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0 Project Summary

Human-Centered Computing (HCC) is a multidisciplinary program designed to guide the future development of computing so as to maximize its value to society. In the midst of an explosive growth period, computing is reaching into the work and leisure lives of most people in the developed world. The impact of the information revolution is still unfolding, but it is clear that literacy in computing is one of the highest priorities for the classroom and workplace. The imperative for computer literacy now can be reasonably compared with the imperative for universal literacy in the nineteenth century. But Computing is hard for non-technical users to master, and even among those that do, there are sharp limits to what they can accomplish compared to technical "power users". So while computing seems to be becoming ubiquitous, its full potential is certainly not. The great technical advances we have seen are undermined because only a fraction of the population can fully use them. Better understanding of human cognition is certainly needed, but also of the social and economic forces that ubiquitous computing entails.

Computing is agent of rapid and often painful *change*. Without understanding and planning in this process, the gulf between the information-technology haves and have-nots will widen still futher. Computing must now be considered *not only* as a technology used by individuals, but *as a powerful economic and social force*. It is essential for new computing research programs to be created which approach and study it as such, and which guide its growth to maximize its benefit to society globally.

HCC is a vision for computing research that integrates technical studies with the broad implications of computing in a task-directed way. HCC spans computer science and several engineering disciplines, cognitive science, economics and social sciences. Our HCC center is focussed on two specific applications (classrooms and manufacturing industry). We consider those two targets to be the most important for near-term study.

K-12 and University Education Clearly, education directly affects the preparation of the next generation of computer users. HCC considers not only the program of how to "teach" computing, but how computer systems should be conceived, designed and presented to human beings. It shapes computing to human needs rather than the other way around.

Manufacturing industry Manufacturing is an important example of the next generation of computing applications which move from office or information spaces to "object-oriented" spaces. It entails hands- and eyes-free use of computers, wearable interfaces, ambient computing, and high levels of interaction and persistence. It involves more intensely "personal" computer systems than are in wide use today.

The University of California Berkeley and its principal partner, the International Computer Science Institute, are uniquely equipped for this ambitious program. The factors that make them so are

Academics Extraordinary strength in computer science, engineering, the physical sciences *and* the social and behavioral sciences, and with top departments and researchers in all the areas in the scope of this proposal.

ICSI HCI Research The principal partner is the International Computer Science Institute. ICSI is a research group in downtown Berkeley with an average of 80 resident researchers, and close ties to Berkeley Computer Science. ICSI recently set a new research agenda and named human-computer interaction (HCI) as one of its three main thrusts. That is, the HCI program at ICSI will house approximately 30 HCI researchers

Cognitive Science A leading interdisciplinary group in Cognitive Science, with strong links to Computer Science and with particular strength in metaphor research which will be critical for future human-computer interaction research.

Company Participation Proximity to Silicon Valley and numerous computer companies with a strong interest in human-computer interaction generally, and this project in particular. We hope to make strong ties to other companies as well, following our thesis that human-centered considerations are important throughout Computer Science and Engineering. Six companies are listed as partners later in the proposal. We expect that to grow to several dozen if this project reaches the full proposal phase.

SIMS The School of Information Management and System (SIMS), a multi-disciplinary graduate school at Berkeley which studies computing from many different disciplinary perspectives. Several SIMS faculty will play important roles in this project, and SIMS will house the central research facility for it.

1 Human-Centered Computing: Research Agenda

Human-Centered Computing (HCC) is a multidisciplinary program designed to guide the future development of computing so as to maximize its value to all of society. In the midst of an explosive growth period, computing is reaching into the work and leisure lives of most people in the developed world. The impact of the information revolution is still unfolding, but it is clear that literacy in computing is one of the highest priorities for the classroom and workplace. The imperative for computer literacy now can be reasonably compared with the imperative for universal literacy in the nineteenth century. And one must anticipate that future computing will touch people's lives in many ways beyond the desktop and the tasks we use it for today, and that there is no reasonable way to "opt out" of the information age.

But there is a long way to go before computing is a tool for the masses [CSTB]. Computing is hard for non-technical users to master, and even among those that do, there are sharp limits to what they can accomplish compared to technical "power users". So while computing seems to be becoming ubiquitous, its full potential is certainly not. The great technical advances we have seen are undermined because only a fraction of the population can fully use them. Better understanding of human cognition is certainly needed.

But technical and cognitive analyses are not enough. Computing is agent of rapid and often painful *change*. People who do not adapt to the change can be made redundant or their work de-valued. The personal computer is one of the triggers of the information revolution, but computers are still a long way from being "personal". Yet that trajectory is clear, and the future is approaching alarmingly fast. We are destined to rely on computing for our financial, social and physical well-being, more than any other technology we use today. The future rears before us with ubiquitous sensors, smart appliances, electronic commerce, wireless, medical informatics, multimedia experiences and wearable computing. These technologies will change our lives profoundly. The effects of this change are complex and multi-layered (individuals, groups and societies). Without understanding and planning in this process, the gulf between the information-technology haves and have-nots will widen still futher. Computing must now be considered *not only* as a technology used by individuals, but *as a powerful economic and social force*. It is essential for new computing research programs to be created which approach and study it as such, and which guide its growth to maximize its benefit to society globally.

