Using Digital but Physical Surrogates to Mediate Awareness, Communication and Privacy in Media Spaces

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Abstract: *Digital but physical surrogates* are tangible representations of remote people (typically members of small intimate teams), positioned within an office and under digital control. Surrogates selectively collect and present awareness information about the people they represent. They also react to people's explicit and implicit physical actions: a person's explicit acts include grasping and moving them, while their implicit acts include how they move towards or away from the surrogate. By responding appropriately to these physical actions of people, surrogates can control the communication capabilities of a media space in a natural way. Surrogates also balance awareness and privacy by limiting and abstracting how activities are portrayed, and by offering different levels of salience to its users. The combination of all these attributes means that surrogates can make it easy for intimate collaborators to move smoothly from awareness of each other to casual interaction while mitigating privacy and distraction concerns.

Exploring different surrogate designs and how they work together can be straightforward if a good infrastructure is in place. We use an *awareness server* based on a distributed model-view-controller architecture, which automatically captures, stores and distributes events. We also package surrogates as physical widgets or *phidgets* with a well-defined interface; this makes it easy for a programmer to plug a surrogate into the awareness server as a controller (to generate awareness events), or view (to display events that others have produced), or both. Because surrogate design, implementation and use is still a new discipline, we also present several issues and next steps.

Keywords: Ambient displays; Awareness; Casual interaction; CSCW; Groupware; Tangible bits; Ubiquitous media spaces

1. Introduction

Digital but physical surrogates are "out-of-the-box" physical representations of remote people – typically members of small intimate teams – positioned within a person's environment. As we will see, surrogates create a media space. They embody awareness information of others, present opportunities for interaction, react appropriately to a person's explicit and implicit actions, and control the appearance of the communication channel.

Using out-of-the-box devices to represent activities of distant people is not a new idea. As we will summarise in Section 2.4., artists and researchers alike have proposed or built one-of-a-kind systems that play with this notion. Since this breakthrough work has been done, it is time to think more deeply about the ways these ideas can be replicated, structured and applied. This foreshadows an ambitious research agenda. To place this into perspective, our current understanding of conventional graphical user interface design has required 30 years of research and evolutionary development since the breakthroughs made by Sutherland [1] and Engelbart [2].

Our own belief is that physical devices present new opportunities for thinking about and designing media spaces. Our two particular goals are to design and leverage these surrogates to:

Goal 1: Support the smooth transition from awareness, to casual encounters, to conversation, and to work.

Goal 2: Mitigate privacy and distraction concerns endemic to most awareness systems.

In this paper, we describe the idea of digital but physical surrogates and how they can facilitate casual interaction between intimate collaborators. First, we briefly review why casual interaction between collaborators is beneficial and how technology can help this happen even when collaborators are separated by distance. We include a summary of a small set of design goals and trade-offs, and how alternate approaches for casual interaction based on physical devices can be used instead. In Section 3, we present our own variation of this latter idea by illustrating a variety of digital but physical surrogates that we have built in our laboratory. In Section 4, we broaden the discussion by reasoning that these surrogates can mitigate concerns about distraction and privacy: they can portray limited and abstracted representations of another's activities, and they can present different degrees of salience. Section 5 briefly describes the underlying architecture behind our system, while Section 6 summarises our usage experiences. Because we recognise that this work is at the beginning of a broader research agenda, we close the paper by indicating several research issues and the next steps that should be taken.

2. Casual Interaction

2.1. The problem

The backbone of everyday coordination and work between co-located team members is *casual interaction*, the spontaneous and one-person initiated meetings that occur over the course of the day [3]. The glue behind these interactions is *informal awareness*, where people track and maintain a general sense of who is around and what others are up to as they work and mingle in the same physical environment [3,4].

Yet casual interaction is problematic in distributed communities. It is no surprise that casual interaction drops exponentially with distance [3]; awareness of others and, consequently, opportunities for interaction diminish considerably when people are out of sight. Substituting an electronic communication channel is not enough: while groupware is readily available, people still have considerable trouble establishing real-time electronic contact [4]. If casual interaction is to be supported, systems must also provide community members with some measure of awareness of who is around and how available that person is for conversation, as well as a very lightweight means to move from that awareness to an encounter to communication and work.

2.2. Conventional approaches

CSCW researchers are quite aware of this problem, and many have developed methods for providing informal awareness and mediating casual interaction in distributed communities. These include:

- ***media spaces***, where people select offices and common areas at remote sites via a switching mechanism, and then view these sites through continuous (always on) video [5];
- ***video glances***, where a "call" to a remote person's office creates a brief two-way video-only connection (the glance), and where one or both parties can extend this glance into a full video/audio call [e.g. 6];
- ***periodic video snapshots***, where the community is presented on one's screen as an array of small low-fidelity images updated every few minutes [7,8];
- ***iconic indicators***, where stylised icons portray abstractions of awareness information [9,10,11]. Figure 1 illustrates an example we have built.

2.3. Design goals and tradeoffs

A variety of design goals and tradeoffs underlie those systems that support casual interaction between distant-separated collaborators, as summarised here.

