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It's difficult to see the ecological impact of IT when its benefits are so blindingly bright.

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The 'Invisible' Materiality of Information Technology

THERE ARE SIGNIFICANT material impacts from extracting, processing, maintaining, and ultimately disposing of the materials used to support information technology, as well as from producing the energy used both by the devices in operation, as well as in their production and disposal. Yet these material impacts are largely invisible and receive substantially less attention than discussions about the technical aspects and benefits of information technology. We use the term *materiality* to encompass all of these aspects and more—a comprehensive accounting of the ways in which information technology impinges on the physical world.

Consider as an example the Internet of Things (IoT). The number of IoT devices is growing rapidly, with projections by some analysts of 20 billion to 30 billion devices by year's end.[11] This sharp increase in the number of IoT devices, along with supporting infrastructure, will result in significant consumption of materials and energy and production of waste. Despite this, a recent U.S. Government Accountability Office report on IoT[36] has only a brief mention (two paragraphs in a 70-page report) of the issue of electronic waste resulting from the increasing use of IoT technology, and nothing on the consumption of raw materials and energy. The top 10 results of an Internet search for "Internet of Things" shows a similar pattern: only two out of 10 of the results discussed any potential downsides with respect to materials, energy, and waste, and even within those two, there were five to 10 times more mentions of potential positives than negatives. And IoT is but one example among many.

Research, development, and uptake of computing and information technology has proceeded at an ever-accelerating rate, with only minimal consideration of material impacts, which might lead one to conclude that all is well. However, this great success carries with it an increasing negative material impact. At one time, such impacts could safely be absorbed in the Earth's natural processes and ecosystems; but we are now in an era (sometimes aptly named the Anthropocene) in which the safe operating boundaries for many of these processes and ecosystems are being transgressed by human activity.[30]

Information technology (IT) is a significant contributor to activities of these sorts.[2,3,10,18] This is not to say that many of these activities are inappropriate—to the contrary, many are appropriate, and in some cases are making a positive contribution to limiting environmental impacts of human activities. What we are instead arguing is the material side is largely invisible. There are some important examples of grappling with issues around sustainability and the material side of IT,[20] but by and large the result of this invisibility is that discussions and debates about its positive versus negative material impacts are often simply not occurring.

Why *are* these material impacts largely invisible? Is this simply a result of highlighting where most of the attention of technologists, business people, consumers, and others is focused, or are there structural forces that more actively push toward minimizing the visibility and consideration of these implications? We bring a broad and long-term view on human values and technology (value sensitive design)[9,15–17] to these questions and suggest that in fact there are such forces, and they work together, reinforcing each other. Specifically, we call out five overarching categories of forces: disciplinary norms and practices of computer science, metaphor, utopian visions, visibility of hardware, and economics. Finally, we argue the computing and information community is uniquely positioned to respond to these challenges, both in substance and in public understanding, and explore what (if anything) might be done.

Disciplinary Norms and Practices of Computer Science

One force arises from certain key intellectual moves in computer science. Many parts of the discipline involve setting aside the materiality of computing, abstracting away the physical manifestations to concentrate on information and computation. These powerful intellectual moves allow us to concentrate on key aspects of the phenomenon under consideration and to ignore irrelevant or lower order ones. For example, in theoretical computer science, the concept of Turing equivalence captures the fact that many classes of computers have equivalent computational power (setting aside the limitations of finite memory), even though the machines might have totally different sorts of material realizations or might be purely theoretical constructs. Similarly, complexity theory encompasses results such as the time and space requirements to solve particular problems, independent of the physical machine on which the algorithm is being run. In programming languages, high-level languages abstract away the details of memory allocation and deallocation, let alone the physical manifestation of that memory; in computer networking, protocols often abstract away the physical substrates that implement the networks. There are enormous benefits flowing from these moves to both computer science as a field of research and to information technology as an economic sector—research results apply much more generally, for example, and existing protocols, APIs, and software can take advantage of different and improved hardware.

