ORIGINAL ARTICLE

Structures, forms, and stuff: the materiality and medium of interaction

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Abstract Though information is popularly, and often academically, understood to be immaterial, nonetheless, we only encounter it in material forms, in books, on laptops, in our brains, in spoken language, and so forth. In the past decade, HCI has increasingly focused on the material dimensions of interacting with computational devices and information. This paper explores three major strands of this research—tangible user interfaces, theories of computational materiality, and craft-oriented approaches to HCI. We argue that each of these offers a formulation of the materiality of interaction: as physical, as metaphysical, or as tradition communicating. We situate these three formulations in relation to debates on the nature of media, from philosophical aesthetics (the ontology of art, in particular), media studies, and visual cultural studies. We argue that the formulations of materiality, information, and meaning from HCI and those from the humanities have deeper underlying similarities than may be expected and that exploring these similarities have two significant benefits. Such an analysis can benefit these differing threads in different ways, taking their current theories and adding to them. It also serves as a basis to import philosophical art concepts in a robust way into HCI, that is, not simply as prepackaged ideas to be applied to HCI, but rather as ideas always already enmeshed in productive and living debates

that HCI is now poised to enter—to the benefit of both HCI and the humanities.

1 Introduction

As the physical forms of computation have gotten smaller and more flexible, and as the uses of computational devices have become more varied, there has been an increasing desire in HCI to understand the material basis of these devices. This desire to understand materiality as it pertains to computing—the stuff it is made of [1]—examines physical properties from a variety of different perspectives and disciplines, not only with respect to their materially specific abilities to support functionality and task completion, but more broadly how materials contribute to the aesthetic qualities of a design, which range from pleasing experiences to the ongoing cultivation of our perceptual, imaginative, and empathic skills [2]. To do this, HCI has pursued a number of different perspectives from a number of different disciplines, such as cognitive science, psychology, and aesthetic philosophy.

One approach to the study of the materials of interaction has been to view physical interfaces in terms of their functional affordances, both perceived and actual [3, also see 4 in this issue] and how they come to represent information tangibly [5]. An alternative formulation finds the material of computing in computation itself [6], including states, transitions, and events. This second perspective, in turn, has been challenged on the basis of whether information can even be a material, and if so, what properties can be attributed to it [7]. A third approach emphasizes the

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communicative roles of materials, from examining the ways that materials "talk back" [8] to designers, shedding light on the process of creation, as well as how traditions of expression and making are transmitted through materials [9].

Even this brief survey of research on materiality in HCI reveals opportunities. One opportunity is to further clarify and develop different senses of what we mean by "material." Is it simply the physical dimension of a given interaction, best understood with the concept of affordance mediating between a specific physical feature and particular perception of its meaning and/or interactive potential? Or is it something more metaphysical—computation itself—that is the true material while the physical objects it inhabits are seen as its surface manifestation? Equally, is the significance of materiality to be found in our improved ability to understand the relationships between specific concrete physical features and usable functionality, or is it to be understood more broadly as a material substrate for expressive traditions? Issues such as these were addressed in the CHI 2012 workshop on materials and materiality, which sought to "lay the groundwork for developing a common and productive understanding of digital material and materialities" [10]. As was part of the findings of that workshop, understanding of materiality as it pertains to HCI may in fact require a range of alternative formulations to explore materiality in appropriately multifaceted ways.

As designers and design researchers view the physical, computational, and cultural aspects of material interactions in HCI, these three formulations help us perceive what is valuable in them. Arguably, they contribute towards the "deeply situated understandings of practice [that] produce not only meaningful artefacts but also useful descriptions of their composition, appreciation and usefulness" [11]. These framings not only help designers read designs materially but can also help us understand ways that users construct tacit understandings of what they expect from a design. They aid in the creation of what Janlert and Stolterman describe as the "character" of an artefact [12]. This character combines the divergent aspects of an artefact in a manner that can contribute a sense of unity and understanding to new artefacts. This kind of unity allows users to make comparisons between previous artefacts and new ones. Similarly, Bergström et al.'s [13] concept of "becoming materials" shows how "unique characteristics of these new materials" are grounded in "a range of external climate, environmental and human factors." Thus, the perceived unique aspects of new materials have a basis in what has physically existed before as well as social conventions. Similar conceptualizations have been developed in philosophy and applied in visual cultural studies, including design studies, for decades. Visual cultural theorist Barnard [14], for example, paraphrases the hermeneutic philosopher Gadamer to explore how people's prior and existing experiences and expectations shape—and make epistemologically possible—their understandings of visual cultural works, from Renaissance Christian paintings to postwar motor scooters, in the first place.

We take the position in this article that theories of materiality in HCI are in some ways working towards (and even reinventing) the conceptual role that "medium" plays in the ontology of art and design. The ontology of art and design is an area of philosophical aesthetics [e.g., 15–17] and visual cultural theory [e.g., 14, 18, 19], and which has a long history [e.g., working chronologically backwards, 20–22] that deals with questions such as the following:

- What is a given medium, such as a painting or film, and how can it be distinguished from other media?
- In what ways does a given medium constrain or resist expressive possibility?
- How does a medium make possible distinctive aesthetic experiences that are difficult or impossible to achieve in other media?
- What role does (or should) medium play in the evaluation of a given work?

Recent media theory is one resource to explore the loaded relationships between physical forms, signifying conventions, expressive possibilities, experiential effects, sociocultural significance, and overall character of a type of human-made work.

The intent of this article is reconstructive: we hope to consolidate several lines of thinking in hopes of amplifying the gains already made by the diverse theorizations of materiality that are emerging in HCI; specifically, we aim to do so by situating them into a dialogue with the concept of medium. The intent of this is not to combine these divergent theories into "one theory to rule them all," but rather to show how the different perspectives could, respectively, see benefits from conceptualizations like this. To do so, we will sketch out three views of materiality in HCI, teasing out what we see as their underlying assumptions and some specific contributions to HCI. We will then juxtapose this three-part reading against our reading of media theory. We will argue that the overlaps between the HCI and arts and media-based theorizations are similar in key ways and justify the cross-pollination of ideas, which we then explore.

