Mimetic Machines: Collaborative Interventions in Digital Fabrication with Arc

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ABSTRACT

This paper examines the collaborative process of developing Arc, a computer numerical controlled (CNC) engraving tool for ceramics that offers a new window onto traditional forms of craft. In reflecting on this case and scholarship from the social sciences, we make two contributions. First, we show that fabrication tools may integrate multiple and distinct roles (as copiers, translators and connectors) in their production of form, selectively limiting the agency of the maker and machine. Second, we situate small-scale manufacturing in a wider historical context of "mimetic machinery": machines for mechanical reproduction that draw their symbolic power from a material connection with the phenomena represented (in this case, sound and gesture). We end by sharing lessons learned for fabrication research based on this study.

Author Keywords

Digital craft, performance, digital fabrication, research-through-design, design inquiry, mimesis.

ACM Classification Keywords

K.4.0 Computers in Society: general.

INTRODUCTION

Over the last decade, a new project of reproduction has entered HCI. 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 within HCI contend that such systems have created nothing short of a "revolution"—enabling new forms of small-scale manufacturing and technological empowerment [26]. Laser cutters produce modular furniture in garages and workshops [25]. Shoe-boxed-sized 3D printers create jewelry through additive manufacturing [16]. And computer numerical control

Figure 1: Miller inspecting the ceramic pot he created with the Arc machine.

(CNC) looms weave textiles patterns with shared digital files [13]. At the other end, analysts view digital fabrication as commodity fetishism: extending capitalist modes of for-profit production to accommodate small-scale manufacturing, often reinforcing privileged technical authority along the way [20,23]. For instance, Roedl et al. [23] emphasize the tendency of "maker" 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 [29], hacking [15], and craft [24].

This paper pulls back from these productivist and critical framings to consider fabrication as a mode of inquiry, a window into the sociotechnical imagination of craft. To do this work, we developed Arc, a computer numerical controlled (CNC) engraving tool for ceramics that carves material according to surrounding sounds and actions. We draw on eight months of fieldwork and technical development of Arc in a clay studio and scholarship from science and technology studies and cultural studies to make two arguments. First, we suggest Arc exposes multiple roles for systems of digital fabrication in the workshop: as copier, as translator and as connector, selectively limiting agency through each encounter. Second, locating these machines in the historical context of "mimetic machines" shows that tactile media may throw into question the bounds and competencies of production: how algorithms shape measurement and interpretation to become a source of "fetishlike power" [16, 27]. While we developed Arc to build new imaginative frames

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into practices of digital fabrication, we soon found the symbolic value of small-scale manufacturing took precedence.

RELATED WORK

This examination of digital fabrication builds on studies of making and craft [5,12,13,15,17,21] and interventionist design research [6] that have gained recent traction within HCI due to the different ideas of design and use they propose. Advocates claim makers "are reshaping how people consume and interpret the handmade" [13,p.xi]. This includes the "maker movement" typified by projects featured in the popular DIY magazine *Make* and transnational Maker Faires. Around digital fabrication in particular, design researchers consider what can be learnt through the development of new tools [8,25]. Zoran and Paradiso [28], for example, present an interactive milling tool that pushes back at the hand that holds it. From computer-controlled embroidery [10] to plush toy construction [19], this machinery explores the production of custom 3D shapes through varied textures and materials. In the domain of ceramics, we find several additional examples, from audio-recorded stories inside the ceramic vessels [10] to blurring the boundary between ceramic craftsmanship and technology more broadly [17,13,16]. Artist Geoffrey Mann's *Crossfire* comprises vessels that visualize the sound of an argument passing through them.

Most connected to our project is a recent body of work examining the material performances that become core to process of meaning making [6,7], and not just background activities. Cheatle and Jackson's [5] recent examination of digital fabrication in the context of a fine art furniture studio, finding that such tools live in historically complex systems of value that shift the very content and form of their use. As a practice that inhabits the edges of manual, mechanical and digital worlds, ceramic work extends these questions of value for digital fabrication.

