Next steps for sustainable HCI: new directions, new foundations

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Abstract

The role of HCI in addressing the challenges of sustainability remains unclear despite ongoing interest. Motivated by this state of affairs, the SIGCHI HCI & Sustainability Community organized a workshop at CHI 2014 to "grapple seriously with the community's unresolved differences; find concrete ways to support work that builds on existing sustainability knowledge within and beyond HCI; and find concrete ways for HCI to contribute to achieving sustainability." Workshop participants charted a new direction for sustainable HCI, discussing lessons learned from the first seven years of sustainable HCI research; aims for future research; immediate practical challenges; collective projects to be undertaken to address these challenges; and emerging issues. Despite this progress, fundamental questions remain. Specifically, workshop participants declined to explicitly address the questions of what is meant by "sustainability;" what is known about how it might be achieved; and what HCI's role might be in achieving it. In this paper I draw on research in the natural and social sciences to offer preliminary answers to these questions. I hope these answers will contribute to the development of sound interdisciplinary theoretical foundations for sustainable HCI's new direction.

The paper proceeds in six sections. In the first section, I describe the motivation for the workshop, of which I was lead organizer; the workshop process; the workshop outcomes in brief; and the structure and theoretical approach of the remainder of the paper. In the second section, I report the rough consensus that emerged at the workshop at greater length. In the third section, I offer an interpretation of "sustainability." I observe that, strictly speaking, sustainability is a property of a process in a context over a period of time, not an end in itself. Yet when referring to global industrial civilization in the context of the Earth system, researchers, policymakers, and activists often define sustainability with a list of properties proponents believe will characterize a civilization that is not only sustainable in this technical sense but also desirable. Thus sustainability as a social project is much broader, aiming, e.g., to meet the needs of a larger human population, sustain ecosystem health, and reduce hunger and poverty. In the fourth section, I offer a perspective on how sustainability in this broad sense might be achieved. I propose that if sustainability is achieved, it will be done largely by reconfiguring the institutions and infrastructures of the global industrial civilization. I briefly discuss the dynamics of institutional and infrastructural change in the context of the Earth system. In the fifth section, I propose a role for HCI in supporting efforts to achieve sustainability. I propose that HCI can contribute significantly, even pivotally, to efforts to achieve sustainability through reconfiguration of institutions of infrastructures. I note that a "way in" for sustainable HCI researchers is the constitutive role of information in institutions and infrastructures. The sixth section summarizes, points briefly to potential future work, and concludes.

We want to change things *for real*, not just write papers.
—Elina Eriksson, workshop participant

1 Introduction

Six years after the workshop on "defining the role of HCI in the challenges of sustainability" (Huang et al. 2009), that role remains unclear. In 2010, Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir identified five distinct genres in sustainable HCI (hereinafter "SHCI"). These genres had significant unintentional redundancy; significant but unexamined differences in assumptions, methods, and outputs; and little connection to sustainability research or practice outside HCI (DiSalvo et al. 2010). Since 2010 the field has continued to grow conceptually, with, e.g., accounts of "everyday practices" (e.g., Strengers 2011; Håkansson and Sengers 2013); rich connections to practice theory (Pierce et al. 2013; DiSalvo et al. 2013); discussion of "undesigning" (Pierce 2012); design fictions (Wakkary et al. 2013); calls to activism (Knowles et al. 2014); and speculations on large-scale social collapse (Tomlinson et al. 2012, 2013). But, with the exception of intensifying critiques of persuasive design (e.g., Purpura et al. 2011; Brynjarsdóttir et al. 2012), the conceptual inconsistencies in the field have yet to be explicitly addressed.

Motivated by this state of affairs, the SIGCHI HCI & Sustainability Community (hereinafter "HCI&S"[1]) held a workshop at CHI 2014 that aimed to "grapple seriously with the community's unresolved differences; find concrete ways to support work that builds on existing sustainability knowledge within and beyond HCI; and find concrete ways for HCI to contribute to achieving sustainability" (Silberman et al. 2014). Discussion at the day-long workshop was oriented by eight questions (ibid.):

1. What is sustainability?
2. What do we know, from within and beyond HCI, about how sustainability might be achieved?
3. What crucial open questions remain?
4. How can HCI research help achieve sustainability?
5. How should HCI & Sustainability research be evaluated (e.g., is it possible or desirable to review papers in different genres with one coherent framework)?
6. How can the community use critiques of past work to develop new, more productive approaches?
7. How can we make better use of sustainability knowledge from outside HCI?
8. How can we encourage work that contributes substantively to practical efforts to achieve sustainability?

[1] I use "sustainable HCI" or "SHCI" to refer to the field. "The SIGCHI HCI & Sustainability Community," or "HCI&S," refers to a formal organization, not a "community" in the colloquial or sociological sense.

After a brief welcome from organizers, workshop activity proceeded in five parts. First, all participants introduced themselves briefly. Second, participants formed groups to describe their experiences in sustainability research and practice and SHCI specifically, and explain their motivations for attending the workshop. Third, all participants gathered together to report and further discuss themes that emerged within the small groups. After lunch, participants formed new groups based on common themes or shared interests that emerged in the morning session. Four groups formed. Three formed around topics: sustainability metrics; social and cultural aspects of sustainability; and future scenarios. The fourth group self-identified as "radicals." Groups were asked to address the eight orienting questions of the workshop. Finally, all participants gathered again to report and further discuss their findings. Detailed notes were taken by three of the organizers, synthesized by the lead organizer, and circulated among all participants for feedback.

A rough consensus emerged from this process. Thus far in SHCI, we have largely tended to: (1) refrain from articulating clear sustainability aims; (2) build prototype systems with limited deployment and do small field studies; (3) draw on work within rather than beyond HCI; and (4) focus on technological novelty. While SHCI has as yet had little impact outside HCI, we have learned much. As SHCI grows up, we aim to: (1) specify sustainability aims in our work; (2) work on longer time scales; (3) connect to sustainability efforts outside HCI; (4) build and support systems people use and do studies to inform design and operation of systems in use; (5) move beyond simple models to grapple with the full multi-scalar complexity of "wicked" sustainability problems; and (6) address the full diversity of sustainability challenges by reading and collaborating widely. We identified four challenges to this work: (1) the one-year conference publication cycle; (2) the difficulty of substantive collaboration; (3) the blind, one-step conference review process; and (4) evaluation and production norms. To start addressing these challenges, participants agreed to develop, under the aegis of HCI&S: (1) a submission pre-review process and (2) an SHCI knowledge base. And participants identified at least four emerging issues that may pose long-term challenges: (1) the tension between sustainability and the aim of economic growth that supports the industry of which HCI is part; (2) the tension between the need to think deeply and collaborate widely and the need to act quickly; (3) the tension between respecting the values of users and preventing users from acting on values whose enactment harms others; and (4) the relationship between technology and sustainable social change.

Despite the progress achieved at the workshop, participants declined to address the first four orienting questions of the workshop directly. But I remain convinced of the long-term importance of these questions if SHCI is to make substantive practical contributions to achieving sustainability. Thus the remainder of this paper proceeds as follows. In the second section, I present at length the rough consensus that emerged at the workshop. I discuss four lessons learned over the past seven years of SHCI research revealed by the discussion; six aims for future SHCI research; four challenges to achieving these aims; two projects to be undertaken by HCI&S to begin addressing these challenges; and four emerging issues. In the sections that follow, I draw on research in the natural and social sciences—especially sustainability science, institutional analysis, and science and technology studies (STS)—to offer preliminary answers to the most foundational orienting questions of the workshop: *What is sustainability?*

How might sustainability be achieved? and *What might HCI's role be in achieving sustainability?*

In the third section, I extend research in ecological economics (e.g., Costanza and Patten 1995) to propose that sustainability is a property of a specific process, system, or set of practices considered in a specific context or environment over a specific period of time. In this view, a process, system, or set of practices "is sustainable" in the context or environment under consideration, over the time period in question, if it survives or persists. A strength of this definition is that it is clear and operationalizable. Yet in this view, sustainability is simply a technical property of a system. It cannot serve as a human end; it cannot motivate social, political, or design action. When referring to global industrial civilization in the context of the Earth system over the forseeable future, researchers, policymakers, and activists often define sustainability with a list of properties they believe will characterize a civilization that is not only sustainable in this narrow technical sense but also *desirable* (e.g., World Commission on Environment and Development 1987; Costanza et al. 1991, 1997; Costanza and Patten 1995; National Research Council 1999; National Science Foundation 2012). Thus sustainability as a social project must be distinct from sustainability as a technical property of a system. Appropriately, then, participants to this broader sustainability discourse often describe sustainability in concretely social aims (e.g., reducing hunger and poverty).