1. Provide appropriate awareness information that people can interpret with little effort.
2. Support a smooth transition of people moving from awareness into conversation. At issue here is whether there is a need to open a separate communication channel, and the

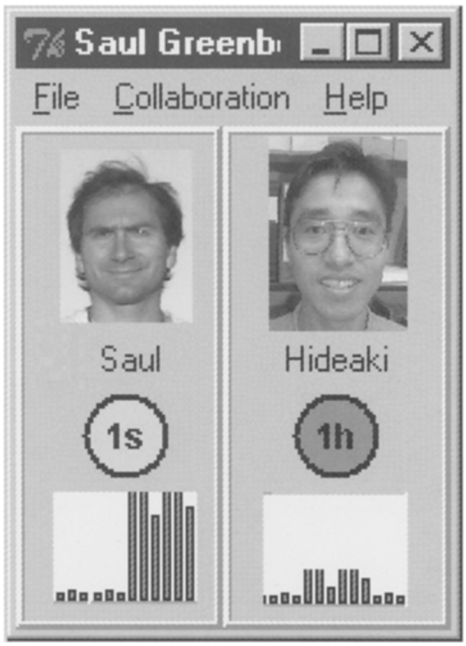


Fig. 1. Our iconic indicator. Images fade as the remote person's interest in the local person decreases [9]. Lights indicate by colour [10] and text how much time has passed since the person last touched their computer. Bar charts graph the degree of a person's motion over time e.g. Saul has recently entered his office, while little activity has been seen in Hideaki's office.

amount of work the person has to do to open that channel

3. Balance the effects of giving too much information, where the information presented runs the risk of being distracting rather than helpful. At issue is whether the information is presented in the foreground of consciousness (with high risk of distraction) or in the background (which risks being overlooked).
4. Balance awareness with privacy. Issues include how and where reciprocity should be maintained [12], the degree that one is allowed to intrude into another's space, the degree of control over what information is presented to others and what channels are opened, and maintaining social cues that let people prepare for others coming into their space.

Aside from these design issues, we are particularly concerned with the fact that most media space approaches channel awareness and communication through a single device [13], typically a computer. This leads to several implications of how media spaces are developed and used within conventional graphical user interfaces.

1. Awareness displays compete with other computer programs. Dourish and Bly [7] report that Portholes users often could not see the video snapshots of others because they were hidden under other windows, an experience we shared in our own use of iconic indicators. The screen is too busy a place for displaying awareness information.
2. For many people, a computer is a peripheral, seldom-used device. People cannot attend to awareness information if they are not attending to the computer.
3. The single display may represent several people, several communication channels, and several groupware applications. The consequence is an overly-complex interface for establishing communications with particular people and switching between them [14].

2.4. An alternative approach: physical devices

We can partially solve these three problems while still satisfying the awareness design goals by using physical devices [15] (separate from computer screens) to capture and present a remote person's activities. As mentioned in the introduction, this is not a new idea, and many "one-of-a-kind" systems have been developed both by artists and by researchers, as summarised below.

A variety of art installations suggests approaches for using physical devices to support an abstracted sense of awareness. In all of them, the devices do not present themselves as traditional computers even though the underlying communication and control system is computational.

A first approach promotes interpersonal intimacy over distance. With *Feather* and *Scent*, a traveller's manipulation of their partner's surrogate (e.g. a picture) is presented as events in their partner's environment, i.e. as a feather drifting within a cone, or as the release of a pleasant scent [16]. (See also [17, 18] for a discussion of how awareness can be presented as pure abstract representations.)

A second approach promotes play, where manipulating one toy encourages another to respond on its counterpart. For example, *Shaker* [16] encourages symmetric play, where shaking a sending device causes a receiving device to vibrate. *Hand Jive* is another pair of devices designed for play, each with two movable but connected balls [19]. Moving a ball on one device causes its partner ball to move on the other; people play together by developing patterns of movement and rhythms. Similarly, inTouch [20] is a haptic device that gives the illusion that two distance-separated people are manipulating the same physical device. It comprises two devices, each consisting of three cylindrical rollers mounted on a base. When a person rotates one of the rollers, the corresponding roller on the remote object rotates in the same way. Through force feedback, the two partner can feel, stop, or counter each other's motions.

A third approach uses networked furniture to promote awareness between those who use them. The *Internet Bed* relays an abstracted sense of presence between intimates on different beds [21]. For example, the presence and motion of a person on one bed may be translated into warmth and heartbeat sounds on the other bed. Similarly, the *Bench* warms a bench in one location to reflect a person sitting on another bench. What makes this especially interesting is that the benches will gradually open a voice channel when strangers sit on equivalent spots [22].

We can also enrich direct communication by channelling it through a variety of everyday physical devices situated in one's environment, which Buxton described as *ubiquitous media spaces* [13]. These devices take advantage of architecture, where the media "preserves or builds upon conventional location-function-distance relationships". Buxton's work concentrated on integrating video into this space. Examples include his Hydra units for multiparty videoconferencing, where each unit (comprising a small video display, camera, speaker and microphone) acts as a video surrogate for a remote person. Some awareness is supported by situating these devices in strategic locations: mounting a Hydra unit above an office door means that people can "walk by" and "glance in" via video. The office occupant can see who is going by and respond if desired.

As mentioned in the introduction, we wanted to reflect on physical devices as new opportunities for thinking about and designing media spaces. Our own solution of digital but physical surrogates combines into a single device the artistic community's use of physical devices for awareness, Ishii's notion of tangible interfaces [15,20], and Buxton's use of video surrogates for communication within a ubiquitous media space [13,14]. We also use the notion of reactive rooms, where devices within a room are controlled automatically by inferring a person's intentions from their actions within the room [23].