ARC: MILLING TOGETHER

Arc is a digital engraving machine that mimics the sounds and actions of makers based on computational analysis of surrounding gestures and sound. The machine moves a ribbon tool for cutting clay in response to the rhythm, volume and pitch of the sound, the gestures of the maker, and how the maker configures the machine's sensitivity. The core system consists of three parts: (1) a mechanism that analyzes sound and gesture data captured by simple sensors; (2) a custom engraving instrument that sculpts material on the potter's wheel in response to this analysis; and (3) mobile phone software for changing the sensitivity of the machine and software algorithms. For example, a maker can shift the association between pitch, volume, and gesture to movement by repositioning a lever on a mobile phone interface. That interface then wirelessly communicates with the engraving mechanism.

The application runs on the iOS 8.4 platform with an iPod touch (5th generation). It wirelessly connects with output using the Open Sound Control (OSC) protocol. The microphone is embedded in the phone, which processes the sound (i.e., voice, music played from a phone, etc.). The software extracts the volume of the incoming sound in reference to the value of the volume slider, which corresponds to a multiplied value of the specified volume. In addition to the volume, the software recognizes the peak frequency if its amplitude is greater than the threshold value set by the slider interface. This allows the user control over the sensitivities of pitch and volume, individually. We then send the pitch and the volume of sound input to the hub application (built with Processing) running on a laptop (Mac Book Pro) that controls the behaviors of the output machinery. The hand gesture recognition uses a Leap Motion sensor to detect velocities of the index finger, measuring its elevation and (lateral movement). We multiply the values of the sliders for depth and height as weight coefficients on each vector of velocity. We then communicate each variable to the hub desktop application. The derived value of the vector of velocity of each axis (elevation & lateral motion) is multiplied by the set slider value as weight coefficients.

The output machinery consists of a rotating table on which a material object is placed, a machine arm that engraves the object and an elevation structure to control the height of the machine arm. The elevation system is structured as a threaded rod bolstered with four linear bearings controlling the elevation of the machine arm. The stepper motors controlled by a micro controller (Arduino Uno R3) drives the machine arm and the elevation structure. The mobile software determines the elevation based on the elevation-axis velocity of the index finger or the pitch received. The machine arm is structured as a crank, and the value for volume and velocity of the lateral-axis received from the mobile software, determines the distance an arm extrudes. As the received value increases, the extrusion of the machine arm moves closer toward the center of the rotating table. The elevation-axis velocity of the index finger or the number of frequency band received from the mobile application determines the elevation. As the hub application receives the elevation-axis velocity, the elevation of the ribbon tool is responsively determined.

BUILDING COLLABORATIVELY

The Arc system came about through a collaboration between maker-scholars at the University of Washington and Seattle-based ceramic artisans Adrien Miller and John Ellefson. Miller is a sculptor with a background in painting and photography (once telling us, "*I like to sneak art into everyday objects*.") Much of his work takes the form of portraiture that he creates based on photos of individuals. Ellefson by contrast calls himself a potter because of its less "*pretentious*" connotations. His ceramic objects focus on the urn and its narrative potential.

Our work with Miller and Ellefson began at Florentia Clayworks, a ceramics studio in Seattle, Washington home seven ceramic artists who collectively rent and care for the space. The workshop contained a range of pottery wheels, electronic hand tools (such as saws and drills) and a large kiln. No tools for digital fabrication like laser cutters or 3D printers had entered the space and the artisans had no plans to bring them in. Miller and Ellefson both find the draw of clay work in the physical interaction with clay ("*as a method of understanding your world and work you lose something*," Ellefson explains.)

During our first visit we told the artisans we wished to explore the introduction of digital fabrication processes in ceramic work. We presented them with a linear motor whose movements corresponded to a digital 3D model displayed on a mobile phone. The initial prototype worked much like a subtractive 3D printer wherein digital renderings drive tangible design. In the scene that follows we describe our initial discussions that would lead to Arc.

