories. We then describe how the work of re-presencing and feminist design methodologies may be used to confront limits of historical records. The remainder of the article describes the context of *Making Core Memory*, our participatory workshop. With this case we argue material encounters have a unique capacity for opening an indeterminate past to illuminate the networks of labor called into being by technological artifacts.

Engineering Histories and the Representation of Gendered Labor

[7] *Moon Machines*, Docuseries, 2008.

[8] Eldon C. Hall, *Journey to the Moon: The History of the Apollo Guidance Computer* (Reston, VA: American Institute of Aeronautics and Astronautics, 2000); Don Eyles, *Sunburst and Luminary: An Apollo Memoir* (Boston, MA: Fort Point Press, 2018).

[9] Vivian Sobchack, "Media Archeology and Re-Presencing the Past," in *Media Archaeology: Approaches, Applications, and Implications*, ed. Erkki Huhtamo and Jussi Parikka (Berkeley, CA: University of California Press, 2011).

[10] Sobchack, 325.

[11] Sobchack, 324.

Representation has been a key issue for communication scholars working from a variety of perspectives. From critical theorists to media effects empiricists, media studies scholars have sought to understand how the representation of social groups reinforces social positions and maintains inequality [12]. At the core of this issue is both *a lack* of representation and troubles with *the way* people are represented. Across American film, TV and digital content, the number of speaking roles for women and people of color don't reflect the American population[13]. And, when their stories do appear, roles are often one-dimensional—omitting the wide variety experience within these categories[14].

Representations of women in technology fields are especially scarce. For example, women portray just 7% of movie characters employed in computing—despite being about 20% percent of the real life computer scientists and computer engineers[15]. In non-fictional accounts, men readily feature as central figures in histories of engineering developments, but women rarely appear positioned as central innovators[16]. When historical accounts do implicate women in engineering procedures, women typically assume clerical roles that are framed as unimportant. Such media engagement reinforces gendered associations between men and technology professions and accordingly effects perceptions of who is technological. Stereotypes like these are a key factor in discouraging women from participation in science and technology [17]. Indeed, the foundational research of Linda Gottfredson reveals that children begin to define their career aspirations based on gendered "occupational images"[18] as early as age six[19].

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[12] James Lull, "Ideology and Consciousness," in *Media, Communication, Culture: A Global Approach*, 2nd ed (New York, NY: Columbia University Press, 2000).

[13] Stacy L. Smith, Marc Choueiti, and Katherine Pieper, "Inclusion or Invisiblity: Comprehensive Annenberg Report on Diversity in Entertainment," Media, Diversity and Social Change Initiative (Los Angeles, CA: University of Southern California, February 22, 2016).

[14] Douglas Kellner, "Cultural Studies, Multiculturalism, and Media Culture," in *Gender, Race, and Class in Media: A Text-Reader*, ed. Gail Dines and Jean M. Humez (Thousand Oaks, CA: Sage, 2003).

[15] Handlesman, Smith, and Ford, "Shining a Light on Untold Stories in STEM"; Catherine Hill, Christianne Crobett, and Andresse St. Rose, "Why so Few? Women in Science, Technology, Engineering, and Mathematics" (American Association of University Women, 2010), http://www.aauw.org/research/why-so-few/.

[16] Judy Wajcman, *Feminism Confronts Technology* (Cambridge, UK: Polity Press, 1991).

[17] Hill, Crobett, and St. Rose, "Why So Few?"

[18] In this case, occupational image isn't just media images but akin to a generalization or stereotype. Occupations coded as masculine and feminine held with a high level of consistency across respondents.

To challenge these entrenched beliefs, advocates have begun to highlight women's contributions to science and technology history. For example, the 2016 hashtag #blackwomendidthat reminded the world of figures such as Shirley Jackson, inventor of the touchtone telephone and the fiber-optic cable, and Alice Bell, the chemist who developed a transformative treatment for leprosy a year before she died at 24. Stories like Jackson's and Bell's focus on what Sandra Harding terms "women worthies"—the unsung figures who overcame structural obstacles in pursuit of scientific accomplishment[20]. Their narratives rewrite women into scientific histories as inventors and pioneers of scientific discovery.

However, such recognition only goes so far. Even as women worthies signify an important cultural turn toward recognizing absences, they reflect only a narrow portion of women's contributions to science[21]. Through a focus on individuals and on intellectual achievement, they illuminate the remarkable rather than the ordinary[22]—aspects of science that are brimming with the stories of women. By recognizing less visible and dramatic roles we begin to see that women's contributions to science are enormous and ever-present, rather than novel. Women, and especially working class women of color, have always done the low status, material labor just below the surface of discovery. Women measured the brightness of stars at the Harvard Observatory[23], calculated the flight paths for the Apollo space program[24], and produced the first computer programs for ENIAC[25]. However, managers' accounts of this work often framed it as secondary or menial. For example, Carolyn Marvin[26] demonstrates how the supervisors of female telephone switchboard operators undermined their considerable electrical knowledge by framing them as chatty and distracted.

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[19] Linda S. Gottfredson, "Circumscription and Compromise: A Developmental Theory of Occupational Aspirations.," *Journal of Counseling Psychology* 28, no. 6 (1981): 545–79, https://doi.org/10.1037/0022-0167.28.6.545.

[20] Harding, *Whose Science?*

[21] We take technology to be a particular sub-culture within the scientific field. For a more in-depth discussion of this relationship see "From Science to Technology" (p. 13-15) in Wajcman, *Feminism Confronts Technology*.

[22] Harding.

[23] Dava Sobel, *The Glass Universe: How the Ladies of the Harvard Observatory Took the Measure of the Stars* (New York, NY: Viking, 2016).

[24] Shetterly, *Hidden Figures*.

[25] Jennifer S. Light, "When Computers Were Women," *Technology and Culture* 40, no. 3 (1999): 455–83.

[26] Carolyn Marvin, *When Old Technologies Were New: Thinking about Electric Communication in the Late Nineteenth Century* (New York, NY: Oxford University Press, 1988).

Feminist scholars argue that devaluing the work of people in the scientific margins results in their substantive contributions being excluded from the historical record, diminishing perceptions of women's engineering know-how and insight today. Whether in scholarly accounts or popular media, people readily define technology through masculine activities that have historically excluded women through a gendered division of labor[27]. Such accounts focus on disembodied ideas, products, and solutions. Given the gendered history of management, this selective reading of technological contributions renders men central protagonists in historical narratives and positions other work on the periphery or fails to position it at all. The ephemeral nature of the processes, bodily experience, and feelings contributed to scientific and technological developments makes those activities harder to render and easy to overlook.

