View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by UCT Computer Science Research Document Archive

AI & Soc (2005)
DOI 10.1007/s00146-005-0018-1

ORIGINAL ARTICLE

Edwin H. Blake · William D. Tucker

User interfaces for communication bridges across the digital divide

Received: 1 December 2004 / Accepted: 2 June 2005
© Springer-Verlag London Limited 2005

Abstract Connecting people across the "digital divide" is as much a social effort as a technological one. We are developing a community-centred approach to learn how interaction techniques can compensate for poor communication across the digital divide. We have incorporated the lessons learned regarding social intelligence design in an abstraction and in a device called the SoftBridge. The SoftBridge allows communication to flow from endpoints through adapters, getting converted if necessary, and out to destination endpoints. Field trials are underway with two communities in South Africa: disadvantaged Deaf users and an isolated rural community. Initial lessons learned show that we have to design user interfaces that allow users to understand and cope with delay. We also learned that social concerns are often more important than the technical issues in designing such systems.

Keywords Community-centred · Digital Divide · Information Society · Multi-modal · User interface · User-centred design

1 Information Society and Digital Divide

One might characterize a developing country as the one where there is a great need for better and more equitable access to resources. We view an *information society* as the desired outcome of the information revolution sparked by information and communications technology. *Knowledge* resources can potentially be distributed to the *have-nots* without taking away from the *haves*. Information technology (IT) can be used in a developing country to extend the distribution of

---

E. H. Blake (✉)
Department of Computer Science,
University of Cape Town,
7701, Rondebosch, South Africa
E-mail: edwin@cs.uct.ac.za

W. D. Tucker
Department of Computer Science,
University of the Western Cape UWC,
7535, Bellville, South Africa
E-mail: btucker@uwc.ac.za

scarce knowledge resources. Building an information society demands the formulation of clear goals for society. Technology cannot be appropriately applied when what is appropriate is not known, but whatever the societal goals, we can assume that IT can provide a cost-effective way of reaching *some* of those goals.

The term *digital divide* refers to the major disparities in the penetration of the information society in the developing world. It is the growing gap that exists between those who have access to the Information Society and those who are deprived of such access due to cultural bias in the applications and contents, gaps in their education (eg., illiteracy), personal handicap, poor digital infrastructure, or lack of appropriate computer equipment.

The South African digital divide grows out of a history of division and historical backlogs for large groups of people: a particular South African version of colonial history. The digital divide also arises from global circumstances which apply to all developing countries. Thus there are two aspects to the digital divide:

(a) Global digital divide: The global disparity between those countries at the forefront of the information economy and the developing countries.
(b) Local digital divide: This refers to the disparities between groups in a particular country.

2 Bridging the divide

Bridging the digital divide is the effort to provide increased access to information and communication to those who have little or none at all. "Communication bridges" involve social dynamics as well as the technological tools that support social interaction. Our community-centred approach has produced innovative systems that provide new solutions to the issues that arise in building communication bridges. We support our user communities with new communication systems that are adapted to their requirements.

We mean quite literally that we build new computer-based artefacts that act as automatic communication bridges between various groups. The basic building block is a *SoftBridge*, introduced by Lewis et al. (2002, 2003). One application is to bridge communications between disadvantaged Deaf users by translating from text to speech and back again (Tucker et al. 2003). Another is to provide access to professional medical information for nurses in remote rural clinics, in the face of frequent power and other infrastructure outages (Chetty et al. 2003, 2004).

We are developing a methodology to support this design process as well. We have found that sophisticated bridging systems impose delays upon the communication process. Additionally, the unreliable nature of the infrastructure also can result in extended breaks in communication. Thus, compensating for delay is of major importance in building automatic communication bridges across the digital divide.

Allowing communications between different groups across the various digital divides requires a number of innovations. The issues we intend addressing are:

1. Changing in the way we design IT-based applications and contents
2. Putting the notion of bridging and translation central to our software systems and building that intelligence into the system
3. Exploring human computer interface techniques to deal with delay.

In the next section, we discuss a methodology for designing appropriate IT solutions. Then in the section on Automatic communication bridges we present our abstraction that incorporates the social intelligence, namely the SoftBridge. In the Current Status section we discuss the preliminary results from deploying our systems in two disadvantaged communities, one urban and the other rural. Finally, we provide a short conclusion.