We have created a multidisciplinary program called "Human-Centered Computing" (HCC) to addresses this imperative. HCC spans computer science and several engineering disciplines, cognitive science, economics and social sciences. It is extremely broad from a disciplinary perspective, but tightly focussed on specific applications (classrooms and manufacturing industry). We consider those two targets to be the most important for near-term study.

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Manufacturing industry Manufacturing is an important example of the next generation of computing applications which move from office or information spaces to "object-oriented" spaces. It entails hands- and eyes-free use of computers, wearable interfaces, ambient computing, and high levels of interaction and persistence. Such systems are more intensely "personal" than those in use today, and raise many questions about privacy, psychological and physical well-being, and social change.

Our agenda is driven by an understanding of cognitive, social and economic factors first. We emphasize the importance of the context (workplace or educational) under study and the complexity and diversity of human behavior in such contexts. The project builds upon and resonates with much work in HCI (Human-Computer Interaction). The shift in perspective with HCC is (i) we conceive it as a theme that is important for all computer-related research, not as a field which overlaps or is a sub-discipline of computer science, and (ii) computing connotes both concrete technologies (that facilitates various tasks) and a major social and economic force.

Computing is understood to comprise computers, networks, sensors, actuators, software etc. i.e. any information technology that may play a role in facilitating the task. We want to avoid preconceptions about what computers look like, where they are, and what they do. Instead, computing is fashioned as infrastructure *around a human activity*. The challenge will be as much to understand the task, which involves complex human behavior of individuals, groups and societies, as it will be to find technical solutions. Our HCC center will define group partnerships to approach these challenges systematically.

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In the next section (2) we describe our educational and industry application contexts. In section 3 we describe the cognitive and social/economic themes that inform the technical components. Section 4 is a HCC view of computer science, with Human-centered interfaces, applications and systems. Section 5 is our management plan, 6 is academic and other participants and 7 is campus resource commitments.

2 HCC Application Contexts

2.1 K-12 and University Classrooms

One of the great promises of computing is as an autonomous learning tool. That is, the computer is both teacher and topic. More than a labor-saving ploy, from a HCC perspective, autonomous learning removes the student's dependence on a highly-trained human instructor, and so places all learners on the same first step. The deployment of autonomous learning systems reduces to deploying the technology, a much simpler social problem than retraining the teachers (while the learning system simplifies that process also). Ideally, autonomous tools will ubiquitously infiltrate every aspect of the learners' lives, helping learners perform such tasks as reducing the complexity of a scientific problem, identifying potential isomorphs that might elucidate the characteristics of the problem, and directing learners to resources relevant to the problem [Linn 96].

Autonomous learning should be driven by understanding of human cognition, both at a deep level, and in the various heuristics that successful learners use. A pilot project by Prof Linn is exploring two promising procedures for computer-assisted learning. The first is computer presented prompts delivered when students are solving complex problems. Preliminary research shows that generic prompts that ask students to think work better than more specific prompts designed to elicit particular connections in the context. This perplexing and interesting finding deserves further investigation. A second tool for learner autonomy involves tools for organizing an argument. The tool is called SenseMaker and its used to organize Internet URLs to form an arguments. In the KIE (www.kie.berkeley.edu) research program, researchers looked at the contribution of various argument frames, contrasting frames designed by teachers and curriculum developers with frames designed by students.

The HCC center will add two themes to autonomous learning. The first is the role of metaphorical reasoning in learning. Metaphor research will be discussed later in its own section 3.1. We simply note here the importance of the language used, both by the system and by the learner, for discovering the metaphor system. The second theme is spatial reasoning. The 3DDI project (section 4.1.3), which shares several investigators with the HCC, is developing next-generation direct-manipulation and simulation tools for 3D content. These will allow learners to rapidly explore, experiment and record the behavior of simulated physical worlds.

2.2 Manufacturing Industry

Future computing will consist not only of passive desktops, but of sensor-based, highly interactive, "persistent" systems. These systems will be both wearable and ambient (distributed into the environment). They will free the user's eyes and hands to interact with objects (rather than the computer) while acting as an information and computation service. Manufacturing is an excellent and challenging context for HCC research, not only because it is a naturally "object-oriented" workplace, but also because the environment is rich with dynamic state. That is, production machines often have complex state in their control systems, are undergoing wear and aging, and consume various resources including lubricants, glues, fasteners etc.

Consider the human activity of a Foreman's walk-through the factory floor. Normally the foreman would use human senses (including looking at various indicator gauges) to check that the line is functioning satisfactorily. A computer-augmented version of the walk-through adds many non-human senses but otherwise mimics the activity. To begin, each machine is richly instrumented with heat, vibration and stress sensors. The foreman wears a lightweight eyeglass augmented-reality display in a hardhat, and is able to "see" inside each bearing and shaft and notice from its color the temperature and stress, and "hear" the vibration levels. (S)he can also notice which inspection stations have had high rejection rates, and query the inspector in person as to what kind of defects occured. In the event of an actual or imminent fault, the foreman can call up safe shutdown and repair procedures from the company information servers, and instantly call for maintenance staff and replacement parts.

