‘This All Together, Hon?’ Ubicomp in Non-office Work Environments

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Abstract. Ubiquitous computing technologies offer the promise of extending the benefits of computing to workers who do not spend their time at a desktop environment. In this paper, we review the results of an extended study of non-office workers across a variety of work domains, noting some key characteristics of their practices and environments, and examining some challenges to delivering on the ubicomp promise. Our research points to three important challenges that must be addressed, these include: (a) variability across work environments; (b) the need to align disparate, sometimes conflicting interests; and (c) the need to deal with what appear to be informal ways of creating and sharing knowledge. As will be discussed, while daunting, these challenges also point to specific areas of focus that might benefit the design and development of future ubicomp systems.

1. Introduction

Within the computing industry there is a longstanding and widely shared belief that computing needs to come “out of the box” and fit into the world more seamlessly [1], [2], [3]. This vision seems particularly appropriate for those many work domains that lie outside the canonical office environment. There are many types of workers who do not spend their days at a desktop, but nonetheless have the need to create, share and access information, and thus could seemingly derive benefits from access to digital technology. From vineyards to construction sites, hospitals, manufacturing and retail, ubicomp technologies seem poised to fill a need currently unaddressed by traditional computing technologies.

Yet for all the interest, the broad-scale deployment of ubiquitous computing has been elusive. Davies and Gellersen [4] lament that, despite the accumulation of over a decade of research, “many aspects of Mark Weiser’s vision of ubiquitous computing appear as futuristic today as they did in 1991.” The authors point out numerous barriers, from social and legal considerations of privacy to the lack of effective business models, in addition to technological issues, that still face developers.

This paper attempts to build on some of these initial insights, addressing the issue in the context of non-office workplace settings. It is drawn from ethnographic research focused less on ubicomp technologies and more on the kinds of environments into which it might fit. Our concern was with real-world adoption on a broad scale. What are the factors that might enable (or inhibit) truly widespread use of

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such new technologies as sensor networks, RFID tags, ambient displays, or other technologies – and what will the implications be for ordinary human beings? Our approach derives from the recognition that work organizations are complex systems, requiring an understanding of human practices and embedding processes on a number of levels, from highly personal subjectivities to social, cultural, political and economic systems that interact at the workplace. Any technological deployment must be viable across all such systems to persist and scale.

1.1. Projects Contributing to This Paper

As mentioned, this paper draws on several projects. Following is a brief summary of projects themselves.

Agriculture. In 2002 and 2003 researchers from PaPR conducted a variety of ethnographic interviews and observations with vineyard owners, vineyard workers, vineyard managers, wine makers, and others involved in the viticulture industry in Oregon's Willamette Valley. In late summer 2002 the team deployed a small number of "Berkeley Motes" in an Oregon vineyard. We later deployed 65 networked sensors at a vineyard in the Okanagan Valley, British Columbia, as part of a collaboration with researchers from the Pacific Agribusiness Research Center. These deployments uncovered many technological issues, but more importantly, issues relating to the human labor and associated costs necessary for a successful sensor network deployment [5,6].

Retail Point of Sale. During this same period, a separate team examined ubiquitous computing potential in retail environments, noting that large retailers and consumer products companies had both identified the retail space as a potential point of cost savings and efficiencies. This research ultimately focused on issues of worker agency in the retail transaction [7]. Methods included ethnographic interviews with workers and mangers at nine retail sites, with an effort to maximize differences among the sites in terms of sales volumes, store size, business models, etc.

Construction. A third team investigated issues relating to the construction industry. This research, which took the team to roughly half a dozen construction sites and involved roughly twenty interviews, was primarily ethnographic in nature and did not progress to conceptual prototypes or trial deployments.

Manufacturing. A fourth team examined issues relating to the use of ubiquitous computing technologies in relation to a highly rationalized manufacturing environment – Intel corporations own manufacturing facilities. Intel's microprocessor "fabs" represent environments of heavily centralized command and control, and yet some efforts have recently been made to provide more local resources. This work involved ethnographic interviews and observations on the manufacturing floor. We also explored conceptual prototypes in discussions with various members of the work organization.

Other sites. Finally, in addition to drawing on literature from reach in Computer Supported Cooperative Work (CSCW) and Human Computer Interaction (HCI), we derived additional insights for this paper from our own prior research across a variety of work domains, including salmon fishery in Alaska, rural veterinary medicine in Iowa, medical clinics and hospital settings in Portland, Oregon, television news production, pulp and paper manufacturing, and event planning and production in

Vancouver, British Columbia. In all such cases, workers both created and accessed vital productive information, yet had limited access to computing or desktop environments.