As with all abstractions and models, a key aspect of using them well is to understand when it is appropriate to simply use them, and when one needs to peer into the black box, that is, bring back into view some of the properties that were abstracted away. The vast majority of experienced programmers at some point will have needed to address issues of efficient use of memory, which is ultimately a consequence of the realization of the computation on physical devices. Similarly, skilled Web designers often need to consider download speeds for different possible layouts and choices of content. As a third and perhaps less familiar example, for applications that can tolerate inaccuracies, programmers can sometimes trade-off energy use and accuracy, that is, reducing the energy consumption of a given program at a cost of lower accuracy. We also note that for some subfields of computer science (for example, robotics and computer architecture), the material is very salient. Similarly, on the engineering side, corporations running large datacenters, for example, are very aware of the energy consumption of these centers and strive to minimize those costs. Moreover, even the more abstract subfields of the discipline, in particular computer science theory, have been influenced by material considerations. For example, several of the founding papers in the famous *Automata Studies* collection[34] start from clearly material considerations, for example, von Neumann's paper on the synthesis of reliable organisms from unreliable components, which is motivated by the unreliability of vacuum tubes and biological components.

Figure 1. A typical cloud computing image.

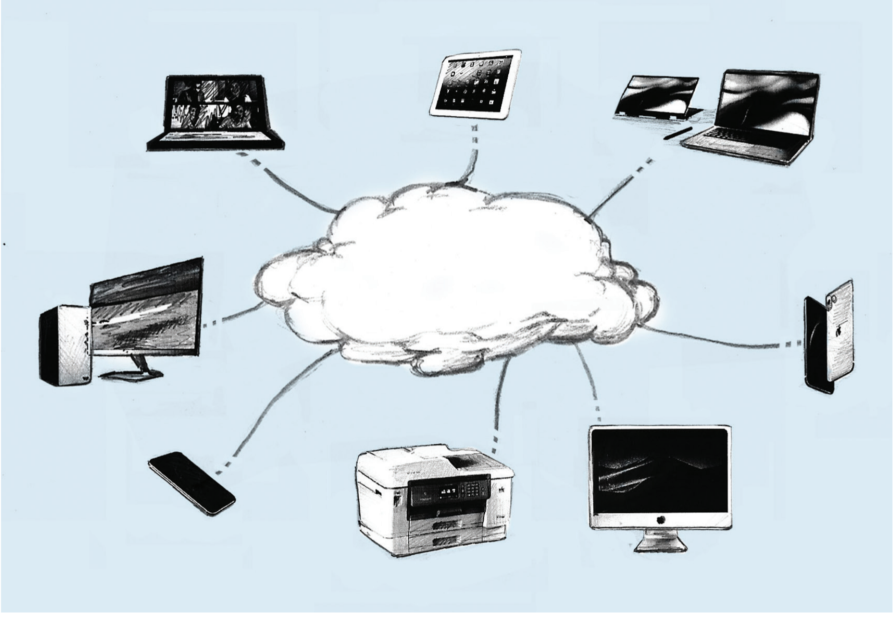

IMAGE BY ANDRIJ BORYS ASSOCIATES

These disciplinary norms and practices of computer science do not per se hide the materiality of IT—as noted earlier, good engineering practice dictates that on some occasions we must peer into the black box—but these intellectual moves do make this materiality easier to minimize or to ignore. In addition, they ready the terrain for other forces, as we will discuss, to push back directly on considering the material side of information and computation.

Metaphors We Compute By

Lakoff and Johnson[23] discuss a central property of metaphors: the systematicity that allows us to comprehend one concept in terms of another necessarily highlights some aspects while hiding others. For IT, computing metaphors that hide the material impacts of IT constitute another force.

One important metaphor here is that of "cloud computing," which conjures up images of something light and insubstantial, floating up in the sky. This metaphor highlights that the servers and their supporting infrastructure are located someplace else, and that users of the cloud need not concern themselves with how they are maintained, monitored, powered, cooled, and so forth; it tends to hide that they are even material at all.

Visual representations of the cloud often make explicit these metaphorical implications. Figure 1, for example, shows a typical diagram for the cloud. Notice the peripherals are highlighted (for example, laptops, mobile phones, and printers); however, the cloud itself is represented as a blob that hides its materiality in toto (for example, no servers, cables, cooling, energy sources, and so forth).

