Means and Ends in Human-Computer Interaction: Sustainability through Disintermediation

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ABSTRACT

There has been an increased interest in broader contexts from ecology and economics within the HCI community in recent years. These developments suggest that the HCI community should engage with and respond to concerns that are external to computing yet profoundly impact human society. In this paper we observe that taking these broader contexts into account yields a fundamentally different way to think about sustainable interaction design, one in which the designer's focus must be on a) ecological limits, b) creating designs and artifacts that do not further a cornucopian paradigm, and c) fundamental human needs.

It can be hard to be responsive to these contexts in practical HCI work. To address this, we propose that the design rubric of disintermediation can serve as a unifying approach for work that aims to meet the ecological and economic challenges outlined in the literature. After discussing the potential use and impact of disintermedation, we perform an analysis using this design rubric to several key application areas.

Author Keywords

Sustainable computing; Sustainable HCI, Sustainability; Complexity; Disintermediation

ACM Classification Keywords

H.5.m Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION

Concern about environmental sustainability has motivated significant work in the area of Sustainable HCI and Sustainable Interaction Design over the past decade. Beginning with the work of Blevis [6] and Mankoff et. al. [51], there has been an increasing interest in the overlap of computing generally and HCI specifically with sustainability. This interest has grown for years both among HCI researchers [19, 29, 43, 83] and in computing in general [38]. There has been a recognition of the need to integrate sustainability goals into the process of user-centered design along with analyzing the role of computing within a broader ecological scope.

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However, the Sustainable HCI perspective is one that is challenging to engage with, as it is difficult to strike the right balance. Some work tends to address sustainability concerns only superficially while other work delves so deeply into ecology that the HCI questions are lost, as we noted previously [67]. Nevertheless, strong work on this topic manages to avoid these pitfalls and advances our understanding of design criteria that have often been ignored in the past [3, 11, 24, 31, 41, 61, 93].

Recently, three works have challenged our collective thinking about HCI in regard to broader contexts from ecology and economics. Our prior work [67] identified ecological limits as key to selecting appropriate problems and responses in the area of Sustainable HCI. Preist, Schien, and Blevis [69] analyzed the unsustainable cornucopian paradigm and its often-implicit implications for design. Ekbia and Nardi [23, 24] identified political economy generally and inequality specifically as oft-ignored sources of concern that demand a shift in thinking in HCI.

In this paper we observe that combining these three important threads of thought leads to a fundamentally different set of goals for user-centered design, one in which the designer's focus must be on a) fundamental human needs (per Ekbia and Nardi), b) designs and artifacts that do not further the unsustainable growth-based cornucopian paradigm (per Preist et al.), and c) designs that are responsive to ecological limits (our prior work).

However one might note that this new perspective appears on its surface awfully limiting, and, further, lacking cohesion, as these mandates may appear too dissimilar and too broad to be useful in guiding system design. That is, how would a designer go about leveraging the insights of these works—regarding economics, ecology, and unsustainable practices—in practical HCI work? Our aim in this paper is to answer this question: we propose a design rubric—*disintermediation*—that can unify these themes and provide practical direction.

Disintermediation involves the re-engagement of entities—removing intermediaries—in a human-computer system. It is more accurately viewed as a *re*-design approach, since it focuses on redesigning existing systems that have potentially-undesirable layers. Thus applied in user-centered design, the role of disintermediation is to identify layers within a system that can be removed while retaining the key functionality of the system, and without diminishing the system's usability or usefulness to the user. However, at this abstract level it may not be apparent how disintermediation can unify these disparate threads of thought.

Our aim is to extract lessons from these three prior works, show how they argue for a new perspective in user-centered design, and show how the idea of and practice around disintermediation could unify this new direction. Specifically, they indicate that for human society to be sustainable, it must remain within planetary boundaries—impacting natural systems in ways that to not exceed their replenishment or repair; this is the core of what we mean by sustainability in this paper. However, the cornucopian paradigm [69] is part of a growth-based economic system, something that cannot continue on a finite planet, especially given that many planetary boundaries have already been exceeded by human society. At the same time, given that human well-being and human needs are not directly tied to such growth, we can then seek technological responses that meet those needs *without* growth (and therefore without increasing humanity's ecological impact) while taking care to meet other important economic challenges such as inequality. After we discuss this basic narrative that follows from prior work, we then perform a critical analysis and redesign of several categories of systems that are user-centered but fail to meet these new objectives. Finally, we discuss how disintermediation can help us achieve sustainability goals.