In the fourth section, I address the question of how sustainability, conceived as a social project, might be achieved. I propose that if sustainability is achieved, it will be done largely by reconfiguring the institutions and infrastructures of the global industrial civilization. I draw on research in food system change to describe this process. I note specifically that institutions and infrastructures cannot be changed by just anyone. Rather, institutional and infrastructural change often requires action from specific individuals in specific institutional locations. This means that the process of reconfiguring institutions and infrastructures is necessarily a process of *situated* reconfiguration.

In the fifth section, I describe a possible role for HCI, and specifically for sustainable HCI research, in the situated reconfiguration of the institutions and infrastructures of the global industrial civilization in service of sustainability as a social project. I highlight the role of information systems and practices in constituting, sustaining, and changing institutions and infrastructures. And I describe how the strategic design, operation, and maintenance of information systems could contribute significantly to reconfiguring those systems toward sustainability.

The sixth section summarizes, points to next steps, and concludes.

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This paper goes somewhat afield from the traditional analytical scope of HCI research. It is part of a genre of contributions that aim to "take stock" of recent developments in a subfield of HCI or HCI as a whole. Such papers have been part of HCI since its early days (e.g., Bannon 1991; Newman 1994; Whittaker et al. 2000). In recent years such contributions have examined HCI's relation to other fields (e.g., Clemmensen and Nørbjerg 2004) as well as subfields of, or particular approaches to, HCI (e.g., Bardzell 2010; Kaptelinin and Nardi 2012). Within sustainable HCI, the widely-cited 2010 paper "Mapping the landscape of sustainable HCI" (DiSalvo et al. 2010) also falls into

this genre. So too does the even more ambitious "map" developed by Knowles et al. (2013) of sustainability research in computing broadly. The work by DiSalvo et al. (2010) and Knowles et al. (2013) made clear what sustainable HCI research has been thus far. They foregrounded inconsistencies within sustainability research in HCI and computing and opportunities to connect to sustainability research outside computing. This paper draws on sustainability research outside computing to attempt to resolve some of those inconsistencies.

This effort is informed by the literature on complex systems in a range of disciplinary traditions, including cybernetics and systems theory (e.g., Forrester 1968, 2009; Churchman 1968; von Foerster 1979; Macy 1991; Axelrod and Cohen 2001; Bossel 2007; Meadows 2008), systems ecology (e.g., Patten and Jørgensen 1995; Jørgensen et al. 2007; Ulanowicz 2009), human-environment interaction research (i.e., ecological economics, coupled human-natural systems research, and social ecology; e.g., Ostrom 1990; Costanza et al. 1997; Dietz et al. 2003; Liu et al. 2007; Ostrom 2009, 2010; Lejano and Stokols 2013), and the humanities (e.g., Jullien 1995; Bennett 2005, 2010; Stengers 2005). These literatures develop a diverse set of perspectives with occasionally conflicting details (and some prefer other terms to "system"). And while in a fundamental sense no such thing as a "system" exists "objectively" in the world—a system is something one *sees*—there do exist "natural" levels of analysis and more or less appropriate places to draw boundaries around systems. And there does exist a basic "systems worldview." This worldview can be explained with a relatively small number of propositions. The following are adapted from Meadows (2008).

A system is a set of things interconnected in such a way that the collection produces its own pattern of behavior over time. A system is "more than the sum of its parts." That is, the behavior of a system cannot be predicted from knowledge of its parts in isolation; the manner of their interconnection is crucial. Many of the interconnections in systems operate through the flow of information. Information is rarely immaterial. The movement of information within a system often relies on the movement of physical objects or variations (e.g., electrical impulses) between parts of the system. The behavior of a system reveals itself as a series of events over time. *Stocks* and *flows* are fundamental elements in systems. A stock is a quantity of a material at a location in a system (e.g., the water level in a bathtub). A flow is movement of material from one place to another (e.g., water draining from the bathtub). While stocks are measured with quantities of a single unit (e.g., liters), flows are measured as rates (e.g., liters per minute). If the sum of outflows from a stock exceeds the sum of inflows, the stock level will fall, and vice versa. If they are equal, the stock level will reach a (dynamic) equilibrium. Stocks act as delays, buffers, or shock absorbers in systems, and allow inflows and outflows to be decoupled. Feedback loops, delays and environmental conditions strongly affect system behavior. Systems are often hierarchical, and often self-organize. And the relationship of a system to its environment can be described, often quantitatively, in terms of efficiency, resilience, adaptability, and sustainability.

This view will inform the discussion in later sections of the paper. Yet the most immediately salient lesson of systems theory is that to understand the relationship of a system to its environment, we must understand the system-environment relationship *as a system itself*. Thus to understand the role of HCI in addressing the challenges of sustainability, we must look outside HCI. We must discern, to the extent possible, the

whole structure and dynamics of the challenges of sustainability, and identify the elements and dynamics that shape, and could be shaped by, the actions of HCI researchers. Understanding the structure and dynamics of a whole does not mean understanding it in arbitrarily fine detail. It means refraining from making analytical cuts for the sake of *convenience*, but making, to the extent possible, only those analytical cuts justified on the grounds that the dynamics of the excluded elements have a negligible effect on the outcomes of interest. It is in this spirit that I aim to help orient and evaluate SHCI research by situating it within understandings of sustainability, ecosystem dynamics, and institutional change developed in the natural and social sciences and the practically oriented sustainability science literature. I hope that this work will contribute to a broad and substantive response to the calls by SHCI researchers, especially DiSalvo et al. (2010), Knowles et al. (2013), and the 2014 workshop participants, to align and connect SHCI with ongoing sustainability research in other fields and sectors.

2 What have we learned from sustainable HCI?

Workshop participants declined to address the first four orienting questions of the workshop—*What is sustainability? What do we know, from within and beyond HCI, about how sustainability might be achieved? What crucial open questions remain?* and *How can HCI research help achieve sustainability?*—directly. Even as a group of scholars and practitioners with a broad range of experience in sustainability and information technology—or perhaps *because* of this experience—participants rejected the idea that we could devise a single interpretation of sustainability to orient and evaluate future SHCI research. Workshop participant Maria Håkansson noted that definitions of sustainability or sustainable development such as those offered by the National Research Council (1999) and the Brundtland Commission (World Commission on Environment and Development 1987), while helpful for drawing attention to the broad dimensions of sustainability (e.g., hunger, energy, pollution, poverty, education, shelter, employment, water supply, climate stability, and ecosystem stability and services), can quickly become overwhelming in the context of thinking concretely about things we as HCI people can do. Yet all participants agreed that SHCI research should articulate study- or design-specific sustainability *goals* on a paper-by-paper or project-by-project basis. Most participants agreed that "sustainability is a process, not an endpoint"—a view that resonates with the research and policy literature on sustainability proper. For example, the authors of the National Research Council's 1999 report *Our Common Journey: A Transition Toward Sustainability* write:

> The metaphors of "journey" and "navigation" in the work reported here were adopted with serious intent. They reflect the [authors'] view that any successful quest for sustainability will be a collective, uncertain and adaptive endeavor in which society's discovering of where it wants to go is intertwined with how it might try to get there. Also, they reflect the view that the pathways of a transition to sustainability cannot be charted in advance (National Research Council 1999, p. 3).