Several HCC faculty from Mechanical and Industrial Engineering (Wright, Kazerooni, Goldberg) have strong involvement already with manufacturing, and couple that with expertise at building the new interface hardware, and controlling it. Profs Wright, Kazerooni and Sequin will design and build wearable systems as suggested above. Prof. Goldberg will work on distributed instrumentation, and on automatic analysis of sensor data to provide higher-level information to the human. Our pilot activity, once suitable hardware is developed and tested in Berkeley, will move to field tests at Ford Motor Company. Ford is a major partner in Prof. Wright and Sequin's Cybercut project [Wright and Sequin 97].

Many of the technical aspects of the wearable systems are described later in this proposal. Of great importance in the HCC will be the social and cultural implications of such devices. How do people feel and react to others while wearing, using, or being connected to such machines? These questions are just as important as the technical ones if such hardware is to be deployed rapidly and responsibly.

3 HCC Themes

In this section, we describe the two themes that inform the technical research for the HCC. The first is cognitive modeling: understanding humans as individuals, while the second is economic and social: understanding humans in societies.

3.1 Cognitive Models and Metaphors

Recent work (much of it at Berkeley) has revealed the central role of metaphor in cognition and language understanding [Lakoff et al. 80, Lakoff and Nuñez 97]. We argue that in fact all abstract concepts are grounded through metaphorical mappings in more concrete concepts and these mappings pervade all of our thinking. Consider, for example, all of the inferences that have arisen from the "information superhighway" metaphor.

From the perspective of HCC, the metaphor embodied in an interface determines how a person thinks about the system being used. This becomes increasingly important as the systems become more complex and the user's knowledge of the detailed system functioning becomes ever more indirect. Of course, the "desk top" metaphor has been effective for many years, but its limitations are also well known [Raskin 97]. There are many experimental designs using a wide variety of other (almost always spatial) metaphors to help users organize and work with their information. It is possible that intuition and experimentation will yield the many new metaphors needed for HCC, but we believe that success is more likely to come from a more systematic and scientific approach, based on expertise in metaphor structure and use.

One particularly attractive idea is to build system interfaces based on active, rather than passive metaphors. In particular, all languages examined to date rely heavily on the metaphor that achieving a goal is conceptualized as a taking a journey. This *event structure metaphor* includes explicit notions of source, path, goal, resources and obstacles. Particularly in the envisioned scenarios, the person using a computing system is doing something more like a goal-directed journey than working on a desk-top. We believe that we can exploit these general properties of the human conceptual system to produce a qualitative change in the usability of information systems. This requires active knowledge representations, but much of the basic work has already been done as part of a Cognitive Science collaboration on understanding natural language. The continuing campus/ICSI work on speech and natural language understanding (section 4.1.1) will also play a major role in the project.

Metaphor is also an important tool for understanding how learners progress along the full path from naive introduction to expertise in K-12 classrooms. Computers are becoming a significant part of the daily experience of many people, and computer jargon is well-established. In an interesting reversal, there is evidence already of metaphors being re-injected into the world by computer literati. This raises intruiging possibilities for mathematical and scientific learning in schools. Can students extrapolate their experience with computers to be a foundation for learning school subjects that are traditionally difficult to teach? Can play with simulation games build a good metaphorical basis for understanding system dynamics? Can students familiar with programming variables learn algebra much more quickly?

3.1.1 Computational Models of Behavior

An important piece of HCC is understanding the social and economic implications of computing. But how does one extrapolate from a single computational tool to a social context with thousands or millions of people using it? How does one understand the deployment itself, and competition between different tools? In computer science, Prof. Russell [Binder et al. 97] has developed a family of complex probabilistic models called dynamic probabilistic networks, which are sufficiently rich and flexible to represent a wide variety of complex physical processes (such as speech production) and human behaviours (such as driving in heavy traffic). These models can be learned directly from raw physical observations such as audio and video, and can then be used to recognize and predict behaviours such as uttering particular words or changing lanes without signalling. In addition to offering a promising technology for important interface tasks such as speech and gesture recognition, these models provide a path from studies with a handful of (real) human subjects, to simulations of large groups with different backgrounds, skills and resources.

3.2 Social, Cultural and Economic Impacts

Berkeley sociology has been a leader in interpretation of the social impact of technology. Seminal works such as Prof Fischer's [Fischer 92], [Fischer 98] and Prof Castells' trilogy [Castells] chart the implications of technologies from the telephone through the internet. Sociological understanding of human interaction is a key piece of the HCC agenda. People constantly incorporate and process information from within social contexts, contexts that are often unnoticed, underanalysed, or misunderstood by outsiders. Revealing, describing, and understanding social contexts will determine the effectiveness and success of human-computer interaction. Conversely, exploring human-computer interaction will provide invaluable data for sociologists concerned with issues of equity, sociocultural difference, and community. We focus, in particular on four issues:

Diversity. To serve the needs of the broadest population, human-centered computing will need to ensure access to and incorporate the needs of a diverse population. e.g. Autonomous learning tools need to adapt to the background and skills of the various learner groups.