2 Three views on materiality in HCI

Since all interaction design has a material dimension, references to materiality can be found throughout HCI, including its history and its subdomains. To give ourselves

sufficient space and focus to develop our research themes productively, we limit our discussion to three active trends in the theorization of materiality in HCI. We chose these three because all three are active and influential in HCI today and because they reflect very diverse possibilities of how this topic can be approached. We note at the outset that we do not intend to side with one over another; we believe that each of these approaches contributes value to the field. The three views are tangible user interfaces (TUIs), computational materiality, and craft and/as HCI.

2.1 TUIs: physical materials

Similar to graphical user interfaces (GUIs), TUIs focus on presenting information from computation (see also Giving Form), replacing graphics with physical objects. Durrell Bishop's Marble Answering Machine provides an often-cited early example, taking the information that would normally be associated with a telephone answering machine and attaching it to physical form, in this case marbles [23]. Fitzmaurice et al. [24] extended this line of thinking into "graspable user interfaces," examining ways that different physical forms could allow for greater manipulation of digital information in terms of transducers operating in space and time. This placed early emphasis on task completion and efficiency—the ways that physical objects could yield greater control over digital information. At an early point, such research formulated materiality largely in terms of the tightly coupled relationships among physical forms, information representation, and functionality.

Ishii and Ullmer [5] later returned to the idea of making data tangible with "Tangible Bits," focusing on the "seamless coupling" of "our physical environment and cyberspace". This idea combined the previous ideas of graspable UIs as input and new representations of data as output. Continuing this line of thought, an iceberg analogy was adopted, with the visible top of the iceberg representing the physical input and output, and the submerged portion representing the underlying data [25]. As the iceberg combines the physical and the digital, "immediacy" combines input and output, striving for the "coincidence of input and output spaces and real-time response" [25]. Exemplary of this approach is the Recompose Table, described in [26]. This interface is composed of pins that can be both read and actuated through gestural movement or direct manipulation. The table itself is an abstraction of that control, focusing on the functional way that the tangible aspects allow computational control of the actuators and communicate the results of that control. The collapsing of the physical into the digital and input into output presents a concept of the physical that is not only functional but also minimal.

As a means of scrutinizing the relationship between the physical and the digital further, Hornecker problematizes the concepts of tight coupling and immediacy. Through testing Ar-Jam books, she found that the tangible paddles used to control characters did bring the desirable "naïve physics" notion of moving in three dimensions, but also brought along unexpected, and not intended, reactions that still very much focused on affordances of the physical [27]. In other words, the physical interface was not "transparent" but called attention to itself as physical material. Hornecker's examination raises new questions about the ways that data and physical representations relate, but nonetheless, she still places value on obtaining a sense of how function can be minimally imbued in form.

As TUIs have moved from marbles representing phone messages to paddles controlling characters in a children's story, aspects of the physical definition of medium emerge. Both the marble answering machine and the bricks conceive of the material in functional ways. The marbles act in terms of presence and absence, using the physical aspect of colour only as an arbitrary differentiator between messages. The bricks are described in terms of how they can be grabbed, but the material used is referenced only as the type of transmitter employed—a means to the end of communicating with the processor. The Recompose Table combines functions of representation and control. Even with a focus on the unplanned and extraneous aspects of the forms of the paddles used in Ar-Jam books, there is still a theme of how this operates with respect to functional affordances.

Any emphasis on how the material functions, in terms of its physical properties, also places value on how efficiently that material can function. This view thus presents physical-functionalist minimalism—which we view as an analogue to the notion of "transparency" advocated by Nielsen and Norman for GUIs in the past—as the core material value of tangible interactions in HCI.

2.2 Computation as material: a metaphysical materiality

If materials are understood as the elements or components out of which designs are made, there is no reason to limit materials to the physical realm. Examining how computation can serve as a material in its own right leads to an interesting set of issues. As Vallgårda and Sokoler [28] describe "the inner workings of a computer are physical and have the ability to affect other materials, (but) they are not perceivable through the human sensory apparatus and can therefore only be studied and used for design in composition with other materials." This suggests that the materiality of computation is best observed indirectly

through the artefacts that employ it and interactions with those artefacts.

Vallgårda and Redstöm take this approach of looking at computational artefacts as designed, physical objects. One such artefact, Chronos Chromos Concrete, combines computational elements with concrete to allow it to dynamically change its appearance [6]. The concrete still behaves as it would normally in terms of structure, but its appearance can be changed computationally. This "computational concrete" has a computational *structure* of nickel chromium wires as well as a *surface* of different currents that result in a change in temperature in those wires [6]. The *structure* and *surface* of the artefact are difficult to perceive in isolation. They become visible when thermodynamic ink mixed into the concrete reacts to those fluctuations in temperature [6]. To answer to the difficulty in perceiving the digital material without other materials, Vallgårda and Redstöm introduce the notion of "computational composites":

> "Expressed more precisely, a computational composite can exist in a number of *states* (e.g. colors, shapes, or positions). Whenever a set of conditions is met, a *transition* towards a new state is begun. The conditions and their fulfillment are *controlled* or *computed*…"[6]

On this view, the material of computing, a "computational composite," is structured according to computational logic—states, transitions, controlling algorithms, events, etc.—but that these states have both physical and logical manifestations. It is important to note, however, that in contrast to the TUI view sketched above, for Vallgårda and Redström, the primary material is the computational, and the physical elements play a role of revealing the properties of that material.

Developing Vallgårda and Redström's concept of composite material, Robles and Wiberg introduce a concept of *texture* as a means of "articulating material relations between the physical and digital." This concept is deployed to describe the specific ways that different computational and physical material properties work in conjunction to achieve a certain textural quality [29]. As an example, IceHotel X combines computation and the material of ice. This involved a process of "bringing the raw ice to life" through "common tropes like open fires, northern lights, blizzards, and glowing stars" [29]. While the states may be less discrete than in Vallgårda and Redström's description, the animations still imbue the ice with change.