However, our goal is to go beyond simply creating yet another set of devices; rather, we want to use them to help develop our thinking into how these devices can be applied. In particular, we wanted to create surrogates that explicitly helped intimate work collaborators move from awareness to encounters to communication to work. We also wanted to see how such surrogates could be designed to mitigate privacy concerns by transmitting only selected awareness information and by having people control what was transmitted and received by both explicit and implicit actions.

We first set the scene by illustrating with our own examples what we mean by these digital but physical surrogates, and how they help people move from awareness to interaction. We will defer discussing how surrogates balance awareness, privacy and distraction until a later section.

3. Moving from Awareness to Interaction

Goal 1. Support the smooth transition from awareness, to casual encounters, to conversation, and to work.

In this section, we contend that surrogates can be designed to satisfy our first goal. We do this by briefly presenting a progression of surrogates that we have built, and the ways they can be combined (a video is also available that documents our examples [24]):

- surrogates that indicate activity and availability of remote people,
- surrogates used by a local person to indicate interest in a remote person,
- surrogates used to embody the communication channel and to manage the media space.

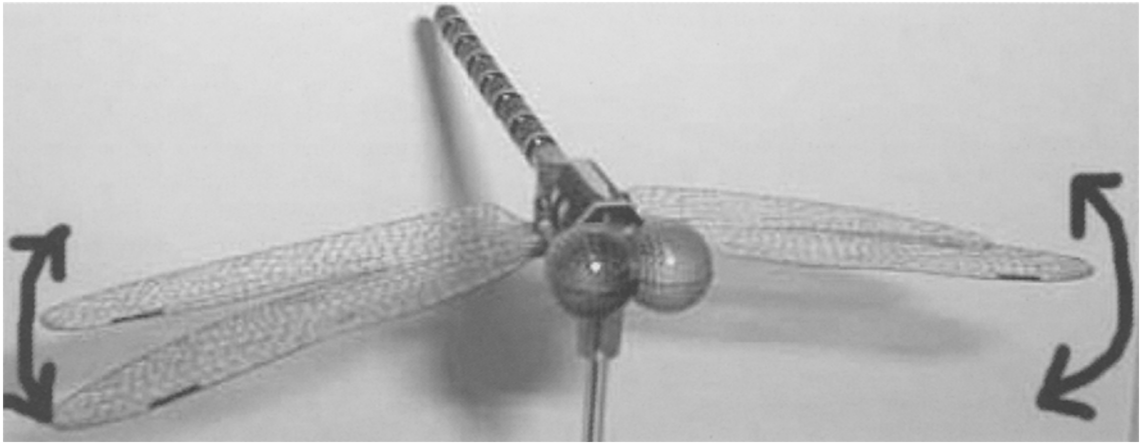
We should mention that our devices are prototypes, constructed using toys, hobby models and simple sensor technologies. These give them a somewhat whimsical appearance. The form factor of these surrogates would, of course, change significantly if they went out to product.

3.1. Surrogates that indicate activity and availability

The first class of surrogates illustrates how activities of a remote person can be embodied within a physical surrogate located in a local office. They assume that some information about the remote person has been captured and is now available locally for display (see Section 5). This class of surrogate is responsible for presenting that information in a way that the local person will be aware of some aspect of the other's activity, which he or she can then use to infer availability.

The dragonfly surrogate is an off-the-shelf motorised model altered so that its motor is under digital control (Fig. 2a). The dragonfly's activity corresponds with bursts of activity by the remote person (we detect this using a video-based motion sensor we have built). When the remote person is inactive or absent, the dragonfly too is inactive. As a person enters the room or becomes active, the dragonfly flaps its wings furiously and audibly for a few moments, but then quickly slows to gentle and quiet wing motions for about a minute afterwards. This is somewhat equivalent to a person in an open office noticing large movements of the coworkers inhabiting the shared space. Thus the dragonfly portrays changes of states in activity.

The peek-a-boo surrogate attaches a figurine atop a servo motor (Fig. 2b). The surrogate faces the wall when the remote person is unavailable or inactive (e.g. when the person is out of the office), but rotates to face the local person as the remote person is noticed. When the surrogate rotates, a slight sound is produced which also attracts



a. Dragonfly surrogate.

b. Peek-a-boo surrogate.

c. Light show surrogate.

Fig. 2. Three surrogates indicating activity and availability.

peripheral attention (the larger the rotation, the longer the sound). As long as the person is active, the surrogate continues to face forward. On inactivity, the surrogate eventually faces backwards. Consequently, one can estimate another's availability at any time by glancing at the surrogate's orientation: the more it faces oneself, the likelier the other person is actually present. The novel aspect of this surrogate is that – unlike the dragonfly – the surrogate represents not only changes in state, but also a person's current state through its orientation.

The light surrogate displays another person's activities as the movement of light patterns across the ceiling of a room (Fig. 2c). Inspired by Ishii and Ullmer's use of light reflection from water onto a ceiling to create an ambient display [15], we project light through a water-filled glass tray. The tray contains coloured particles, and an immersed motor under computer control swirls the water whenever the remote person's activity is noticed. This illustrates that surrogates can present information in the background of consciousness (i.e. as an ambient display;

[15], and that surrogates can be abstract entities [17,18] as well as figurines.

Discussion: These surrogates act as physical counterparts to iconic indicators (e.g. Fig. 1), as they show abstracted activity information. They not only can show transient events as they happen (as done by all three surrogate examples), but can also remember state (as with the peek-a-boo surrogate). They have the advantage of being part of the physical environment, and thus can be seen and heard even when the person is not attending the computer. They can also be positioned anywhere in the environment, where their placement can influence how they are perceived, i.e. as foreground or background devices. They can also be "blended" into the architectural space, e.g. in terms of how the light surrogate interacts with existing light levels [15]. Of course, a variety of other designs is possible. For example, we can instrument everyday appliances to act as surrogates, such as lava lamps, fans, and so on.