Our point in conducting this research was to look for patterns beyond the particulars of site or even industry. Computing as a tool for knowledge production has thoroughly colonized offices as we know them, but its application is spotty beyond. Why is that? What is it about these other sites that has defied computerization so far, and do new technologies offer the possibility of changing that?

2. The Challenge of Ubicomp

Key to the ubicomp vision is the notion of “computation that inhabits our world, rather than forcing us to inhabit its own.” [8]. Weiser suggests that ubicomp systems “may reverse the unhealthy centripetal forces that conventional personal computers have introduced into life in the workplace.”[9] As our understanding grew of the domains described above, our appreciation grew for just how challenging the ubicomp call to action really is.

2.1. Eliminating “Unhealthy Centripetal Forces”

Our research suggests that conventional personal computers are neither wholly responsible for the “unhealthy centripetal forces” of personal computing, nor are these forces necessarily counter-productive. They have not only enabled computing to happen, but have allowed organizations to thrive.

Personal computers have emerged in an ecology of social practices and physical arrangements whose origins (for the sake of brevity) can be traced to what Foucault [10] has called the *examination*, a mode of power involving the disciplined ordering of subjects (read: rows and columns) enabling a regimented, documentable surveillance of subjects over time. From the late seventeenth century onwards, the examination has diffused from the military examination into virtually every domain of Western life, from the classroom, to the hospital ward, to its most notorious manifestation in Jeremy Bentham’s *Panopticon*.

In the commercial workplace, the role of the examination has been no less important. In the factory, the power of surveillance enabled by the disciplined ordering of bodies, combined with new ways of representing productivity, profitability and liquidity, led to new forms of management and new needs for structured, document-borne representations of information related to productive work. These innovations in management and work practice certainly contributed to the industrial revolution no less than the steam engine.

With the rise of the modern bureaucratic office, document based representations of work and other formalized written communications exploded. Documents became (and continue to be) a vital point of contact between workers [11]. In the latter part of the nineteenth century “a veritable revolution in communication technology took place” in response to this explosion, giving rise to such familiar technologies as vertical file cabinets, carbon paper (for duplication) and typewriters [12]. These artifacts were more than just stubborn metaphors for personal computing, they were inventions that enhanced productivity in offices. A whole constellation of social, economic and practical arrangements thus pre-existed the PC, and enabled its appearance. The PC is not solely to blame for the fact that, "Even today, people holed up in windowless offices before glowing computer screens may not see their fellows for the better part of each day" [13]. Historical forces thus have shaped the organization of work in the office. In many ways the PC has simply taken advantage of that.

Furthermore, the constraints associated with PC use have been productive. The stability of office environments, the reliance on document-based representations of knowledge and the institution of specific forms of literacy have enabled the rise of what Peter Drucker has famously called the "knowledge worker". [14]. Discussions of "computer literacy" often focus on the technical knowledge required to *operate* a PC, but in fact PC use for most people also requires mastery of specific, usually technical, forms of literacy associated with knowledge work. The *examination* has, after all, diffused to that most recognizable of data structures, the array, and its various manifestations in spreadsheets, databases and web forms. This "slender technique" that unites knowledge and power is so pervasive we hardly think of it as an invention. And yet, it is inextricably tied to specific forms of literacy, skills in reading, analyzing and understanding the ordered presentation of subjects often associated with knowledge work.

Dourish has suggested that an important element of embodied interaction is a model of artifacts-in-use "that rejects a traditional separation between representation and object."[15] Historically, however, this separation has been amazingly productive in knowledge work. Science, law, finance and countless technical and commercial professions have benefited enormously from the rise of conventional representations and disciplined abstractions that enable articulation via documents. Document-centric work benefits, in turn, from familiar and stable physical arrangements and environments (that is, offices) that, while not always pleasant, liberate workers from unbounded variability, thereby enabling productive collaboration. One might even go so far as to say that PCs have effectively become "invisible" in much office work – people most often pay attention to the contents of electronic documents, not the technology itself.

The PC is thus neither as singularly responsible for the current state of office work, nor is that state of affairs necessarily "unhealthy" in every respect. This is not an argument for preserving the dominance of the PC, or to advocate imposing the constraints of the modern office on other domains, but rather a call to researchers to consider how constraints enable as well as limit human action. A goal for the design and development of ubicomp systems might be to identify and understand how to capitalize on productive constraints – boundaries within which to profitably operate.