In both the proceeding examples, computational material is viewed as part of a combination with a physical material. Alternately, Dourish and Mazmanian describe information as a material on its own, and its properties are revealed in the process of interacting with that material.

They use digital photography as an example, where they begin by contrasting traditional film photography against digital photography. As they describe it, this change "allows us to rethink what is 'worthy' of photographic documentation," but still "needs to be incorporated into an existing set of conventions, understandings, and procedures" [7, pp. 13–14]. The addition of digital technology has changed the ways that activities have been conceptualized. Whereas the proceeding perspectives focus on changes to the physical medium, the change here is in how the introduction of computation changes the ways of conceiving human practices and conventions surrounding the creation and consumption of human works.

The three views introduced in this section take a decreasingly physical view of materiality. Whereas the TUI formulation is tightly linked to physicality, Vallgårda and Redstöm suggest that abstract computational structures are nonetheless part of the materials of digital artefacts. However, their formulation nonetheless leaves physical and computational as distinct, if collaborating, categories. Robles and Wiberg, in proposing texture, suggest irreducible wholes—textures—that are composed of computational and physical structures but which cannot be reduced to either. Dourish and Mazmanian's view resituates the whole conversation away from the literal artefact in-itself and replaces it with *interaction* as the locus of material properties, and the notion of a tradition of expressive, signifying, and consumption practices, stressing the materially constitutive role of these practices in the material substrate of the work itself. This entire line of reasoning thus offers a metaphysical account of materiality, calling our attention to a whole set of concerns that are not a central part of the TUI account, in particular the notion of *change*, firmly positioning interaction in the fourth dimension [see also *temporal change* in [30] in this issue].

2.3 Craft and/as HCI: materiality as tradition communicating

Though the TUI and computational materiality perspectives differed in their respective foci on physical versus metaphysical takes on the materiality of HCI, both broadly speaking can be described as ontological, in the sense that they are seeking to describe what digital materiality is. The Dourish and Mazmanian piece, in raising the role of conventional signifying practices in digital photography, gestures towards the communicative dimension of materiality. The rising area of craft-related research in HCI [see also 31 and 32 in this issue], building on recent re-evaluations of the role of craft in society [33, 34], has also taken up the issue of communication. It does so through both an examination of the various materials of craft practice and the materiality of interactions with those materials.

Specifically, HCI craft researchers have investigated the ways that technology and craft are increasingly being leveraged together to advance a notion of making, interacting, or working with integrity, that is, "craftsmanship"; to support individually fulfilling creative and/or self-expressive practices; and to contribute aesthetic and economic value to diverse publics [11].

A system that has explored such intersections is SPYN, an application that allows "knitters to associate geographic locations, activities and musings to positions on knit fabric while knitting" [9]. Rosner and Ryokai [9] position SPYN at the "intersection of tradition and modernity," foregrounding historically significant sociocultural trends in their analysis of materiality. By examining and juxtaposing the old and new, these different examples show how material and the associated techniques combine through creative processes. In another work, Rosner and Taylor examine book binding as a means to understand concepts of longevity. They describes how "in restoration work, books, as technologies, become agents of recovery—of fading techniques, of cultural traditions, and of intimate interactions" [35]. In these examples, digital materials are inseparable from traditions of practice: these practices are represented in and enacted through, and by means of, digital materials.

Buechley and Hill [36] expand on these themes with the LilyPad Arduino—a microcontroller specifically designed to imbue fabric with digital properties. One goal of their work is "to question traditional disciplinary boundaries and to expand disciplines to make room for more diverse interests and passions" [36]. Similar to how the Lilypad allowed for textiles to be integrated with digital capabilities, Buechley, Hendrix, and Eisenberg's Computational Sketchbook employs conductive paint so that it "enables people to—relatively quickly and easily—meld the creative affordances of paper and computation to make interactive paintings and sketches" [37]. As with SPYN, these examples take the traditional practices of textiles and papercraft and extend their communicative potential by way of digital augmentation. In doing so, these applications are doing more than facilitating the individual expressions of those who work with them: they are also transmitting and reinvigorating material traditions of making.

The craft view helps explore the communicational dimension of material interactions, foregrounding ways that all aspects of interaction—including design, everyday use, and even research—are rooted in tradition. This may include the use of traditional materials augmented with new properties or traditional practices augmented by new practices, but the focus remains on communication that is rooted, in an important sense, in previous habits. The craft HCI examples provided focus their investigative gaze on entire historical traditions of creation and expression. The messages that are communicated through these means are seen as benefitting from refinement and reenforcement over time, as craftspeople and the recipients of their crafts co-construct meaning through them. Even in name, "craft often carries connotations of tradition and even bygone eras" [11].

2.4 Summary of the three views

The process of examining the history of thinking about TUIs, computational material, and craft has shifted our focus among physical, metaphysical, and communicative dimensions of materiality. TUI research has helped us understand the minimal functional properties of the *physical material*, mediated by the psychological notion of affordance. As a result of a focus on function, the physical definition of medium is evaluated in terms of immediacy, resulting in an orientation towards materials that is deliberately minimal. The second view, the notion of *computational material*, is conceived of in terms of how it can structure and reorganize physical reality through changes over time, be they situated within the physical aspects of a computational artefact or in the act of interacting with that artefact. Finally, the third view we presented, craft and/as HCI, foregrounds a notion of *traditional materials*. This view positions interaction design within other communicative traditions, integrating and extending them, as a living descendent and inheritor of its riches. In doing so, it also provides a mechanism to link interaction designs to holistic experiences of expression and understanding.

In the next section, we explore some recent theorizations of the notion of *medium* from philosophical aesthetics, film and media studies, and visual cultural studies to enrich our thinking: learning both from theories developed in those fields and from criticisms and refinements of those theories.