LESSONS FROM SUSTAINABLE HCI

The alluring promise of Sustainable HCI is to decrease the ecological impact of current unsustainable social practices by using interactive digital technologies to change human-computer systems and to ambiently increase people's awareness, to persuade, sense, nudge, challenge, convince, confront, design or in general to bring a critical sustainability lens to user-centered design [19, 29, 43, 83]. In this section we review the relevant lessons from Preist *et al.* [69], from our prior work [67], and from other Sustainable HCI work in the literature.

Fundamentals

Sustainability is a concept about the journey of human societies towards a stable equilibrium with the natural world [79]. It is impossible to precisely pinpoint when a society crosses the boundary from sustainable to unsustainable—that is, when its use of and impact on natural systems exceeds their natural replenishment and remediation—nor would it be possible to pinpoint when an unsustainable society has sufficiently adjusted its practices to be characterized as "sustainable". However since the concept of sustainability, at its core, captures a trajectory rather than a position, it is possible for a society to "overshoot"—to be on an unsustainable trajectory without having yet faced the consequences of that overshoot [12, 77, 99–101]. We cannot know where modern technological society resides in such an arc, but scientific evidence indicates *both* that overshoot began some time ago—likely 2-3 decades ago [56, 100]—and that consequences are becoming ever more apparent [33, 36, 37, 55, 80, 87, 88].

The goal of much sustainability research is to respond to the urgent challenges identified in the research literature in the natural sciences, which indicate that many important biophysical limits have been exceeded by global human society [80, 88]. We are living in an age of ecological overshoot [12, 100] and are in a mad dash appropriating resources from all other species on Earth as well as appropriating "phantom carrying capacity", e.g. imports from else*where* (foodstuff from other places, so-called "ghost acreage") [8] and imports from else*when* ("fossil acreage", energy from prehistoric sources in the form fossil fuels) [12, 34]. This cannot be sustained indefinitely, and this overshoot is manifested not by just one dimension of unsustainable practices, but dozens—from carbon emissions to aquifer depletion to eutrophication to species loss [88]. The literature outside of computing is clear: massive deleterious changes in the global ecosystem are taking place due to human actions, and little has been put into place to prevent the situation from escalating. In a worst-case scenario, we could very well pass various tipping points that trigger self-reinforcing feedback loops in the global ecosystem, with severe consequences for life on the planet [48, 55].

It is these challenges that Sustainable HCI researchers are responding to. However, as we noted in prior work [67], sometimes this perspective can be too narrowly applied in research, yielding analyses and systems that do not engage with the global ecological challenges we face, and rather focus on small, incremental, and peripheral issues. Instead of aiming to incrementally improve the efficiency of computing systems, for example, we argued that we should instead evaluate global ecological limits and keep those boundaries in mind when doing design, aiming to build systems that do not contribute to overshoot. After discussing prior work that was purportedly sustainable, we discussed the importance of choosing appropriate (not too narrow) system boundaries when evaluating the sustainability of a system, as well as the importance of having a holistic approach to the challenges of sustainability.

Computing's Role

In a society that is technologically dominated and mediated, computing has a large role to play in the future of societal sustainability. This is not only due computing's impact on the global ecosystem (e.g., due to power consumption, e-waste, etc.) but also due to the patterns of human-computing behavior that trace out the path of much that takes place in industrial economies today.

Sustainable HCI research encompasses two subfields: sustainable computing and computing for sustainability. The former aims to decrease the footprint of computing itself while the latter broadens the target and examines the role of computing in improving the sustainability in other societal sectors.

Despite many years of work on the subject, the former has remained tractable and yet insufficiently broad or impactful—as computing has a limited, though increasing, impact globally relative to other sectors [50, 72, 73, 96]—while the latter has remained hopelessly daunting and complex—as improving societal sustainability easily runs aground due to economic, political, cultural, biophysical, and other factors that are far beyond the ken of computing researchers.

Preist, Schien, and Blevis [69] dissect the cornucopian paradigm, its implications for the design of computing infrastructure, and the consequent (un)sustainability that results from following the current trajectory. Through various examples, they show how current design practices and technical and business drivers together further the expansion of networks, services, data centers, traffic, devices, and the like. These trends naturally increase the environmental footprint of computing at a rapid pace and follow a trajectory of an ever-expanding unsustainable cornucopian bonanza.