2.2. Sustainable Alignment of Disparate Actors

At least part of the appeal of the ubicomp vision has been an explicit agenda of both empowering end users and alleviating the stresses associated with the use of current technologies. "Machines that fit the human environment instead of forcing humans to enter theirs will making using a computer as refreshing as taking a walk in the woods"

[16]. Creating a “walk in the woods” experience is one thing; it is quite another, however, to create such an experience that also contributes to a productive system, as the technologies and inventions described above all did.

Productive work regimes are complex autocatalytic systems [17]; the activities of any worker must be brought into alignment with other workers in the service of the overall sustainability (usually meaning “profitability”) of the system as a whole. This alignment, as Hutchins [18] (drawing in turn on the work of David Marr) points out, has an interesting implication. The behavior of the system as a whole is defined differently than the definition of any constituent parts. The activities of individual participants in the system must be aligned to produce that emergent, system level behavior.

This is complicated by the fact that in many cases, those with financial, managerial and decision-making power in productive work organizations are often more inclined to invest in technologies that enhance the performance of the system as a whole, rather than providing benefits to individual participants within the system. To put it bluntly, management often doesn’t care about providing a “walk in the woods.” The history of technology investment, in fact, might be traced as a tension between the needs of management to reduce costs and find efficiencies, and the needs of workers for employment, empowerment and decent working conditions. This tension has been well recognized in CSCW research and ethnographic studies of workplaces [19], [20], and in many ways marks the history of political economy [21]. It is particularly acute in many of the domains we studied, where unlike their relatively empowered “knowledge worker” colleagues, many of the workers we observed had little agency in determining their own activities. In fact, as Suchman and others have pointed out, the practices and activities of many workers at lower levels in the organization are often rendered “invisible” in formal accounts [22].

The challenge, then, of Weiser’s laudable vision is more than what is stated. Computing must be more than refreshing as a walk in the woods – it must enable creation of knowledge or other products that circulate among constellations of actors. These constellations, in turn, must be productive and sustainable in larger economic and social systems. The following sections examine this dual challenge from a variety of angles. First, there is a question of the economics of managing variability: how will the variability of physical environments outside the office be effectively and economically addressed? Second, from a “political” perspective we ask: what does one do when the desired practices of individual workers seem to stand at odds with the “needs” of the organization as a whole? Finally, we explore the question of how human knowing and meaning-making might co-exist with systems that have no such capability. In each section we present first a general statement of the challenge, followed by a brief suggestion on implications and how to approach it.

3. Addressing the Costs of Variability

The prior section examines some of the reasons for the success of the PC and its relationship to the sustainability of office work. However, as we get out of the office, into environments where workers directly engage not just structured representations but objects themselves, there seems to be both need and potential for a different approach to computing. Central to the pervasive and ubiquitous computing agenda is the idea that computing artifacts such as wirelessly networked sensors will be dispersed and embedded in numerous physical environments, allowing more direct interactions with the world of "atoms". A problem, however, seems to arise with the tremendous variability across such environments. Office computing is characterized by a fairly circumscribed set of applications, that have enabled hundreds of millions of people to do things like share email, calculate spreadsheets or surf the web. Can we expect such "easy" scaling outside the office? We briefly examine this question in terms of a simple economic issue: the labor involved in deploying and extracting value from sensor networks.

3.1. Variability Among Sites

We couch this discussion in a recent study of sensor networks in agriculture – more specifically, viticulture, the raising of wine grapes. Our research took us to a variety of vineyards, and involved both a brief deployment in an Oregon vineyard and a much more extensive deployment in British Columbia. In both these deployments, researchers used Berkeley motes designed to monitor daily temperature fluctuations and aggregated heat units, which are considered important for initiating harvest and making other decisions in the vineyard. In the Oregon setting, climate conditions are more moderate and humid, with more precipitation than in the British Columbia setting. These differences, along with differences in local topology, the distribution of crops, and chance elements such as the presence of a point source of RF interference, meant that the distribution of the motes in each vineyard required considerable local planning and adaptation, including some amount of pure trial-and-error. As the researchers point out, "Site-specific characteristics will have a profound effect on the ability of mathematical models to predict variation. A hillside site with many swales draining the cold air from the hilltop will require more sensors… A flat plain with little variation in topology will require fewer temperature sensors…"[23].

Beyond the question of network density lie other issues, which will vary not only according to climate but according to specific needs. Different data will require different types of sensors (e.g., chemical sensors, temperature sensors, moisture sensors, etc.) as well as sampling rates, form factors and even physical positioning. Sensors for soil chemistry or conditions, for instance, would obviously need to be on the ground, while the sensors for our deployment (designed for accurate temperature readings at the level of the fruit) required being suspended above the ground, on the vines. Even if one accepts the proposition that the material cost of sensor network technology may be on the order of pennies per unit some day, it does not necessarily follow, based on our data, that motes will one day "be deployed like pixie dust." [24] Labor and skill will be required to properly deploy such sensors. The question is: who will provide that labor? In our own deployments we found that the skill required to successfully lay out a network was beyond the level of most agricultural researchers, let alone ordinary farmers.