Definitions of technological contribution that are limited to universal, intellectual advances are at odds with the trailblazing work of feminist philosophers such as Saidiya Hartman[28], Sara Ahmed[29], and Anna Tsing[30] who stress the situated nature of knowledge—which is always partial, never universal, and produced through particular embodiments[31]. Within their disparate sites of epistemic intervention, they thread together a deep appreciation for the under-valued forms of subjectivity missing (or removed) from the historical record. Their perspective calls for a rewriting of cultural histories, pushing beyond simple binary conceptions of the relationship between cognition and manual work to see the myriad types of scientific knowledge that constitute the field at every level.

As Susan Leigh Star and Anslem Strauss observe, it is difficult to make manual work visible. Scholars create narratives through connecting actions to personal biographies[32]. Yet, the nature of industrial production requires labor to be broken down into discrete, learnable parts. Many individuals can perform a single task and any task is only a portion of a much larger accomplishment. Unlike the

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27 Judy Wajcman, *Feminism Confronts Technology.*

28 Saidiya V. Hartman, *Lose Your Mother: A Journey along the Atlantic Slave Route*, 1st ed. (New York, NY: Farrar, Straus and Giroux, 2007).

29 Sara Ahmed, *Living a Feminist Life* (Durham, NC: Duke University Press, 2017).

30 Anna Tsing, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins* (Princeton, NJ: Princeton University Press, 2015).

31 For an incisive review of this technoscientific feminist literature see Kristin Asdal, Brita Brenna, and Ingunn Moser, *Technoscience: The Politics of Interventions* (Oslo: Oslo Academic Press, 2007).

32 Susan Star and Anselm Strauss, "Layers of Silence, Arenas of Voice: The Ecology of Visible and Invisible Work," *Computer Supported Cooperative Work (CSCW)* 8, no. 1 (1999): 9–30, https://doi.org/10.1023/A:1008651105359.

stories of inventors, the experiences of task workers are fractured into small parts that seem insignificant even to the people who hold them. Routine manufacturing work appears ordinary—neither valued nor unique—making it possible to overlook the accounts in the historical record (or, most commonly, not document them in the first place). Feminist scholars of computing thus expose the pervasive masculinization of technology cultures by highlighting how technology histories are defined by the strategies of cultural narratives.

How can we tell stories about ordinary women who do the kinds of technical work often categorized as menial and routine? By working with and extending media archeology as a methodology for "re-presencing," we explore a potential avenue for narrating the technological past. Though diverse in its objects of analysis, media archeology scholarship is connected through the belief that it is possible to make the past *present*—an intellectual project that Vivian Sobchack calls "re-presencing"[33]. Re-presencing is the process of giving the absent past a sense of existence in the present[34]. Through touching and operating historical technologies, history becomes an act of opening-up and discovery rather than comprehensive interpretation[35].

Storytelling occupies a contested space within media archeology scholarship. Cultural historians engage media archeology as a method for creating counter narratives, while materialist scholars, such as Wolfgang Ernst, argue for letting the artifacts speak[36]. Materialist scholars attune us to the physical qualities of information technologies; the qualities that exceed recorded content. They see media archeology as a method of challenging text-centered histories that have overlooked the physical nature of *things*[37].

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[33] Sobchack, "Media Archeology and Re-Presencing the Past."

[34] Sobchack, 323.

[35] Sobchack, 327.

[36] Jussi Parikka, "Operative Media Archaeology: Wolfgang Ernst's Materialist Media Diagrammatics," *Theory, Culture & Society* 28, no. 5 (2011): 52–74, https://doi.org/10.1177/0263276411411496; Elodie A. Roy, "For a Radical Media Archaeology: A Conversation with Wolfgang Ernst," *Necsus*, May 28, 2017, https://necsus-ejms.org/for-a-radical-media-archaeology-a-conversation-with-wolfgang-ernst/

[37] Wolfgang Ernst, "Between the Archive and the Anarchivable," *Mnemoscape*, 2015, https://www.mnemoscape.org/single-post/2014/09/04/Between-the-Archive-and-the-Anarchivable-by-Wolfgang-Ernst; Wolfgang Ernst, *Digital Memory and the Archive*, vol. 39 (Minneapolis, MN: University of Minnesota Press, 2013), 36.

However, as Laine Nooney reminds us, the artifact has its limits[38]. Reinstating missing objects—and their associated female creators—into histories of technology does little to account for their absence. Nooney observes that media archeology projects often discard the structures of privilege that make up "the dirt" from which historically buried objects are excavated. Parikka and others have acknowledged that materialist scholarship is curiously devoid of people, the ones who interact with technology and the ones who create it[39]. For example, Ernst uses core memory as an illustrative figure in public scholarship to discuss the changing logic of archival storage[40]. This attention to core memory's technical characteristics enlivens the forgotten artifact and reinstates it as an exemplar of a still unfolding history of digital memory. Yet, it also leaves another history dormant. The tiny ferrite cores and suspending wires elide a point of significance that one may never know from looking at their structure: that core memory planes are the product of women's handwork.

The *Making Core Memory* project explores and extends re-presencing as a potential avenue for feminist media archeology scholarship. We enliven a history of the bodily, material processes of core memory manufacturing for the Apollo Guidance Computer (AGC). Neither archivists nor technology scholars collected first person accounts of the women who made core memory and our attempts to record original oral histories have been unsuccessful. In light of this emptiness, we created a workshop that invites participants to engage in collaborative acts of core memory weaving. Through the weaving, participants develop sympathetic understandings of technology making experiences that have been lost to history. In this engagement presence isn't merely an awareness of existence—an occurrence added to a timeline. Presence is a physically felt unfolding.

Methodologies of Re-Presencing Media Technology History

Methodologically, critical scholars of design and media increasingly broker the study of computing and cultural production through a wide array of speculative invention. Sociologists deliver performances that expand contemporary forms of knowledge

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[38] Laine Nooney, "A Pedestal, a Table, a Love Letter: Archaeologies of Gender in Videogame History," *Game Studies* 13, no. 2 (December 2013), http://gamestudies.org/1302/articles/nooney.

[39] Parikka, "Operative Media Archaeology."

[40] Wolfgang Ernst, "Radically de-Historicising the Archive. Decolonising Archival Memory from the Supremacy of Historical Discourse," *L'internationale*, February 2, 2016; Ernst, "Between the Archive and the Anarchivable."

representation[41]. Humanists turn to carpentry and electronic tinkering as tools for future-oriented interrogation and modeling[42]. Critical makers question and reconfigure status quo exhibition design[43]. Media archeologists expand and invert these sensibilities by examining projects that interrupt conventional encounters with narrative, futurology, and design.