Relatedly, sustainability scholar Joseph Tainter writes:

> Sustainability is an active condition of problem solving, not a passive consequence of consuming less (Tainter 2006, pp. 93, 99).

Participants' indirect answer to the question of what sustainability is—"define it yourself"—laid the groundwork for our answer to the fifth question—*How should HCI & Sustainability research be evaluated?* Researchers, participants agreed, should define their own evaluation criteria. However, such criteria should not be arbitrary, or restricted to HCI criteria such as usability, efficiency, or user satisfaction. In addition to HCI criteria by which they evaluate their work, SHCI researchers should derive *sustainability* criteria from natural and social scientific research germane to the sustainability issue(s) they aim to address.

This perspective set the tone for workshop participants' answers to the later questions—*How can the community use critiques of past work to develop new, more productive approaches? How can we make better use of sustainability knowledge from outside HCI?* and *How can we encourage work that contributes substantively to practical efforts to achieve sustainability?* To better integrate knowledge from within and beyond HCI, and to support work that contributes to practical sustainability efforts, participants agreed, researchers should read and collaborate widely. Participants agreed that SHCI researchers should try to understand the broader ecological, economic, social, political, and historical contexts of their work, and especially the dynamics of the processes through which the issues indexed by the term "sustainability" have arisen. Yet participants realized this was a tall—perhaps impossible—demand for researchers already tasked with keeping up with theoretical and technical developments within HCI; teaching students; and meeting service obligations in their home institutions as well as in the institutions of HCI. The alternative is to collaborate widely—both with researchers in other disciplines and with practitioners in government, business, civil society, and activist movements. While such broad collaboration is not easy either—indeed the practical challenges have been discussed at length by sustainability scholars as eminent as the late Elinor Ostrom (Poteete et al. 2010)—participants agreed that broader collaboration will be central in making SHCI more rigorous and impactful.

Maria Håkansson foreshadowed much of the substance of the workshop discussion in her position paper (Håkansson 2014) when she asked:

> How [do] we in HCI need to change as an academic field to better reflect sustainability as an important goal? How can we change from being a technology-oriented field that stresses novelty and technical advancement to a field that accepts more alternative forms of engagement with technology that better support sustainability? Building on Blevis' suggestions to address recycling, reuse, and renewal (Blevis 2007), how can we break from the cycle of newness in our own field?

SHCI researchers, we realized at the workshop, have learned much over the last seven years. These lessons have been presented—sometimes piecemeal, sometimes together—in individual publications (e.g., Goodman 2009; Dourish 2010; DiSalvo et al. 2010; Knowles et al. 2013) and discussed by small groups in past workshops and panels (e.g., Busse et al. 2012). But we feel comfortable claiming that a rough consensus has finally emerged: not only do SHCI researchers know what has worked, what has

not, and where to go next—now we also *know that we know*. This "common knowledge" is a crucial prerequisite for collective action (Chwe 2003). The remainder of this section proceeds in five parts. First, I present the lessons learned from the first seven years of SHCI research. Second, I describe the kinds of research workshop participants agreed we should work on now. Third, I describe institutional challenges to this work. Fourth, I describe two projects under way under the auspices of the SIGCHI HCI & Sustainability Community that aim to contribute to addressing these challenges. Fifth, I describe longer-term challenges.

2.1 Lessons from the first seven years of sustainable HCI

Our six core lessons derived from the first seven years of SHCI research can be summarized as follows: *The issues indexed by the term "sustainability" pose severe challenges to existing HCI theories, methods, and institutional processes.* HCI "business as usual" is not well positioned to contribute substantively to efforts to address the challenges of sustainability. Specifically:

1. Refraining from articulating clear sustainability aims impedes assessment of our efficacy in contributing to sustainability. A single definition of sustainability is not needed, or perhaps even appropriate, for the whole SHCI community. The relative salience of the diverse concerns indexed by the term "sustainability" (e.g., energy, pollution, poverty, employment, water, climate, ecosystem health) varies widely between communities. But we cannot assess our effectiveness at contributing to efforts to achieve sustainability if we do not make clear what we mean by the term, at least on a paper-by-paper or project-by-project basis.

2. The processes that give rise to the issues indexed by the term "sustainability" are larger in time, space, organizational scale, ontological diversity, and complexity than the scales and scopes addressed by traditional HCI design, evaluation, and fieldwork methods. Humans have been burning fossil fuels for centuries, and while consequences have only become clear in the last few decades, they will likely intensify for at least another century. These effects, and knowledge about them, affect technology users' everyday practices through complex webs made up of ecosystems, institutions (e.g., governments, policies, markets, corporations, nonprofit organizations, informal associations, civil society, social norms, and mass and social media), and infrastructures, all of which change over periods of months, years, and decades. User studies of prototype systems or field studies that last for weeks or months are rarely long enough to capture these dynamics or substantively explore the potential roles of information technologies and practices in responding to or preparing for such changes.

3. Most sustainability-oriented research and practice takes place outside HCI. The scientific foundations for a popular awareness of sustainability issues were laid in the late 20th century through the work of researchers in systems dynamics, climate science, Earth systems science, ecology, human and social ecology, and geography. The human implications of global environmental change were explored by scholars in new subfields in the social sciences and humanities such as ecological economics, environmental ethics, ecophilosophy, social ecology, and, more recently, social-ecological systems and coupled human-natural systems. In the last 20 years, discourses linking

these fields of study with related discourses in other sectors (e.g., environmental management and environmental law in government, the environmental justice movement in civil society, corporate social responsibility in industry, and environmental reportage) have emerged under the banners of sustainable development and sustainability science. These discourses significantly predate computing discourse on sustainability, which developed in the mid-2000s. But like SHCI, they include a core commitment to translating knowledge into action at scale. We stand to gain a great deal by drawing on the experience and concepts of these researchers and practitioners outside HCI.

4. There is a great deal of research and practice underway outside *and within* HCI that, though not intentionally or explicitly sustainability-*oriented*, is relevant to sustainability work. For example, work within and outside HCI aiming to support the "sharing economy;" "collaborative consumption;" "do-it-yourself" activities; repair, appropriation, reuse, and maintenance; civic engagement; and effective democratic governance may align well with explicitly sustainability-oriented work. Additionally, SHCI may be able to learn from researchers of, and participants in, social movements, especially regarding their use of information tools.

5. Thus far, sustainable HCI research has had little impact outside HCI. This is not necessarily a failure. Early system development efforts within SHCI tended to see sustainability as an application domain for HCI business as usual. Yet as we have come to realize the severity and magnitude of the challenges of sustainability and the multi-scalar, transdisciplinary nature of the processes that drive them, we have come to see "sustainability" less as an "interesting" topic for research and more as a practical ethical imperative. This realization drives our current efforts to reach beyond HCI, both for theoretical and methodological inspiration and for allies in doing the practical work of grappling with the complexities and particular "unsustainabilities" of particular sociotechnical systems and situations.

6. There is a tension between the valorization of technological novelty in HCI and sustainability goals. This has been widely acknowledged since the inception of sustainability research in HCI, e.g., in Blevis' foundational and award-winning 2007 paper (Blevis 2007). The last five years have seen efforts to explicitly valorize design work that does not produce technological novelty, with discussions, e.g., of appropriation, maintenance, and repair (Huh et al. 2010); the "implication not to design" (Baumer and Silberman 2011); "undesigning technology" (Pierce 2012); and technology non-use (Baumer et al. 2014, "Refusing, limiting, departing"). Yet a vague anxiety persists among SHCI researchers that valorizing non-use, even when warranted by *sustainability* considerations, puts them at odds with a central, if implicit, tenet of HCI at large. Few if any SHCI researchers argue against the development of all novel technologies; rather, the question is how to deploy both existing and novel technologies effectively in service of meaningful sustainability goals. Resolving the tension between the sometimes apparently "anti-technological" implications of sustainability discourse and HCI's traditional valorization of invention, novelty, and innovation as ends in themselves will require the development of a nuanced, flexible, and sensitive discourse that might be called *appropriate* or *responsible* innovation (cf. Edgerton 2006; Grimpe et al. 2014).