User interfaces to sensor networks will likewise need to be optimally tuned, in this case within a vast space of possibilities. Raw "data dumps" from sensor networks proved entirely unintelligible to virtually all parties involved in the ordinary production of wine grapes. At the opposite extreme, completely automated systems that take control out of workers’ hands (for instance in irrigation or pesticide treatments) were regarded with considerable suspicion by those we interviewed: environmental conditions and appropriate responses are still too poorly explicated to be trusted to logic-based solutions. Thus, skillful UI design providing data interpretation, with clear implications for required actions, would seem to be an element of a successful deployment. While those we interviewed indicated a preference for map-based representations of vineyard, it was not clear that existing GIS databases could be leveraged – at least some custom mapping would be necessary to provide the level of detail routinely used.

From a purely economic point of view, it is difficult to tell whose labor might be enlisted to address all these needs. The diversity of local needs and environments described above seem to require “local knowledge”, that is, people with sufficient knowledge of the domain and local environment to make informed decisions. Deploying and harvesting data from networks does not seem to be a task for non-local technicians. Map design would require at least some “ground truthing,” and UI’s need to be tuned to individual needs and skills. Conversely, it seems unlikely that grape growers will have the desire, ability or resources to become network engineers or custom UI designers. The real economics of sensor networks thus has yet to be worked out. The “total cost of ownership” of such systems is clearly uncalculated as yet.

It is not clear these are simply issues facing an immature technology (which sensor networks remain as of this writing), as if in the future such customizations will take care of themselves. Raising grapes is sufficiently complex that contingencies of network architecture, data types, and modes of representing information may always be highly variable, and require considerable local design and tuning. Nor is this an issue facing only the seemingly exotic world of viticulture. There is considerable variability and local contingency in all of the work environments we studied. Even in Intel’s manufacturing facilities, which are explicitly designed to eliminate variability, local knowledge of the particular environment constituted a vital part of the sustainability of systems. In construction, as we were told simply (and on multiple occasions), “every building is different.”

3.2. Implications for Design

Just to reiterate: one of the goals of this paper is to begin to get an understanding of the long-term prospects for ubicomp technologies in the economic, social and political systems that constitute non-office work environments. Following are two simple guidelines that might be used in early evaluation of ubicomp development.

Bound development with productive constraints. While smart environments are interesting illustrations of future visions, it may be that they try to tackle too many problems, and do not lead to the development of easily transferable results. It seems that designing for specific, modular tasks provides a more productive constraint, and one that potentially transfers to other domains more easily. This recommendation seems to echo that of other ubicomp researchers (e.g., [25]). Our brief natural history of the office suggests that constraints have played a positive role in the development of computing so far. The trick for future development is to identify, amidst the apparently greater variability in non-office work environments, productive constraints to exploit.

Maintain a consideration for "total cost of ownership" by allowing decentralized creation. It is not enough to suggest that the cost of the technologies may plummet to pennies per unit or less, or even that such new technologies may come complete with their own infrastructure "for free". The total cost of ownership includes the human labor and expertise to put the technology in place and extract value from it. In this regard, it seems vital that the industry strive to enable decentralized creation and design. As discussed, local variability requires that design happen "on the ground." In the environments we studied, not surprisingly, we did not find many individuals with extensive wireless networking or software knowledge. To scale successfully, the deployment, integration and harvesting of data from tags and sensors will have to be accessible to individuals with little or no technical background. As it stands, there is little evidence to suggest that "end user programming" in these messy environments will be any easier than in the world of desktops.

Tagging and sensing systems often seem to be used to eliminate the role of human workers in the creation of digital information. In the best applications of this approach, the technology creates information beyond the limits of human attention or perception, for example with persistent sensors in vineyard applications, or the use of motes to track vibration on equipment in a manufacturing facility (for proactive maintenance). While the labor involved in deployment remains an issue, it may also be that the physical organization of space, coupled with a noting of the time, provide enough structure for some of the lightweight, "unofficial" kinds of worker-to-worker communications that formed an important practice in virtually all the domains we studied. By incorporating tools for simple, *in situ* annotations tagged with both time and location information, such systems might be leveraged tremendously. Workers able to direct their own or their colleagues' attention to important aspects of both their physical environments and digital information will find data much more useful. This must be incredibly simple: for instance, an enologist using such a system should be able to make a note about a particular vine as he walks the vineyard tasting fruit, without even having to stop. Most importantly, such tools seem most likely to succeed as notes for co-workers (or selves), as opposed to "inputs" to more formal systems that rely on heavily structured data.