Culture. Working with a broad range of people will demand a sensitivity to the learned, sociocultural differences among human interaction patterns.

Group dynamics. As people begin to interact with each other, facilitated by technology or not, more lasting relationships form. By studying computer-mediated human-human interaction, we can better understand whether and how it replicates or distorts "natural" group dynamics and suggest what properties of those dynamics are most important to support.

Technological change. We are interested in the change implied by technology and in facilitating or hindering factors. For example, teachers's authority may be undermined by tools which their students master without their help.

3.2.1 Economic Impacts of Information Technology

Much of the work on the fundamental work on economics of information technology has been done at Berkeley by economists such as Joe Farrell, Richard Gilbert, Michael Katz, Dan Rubinfeld, Carl Shapiro, and Hal Varian. (This group includes 2 former chief economists for the FCC and 3 former chief economists for the Department of Justice.) Shapiro and Varian have recently co-authored a trade book on these topics [Shapiro and Varian 98]. The groundwork has been laid, but there are still many important questions surrounding this set of issues that have yet to be illuminated. In particular, the public policy implications of many of the following issues are still poorly understood.

Switching costs. Information systems are often comprised of several systems that interoperate: hardware and software, disk drives and media, operating systems and applications. Switching a single component of the system may incur significant switching costs. Lock-in is an acute issue for manufacturing industry (physical plant and well as IT), but corresponding factors apply to IT in the classroom and to teachers familiarity with it. Courseware is often multi-layered, with each layer being somewhat standard but often with limited compatibility with other layers.

Standards. The countervailing force to high switching costs are standards for interoperability. Will such standards emerge naturally, or must them be imposed? When is it in the self-interest of a firm to produce interoperabile products? In particular, how will schools and universities maximize interchangeability (and avoid obsolescence) of courseware?

Network effects. The value to a user of many kinds of information technology depend on the number of other users. For example, the value of a fax machine, email, the Web, or a piece of distance-learning courseware to one person may depend on how many people adopt it. These "network effects" have been extensively studied by economists in the past 20 years and raise the same issues noted above: what is their impact on individual schools, industries and societies?

Organizational structure. A fourth topic that involves both economic and sociological analysis is the effect of information flows on organizational structure. The rise of intranets will have a profound impact on how organizations function, and improved theoretical and empirical understanding of these impact is essential.

4 HCC View of Computing Research

The HCC view of computing partitions the field into interfaces, applications and systems, but with a human-centered slant on each. In the following, we describe topics that contribute to our center vision and the educational and industrial contexts we focus on.

4.1 Human-Centered Interfaces

4.1.1 Speech and Language Understanding

Prof. Morgan (ICSI and EECS) has had a long-term interest in robust speech recognition under relatively uncontrolled conditions (both in terms of the acoustic environment and speaking style) [Morgan and Bourland 95]. The wearable application we described for industry presupposes a very robust speech interface. We propose that a key piece to the improvement of such systems is the incorporation of a relatively large number of acoustic mappings to probability sequences. Each mapping would view the acoustic input from a different "perspective," and would generate a sequence of probabilities associated with that perspective. In current systems, there is a single such perspective (which is a feature vector consisting of something like a short-term spectrum or cepstrum, evaluated 100 times per second), and the stream of feature vectors is used to estimate a corresponding stream of phonetic probabilities. A multi-perspective system can succeed when just one of its perspectives is uncorrupted. A corollary benefit is that such a system is much better equipped to handle large speaker diversity, so that particular groups of speakers are not alienated from the technology because of their background.

4.1.2 Tactile Interfaces

The human hand is a wonderfully powerful input-output device for manipulating the natural environment. Furthermore, manipulation of physical objects is (almost) a universal skill, so interfaces based on haptics and 3d virtual objecst support a very broad range of users, without new skill learning. In contrast point and click interfaces make the task much more difficult than it needs to be by using planar interfaces with only visual feedback.

Our long term goal is to develop wearable tactile display hardware and haptic rendering algorithms for hands which, in combination with 3D visual displays, create the realistic sensation of manipulating and feeling rigid and compliant objects [Nicolson and Fearing 95]. This tool is useful both for learners manipulating 3DDI simulations (e.g. for physics or biology classes), and for many tasks on the factory floor (e.g. learning to perform tasks by touch when there is too much clutter to see the target). Our state-of-the-art tactile displays have 25 display elements per square centimeter, designed to be worn on a glove. The key technology we are developing is micro-fluidic actuators using micro-valve arrays. Fluidic techology should give us a low-cost, light weight, and wearable tactile display.