2.2 What now?

To contribute more substantively and effectively to ongoing efforts to achieve sustainability, we aim to:

1. Specify and operationalize sustainability goals in our work, and articulate our approaches to evaluating our work in view of those goals. Sustainability goals and approaches for operationalizing them have been discussed in SHCI since Blevis' foundational 2007 paper presented a rubric for sustainable interaction design (Blevis 2007); e.g., in 2010 Silberman and Tomlinson considered sustainability "principles," "heuristics," and "indices" for evaluating SHCI work (Silberman and Tomlinson 2010). In view of the rough emerging consensus presented in this paper, we expect a lively discussion of how to prioritize, operationalize, quantify, and sensitively assess context-specific trade-offs between sustainability goals to develop in the next few years of SHCI research. For now, we call on SHCI researchers to be as clear as possible in orienting and evaluating design work with respect to *sustainability* goals discussed in sustainability discourses outside HCI (e.g., sustainable development, sustainability science, climate activism, environmental justice).

2. Do research that considers, and even takes place over, longer time scales than is typical within HCI. To more fully appreciate the interlinked social, economic, and ecological contexts and effects of design interventions, and their implications for future designs, we call for an expansion of the temporal scope of analysis of SHCI user and field studies. This does not *necessarily* mean doing longer-term studies, although longer-term studies would be appropriate. It does mean considering, as rigorously as possible, the long-term social, economic, political, and ecological processes that might influence the adoption, use, and effects of a particular technology. This is not the first time this has been called for in SHCI or even HCI broadly. The most well-known may be the call by Nathan et al. in 2008 for designers to "envision systemic effects on persons and society throughout interactive system design" (Nathan et al. 2008). Discussions about designing systems for use over multiple human generations (Yoo et al. 2013) or over periods spanning the rise and decline of whole societies (Tomlinson et al. 2012, 2013) are also relevant resources. Yet it seems likely that most of the conceptual resources we will need to think rigorously about the ways in which deployed technologies will interact with long term social and ecological processes lie outside HCI—for example, in transdisciplinary discourses such as science and technology studies, sustainability science, and ecological economics.

3. Draw from, support, and directly engage with sustainability-oriented and sustainability-relevant work outside HCI. To substantively engage sustainability issues on the appropriate social, physical, and temporal scales will require connecting with concepts, methods, people, and ongoing work in other fields (such as those named above) and sectors (namely policy, industry, civil society, and social movements). This will be a time-consuming and difficult task however it is approached, but it is increasingly clear that it is the way forward if SHCI research is to become more relevant to addressing sustainability issues in practice.

4. Build and support systems people use in their everyday practices, and do field studies that inform design and operation of such systems. HCI researchers have built and maintained systems used in people's everyday practices—i.e., outside

the methodological context of a user study—before (e.g., Ferris et al. 2010; Patel et al. 2010; Dimond et al. 2013; Irani and Silberman 2013). But most HCI studies—be they prototype-based or fieldwork-based—are primarily oriented toward influencing HCI design practice through the production of knowledge, and oriented only secondarily, if at all, toward directly supporting or influencing particular practices over long-term use. This is largely true even of prototypes of persuasive systems whose stated design aims are to influence user behavior. On this topic we extend the work of Gillian Hayes, who in 2011 explored the relationship of action research to prosocial projects in HCI (Hayes 2011), to call explicitly for more action research in SHCI. While action research is demanding, SHCI researchers have done it before (e.g., Aoki et al. 2009), and we believe strongly that one path to greater impact is through the deep and ongoing stakeholder engagement exemplified by action research projects.

5. Move beyond simple models to grapple with the full multi-scalar complexity of "wicked" sustainability problems. Neither climate change nor any other of the myriad sustainability challenges confronting our global society in this century will be addressed at a single point or through a single "lever." While sustainability "leverage points" as discussed in the systems literature (e.g., Meadows 1999, 2008) may exist, many of them are in the hands of policy makers—whose hands are tied by social norms, political inertia, and industry lobbyists. The recent explorations of "practice" in sustainable HCI (e.g., Pierce et al. 2013; DiSalvo et al. 2013) constitute strong steps toward grappling with this multi-scalar complexity. When we look at individuals through the lens of practice, the ways in which their behavioral choices are constrained becomes more clear. This realization motivates us to consider ways SHCI researchers might support broad efforts to make changes to larger systems such as institutions, infrastructures, and policies. Such efforts will entail difficult and open-ended collaborations with a broad range of stakeholders—who will not always agree on frames, ends, or means. Facing fully the social and political complexity of even understanding what the issues *are* is an essential step on the path to contributing to efforts to address them.

6. Address the full diversity of sustainability issues. Categorized by sustainability topic, SHCI research to date has focused largely on consumer behavior with respect to energy, transport, food, and water. In addition to considering larger scales (e.g., community, metropolitan, regional, national, international, global), as discussed above, taxonomies in the sustainability science literature such as that offered by Robert Kates (2010) suggest a broad range of thus-far overlooked points of engagement. Under the category of "human well-being," Kates lists nine focus areas: population; health and well-being; poverty and affluence; habitation and transportation; peace and security; energy and materials; water and sanitation; and disasters. Realizing goals in these domains relies on the condition of natural systems, which Kates discusses in seven further areas: global climate and stratospheric ozone; land; atmosphere; water; oceans; biodiversity; and ecosystem services (Kates 2010). We have yet to engage most of these topics—or the interactions between them. Doing so effectively will require reading and collaborating much more widely than we have done thus far in SHCI.

2.3 Challenges

We identified four immediate challenges to developing and supporting these emerging approaches to SHCI work. They are:

1. The one-year conference publication cycle. The one-year conference publication cycle and resulting pressure to publish, or at least submit, something new every 12 months incentivizes researchers to do work that offers "quick wins," and disincentivizes time-consuming work that does not offer a clear and immediate path to publication—such as reading in new fields or building new relationships, e.g., with scholars in other fields or potential technology design stakeholders in other sectors.

2. The difficulty of substantive collaboration, especially across fields and sectors. The wide variety of barriers to effective collaboration, especially when collaborators have different intellectual backgrounds and may be geographically remote, has been discussed at length in fields as diverse as science and technology studies (e.g., Cummings and Kiesler 2005), computer supported cooperative work (CSCW) (Olson and Olson 2000; Olson 2009), and sustainability science (Poteete et al. 2010). And HCI researchers are often exposed to these difficulties in practice in the contexts of designing, carrying out, interpreting, writing up, submitting, and reviewing research. SHCI is no exception; indeed the debates of the last few years (e.g., DiSalvo et al. 2010; Brynjarsdóttir et al. 2012) arise from the disparate ontological, epistemological, and methodological traditions among the disciplines that make up HCI generally and SHCI specifically. Developing the intellectual competencies and interpersonal relationships necessary to collaborate effectively with natural and social scientists, not to mention businesspeople, policy makers, civil society leaders, and activists, will take a great deal of time, commitment, and patience.

3. The blind, one-step review process in our most prestigious publication venue, the CHI conference. This process, a part of HCI's heritage that harks back to days when research was synonymous with scientific objectivity, inhibits dialogue, especially between researchers just entering SHCI and established SHCI researchers. This makes it hard for researchers entering SHCI to learn about the field, and contributes to the persistence of a genre of submissions that reproduce the now-acknowledged shortcomings of old work. Instead of engaging in a transparent dialogue with the authors of such submissions, by which they might be brought "up to speed," reviewers must be firm in order to ensure that such submissions are not accepted and the conversation within the subfield can move forward. An unfortunate result of this is that researchers new to SHCI, if unsuccessful at first, only get a little direct feedback every year. This is especially the case if they do not come to the conference until they submit a successful submission. Procedural strategies such as instituting a "revise and resubmit" category with shepherding, as in CSCW; allowing open, non-anonymous submissions and/or reviewing, as in alt.chi; and/or allowing authors to indicate that they are new to the field (without necessarily revealing their identities) might help address this challenge.