Impact of Sustainable HCI

While it is important, necessary, and laudable to work on lowering the environmental footprint of computing itself, such work is ultimately too narrow and will remain insufficient. This is for two reasons. The first is that the footprint of computing, while growing, still represents only about 2 percent of global energy use and a comparable amount of materials [50, 71, 72, 96]. The second reason is that proposed efficiency gains easily evaporate due to various rebound effects [30, 65, 78] such as Jevons's paradox [40]. Thus while we believe it is important to make computing more efficient, and to power computing infrastructure using energy from renewable sources, the impact of such work on societal sustainability will remain small.

The other direction that Sustainable HCI (and the larger non-HCI field of ICT for Sustainability more generally) offers is to utilize and leverage the potentially beneficial effects of digital technologies in such a way that its footprint is more than compensated by carbon emission reductions and similar sustainability improvements in *other* parts of industry and society. A paradigmatic example is to decrease travel by using digital technologies for videoconferencing. Another is to use use digital and various concordant technologies (sensors, Internet of Things, etc.) to increase the "smartness" and efficiency in other sectors of society, for example by deploying smart grids, smart home technologies, and through smart cities initiatives [7].

This approach promises to have larger impacts (see [28]) but will also have to bear increased costs both in terms of money (investments), efforts, and complexity. This approach also tries to reform the system incrementally "from the inside" but it is far from certain that emissions, pollution, or resource throughput can shrink/decrease as much and as quickly as is needed.

Our aim in this paper is largely with respect to the latter thread of Sustainable HCI—computing for sustainability—and later we detail how we view disintermediation as a key design rubric to that end.

Growth and its Impacts

All industrial and post-industrial economies are organized around the concept of economic growth, which is seen as a universal aim for national policy. However, as Daly has observed, in our current situation, this growth has become "uneconomic"; that is, the marginal benefits of the growth in production and consumption are outweighed by the marginal costs of growth, when including external costs such as negative effects on the environment [15]. These negative externalities are largely due to ecological impacts.

We begin from the observation that growth—economic and material—is central to this cornucopian paradigm, and that it is a core challenge in sustainability research. While in theory it is possible for economic growth to decouple from material growth, and have no negative sustainability impact, in the history of the past century there are no known instances of this happening in a sustained fashion, except for narrow examples limited to a product or sector. Thus economic growth and material resource consumption proceed in tandem, along with the arc of cornucopian technologies.

With GDP as a measure and with GDP growth as a national (and international) policy goal, and given the ecological impacts that research indicates are taking place as a result of the expansion of societal demands on the ecosystem, the concept of uneconomic growth becomes harder to ignore.

However, another key observation of Daly (and others) is that GDP growth is not supposed to be an end, but a means to an end: increased human well-being. It has long been recognized that growth is not fundamental, but rather something that arises out of policy goals and the structure of financial systems in the economy [14]. Therefore, if GDP growth and human well-being decouple then we can pursue the latter without the former. A corollary is that if we can decouple growth from human well-being we can be less concerned if GDP actually declines (i.e., degrowth [13]) as long as well-being stays the same or improves. Human well-being is of course much more challenging to measure than GDP, but with the urgent need to address sustainability issues today this is a challenge worth addressing head on.

Economic growth generally, and GDP growth specifically, is key to how we evaluate economies. The theory goes that if we have economic growth then people are wealthier, and this enables them to meet their needs better, increasing overall welfare. One key source of growth is monetization of goods and services that were previously outside the money economy. In recent decades, this happened in many economic sectors. For example, in the food industry there has been a dramatic increase in the packaging of fresh and prepared foods rather than simply selling basics that must be cooked at home; in doing so, the work involved in food preparation is monetized. By monetizing, these economic interactions can be easily measured, but that is not the only consequence: they are expressed in terms of a money whose supply is dominated by debt (e.g., the vast gulf between M3 and M0 money supplies), which must grow [46]. As a result, there are increasing claims on underlying real natural resources, which in turn must be extracted at a greater rate to keep up with demand, furthering ecological overshoot.

Thus for the rest of this paper we will concern ourselves with the end goal of improving human well-being without regard to growth.

Responses to Unsustainable Growth

A natural strategy for fixing the unsustainability of industrial society is at the policy level. Indeed, it has been argued for decades that the right set of policy responses can remedy the sustainability challenges we face [56]. We do not disagree. However, despite the awareness of these challenges for quite some time, few nations have implemented sufficient policy changes to achieve sustainability. As a result, while we do view policy changes as the ideal remedy for sustainability challenges, such changes are challenging to achieve through computing research and HCI research specifically.