3 Computational materiality as medium

It is a well-documented trend that HCI has in the past decade looked increasingly towards cultural theories, largely a reaction to the increasingly non-professional and everyday orientation of today's (and tomorrow's anticipated) technologies [38–40]. Another way to characterize this trend is that of the gradual reunion of the twins separated (at least in academic research) at birth: HCI and new media. This converging trajectory adds some urgency to questions surrounding the ontology of interaction designs. Are TUIs a medium? What are the relationships among tactile interaction, robotics, critical design and new media? What do "users" (HCI's formulation) and "audiences," "publics," or "readers" (arts and media formulation) have in common?

While in this paper we have no pretensions of substantively addressing such difficult questions, we do hope to introduce some benefits to thinking about material interactions from the perspective of a medium. Nor are we the first to think of HCI in terms of medium theory. Arias, Eden, and Fischer describe the strengths of physical media in terms of their ability to convey information, focusing on aspects such as "direct, naïve manipulability," how "the tactile aids understanding and retention," and how "objects act as a means of focusing the conversation and a conduit for emphasis, feeling, and conviction" [41]. Fernaeus examines media in HCI as "the potentials of computers for expressing and sharing ideas" [42]. Dourish and Mazmanian examine the communicative media of photography and simulations as a means of understanding the materiality of such communication [7]. These perspectives all emphasize the communicative properties of medium. They also show varying degrees of interest in how physical properties and computation function as part of that communication. We will add to this work by more systematically exploring the relationships among physical materiality on the one hand and expressive and signifying conventions on the other, and then exploring some of the practical implications of these relationships.

3.1 Defining medium

The notion of a medium typically begins from the banal point that a medium is that which mediates between two things, suggesting a more or less instrumental notion of medium [16], which is common in communications theory. Yet the notion need not be simplistic. For example, Bolter and Grusin write,

> "a medium is that which remediates. It is that which appropriates the techniques, forms, and social significance of other media and attempts to rival or refashion them in the name of the real." [43, p. 98]

This formulation of medium holistically brings together formal, historical, and political considerations.

New media theorist Manovich makes a similar move. Observing that generations of film scholars have gone to the trouble of reconstructing the first decades of the emergence of film as a medium, Manovich notes that we have an opportunity today to chronicle the emergence of digital media in its earliest days, in real time as it unfolds.

> "What follows is an attempt at both a record and a theory of the present. Just as film historians traced the development of film language during cinema's first decades, I am to describe and understand the logic driving the development of the language if new media." [19, p. 7]

Manovich here is characterizing a medium as constituted by a sort of "language," and he is using the term in a technical and specialized way: by *language* he means "the emergent conventions, recurrent design patterns, and key forms" that collectively provide "strategies for organizing information and structuring the viewer's experience" [19, pp. 12–13]. Such a formulation allows a researcher to conceive of the history of a medium as "a succession of distinct and equally expressive languages, each with its own aesthetic variables, and each closing off some of the possibilities of its predecessor" [19, p. 8]. Manovich's notion, like Bolter and Grusin's, is emphatically holistic: it sees historical developments, concrete material forms, information structures, and social meanings as inseparably connected together.

In an effort to synthesize different conceptualizations of medium in the philosophical literature, Ted Cohen distinguishes three common views of medium in an unpublished Ph.D. thesis, as paraphrased by aesthetic philosopher Daniel Herwitz, 2008:

- "First, a medium is *physical stuff*, as in, my medium is oil paint, or fresco, or wood, or ceramic glass "[17, p. 113, emphasis added]. Physical properties are the most immediately accessible part of medium due to their sensual nature.
- "Second, there is the notion of a medium in a more *metaphysical* sense. As in, the medium of architecture is space, music time and tone, film, projected light" [17, p. 113, emphasis added].
- "Third, a medium is something like *the viscous substance through which flows a message*, a medium is a particular field of representation and expression, social action and individual meditation" [17, pp. 113–114, emphasis added]. The notion that paint or words resist the artist seeking to express herself, Schön's [8] notion of back-talk, and the transmission of craft practices across generations are all examples of this kind of thinking.

One way to read this list is that these three views may be distinguishable, but they are not necessarily exclusive. We view a given medium as comprising all three of the above—at the same time. Further, a medium combines all three in a distinctive or unique way. That is, a building is brick and steel, space, and a field of representation and social action. If this "all of the above" view is correct, it helps underscore why design is such a complex activity, laden with implications for and from both the arts and sciences.

As should be obvious by this point in the essay, the three views of materiality research in HCI that we summarized above—TUIs, computational materiality, and craft HCI—have recapitulated all three of the formulations of medium

that Cohen (via Herwitz) identifies as being in broad currency. This is not to suggest that HCI has reinvented the wheel, as if no one in HCI had ever heard of media theory. Rather, it underscores some continuities between HCI thought and theorizations of media and the ontology of art. Those continuities, in turn, reveal opportunities to cross-pollinate between HCI and humanistic studies of media. In the remainder of this section, we will do so first by introducing what is known as *the medium-specificity hypothesis* and explore its potential applications in HCI, then we will consider recent criticisms of the medium-specificity hypothesis, with the new ideas that have emerged from such criticisms, and we will explore their applications to HCI.