4. Evaluation and production norms in research funding agencies and our home institutions. At least three factors within funding agencies and universities contribute to a difficult environment for the development of the kind of research this paper advocates for. First, the legacy of positivist, ostensibly objective science, especially within engineering and computing, can contribute to resistance to more socially en-

gaged research. In a research environment culturally dominated by the norms of engineering and the "hard sciences," it can be difficult to secure, or even ask for, time or money to establish the relationships with outside stakeholders that are required for deeply engaged design work. Second, the intense pressure to produce many publications, and rapidly, disincentivizes long-term work; socially engaged work; and work that may not result in easily publishable expositions of technologically novel "solutions." Third, the difficulty of evaluating the quality of multidisciplinary work and the intense time pressure under which all members of the research community work has contributed to an environment in which researchers are evaluated by the volume of their scholarly output rather than by its quality. This poses a significant professional disincentive to multidisciplinary, long-term, collaborative, socially engaged work (cf. Poteete et al. 2010).

2.4 SIGCHI HCI & Sustainability Community projects

As small steps toward addressing the challenges identified above, the SIGCHI HCI & Sustainability Community ("HCI&S") has begun two projects:

1. A community pre-review process for submissions to the sustainability track at the CHI conference. Authors of submissions intended for the sustainability track at CHI will be invited to submit their papers to a "pre-review" process stewarded by a volunteer group of established SHCI researchers. These established researchers will give submission authors detailed feedback. Authors will be asked to submit their manuscripts to the pre-review process at least two weeks prior to the official CHI deadline. In the event of a large number of pre-review submissions relative to the number of volunteer pre-reviewers, manuscripts from researchers new to SHCI will be given priority. If successful, we hope that this pre-review process will mitigate some of the consequences of the one-year conference cycle and the official review process.

2. A collaboratively-maintained HCI&S online "knowledge base." The first iteration of the knowledge base will contain: (1) an annotated bibliography of foundational sustainability-oriented and -relevant research within and outside HCI; (2) a collection of concise, encyclopedia-style entries describing SHCI-relevant concepts; (3) a timeline of sustainable HCI research; (4) a group blog; and (5) a list of people and institutions involved in SHCI research. A group of volunteers, consisting of both established and new researchers, will be recruited from within SHCI to develop and maintain the knowledge base. The "knowledge base team" will consist of four working groups—one each for the bibliography, "encyclopedia," timeline, and blog—as well as a list maintainer, programmer, and coordinator. We hope the knowledge base will ease the burden on individual researchers—especially those new to SHCI—of understanding the field's connections to other fields of research and practice; developing competence and confidence in the methods appropriate to multidisciplinary, multi-scalar, deeply socially engaged work; and building the collaborative relationships required.

We do not know how to substantively address the challenges posed by the pressures generated by funding and promotion norms. We believe we can and should continue to work within our home institutions and the institutions that fund work in our research communities to make the case for explicitly supporting the kind of work we advocate here. Yet as is often the case, the practices of some "purposefully marginal groups"

(cf. Tomlinson et al. 2013) offer provocative and hopeful pointers should these efforts not prove broadly successful. Although not necessarily *purposefully* marginal, strategies developed within communities of researchers in the humanities and social sciences, who have long struggled with funding challenges, are instructive. The Duke Collective, a small group of humanities graduate students at Duke University, began to collectivize their stipends and grants in 2012, establishing a process of "wage sharing" (Student Union of Michigan 2014; Duke Collective 2014). Directly relevant to the aims of SHCI, the New York City-based Superstorm Research Lab is a "mutual aid research collective" that aims to help make New York "a more sustainable city, even a leader in the field of climate change sustainability, by rebuilding infrastructure, programs, and fundings in ways that address social, economic, and environmental justice for all neighbourhoods and groups" and "connect research and action, academia and wider community needs" by enacting "change and collaboration within our own academic community, as well as [developing] methodologies and partnerships that exemplify our values" (Superstorm Research Lab 2013, "About us"). The Lab works toward these goals by holding weekly meetings with a facilitator rather than a leader; making decisions by consensus; distributing responsibilities "as evenly as possible"; holding skill shares; holding "salons" with other researchers; supporting members' work-life balance; and co-writing and sharing grants (Superstorm Research Lab 2013, "What is a mutual aid research collective?"). Science fiction writers such as Bruce Sterling have offered even more provocative, yet not impossible, directions for reorganizing academic work (e.g., Sterling 2005). Past, ongoing, and future work by SHCI researchers investigating how social movements take collective action with little or no funding—e.g., Lisa Nathan's work on ecovillages (Nathan 2011) and Xinning Gui's work on the transnational Transition Movement (Gui 2014)—may also yield strategies for both reducing costs and effectively allocating those funds that are available to us.

2.5 Emerging issues

The projects described above are small steps toward addressing some of the existing institutional challenges to more engaged and effective SHCI research. Yet larger and more fundamental issues loom on the horizon. These issues may appear theoretical or abstract, but they have concrete consequences. Workshop participants identified four of particular relevance to future SHCI work. They are:

1. The tension between sustainability and the aim of economic growth that supports and orients, if implicitly, the industry of which HCI is part. Achieving sustainability at a global scale will involve reorganizing the global economy to acknowledge the limits to indefinite growth in material throughput. While this may seem radical, the evidence of the fundamental ecological unsustainability of an economy that grows indefinitely in material throughput in the context of a finite planet, and ecosystems' finite ability to regenerate natural resources and absorb wastes, is now incontrovertible (e.g., Steffen et al. 2004; Millennium Ecosystem Assessment 2005; Intergovernmental Panel on Climate Change 2007). These limits are widely accepted in fields such as Earth systems science, ecological economics, geography, social ecology, political ecology, and ecophilosophy, and are taken for granted in the discourses and practices of social movements such as the Transition Movement, the global ecov-

illage movement, permaculture, and the degrowth movement. Yet HCI as a field has historically been allied with the growth of computer use, the growth of the computing industry, and growing material throughput in the economy. This tension was raised even in the earliest SHCI publications (e.g., Blevis 2007), but as a research community we have yet to elaborate its full implications or explicitly consider ways to negotiate it. If future SHCI research is to commit to supporting efforts to achieve sustainability in practice—that is, to "change things *for real*," as Elina Eriksson said in the workshop—significant theoretical, methodological, and practical efforts in this direction will be needed.

2. The tension between the need to read broadly, think deeply, and collaborate widely and the need to act quickly. The consequences of climate change, ecosystem degradation, and other sustainability issues are upon us, and are likely to intensify over the next century. As noted repeatedly above, we believe that developing HCI research that contributes substantively to efforts to mitigate these consequences and address the institutional and infrastructural practices and arrangements that have caused them will require us to broaden our theory base and collaborate with researchers in other fields as well as policy makers, businesspeople, civil society organizations, and activists. Yet, again as noted above, developing the intellectual competencies, interpersonal relationships, and institutional processes required to support such collaboration will take time. Developing SHCI research that substantively contributes to efforts to achieve sustainability will require researchers to balance the goals of, on one hand, acting quickly, and, on the other, reading and collaborating widely and thinking deeply to improve the efficacy of our action.

3. The tension between respecting the values of users and preventing users from acting on values whose enactment harms others. The user-centered tradition in HCI proposes, roughly, that the user is always right. In this view, if the user makes a mistake, it is not a "user error" but rather the fault of the designer for failing to predict and prevent it by anticipating the user's desires, expectations, and understanding of the system. The persuasive tradition in SHCI has broken somewhat with the user-centered view in positioning, at least implicitly, the designer as the expert on what counts as "sustainable." While this approach has been vigorously criticized on the grounds that HCI researchers are experts neither on sustainability nor on the everyday practices of users into which most persuasive technologies must fit, it points to a philosophical, political, practical, and perhaps even legal tension SHCI as a community has yet to explicitly face. If climate change, for example, has adverse consequences for most of humanity and non-human life, and SHCI researchers see an opportunity to use, e.g., persuasive or even coercive technology to avert some of these consequences, should we take it? All persuasive technologies developed by SHCI researchers to date can be turned off by their users. But we can imagine, without too much difficulty, a future in which SHCI researchers build systems deployed by governments to enforce citizen or corporate compliance with environmental regulations, or systems used by activists to pressure corporate or government decisionmakers into taking particular actions. Addressing sustainability issues requires political action, so SHCI researchers cannot remain apolitical. Developing a coherent, principled, or even intelligible politics of design will require us to reflect explicitly and systematically on the political and economic stakes of our work. Doing so may in turn require us to develop richer

understandings of these domains of human action than are typically used to directly inform systems design in HCI.