Instead, we can reflect on the fact that computing today is pervasive and is the organizing technology that both drives much growth and is driven itself by growth. As a result, computing can itself affect the sustainability of society as we as researchers can help change the plumbing and the windows through which we examine the world, even without directly making policy changes. It is this ability and centrality of computing that Sustainable HCI research can leverage.

Intermediation

There has long been a search for an all-encompassing explanation for today's unsustainability and for a silver bullet solution to remedy it. We do not believe either exists. Here we focus on one explanation—intermediation—and one response—disintermediation—that have significant merits.

Much of the GDP growth that takes place in today's global economy stems from intermediation, as much of the new monetary wealth being generated today involves the abstraction of some resource (e.g., previously-unacknowledged labor, natural resources and ecosystems, etc.) and the addition of layers of social, technological, and economic intermediation to control the flow of that resource and bring it within the money system. Often these layers of intermediation are tightly woven together using new technological systems (e.g., complex just-in-time global supply chains).

A complete analysis of intermediation in the global economic system is far beyond the scope of this paper, so for the sake of space we give two short (non-computing) examples of where intermediation has led to unsustainable practices in recent decades.

First, consider the industrial food system and specifically the raising of grazing animals in concentrated animal feeding operations [68]. What was once universally a simple and relatively sustainable practice—as grazers fed on grass and their manure helped build the soil—was turned into a wholly unsustainable practice through intermediation. The grazing animals were separated from the grassland and a feeding operation was placed in between the animals and their food source. The feeding operation was tasked with providing high quantities of calorie-dense, non-perishable food (e.g., corn) which had to be grown elsewhere and transported, and further required synthetic fertilizer inputs (from fossil fuels) as no manure was present to nourish the plants and pesticides, herbicides, and other chemicals (also from fossil fuels) to maintain the crop. The manure from the grazing animals then had to be collected and disposed of in some way. As Wendell Berry puts it, "[t]he genius of American farm experts is very well demonstrated here: they can take a solution and divide it neatly into two problems." [5].

Second, consider the transformation of the global manufacturing system over the last four decades. Industrial production has rapidly become globalized, with material resources abstracted and intermediated in a global just-in-time supply chain built by large multinational corporations that source resources where they can find them the cheapest, employ labor where the labor is cheapest, and take advantage of the relatively low cost of fossil fuels for the transportation of materials and products [49]. This intermediation hides the true ecological and human cost of the products, as resources are sourced where they are cheapest and unregulated, and the ease with which global resources are made available via modern information systems hide the true impact of their use (and later, their disposal).

Disintermediation and Sustainable HCI

Thus far we have argued that: 1) sustainable HCI research is likely to be most impactful when addressing societal sustainability challenges, 2) as long as growth and its attendant impacts continue, it will likely be difficult for sustainable HCI research to increase societal sustainability, and 3) examining the factors involved in the global economy today, specifically the process of intermediation, provides a promising new avenue for a broad range of sustainable HCI research. These observations lead us to conclude that disintermediation—the redesign of systems to remove intermediaries—can be applied in many specific applications of computing and can serve as a key technique for Sustainable HCI.

In line with Joseph Tainter's work [91, 92], we argue that (increasing) complexity in itself is unsustainable as more resources have to be diverted to maintain (the increasingly complex) system itself *and* the marginal utility of solving the next (and the next and the next) problem diminishes over time (e.g., low-hanging fruits tend to be picked first as the costs are low and the benefits are high).

It thus follows that ever-increasing complexity is deeply problematic from a sustainability point of view [66]. What would be desirable is instead to decrease complexity down to a level that retains most of the benefits of complexity but with much lower costs. This would entail seeking solutions in the process of disintermediation, which involves removing intermediaries to simplify a system while simultaneously maintaining most or all of the system's benefits; in prior work we analogized this process to that of refactoring software and other computing systems [75].

POLITICAL ECONOMY

In a pair of papers, Ekbia and Nardi introduced the connections between political economy and HCI [23, 24]. Their observations mirror those in the sustainability discourse: that important questions are being ignored and moreover by choosing to ignore political economy we are not neutral, but instead are perpetuating a set of values, assumptions, and perspectives that in recent times have led to greater social inequality:

> *Our contention is not that HCI researchers and practitioners are unaware of the relationship between economy and technology; rather, that this does not typically figure in any deep way into our theories, practice, and*

designs. We in HCI face the reality of the larger economic system and its impact on our daily life and work, but we do not incorporate these understandings into our research and practice to the extent that we perhaps should. [23].