4. Supporting Informal Articulation Work

The prior section raised the issue of how considerable environmental variability across sites might raise economic challenges for ubicomp technologies. This section addresses a different kind of variability. As mentioned, in sustainable systems, the activities of individual workers are aligned to produce an outcome that is defined at a different level of description. There thus exists a basic tension between the needs of the organization as a whole and the needs and desires of individual participants – the workers who make up that system. The tension is heightened by the fact that, in manufacturing, construction, retail, agriculture and many of the other non-office environments we studied, the workers we observed hold little power in their organizations. Their productive “alignment” is largely the result of an enforced work routine.

4.1. “Formal” and “Informal” Work

Consider an example from Intel’s manufacturing environments, the facilities wherein silicon wafers are turned into microprocessors. These are environments where the logic of manufacturing command and control has reached an extreme. The environment is orders of magnitude cleaner than a typical hospital operating room. Workers wear full body outfits, complete with Plexiglas face masks, to protect the environment from human impurities, not the other way around. The entire operation is subjected to intense scrutiny and management via roughly half a dozen centralized computing systems (dozens more among the various production “tools” in the factory) and a global team of technicians, engineers and managers numbering in the tens of thousands.

In an experiment in 2002, local management at one particular facility provided handheld computers to all technicians. The devices and wireless networks enabled a variety of *ad hoc* communications among technicians. Some of these communicative practices stood in stark contrast to “official” systems of knowledge creation in the factory – and in fact raised alarm. Such was the case with process specifications, the explicit, step-by-step instructions for the maintenance and use of sophisticated tools in the manufacturing process.

From the perspective of engineering and management, these specifications are held to be invariable from factory to factory on a global basis. They are created and protected from unauthorized change through a laborious process involving formal on-line submission procedures (by technicians or engineers) and layers of engineering approval at the local, regional and global level. They are, as one engineering manager explained to us, the company’s “family jewels.”

For factory technicians, the “specs” are a resource for action – they provide instructions on various aspects of production. But as a resource, they are less than optimal. They are mildly onerous to wade through in search of a particular piece of information. They are impossible to change, even when “everyone” knows that there are better ways to do things. In short, they are too rigid and immutable. So, not surprisingly, the techs used their handhelds to “clip” portions of the specs (usually lists or reference numbers, measurements and settings, etc.) they found they needed most but could not remember easily.

In this case “spec clipping” introduced a direct tension between the “system” needs and “individual” needs. Process engineers and managers saw it as threatening to the integrity of the process – techs ran the risk of saving and sharing outdated information. The technicians, conversely, found that wading through virtual pages of written specs to find the right piece of information, or to go through the “hassle” of submitting updates, to be tedious and unproductive. Simple, easy-to-use and largely ubiquitous computing technologies, then, while potentially highly valuable to technicians, were regarded as a threat to the overall system itself. Engineers and managers effectively banned the use of handhelds for accessing process specifications.

4.2. Implications for Design

Think systemically. To say that new technologies should be designed with human needs in mind is no longer enough in ubicomp systems. Which humans do we design for in complex, multi-participant systems? The computing industry has grown accustomed to thinking about "the end user," as if there is only one. Even considering multiple end users, without thinking about how they align to produce sustainable systems, is insufficient. Disciplines such as CSCW have at least paid sustained attended to both individuals and the systems they form [e.g., 26, 27], but the actual trick of designing to please users and align their activities requires a level of engagement that can be both expensive and elusive. New models of design, perhaps closer approximating those evolutionary processes that have created sustainable ecosystems and cultures might have to be emulated. The challenge of satisfying multiple, dynamic constraints will tax not only engineering skills, but interaction design, human factors, evaluation and testing.

Most importantly, designers must remember that power plays a clear role in work organizations. Technicians themselves have little say-so in determining how process specifications are applied or modified. They are not alone in this regard. Agricultural workers, retail clerks, construction laborers and others we studied have little agency in their respective work environments. This statement is not meant as a value judgment, but rather an observation of a condition that will clearly affect the fate of particular technologies, and is unlikely to change in the near future. Almost by definition, successful technologies have always served the needs of *some* people. Most often, this has meant those who are responsible for extracting profitability from work organizations.