3 IT application and contents design methodology

We believe a user-centred approach is most appropriate for designing our systems. We considered a number of approaches, using ideas from *Critical Action Research*: Lewin (1948), Stringer (1997), and Carr and Kemmis (1991). We have a cyclical software development method based on the participatory design and prototype evaluation. We retain the cycles of critical action research: diagnosing, planning, implementing the plan, observing results and reflecting on the results. Evaluations of each acting stage form the basis for correctly planning the next step in the process. Each evaluation may lead to modifications in the final goal.

Critical action research has a strong emphasis on the empowerment of groups. It involves facilitating a change in a community by facilitating action. This is done in collaboration with the community members. The flaw in this in terms of design, from our point of view, is that it assumes at least a degree of sophistication of the user community in relation to technological possibilities and ability of software designers to bridge the large cultural and linguistic gaps. Meeting these requirements is often impractical.

The cultural gaps can be enormous. The technological requirements exist within a complex web of other needs, relationships, and societal obligations. Misinterpretation (on both sides) and unexpected needs are common. It is difficult for IT practitioners to appreciate, for example, how an IT empowerment exercise may threaten power relations in such communities with dangerous consequences for several participants. For many reasons, therefore, end-user participation in the process can be problematic. Dray and Siegel (2003) have found a similar need for a wide, and culturally sensitive, view on the software process.

Our approach is to extend the team with advisers and consultants who are drawn into various stages of the design and development process. We have used the services of nongovernmental organizations (NGOs), other researchers already involved with a particular community, and professionals serving the community in other capacities (e.g., doctors). In the initial stages, these people form our "human access points" into the community. We engage a wider community rather than focus on the particular individuals who will be the users of the system. We strive to be aware of social subtleties. We call this a community-centred approach. Nishida (2002) has referred to two aspects of social intelligence: (a) the "conventional" one of an individual's capacity to act wisely in accordance with social rules and (b) the ability of a system to manage complexity of interaction. In our case, this corresponds first to requiring designers to discover and operate within the rules of the community (our community-centred method) and second to design a system to deal with some of the complexity (our SoftBridge abstraction).

The drawback in terms of experimental results is that a design by such a large team and the iterative development processes do not lend themselves to easy documentation of results. There is no defined group of users that can serve as experimental subjects – all are co-designers. Therefore, we can only strive to combine largely qualitative work with some quantitative empirical results wherever possible. A measurement system operates alongside the technology development cycle. Starting with an initial baseline, participants are surveyed to determine how they tolerate problems with their communication systems. Further measurements are made as subsequent software modifications are introduced in the field. The software is also instrumented to record activity metrics, such as actual usage and latency. These metrics are correlated with the participants' subjective experiences to give a measure of how well the interaction mechanisms compensate for problems with the bridge. This corresponds to Fujihara (2001) on control conditions: that is, using the system with and without the proposed enhancement as a means of measuring effectiveness within a spiral of developments.

3.1 Example: combining qualitative and quantitative data

In the trials of our tele-health system, MuTI, we collected qualitative data through semi-structured interviews. The themes were that the semi-synchronous approach would address the real-world problems of power outage, network downtime, and especially (un)availability of the doctor.

Quantitative data were collected by the system by logging various actual activities. We saw that the nurse instigated numerous requests that were mostly ignored by the doctor.

It is also interesting to note that during the interviews the nurse said she was using the system while the logs showed that exchange of messages rarely occurred. This is an aspect of the culture where a questioner invariably gets positive answers as a matter of politeness even if these are not actually true!

4 Automatic communication bridges

Our underlying systems-level abstraction is that of a generalization of the notion of quality of service in networked communication. Tucker et al. (2004) call this "quality of communication". It refers to the ability of a system to support communication by bridging between different user abilities, sensory and media modalities, infrastructure capabilities and terminal equipment facilities. In terms of "social intelligence" it reflects the aspect of the social intelligence of users to conduct meaningful exchanges in spite of the limitations of technologies ("where there is a will there is a way") as well as the aspect of social intelligence of the system where it adapts automatically to the user and system capabilities and bridges between different communication paths.