4.1.3 3D Direct Interaction

Berkeley computer science hosts the 3DDI project (`www.cs.berkeley.edu/~healey/MURI`), an interdisciplinary DoD research center on 3-Dimensional Direct Interaction. The goal of 3DDI is to develop the spectrum of technologies to allow people to interact in natural ways with 3-dimensional virtual objects, without wearing glasses, gloves or other hardware. 3DDI has focussed on the hardware technologies (3D real-time scanning, 3D autostereoscopic displays), and the algorithms to capture, render and simulate 3D content. It includes Profs. Canny, Malik, Forsyth and Sequin from the HCC project. 3DDI will contribute strongly to novel K-12 educational tools, providing a natural and simple way to explore, do experiments and record results in certain science subjects. Rigid body simulation is available now, and work is underway on real-time deformable simulation which provides a good substrate for simulation of biological items as well as demos for physics or math classes. 3DDI will also provide a variety of functionality to the wearable factory application, allowing the wearer to test and rehearse a maintenance operation, to see inside the machines and to sort through and find all the similar-looking screws and bolts of a disassembled mechanism.

4.2 Human-Centered Applications

These applications, although quite different, are unified by several HCC themes. One of these themes which will be important in future HCC applications is support for informal human expression. These applications preserve connotation and richness of meaning by allowing a user to express in a natural medium rather than constraining them to machine syntax.

4.2.1 Informal Design Tools

People engaged in creative and communication tasks tend to use ambiguous forms of speaking, writing, gesturing, and sketching when communicating ideas with others. Most computer system interfaces are not designed to support this style of interaction. Prof. Landay has been engaged for some time in the design of sketching interfaces for user interface prototyping. The sketch interface replicates the tools most familiar and comfortable to human designers. The goal of this research is to answer several basic questions about informal user interfaces:

Domains For which domains and tasks are informal user interfaces more effective than traditional graphical user interfaces?

Hardware Are alternative devices, such as large display surfaces and two-handed input, more appropriate than traditional systems in these domains?

Production How should an application translate between informal and more finished representations and when is a view that mixes both styles of representation more appropriate?

Recognition What role does recognition technology play in supporting informal interfaces?

Informal interfaces are particularly appropriate in the factory setting for improvising repairs or communicating faults to a production engineer upstream. They have intruiging possibilities for educational use. A learner, having just learned about Newton's laws, is asked to sketch a ball and draw a velocity vector next to it. But after completing the sketch, the sketched ball starts to move with the prescribed velocity, bouncing against the pen lines on the learner's screen. Such functionality is not difficult given already demonstrated technologies [Landay 96]. Such an interface is very attractive as an autonomous learning tool because there is no (irrelevant) procedural interface to be learned for placing ball and setting velocities, only the physical concepts themselves. Once a satisfactory conceptual sketch is drawn up, the learner can compile a production drawing which is esthetically cleaner and has a more realistic appearance.

4.2.2 Synthetic Knowledge Work Environments

One important aspect of knowledge work involves collaboration, especially asynchronous collaboration, such as the foreman to production engineer sketch mentioned earlier. That communication will often be a critique or ammendment to a design document written by the engineer. Empirical research [Sellen and Harper 97] suggests that, while people generally use electronic authoring capabilities to create a document, collaborative work, such as reviewing someone else's document, is still largely the domain of paper.

At least part of the problem is that the affordances of paper are superior to those of digital documents in a number of ways. Recent work, such as Multivalent Documents [Phelps and Wilensky 97] attempts to provide electronically some of these affordances. Once capabilities such as annotation can be done electronically, they immediate manifest many advantages over paper methods, and can even provide novel functionality, etc., annotations can be executable as well as declarative. In the context of the HCC, we propose to explore new interaction modes (sketching on physical paper and using computer vision, gesturing, touching documents) for document annotation. These work well in the factory context where the computing is ambient and there is need for rapid, ubiquitous and simple modes for making critiques.

4.2.3 User-Centric Information Access in the HCC

The rapid growth of the World Wide Web has made us all aware of the huge volumes of available information and the pressing need to develop better ways to organize, select, store, and use this information. While much research in information retrieval has focused on ranking algorithms, the real stumbling block for many users is the human-computer interface [Hearst 97]. Novel interfaces to complex, abstract collections of information have been designed and assessed using what is currently understood about human cognition. However, research into human cognitive and social processes is not always directed specifically to issues surrounding information understanding and use.

The HCC center will enable us to design and develop information access interfaces *in tandem* with research on human cognition and social processes. We will place a special emphasis on discovering what forms of information organization and presentation are appropriate for different users in different contexts. For example, biology students scanning an online museum will have different goals than casual visitors. Tradesmen, foremen, and engineers looking for information about a stamping machine have different backgrounds and will likely be looking at different things for different purposes. Investigations are needed to determine, from the users' point of view, how information is received and understood in various contexts.

4.2.4 PRoPs and Informal Gesturing

We are building physical [Paulos and Canny 98] and virtual avatars to support human-human interaction at a distance. The physical avatars are called PRoPs and are wireless, internet-connected telerobots. They are not anthropomorphic, but instead are designed as simple machines that support a broad range of activities. PRoPs are designed to fill in the gaps left by conventional teleconferencing technologies. We are also building more traditional (virtual) avatars to allow quick prototyping of PRoP functions. In both cases, preservation of the full richness of human gesture is important. The HCC will be critical for our understanding of what channels of interaction occur between people, so that we understand their priority for electronic mediation. And the use of telerobots as proxys for people raises many psychological and sociological questions. The HCC is the ideal vehicle to study them. PRoPs are a general-purpose telepresence technology, but certainly have value both for transporting school students to exotic locations, and for allowing key workers in large manufacturing organizations (like Ford) to rapidly "move" from one location to the next.