The research team joins Ellefson and Miller at the Clay Works Studio. Ellefson begins sketching ideas for a fabrication machine. "If there's some algorithm that would alter with my gesture so that I didn't full understand how — what shape it would take," he says, staring at our prototype's jerky arm movement. "Rather than just uuuuuun," he says, imitating the recurring motor noise with regular movement. "Not that I really understand anything about how algorithms work or how to do that. But I get the sense that […] the parameters aren't linear. And the non-linear thing is the thing that's somehow interesting." Ellefson explains how everyone has a unique way of handling clay: appreciating how people have their own habits of gesture. Miller stands back from the prototype. "One idea I'm having just looking at it," he begins, "essentially having whatever my input is with my hand be mimicked by the machine." Miller demonstrates concurrent movement wherein the machine reproduces his hand gesture at the wheel. "So you're one half of the equation and here's the other half?" Ellefson asks with excitement. Miller nods (Figure 2).

The above vignette illustrates the artisans' early responses our project, imagining an alternative engagement with machine fabrication. Miller's proposal for an interaction that blends the maker and machine — the latter mimicking the former — ultimately expands the kinds of fabrication techniques used in the studio and those used beyond it, such as within 3D ceramic fabrication labs. The idea stems from Miller's recent experience showing people how to throw clay by asking them to think of the wheel as a clock face where forces push at opposite ends. But from watching the uneven movements of a linear motor, the artisans develop other ideas for creating compelling formal interventions and imagery. Along the way, Miller embraces unexpected rhythms, suggesting ideas for cultivating a soft agential presence on the ceramic stage. Soon mathematical metaphors take hold: "parameters," "algorithms," "linearity," and "equations." Ellefson focuses on non-linear parameters and mystery of computational algorithms.

Figure 2: Miller explaining the mimicking gesture of machine.

In the sections that follow we see how this concern for extending the ceramicist's hand becomes indicative of the multiple roles Arc could potentially play. As Arc develops alongside other projects in the studio, it highlights unique priorities for the makers. In the process, we foreground three facets of digital production — coping, translating and connecting — each of which suggests paths for developing the symbolic life of 3D printing.

Copying

Early iterations of the machine followed on Miller's suggestion for collaborative production to begin tracking hand gestures in isolation. While experiencing this technique for the first time, Ellefson describes the instrument as a "*pantograph sort of thing*," creating patterns originated by the hand. The pantograph instrument, whose mechanism developed in the early 17th century, enables the movement of an arm (often tracing an image) to produce the movement of another arm. These movements may happen at different scales, enabling both the reproduction and magnification of an image.

However, despite developing a closer relation to the pantograph over time (increasing its accuracy), later versions of the machine could feel abrasive. At one point Ellefson refers to Arc as "a ticker tape machine," coarsely copying the finger's movements. He bends over the machine arm to inspect its precision, making several suggestions to improve this accuracy. He recommends alternate material and mechanics – from wood to metal and from a height-axis piston to a height-axis threaded screw. Miller worried that a delay in height-axis shifting inadequately constrained his movements. Much like a photocopier, Ellefson and Miller expected Arc to reproduce the forms that came before – making precision and scope core concerns.

Translating

The features of Arc that became particularly intriguing for Ellefson and Miller concerned its ability to translate a human action. Miller focused on the regularly placed incisions it made on the top of the bowl, marks he said he had trouble producing by hand. Once the machine involved mimicry of sound, Miller read new possibilities: "*You can record conversations on there*." He proceeded to ask Hidekazu to play a recording of Brian Eno, partially in jest (as a clichéd reference to performance art) and partially as a test of its boundaries (how the would machine translate these sounds). As the song played, the rhythmic sound Arc created as the Arc jutted back and forth fed back into its speakers, subtly influencing the movements of the machine.

More visibly, the song's higher pitches moved the arm's z-axis at an imperceptible pace. The volume, by contrast, moved the arm faster. Even adjusting these features proved unsettling, suggesting the delay could not be sufficiently overcome. Ellefson and Miller grew more interested in how the arm created marks along the z-axis. "*It's beautiful*," Miller told us, reflecting on a pot he had glazed and put through kiln. As a translator, Arc selectively listened to the digital descriptions of 3D form (via gesture and sound). These invisible decisions to amplify or ignore patterns of activity, seemed to embrace ambiguity, prompting a certain desire for surprise — affective, formal, and aesthetic. Through translation, Arc presented possibilities for revision, iteration, deletion and breakdown, concepts that push at HCI's current understandings of digital craft. These roles not only suggest attending to digital fabrication beyond moments of imitation, they also recommend recovering alternative characterizations of reproduction that have long emerged through the craft practices and representations.