By themselves, these surrogates suffer problems similar to iconic indicators. While they indicate serendipitous and opportune moments to contact others, it may be difficult for a person to take advantage of these opportunities if these surrogates are disconnected from the communication channel. The person is forced to select and activate a communication channel explicitly through some other mechanism. Thus we expect that opportunistic interaction would be rarer as establishing contact involves an explicit choice and extra work. We will show shortly how this limitation can be removed.

3.2. Surrogates used to indicate interest in others

The next class of surrogates illustrates how one person can explicitly express different degrees of interest in a remote person as well as one's availability for interaction by manipulating a surrogate. These facilitate one-person initiated encounters.

The mutant ninja surrogate is a figurine located in co-author Greenberg's office that represents (in this case) co-author Kuzuoka (Fig. 3a). It transmits rather than presents availability information. When Greenberg holds the figurine (which is instrumented with a heat sensor), Kuzuoka is notified that Greenberg is interested in him. For example, the peek-a-boo surrogate mentioned in Section 3.1. may rotate back and forth a few times to attract the remote person's attention, or the light surrogate may swirl at a higher level of intensity.

The responding surrogate is a figurine whose position relative to another surrogate defines the degree of interest one has in the remote person. In Fig. 3b, for example, the local person explicitly positions their responding surrogate (seen in the foreground) relative to the peek-a-boo surrogate (in the background). If positioned on the stage facing the peek-a-boo surrogate, the remote person will be notified by some mechanism (see Section 5) that the local person is very interested in them and is available for communication. A lesser degree of interest and availability is indicated by moving it off the stage, and no interest by tipping it over. Light sensors in the stage and the base of the responding surrogate are used to detect these positions.

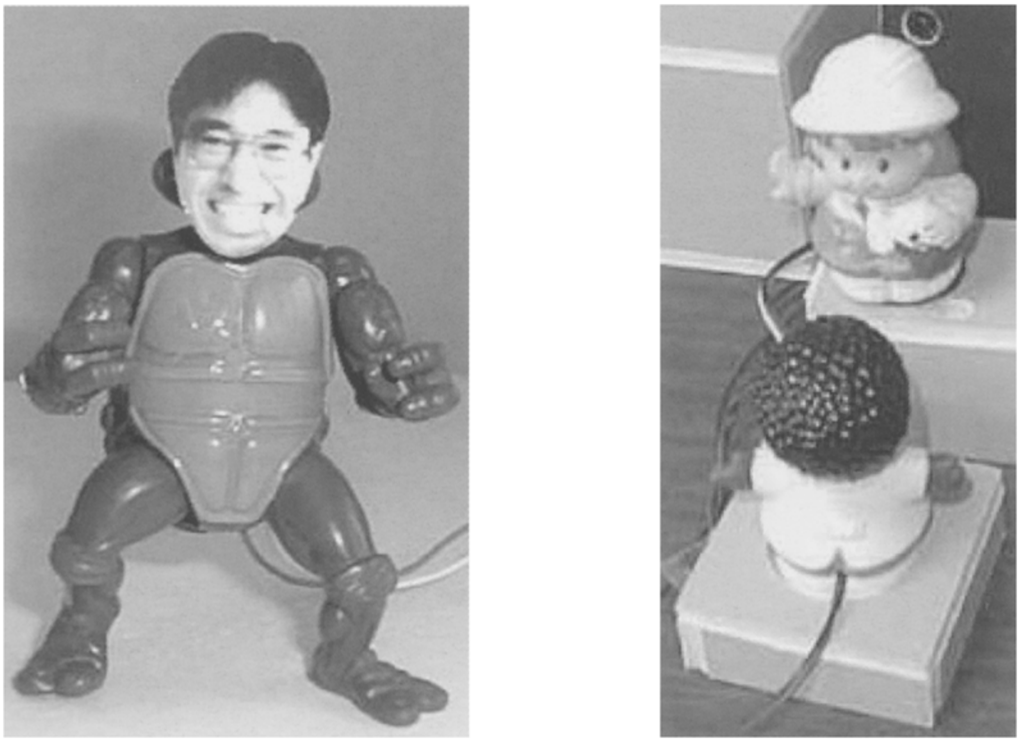
The proximity surrogate represents a remote person. It is instrumented with an ultrasonic sensor that measures how close the local person is to the unit, i.e. the local person indicates interest in the remote person simply by moving close to that person's surrogate (an example will be shown in the next section).

Discussion: These surrogates react to people's actions in different ways. The first two require explicit acts on the part of the local person, in this case a holding act and a positioning act. In contrast, the proximity surrogate reacts to an implicit and somewhat more natural act, where one's interest in the other is automatically calculated as a function of distance (this assumes the surrogate is positioned in an appropriate place within a person's office). An interesting side effect is that accidental interest can be transmitted whenever the person happens to move close to the surrogate, which opens the door to opportunistic encounters.

The surrogates are novel in that they also "remember" a person's interest in another person in different ways. Only momentary interest and availability are shown by holding the mutant ninja, and by being close to the proximity surrogate. In contrast, the responding surrogate remembers interest as a continuous state that shifts only when it is repositioned.