3.2 The medium-specificity hypothesis

A common belief both in various scholarly fields and in everyday life is that each communications medium is unique, that its uniqueness is somehow grounded in its materiality, and that each medium is uniquely positioned to enable certain modes of expression and afford certain aesthetic experiences. So, for example, Clement Greenberg in the 1960s writes, "The arts are to achieve concreteness, 'purity,' by acting solely in terms of their separate and irreducible selves. Modernist painting meets our desire for the literal and positive by renouncing the illusion of the third dimension" [cited in 44, pp. 5–6]. That is, because painting is physically two dimensional, painting should explore two-dimensional expression purely, rather than attempting to simulate in it three-dimensional forms, for example, via perspective. In this, Greenberg was following a hallowed tradition back to the eighteenth century, in which Lessing [21] argued in his *Laocoön* that poetry and painting have different aesthetic purposes, the former being a temporal form and the latter being a spatial form. Philosopher of art and film Noël Carroll formulates this doctrine in very precise terms:

> "The medium-specificity hypothesis holds that each art form has its own domain of expression and exploration. That domain is determined by the nature of the medium through which the objects of a given art form are composed. Often the idea of 'the nature of the medium' is thought of in terms of the physical structure of the medium. The medium-specificity thesis can be construed as saying that each art form should pursue those effects that, in virtue of its medium it alone—i.e., of all the arts—can achieve. Or the thesis might be interpreted as claiming that each art form should pursue ends that, in virtue of its medium, it achieves most effectively or best of all those effects at its disposal." [44, pp. 6–7]

Applied to digital interaction, the medium-specificity theorist might point to the dialogic nature of interaction between human and computer, for example, as that which digital interaction alone of all the arts can achieve. All of this might seem to be a very academic (and perhaps even silly) discussion on its face, but in fact, the medium-specificity hypothesis is a powerful idea that can do a lot of practical work for researchers, students, and practitioners of a given medium.

The medium-specificity hypothesis has been used heavily in film studies. A classic expression of it can be found in Kracauer, who wrote, "Film … is uniquely equipped to record and reveal physical reality and, hence, gravitates towards it" [45, p. 144]. Another classic variation is from André Bazin:

> "The cinema is objectivity in time. The film is no longer content [as photography is] to preserve the object, enshrouded as it were in an instant, as the bodies of insects are preserved intact, out of the distant past, in amber…. Now, for the first time, the image of things is likewise the image of their duration, change mummified as it were." [46, pp. 14–15]

Bazin goes on to develop a range of aesthetic criteria about how to leverage these material qualities of film in ways that are both aesthetic and ethical. The examples could pile up, as even casual familiarity with the history and philosophy of film reveals that the medium-specificity hypothesis is heavily featured in the literature.

Why are film theorists so preoccupied with medium-specificity? There are two reasons. First is that the medium-specificity hypothesis draws attention to film's materiality as a source of aesthetic insight. As Davies writes, paraphrasing the philosopher of art Wollheim, a medium-specific approach takes

> "account of the manner in which the artist's *conceptual* activity proceeds by reference to the public medium in which she works—the medium *in terms of which* she thinks as an artist—and also of the ways in which the *recalcitrance* of the medium in which an artist works enters crucially into the creative process, and into the sorts of qualities we attend to and value in appreciating works. It is even arguable that because of their resistance to manipulation that certain materials are selected as vehicles for artistic expression." [16, p. 182, emphases in original]

Cohen's formulation of a medium as a *viscous* channel of expression takes on more significance here. The viscosity not only mediates the communication (i.e., serving as "noise" in Shannon's information theory), but it also mediates compositional (or design) processes themselves. And this fact, in turn, shapes an audience's aesthetic

appreciation of work in that medium, not only for the message it conveys, but for the skill required to convey such a message specifically in that medium. We will look at each of these two implications individually.

First, a medium-specific understanding more deeply takes into account the fact that when artists compose, even their mental acts are mediated by the materiality of the form. This has implications for their identity as an artist, and it also has implications for creative processes: as philosopher of art Jerrold Levinson observes, composers compose with specific instruments and their acoustic qualities (e.g., timbre, volume, pitch) in mind [47]. In short, the medium-specificity hypothesis helps create a community of creators who can think with and through the relationships between materiality and aesthetic significance in similar ways. For a newly emerging medium, as was the case of film in the twentieth century, such a consensus was important. The discovery and theorization of montage, for example, gave early filmmakers a common identity and focus.

At the same time, the medium-specificity hypothesis contributes to our understanding of how audiences are able to appreciate the complexity of a symbolic expression in a physically recalcitrant form, and indeed material recalcitrance is often a major reason we appreciate certain artworks; it is hard to imagine appreciating either a sonnet or the recompose table without the awareness of the difficulty of working with their material forms. Thus, a theoretical understanding of medium facilitates aesthetic appreciation, because we have a more grounded sense of a work as a certain kind of material accomplishment. Even a child understands that "painting within the lines" is extremely difficult given the liquidity of paint and can aesthetically appreciate the painting of a master who manages to avoid such sloppiness. Such a simple understanding emerges over our lives, and our exposure to different art forms to the point that we have increasingly refined appreciation for material-technical achievements within artworks, including reflexive understandings, such as our appreciation of Jackson Pollock, who leverages the liquidity of paint in ways that make us rethink our aesthetic predispositions concerning the material. The "medium-specificity thesis is of great heuristic value insofar as it entreats students to think deeply about the specific elements of their trade" [44, p. 17]. Returning to film, then, we note that the medium-specificity hypothesis remains important today, even given film's relative maturity, because it facilitates viewers' deepening appreciation of the aesthetics of the medium and it facilitates the education of those aspiring to create within it.

The second reason the medium-specificity hypothesis has been raised so much in film studies extends the first: by articulating what film is uniquely able to do, film theorists effectively create a social justification not just for film, but also for the *study of* film as its own autonomous academic discipline [44]. If film is seen as a subgenre of photography or of narrative fiction, then film scholars will have to work out of academic departments of photography or literature, and students will learn about film from photography or literature teachers. Thus, autonomy for film implies autonomy for those who study film. The medium-specificity hypothesis had the pragmatic effect of helping film studies emerge as an autonomous field of study, with its own academic departments, journals, and theories.

The implications for those specializing in the research, theorization, and/or design of material interactions should be clear: the medium-specificity hypothesis can provide an emerging young research domain with an intellectual means to link together the materiality, expressive possibilities, aesthetic effects, historical contexts, and consensus-based evaluative norms for the medium. Politically, it legitimates the creation of a space with autonomy for self-determination, both intellectually and practically (e.g., in terms of funding and institution building). And pedagogically, it offers accessible ways for both prospective creators and consumers of the medium. HCI researchers who seek to advance a more material formulation of their field will need to do all of these things to generate the critical mass that we believe we will need to be successful.