The origins of the term "cloud computing" are disputed. One early and influential use was by Eric Schmidt, then CEO of Google, in a Search Engine Strategies Conference conversation in 2006:[33]

> It starts with the premise that the data services and architecture should be on servers. We call it cloud computing—they should be in a "cloud" somewhere. And that if you have the right kind of browser or the right kind of access, it doesn't matter whether you have a PC or a Mac or a mobile phone or a BlackBerry or what have you—or new devices still to be developed—you can get access to the cloud.

However, there are earlier uses of the term. Business plans from 1996 use the term "cloud computing" in a way that would be familiar today.[29] The authors of those plans state that it was born as a marketing term, which suggests there may have been some awareness of the implications of the metaphor. This usage in turn drew on a convention, used by network design engineers, to loosely sketch the other networks that theirs hooked into as a rough cloud-shaped blob.[31] On the one hand, this convention represents a powerful design technique—abstracting away irrelevant details (as noted in the section "Disciplinary Norms and Practices of Computer Science")—but at the same time, it implies these details, including the material implications of these other networks, are not relevant to the task at hand.

Another term with metaphorical connotations is "ethernet," named after the "luminiferous ether" (or "luminiferous aether"),[24] a hypothesized medium through which light travels. While the existence of the luminiferous ether was disproven by the famed Michelson-Morley experiment in 1887, the metaphor of an omnipresent, passive medium lives on in networking terminology, perhaps suggesting, as did the luminiferous ether, something almost invisible. The term thus highlights the ubiquity and convenience of the network while hiding its material manifestations as cables, routers, and other hardware.

The "agent" metaphor, as exemplified in early presentations such as the Apple Knowledge Navigator video[1,39] and the Starfire concept video from Sun Microsystems,[35] and now at least partially realized in systems such as Siri from Apple and Alexa from Amazon, centers on an intellectual rather than a material view of computation. Software agents ("bots") en masse roaming the Internet embed the metaphor of agents within the cloud. The result is a densely populated society of disembodied agents with limited if no material reality. In all these cases, hidden from view is the vast material apparatus underneath.

Utopian Visions

Another force derives from utopian visions of technology. One notable example is Mark Weiser's vision of ubiquitous computing in which the technology "fades into the background." Weiser writes:[38]

> The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it. ... We are therefore trying to conceive a new way of thinking about computers, one that takes into account the human world and allows the computers themselves to vanish into the background.
>
> Such a disappearance is a fundamental consequence not of technology but of human psychology. Whenever people learn something sufficiently well, they cease to be aware of it.

Thus, Weiser's vision is even broader: as this technology becomes truly embedded in human activity we won't be aware of it at all. As the field of ubiquitous computing has evolved, with computation embedded in walls, clothes, and so forth, the materiality to support it is often physically and intentionally hidden from the user. Indeed, this material disappearance is often considered evidence of good design.

The "agent" metaphor, in particular in its early presentations such as the Knowledge Navigator and Starfire, is also another utopian vision. These virtual agents are typically accessible via peripherals such as screens or phones, doing the bidding of those they serve. In some current systems, Weiser's vision of ubiquitous computing blends with that of agents with, for example, personal software agents that remotely control household thermostats and lighting. To our point, no hint of the infrastructure to support such computing visions is apparent.

Yet another utopian vision underlies an "information society" in which bits replace atoms—ignoring the material underpinnings of those bits.[6,12] Nicholas Negroponte in *Being Digital*,[25] for example, writes:

> World trade has traditionally consisted of exchanging atoms. ... This is changing rapidly. The methodical movement of recorded music as pieces of plastic, like the slow human handling of most information in the form of books, magazines, newspapers, and videocassettes, is about to become the instantaneous and inexpensive transfer of electronic data that move at the speed

of light. ... This change from atoms to bits is irrevocable and unstoppable.

It is worth emphasizing this last sentence. It claims there is an irrevocable and unstoppable change from atoms to bits: the material vanishes.

