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APPROACHING DESIGN AS INQUIRY

Magic, Myth, and Metaphor in Digital Fabrication

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Over the last decade, a new project of reproduction has entered public life. Cultures of making have given rise to systems for digital fabrication that create tactile media out of metal, plastic, wood, and clay. At one end, advocates like Chris Anderson (2012) contend that such systems have created nothing short of a "revolution"—enabling new forms of small-scale manufacturing and technological empowerment (Hatch 2014; Lang and Demarest 2013). Laser cutters produce modular furniture in garages and workshops. Shoebox-sized 3-D printers create jewelry through additive manufacturing. And computer numerical control (CNC) looms weave textiles patterns with shared digital files. At the other end, analysts view digital fabrication as commodity fetishism: extending capitalist modes of production to accommodate small-scale, "means-end" production, often reinforcing privileged technical authority along the way (Ames et al. 2014; Bean and Rosner 2014; Reed 2016). For instance, maker enthusiast Leah Buechley (2016) emphasizes the tendency of "maker" publications and events to speak to college-educated, upper- and middle-class white men. Others break open the category of technology to detail forms of care work (Toombs 2015; Reed 2016) and craft (Rosner & Fox 2016).

This chapter departs from these productivist and critical framings to consider an integrative approach to *design-as-inquiry*: folding together practical tools of technical development (in this case, digital fabrication) with theoretical tools of social inquiry (in this case, the mimetic faculty). To examine emerging sites of digital and material production, I turn to metaphors of extraction and capture underpinning the mimetic discourse of Walter Benjamin and Michael Taussig. I draw on Taussig's "theory of magic" to critically examine what it means to build a mimetic machine via digital fabrication systems and forms (1993: 59). A mimetic machine not only imitates phenomena but also takes a certain "sheen" from the thing it seeks to represent (231). In this examination, I show how tactile media throw into question the bounds and competencies of production: how algorithms shape measurement and interpretation to become a source of magical power.

To begin this inquiry, I turn to the spectacle of fabrication in three projects: two programs of engineering from researchers at MIT (Follmer & Ishii 2012; Zoran & Paradiso 2013), and

our research team's own development of an engraving tool, called "Arc," for ceramics. The first project, KidCAD, relinquishes object histories by physically copying an existing object on a scanning bed. The second project, FreeD, respecifies the machine's relationship to the hand by providing invisible haptic feedback. In the third project, Arc, our research team variously connects these questions of provenance, collision, and mimicry by moving an engraving instrument in response to surrounding gestures and sounds.

While the first two projects stem from productivist agendas that seek new processes for design, the final project develops out of our research team's collaboration with ceramicists through an approach to design-as-inquiry that comprises an integrative program of ethnographic interviews, conceptual development, and technology building. Treating design-as-inquiry here involves interventionist and collaborative methods of investigation that ask how an engagement with design may expand and shift what we know. Conversely, it prompts us to consider how social inquiry may help us, as analysts of the sociotechnical, get hold of design—to theorize and imagine design differently.

This approach draws on design-led approaches of critical, adversarial, and speculative design/making that consider the limits of digital production (Ratto 2011; DiSalvo 2012; Dunne & Raby 2013). For media studies scholars, processes of design present possibilities for empirical study of studio practice and downstream networks of maintenance and repair (Jackson & Kang 2014; Cheatle & Jackson 2015; Rosner & Turner 2015). For example, Elizabeth Goodman's (2013) ethnographic study of interaction design teams sheds light on the performative practices that organize work and enliven otherwise static deliverables. For digital humanists, processes of design offer unusual moments for conceptual interrogation. Approaches of this sort include Galey and Ruecker's (2010) assessment that digital prototypes may work as forms of argument and Matt Ratto's (2011) critical making workshops, which similarly rely on hardware programming to examine the limits of social theory, such as Marcel Mauss's theory of the gift economy. In other work, Hancock and colleagues (2013) suggest bibliotextual scholarship may productively work as a design-oriented practice, taking practices of "reflective design"—the promotion of critical, exploratory inquiry—to the study of the book. From printable prosthetics to portable water pumps, design projects shape the connections people make, the spaces they move through, and the sociopolitical infrastructures they inhabit (Bennett et al. 2016; de Laet & Mol 2000; Jungnickel 2015; Suchman 2011). The tools generated by each of these projects I have come to call "mimetic machines" (after Taussig 1993: 58–59, 219–20): systems that create sensuous (and not just functional) copies of existing forms, actions, and sounds. Beyond a study of mimesis, these cases serve to illustrate a program of design inquiry that proffers tactility as central to research practice.