Media archeology, in particular, explores technological assembly and repair as a means of recognizing and enhancing stories that are absented, silenced, or forgotten within contemporary consideration[44]. Media archeologists seek to shed light on the nature of "zombie media"— those media resources that are *living* (as in still functional) as well as *dead* (as in obsolete)[45]. Examining older forms of media and communication technology from Polaroids to vinyl records, scholars increasing turn to forms of critical making and reproduction to not only replicate a particular functionality but also learn about the situations in which those functioning systems developed[46].

Here we intervene in what Sobchack calls the "undisciplined discipline"[47] of media archeology to re-examine its longstanding indifference to embodied knowing. In an appeal to the tactics of design, our recuperations do something more than advance an understanding of history or practice. They also draw new attention to the lives, practices, and legacies suppressed by dominant technocultures. This positions media technologies as a stage for historicizing inasmuch as futuring and for intervention inasmuch as inquiry. Scholars forge archival questions from material installations and craft material investigations from historical developments.

Experiences with re-presenced media have the capacity to radically challenge accepted understandings of technology development. Through surfacing the

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[41] Celia Lury and Nina Wakeford, *Inventive Methods: The Happening of the Social* (Oxfordshire, UK: Taylor and Francis, 2012).

[42] Ian Bogost, *Alien Phenomenology* (Minneapolis, MN: University of Minnesota Press, 2012); Charity Hancock et al., "Bibliocircuitry and the Design of the Alien Everyday," *Textual Cultures: Texts, Contexts, Interpretation* 8, no. 1 (2013): 72–100, https://doi.org/10.14434/TCv8i1.5051.

[43] Matt Ratto, "Critical Making: Conceptual and Material Studies in Technology and Social Life," *The Information Society* 27, no. 4 (July 2011): 252–260, https://doi.org/10.1080/01972243.2011.583819; Bruno Latour and Peter Weibel, eds., *Making Things Public: Atmospheres of Democracy* (Cambridge, MA: MIT Press, 2005).

[44] Jussi Parikka, *What Is Media Archaeology?* (Malden, MA: Polity Press, 2012), 14.

[45] Garnet Hertz and Jussi Parikka, "Zombie Media: Circuit Bending Media Archaeology into an Art Method," *Leonardo* 45, no. 5 (2012): 424–430, https://doi.org/10.1162/LEON_a_00438.

[46] Jentery Sayers, "Design without a Future," *Interactions* 23, no. 6 (2016): 74–76, https://doi.org/10.1145/2991893.

[47] Sobchack "Media Archeology and Re-Presencing the Past," 327.

forgotten and strange parts of media history, we make obsolete technologies present (again) in our technological imaginaries[48]. Implored by technology, we recognize both an artifact's previous absence in the lineages of media histories and the fact that, in actuality, it'd been there all along—if undocumented—as a contingent aspect of our present day technological field. The *Making Core Memory* project invites us to extend this thinking to the people, locales, and histories of practice that can be brought back into being *along with* their associated artifacts.

Watches, Weavers and Textile Work

The history of computing is a history of textiles. In 1837, Charles Babbage used the punch card technology of the Jacquard Loom to conceptualize the analytic engine[49]. It was a machine that could automate mathematic calculations and was the earliest inkling of a modern computer. Babbage's collaborator, Ada Countess of Lovelace, described the analytic engine as "weaving algebra"[50]. One hundred and thirty years later, Fairchild Semiconductor put Navajo women to work on integrated circuit manufacture in Shiprock, New Mexico[51]. In their marketing materials, the company used their perception of Native American women as skilled craft workers to explain the successful production in the plant. Lineages of material labor (represented by rug weaving) were used to harden the notion that dexterity and emotional investment came naturally to indigenous people[52].

Between the punch card and the integrated circuit is an interlude in information storage technology called "core memory." Throughout the first two decades of the cold war, core memory stored information using tiny magnetized ferrite cores. Typically, ferrite cores were assembled into squares called arrays or planes. Each core stored one bit of information, with the magnetic polarity indicating either a 1 or 0 of binary code. For the Apollo moon missions, the Massachusetts Institute of Technology (MIT) Instrumentation Laboratory developed

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48 Sobchack, "Media Archeology and Re-Presencing the Past."

49 Isaacson, *The Innovators*.

50 Ada Augusta Lovelace, *Ada, the Enchantress of Numbers: A Selection from the Letters of Lord Byron's Daughter and Her Description of the First Computer*, ed. Betty A. Toole, 1st ed. (Sausalito, CA: Strawberry Press, 1992).

51 Lisa Nakamura, "Indigenous Circuits: Navajo Women and the Racialization of Early Electronic Manufacture," *American Quarterly* 66, no. 4 (2014): 919–941,1169.

52 Nakamura, 928.

a unique form of core memory called "core rope memory"[53]. Core rope memory stored information using a physical distinction. The Apollo missions used both types of core memory, but core rope memory is an especially evocative object. Core rope memory transformed software into hardware. When digital information is made material, it helps us to see the hands that bring technology into being [54].

Core rope memory is a technology built in the shell of the American textile industry. Beginning in the 1950s, electronics companies moved into the textile mill buildings that had stood vacant for years as symbols of a struggling New England economy[55]. Reports of the time celebrated the potential of high-technology industries to revitalize communities that had once been built to support the workers of fabric production and now faced unemployment as high as 37 percent[56]. Over the next ten years, these dreams were realized. The region became known as "the Golden Semi-circle," named for the flourishing technology businesses located along highway Route 128[57].

The success of the Golden Semi-circle was produced through an incredibly prosperous blend of government contracts, academic laboratories, and private companies. This region exemplified the "military-university-industrial" complex that drove early computer innovation, and laid the foundation for the shape of the technology sector we know today[58]. A 1961 *New York Times* article reports an intermingling of ideas in "campus-type" environments[59] where this model itself was viewed as the region's greatest invention[60].

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[53] Eldon C. Hall, "MIT's Role in Project Apollo: Final Report on Contracts" (Cambridge, MA: MIT Charles Stark Draper Laboratory, August 1972), 91.

[54] As Sareeta Amrute observes, much is gained from "reconceptualizing cognitive work as a kind of labor that plays out both materially and symbolically across a terrain of race and difference." Sareeta Bipin Amrute, *Encoding Race, Encoding Class: Indian IT Workers in Berlin* (Durham, NC: Duke University Press, 2016), http://dx.doi.org/10.1215/9780822374275.

[55] John H. Fenton, "Electronics Puts Life in Idle Mills; Raytheon Project at Former Woolen Plant in Andover Typifies Development," *The New York Times*, June 26, 1956, sec. Archives, https://www.nytimes.com/1956/06/26/archives/electronics-puts-life-in-idle-mills-raytheon-project-at-former.html.