4. The relationship between technology and sustainable social change. The role of technology in supporting, or even catalyzing, social change is hotly debated in many fields. Thus far the "social impacts" of information technologies especially have been mostly unplanned. As SHCI researchers we face the task of developing technologies to support social action toward specific social objectives. While those objectives are not primarily technological, technology in general and information technology in particular can play a role in achieving them. But what roles are appropriate and desirable and what inappropriate or undesirable is not yet clear. Can technology design catalyze sustainable social change? Or for change to be sustainable, must design follow existing trends and intentions? In practice, SHCI researchers will likely "try everything"—but eventually, we will likely accumulate enough experience to develop theory, or at least heuristics, to guide future efforts.

3 What is sustainability?

Collectively, workshop participants reflected on lessons learned from the first seven years of HCI and made explicit the new research direction individuals and small groups of SHCI researchers have been working to develop in the last few years. I count this as significant progress and believe it will contribute to the development of more impactful SHCI research. Yet despite this progress, participants declined to address the most foundational orienting questions of the workshop: *What is sustainability? How might sustainability be achieved?* and *What might HCI's role be in achieving sustainability?* Rather than articulating one or several collective responses to these questions, we elected to defer this task to individual researchers. Given the time constraints of the workshop; the diverse disciplinary and practical backgrounds of the participants; and the potentially contentious, time-consuming, and unproductive nature of theoretical arguments about definitions, this was likely a good choice. But these questions are unlikely to go away. Rather, they will persist in debates about methods, evaluation, and what counts as good sustainable HCI research. If we do not address these questions explicitly and publicly, they may be answered haphazardly in paper Q&A sessions and through the form fields of the conference submission reviewing system. Then SHCI research will be oriented not by shared and well-considered interpretations of sustainability but by intuitive, popular, or, at best, well-considered but idiosyncratic and potentially incommensurable ones. In this and the next two sections, motivated by the possibility of avoiding this outcome, I offer preliminary answers to these questions grounded in relevant natural and social scientific literatures. These answers are intended not to settle the matter decisively but to show that coherent answers are possible and to encourage the community to engage the questions collectively rather than leave individuals to struggle with them alone.

In this section, I consider two interpretations of the term "sustainability." The first is technical in the sense of being clearly operationalizable, quantitative, and largely separable from human values or judgments. This interpretation emerges directly from the "systems worldview" elaborated at the end of the first section of the paper. The sec-

ond interpretation relates to sustainability as a social, political, economic, and cultural project, as in "sustainable development" (e.g., World Commission on Environment and Development 1987) or "the transition to sustainability" (e.g., National Research Council 1999). This interpretation builds on the practical discourses of sustainability science, policy, and activism.

3.1 Sustainability: a systems view

In the systems view, sustainability or unsustainability is a property of a process, system, or set of practices considered in a specific context or environment over a specific period of time. A process, system, or set of practices "is sustainable" if it survives or persists in the specified context or environment over the specified period of time; it is unsustainable otherwise. If the time period in question is in the past, the question of sustainability or unsustainability is a historical one; if part of the time period lies in the future, any claim of sustainability or unsustainability is a prediction (e.g., Costanza and Patten 1995).

By "sustainability is a property of a process in a context," I mean that "sustainable" and "unsustainable" are adjectives that can be used to describe things (nouns) that can be described as processes (or systems or sets of practices; hereinafter I use "process," as from a systems-theoretic perspective the terms are roughly interchangeable). Things that cannot be described as processes, such as inanimate objects, cannot be meaningfully described as sustainable or unsustainable. The sustainability or unsustainability of a process cannot be inferred from knowledge of the process alone. It only makes sense to say that a process is sustainable or unsustainable in some context. For example, unaided human breathing is unsustainable in the vacuum of space, but sustainable at sea level on the Earth. Finally, given a well-specified context and period of time, a well-specified process is either sustainable or unsustainable. There may be some uncertainty associated with measurement or prediction, but any conceptual uncertainty results from analyst error—e.g., failing to specify the process or context sufficiently well.

"Process" denotes any series of events which recurs. Being a *series* of events, a process has a first event and a last event, and the ordering of events is a property of the process. Being a series of *events*, each with preconditions and effects (which themselves may be preconditions of other events, and which may vary depending on the context in which they occur), a process has preconditions and effects.

"Context" is a notoriously difficult term in the analysis of designed systems and the interactions they occasion. Dourish (2004) writes that in the phenomenological view, context, rather than being representable information, is a relational property which arises from activity. Whether something is "in the context" of an activity at a particular time is not fixed but depends on the details of the activity. Activity and context are not distinct but mutually constitutive.

This view of the relation between activity and context recalls the similar distinction between "system" and "environment" in systems theory. While "objectively" there is no distinction between process and context or system and environment, in any particular analysis there always is, even if only implicitly. That is, the distinction is not a property of the world but of our way of seeing it. "System" denotes *that which is*

analyzed or represented in detail, while "environment" denotes that which is represented only schematically or selectively. Similarly, "process" denotes that which may be reconfigured by design intervention, "context" that which is taken as given. The boundary cannot be inferred from first principles; it is drawn according to the details of a particular analysis or engagement. The boundary between context and what might be called "non-context"—that which lies beyond context and is irrelevant to the analysis at hand—is similarly arbitrary. But like the boundary between process and context, it must be drawn for analysis to occur. And while these boundaries cannot be drawn from first principles alone, there are better and worse places to draw them.

As noted briefly above, one implication of this view is that there is no such thing as a sustainable object. If only processes can be sustainable or unsustainable, then any claim that an object is inherently sustainable or unsustainable is either an exercise of poetic license (e.g., if an object is used in speech or writing to stand in for a process, practice, or set of practices) or meaningless. If made seriously, such a claim is a category error. If shorthand for a claim that the object will induce more or less sustainable practices regardless of user or context, it is a technological determinism. For example, there is no such thing as a sustainable *or unsustainable* car, phone, computer, or fence. These objects may enable or support sustainable practices, or be produced sustainably. But they are in themselves neither sustainable nor unsustainable. Nor can they be more or less sustainable than other objects. "Suburbia is unsustainable" and "this phone is more sustainable than that phone" are meaningless propositions, even if "suburbia," "this phone," and "that phone" are well-defined. They are like the proposition "this rock is sustainable." Suburbia, phones, and rocks are objects, not processes. They have neither preconditions nor effects; they are therefore neither sustainable nor unsustainable. Suburban driving, however, is a process, with preconditions and effects. It can therefore be evaluated for sustainability; the statement "suburban driving is unsustainable" is true or false rather than meaningless. Whether it is true or false depends on our definitions and the scope of a particular analysis. To plan or evaluate an intervention to make a process more (or less) sustainable, the whole process must be analyzed in its context.

No process is indefinitely sustainable. For example, Earth's orbit around the sun is unsustainable. In a few billion years the sun will expand, destabilizing Earth's orbit and eventually engulfing it. This example makes one thing clear: to say that a process is sustainable is meaningless without an indication of *for how long*. To say that one process is "more sustainable" than another *can* mean that it is sustainable for a longer time. But it can also mean that it is sustainable in a wider range of contexts, so the equivalence between "more sustainable" and "sustainable for a longer time" should not be taken for granted. When describing one process as more sustainable than another, we should explain what we mean.