"Data"—instantly, expansively, anywhere, anytime—is still another utopian vision in which materiality has little presence. Versions of this utopia can be found in Berners-Lee's vision for the World Wide Web with open access for all[5] and in the "cornucopian design paradigm"[28] found in human-computer interaction.

All of these metaphors and visions—cloud computing, ethernet, agents, ubiquitous computing as technology that fades into the background, an information society in which bits replace atoms, and data accessible anywhere and anytime—have substantial currency in popular and business culture and consequent impacts on the visibility of the materiality of IT.

Where Has All the Hardware Gone? (And energy? And water?)

But if the digital is in actuality grounded in the material, where is all that materiality hiding? Buildings full of servers are generally out of sight and out of mind, even without the highlighting and hiding arising from the cloud computing metaphor. Very likely most people have never been in a server warehouse. Even for people who live near one, in some cases its considerable consumption of water and electricity is concealed in part due to secrecy agreements signed with local governments.[13] There is also a disconnect between physical infrastructure and personal use—it is also likely that most people do not know where their data is stored or requests are being processed (the privacy-conscious might at most know which nation the servers are in, given the different regulations); and of course one of the typical features of cloud computing is that service providers can seamlessly shift the storage and processing to different locations.

The devices that users do own and see, such as smartphones and tablets, have become smaller and smaller. These devices are largely sealed as well—a typical smartphone, for example, is a thin, sleek case with a glass screen, with no external suggestion of the tightly packed chips, batteries, sensors, and so on that are inside that case. Taken together, these designs nudge toward minimizing awareness of their overall material footprint.

Growth that requires ever-more material resources cannot continue forever in a finite world.

Economic Forces

There is also a constellation of economic forces that work against recognizing materiality in IT.

In the developed world, there is a powerful and widespread culture of consumption and rapid obsolescence around electronic devices, with pressures to have the latest devices, including as part of one's self- and public image. This culture of consumption is accompanied by a throw-away mentality that often makes older devices almost worthless—but still needing disposal. For example, consumers by and large are disinterested in heirloom digital devices (for example, an older iPad), both because companies do not provide ongoing support for hardware or software and because, seemingly by intention, designs fall out of fashion.[7] Moreover, according to Koebler[22] many large companies (for example, Apple, LG, John Deere) make their devices difficult or impossible for most people to fix (for example, creating software that limits repair, restricting the availability of replacement parts, and minimizing authorized repair programs).

Smartphones and other personal electronic devices can also be highly addictive. This problem is seeing increased attention, both in general and for particularly problematic situations, such as texting while driving, parents at playgrounds, and students in classrooms or while studying, among many others. However, the focus of this attention is primarily on the impacts for social interaction, self-image and self-esteem, safety, child development, effects on learning, ability to think deeply and in a sustained fashion, and the like. These are all important concerns. But the material and energy impacts of this addictive and pervasive use are often ignored, although that is a significant result as well.

A related force arises from one of the widespread business models for providing software and services, which Zuboff has called *surveillance capitalism*.[40] Currently, many consumer services, such as search, personal email, social media, news, and others, are paid for by accumulating vast amounts of personal information about end users and targeted advertising. These advertising and marketing schemes, powered by user data, in turn feed into and reinforce consumerism. Implementing these schemes also results in a powerful set of price and social signals to consume lots of these services: more use implies more advertising revenue and more data about user activities, interests, and preferences, thus motivating companies to encourage consumption. And so the circle goes.

For example, Facebook devotes a huge amount of effort toward hooking in its users to maximize user time on the site and generate massive amounts of user data—the addictive nature of smartphones and other personal electronic devices is not entirely an accident. In promoting gmail, Google advertises "never delete another message—just archive it!" Note that the gmail slogan celebrates the opportunity to save all that email (and implicitly messages "no need to consider the material aspects"). The implication is that people are being archaic if they worry about how much storage email consumes or how much processing is needed when searching a large email archive; and they are probably going to delete something they will eventually want if they don't just archive it. These business practices, and the many others like them, require more and more data centers and processing power.