[56] John H. Fenton, "Old Textile Center Stages a Comeback," *The New York Times*, May 27, 1956.

[57] Henry R. Lieberman, "Technology: Alchemist Of Route 128: Boston's 'Golden Semicircle,'" *New York Times*, 1968; see also: Anna Lee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge, MA: Harvard University Press, 1994).

[58] Isaacson, *The Innovators*.

[59] John H. Fenton, "MIT Offers Spur to Area Economy," *The New York Times*, January 15, 1961.

[60] Lieberman, "Technology."

At the center of the Golden-Semi Circle was Waltham, Massachusetts, home of the electronics company Raytheon. By 1961, Raytheon employed 36,000 people in the 35-mile radius around Boston[61]. Employees at Raytheon worked on a variety of projects—ranging from everyday consumer electronics, like microwaves, to the guided missiles that had earned the company $56 million dollars in government contracts[62]. The missile guidance systems, in particular, provided the rationale for Raytheon to receive a subcontract from General Electric to manufacture a similar system for an extraordinary project. They built a computer for human space flight.

In 1961, computing still relied on the punch card technology proposed by Babbage and Lovelace over 100 years before. These room-sized machines were heavy and large, making them poorly suited for a mission where minimizing size and weight was essential. Traveling to the moon would require a light and compact form of information storage that could survive the threat of power loss[63]. Core memory met this challenge by storing information on foldable beaded ropes that could fit into the cone of a rocket.

The software programs for the Apollo Guidance Computer were permanently stored within core rope memory[64]. Once wired, the ropes were nearly impossible to change[65]. Margaret Hamilton and her team at the MIT Instrumentation Laboratory had to write the programs perfectly—at a time when software engineering was so new it was barely recognized as a field[66]. As the "rope mother," Hamilton directed the creation and verification of all of Apollo's onboard software programs[67]. The program listings created at the Instrumentation

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[61] John H. Fenton, "MIT Offers Spur to Area Economy."

[62] Fenton, "Electronics Puts Life in Idle Mills; Raytheon Project at Former Woolen Plant in Andover Typifies Development"; "Raytheon Wins 5 Contracts," *The New York Times*, June 28, 1960.

[63] David A. Mindell and Shane Hamilton, "A Brief Historical Introduction to the Apollo Guidance Computer," Apollo Guidance Computer History Project, 2002, http://authors.library.caltech.edu/5456/1/hrst.mit.edu/hrs/apollo/public/histintro.htm.

[64] *Computer for Apollo* (MIT museum collections, 1965), https://www.youtube.com/watch?v=ndvmFlg1WmE.

[65] Jonathan Fildes, "Weaving the Way to the Moon," *BBC*, July 15, 2009, http://news.bbc.co.uk/2/hi/technology/8148730.stm.

[66] Robert McMillan, "Her Code Got Humans on the moon—And Invented Software Itself," *Wired*, October 13, 2015, https://www.wired.com/2015/10/margaret-hamilton-nasa-apollo/.

[67] Anyone, regardless of gender, could be considered a "rope mother." Jamie Rubio Hancock, "Margaret Hamilton, la pionera de la programación que llevó el Apolo a la luna," *Ediciones El País*, December 25, 2014; John R. Garman, NASA Johnson Space Center Oral History Project, interview by Kevin M. Rusnak, March 27, 2001.

Laboratory were translated into binary code, punched into tape[68] or cards[69] and shipped to the Raytheon factory in Waltham[70]. There, the tapes helped position the “weaving machines”[71] women used to transform software into hardware.

Core rope memory was made by hand. In every core rope there were three kinds of wires, each threaded by “operators” at a Raytheon factory in Waltham. Apollo engineers called this process the “LOL method” for the little old ladies who did the work[72]. Sometimes alone and sometimes in pairs, operators passed a needle back and forth through a matrix of ferrite cores. The sense line was especially important. It passed through or around the cores in a pattern, based on the 1s and 0s of binary code. The pattern was determined using a machine that automatically selected the cores in sequence[73]. The operator threaded the open core, pressed a button, and threaded the next—creating a pattern that comprised the software program.

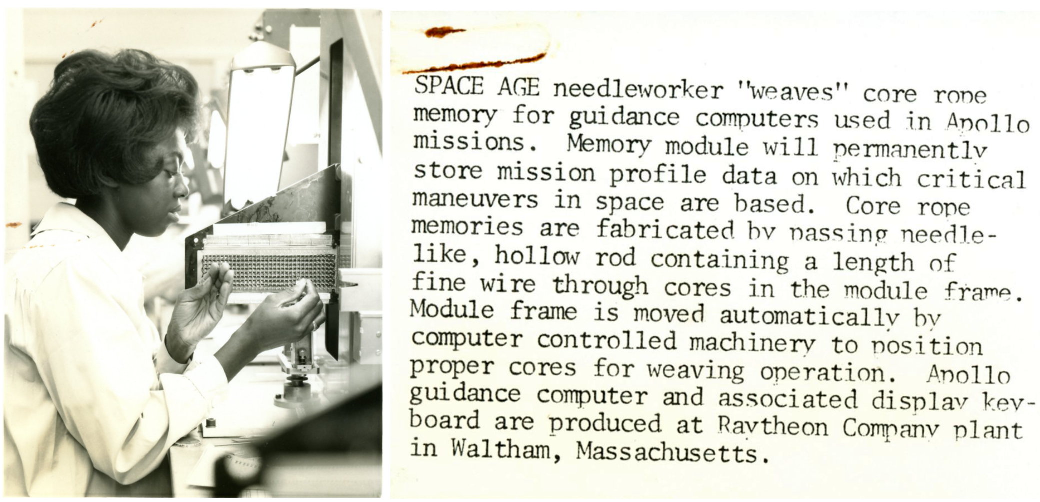
SPACE AGE needleworker "weaves" core rope memory for guidance computers used in Apollo missions. Memory module will permanently store mission profile data on which critical maneuvers in space are based. Core rope memories are fabricated by passing needle-like, hollow rod containing a length of fine wire through cores in the module frame. Module frame is moved automatically by computer controlled machinery to position proper cores for weaving operation. Apollo guidance computer and associated display key-board are produced at Raytheon Company plant in Waltham, Massachusetts.

Figure 1 – (Left) An unknown woman weaves core memory in a photograph from a Raytheon Apollo 11 Press Kit. (Right) Photo caption describing the woman as a “space age needleworker.” Raytheon

[68] Eldon C. Hall, *Journey to the Moon: The History of the Apollo Guidance Computer* (Reston, VA: American Institute of Aeronautics and Astronautics, 2000); David A. Mindell, *Digital Apollo: Human and Machine in Spaceflight*, Inside Technology (Cambridge, MA: MIT Press, 2008).