We call the abstraction, "SoftBridge", and have implemented several SoftBridges as computer artefacts. As an example of an actual implemented prototype, Lewis et al. (2002, 2003) demonstrate how a SoftBridge can tackle certain bridging operations (see Table 1). This SoftBridge translates between text from Internet-based chat and voice on the public phone system. Using freely available software tools, it easily converts text to speech. However, we have had limited success in translating spoken English into text. In the meantime, this automation is simulated in practice by a human who acts as the speech-to-text translator.

Another SoftBridge, called MuTI (multi-modal telemedicine intercommunicator) was developed by Chetty et al (2003, 2004). This SoftBridge prototype (see Table 2) relays text, images, and video in semi-synchronous fashion between users with a peer-to-peer architecture. The native languages of the users on either end differ, for example Dutch and Xhosa, but so far the users communicated in English, a second language for both. We have conducted field trials with MuTI in a remote rural community to enable a nurse at a small clinic to communicate with a doctor at a nearby hospital.

What has become clear by working with these prototypes in the field is whatever the SoftBridge is, the users will almost certainly always have to deal with *delay*. The processing inherent in the SoftBridge imposes the delay. This is especially noticeable in the Deaf Telephony SoftBridge where text-to-speech and speech-to-text translation produces processing overhead. However, larger-scale delay issues also arise in that the Deaf participants have transportation issues reaching the community centre where the system is located.

For the MuTI SoftBridge, as long as the network infrastructure is functional, propagation delays should be minimal. However, large-scale delay in delivering messages arises due to poor infrastructure in rural areas. Extended power out-

Table 1 The Deaf telephony SoftBridge enables a Deaf user on a PC to communicate with a hearing user on the telephone system (PSTN). The system automatically converts Deaf text to speech on the handset, but relays the speech from the hearing user to a translation operator to send text back to the Deaf user

	Deaf User	Hearing User
User	Written Text	Speaking/hearing
Modality	Text In/Out	Voice In/Out
Interface	IM Client	Audio
Device	Community PC	Handset
Network	Internet ADSL	PSTN

Table 2 MuTI is another SoftBridge that enables synchronous voice communication when the network is up and both parties are available. However, a store-and-forward mechanism is utilized when those conditions cannot be met. End-users can also exchange high resolution digital images, and the doctor can view video clips

	Doctor at Hospital	Nurse at Clinic
User	IT savvy	IT learner
Modality	Text, Voice, Image in	Text, Voice, Image out
Interface	GUI, Speech	GUI, Speech
Device	Laptop	Handset, webcam
Network	Unreliable WiFi	Unreliable WiFi

ages are common place in remote South African rural areas. Phone lines can often be down as well (copper wire is stolen). We have also found that the work schedules of the doctors and nurses in these populous remote areas also add up to large-scale delay because they are severely overburdened. A useful system must be able to switch seamlessly between synchronous and asynchronous modes of communication.

Our first result, namely the necessity of delay, may seem mundane, but it has far-reaching implications. Dealing with delay or latency in a socially intelligent fashion is therefore a prime problem and a focus of some of our current user-based research. The user must retain an appropriate sense of *co-presence*, as discussed by Zhao (2003), of the other person with whom these is being communicated. If the link is down but the person can still be contacted, albeit with delay, that sense of the other person must remain being there. Alternatively, if the link is up but the other person is absent, that fact has to be communicated.

We are concentrating on adapting communication content and its interfaces to user capabilities. By capabilities, we do not only refer to computer hardware and software, but also the capabilities of the user. Tucker et al. (2004) present five layers to bridge: the underlying *network*, hardware *devices*, the human computer *interface*, communication *modality*, and the actual *users*. These adaptation processes at some or all of these layers are performed by a SoftBridge. It is an embodiment of social intelligence design, both as an abstraction and as a concrete artefact. A SoftBridge enables us to design and, where practical, build applications that bridge vastly different access equipment (telephones, cellphones, hand-held mobile Internet Protocol (IP) devices, laptops, personal computers, head-mounted displays (HMDs) to communicate seamlessly using various communication media (text, voice, video, virtual reality) without regard to the underlying mechanics of the process.