Case Studies: Designing for Cultures of Making

This examination of digital fabrication as social and cultural inquiry begins with digital machinery for mimesis. From building circuitry to knitting sweaters, making practices have gained visibility within digital humanities due to the alternative framings of design and use they present. Although seemingly pervasive, making remains varied in its scale and purpose. Advocates claim makers "are reshaping how people consume and interpret the handmade" (Levine & Heimerl 2008: xi). While we often think of craft as domesticated by homemakers (often women) in living rooms and manufacturing as organized by professionals (often men) in factories, in these settings we see craft and manufacturing collide through material experi-

mentation. Through examining how people make things and share them with others, scholars question how digital tools enable, enhance, circumvent, or detract from people's engagement and connection with the world (McCullough 1998; Gauntlett 2011; Roedl et al. 2015). Next I turn to three projects on digital fabrication that attempt to extend and clarify the work of makers through mimetic production. Each invites questions of development around systems that selectively limit the forms of agency bestowed upon humans and machines.

KidCAD: Mimicking Objects

Drawing on the metaphor of clay stamping, MIT Media Lab researchers Follmer and Ishii (2012) designed KidCAD to enable children to copy and reproduce toys. The machine uses existing physical objects as the "original" forms from which 3-D fabrication follows. To create the scanning bed, the designers used a substance that models objects as they deform its malleable surface. Like SketchChair's (2011) developers, who provide an interface for designing and building chairs with laser-cut and CNC-routed parts, makers can use KidCAD to modify and extend the objects without engaging a graphical user interface (GUI) or 3-D printing software. The machine also enables customization through varied textures and materials. Customization concerns the capacity for people (consumers) to change printed features in an ad-hoc manner rather than fall back on decisions made by a commercial product manufacturer (producers), an interaction Follmer and Ishii connect with "remix culture" (2012: 2402). In a "user evaluation" with thirteen children visiting their lab with parents in tow, they asked the children to create two animals and compose a story with the system. Looking for themes across the group, they found the system worked as a pictorial canvas, enabling children to create scenery as if drawing with objects (2409).

For digital humanists, this project may recall Elliott, MacDougall, and Turkel's (2012) discussion of "New Old Things" for historical research. The machine invites makers to appropriate already meaningful artifacts as a "new medium" for narration (Elliott et al. 2012: 122). The appropriation of the old allows for an exploration of how tacit knowledge and performance can produce (and limit) meaning. KidCAD users may develop a tactile version of "traditional copy and paste" (Follmer & Ishii 2012: 2402). In this process of copying, Follmer and Ishii "hope to expand children's view of what objects are and what they can be" (2401). Along the way, the apparatus may also enable children to shape the world in their own image. In circumventing prevailing market relations (consumer-producer), Follmer and Ishii not only develop tools for expression, but also rethink an "original" object through the technological imagination of the individual.