Ekbia and Nardi argue for a focus on more fundamental human needs and on human well-being as a design goal. They also exhort designers to be conscious of value, class, labor, and social control. To our surprise, and as we briefly examine in this section, the strategy of disintermediaion is responsive to all of these concepts of political economy and, even better, in exactly the ways that Ekbia and Nardi identify.

In this section we outline some of their arguments, and then connect those arguments to the rubric of disintermediation.

Value

Ekbia and Nardi, in line with Preist et al., observe that value and the production of wealth have become inextricably linked to a growth-based economic system that does not know any limits and in which money is the primary store of value to be sought. Given the hyper-growth of computing and technology sectors over the last three decades, economic growth at large is increasingly linked to the development of new digital technologies.

Given that the size of the economy depends on both the amount of money in circulation and the velocity of said money (e.g., the pace at which it circulates in the economy), it is possible to increase profits in financial markets and elsewhere by increasing the velocity of money flowing through the system. Information technologies have been very helpful in this regard by lowering barriers and increasing the speed of transactions. This also means that today's financial system favors investment in technologies that specifically aim to further increase the velocity of money (e.g., to service the needs of financial markets and actors).

Class

At its core, class is about economic differentiation: placing the control of economic systems in the hands of some (few) and not in the hands of (many) others. The creation of increasing levels of intermediation in complex economies presents more opportunities for economic differentiation and class structures, as does the concentration of wealth through these structures.

Ekbia and Nardi [23] argue that the computing systems we design often disproportionately benefit the comfortable middle class (which makes sense economically according to a capitalist logic) while the needs of low-income communities [16], disadvantaged communities [18], disadvantaged job seekers [17], or the homeless [102, 103] are less often served by the systems we develop. The same is of course also true for systems developed to serve the impoverished in the global South [104, 105].

Labor

Much labor in the digital economy is unacknowledged, unpaid labor that is done by many for the benefit of the few (platform owners) [22, 44], such as filling social platforms with contents [47], developing a computer game mod [84], or by producing a cultural product (e.g., a documentary movie) without being sufficiently rewarded to be able to get by without a second job [94]. Some tasks that do receive monetary remuneration do so at a level far below the legislated minimum wage [39] or below what is needed even to just get by [20, 42]. The wealth that is created in many technology companies, and the astronomical valuation that companies with a few dozen employees can have, comes from the free distributed work of the users of those services.

Social Control

Technologies that purport to be human-centric have just as often created means for social control, as Ekbia and Nardi observe, in that they enable surveillance and disconnection:

> *Although technologies such as the Internet are used for emancipatory purposes, they have also turned into instruments of surveillance, control, and coercion. Many technologies provide effective control and surveillance mechanisms for the organizations that employ or provide services to us. [...] Thanks to digital technologies, what is lost to reduced bureaucratic control is more than rebalanced in capital's favor by continuous access and surveillance.* [24].

The often-repeated adage "if you're not paying for it, you are the product" is backed up by numerous examples of how collected data has been shared, used in ways not advertised or intended, sold or stolen [10, 25, 95].

Disintermediation and Political Economy

As we mention above, disintermediation is, surprisingly, an appropriate and direct methodological response to these four axes of political economy (and their impacts) described by Ekbia and Nardi. That is, not only does disintermediation have the potential to help achieve societal sustainability, but some of those very properties of the approach also serve to address the political economy concerns outlined by Ekbia and Nardi. It is important that this is the case, as it would be unfortunate for a design technique that improves sustainability to simultaneously increase inequality.

Value

A disintermediated system is one in which we have removed economic mechanisms designed to extract wealth from existing flows of goods and services. Moreover, disintermediation taken to the extreme can serve to eliminate the possibility of wealth extraction. This occurs in a way that is almost definitional, but also true: by virtue of removing intermediaries in an economic system (e.g., financial institutions) between two parties, those intermediaries lose the ability to take a cut of the wealth flow. In doing so, we enable a more ecologically-based accounting of value (donor value) as it is easier to trace value to its ecological root (i.e., the ecosystem services that underlie the human economy), as opposed to conventional receiver (market) measures of value [64].

Class

System structures that entail more layers of indirection, especially in the form of hierarchies, create more chances for class structures to strongly emerge. This is due to the fact that each layer of intermediation must be controlled by some party, and thus each layer can be controlled by a different party than the end user. Fundamentally, disintermediation tends to have the effect of deconstructing hierarchies and empowering each entity in a system to have the power of choice and control, thereby hindering class differentiation.