3.3 Against the medium-specificity hypothesis

As an interdisciplinary field that frequently imports ideas from other fields, HCI sometimes has a bad habit of borrowing a concept or idea without acknowledging, let alone engaging with, the fact that that concept or idea is controversial or problematic in its own field. The medium-specificity hypothesis is an example of an interesting idea that is nonetheless controversial in its originating fields: many philosophers today have attacked it, and the specific nature of that attack reveals much about materiality that has application for HCI. We focus on two criticisms of the medium-specificity hypothesis. First is its implicit essentialism, and second are its own internal logical difficulties.

We begin with the criticism that the medium-specificity hypothesis is essentializing. The argument here is that if it is the case that material qualities predetermine a given medium's aesthetic ideals, then there is no possibility of genuine artistic evolution within that medium, beyond simply discovering that timeless ideal; its aesthetic norms, effects, and creative processes should be unchanging since they depend on physical properties that presumably never change. But we know that this is not the case, as feminist film theorist Mary Ann Doane writes:

"Despite its essentialist connotations, medium specificity is a resolutely historical notion, its definition incessantly mutating in various sociohistorical contexts. At its birth, the cinema's most striking characteristic was, in fact, its indexicality [i.e., that its image is caused by reality through mechanical capture], commented upon in countless newspaper and magazine articles that heralded the new technology's ability to capture time and movement—what invariably went by the term "life itself." But with Griffith and Eisenstein, in entirely different ways, and with the rationalization of film as an art, editing or montage emerged as the principle of cinematic form and the true potential of the medium." [48, p.129]

Doane is observing that at different times in the history of film, different candidate aspects of film have been put forward as what film is uniquely capable of. The changes suggest that some combination of technological innovation and/or aesthetic taste—and not merely physical properties—shape what theorists and practitioners of a medium perceive to be a given medium's unique capabilities.

The immediate implication for HCI is that a temporal or genealogical sensibility is needed for research on material interactions. That has two implications. One is that it is unreasonable to expect the discovery of atemporal laws, like Fitts' Law, as an outcome of our research, at least inasmuch as we are taking specific forms of materiality seriously. Second, it means that any research we pursue today about material interaction should not be blind to precursor interactive forms and practices because users will not be blind to them, but rather *scaffolded* by them. That is, precursor interactive forms provide mental models, attitudes, habits, and expectations that users will bring forward into interactions with new materials. Such models, attitudes, and behaviours can be leveraged, or possibly discouraged, by designers innovating on material form, but they must not be ignored.

The second criticism we will consider is that the medium-specificity hypothesis has internal confounds. The philosopher Noël Carroll develops an extensive argument against the medium-specificity hypothesis on logical grounds [44]. Some of the objections most relevant for our purposes are summarized below:

1. It is unclear how to move from the physical form of a medium to its aesthetic *telos*. In other words, just because we know that music is a sequence of tonal pitches, rhythms, timbers, etc., does not mean that we can derive from that an ideal form of music.

Carroll adds to this point that if we abandon a "pure physicalist" account of a medium's materiality, then "It is no easy task to identify the basic materials of a medium" [44, p. 8].

Carroll is making a distinction here between the pure physicality of the medium, on the one hand, and the aesthetic goals that we attribute to that medium on the other. Not unlike Doane, he notes that we cannot ever seem to establish a tight coupling between the two.

2. When a new medium emerges, artists working within it surely are influenced by existing art forms and traditions. There is no "pure" place for them to start.

The medium-specificity hypothesis isolates one medium from the next. If this were true, one might imagine a hypothetical scenario in which a medium is suddenly born *ex nihilo* and its practitioners have nothing but physics to guide their aesthetic exploration of this medium. But of course that is not the case, as emerging media are inevitably tied to—even transgressively tied to—prior media forms in the representational techniques, expressive modes, and sociocultural impacts [43]. The practical implication of this point is that an investigation of the interactive possibilities of emerging new materials cannot simply depend on the physical affordances but also the human traditions that have already constructed conventional uses, meanings, and techniques with those materials.

3. The hypothesis would seem to have us reject excellence in art where the medium is not being used in its unique capacity. Carroll here uses the example of Groucho Marx's monologue, which properly belongs to the theatre not film, as examples of excellent art that violate the medium-specificity hypothesis.

Focusing on either physical affordances or human conventions that are uniquely possible thanks to given material computational artefacts might draw our attention away from other, non-unique affordances or conventions that are nonetheless worthwhile.

Often in the act of critiquing a concept, new refinements and even new concepts emerge. So it is that out of attacks on the medium-specificity hypothesis, like Doane's and Carroll's, there emerged a new distinction between the physical medium and the artistic medium. This particular distinction was introduced by Margolis and the idea is as follows: the *physical medium* refers to the literal physical dimensions of the work, pigments in paints, the absorption properties of canvas or wood, etc. The *artistic medium* is "a purposeful system of brushstrokes" [Margolis, cited in 16, p. 183]. Likewise, Davies paraphrases, "the physical medium of body movements is to be distinguished from the artistic medium of articulated steps" in dance [16, p. 183]. In other words, Margolis' distinction leaves us room to say that a digital image has two different types of material basis: a collection of colour values stored in a 2D grid and compressed with particular algorithmic schemes and displayed on backlit glass, and an aesthetic basis, the latter of

which reflects the human history and human system of expressive signifying practices and conventions of photography, image-making, portraiture, etc. Both of these are legitimate formulations of materiality, and both extend equally to all material forms of computing. As noted earlier, similar argument about digital photography appears in [7].

Noël Carroll pushes this argument one step further. Having demonstrated both the logical confounds of the medium-specificity hypothesis while nonetheless recognizing its apparently productive use throughout the history of the arts, he claims that when someone asserts the medium-specificity argument, what they are really doing is advocating for a particular *style* within a medium over another. In other words, "what is urged under the banner of medium specificity is linked to implicit conceptions of preferred artistic styles" [44, p. 18]. If Carroll is right, then focusing on the physical materials themselves may not be the best unit of analysis; instead it is the conventional, symbolic, and sociohistorical layer, which subsumes but is not reducible to the physical, which may be the best unit of analysis. If he is right, then it has implications for how we position ourselves as theorists of a given medium.