Prices can provide strong economic signals about materiality, but the current advertising-supported business models for infrastructure makes those signals largely invisible to the end user. For example, there is no fee per search for Web searches, and users can save vast numbers of email messages without incurring a fee. Of course, the price is still paid in the end, even if it is not readily apparent to the end user—it is built into the cost of the goods and services purchased from the advertisers, and also manifests in the negative externalities of vast collections of personal information and in the environmental impacts of producing and eventually disposing of the underlying hardware.

To connect with the earlier discussion on metaphor, Eric Schmidt in the interview cited there states: "And so what's interesting is that the two—cloud computing and advertising—go hand-in-hand." Indeed.

A Claim and Three Questions

- **The materiality of information technology is largely invisible.**

- **What's at stake with this invisibility (and why should we care)?**
- **What forces contribute to this invisibility?**
- **What (if anything) should the computing and information community do about it?**

More broadly, our overall economic system is currently predicated on unending growth. The IT industry has linked itself strongly to this ethos, with some particular manifestations being the constant need for novelty, the accompanying throw-away culture around consumer electronics, and the glorification of disruption for its own sake. Yet growth that requires evermore material resources cannot continue forever in a finite world.

One response to this observation about unending growth is the idea of decoupling: despite the limitations of the physical world, we can still have unending economic growth because we can separate growth from the use of materials, for example, we could grow a service economy rather than a material economy. Making decoupling work requires absolute decoupling (using fewer materials in total), not just relative decoupling (using materials more efficiently, but potentially still using more materials in total). An in-depth discussion of decoupling is beyond the scope of this essay—but to date there has been no evidence of absolute global decoupling,[19] the relevant sphere given our globalized economy in which material flows occur. See Jackson[21] for more on this issue and additional references.

What Could Be Done?

Here, we sketch some ideas for what might be done to counter the forces that work against considering the materiality of IT, and when appropriate to increase the visibility of the negative impacts in terms of materials, energy, and waste. While the focus of this article is visibility, there are also a few thoughts here on how increased visibility might translate to mitigations.

Of course, increasing visibility is not always desirable; however, making some phenomena visible can be useful if doing so surfaces important considerations. The considerations might be important for any number of reasons, including economic, engineering, environmental, or moral ones. Given the very large impacts of information technology in terms of raw materials, pollutants, energy, and waste, we argue this is one such case.

Disciplinary norms and practices. We earlier noted how certain key intellectual moves in computer science involve setting aside the materiality of computation, abstracting away the physical manifestations to concentrate on information and computation; at the same time, a key aspect of using this abstraction well is to understand when it is appropriate to simply use and when one needs to peer into the black box, that is, bring back into view some of the properties that were abstracted away. Currently, the properties brought back into view are typically such factors as bandwidth, power consumption (particularly for mobile devices), processing time, and memory use.

Within fields and subfields, we can scrutinize our work for ways in which it masks or minimizes materiality. For example, in the HCI sustainability community, up until recently the material side of cloud and other digital infrastructure has received significantly less attention than that of the devices that users see and use, despite its having a similar or even larger environmental footprint.[28]

There are also opportunities to incorporate this materiality perspective into ongoing research activities. For example, a topic of current research is developing algorithms that allow for trade-offs between energy use and accuracy, and further, adding support to high-level programming languages for making these trade-offs[28,32]—so allowing some of the benefits of reasoning with higher-level abstractions while at the same time being able to consider the consequences for energy use of trade-offs. As another example, there could be similar efforts to make the energy use by servers visible while still using higher level abstractions (either in debug mode for developers, or for helping instrument end-user applications).

In terms of training the next generation, one targeted educational approach is to focus on interface designers, software engineers, hardware engineers, and others, bringing in consideration of the materiality considerations of the technologies they are developing, along with developing engineering intuition and guidelines as to when considering these materialities is important. This overlaps with the properties already typically brought into view, but is not identical—for example, usually designers of mobile applications focus on how fast the battery in the mobile device is drained, rather than overall power consumption (including power used by servers, the device while plugged in, for manufacture and disposal, and so forth).