3.3. Surrogates that embody the communication channel and manage the media space

The previous examples illustrate how surrogates can embody awareness information, as well as how



a. Mutant ninja surrogate

b. Responding surrogate

Fig. 3. Two surrogates used to indicate interest in others.

they can be manipulated to transmit interest in others. However, it would be difficult to move into interaction unless they were connected to the communication channel. Here, we will show how surrogates can both embody the communication channel that forms part of the media space while still allowing people to control both awareness and the "quality of service" delivered over the communication channel [25].

The Active Hydra surrogate embodies a video and audio connection to a single remote person within a proximity surrogate. We recreated Buxton's Hydra units [13,14] which integrates into a single compact device: a camera and microphone for capturing the local video and audio, with a display and speaker for presenting the remote audio and image (Fig. 4). We then instrumented these units with an ultrasonic sensor, making it behave as a type of proximity surrogate. The actual sensor is seen resting atop the Hydra unit.

Unlike Buxton's original Hydra unit, the presence or absence of the audio and the quality of the video portrayed within the surrogate, as well as the presence of groupware on the computer display is

Table 1. How "quality of service" relates to "interpersonal" proximity in the Active Hydra unit.

	Close	Medium	Far away
Close	Video, audio	Video	Glimpses
Medium	Video	Video	Glimpses
Far away	Glimpses	Glimpses	Glimpses

controlled implicitly by people's position relative to the surrogate (Table 1). When both are close to their Hydra surrogates, the full audio/video channel is available. If one or both people move away from the surrogate, audio is disabled. Moving even further away degrades the video to occasional glimpses into each other's space, i.e. a 0.5 second of video is visible between 3 seconds of black. In essence, the Active Hydra mimics the way proximity is used implicitly by people. People notice others when they move towards them, and conversations usually begin when people are close together. At the other extreme, both communication and awareness of what others are doing decrease as people move further apart.

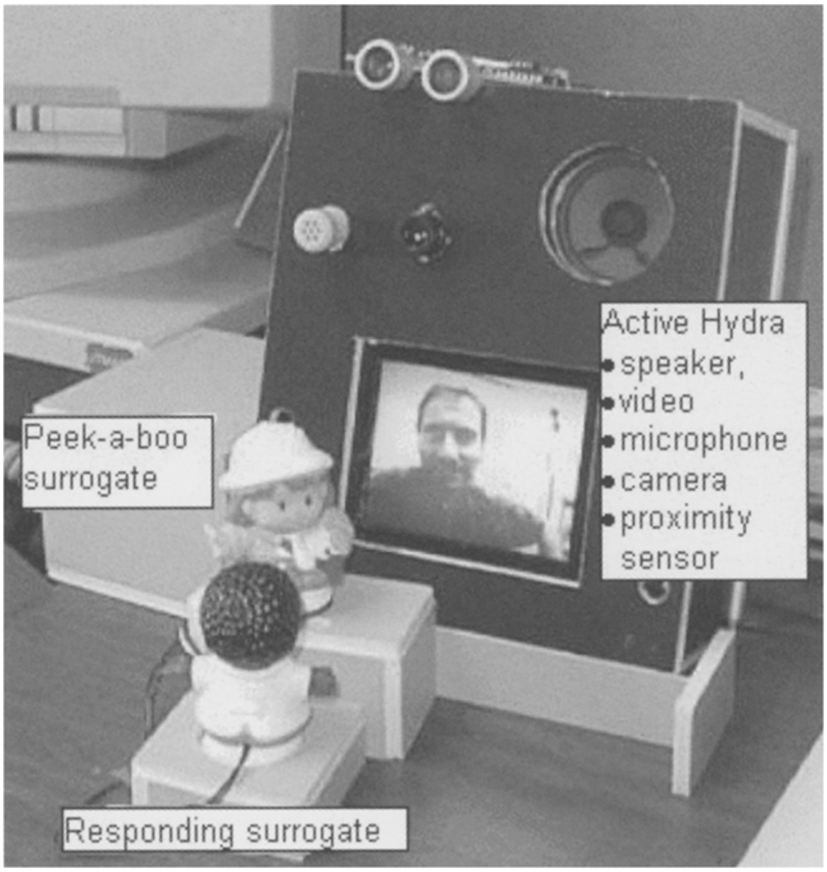


Fig. 4. The Active Hydra surrogate that embodies the communication channel, in combination with the responding and peek-a-boo surrogate.

Combining surrogates: We can combine and/or merge all these surrogate types to provide awareness and to manage communication quality both explicitly and implicitly. For example, people can use the responding surrogate not only to indicate availability to others via (say) the peek-a-boo doll, but to further control the quality of service delivered over a communication channel embodied within the Active Hydra unit. This is displayed in Fig. 4.

Consider the state table shown in Table 2 which determines how communication is managed as a function of both the explicit placement of the responding surrogate (on, off or tipped), as well as

Table 2. Quality of service as a function of both proximity and the responding surrogate state. V is video, A is audio. Numbers indicate the service level. 0=no service, 4=full service, in between values are partial services.