> "The task of the theorist of an art is not to determine the unique features of the medium but to explain how and why the medium has been adapted to prevailing and emerging styles and, at times, to either defend or condemn the prevailing or emerging purposes artists pursue. Such debate should not proceed by arguments about what the medium dictates, but rather by finding reasons—artistic, moral, and intellectual—that count for or against those styles, genres, artworks, and their subtending purposes which confront us." [44, p. 18]

For material interaction, it is not the brute physicality of the artefacts that should draw our attention, but rather the particular ways in which that physicality is brought into tactual and embodied human practices. The challenge, then, is not just to design materially innovative new artefacts but also the "reasons—artistic, moral, and intellectual" for evaluating our own success.

4 Illuminated clay considered as a medium

To explore and illustrate how these concepts of medium and medium-specificity apply to tangible interactions, we will critically interpret Illuminating Clay. Illuminating Clay is a TUI that was created through the MIT Media Lab's Tangible Media Group. Ratti and Wang state that the interface combined Geographic Information Systems (GIS) with a tangible, clay-based interface in order to "give

physical form to digital information, seamlessly coupling the dual worlds of bits and atoms" [49]. Chronologically located between graspable bricks as controlling elements and the "Iceberg" metaphor, this interface attempts to exploit both the controlling and representational affordances of clay as a material.
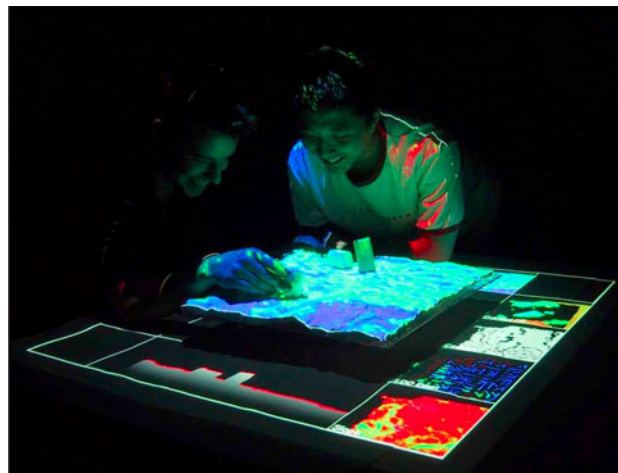
The Illuminating Clay Interface, image taken from [38]

The interface for Illuminating Clay has two major components—the projected GIS system, which relays informational output, and the malleable surface upon which it is projected. The actual material of the surface is Plasticine, a polymer clay, over a metal mesh—creating the desired levels of malleability and tensile strength [50]. The clay lends the surface the ability to be moulded, creating forms that are more natural and flowing. Ishii et al. describe this as "continuous," making an important distinction from the discrete objects employed in many earlier TUIs [51]. Changes to the clay are picked up by the GIS system, resulting in changes to the projected image. As an example of possible use, Piper et al. describes how making adjustments to the clay would result in changes to the projected information:

> "The projection displays the direction of water flow in different regions of the model. As the professor flattens the crest of a hill the student observes how the drain direction changes within the model." [52]

As a device that leverages the continuous, form-making capabilities of clay in combination with landscaping practice, Illuminating Clay makes for an interesting application of the medium of tangible interaction. As a starting point, we will examine Illuminating Clay as it pertains to the physical, metaphysical, and communicative views of medium introduced earlier.

As was noted earlier, the physical theme of media, with respect to TUIs, places emphasis on functional minimalism as a medium-specific aspect. Coming out of the MIT

Tangible Media Lab in 2001 Illuminating Clay carries forward this emphasis on physical, functional minimalism. As a representation of the data, the clay is reduced to its ability to represent variations in height creating a topography where these variations can be seen and manipulated.

Yet, within this manipulation, a strange turn on minimalism can be seen. One of clay's greatest material assets is its ability to give control in a "continuous" manner. As an interface, this allows for manipulations that can be quite subtle and nuanced. It also stands in opposition to the discrete precision of the data itself, introducing a level of complexity to the possibilities of shape and form. The representation of what would constitute a large hill, as opposed to a small hill, is less discrete than would be with the simple placement of an icon on a map. This change from the simple physical representations found in other TUIs could be viewed as a dramatic change with respect to the medium-specific notion of physical minimalism. Alternatively, we might view it more as a change in the nature of that *representation*. While the physical theme of tangible interaction's medium places focus on data representation and control, the clay takes on a double-duty of representing both data and the natural world. It creates a model of larger geographic structures. The complexity of control, and therefore interaction with the artefact, is not necessarily a result of data representation, but rather it is rooted in the way that Illuminating Clay creates a model of the real world. In this way, the concept of *height* is what is represented from the data, while the concept and control of *elevation* comes from the natural world. The clay is functionally minimal in the way that differences in height are used as part of data representation, but also complex in how nuanced control has been added to better model and represent landscapes in the real world.

In the same way that functional minimalism is both exemplified in Illuminating Clay and yet also transformed into something more complex, we see a similar shift in the metaphysical aspect as computational change. The results of computation are projected onto the clay where "the matte white finish (of the clay) is highly suitable as a projection surface" [50]. In this way, the clay itself serves as a screen where colour and informational readouts show how natural effects, such as the flow of water in the example, are changed by its topography. As with the physical properties, this interface alters the nature of change as a result of computation, in ways that may seem surprising. As a surface onto which an image is projected, moulding the clay changes the nature of that projection. Straight lines become bent as they conform to the warped surface. Areas that are closer to the viewer, due to elevation, appear ever so slightly larger than those that are lower. Change, then, is more of a dialogue between the physical and the digital within this artefact. While

computation acts on the surface of the clay through a projected image, the clay acts back upon that image by changing it. Similar to the deviations from functional minimalism, these changes seem to be rooted in the nature of representation. As a representation of the data, the surface of the clay alters it, but by shifting perspectives to view the whole interface as a representation of the natural world, these changes make sense. When viewed from above, straight lines contour along with the surface of the earth and objects that are closer appear larger. As with the physical theme, the metaphysical theme of medium in Illuminating Clay is changed in a way that points an emphasis on a certain kind of representation.