Connecting

What surprised the makers most visibly, however, concerned a desire for extending the sensitivity of the machine. Early on, Miller described clay work as *"a quiet and self-contained performance*." While watching the movement of the Arc arm, Miller wanted the machine to react to more than his touch, suggesting it should respond to sounds as well. He explained: "*I think of performance as being very body based: the physical gesture of moving limbs. How do we stretch out and bring awareness of the space around us into this small container of what we're focusing on?"* Through music, Miller positioned Arc to provide a window onto the wheel, a contained and focused performance.

During our final session, the height-axis refused to budge. Miller stopped using the machine in frustration. He turned to Ellefson in disappointment, noting the machine's impoverished ability to demonstrate the subtlety of the hand's gesture. By entering into a theater of digital fabrication, the makers exposed pottery production to new questions of performance and control. How should the machine interpret the hand? How should the hand interpret the machine? Through making marks in clay with Arc, the potters created a visible and durable connection to those moments of breakdown and adoption of Arc. While copying implies an imitation of form or content, connecting here highlights the maker's continual ties with the phenomena reproduced, a process that invites questions of authenticity, or ways of evidencing the presence of the maker in the act of making.

POSITIONING ARC AS A MIMETIC MACHINE

In his brief 1933 essay on mimesis, cultural critic Walter Benjamin outlined the key role of mimicry in all human endeavor. "*Perhaps there is none of [a person's] higher functions in which his mimetic faculty does not play a decisive role*" [2, p.343]. In a remote past, imitations of astrological processes took the form of dances signifying recognizable reenactments of the sky. Mimesis sustained more than similarity; it captured "magical correspondences" [2, p.334] with the phenomena represented.

Decades later, anthropologist Michel Taussig read Benjamin's commentary as a statement on sociotechnical life. He argued that contemporary "mimetic machinery" enables a resurgence of ancient "magic" (1993: 59). Film cameras create powerful analogies with the phenomena depicted by its moving imagery, and sound recorders apprehend the same from audio traces. This mimetic machinery comprises a range of apparatuses, from engraving and etching to lithography, photography, and film. It also began to explain the holding power of technology, or what Ames [1] has recently called charisma.

Like the analogue photograph and film cameras that came before them, our integrative program of ceramic work showed how tools of digital fabrication (and here Arc) hold a certain symbolic power. Despite finding themselves "*skeptical*" of 3D printing technology, Ellefson and Miller enlivened our ideas of what fabricators could become. The "*fetishlike power*" [27, p. 59] of their fabricated form did not rely solely on imitation or translation.

This form of contagion—or what anthropologist James George Frazer called the *Law of Contact*—represents a crucial aspect of Arc's integration of roles [8, p.220]. Confronting the fetish quality of fabrication requires us to create a kind of "relating to" that displaces the concept of function – framing the ceramic process as part of other relations (coping, translating, connecting). It also acknowledges an indefinable tactility of vision, how making gesture and sound durable entails stabilizing actions in tangible media (tape cassettes, CDs, vinyl, hard disks). For HCI, this contagion casts new light on "WYSIWIG" production – showing what you can see and what you get from digital fabrication is less a matter of function than a capacity for creating a symbolic hold on the thing being reproduced (and keeping that thing "*alive*" [1]).

CONCLUSION

The stories above begin to illustrate how the concepts of copying, connecting and translating extend HCI debates around human-object relations and creative practice in ways that call attention to the symbolic value of digital reproduction. This means looking beyond the human-machine interface (c.f. [28]) to the complex arrangements and histories of meaning making on which it depends. As an analytic matter, Arc's multiple roles suggest recognizing the limits of mimetic metaphors for characterizing digital craft processes (both their content and form). Approaching the connecting and translating of material expression expands the "capture and extraction" logic underpinning many HCI projects of fabrication. In doing so it also adds precision to the socio-material metaphors of "entanglement" or "intra-action" [2,30] that characterize the co-constitution of matter and meaning underway.

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