			Close			Medium			Far	
		on	off	tipped	on	off	tipped	on	off	tipped
Close	on	V4 A4	V3 A4	V2 A1	V4 A4	V3 A4	V2 A0	V4 A3	V3 A3	V2 A0
	off	V3 A4	V3 A4	V2 A0	V3 A4	V3 A2	V0 A0	V3 A3	V2 A1	V0 A0
	tipped	V2 A1	V2 A0	V1 A0	V2 A0	V0 A0	V0 A0	V2 A0	V0 A0	V0 A0
Medium	on	V4 A4	V3 A4	V2 A0	V4 A3	V3 A2	V1 A0	V4 A2	V3 A2	V1 A0
	off	V3 A4	V3 A2	V0 A0	V3 A2	V2 A1	V0 A0	V3 A2	V2 A0	V0 A0
	tipped	V2 A0	V0 A0	V0 A0	V1 A0	V0 A0	V0 A0	V1 A0	V0 A0	V0 A0
Far	on	V4 A3	V3 A3	V2 A0	V4 A2	V3 A2	V1 A0	V4 A1	V3 A1	V1 A0
	off	V3 A3	V2 A1	V0 A0	V3 A2	V2 A0	V0 A0	V3 A1	V2 A0	V0 A0
	tipped	V2 A0	V0 A0	V0 A0	V1 A0	V0 A0	V0 A0	V1 A0	V0 A0	V0 A0

the proximity of people to the surrogate (close, medium and far distances). V is video, A is audio. The numbers following the letter indicate the quality of service level. 0 is no service, 4 is full service, and in between values represent partial services[1]. For simplicity, the table omits how other surrogates react to state changes.

Discussion: By having surrogates react to both implicit and explicit acts, we can create equivalents to many natural situations. To model mutual availability and intentional communication, a full two-way communication channel is established *only* when both people are close to the Hydra unit and when both have positioned their responding surrogates on the stage (as indicated by V4/A4 cell in the upper left corner of the table.) One person can show disinterest by moving away from the Hydra surrogate (the 1st cell in row 7 with the values V4/A3), by tipping the responding surrogate over (the 1st cell in row 3, with the values V2/A1) or by doing both (the 1st cell in row 9, values V2/A0). Similarly, we can model two people bumping into each other or moving towards each other with the intent of talking by having the two off-stage surrogates show only video unless people are close to them, in which case the audio channel would be automatically enabled.

When the communication channel is degraded considerably, the peek-a-boo or equivalent surrogate can still provide basic awareness information. This increases the chances of serendipitous encounters, decreases distraction, mediates privacy, and decreases effort (because implicit actions have consequences as well). Thus the permeability of the communication and groupware channel becomes a function of both implicit personal proximity to the surrogate as well as the explicit positioning of the responding surrogate. Consequently, through these surrogates people can easily stay aware of others and move intuitively into lightweight casual interaction.

This combination of surrogates presented here is novel – as far as we know, these have not been done before.

[1]These values may be implemented by different systems in different ways. In the first version of our system, we used analog video and audio, and we can only control whether these signals are either on or off. Thus we interpret V0 as no video, V1–V2 as glimpse mode, while V3–V4 is always on. In contrast, our second version uses a digital video and audio stream, where we distort the stream using various algorithms as a function of particular surrogate states (see Section 7).

4. Balancing Awareness, Privacy and Distraction

Goal 2. Mitigate privacy and distraction concerns endemic to most awareness systems.

We contend that surrogates can mitigate concerns about distraction and privacy because they can portray limited and abstracted representations of another's activities, and because they can present different degrees of salience.

4.1. Limiting and abstracting. How activities are portrayed

When one can see exactly what another is doing, such as in always-on video, the risk of privacy violation is high. In contrast, surrogates (excepting the Active Hydra) are caricatures with only limited ability to express information. Consequently, surrogates are best suited for portraying only limited notions of availability that abstract one's activity [17,18]: while still providing a general sense of availability, this lessens the risk of intrusion. Thus surrogate design includes the decision of what measure of activity and availability is captured (see Section 5 and video [24]), and how those measures are mapped onto the surrogate (e.g. as light, sound, or motion). When done well, these abstractions can be quite expressive, even though the source of how that information is gathered is invisible. For example, the orientation of the peek-a-boo doll implies a playful but fairly literal notion of a remote person's presence and activity level. The light surrogate can present the same information in a more abstract and aesthetic manner. Still, there is a tradeoff. While abstract representations are more protective of privacy, inferring another's availability from these abstractions is more error prone, causing occasional unwanted interruption or lost opportunities.

Choosing an appropriate quality of communication service also preserves privacy and minimises distraction. In previous sections, we have already described how the Active Hydra limits our direct view into another's space by combining both explicit control of the channel with implicit acts, such as proximity to the communication device. To further guard against privacy and distraction, these are reciprocal views whose fidelity depends upon the state of both people's surrogates and proximity, as detailed in Tables 1 and 2. With reciprocity, mutual interest balances what is visible on the communication channel.

4.2. The salience of awareness portrayals

The *salience* of awareness portrayals is the degree to which awareness information is perceived in the foreground of consciousness. This is not an absolute measure, for even inconspicuous information portrayals can be of high salience if one is waiting for it, e.g. a lover's tap on the window [26]. The likelihood of distraction is greatest when displayed information is so conspicuous that high salience is unavoidable. At the other extreme are ambient displays with low salience [15] and minimal distraction, but which risk overlooked opportunities for collaboration.

Physical surrogates can express different levels of salience. First, the surrogate's position within a room affects its salience: when placed close by and within one's normal field of view, it is a foreground, highly salient device. If positioned further away and out of direct line of sight, it becomes a background, less salient device [13, 15]. Second, the actual design of the surrogate embodies different levels of salience. The furious beating of the dragonfly's wings, for example, is very noticeable and almost always attracts attention, while the gentle flapping does not. Similarly, very large visual changes within the light surrogate are noticeable, while subtle changes are not. With the peek-a-boo surrogate, salience corresponds with changes in state: small changes result in small movements and slight sounds; increasingly larger changes produce more salient movements and sounds.