A SoftBridge can also adapt to the user. For instance, if a user is blind, then the system would only deliver audio, or translate text into speech. If a user is Deaf, speech would be converted into text or into sign language. As another example, we could extract human communication from an information and graphics-rich collaborative virtual environment (CVE) and bridge it to a low-end user. Consider a text chat tool inside an immersive CVE with an IP bridge to a text chat tool running in a web browser. The content (text) and endpoint (HMD and video display) abilities remain, but the interfaces are bridged. User preferences and profiles can also be taken into account. For instance, if the sender is a male, he may prefer that messages from him are read out in a male voice.

5 Current status

Field trials are underway with two communities in South Africa. An NGO called Deaf Community of Cape Town (DCCT) serves a “disadvantaged” Deaf community that is marginalized from mainstream communications due to both poverty and hearing disorders. Voice/text relay enables a Deaf person to use a “text telephone” to communicate with someone on a normal telephone via an operator with both devices. Because this service is not available in South Africa, we have built an automated voice/text relay system based on web services. As noted before, automatic speech recognition not only introduces delay, but also performs poorly, especially with South African-accented English. Tucker et al. (2003) report on preliminary trials and how they influenced the back-end development.

The second community, constituting an entirely different scenario, is located in a remote rural region. Tsilitwa (Eastern Cape, South Africa). This region has a clinic without a doctor and serves roughly 10,000 people. The Centre for Scientific and Industrial Research (CSIR) installed a wireless Ethernet network with basic voice and video over IP to allow the clinic nurses to communicate with a doctor in a neighbouring village. However, the system was rarely used due to frequent power outages and schedule conflicts. Visits to Tsilitwa, workshops with the CSIR, and frequent communication with a local NGO called bridges.org, have together yielded software requirements for a multi-modal store-and-forward system to overcome the power problems. A prototype has been deployed by Chetty et al. (2004).

5.1 Initial results from the Deaf-Hearing Bridging Project

As noted before, our research proceeds in cycles. The first cycle of testing of the Deaf telephony project involved a single Deaf user, as reported by Tucker et al. (2003). Based on frequent communication with a "human access point," a communication-disorder researcher working with DCCT for a number of years, we came up with the basic requirements for an automated relay system. We built several prototypes, and then used one for a laboratory test. We conducted three tests varying the input/output modalities of the hearing user. The Deaf user had a standard text in/text out instant messaging client. The hearing client used the following specific modality combinations: text and text-to-speech (TTS) in/text out, TTS in/text out and TTS in/text and automatic speech recognition (ASR) out. The SoftBridge logged the conversations for subsequent analysis.

The trial showed a largely successful conversation. Success factors included: (a) a text and computer literate Deaf user who is familiar with research practice, (b) using the system to explain the research as we conducted it (instead of using an interpreter), and (c) that the multi-modal bridging capabilities overcame the expected shortcomings of TTS and especially ASR. This cycle revealed that:

1. Deaf users use a different grammar (related to South African Sign Language) and this cannot be automatically corrected for hearing users.
2. ASR is inadequate to the task of recognizing South African English and other South African Official Languages and in the meantime we will have to mimic ASR by employing a person to provide the service.
3. Presence indicators are needed to show continuation of the conversation when there is no visible activity due to delays.

We made the necessary changes in the software addressing points 2 and 3 above that clearly aligned to the user interface. However, due to subsequent meetings with our "human access points", namely our research partner and DCCT, we realized that modifying the software was not enough. We needed to train the Deaf end-user community to be able to use the next version of the software. Therefore, we delivered a tailor-made training course and administered the course to 20 participants (Glaser et al. 2004). After the course, we made several PCs available during specific times of the week, always with one of our research team present with a Deaf interpreter. We learned that we should actually continue these "practise" sessions for several months before testing out our automated relay software. These sessions mainly consist of hand-holding through typing tutor and email use. Instant messaging has not proven popular. This is due to two reasons. First, the hearing users who the Deaf wish to contact do not have readily available Internet access. Second, the Deaf find it difficult to travel to the community centre and therefore have very limited time in front of the shared PCs. We are currently arranging more PCs for the centre, and are about to commence the next round with a more recent SoftBridge prototype. We expect enthusiastic use of the software since DCCT leaders have been instrumental in the "practise" sessions and have begun to weave the PCs into the fabric of the community centre.