Metaphors. Turning now to metaphors, what characteristics would better metaphors have? What would they highlight, and what would they hide? Without being overly prescriptive, better metaphors from the perspective of materiality would appropriately highlight the materiality of IT, while hiding unnecessary details about that materiality. Consider the cloud computing metaphor. Instead of the typical fluffy cloud image that hides completely the material aspects of computing infrastructure (see, for example, Figure 1), alternative images that provide some indication of the material aspects of the infrastructure, such as servers and cables inside the cloud, would be an improvement (compare with, for example, Figure 2). If such images for the cloud became commonplace, they would go some distance toward increasing awareness of the materiality of the current IT ecosystem.

On the surface, the strategy of modifying existing, entrenched metaphors may seem the easiest approach, as it brings some aspects of materiality forward without disrupting shared cultural frames. However, not all metaphors will be amenable to such "materialization" and, in some cases, alternative metaphors may be better for a host of reasons. Accordingly, another strategy entails developing new metaphors that better reflect materiality. These new metaphors could then co-exist with existing ones, or perhaps even supplant them.

New opportunities for designing and spreading well-chosen metaphors arise alongside new technologies. Sometimes the new metaphors come first—providing utopian visions that help guide technical work—and sometimes they arise alongside or after the technology, for example as part of an effort to provide a popular explanation of a new technology. As the field moves forward with future innovations and metaphors are generated to communicate about those visions and innovations, attention should be paid to how materiality is reflected. We can intentionally develop future metaphors to help highlight materiality in an appropriate manner. Overall, whatever metaphors the field settles on going forward should not so comprehensively hide the materiality of IT.

Envisioned futures. Utopian visions of technology can inspire and help guide our technical work. All too often, these visions neglect to bring forward the materiality of IT in meaningful ways. But what if this were not the case? Imagine a utopian vision that is intentionally grounded in the natural world as a base for any anticipatory future. Within and bounded by the natural world is human society, with a goal of prosperity and supporting human flourishing—but likely with a different understanding of prosperity than at present, one that respects the inherent worth, regenerative cycles, and limits of the natural world. Government in turn is subservient to society, and finally the economy is subservient to all three other systems.[4] This vision is in sharp contrast to our current system, in which the economy takes priority. With the natural world at the center, material implications would be forefront. Impacts on the material and social worlds would drive and constrain IT development. Such a vision stands in stark contrast to those such as Weiser's disappeared technical infrastructure or Negroponte's atom-less bits. Instead, utopian visions like this and others can help the field imagine and innovate within the bounds of an actual realism that is the materiality of the natural world we live in.

In the meantime, for anticipatory futures that require less far-reaching transformations, we can uncover the hidden materiality of those visions and weave those into these futures. For example, we can amend the Weiser ubiquitous computing vision to foreground the enormous IT ecosystem needed to support such disappearance of technology for the end user—we can tell stories of where the massive amounts of data are stored, processed, and reconfigured and of how much and what sorts of data are collected and by what means. Similarly, we can amend the Negroponte vision to foreground the atoms (for example, servers, cables, satellites, and so on) needed in reality to support visionary interaction models (but no longer of "atom-less bits").

More generally, for any anticipatory IT future, we can press the futurists to tell us about the materiality of their visions—the physical components, the infrastructure, the energy use, the frequency of replacement, the waste and the disposal. To be meaningful, such discussions will need to encompass the appropriate scope and scale—for example, a vision of every home in the U.S. equipped with sensors and smart controls must also include the material consequences of this vision both in the U.S. and also worldwide, including wherever the hardware is manufactured and eventually disposed of, the energy use, and so on.

Visibility of hardware. The material impacts of designed artifacts, including energy use, can be made more visible.[27] For example, some paper goods now advertise how using recycled products reduce consumers' carbon footprints; likewise, light switches can be labeled to remind users of the energy requirements. In an effort to make IT hardware more visible, technology development proposals could include a "materiality impact statement" (either standalone or as part of a larger social impact statement). Such statements might include a list of the metals, minerals, plastics, and other materials contained in the hardware, a description of their energy consumption, provenance, and processing, and a plan for reuse, recycling, or disposal. For IT professionals, the targeted educational approaches discussed earlier also help to make the hardware more visible in design and other discussions.