Look for key points of articulation. The goal, then, is to be able to demonstrate that amenable computing technologies will enable alignments of work practices that are profitable for the organization as a whole. This is no easy task, particularly with regards to those workers whose contributions are invisible at upper levels of management. One way out of this potential bind may lie at those points where workers perform what Giddens [28] has called "face work." Key to the notion of "face work" is the recognition that it happens at the juncture between those parts of work organizations that have crystallized into formal structures, and the relatively less constrained world of ordinary human interaction. To illustrate, we offer an example from our construction research.

In construction, a strongly adversarial system persists. Contracts are typically awarded through highly competitive bidding systems. Low bidders who manage to land the job inevitably operate on the very cusp of survival. Their natural inclination is to effectively renegotiate contracts by finding fault with plans and specifications after winning the bid, thus enabling a marginally greater return on the job. The resulting situation, according to some, appears "broken." As one architect informed us, "Lawyers and insurance companies play too important of a role in this industry." And yet, the system persists, largely because – however painfully – all the forces align in the successful production of buildings.

In the midst of this apparent chaos are points of possible technological intervention. Specifically, certain individuals – construction supervisors in particular – occupy key roles in the system. They are responsible for on-the-ground management to ensure that work happens and that the needs of the overall system are met, in the form of a building that fulfills code and specifications. They are the ones engaged in working out the on-the-ground meanings of the wrangling over specs and plans. This bit of structure might be leveraged by developers. By making the right tools available as resources at such key points in work organizations the technology may be leveraged for the greatest overall value.

More specifically, consider the case of changes to work plans. At a very large construction site, thousands of so-called RFIs ("requests for information") may be generated, typically when construction workers identify contradictions or irreconcilable differences in plans (for example, when a given design will cause a pipe to intersect a beam or other solid surface). Typically, site supervisors are responsible for authoring RFIs. By automating some aspects of the process – for instance by automatically encoding location information, and providing speech or pen-based user input – the work of supervisors might be made a little easier. By enabling electronic sending and tracking of these, the overall work process would be more efficient. The key to delivering value seems to lie not in wholesale automation, *per se*, but rather in providing a few additional resources, and simplified "authoring", at a point where loosely structured communications seem to require them.

Would ubiquitous computing make the working lives of construction supervisors better? Possibly, if designed well enough to expedite the "paper work" and preserve the ability to "walk the buildings." Could such technologies enhance profitability? It seems so, given their ability to speed up production. It remains to be seen, however, how many analogous situations might be present in non-office settings.

5. Machine "Actions" and Their Effects

The "design implications" of the two prior sections treated computing as a resource for what Dourish [29] has called "embodied interaction"– that is, as a rather passive tool for use by humans in their creation of meaningful action. But it would be naïve to expect all new computing systems to remain so passive. The allure of technology has long followed an obsession with automating human labor in pursuit of financial return. Computing artifacts have long offered the tantalizing possibility to take actions themselves – this is certainly the vision of "proactive computing" [30], activity modeling, and other computing agendas. As long as computing offers this possibility, those charged with lowering costs of production or otherwise increasing returns will inevitably look to computers to take concrete actions in the work environment – and these actions will inevitably have effects on their human counterparts. Rather than identifying promising applications for such technologies, this section examines how successful applications might behave relative to their human counterparts.

5.1. "Embodiment" Is a Human Thing

We start with a rather blunt observation that, no matter how sophisticated they may be, computers will never experience a work setting (or any other setting) as humans do. As much research has begun to demonstrate, human knowledge and understanding are deeply reliant on and structured by the fact that we inhabit physical bodies with certain perceptual and cognitive equipment not found on any computers [31, 32].

Consider a rather trivial example, from trials of a simulated “automatic checkout” experience in our study of retail environments. In one set of trials, a shopper’s items (each individually fitted with RFID tags) were automatically scanned, totaled and listed in a single, compressed event - the ultimate “self checkout” experience. Despite the apparent appeal of this concept in the popular imagination, our “shoppers” (participants in the trial) found the experience disconcerting. It lacked the social rituals by which a deceptively intricate and ritual-laden transaction – the transfer of property ownership – is accomplished. This discomfort was marked in some circumstances. Midway through trials the RFID reader began to register and charge shoppers for items resting squarely in the baskets of other subjects, who were waiting in line.

While one might argue that a better tuning of the RFID reader, or a better positioning of shoppers in the checkout line, might have solved the problem, these beg the deeper issue: due to a severely limited “sense” of the situation, there was no way for the point of sale system to disambiguate what was obvious to the shoppers – some items were in a different shopper’s basket. As Suchman [33] demonstrated in a classic study of “smart copiers”, the computing system caused tremendous disruptions largely as a result of its inability to access the moment-by-moment contingencies of context and environment.