4.3 Human-Centered Systems Research

4.3.1 A Toolkit for Human-Centered Computing

Because the nature of HCC stresses interactions between the human user and the computer system, a critical component of any HCC system design is the specific protocols and communication channels for how those interactions are carried forth. One particularly important area of HCC application design is the capture, manipulation, presentation of multimedia data formats like audio, video, 3D and sketch data. Though there now exists a bulk of work on multimedia toolkits, no existing programming model successfully integrates state of the art technologies across communication protocols, user-interface design, computer vision, authoring, and visualization.

We propose to leverage ongoing work at U.C. Berkeley on multimedia toolkits by Prof. McCanne (developer of the Mbone video tool vic) [McCanne et al. 97] and others for the design of next-generation toolkits for human-centered computing. This work will develop a common architecture that will provide a platform for horizontally integrating and synthesizing diverse technologies across collaborative research sub-groups of the HCC center. This approach will lead to HCC system designs that are far more powerful than any single group could produce working, for instance, on one isolated HCC problem.

While knowledge gained through the design of this HCC toolkit would be beneficial in its own right, far more crucial benefits are reaped from the capabilities provided to center by such a toolkit. A key goal of the toolkit infrastructure is to enable rapid prototyping of HCC components that can be deployed and evaluated in the context of real user communities. To this end, we propose to apply the toolkit and its constituent HCC components to the instructional environment at Berkeley by giving students experimental access to a ubiquitous computing infrastructure in the classroom. Early efforts in this direction have included classes taught in the computer science collaboration lab (CoLab) in Soda Hall using a variety of MM software tools and integration strategies as described in 4.3.2.

4.3.2 Smart Spaces and Active Infrastructure

The "illustrated factory" example from earlier is difficult enough to achieve as described. But what if after the foreman's diagnosis factory, an outside contractor is called in to fix the problem? The contractors own A/V system and diagnostic tools must communicate with the companies. It must discover what kinds of sensors are in operation, what format the data is in, and what kinds of display devices might be available nearby. Similar problems arise in the context of giving presentations at a remote location with unfamiliar equipment. Prof. Katz and others in Computer Science are developing the tools to provide an intelligent, universal interface to the unkown infrastructure [Seshan et al. 97].

There are many research issues associated with realizing this vision of physical spaces that can announce their services (sensors, information servers, computation servers, but also environmental controls like lighting, heating, and ventilation) and adapt them to the preferred interfaces expected by users. Our goal is to design, implement, and evaluate such a ubiquitous service architecture and discover how it can be used to enable "universal remote controls," that is, a single portable, wirelessly connected device that can be used by an individual to interact with the physical world around them.

4.3.3 3D data representation

Prof. Zakhor has been a leader in 2D image compression methods. In future, much content will be either authored as 3D, or will be captured as 3D using computer vision or the kinds of hardware scanner mentioned in the description of the 3DDI project earlier. Thus 3D compression will be an important component of future computer applications for collaboration or immersive 3D interfaces for a variety of tasks [Chang and Zakhor]. Key technical problems to be solved in this area are: (a) what constitutes an optimal representation of the object or the scene? (b) what is the best camera trajectory to ensure that arbitrary view generation can be done satisfactorily from any angle? (c) how does one avoid occlusion problems? (d) what is the best user interface between the remote human observer and the compact representation in order to generate a feeling of being present? As we discussed above, this can have profound effects in the classroom.

5 Management and Collaboration Plan

In a project of this size, it is a challenge to create and nurture the close collaborations necessary to take advantage of the center's potential. We have carefully structured the center and its activities to foster those collaborations, imitating other successful interdisciplinary projects. Prof Canny currently directs the 3DDI project, a 10-PI, $1M/yr multidisciplinary project on 3D Direct Interaction. The most successful part of 3DDI has been the interdisciplinary collaboration between computer scientists and devices researchers and physicists, on two breakthrough devices, one for real-time 3D scanning, and the other a true 3-dimensional occluding display. This collaboration will from the core of the manufacturing focus of the HCC center. Existing collaborations across Cognitive Science will from the core of the education domain.

This project has much larger scope, and individuals with widely varying interests and backgrounds. In addition to two application foci, we have set up four interest groups. The interest groups are also multidisciplinary, but focus on a common goal or theme. From these groups, we expect to spawn further close knit collaborations (2 or 3 researchers) that will lead to the important results we expect, some of which we have described in the body of this proposal. The group leaders also serve as an advisory committee to the director and co-director.