Labor

Intermediaries in digitally-mediated labor can leverage such layers to benefit from the labor (often free labor) of others. By disintermediating we can avoid this problem (though other graph structures may emerge over time).

Social Control

One of the most insidious effects of the proliferation of cloud-based services—those rightly scorned by Preist *et al.*—is not just the obscuring of where resources come from and the furtherance of the cornucopian paradigm. It is that a system with many intermediaries, especially where those intermediaries concentrate power (per the challenges above), is one in which social control can be exerted via those powerful intermediaries. This has appeared in its most extreme form in recent years in countries that suppress free speech online (e.g., in online social networks), as these online services now function as gatekeepers of communication between people in a way that did not exist in the past [59]. A disintermediated system, on the other hand, is one in which there is less room for centralized social control, manipulation, or censorship.

IMPLICATIONS FOR DESIGN

In this section we examine the intersection of increasing human well-being, HCI research, and the implications of the application of disintermediation as a design rubric. We here exemplify the principle of disintermediation by applying it to few areas of daily life: food, work, communication, and transportation.

To keep our discussion concrete, we focus on *both* commercial systems, such as online social networks, and noncommerical systems, such as grassroots instances of "collaborative consumption" [9], and will refer (primarily) to HCI research that delves into and analyzes such work [4, 32, 90]. Our examples are chosen to illustrate how the design rubric of disintermediation could be applied to areas that correlate with increasing human well-being in modern society, such as meeting primary human needs such as food and transportation and secondary needs such as communication and employment.

Food

Today's global industrial food system has supplanted traditional, more sustainable methods. In part this is because industrial agriculture leverages mechanization, chemical fertilizers and pesticides, and genetic engineering, all of which have decreased costs and increased efficiency. However the purported cost and efficiency gains have only held true in a narrow accounting; the environmental and social impacts of this approach to agriculture have been devastating [2, 27, 68, 86, 97]. The woes of industrial agriculture can be seen as a consequence of the abstraction of plants as machines that take water, N-P-K, and sunlight and turn it into food. Indeed, industrial agriculture companies such as John Deere now say this explicitly, as they claim that "a farm is a factory in a remote area" [98]. This also involves the intermediation of natural processes that enable the decomposition of animal and plant wastes to replenish the soil, whereas sustainable, disintermediated, perennial crop systems help stabilize the soil and increase fertility (vs. tilling, which provides a short-term boost in soil fertility with long-term consequences), as do similar natural methods that ensure the sustainability of a natural system of food production.

Many of the computing systems that have been developed for agriculture have remained within this industrial food paradigm, and so have served to further it (and amplify its intermediation) rather than reforming the system structure itself. There has, for example, been substantial work on the Internet of Things in the context of agriculture, placing sensors and actuators throughout a farm to increase the efficiency of the system to increase yields and/or decrease costs. However, as Odom and others observed [63], this is not a clear win.

Not only have the processes of food production become intermediated, but so have the processes of bringing that food to people. An extreme example of this is soylent [21], in which food is processed to the extreme to produce a single synthesized product that in concept has all the nutrients required to sustain a person. In addition to the food products themselves, the distribution channels for food have only recently begun to revert to older, localized practices, such as farmers markets and community gardens [45].

In recent years there have been a few proposals for alternatives to this industrial food system and the role that Sustainable HCI research can play. One example is our work on Computational Agroecology [74], which focuses on the planning, implementation, and management of alternative, complex agroecosystems that are modeled after natural systems and aim to produce high yields while ensuring sustainability. Farms based upon agroecology are in effect disintermediating relative to the industrial food system: they no longer require much or any external or synthetic inputs, and instead leverage natural ecosystem services to create a sustainable food system [62]. Community-supported agriculture extends this model to the process of farm financing and food distribution.

This disintermediated model could be extended to one in which a network of local agroecology-based farms supply food, along with local community gardens and individual backyards, and users use computational tools to gather together this food from these disparate, local, and direct sources. In this model, while technology would be adding some amount of intermediation (to help find the food locally), this would be replacing other intermediaries (e.g., large grocery stores and their long-distance supply chains) and doing so in a way that connects people directly to their food's source.