[69] Fildes, “Weaving the Way to the Moon.”

[70] Paul Ceruzzi, “The ‘rope mother’ Margaret Hamilton,” *Smithsonian National Air and Space Museum*, March 11, 2016, https://airandspace.si.edu/stories/editorial/rope-mother-margaret-hamilton.

[71] Mindell, *Digital Apollo*.

[72] *Moon Machines*.

[73] *Computer for Apollo* (MIT museum collections, 1965), https://www.youtube.com/watch?v=ndvmFlg1WmE.

photos courtesy of the collection of David Meerman Scott, author of *Marketing the Moon: The Selling of the Apollo Lunar Program*.

In popular accounts, the women who wove core memory are often reported to be former textile workers[74]. The core memory production process has such similarity to needlework and weaving. It would be poignant to think that their expertise could have been applied so directly—simply switching the threads for wires. But, this fact remains unsubstantiated. In oral history interviews, engineers from the Apollo projects recount that the women who made core memory had previously been employed by the Waltham Watch Company[75]. Waltham Watch had laid of its entire workforce in the early 1950s, creating an available labor pool with experience in precision manufacturing[76].

Rather than being the direct product of textile workers, it seems more likely that core memory is the product of a larger histories of manufacturing in New England—in which textiles, and women especially, played a significant part in the routines of industrial labor. A 1920 newspaper article reported that the typical watchmaker was a young girl[77].

> "Women's small and agile hands are especially adapted to the work of certain industries. Women make and assemble the delicate parts of adding machines, office appliances, electric lamps..."

Weaving, watchmaking, and core memory manufacturing share the qualities that have defined women's work throughout industrial history. Managers feminized factory labor as the delicate and repetitive, suggesting women's nimble fingers and patience naturally fit the conditions of high-tech manufacturing and casting women as the ideal factory laborers[78].

Forty years after the Apollo missions, MIT Instrumentation Laboratory deputy director Eldon Hall reflected on the women who manufactured components for the Apollo Guidance Computer. Weaving core ropes required extraordinary patience, he said. But, working at Waltham Watch's tool division had required something similar. There had been "tender loving care in that work too." The

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74 Jonathan Fildes, "Weaving the Way to the Moon," *BBC*, July 15, 2009, http://news.bbc.co.uk/2/hi/technology/8148730.stm.

75 Ed Blondin, David Bates, and Eldon Hall, Apollo Guidance Computer History Project, interview by David A. Mindell and Shane Hamilton, November 30, 2001.

76 Blondin, Bates, and Hall.

77 "Woman's Place in Work," *The New York Times*, February 15, 1920.

78 Nakamura, "Indigenous Circuits"; Stephen Monteiro, *The Fabric of Interface: Mobile Media, Design, and Gender* (Cambridge, MA: The MIT Press, 2017).

precision manufacturing on both these lines required an attentive eye and a steady hand. Hall went on to say, "Those little old ladies were essential"[79].

Hall's recollection paints an uncommon picture of innovation work. For him, computing was a natural field for women who had long been precision workers. Women powered innovation and innovation was powered by care. As harbingers of patience and love, the gendered figure of the weaver re-inscribed certain stereotypes while challenging others. Through re-presencing the process of core memory weaving, these contradictions co-exist as they haunt our experience of the past.

The Making Core Memory Workshop

Like many media archeology projects, *Making Core Memory* "starts from the middle," in a tangled knot between the past and the present[80]. Creating the workshop series was not just an act of translation, taking an already existing body of scholarship and making it interesting to public audiences. There was no definitive historical source to draw from: no text to adapt into a screenplay. Rather, this work involved an unwritten history – and parallel acts of searching, excavating, building, guessing – and all throughout inviting the public into that process.

We sought to design a workshop that could communicate the story of the core memory weavers by engaging people in material encounters with the artifacts, production process, and history of core memory technology. These encounters took two primary forms: 1) the weaving of core memory "patches" and 2) interaction with a Core Memory Quilt.

[79] Blondin, Bates, and Hall, Apollo Guidance Computer History Project.
[80] Parikka, *What Is Media Archaeology?*, 5.

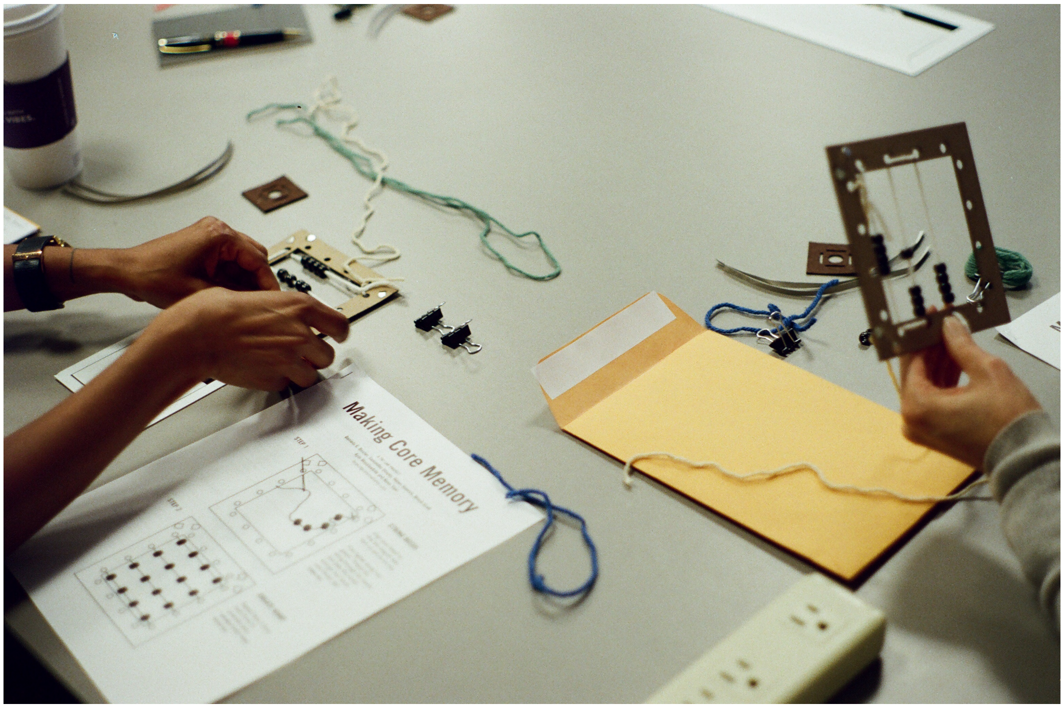

Figure 2 – *Making Core Memory* workshop instructions and patch kits containing chipboard looms, yarn, beads, felt "buttons" and copper tape.