6 Initial results from the Rural Tele-Health Project

The tele-health software was deployed over the course of 2004. We visited the target community at the rural site six times. The first visit was for orientation, and the second for presented a paper prototype. Introduction of the software occurred upon the third visit. We were able to introduce two modifications in subsequent visits, and during the most recent visit we only collected data. In introducing the software, we have been struck by the complicated community interactions that determine whether an IT solution will be accepted. For example, we found that the doctor and nurse had not once met each other face-to-face until we began our research cycles. The power definitely sits with the doctor: system use is entirely dependent on the doctor responding to a nurse's enquiries. We also had to negotiate sensitive community politics during and between visits.

The essential idea is to allow a nurse in an outlying village to communicate with the solitary doctor at a village hospital about 12 km away. A video conference link, or even a synchronous Voice over Internet Protocol (VoIP) call, is problematic because frequent power failures render networks useless for lengthy periods. Due to the shortage of staff at the hospital, tele-medicine is an additional workload for the doctor who is solely responsible for the entire hospital. It is difficult to schedule times when a synchronous tele-medicine consultation can occur.

We determined that combining a store and forward approach with synchronous VoIP would resolve the communication problems. Store and forward was explained to participants in terms of voice-mail on cellular telephones and everyone was familiar with these. A store and forward user interface allows patient data to be captured at any time and then sent to the recipient site when a network connection becomes available. We decided to introduce laptops since they provide several hours of battery life. This means that data can be captured even during a power failure and as long as the battery-power lasts. The store and forward interface was introduced for both the doctor and the nurse. Both of them indicated that they thought the store and forward system would be superior to the existing real-time only system.

In order to still allow for real-time communication, we architected the software to support both synchronous voice calls and asynchronous sending of multi-modal messages between the clinic and the hospital. At some point, the availability of recipients can automatically determine the appropriate communication stream and interface. These communications can contain text indicating the patients' illness and medical history, digital pictures of the patient or particular problem area, and voice recordings. We are currently working on a prototype to add semi-synchronous video as well.

Our visits over the 9 month period operated as follows: collect baseline data from the previous cycle (including usage statistics and qualitative feedback on the system for changes in the next cycle), introduce and train on the new prototype, and ensure that the system worked before we left. For the first 3 months, we found that the nurse used the system only nine times, and the doctor only eight. There were only 3 days when a synchronous communication could occur. We recognized that we especially needed to support the doctor to use the system, and made an extra effort to befriend him. The next cycle was a bit more encouraging: the nurse created 20 records, yet received only four back from the doctor. The doctor, however, did attempt to call the clinic 14 times. During the last cycle, the system went almost entirely unused. We feel this is mostly due to the fact that the doctor returned to Cuba at the end of the period and there was no replacement.

7 User experience

Our trace files and database logs showed that MuTI usage was low overall. Initially, the system was hardly used but the usage increased over the evaluation period. It declined again at the end when the doctor was leaving. The nurse in the clinic used MuTI more than the doctor at the hospital; this was due to the doctor's busy schedule.

The participants used MuTI to send records and make calls. Though calls from both parties were frequent they were generally unanswered by the other party due to the busy work schedules. The participants then resorted to voicemail rather than text. This clearly indicates the infeasibility of the previous system, which MuTI replaced, that tried to emulate a telephone over IP.

In interviews the doctor especially found the asynchronous aspect of MuTI very useful. He gave examples wherein he was able to gather more information on a case with in his time and could respond to the nurse. In interviews, all parties agreed that the indicators of co-presence, that is, indications of presence even when that the other party was not available, were very important.

A cultural factor affecting the design of the system was that the participants did not criticize the MuTI interface very much. Criticism is seen as a sign of disrespect. The designer has to be aware and phrase questions so that the users can respond with positive suggestions.