FreeD: Milling Against

In a second project of digital production, Zoran and Paradiso, also hailing from the MIT Media Lab, developed FreeD to "merge" qualities of digital fabrication and traditional craft, enabling "authentic engagement" with material through computational tools (Zoran & Paradiso 2013: 2613). FreeD is an interactive milling tool that pushes back at the hand that holds it. As a freehand apparatus, the device corresponds to a common hand tool, such as a chisel, which makers can use with skill and dexterity. Yet FreeD also keeps track of its location in space to reconnect the maker's motions with those of the machine. To accomplish this tracking, the system integrates a prespecified digital model with limited features of the maker's gestures, all with the goal of "re-introduc[ing] some of the craft values into digital fabrication"

(2614). The system reacts to the maker's actions when the actions "put the model at risk" (2614). For example, the designers developed an algorithm to minimize the chance that a bit will enter the volume of the model. The machine pulls the carving tool back when it senses this issue. As the bit moves farther from the surface, the software pushes the shaft to a pre-specified position. In subsequent tests, Zoran and Paradiso later assessed the accuracy of FreeD, producing artifacts within 2.5mm of the original form (2615).

Beyond guiding the development of form, the FreeD project positions the software's algorithm as a central yet hidden feature of production, prompting new questions of the handmade. What do Zoran and Paradiso mean when they assert the importance of handwork in digital production? Where do they locate the hand as evidence of intent? How do they account for the agency and responsibility of the maker when they take digital mimesis as a starting point for handwork? For FreeD users, the body and machine become part of the same machinery: collaboratively reproducing a digital model but with different degrees and arenas of control. The body follows an algorithmic pattern as well as the underlying digital specifications the algorithm interprets. Speed of the milling and movements of the shaft become a form of communication, showing the maker not only where the machine detects the location of the bit (in relation to the surface of the digital model), but also the very nature of digital specification, a technique paralleling the control mechanisms built into new autonomous vehicles (Markoff 2010). In that sense, Zoran and Paradiso do more than develop instrumental tools. They take up a procedure of minimizing risk to prompt new concerns for "authenticity" and what evidences the intention of the maker.

Arc: Milling Together

Our third project, Arc (see Figure 52.1), came about through a collaboration with University of Washington students, Hidekazu Saegusa and Thomas Tran, and Seattle-based ceramic artisans, John Ellefson and Adrien Miller (Saegusa et al. 2016). Saegusa is a design technologist with a master's degree in engineering, a bachelor's degree in media arts, and formal training in sound and image analysis. Tran is a photographer with a bachelor's degree in environmental science. Miller is a sculptor with a background in painting and photography. Much of his work takes the form of portraiture that he creates based on photos of individuals. By contrast, Ellefson calls himself a potter because of its less "pretentious" connotations, he explained to me. His ceramic objects focus on the urn and its narrative potential.

Together we created Arc, a machine that variously reproduces the actions and intensions of makers based on the computational analysis of surrounding gestures and sound. The machine consists of three parts: first, a mechanism that analyzes sound and gesture data captured by simple sensors; second, a custom engraving instrument that sculpts material on the potter's wheel in response to this analysis; and third, an interface for changing the sensitivity of the machine and software algorithms. For example, a maker can shift the association between pitch, volume, and gesture by repositioning a lever on a mobile phone interface. That interface then wirelessly communicates this analysis to the engraving mechanism. In early versions of the machine, the software focused on gesture alone. In response, Miller and Ellefson noted the machine's impoverished ability to mimic the hand. But once it involved mimicry of sound, the artisans read new possibilities. "You can record conversations on there," Miller told me as he created a pot with our design team (see Figure 52.2). Ellefson found the final version of Arc compelling for its variety of soft, vivid layers that contrasted with its initial version, which, he explained to me, "felt kind of like a ticker tape machine."

Figure 52.1 Ceramic artist Adrien Miller watches the Arc engraving tool, placed on top of his own pottery wheel, move across the clay as he gestures around it.

Source: Thomas Tran.

Figure 52.2 Ceramic artist Adrien Miller inspects the ceramic vessel he made with Arc.

Source: Thomas Tran.

Figure 52.3 Design and ethnography team (John Ellefson, Daniela Rosner, and Hidekazu Saegusa) discuss early experiments around the Arc machinery.

Source: Thomas Tran.