At the *Making Core Memory* workshop, each participant receives a kit containing a 5-inch chipboard loom, yarn, beads, a plastic needle, a felt square, and two strips of copper tape. Yarn and beads stand in for the wire and ferrite cores used in actual core memory technology. Through the workshop, we invite the participants to partake in a weaving process akin to that of the core memory weavers. The scale of the chipboard loom is equal to only a few millimeters of actual core memory planes. Once the weaving is finished, participants use the felt and copper tape to create a simple electronic switch. The switch is attached to conductive purse snaps that are installed at the corners of the looms and correspond to squares on the Core Memory Quilt[81].

Connecting a finished patch to the quilt squares completes an electric circuit, causing two things to happen. First, the Core Memory Quilt plays an audio recording about the history of the Apollo Guidance Computer project. The brief

[81] This essay focuses on the patch kits. For an in-depth discussion of the functionality, design, and findings from the Core Memory Quilt, see: Daniela K. Rosner, Samantha Shorey, Brock Craft and Helen Remick, "Making Core Memory: Design Inquiry into Gendered Legacies of Engineering and Craftwork," in *ACM Conference on Human Factors in Computing Systems (CHI '18)*, 2018.

clips share the perspective of the AGC engineers and Raytheon managers, reflecting on core memory production. The audio is sourced from documentary projects[82], the Apollo Guidance Computer history project[83], and newspaper article[84]. Secondly, connecting a patch also triggers the Core Memory Quilt to tweet a 120-character version of the clip from @lolweavers account. The 120 characters reflect the storage capacity of actual core memory planes[85] that are also installed on the quilt.

Figure 3 – (Left) Threading the orthogonal "sense wire" in a core memory patch. (Right) Completed core memory patches are installed on the electronic quilt. Pressing the central button triggers a recording of historical audio from the Apollo Guidance Computer engineers.

The Core Memory Quilt integrates electronic-textile (e-textile) components, such as conductive thread, with traditional quilting materials to further entwine fabric metaphors with core memory technology. The quilt was sewed and co-designed by our collaborator, Helen Remick. In her past work, Remick has used outdated technologies ranging from slide film to CDs to create intricate textiles. Her expertise in using unusual materials and the foundational skills of quilting were key to designing solutions for circuitry insulation and functionality. Brock Craft,

[82] *Moon Machines*; *Computer for Apollo*.

[83] Mindell and Hamilton, "A Brief Historical Introduction to the Apollo Guidance Computer."

[84] Fildes, "Weaving the Way to the Moon"; Paul Ring, "When Waltham Went to the Moon: Area Companies Helped Apollo 11," Waltham Daily News, July 20, 2009, http://www.wickedlocal.com/article/20090720/News/307209878.

[85] The core memory planes are from the Digital Equipment Corporations PDP-8, the "first full scale, general purpose computer selling for under $10,000"; "Small Computer Handbook" (Digital Equipment Corporation, 1966).

who assembled the software for the Arduino microcontroller that enabled the tweets and audio, assisted Remick. Craft is a technologist with an interest in obsolete technology and also helped to interpret the patents that informed the patch kit design.

To date, the *Making Core Memory* workshop has been held nine times with over one hundred participants. The participants have been from a variety of intellectual communities: technology historians, design educators, makers and librarians. The following reflections are based on our experiential accounts of the workshop, as organizers, and informed by field notes and audio recordings of each session.

Tedious, Time Consuming and Subject to Error

Defining the meaning of work is an action imbued with power. Managers and other over-seers are often the people who set these definitions, rather than the people performing them[86]. In the case of the Apollo Guidance Computer, the voices of engineers tend to define what we know about the AGC project. In oral history interviews, the reflections of MIT engineers acknowledge the importance and expertise of the core memory weaver's work. Yet this perspective is complicated by the accounts of Raytheon managers, which are more publicly visible.

In 1965 the MIT Science Reporter visited the Instrumentation Laboratory to document the "miniaturized computer" that the Lab was designing for the Apollo missions[87]. The twenty-nine minute film walks through each level of the navigation system in language that's understandable to an educated, but not expert, audience. After explaining what the AGC does and how it stores information, they visit the Raytheon factory in Waltham. Hosting the tour is Jack Poundstone, the Raytheon Apollo engineering manager. Poundstone speaks with the reporter, as rows of women work industriously and wordlessly behind them.

Poundstone describes the work of "a pair of girls" who are passing a needle back and forth through a matrix of ferrite cores. With the push of a button, the matrix changes to open a new aperture for the next pass of the needle. "She doesn't have to think about which core it goes through next?" the reporter asks "No, the machine does that for her" Poundstone responds[88].

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[86] Star and Strauss, "Layers of Silence, Arenas of Voice."
[87] *Computer for Apollo.*
[88] *Computer for Apollo.*

A focus on the mechanized nature of the work is a perspective shared by Lee Woodworth, the Raytheon Apollo line engineer who oversaw training and implementation of manufacturing for core rope memory. In an original interview conducted for this project, Woodworth explained the manufacturing process as mostly "actuating"—or pushing a button. "The operator could have been anyone, because the machine was automated," he said.

What then, of our narrative—of the story we were trying to tell about the weavers? While some of the Instrumentation Laboratory engineers described the work as skilled, Poundstone and Woodworth had worked on the Raytheon factory floor. Without the stories and experiences told in the words of the weavers, the Raytheon managers were the closest accounts to the actual work. Yet, histories are entwined with the person remembering them. Because of Woodworth's role at Raytheon, it makes sense that he saw the work as routine. He wrote the procedures. Core memory weaving had to be a process that could be concretized, taught, and performed interchangeably.

Automation is as much about efficiency as it as about pedagogy[89]. Recalling that the first "computers" were people who performed simple portions of larger equations, it becomes clear that the foundations of automation are processes that can be broken down into easily instructed units[90]. In the early 1800s, de Prony's logarithmic tables were specifically inspired by the division of labor in pin factories—another textile connection!—described by Adam Smith in *A Treastise on the Wealth of Nations*[91]. In the twentieth century, women largely performed this clerical work. For example, the government's Willow Run Laboratory used female students at a Michigan highschool. "The first girl in each row was given the first step, and then passed it to the second girl and on down the line. The last girl would bring up the sheet"[92].

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[89] We are indebted to a conversation with Lorraine Daston at The University of Washington's Simpson Center for the Humanities where she challenged a question we posed about efficiency with this observation.

[90] Wendy Hui Kyong Chun, *Programmed Visions: Software and Memory* (Cambridge, MA: MIT Press, 2011), 20.