Workplace

Hoffice ("home office") is a disintermediated solution to having (access to) a workplace without having an outside firm (e.g., an ordinary employer or a coworking firm) to provide that workplace. Hoffice consists of a network of members who organize and offer up one-day pop-up workspaces to the other members in the network. In essence, Hoffice enables the creation of ad-hoc, peer-to-peer coworking spaces. Members ("hosts") offer other members ("guests") the use of their kitchen (and/or living room, balcony, kitchen, etc.) as a temporary office for, typically, 4-10 people for a day. Due to the founder's strong philosophical convictions about the value of gift economies, it is unlikely that Hoffice would become a commercial service—the idea of offering up one's kitchen for free to others is a central part of the Hoffice concept.

Hoffice was started in 2013 in Stockholm by the founder and a small group of self-employed social entrepreneurs who lacked a functioning structure for their workdays. Hoffice currently has thousands of members and events are organized daily. There are also numerous smaller Hoffice groups in other Swedish cities as well as in dozens of countries on several continents.

The structure of a Hoffice workspace is interesting in that it is not the disintermediation that directly provides sustainability benefits: instead, it is what the disintermediation enables. Many of those that participate in Hoffice are self-employed and would otherwise be using their own facilities (e.g., heating their homes to work at home, renting commercial office space which then must be maintained, etc.) which comes with its own financial and environmental costs. By consolidating workspaces together via Hoffice, the participants better share resources. Since Hoffice is held largely in Swedish cities with excellent public transportation systems that are widely used, most Hoffice participants have little transportation energy footprint for traveling to their destinations.

Hoffice currently piggybacks on social media for coordination; this could itself use a disintermediated solution, as we discuss below. There is no central clearinghouse for events, though any member can post a note about an upcoming Hoffice event in their home. While there have not been any scientific research papers written about Hoffice, there has been research on related topics within mobility and work, for example "nomadic work" [52, 81, 89] and in the utilization of ad-hoc coworking spaces [26, 85].

Communication

Earlier we noted that many services, even disintermediated ones, may need centralized services (e.g., web-based services or app backend infrastructure). The most common computing services that users interact with today are web-based services that are run by large service providers. Some of these services, such as social networks, are focused on the interactions of users who want to communicate with one another for personal, business, or other reasons. Other services provide a focal point for user collaboration, storing their context and content, providing means for sharing and editing data, and controlling access to that data.

A key aim of cloud systems is the presentation of a unified view of the data stored in the systems from the user's perspective. In most modern cloud-based services the systems are indeed administratively centralized (i.e., stored on systems owned by one company) even if many different physical computers are used in a data center to store the data. In systems terminology, the backend cloud systems in data centers are "scale out" but the administrative control adheres to the older, now-archaic model of "scale up", as we discuss in prior work [70].[1]

The technical structure of these systems has direct impact on the axes identified by Preist *et al.* and Ekbia and Nardi—that of the cornucopian paradigm and of issues of labor. Labor is often provided by users for free while the company who owns the technical infrastructure harvests the monetary values that are created by this arrangement [44]. Ekbia and Nardi use the term *heteromation* [22] to describe:

> *...a labor relation in which humans and machines collaborate (hence "heteromation" vs automation), but where the human occupies a marginal role computationally or organizationally. Heteromation is digitally mediated labor that involves the extraction of economic benefit for someone other than the laborer. The labor is uncompensated or very low cost.* [60]

Several examples of heteromation have been studied in the HCI field but the most well-known and well-researched example is Amazon's Mechanical Turk service [39, 53, 82] which has numerous downsides with regard to labor relations, surveillance, and social control.

Applying the disintermediation rubric to the context of cloud computing, we can decentralize the systems while still providing a coherent view to users. It is the latter that users want, while the former is typically entirely incidental to users (i.e., users wouldn't mind it if Facebook were to no longer run Facebook). While there are numerous technical details that must be addressed to achieve a fully decentralized computing infrastructure that provides similar functionality to cloud-based services, the technical challenges in building such systems are relatively straightforward. However, the HCI challenges that are entailed in building user-acceptable cloud-like services are numerous, as users have come to expect the illusion of infinite computing resources that are transparently and instantaneously available everywhere.

Transportation

There are numerous technologically-mediated transportation services and ride-sharing intiatives today such as Uber, Lyft, Wingz, BlaBlaCar (France and more than 20 other countries), Haxi (primarily Norway) and Skjutsgruppen (Sweden). These services have been studied from an ICTD perspective [1], in terms of labor practice in ridesharing [76], personal ride sharing experiences [58] and for supporting the transportation needs of the elderly [57] in the HCI literature.