We developed Arc to explore responses to emerging practices around ceramic tooling (Saegusa et al. 2016; see Figure 52.3). As a medium that integrates manual, mechanical, and digital production, ceramics offers some interesting features for digital fabrication. Artist Geoffrey Mann's *Crossfire*, for example, uses 3-D printers to create ceramic vessels that visualize the sound of an argument passing through them. From encoding audio tracks in ceramic bowls (Rosner et al. 2015) to playing audio-recorded stories from ceramic vessels (Green Eyl 2009), clay blurs a contested boundary between craftsmanship and digital production. Here, Arc displays multiple roles in the workshop: as copier, translator, and connector. As copier, Arc reproduces the actions that came before, making precision and scope core concerns. As translator, Arc listens selectively to the digital descriptions of 3-D form, suggesting fabrication relies on ambiguity, neglect, and resistance. And as connector, Arc enlivens ideas of what fabricators could become—possibly an assistive tool for those living with limb loss, for example. By occupying the intellectual borderlands of technics and handwork, our project considers fabrication as a mode of inquiry, offering a window into the sociotechnical imagination of craft.

Situating Digital Production in Histories of the Mimetic Machine

Like the systems that came before them, emerging forms of digital production reproduce the workings of older technological ensembles. Film cameras create analogies with the phenomena depicted by moving imagery, and sound recorders apprehend the same from audio traces. In the projects above, KidCAD assumed a role similar to the photocopier, creating momentary

links with an existing object. FreeD followed a standardized format much like Jonathan Sterne's (2012) descriptions of early audio recordings, selectively listening to (or ignoring) the gestures of the hand. Arc operated through negotiation and surprise, providing moments for reproduction, translation, and connection, and moments for overriding them. This machinery comprised a range of apparatuses, from engraving and etching to sonography and sound compression.

Across these projects, digital production took its power from the copy, a mystical sensuousness that Walter Benjamin calls "aura" in the context of cherished artworks (1978: 222–26). Michael Taussig sees the copy's capture and extraction of magic from the original as an explanation for how it produces a "fetishlike power" (1993: 59)—the growing urge, in Benjamin's words, "to get hold of an object at very close range by the way of its likeness" (1978: 223). Mimesis, Taussig argues (through Benjamin), long played a central role in ritual ceremonies within ancient societies. So, too, he asserts, has it impacted the ritual of modern machinery. What emerges from this two-part mimicry is a simultaneously historical and modernist ideal: the compulsion to act as someone or something else. Magic exists only to be subsequently extracted by technical means.

This argument recalls a rich literature on the magic of technological production emerging in histories of engineering and scientific infrastructure. Tracing the establishment of the American electrical industry in the late 1880s, historian Carolyn Marvin points to the audience emerging around electrical engineers (1990: 56). In a cry for public sympathy, this "scientific priesthood," in Marvin's terms, grew aware of their audience's affection for magic and myth. From this, Marvin surmises that, "[a]lthough an express mission of science was to kill magic and myth, electrical experts were deeply implicated in the production of both" (56). A yearning for spectacle remained strong. In a parallel analysis, David Nye traces this technological appeal to early American engineering achievements. Nearly a century after Marvin's sympathetic scientific priesthood, crowds gathering to celebrate the San Francisco Golden Gate Bridge led the bridge to sway and buckle, Nye explains (1994: xi). Unprepared for the unprecedented public turnout, officials perilously overlooked concerns for what Nye calls the "technological sublime," which concerns the representation of engineering developments as emblems of divinity. Water wheels display the same characteristics as the Grand Canyon as well as less engineered natural attractions such as Yellowstone National Park and Niagara (23). Vincent Mosco brings these themes into a sociology of cyberspace in his characterization of the "digital sublime," the magnetic power of the internet, which both enables and contributes to the enactment of myth (2005: 32). Building on Mosco's ideas, Morgan Ames (2014; 2015) introduces the term "charismatic technology" to describe the "uncanny holding power that some technologies seem to have" (2015: 1). She points to the Massachusetts Institute of Technology's One Laptop Per Child (OLPC) project's XO laptop as an artifact with this "charismatic authority" (after Weber 1947), highlighting the drawbacks of relying on the desires of MIT engineers to make the world in their own image (Ames 2014; 2015). Across these concepts—from scientific priesthood to charismatic technology—digital production is steeped in spectacle.