5. Architecture and Implementation

Our surrogate control architecture is centered around a distributed model-view-controller system (Fig. 5). We implement controllers as *input instruments* situated in a person's environment (perhaps as surrogates) that collect information about that person's activities and make it available in a digital form. The model is an *awareness model* [11] that collects this digital information and distributes it to other sites. Views are the surrogates whose behaviour depends upon the state of the data stored in the model. We will illustrate how this works by describing the awareness model, by giving examples of how input instruments control the model, and how surrogates react to data changes. We will also describe how surrogates can be packaged as physical widgets, or phidgets.

5.1. The awareness model

We built the software portion of our system in GroupKit [27], a groupware toolkit that provides a run-time architecture for managing the creation, interconnection and communications of the distributed processes comprising an active conference session. The awareness model is implemented as a GroupKit *shared environment*, a dictionary-style replicated data structure containing *keys* and associated *values*. Shared environments are more than data structures: replicas located on different processes and machines automatically update one other. Consequently, changes to an awareness model instance in one conference process are propagated to the awareness model instances of the other processes, as illustrated in Fig. 5.

For example, consider this code fragment that initialises the model.

```
gk::environment -peer awareModel
set who [user local.usernum]
awareModel set $who.activity              0
awareModel set $who.idleTime              0
awareModel set $who.interestIn.$you       0
awareModel set $who.proximity             0
```

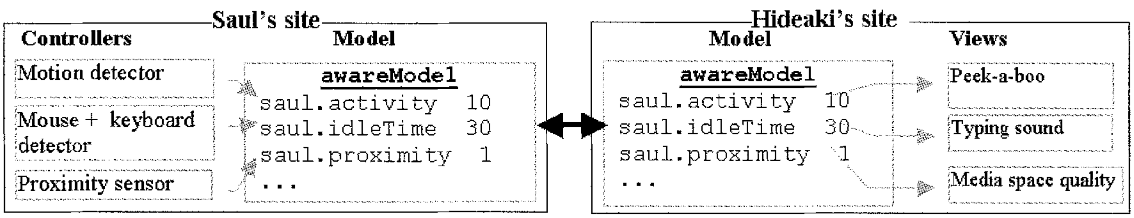


Fig. 5. A simplified awareness model and architecture. Controllers at one site update values in the awareness model. These values are propagated to other sites, and views are altered to reflect the new values. In reality, each site has both controllers and views attached to the model, and the model will have values that describe both local and remote users.

In the first line, GroupKit creates a shared environment (sharing is specified by the `-peer` option) and calls it `awareModel`. In the second line, GroupKit returns a unique identifier for the local user. The remaining lines add and initialise keys and values that contain awareness information about a particular person. `$who.activity` will indicate how active that person is in their office (e.g. 0 is inactive, 10 very active). `$who.idleTime` will describe how long it has been in seconds since a person touched their computer. `$who.interestIn.$you` will indicate how interested the local person is in talking to another person. Finally, `$who.proximity` will store how close a person is to a particular surrogate.

5.2. Controllers as input instruments

We now need to hook controllers into this model. Controllers are simply input instruments that gather information about a person, translate it into some abstraction, and then store it in the awareness model (Fig. 5). These are best illustrated by example.

Our first example is the *proximity sensor* that measures a person's distance from the Active Hydra surrogate. As with many of our sensors, it comprises an analog component (in this case, a sensor that produces ultrasonic sound), a digital component (a counter that measures the time for the ultrasonic sound to echo back), and custom software running on a BASIC Stamp II board (produced by Parallax Inc.) that collects this digital information. Via the serial port, GroupKit software on the local computer polls the BASIC Stamp II board for this digital information and stores it in the awareness model as `$who.Proximity`.

Other input sensors work in a similar manner. The *mutant ninja surrogate* notices if it is being held by using a heat sensor to detect body heat: this value is transformed and stored in the model as `$who.interestIn.$you`. The *responding surrogate* also sets `$who.interestIn.$you`. By measuring the light seen by two light sensors – one at the figurine's base and one on the stage – it can determine if the surrogate is on the stage, off the stage but upright, or tipped over. The *activity detector* compares successive video snapshots taken in a person's office; the difference is then converted into an abstracted notion of activity and stored in the `$who.activity` slot. Finally, the *idle time detector* is software that calculates how long it has been since a person last touched their computer (measured by watching keyboard and mouse usage), and storing it in `$who.idleTime`.

5.3. Views as surrogates

Now that we have an awareness model whose data reflect the state of its controllers, we need to generate the views. Views are surrogates that react in an appropriate manner to changes in the awareness model (Fig. 5). In GroupKit, we do this by attaching callbacks that will be executed automatically whenever a particular value changes in the awareness model. For example, if we are interested in having something react to the activity key in the model, we could include the following line of code.

```
awareModel bind "*.activity"{
   rotatePeekABoo %1}
```

Particular callbacks would then control particular surrogates so that they respond correctly. Again, these are best illustrated by example. The peek-a-boo surrogate comprises a figurine mounted on a servo motor that is controlled by the BASIC Stamp II, which in turn is controlled by the local computer. We attach a callback to the `$user.activity` parameter in the model (e.g. `rotatePeekABoo` as shown above). Whenever this parameter is altered, the callback checks to see which person's activity has changed (by inspecting the `$who` variable returned as part of the %1 argument). If it is the user represented by the peek-a-boo surrogate, the code in the callback directs the BASIC Stamp II to rotate the servo-motor to a particular angle. The consequence is that a low activity value in the model causes the surrogate to face the wall, a high value causes it to face the person, while in-between values are transformed to intermediate rotations.