More obviously than in office settings, perhaps, the innate human ability to collaboratively attune to the environment was evident in virtually all the domains we studied. Workers frequently expressed a preference for direct sensory engagement of the objects and environments themselves – often among multiple modalities. An enologist walked the fields and tasted grapes, “masticated thoroughly,” felt the texture of seeds on his teeth and tongue, while maintaining some peripheral awareness of various other factors, such as his own perceptual experience of the climate, the soil and aspects of the physiology of the plants. A plant manager at an Alaskan fishery climbed into his single engine Cessna and flew over fishing sites, to personally view the positioning of tender boats in relation to the driftnet fishing boats. He needs to “see” the fishermen – and to let them see him (or at least his plane). A construction manager told us he preferred to see work “with my own eyes. I need to walk the building.” Among other things, this physical presence where work happens provides a means of organizing perception, most directly and obviously through the physical organization and traversal of the site itself – or through the physical manipulation of objects (cf. [34, 35, 36]).

If direct perception of the space were all that’s necessary, one might imagine a future wherein highly accurate location sensing might enable a machine to similarly experience a workplace. The problem is, such data does nothing to solve the problem that social means are used to organize perception, often in ways that differ from obvious physical arrangements. In the retail domain, for instance, couples shopping together may be carrying two “separate” baskets that are, in their minds, together. Conversely, as we learned in both trials and ethnographic interviews, individual shoppers may have numerous items in one basket that they nonetheless want to pay for separately, for instance, items purchased for home office versus personal use that need to be separated for tax reasons, or items purchased for a church group that need to be accounted for separately for reimbursement. Both of these situations are cases where the physical organization of the purchase items hardly matches the *social* categorizations being accomplished by shoppers – and, ultimately, clerks.

Thus, even humans can not always know just by looking.

This is perhaps why most workers exhibited a complex and layered approach to knowledge, involving not just direct sensory inputs, but also incorporating the use of formal data (when available), and dialogue with other human beings about what information "counts", and the meanings and implications thereof. By accessing disparate streams of data, workers may find productive new insights about their environments, particularly in situations where expectations of harmony among these streams were violated.

Verbal interchanges were the dominant medium of information sharing in many of the domains we studied. Morning rounds in a teaching hospital, "pass down" between shifts in factory work, and arguments about the routing of a pipe in a construction site, are all primarily accomplished through verbal means, in the midst of ongoing work, in ways that can appear loosely structured and often heavily dependent on the local, physical setting. These verbal interactions accomplish many things. As Goodwin [37] has pointed out, language interacts with the visual field, enabling workers to highlight, code or otherwise fruitfully draw others' attention to relevant aspects. In our observations, we noted that such instruction and knowledge creation was occasioned and organized temporally as well. It was typically by virtue of unfolding contingencies – when problems arose, for example – that workers engaged in explicit discussions of an object or domain that they might not even think to articulate in the abstract (an observation attested in prior research [38]). Such practices, as has been much discussed, are dependent on "context" – which an increasing number of researchers have begun to recognize is not just an objective setting with measurable parameters, but rather a locally negotiated and shared human accomplishment – a contingent understanding of a situation. [39, 40, 41].

While hard for machines, establishing context for a retail worker at the point of sale, is trivial: she just asks. "This all together, hon?" With a simple deictic reference and four-word question, the clerk and customer are able to clearly define which items belong to whom. In fact, there are many things happening at the checkout counter that allow a clear, lightweight contractual arrangement in the transfer of goods – including the courtesy "did you find everything OK?", the display of the cost of items in serial form as they're processed, the lightweight rituals of bagging the items and handing over of a receipt. All of these are scripted social practices designed to provide both clerks and customers with clear indicators that track the progress of transfer of ownership. Each step in this ritual process comes with its own possibilities for recovery from error – for instance, as subjects pointed out to us, they will hesitate when just through the checkout line to check their receipt to make sure there are no violated expectations. "If I wait until I get out the door it's already too late to fix a problem." This "civil but adversarial" encounter, along with all its potential exceptions and errors, is successfully executed countless times each day.

As Davies and Gellersen [42] point out, enabling machines to share such rich contextualized understandings with humans is an unsolved problem "in anything other than extremely limited domains." One might legitimately question whether a shared understanding of context between people and machines in most of the cases described above is not simply unsolved but ultimately *unsolvable*, given the fact that "context" is the product of both embodied and socially constructed understandings.

This is not to say that requiring workers to provide machine-intelligible accounting of their actions is desirable. In fact, among many of the workers we observed, paperwork was seen as a necessary evil, a distraction from the "real work" of being on site, among the fish, the vines, the patients, the tools, the customers. Computing was most often seen as a yet another example "distraction" work. While management may have the power to instigate onerous regimes of self-reporting, workers have always managed to find a way to resist.