[91] Ivor Grattan-Guinness, "The Computation Factory: De Prony's Project for Making Tables in the 1790s," in *The History of Mathematical Tables: from Sumer to Spreadsheets*, ed. Martin Campbell-Kelly et al. (Oxford, UK: Oxford University Press, 2003).

[92] "Human Computers from Pioneer Highschool," University of Michigan History of Electrical and Computer Engineering, accessed April 2, 2018, http://ece.umich.edu/bicentennial/stories/human-computers.html.

In the shadow of these definitions, the *Making Core Memory* workshop engages people in embodied experience. As participants open their packet, we walk them through step-by-step instructions that resemble the work of the operators. Almost immediately there are hurdles. Beads roll onto the floor and the yarn is knotted around the needle. It is difficult to keep the yarn taut, suspending the beads in place. One participant said it's "like surgery to keep the tightness." Another looked at the slack in her completed lines, describing her work as "clumsy."

Despite the lo-fi nature of the materials and relatively generous size of the 5-inch loom, participants find themselves surprised by how time consuming the process is. "Why am I so slow?" one asked, even while she was on pace with the other participants. The work was difficult. "This is hard." Another said "I'm a really detail oriented person, but this is hard. Why can't I get this right?"

These experiences occur between moments of silence in the workshop, heads bent over the looms and needles in hand. "We're really concentrating" one participant explained. As we reached the time limit for our workshop session, a few were still working to finish their patches. "I'm really invested in this," another said. The *Making Core Memory* workshops preserve the contradictions in our gathered histories, that technology labor can be at once both monotonous and skilled, repetitive and satisfying,

Probably the most widely circulated fact about the Apollo Guidance Computer is how little memory it had. The colossal feat of traveling to the moon was accomplished with less storage than is available on the average MP3 player[93]. Yet, when core memory is framed in this way it is purely about its technical capacity, not what it required of the people who made it. After completing their woven patch, a participant—who used "they/them" pronouns—looked at an actual core memory plane artifact we introduced earlier in the workshop. Holding the plane in their hands, they responded with disbelief that it could only contain the information for a single tweet. Thinking back to the effort their patch had required they said, "This is a lot, for not very much." The moment of connection, to the "a lot" of core memory weaving, is key.

Core memory work is the product of a lot of time, a lot of attention and intense focus. The core memory planes are 120 characters of information; they are also 40 hours of women's labor[94]. Participants build these understandings through

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[93] *Moon Machines*.

[94] Emerson W. Pugh, *Memories That Shaped an Industry: Decisions Leading to IBM System*, MIT Press Series in the History of Computing (Cambridge, MA: MIT Press, 1984).

connecting artifact to practice, and practice to history. A workshop participant, who developed the broadcast technology for the Apollo missions, rattled off an accounting of our work on the chipboard looms. “We’re just doing sixteen cores here. There were…” he paused to do the math “sixty-four by two hundred and fifty six … over sixteen thousand cores in Apollo.” Now, the number is more than just storage. It’s sixteen thousand tiny actions by an unknown number of women.

Crafting Our Historical Understanding

Designing the patch kits for the *Making Core Memory* workshop tangled the histories of our artifacts. The core memory ropes, where we focused our historical inquiry, were a minor variation of more widely produced core memory planes. Although the archives of the Smithsonian Air and Space Museum held the Apollo core memory ropes, we couldn’t create something new from those precious artifacts. Instead, we found plenty of core memory planes on eBay. The Apollo missions used similar core memory planes for erasable memory storage. These 5-inch squares were flat and intricately woven—their visual language easily referencing the textile metaphors that underlay their manufacture. We decided to use the planes. The two technologies shared so much that they illuminated a shared lineage of labor.

Our understanding of how core memory was made drew on craft expertise and historical documents. We began with the material, trying to reverse engineer the process. Helen, the master quilter, inferred the sequence of actions from what she knew about weaving.

> “The weaving is so fine on the memory boards that the pattern is not obvious. When we enlarged an image, I could see more or less what the pattern was. I created a frame of foam board and experimented with recreating the weave. There was only one method by which the ferrite beads could end up with three or more wires through them, alternating orientation at 45 degrees left or 45 degrees right.”

The beads would have to be loaded on to the horizontal string (the weft). Then, the vertical string (the warp) would be threaded orthogonally, separating each bead at a unique interstice. Once all the beads for the matrix were threaded the diagonal string would be woven in. This seemed right.

The patents and technical papers we found supported our methods, but they were an odd source of understanding[95]. Each of these documents described machines that were designed to automate core memory making. We had to read for the actions of the weavers, through the machines that were built to emulate them. The documents described frames and jigs meant to hold the ferrite cores in place. One, titled "Method of Wiring Core Memory Arrays," used puffs of air to separate them[96]. The operators then threaded the cores with an orthogonal wire, not unlike the process we were designing.

In these documents are the absent but lingering presence of women's hands and eyes—disappearing, sometimes literally, into air. In the same patent sketch there is the dual eyepiece of a microscope, a machine that's only complete with a human viewer. The patent indicates the microscope is for someone to "make examinations"[97]. Images exist of core memory plane weavers using a similar device, carefully hand threading a sense-line. The weaver's role is predictably absent in documents for automation.

The machine patents describe manual techniques for core memory production as "very tedious, time consuming, and subject to error" but tell us little else about the people who made them[98]. Throughout the *Making Core Memory* workshops, participants have asked us questions we don't know the answers to: How many people did this work? What was the scale of the operation? How were they recruited? There is so little documentation and so few recollections that we can only guess about the lives of the weavers or how they made sense of their work.

Yet, the workshop offers participants an opportunity to build their own understandings and imaginings through their experience. "What was" is an open question that may never be fully known. Yet, even partial understandings open new possibilities for what could be.

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[95] Gerald B. Bardo, Apparatus for wiring personalized core storage arrays, 3,529,341 (Nichols, NY, filed May 8, 1968, and issued September 22, 1970); Herbert K. Hazel and Wolfgang F. Mueller, Method for wiring ferrite core matrices, 3,460,245 (Wappingers Falls, NY, filed April 30, 1965, and issued August 12, 1969).

[96] Hazel and Mueller, Method for wiring ferrite core matrices.

[97] Hazel and Mueller, 6.

[98] Hazel and Mueller, 5.

Collaborating with Ghosts

Media archeology scholarship engages with the materiality of media technologies—the stuff—rather than their content or effects[99]. This makes media archeology a complementary field to the central currents of communication, and a possible method of addressing breakdowns in history that make traditional modes of representation impossible. However, neither artifacts nor singular stories will change the structures that delineate the boundaries of technological history and that position manual processes as merely piece work.