Finally, with regard to the tradition-communicating role of a medium, we can see that the material's communicative powers rely on tradition. As was described in the physical and metaphysical analysis of Illuminating Clay, there is a focus on the interface communicating aspects of the real world, landscapes, through the process of modelling. This modelling of the world is built into traditional material applications of clay. A common substance for a number of applications where levels of tensile strength and malleability are important, landscapers and architects value clay, in particular polymer clay, for its ability to create stable forms that can nonetheless readily be manipulated. Even the practice of using wire, as a supporting element, stems from such traditional applications. This leverages the users' tacit understandings of how to use clay, as related to the amount and type of force required to create specific forms. As part of being a modelling material, the ability to represent natural formations is also part of the medium of clay. Behaving in a way similar to piles of dirt—one of the main building blocks of landscapes—clay allows for the creation of structures that are quite similar to those found in natural topography. So, as the clay serves as a novel representation of data, it equally is very medium-specific, in terms of its use as a traditional communicative material for representation of the natural world.

As we have shown, the use of materials in Illuminating Clay can be analysed using the physical, metaphysical, and communicative aspects of a medium. The clay is reduced to a more minimal controlling agent through variations in height along its surface. The main avenue for change is still computation, with information being projected onto the blank surface of the clay. More so than the other two, traditional communication is emphasized by the use of a material that is commonly used outside of Illuminating Clay for the purpose of modelling landscapes. However, in the changes from those norms, an interesting development can be seen. While theoretical emphasis in TUI at the time had been placed on reducing physical representations to discrete objects, Illuminating Clay created a more flowing representation of data. The precision of moving solid

objects traded for the nuance of moulding a malleable surface. Projecting the results of computation directly on the clay resulted in a merging of data and physical representation where it becomes difficult to disentangle ideas of which is acting upon the other, as well as concepts of input and output. This fits very well within the culture of MIT's Tangible Media Group during that period, with their emphasis on tight coupling, but it also raises questions of how that representation functions, given the discrete and precise nature of computation compared to the flowing imprecise nature of clay. Should this be viewed as a mismatch?

Illuminating Clay suggests that it is not a mismatch, but rather a *style* that cannot be reduced to mere physicality. By style we mean "the constancy, or consistency, in the way an individual, or a group, treats the formal elements of art, or visual culture. It is a consistency in the treatment of line, colour, texture, and other formal elements shown by an individual or a group" [14]. That is, a style is a human convention, not a materially determined feature. Illuminating Clay's style comprises the use of both physical and metaphysical materials to create a representation of the natural world. The decision to represent the natural world in a certain way is a stylistic one, not a physical one, and by extension needs to be analysed and understood as such. In a theoretical context in which focus was largely placed on how physical material could augment digital interaction, Illuminating Clay suggested a perspective in which computation can be used to augment a physical model as a representation of the natural world.

Perceiving these decisions as a style is useful, because it decouples a medium from merely leveraging its physical limitations and suggests the possibility of multiple ways—that is, other styles—in which that physical medium can be used for communicative purposes. For example, it changes the kinds of questions that are important to this interface from "how well does the material represent data?" to "how well can the combination of data and material represent the real world?"

In the same way that considering Illuminating Clay as stylistically modelling the real world changes the kind of questions that can be asked of it, it also suggests new considerations of ways that tangible interactions could be created in this style. This does not point to the stylistic convention of relating an interface to the natural world as the "right" application of tangible interaction, but it does create a stylistic space in which other interface design directions can be considered. Looking more at the ways larger concepts from the real world could be modelled through materials, and ways that those models could be augmented by digital interactions, points in a direction for future tangible interactions to pursue. While this is a

direction of exploration that extends beyond the confines of this article, it is still rooted in an understanding of viewing tangible interaction as an aesthetic and conventional, not just physical, medium. By examining the ways that subtle changes to conventions can result in greater stylistic ramifications, the medium-specific lens has introduced a way to understand, communicate, and direct the nature of the material of tangible interactions.

5 Conclusion

The application of theories of medium to HCI's ongoing research on materiality is not meant to disrupt or transform, nor to shoehorn everything into a single point of view, but rather to fortify and clarify different aspects of these trends. Our most fundamental insight is that material interactions and materiality theory in HCI have developed conceptual vocabularies and research foci that are broadly compatible with medium theory. That compatibility has several benefits, as we have argued. In spite of the divergent theoretical and methodological predispositions of the views presented—the TUI, computational material, and craft HCI views—media theory can accommodate and augment their individual understandings. Thus, thinking in terms of medium provides at least one coherent frame to hold them together conceptually, specifically by suggesting that they are all correct and simultaneously so in all instances. This view, which sees material interaction as a complex unity of physical, metaphysical, and tradition-communicating media elements, in turn points to ways to further research in this area.

We explored in this paper how the medium-specificity hypothesis has been leveraged intellectually, pedagogically, and politically to help emerging media consolidate and form empowering consensus that could nonetheless be applied meaningfully to different approaches to materiality in digital artefacts and interactions. Because material interactions research is partly about understanding an emerging medium, we expect that we, too, can enjoy similar benefits. We also explored how criticisms of the media-specificity hypothesis called attention to its confounds and yielded new and productive formulations and concepts in their own right. Specifically, we believe that the physical medium versus artistic medium can be deployed in material interactions theory to avoid the same sorts of confusions that scholars in art and media disciplines have experienced. This distinction throws into relief the extent to which any given material interaction is physically determined (or at least shaped) by its medium and the extent to which *conventional styles* shape its representational and communicational apparatus.

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