Economic models, laws, and regulations. Prices as economic signals often imply it is appropriate to minimize consideration of the material impacts of IT, since typically these prices do not account for the full life cycle costs of the technology, which includes the environmental and societal costs of material extraction, energy use, and e-waste disposal. Taxes or fees could help change this. A goal could be that prices more accurately account for these full life cycle costs, with revenues going to mitigations of different kinds. This could be complemented by public information, supported by regulation or other mechanisms, for example, by labeling new products with information about their eventual disposal and how to do it well, or explaining how certain full life-cycle taxes or fees are being used, or encouraging reuse and repair.

Services that are paid for by accumulating vast amounts of personal information about the end users and targeted advertising erase price as an economic signal visible to the end user. There are increasing calls to regulate this industry[37] or to treat particular corporations as monopolies subject to antitrust action. However, it seems likely that regulation can only go so far in addressing the material impacts of this portion of the IT industry. We should therefore at least consider alternatives for funding these services, such as government or other societal support (such as co-ops or volunteers) as a part of a civic commons infrastructure. Another is corporations that provide the services on a pay-per-use basis, perhaps using a utility rather than a content model.

More accurate accounting for life cycle costs ("let prices tell the truth") has a strong appeal within the currently prevailing worldview, in which economics plays a foundational role. However, as discussed previously, one can imagine other societies in which the economy is subservient to other systems (the natural world, society, government). In such a society, one goal of such taxes and fees could be to help put bounds on activities that have larger downsides than society as a whole wants to bear. In such a society, these taxes, for example, might be set considerably higher than would be done simply to have them reflect full life-cycle costs and be part of a larger coordinated strategy to enable humanity to live more lightly on the Earth (other components being education, and even attempts to shift culture).

Conclusion and Directions for Future Work

This article has presented some ideas on the forces that push toward minimizing the visibility and consideration of the materiality of digital technologies, in particular their environmental impacts. All of the topics noted here would benefit from exploration in much greater depth.

One direction for future investigation is understanding the mental models that people have of information technology, both of the devices they have personally and also of the server and networking infrastructure that backs them. In the section on metaphor we suggest that the cloud computing metaphor conjures up images of something light and insubstantial, somewhere up in the sky. What mental models do people have of the devices and infrastructure? What is the impact of the cloud computing metaphor on these mental

Figure 2. A revised cloud computing image, with some indication of the functionality and material side of the cloud's contents.

IMAGE BY ANDRIJ BORYS ASSOCIATES

models? Do the models adequately represent the material side?

Do the five overarching categories of forces identified here (disciplinary norms and practices of computer science, metaphor, utopian visions, visibility of hardware, and economics) capture the range of forces, or are there other important ones? Within each category, certainly additional forces could be identified and investigated empirically. We want to highlight the economic forces in particular as central and needing much additional investigation, as well as the possibility of unending economic growth and the decoupling of economic from material growth. This recommendation echoes a key point made by Ekbia and Nardi[14] in connection with human computer interaction research: "Computing and political economy are much more intertwined than current discourse in HCI admits. 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, practices, and designs. ... Researchers tend to focus on the cultural aspects of technology at the expense of the more material and economic facets."

This article is primarily written from the perspective of the developed world.How do these issues play out in the developing world? For example, connectivity is often a challenge there, so assumptions of seamless integration with cloud services break down; but on the other hand, the material side of the cloud may be even less visible than in the developed world. We have also touched on the issue of recycling or disposal of e-waste—and it is often in the developing world where this recycling or disposal happens.

Finally, there should be much more work on specific policies and other approaches to what can be done. Again, visibility is not an end in itself: we want to lessen the negative impacts of IT. While increased visibility may help with this, the results from such interventions by themselves will be quite limited in comparison with what actually must be done to live within the Earth's limits. The dark side of IT's materiality is due in part to particular characteristics of the technology, industry, and discipline, but is also a manifestation of integrated and systemic environmental, economic, and political problems, which must be addressed in a similarly integrated fashion. Imagine for a moment a different society in which there is a larger movement to enable humanity to live more lightly on Earth and within its limits, respecting not only our present generation but ones to come.[17] What is a proper role for IT, industry, and research? And how could we get there?

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