Yet, do the metaphors of "capture" and "extraction" comprise a persuasive paradigm for media studies? Do they help us make sense of this magic and spectacle? Borrowing from Taussig, the copy suggests "something ineffable is being 'brought out' by this interaction of miming bodies and mimetic machinery" (1993: 244): a magical correspondence with the original via engagement with digital tools. However, is something also *inscribed* in materials and then read back or "de-scribed" from them (Akrich 1992)? Is something *revealed* against Heideggerian (1977) background practices (those dominant ways of acting and speaking)? Is something *performed* in line with Butler's (1990) concern for the materialization of sexed

bodies? Is something brought into being through—recalling Barad's (2007) attention to the mutual constitution of meaning and matter—its *entanglement* of tools and bodies?

Or what if we instead followed the logic of versions? Mary Ann Doane, for instance, provides an instructive example in her analysis of cinematic archives—collections that maintain "the aura of the original" film but rely on print and digital copies, or "copies without an original" (2002: 222). Further troubling concerns for originality and durability, Wendy Chun points to software as always open to iteration and alteration, just as its source code purportedly translates instructions in "dead repetition" (2011: 25). For historians of media, the "original" and "copy" flow from task-based interactions that tend to rationalize progress by giving the modern a historical referent.

Locating Fabrication in Theaters of Design Inquiry

Put in historical relief, the above projects suggest a *performative* mode to design. Rather than considering it a part of task-based production, design works as a theater of (re)production. This perspective helps scholars of media understand digital outputs as more than mere copies of an original toy or model. Digital prints (here, a KidCAD print, a FreeD sketch, or an Arc bowl) also evidence the moment of contact made with a phenomenon. This form of contagion—or what anthropologist James George Frazer (2004 [1890]) calls the "Law of Contact"—represents a crucial aspect of integration. The instrumental "user tests" of KidCAD and FreeD resemble Jonathan Sterne's description of early audio encoding listening tests, aiming to transcend their context to build a "universally communicable" format (2012: 153). The Arc project, by contrast, aims to examine its contexts of production, inviting interrogation of its specificity and communicable form (as copier, translator, and connector).

In locating fabrication in a performance of collaborative inquiry, this chapter asks scholars of media and technology to mutually engage their sites of study. This way of getting hold of the digital medium demands tactile intervention. It requires scholars to acknowledge an indefinable tactility of vision that often develops from habit and tacit appropriation (Benjamin 1978: 240). By talking about knowing something, we put ourselves (the knowers) in relation to that thing. In doing so, we create a kind of "relating to" that displaces the concept of "knowing" (Taussig 1993: 26), complicating the logics of "extraction" and "capture" that knowing inhabits. Examining exactly how "relating to" involves tactility calls for different approaches to studying algorithmic cultures. This interventionist, integrative approach to design-as-inquiry begins to address this plea: taking tactility more seriously—as an experience just as central as, and no less mediated than, vision or hearing—in the interrogation of our social world. Confronting the mimetic faculty of fabrication allows media scholars to pull back from the productivist framings of KidCAD and FreeD to use digital fabrication as a tool for comparing craft subjectivities—exposing their resistances, margins, and edges.

My objective here has been to create an account of digital fabrication that helps enrich a budding field of interventionist work across digital humanities and media studies. Toward this end, I have tried to impart some conceptual background and design exemplars and also outline their relation. Although the three projects presented above have different aims, they share a similar potential: suggesting new conceptual pathways emerge when we frame a design project as a mode of inquiry. We learn how machines not only draw readily and repeatedly on the spectacle, but also frame techne as a common ideal. Intersecting histories of technological magic with digital intervention, they serve as a backdrop for "mimetic machinery," exposing the limits of "capture" and "extraction" for explaining the shifting agency of the maker and machine.

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