5.2. Implications for Design

Given the persistent mismatch in human versus machine "understandings" of context, might there yet be a legitimate role for computing systems to take actions in work systems? In this section we attempt to discern not the exact uses of proactive systems, but rather some general characteristics of how they might interact with humans. Here are a few recommendations based on our data.

Pay attention to human ritual. If we target "face work" (of which point of sale is one example) we must be aware that many of the practices that might appear to be easily automated for the sake of "efficiency" might in fact be very important for constructing a social order. Many human interactions – such as the purchase of groceries – may have associated rituals by which people are able to construct meaning and make sense. A first impulse, from an engineering perspective, is to regard such rituals as "inefficiencies" in the pure logistics of such mundane activities as transferring ownership of goods. And, to some extent, on-line shopping has eliminated some of the familiar rituals of daily life. But beware – these rituals are the means by which humans make sense of their world.

Enable human layering. Section 3.2 (above) examines the notion of incremental value through modular, bounded applications. This section builds on that insight. By combining several modular systems, users may be able to accomplish the kinds of layering and triangulation that prove useful, even unexpected results. Our own evidence suggests that by allowing users to fold in a manageable number of additional sources of information about an environment, rather than transforming their work practices entirely, new technologies might meet with more acceptance. By comparing multiple streams of input, even with regard to the most simple sensing or proactive functions, systems may become both more robust and flexible. This simple layering of multiple physical inputs, known as "sensor fusion" in the world of robotics, is perhaps familiar to many readers – note as well that the "fusion" we are referring to here will be accomplished by humans, not machines.

Create systems that take care of themselves. A final insight that emerged throughout this work must be mentioned as well. Tennenhouse [43] suggests that the future of computing will feature humans "above" rather than "in" the loop. Our comparison of computing inside and outside the office suggests that, while there do seem to be opportunities for systems that exhibit a certain proactive ability to serve human needs, perhaps the most successful way to enable humans to (gratefully) exit the computing loop would be to create systems that require less constant human intervention – from finding and downloading drivers to troubleshooting incompatible devices. Perhaps an early opportunity for ubicomp is *inside* the box of PCs and other devices, to create systems that are more "self aware" and mutually compatible. One of the key challenges to the widespread, successful deployment of ubiquitous computing technologies will simply be their ability to take care of themselves, first and foremost. With the potential explosion of complexity introduced by the presence of hundreds or thousands of devices per person, particularly in light of the issues raised above, it seems clear that such systems will have to achieve a level of self-configuration that current computing has not yet approached.

6. Summary

From the above, the challenges seem mildly daunting: much of the work we observed was complexly structured, not easily lent to formal articulation, highly variable, and practiced by workers for whom technology investment and assistance have never been a management priority. Ubicomp systems must align the interests, practices and needs of large, often divergent populations of workers where conflicts, power differences and competing agendas occur, and where communications happen in ways that are difficult to formalize. This alignment must allow a sustainable, productive system to emerge. Because of the considerable variability within and among environments, the design of such ubicomp systems must happen "on the ground", by individuals who have much knowledge about the local environment but little expertise in networking, hardware or software. Yet these non-experts must somehow be enabled to make specific judgments about all these technological aspects for a successful deployment. And, this must all happen in environments where the benefits of several hundred years of "colonization" – in the form of document-centered work practices, typewriters, filing systems and other office artifacts – have not paved the way for the introduction of computing.

And yet, there seem to be opportunities. Taking into consideration the preceding discussions, including the labor required for locally customized deployments, the recognition that new models for design might be needed to satisfy multiple constraints simultaneously, and the fact that humans routinely access multiple, disparate sources of information in the course of work in such environments, it seems interesting to investigate the possibility of pursuing a more evolutionary path to ubicomp deployment. By "layering" modular, well bounded systems with discrete, comprehensible functions, users may find the ability to piece together just those functions they need, such systems might fit the political, economic and social complexities associated with non-office work. Key to the success of such an approach will be the interoperability of such systems. This in itself is no small order; as has been pointed out [44], the issue of integration and interference among components of ubicomp remains a challenge in its own right.

The authors readily admit that none of the ideas in this paper, examined in isolation, appear radically new. The purpose of this study was not to set a radical new agenda for ubicomp, but rather to look at real work environments to imagine how ubicomp technologies might fit. Our hope is that, together, these ideas point to a direction for productive and potentially harmonious ubicomp deployment "in the wild" by pursuing a path that maintains an appreciation for the complexity of systems – the needs of real human beings and the social, economic and institutional processes they create.

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