It is essential for the project that close contact be facilitated between the participants from different disciplines. We are attempting to build a network of bridges across a huge intellectual space. We will build this network out from the scaffolding of current collaborations: Lakoff (Linguistics) and Feldman's (CS, ICSI) long-standing collaboration, Canny (CS) and Fischer (Soc.) who have begun collaboration and have a pending joint NSF proposal, Linn and diSessa's (Education) collaborations with several CS faculty, and the central position of SIMS and its ties to all of the groups in the proposal. Close contact will be essential while these bridges are being built. We have collected an extraordinary group of investigators. They are individuals at the top of their fields, but in addition they have shown genuine enthusiasm and recognition of the importance in the goals of this program, which is ultimately the project's true determinant of success.

Also important will be a (physical) center to be the focus of center activities. SIMS will house the HCC laboratory and is an ideal choice for that function due to its central location and links with many computer-related departments on campus. A 1200 sq-ft space will be dedicated to HCC research and will include video workstations for editing and annotation of video data (most collected externally in classrooms and workplaces), interaction workstations which will include a variety of physical interfaces, and equipment for human usability studies (e.g. eye-trackers) conducted inside the lab. Weekly meetings will also occur in SIMS' building (South Hall).

One full-time administrator will manage day-to-day details of the center activity. Dedicated center staff (administrative, programmers and postdoctoral researchers) will have offices either within the lab area space, or in other locations in South Hall (a second approx 200 sq-ft room is available for center functions). The College of Engineering has committed the funds to furnish the space for the needs of the staff.

The main center management functions will be performed by the following academic personnel:

- John Canny (Computer Science), Center Director and coordinator of Manufacturing focus and industry partnerships.
- Jerome Feldman (ICSI and Computer Science), co-Director and leader, Metaphors and Cogsci Group.
- Marcia Linn (Education in Math, Science and Technology), Education Coordinator.
- Peter Lyman (School of Information Management and Systems), leader, Behavior Group.
- Randy Katz (Computer Science), leader, HC Systems Group.
- Jitendra Malik (Computer Science), leader, New Interaction Modes Group.

Prof. Jerome Feldman, outgoing director of ICSI, will serve as liason with ICSI in coordinating the center's activity with the nascent effort in HCI at ICSI. As mentioned earlier, HCI will be one of ICSI's 3 areas of concentration. We anticipate direct involvement by the new ICSI director, once (s)he is appointed. The group memberships are given on the next page.

5.1 Impact on K-12 and University Classrooms and Industry

K-12 and university education, as we described earlier, is a central target of HCC, not a separable activity. Professor Linn will act as education coordinator, and will track classroom interventions of the various projects in the HCC. Some of these will be technical, others will study the difficulties of social context in effecting change (teacher training, facilities, attitude to technology etc.).

Manufacturing industry outreach will be managed by Prof Wright, who makes regular visits to Ford's Deerfield operation, as Ford is a partner in his Cybercut project. Partnerships with area computer companies will be the responsibility of Prof Canny. Strong industries ties in this project is essential for the project and will be one of the directorship's main functions.

The most successful industry partnerships in recent times at Berkeley have been through summer or part-time industry positions held by graduate students. Such internships form a strong connection between a faculty members research and the companies projects. The center will serve as a connection point between the graduate (and undergraduate) students involved in the project, and various partner companies. More direct partnerships involving faculty members are desirable. Again, the presence of a center provides a single point of contact for industry partners to gain access to faculty expertise in a broad range of HCC areas.

6 Participants

6.1 University of California, Berkeley

The main center management functions will be performed by the following academic personnel:

- John Canny (Computer Science), Center Director and coordinator of industry partnerships.
- Jerome Feldman (ICSI and Computer Science), co-Director and leader, Metaphors and Cogsci Group.
- Marcia Linn (Education in Math, Science and Technology), Education Coordinator.
- Peter Lyman (School of Information Management and Systems), leader, Behavior Group.
- Randy Katz (Computer Science), leader, Digital content Group.
- Jitendra Malik (Computer Science), leader, New Interaction Modes Group.

Center participants are listed below first by group membership, and then by departmental affiliation. Note that many researchers belong to several groups. The first person listed in each group is the leader of that group.

Cognitive/Metaphor group	**New Interaction Modes**	**Behavior Group**	**HC Systems Group**
Jerry Feldman (ICSI,CS)	Jitendra Malik (CS)	Peter Lyman (SIMS)	Randy Katz (CS)
George Lakoff (Ling.)	Nelson Morgan (ICSI,EE)	Claude Fischer (Soc.)	Steve McCanne (CS)
Andy Disessa (EMST)	George Lakoff (Ling.)	Manuel Castells (Soc.)	Avideh Zakhor (EE)
Marcia Linn (EMST)	Marti Hearst (SIMS)	Hal Varian (SIMS)	Larry Rowe (CS)
James Landay (CS)	James Landay (CS)	Andy diSessa (EMST)	Carlo Sequin (CS)
Marti Hearst (SIMS)	Ron Fearing (EE)	Marcia Linn (EMST)	Brian Barksy (CS)
Robert Wilensky (CS)	Paul Wright (ME)	Jerry Feldman (CS)	Jitendra Malik (CS)
Stuart Russell (CS)	Carlo Sequin (CS)	James Landay (CS)	James Landay (CS)
John Canny (CS)	David Forsyth (CS)	Marti Hearst (SIMS)	John Canny (CS)
	Ken Goldberg (IEOR)	John Canny (CS)	
	Kris Pister (CS)		
	John Canny (CS)		