This topic area is challenging to analyze in terms of its intermediation. While a service such as Uber is problematic due to the reasons enumerated above (see "Communication"), so are traditional taxi services with a centralized switchboard and cars aimlessly circling around the city. Thus while non-profit, grassroots ridesharing services attempt to service

[1]In scale-up systems a single node is made more powerful to meet demand rather than increasing the number of small systems to meet the demand in aggregate.

human needs without furthering the unsustainable growth-based cornucopian paradigm, an ideal system would be to a) better make use of the hundreds of millions of half-empty cars that traverse cities and highways, b) support car-free transportation (e.g. walking, biking, buses, subways) in such a way that car transportation needs decrease, or c) to build cities in such a way that transportation needs in general decrease [35]; these ideal solutions are in fact disintermediated forms—either due to their self-sufficient nature or due to the elimination of prior intermediaries—relative to today's common practices.

DISCUSSION

In analyzing existing work in Sustainable HCI and evaluating possibilities for disintermediation, we found that three key qualities consistently arose: decentralization, decommercialization, and decomplexification. Decentralization removes a possible intermediary, decreasing the potential harmful economic challenges that might arise. Decommercialization decreases the growth incentive. Decomplexification decreases the cost of maintaining the system. All three lead to decreased economic growth as it is currently conceived, and as a result have the potential to benefit sustainability while simultaneously not harming (or even improving) human well-being. However we must note that not all approaches to disintermediate will achieve all three qualities in an ideal fashion, and each solution is context specific and comparative.

The concept of disintermediation is at once esoteric and mundane: esoteric because it has seldom been discussed let alone used yet mundane because once explained it is easily applied in many different contexts. However it is both of these qualities of disintermediation as a design rubric that make it potentially impactful, as there is significant low-hanging fruit ripe for disintermediation in many human-computer systems as it does not require specialized knowledge to apply.

Moreover, the potential impact it has as a technique can be seen more clearly from a distance. Returning to our earlier discussion of the implicit and often unquestioned linkage of GDP growth and human well-being, we are reminded that most actions we take in society, even purportedly sustainable ones (e.g., purchasing "green" products), further the growth-based economic system. Thus all evidence from daily life reaffirms that linkage. Disintermediation provides a direct means of severing that linkage: it enables increased well-being without growth, as it disentangles economic relationships, and in doing so has the potential to even decrease GDP. This latter concept is decidedly non-mainstream as an objective, but that is only because of its implicit linkage—that is, it is assumed that decreased GDP, such as in a recession, is always coupled with decreased well-being. What we argue here is that this is not fundamental and thus it is acceptable and perhaps even desirable from an ecological and economic standpoint to encourage disintermediated economic *de*growth rather than intermediated *un*economic growth.

The idea of taking actions to *shrink* the economy as we understand it today might be seen as a radical notion, a far cry from something as seemingly mundane as cutting out the intermediaries in some computing system. However, in doing so we are not arguing for a neo-luddite perspective that eschews new technology. Rather, we are arguing for the design of disintermediated human-computer systems that currently have little financial incentive to be built (thus are less likely to be built by the private sector) but can have the dual benefit of improving societal sustainability while decreasing inequality and the political economy problems that are prevalent today.

In addition to its direct effects on the economic system and growth, and thus on the flow of natural resources through the economy and the structure of the economy with respect to political economy concerns, disintermediation has the side effect that it is likely to enable more sustainable practices. Specifically, a significant cause of the unsustainability of today's global society is the material footprint of goods and their transportation. Intermediaries are more likely to increase the distance goods must travel, involve greater complexity, and source materials based on cost rather than sustainability. Relocalized, disintermediated manufacturing, for example, has the potential to relocalize material sources, transmit information not physical matter over long distances, and produce only what needs to be built.[2]

CONCLUSION

Once an afterthought, HCI is now central to the success of many if not most computer systems. We argue that to the extent that the computing in general and HCI in particular has engaged with sustainability, it has often been treated as a peripheral concern rather than as a central requirement. The exception has been the small body of work on Sustainable HCI and Sustainable Computing. While some of this work has offered well-grounded critique, it has often fallen short on practical advice and on suitable techniques that are concrete enough to be actionable.

In this paper, we have placed sustainability at the center and asked what kinds of computer systems we need to develop to move towards a sustainable society. To this end, we have proposed disintermediation—the removal of intermediaries while retaining the key functionality of a system—as a strategy to decrease complexity, costs, and material throughput in society.

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[2]On the flip side there is debate in the community about the sustainability benefits and drawbacks of processes such as 3D printing, as it localizes material inputs but does not benefit from manufacturing economies of scale [54].

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