As Wolfgang Ernst observed, core memory is like an archive. It is both content (the bits made up of ferrite cores) and how that content is organized (the address structure of intersecting wires)[100]. The organization of archives dictates what can be captured, what kinds of information—what parts of history—"make sense" to keep[101]. For Ernst, media archeology provides a method for analyzing and presenting the material aspects of media that are difficult to render in the narrative forms of cultural studies and historical scholarship. But, could it do more? Could media archeology help us to know, in some way, all that still slips away—even when an artifact has been recovered?

The engagements described above expose how those unacknowledged within the historical setting may actively shape the work both inside and outside the investigative frame[102]. The year that the Apollo 11 landed on the moon, Margaret Hamilton was a thirty-three year old software engineer with a bachelors degree in Mathematics. She was one of the only female engineers on the Apollo project. In an oral history interview, Hamilton recalls that in her previous position as a programmer many of the people working alongside her were women[103]. The same wasn't true as an engineer. During her work on Apollo, Hamilton helped to establish

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99 Sobchack.

100 Ernst, "Between the Archive and the Anarchivable."

101 Nooney, "A Pedestal, A Table, A Love Letter."

102 Star and Strauss, "Layers of Silence, Arenas of Voice"; Susan Leigh Star, "Power, Technology and the Phenomenology of Conventions: On Being Allergic to Onions," *The Sociological Review* 38, no. 1 (May 1, 1990): 26–56, https://doi.org/10.1111/j.1467-954X.1990.tb03347.x.

103 Margaret Hamilton, Apollo Guidance Computer History Project, July 27, 2001, https://authors.library.caltech.edu/5456/1/hrst.mit.edu/hrs/apollo/public/conference1/hamilton-intro.htm.

software engineering as a discipline. Her contributions earned her the 2016 Presidential Medal of Freedom[104] and made her a Lego minifigure[105].

Hamilton's cognitive work, her code and creations, are familiar parts of innovation stories. Once recovered, we know the contribution of these things[106]. The mundane, material work of making computer parts is more difficult to render. As Laine Nooney writes, "The only people we have made historically visible are those we have organized ourselves to see"[107]. Women appear absent (or, in Hamilton's case, singular) in much of Apollo's history because of limited definitions of what labor counts as innovation, and what kinds of knowing are legible in technological history.

Making Core Memory frames interdisciplinary weaving collaborations as imaginative tools to encounter invisibility and representation. From this vantage point, media archeology calls us to work across difference to make apparent the way technology studies reject or becomes complicit in abusive systems of power. Engaging with core memory artifacts does more than remind us of a seemingly anachronistic moment when the pinnacle of modern engineering relied upon a woven rope of beads and wires. The act of weaving is a rekindling of practices, embodied engineering knowledge, and feeling. It gives voice to process[108].

In thinking through these disparate cases, we have found it useful to explore critical fabulations of the past, the materialized stories that serve to collectively recover worlds of practice plagued by extinction and analytic closure, whether by fixed categories of thought or deterministic procedures[109]. Sociologist Avery Gordon calls such moments of encounter a "haunting" — those engagements with ghosts that

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104 Barack Obama, "Remarks by the President at Presentation of the Presidential Medal of Freedom" (November 22, 2016), https://obamawhitehouse.archives.gov/the-press-office/2016/11/22/remarks-president-presentation-presidential-medal-freedom.

105 Eric Berger, "A New LEGO Set Honors the Women of NASA—and It Looks Pretty Awesome," Ars Technica, October 18, 2017, https://arstechnica.com/science/2017/10/a-new-lego-set-honors-the-women-of-nasa-and-it-looks-pretty-awesome/.

106 As Sareeta Amrute reminds, "Although each of these terms—knowledge work, cognitive labor, and immaterial labor—has a specific valence, they are plagued by the same problem. They all-sometimes despite an explicit interest in embodiment—imagine the cognitive worker as a universal, unmarked subject." Amrute, *Encoding Race, Encoding Class*.

107 Nooney, "A Pedestal, A Table, A Love Letter."

108 We are grateful to Alison Powell, who described this project as giving "voice to process" when a draft was presented at the International Communication Association (ICA) Conference in 2018.

109 Daniela K. Rosner, *Critical Fabulations* (Cambridge, MA: MIT Press, 2018); See Saidiya Hartman's coining of the phrase critical fabulation to describe her approach to contending with the limits of the archive around the Atlantic slave trade. In Hartman, *Lose Your Mother*.

connect contemporary subjects to historical apparitions[110]. In her analysis of fiction as an instrument for engaging silenced but ever-present histories of social violence, Gordon shows the haunting to work as social inquiry. "Haunting is one way in which abusive systems of power make themselves known and their impacts felt in everyday life, especially when they are supposedly over and done with (slavery, for instance) or when their oppressive nature is denied (as in free labor or national security)," writes Gordon[111].

To collaborate with media ghosts, we must draw from such sociological haunting and media-making practice to entangle present subjects with past histories. In allowing the ghosts of innovation to take center stage, projects like *Making Core Memory* employ material production to enliven forgotten lives and practices in the present day. They help investigators find an elsewhere for media archeology (different bodies, different processes, and different heritages), a promise that grapples with the methods and limits of representation in media communication scholarship and teaching.

By making together, investigators continue to connect observed phenomena but also push and extend that connective tissue. They make present the often hidden "inarticulate" knowledge of making, maintaining, or transforming with others[112]. This analysis reveals how recuperations can push beyond established communication programs by interrogating media representation as more than a solution or argument. It poses the mix of archival and design techniques as part of a reflexive process of knowing, making, and retelling. As a technique for reworking our present condition from the inside, such collaborations prompt media archeologists to recover responsive capacities for action ("response-abilities") that are never cut-off from the worlds they inhabit[113].

Acts of re-presencing challenge dominant visions of technology innovation that rely on a rigidly defined past to chart a straight line into the future. Innovation is more than the novel and new, it's the incremental and sustaining. Through

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110 Avery Gordon, *Ghostly Matters: Haunting and the Sociological Imagination* (Minneapolis, MN: University of Minnesota Press, 2008), http://public.eblib.com/choice/publicfullrecord.aspx?p=346045.

111 Gordon. xvi.

112 Chandra Mukerji, "The Cultural Power of Tacit Knowledge: Inarticulacy and Bourdieu's Habitus," *American Journal of Cultural Sociology* 2, no. 3 (October 1, 2014): 348–75, https://doi.org/10.1057/ajcs.2014.8.

113 Haraway, *Staying with the Trouble*, 104.

retelling the technological past, we turn a light to the women—working by hand—that are always just out of view. How might their stories inform the way we proceed?

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