Breakdown by department or institute, and abbreviation key:

CS = Computer Science:(12) Canny, Feldman, Landay, Katz, McCanne, Malik, Forsyth, Wilensky, Rowe, Sequin, Russell, Barsky
EE = Electrical Engineering:(4) Fearing, Zakhor, Pister, Morgan
ICSI = International Computer Science Institute:(2) Feldman, Morgan
SIMS = School of Information Management and Systems:(3) Lyman, Hearst, Varian
EMST = Education in Math. Science and Technology:(2) Linn, Disessa
Soc. = Sociology:(2) Fischer, Castells
Ling. = Linguistics:(1) Lakoff
ME = Mechanical Engineering:(2) Kazerooni, Wright
IEOR = Industrial Engineering and Operations Research:(1) Goldberg

Industry and Other Partners

6.2 International Computer Science Institute (ICSI)

1947 Center St. Berkeley, www.icsi.berkeley.edu

Dr. Jerome Feldman, jfeldman@icsi.berkeley.edu
Dr. Nelson Morgan, morgan@icsi.berkeley.edu

6.3 Microsoft Research

One Microsoft Way, Redmond, WA 98052

Dr. George Robertson, ggr@MICROSOFT.com (425) 703-1527

6.4 Xerox Palo Alto Research Center

3333 Coyote Hill Rd, Palo Alto, CA 94305

Dr. Mark Weiser, weiser@parc.xerox.com (415)812-4406

6.5 FX Palo Alto Lab

3400 Hillview Ave. No. 4, Palo Alto, CA 94304

Dr. Joseph W. Sullivan, sullivan@pal.xerox.com (650)813-7572, Fax:

6.6 Interval Research Corp.

1801-C Page Mill Road, Palo Alto, CA 94304

Dr. Krasimir Kolarov, kolarov@interval.com (650)842-6045

6.7 Visteon (Ford) Automotive Systems

16800 Executive Plaza Drive, Dearborn MI 48126

Dr. Charles Szuluk, President (313) 390 9400

6.8 NEC Research Labs

110 Rio Robles, San Jose, CA 95134

Dr. Yoshinori Hara, hara@ccrl.sj.nec.com (408)943-3001

6.9 Adobe Corp.

345 Park Avenue, San Jose, California 95110-2704

Dr. Dan Brotsky, dbrotsky@adobe.com 408-536-4150

7 Resource Commitments

The University of California will commit the following resources for the HCC center if funded.

7.1 Laboratory Space

A 1200 square-foot contiguous space has been set aside for the HCC center in South Hall. South Hall is one of the original campus buildings, is located in the middle of campus, and houses the School of Information Management and Systems (SIMS). This space will be for novel interface and application testing, and for usability studies with human subjects. It will also contain video editing and analysis stations for study of video taken off-site. Space on the Berkeley campus, especially central campus, is exremely precious. So this lab represents a substantial commitment by the University.

7.2 Cash Commitments

The total University commitment for the first five years is approximately $1.575M, comprised as follows:

The Provost for research (Prof. Cerny) has agreed to a reduction in the campus overhead rate by 25%, down to 37.8%. With the current budget, this amounts to a campus contribution of approximately $1.25M for five years, or $250k per year.

In addition, Dean Gray of the College of Engineering will contribute $250k for the center, comprising $50k/yr for five years.

Finally, chair Katz of Electrical Engineering and Computer Science will contribute $75k, comprising $15k/yr for five years.

7.3 Faculty Positions

The School of Information Mangaement and Systems has identified among its priorities human-computer interface and interaction, computer-based communications and networks, electronic commerce/ security/ privacy, electronic documents, management of information systems and services, cognitive/ social aspects of information systems, computer supported collaborative work, and databases/ datamining/ visualization, all of which contribute to the mission of the Center. We anticipate 6 positions in the above areas being open in the next few years. The Computer Science Division this year added HCI to its list of 6 highest priority areas in response to the center activity. The Division does not hire into fixed positions each year, but with at least 6 positions anticipated over the next 3 years, we anticipate a HCC-related hire before or soon after center activity begins.

7.4 ICSI Staff

As mentioned earlier, the International Computer Science Institute has designated HCI as one of its three priority areas. Since ICSI houses on average 80 researchers, the target for ICSI's HCI program should be about 30 researchers. The actual size of this effort will be strongly influenced by the opportunities for visitors and permanent staff to collaborate with Berkeley faculty. ICSI has historically maintained very close ties to Berkeley CS, and several faculty currently collaborate with ICSI researchers. The HCC center will therefore considerably amplify the ICSI HCSI effort, and lead to a larger number and duration of visits by top researchers in HCC areas. On the other hand, while ICSI will certainly build a HCI effort if the HCC center is not funded, the size and strength of that program will be substantially diminished. ICSI's approximately $4.5M annual budget, roughly a third of which should be channeled into HCI, therefore factors in as a substantial partnership commitment.

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