Finally, in this view, sustainability—sustaining *a particular process in a particular context over a particular period of time*—is a means, not an end. If sustainability is a property of a process in a context, it is not a human value, or end in itself. Rather, supporting the sustainability of particular processes (in favor of others) in particular contexts, over particular periods of time, is a human activity oriented toward the realization of particular ends associated with particular values. Unsustainability alone does not justify design or policy intervention into a process. If a process whose effects

are judged "bad" is unsustainable, perhaps no intervention to make it more sustainable is called for. If a process with effects judged "good" is unsustainable over a relevant period of time, intervention may be warranted. Justification of such an intervention always involves subjective judgment or preference. As Tainter (2006) writes succinctly, "People [work to] sustain what they value" (p. 92). Thus the question of *what to sustain* is always bound up in what—which processes, systems, practices, and institutions—is worth sustaining, for how long, at what cost, and for whose benefit (Tainter, pers. comm., 2014; cf. Costanza and Patten 1995). That is, unlike the question of *whether* a given process *is* sustainable, the question of *what* to sustain can never be separate from questions of power and value.

3.2 Sustainability in practice

Thus, unsurprisingly, working toward, or defining, sustainability in practice is complex and often contentious. But the sustainability literature outside HCI does suggest a rough international consensus both on what those goals are and on the nature and origins of the threats to achieving them. Synthesizing a vast, interdisciplinary body of research and policy documents, the contributors to the 1999 National Research Council report *Our Common Journey: A Transition Toward Sustainability* write:

> ...the primary goals of a transition toward sustainability over the next two generations should be to meet the needs of a much larger but stabilizing [global] human population, to sustain the life support systems of the planet, and to substantially reduce hunger and poverty. Using goals outlined in international conventions, we define meeting human needs as providing food and nutrition, nurturing children, finding shelter, providing an education, and finding employment. We define preserving life support systems as ensuring the quality and supply of fresh water, controlling emissions into the atmosphere, protecting the oceans, and maintaining species and ecosystems. We define reducing hunger and poverty as ensuring income growth, employment opportunities, and essential safety net services (p. 31; see pp. 32-48, 59-101, and 233-264 for elaboration).

From the perspective of sustainability science and international environmental policy, the achievement of these goals is threatened by "global change," the interlinked, global, anthropogenic phenomena of climate change, ecosystem destruction and degradation, and nonrenewable resource depletion, among others (e.g., Steffen et al. 2004; Millennium Ecosystem Assessment 2005; Hirsch et al. 2005; Intergovernmental Panel on Climate Change 2007).

In this view, global change is a result of "development," the project of building complex systems—practices, technologies, institutions, and infrastructures—to enable improvements in human well-being (e.g., Vitousek et al. 1997; Tainter 2006; Holdren 2012). Development has been very successful in many parts of the world. But most of the human-made systems built as part of the development project were not designed to account for the limited ability of the nonhuman systems within which they are situated, and on which they rely, to furnish resources and absorb wastes. Nor were

they, for the most part, designed to account for the unintended effects of their operation on parties beyond their intended beneficiaries (e.g., Costanza et al. 1997). Indeed even the long-term well-being of the latter is often scoped out in the technical and political negotiations that accompany their design and redesign (e.g., Dasgupta 2008). As a result, development thus far has led simultaneously to increased well-being for many people; reduced well-being for some people; extensive destruction and degradation of ecosystems, the destabilization of the climate system, and mass extinction of nonhuman species (the sixth mass extinction in Earth's history and the first to be perpetuated by a single species; see Steffen et al. 2004, p. 6); and degraded prospects for the long-term well-being of all, including nonhumans (e.g., Millennium Ecosystem Assessment 2005, p. 1). "Sustainability" describes a condition in which society's institutions and infrastructures support practices that enable survival and well-being for people currently alive without impeding the ability of others—including the unborn and the nonhuman—to develop effective practices that ensure their own survival and well-being (cf. World Commission on Environment and Development 1987, p. 43).

4 How might sustainability be achieved?

As understanding of the dynamics of "environment and development" has grown and spread, international agreement has emerged that the human-made systems implicated in global change should be reconfigured to improve prospects for the future well-being of humans and other species (e.g., World Commission on Environment and Development 1987; National Research Council 1999). Yet our present well-being and survival relies on the continued operation of these systems. Thus achieving sustainability entails reconfiguring human-made systems to reduce the undesirable effects of their operation without interrupting their ability to provide for human survival and well-being in the present (cf. World Commission on Environment and Development 1987, p. 43). Further, systems cannot be reconfigured by just anyone. System change requires concrete action from specific people in specific institutional locations. "Decision makers" in such systems must respond to often conflicting short- and long-term desiderata and the interests of multiple stakeholder groups. Their agency is shaped by existing institutional policies and norms and their own knowledge and social and material capabilities. Institutions and infrastructures are interlinked, and change slowly. Susan Leigh Star and Karen Ruhleder, for example, in papers that have become foundational in the CSCW literature (Star and Ruhleder 1996; Star 1999), describe infrastructure as embedded in other "structures, social arrangements, and technologies"; transparent to use, in that it is often taken for granted, and "invisibly supports" tasks that become routine for particular groups; reaching "beyond a single event or one-site practice"; learned as part of membership in a particular community of practice; shaping and shaped by conventions of practice; standardized, often to facilitate transparent interoperability with other infrastructures; built on an installed base; becoming visible upon breakdown, and changing in modular increments, not all at once or globally (Star 1999, pp. 381-382). The sociologist C. Clare Hinrichs uses the term "remaking" to describe the slow process of institutional and infrastructural change in the North American food system:

> The social location and resource endowments of different individuals and groups afford different skills and opportunities for [system change] work and different understandings of what the work should be. Overall, remaking first involves deliberate, sometimes dogged efforts simply to grasp what currently exists, and it requires second a refashioning of some of the institutions and practices of agriculture and food in more desirable ways... Remaking the food system then suggests neither a revolutionary break nor a radical transformation but rather deliberate, sometimes unglamorous multipronged efforts in areas where openings exist to do things differently. Supporting a farmers' market may never shut down the local big box supermarket, but it does divert consumer dollars to local food producers, consequently helping them stay in business and providing some consumers with fresher, local foods. Such activities quietly and modestly remake parts of the food system. Whether pursued by individuals, groups, or communities, such remaking is not a linear or foreordained process that possesses some clear, known endpoint. It is instead movement in what is hoped to be a more promising direction (Hinrichs 2007, pp. 5-6).

This notion resonates well with the metaphor of "navigation" adopted by the contributors to *Our Common Journey*, quoted above (National Research Council 1999, p. 3). In the language of third wave HCI (e.g., Bødker 2006; Harrison et al. 2007; Sengers et al. 2009), sustainability will be achieved through the *situated reconfiguration* of institutions and infrastructures to enable and support more sustainable ways of life. Sustainable ways of life support the well-being of their adopters and beneficiaries without harming others', or their own long-term, prospects for well-being. The transition to sustainability will occur gradually, as actors situated within existing structures adaptively and collectively find ways to continue "meet[ing] the needs of the present" (World Commission on Environment and Development 1987) while reducing the harm those structures inflict on the prospects for others', and their own, long-term well-being.

5 What is the role of HCI in achieving sustainability?

If sustainability will be achieved through the situated reconfiguration of institutions and infrastructures ("structural change"), the motivating question—what is the role of HCI in addressing the challenges of sustainability? (Huang et al. 2009)—becomes: what is the role of HCI in structural change? To answer this question we must first ask: what is the role of technology, especially information technology, in structural change?

This question indexes a long history of theory and debate on "technological determinism" and "social construction." This discussion has been broad—with roots in philosophy (namely, Heidegger 1954 [2008]), a central locus in science and technology studies (e.g., Innis 1951; Winner 1988; Bijker et al. 1987; Hacking 2000), and implications for fields as diverse as HCI (e.g., Floyd et al. 1992; Dittrich et al. 2002; Bardzell 2010) and urban planning (e.g., Hommels 2008)—and contentious. Yet a rough consensus seems to have emerged over the decades. Shaped by their contexts of

design, technologies create new possibilities for human action. While an outcome of technology use may be physically possible or technically imaginable, social conditions may preclude its realization (e.g., Sassen 2005). Physical possibility is a necessary but not sufficient condition for changing human reality, which is both material and social. Technology is one class of factor among several that influence the outcome of a particular situation or the dynamics of a particular institution-infrastructure system (e.g., Lessig 2006, pp. 120-137; Latham and Sassen 2005; Benkler 2006, pp. 16-18; Toyama 2010; Kallinikos et al. 2013).