8 Conclusion

We have shown how "social intelligence design" can be applied to IP-based communications in a developing country. Aspects of social intelligence influence the systems, the users, and the researchers. It is especially the IT professionals who have to move from a software development lifecycle-based view of systems development, to seeing the microcosm in which their users operate that is, the community and the macrocosm in which everyone exists, that is, the laws of the society.

The implications for IT artefact development is that one has to develop a methodology that can operate in a very sensitive manner within the culture of the users (our community-centred method) and help the users to deal automatically with the complexities of communicating knowledge (abstracted as the SoftBridge). Both these are aspects of social intelligence design.

In the work we have done so far we have shown that, in building a device such as the SoftBridge, dealing with delay is an essential feature. We have argued that this has major implications for user interface design.

Acknowledgements This research was supported by many organizations and people, both fellow researchers and community members. Resources were provided by the NRF, the South African National Research Foundation through its THRIP and Focus Areas programmes, Telkom, Siemens SA and SANPAD, the South Africa — Netherlands Research Programme on Alternatives in Development. The CSIR Information and Communications Technology Section introduced us to village of Tsilitwa and provided the WiFi infrastructure that we used. The NGO "Bridges.Org" acted as a consultant on the applicability of the work. DCCT also worked with us to facilitate the Deaf telephony project. Over the past 3 years, our students have provided many ideas and inspiration, in particular the authors would like to thank Mr John Lewis for developing some of the SoftBridge systems discussed, and Ms Marshini Chetty for developing MuTI and the tele-health research.

References

Carr W, Kemmis S (1991) Becoming critical—education, knowledge and action research. The Falmer Press, London

Chetty M, Tucker WD, Blake EH (2003) Using voice over IP to bridge the digital divide—a critical action research approach. In: Proceedings of South African Telecommunications and Networking Application Conference (SATNAC 2003). George, South Africa, CD ROM Publication

Chetty M, Tucker WD, Blake EH (2004) Developing locally Relevant applications for rural areas: a South African example. In: Proceedings of South African Institute of Computer Scientists and Information Technologists (SAICSIT 2004), Cape Town, South Africa. pp 239–234

Dray S, Siegel D (2003) Learning from Latin America: methodological lessons from emerging markets. In: Proceedings of the contextual invention, pp 9–18

Fujihara N (2001) How to evaluate social intelligence design. In: Proceedings of social intelligence design 2001. http://mailer.kc.t.u-tokyo.ac.jp/synsophy/sid2001

Glaser M, Tucker WD, Mashao D (2004) Preparation of Deaf end-users and the SoftBridge for semi-automated relay trials. In: Proceedings of the South African Telecommunications Networks & Applications Conference (SATNAC 2004), Stellenbosch, South Africa, CD-ROM publication

Lewin K (1948) Resolving social conflicts: selected papers on group dynamics. 1st edn. Harper & Row, New York

Lewis JA, Tucker WD, Blake EH (2002) SoftBridge: an architecture for building IP based bridges over the digital divide. In: Proceedings of South African Telecommunications and Networking Application Conference (SATNAC 2002), Champagne Sports Resort, KwaZulu-Natal, CD ROM Publication

Lewis JA, Tucker WD, Blake EH (2003) SoftBridge: a multimodal instant messaging bridging system. In: Proceedings of South African Telecommunications and Networking Application Conference (SATNAC 2003). George, South Africa, CD ROM Publication

Nishida T (2002) Communicative reality for social intelligence design. In: Proceedings of the IEEE Workshop on Knowledge Media Networking (KMN'02). IEEE

Stringer E (1997) Action research: a handbook for practitioners. Sage Publications, Beverty Hills

Tucker WD, Glaser M, Lewis J (2003) SoftBridge in action: the first deaf telephony pilot. In: Proceedings of South African Telecommunications and Networking Application Conference (SATNAC 2003). George, South Africa, CD ROM Publication

Tucker WD, Blake EH, Marsden G (2004) Open user interconnect and quality of Communication. In: Proceedings of the 7th South African Telecommunications Networks & Applications Conference (SATNAC 2004), Stellenbosch, South Africa, CD-ROM publication

Zhao S (2003) Toward a taxonomy of copresence. Presence: Teleoperators and Virtual Environments, 12(5):445–455. http://mitpress.mit.edu/journals/pdf/pres 12 5 445 0.pdf