In the short term, people mainly use new technologies to pursue existing goals with existing strategies—or, in the terms of practice theory, to support existing practices. These goals and strategies, or practices, are often made explicit in the agreements that make up social institutions and shape the material designs of deployed technologies and infrastructures. The social and material force of agreements that predate the development and deployment of new technologies shapes their use over the short term. This dynamic is captured well by the information scholar Philip Agre in his "amplification model" (Agre and Schuler 1997; Agre 1998, 2002). Drawing on a wide and multidisciplinary literature, he writes:

> When institutions change, it is not because a technology such as the Internet descends and, deus ex machina, reorganizes the institution's constitutive order in its own image. Institutions do often change as a result of the opportunities that a new technology makes available, but it is only through the workings of the institution that the dynamics of the change can be found. As Calhoun puts it, "the main impact [of the Internet], especially in the short to medium term, will be to allow us to do more of the things we were already organized and oriented to do" (Calhoun 1998, p. 382). Nor is the point restricted to the Internet: Fischer (1992) concluded that Americans in the early 20th century used the telephone "to pursue their [existing] ends...more aggressively and fully" (p. 28) and "to widen and deepen existing social patterns rather than to alter them" (p. 262). People in a given institutional setting use a new technology to pursue the goals that the institution suggests, organized by the cognitive and associative forms that the institution instills. If the technology is incomprehensible within the thought forms of the institution then it will probably go unused (Orlikowski 1993). If nobody can devise an action pattern for deploying the technology in ways that mesh with the existing gears of the institution, then no significant effects of the technology's adoption are likely to be found. It follows that the Internet creates little that is qualitatively new; instead, for the most part, it amplifies existing forces (Agre 1998). Social forces are nothing but coordinated human will, and institutions channel human will in some directions more than others. To the extent that institutional actors can pursue existing goals by reinterpreting existing action patterns in terms of a newly available technology, the forces that their massed actions create will be amplified (Agre 2002, pp. 315-316).

Systems do not remake themselves, and technology does not by default tilt remaking or change toward sustainability (e.g., Tomlinson et al. 2011). Over the short term,

logics and dynamics internal to institution-infrastructure systems, in interaction with their environments, shape change, including technology development and use. There is no a priori reason for such logics to be aligned with sustainability, and indeed many of our existing systems predate sustainability discourse.

Yet over the medium to long term, individuals and small groups, both within and outside relevant institutions, with or without institutional support, find ways to deploy technologies in service of new, often previously unachievable goals. As the anthropologist of technology Bonnie Nardi, drawing on recent arguments on the role of materiality in organizational and social life (viz., Kallinikos 2004, 2011; Kallinikos et al. 2013), writes, "humans remake themselves *through* technologies in intended and unintended ways—ways that often profit those in power" (pers. comm., 2013; emph. added):

> The internet has, in the medium term—where we are now—fundamentally changed society. It has brought newspapers to their knees, reconfigured commerce, made everyday surveillance seem normal, and produced a generation of children who spend ten hours a day looking at a screen. We are on the cusp of accepting a two tiered system of education where the hoi polloi get [massive open online courses] and the elite get face-to-face [instruction]. Uses of the internet grow out of ongoing goals and practices, but that does not mean it does not have tremendous impact on society, nor that it does not open up profoundly new ways of being (pers. comm., 2013).[2]

We have done this to ourselves (or, to consider the matter more politically, to one another), Nardi does not need to say, *without intending to*, "through" the internet.

Many of the aims to which the internet, information technology broadly, and perhaps even technology broadly, have been put have had little to with achieving sustainability goals such as "[meeting] the needs of [the global] human population, sustain[ing] the life support systems of the planet, and substantially reduc[ing] hunger and poverty" (National Research Council 1999, p. 31). Such goals have not fit well with the preexisting goals, logics, and practices of institutions *or* individuals. For example, US corporate law developed under the widespread assumption that indefinite economic growth would lead to indefinite improvements in human well-being. This doctrine is now understood to have serious omissions. Namely, it does not account for the finitude of natural resources or of ecosystems' ability to absorb human-produced wastes (e.g., Costanza et al. 1997). Few institutions have yet been reconfigured to reflect this new understanding. Yet efforts are underway. As awareness of the risks of global change spreads, structural change efforts are initiated at many scales: in the lives of individuals and households; in the formal processes of organizations and the material components of their infrastructures; and in the policies and built environments of regional and national governments. The existing structures and practices within such institutions constrain the nature and pace of change, but not immovably. Information systems scaffold,

[2] Although the peer-reviewed literature—especially the sources, cited above, by Kallinikos (2004, 2011) and Kallinikos et al. (2013)—articulate this position well, this less formal articulation from a careful observer of "technology and society" puts it more pointedly. I follow a path established by political scientist Allaine Cerwonka and anthropologist Liisa Malkki in *Improvising Theory* (Cerwonka and Malkki 2007) in including it directly here.

support, and often even enforce particular policies and practices. In this view from the literatures on sustainability science and science and technology studies, HCI can contribute to the transition to sustainability by developing information tools to spark and support efforts to remake institutions and infrastructures.

Happily, the bases and implications of this view align well with the lessons and future aims expressed by the workshop participants and listed in the second section of this paper. The sustainability science and policy literatures offer a wide range of tools for the sustainability assessments called for by workshop participants in future SHCI research. They also point to potential collaborators; models of practically engaged work that considers, or even takes place over, larger time scales than typical HCI research, and grapples substantively with the complex cross-scalar dynamics that give rise to sustainability issues; and an indication of the broad variety of these issues. And the notion of an adaptive journey toward sustainability supports the view that we must monitor our progress—and our contributions to that progress—on an ongoing basis and change course as needed.

6 Conclusion

HCI is well positioned to contribute substantively to "real world" efforts to achieve sustainability and address environmental issues of real importance. We have learned much in the last seven years. As a community, SHCI now aspires to conduct and support research that: (1) specifies sustainability goals; (2) engages with long time scales; (3) connects to sustainability-oriented work outside HCI; (4) aims to build systems used in people's everyday practices or inform design and use of such systems; (5) moves beyond simple models to grapple with the full complexity of sustainability issues; and (6) addresses a broad range of sustainability issues. In this paper I have endeavored to show how drawing on research beyond HCI can help us answer foundational questions in orienting and evaluating SHCI research. Future work can build on this effort both theoretically and practically. Particularly generative theoretical connections wait to be made with the social scientific literature on institutional analysis (e.g., North 1986, 1990; Ostrom 1990, 2005, 2009, 2010). Institutional analysis can help us understand the role of information systems and practices in institutional change. This may help us develop strategies for designing, building, deploying, operating, and maintaining information systems that support institutional reconfiguration toward sustainability. In addition to linking with sustainability research, policy, and practice beyond HCI, we also have an opportunity to build conceptual, methodological, practical, and interpersonal connections to, and explore the potential sustainability implications of, other work *within* HCI, for example action research (e.g., Hayes 2011), public design (e.g., DiSalvo 2009; DiSalvo et al. 2014), human needs HCI (Kaptelinin and Nardi 2012), and practice-based HCI (e.g., Pierce et al. 2013; Wakkary et al. 2014). Broadening and deepening SHCI research in this way will not be easy, and several clear institutional barriers exist. While we do not know how to tackle them all, the SIGCHI HCI & Sustainability Community has begun efforts to help address some of them, and we do not believe any will prove indefinitely insurmountable. At the same time, the goal of contributing directly to sustainability efforts presents an opportunity to collectively

reflect on deep but ultimately practical questions about the aims of HCI as a field in a time of great social, political, economic, and ecological change and uncertainty.

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