Surrogates can monitor more than one model value. For example, the dragonfly surrogate's behaviour responds to two different values in the model. As with the peek-a-boo-surrogate, the `$who.activity` value controls motor speed, causing the dragonfly's activity to reflect the other person's activity. A second callback, however, monitors the `$who.interestedIn.$you` value: if this value becomes high, the dragonfly will beat its wings furiously for a few moments to attract the person's attention. Similarly, the Active Hydra is controlled by both the `$user.proximity` and the `$user.interestedIn.$you` values in the model. When either of these change, the callback inspects

Fig. 6. The Fujitsu device. Through programming, a red and green light in its head can be turned on and off; its hand and head can be raised or lowered; and we can detect when its head is pressed.

their values. Using a scheme similar to that shown in Table 2, it decides what should be displayed in the Hydra's media space[2].

5.4. Surrogates as phidgets

One of the advantages of having a distributed model-view-controller system is that we can begin to think about our devices as physical widgets (or phidgets). As with conventional GUI widgets, the important idea of a phidget is that it presents the programmer with an easily-used entity with a well-defined interface, where details of how the entity is implemented is hidden away.

For example, consider a commercial electronic device developed by Fujitsu Personal Computer Systems Ltd for signaling email arrival (Fig. 6). It has a red and green light in its head; internal electromagnets can raise or lower its head or its right hand; and a press down on its head produces an electronic signal. Yet programming the raw device is awkward. Because it is a serial device, the serial port must be opened and configured to correct settings. The lights and electromagnets are controlled by transmitting a series of bits that controls an internal register. Any user interaction with it must be caught by monitoring the state of the RS-232 DSR line. To simplify this, we reprogrammed this device as an ActiveX component that behaves like a standard widget. The "controller" portion generates events that indicate that its head has been pressed, which can be used to update a model. The "view" portion of this widget packages the appearance of the device, which can be controlled via the model. For example, consider this Visual Basic code segment that adjusts the view of this component (called Surrogate), where an event indicating a remote user's status has just arrived via an update to the model:

```
Select Case DistantUserStatus
  distant person unavailable: turn
  the lights off and put the hand
  and head down
  Case "Unavailable"
    Surrogate.AllOn (False)
  'distant person is active: keep the
  surrogate's head up and the green
  light on
  Case "Active"
    Surrogate.Green = True
    Surrogate.Head = True
  'distant person wants our attention:
  Flip the surrogate hand and head
  4 times
  Case "WantsOurAttention"
    Surrogate.HeadFlip = True
    Surrogate.HandFlip = True
    Surrogate.FlipAndUpdate(4)
  ...
```

The point of the above description is that packaging a device as a phidget makes it extremely easy to program it as a surrogate and to include it within a model-view-controller architecture.

5.5. Discussion of the architecture

The distributed model-view-controller architecture is extremely powerful. In particular, using an awareness model allows a high degree of flexibility, both because it embodies awareness information

[2]Our first implementation uses analog audio and video, and our system (using the BASIC Stamp II) controls relay switches to turn audio on and off as indicated in the table. Our second implementation (in progress) uses digital video and audio, where software progressively masks what is seen/heard on the channel.

as abstractions, and because it is detached from the views and the controllers. Thus designers can craft and/or choose different controllers to gather awareness information: activity may be captured by a motion detector in one environment and by (say) an instrumented chair in another, e.g. [11]. Similarly, different surrogates can represent the same information. For example, the peek-a-boo doll, dragonfly, and light show can all respond to the activity value. One-to-one mappings are not required: surrogates can respond to a combination of values in the model; a change of value can affect several surrogates; or different controllers can affect the values of one or more variables. Adding new types of information to the model is also straightforward, requiring only modest effort to specify the key and its callbacks. Finally, packaging particular devices as phidgets makes it easy to program particular devices.

In practice, we have found it easy to experiment with different controllers and surrogates, treating them almost as appliances that can be plugged into the awareness model. For example, we used the same information in the model to control both the surrogates and the iconic indicator displayed shown in Fig. 1.

6. Usage Experiences

Our prototypes are hand-crafted, physically fragile and in limited supply; consequently they have not yet been deployed outside our research group. However, we (the two authors) have lived in a space populated with evolving versions of our physical but digital surrogates over several months. In particular, Greenberg had a version of the system illustrated in Fig. 4 (including the Active Hydra). Kuzuoka had a similar system that used a dragonfly instead of the peek-a-boo surrogate, and his Active Hydra was controlled only by the responding surrogate (his did not have a proximity sensor).

Even though we were in a co-located space, the surrogate-based media space was extremely effective. Similar to experiences found by other media space researchers, we felt that we were far more "connected" with one another [28]. We are fairly certain that this is due to the media space because our feelings of connectivity were attenuated considerably during system down-times. Through the system, we had frequent casual interactions. Common episodes included quick greetings, social banter, brief conversations used to coordinate and inform one another about ongoing activities, and introductions of a visitor at one person's office to the distant person. However, our experiences differ somewhat in that they were shaped by the nature of the surrogate as ambient display, the positioning of the surrogate within the office, and how the Active Hydra helped balance privacy and communication.

Surrogates as ambient displays: The visuals and sounds produced by the peek-a-boo and dragonfly surrogate proved an effective ambient display (although the cheap motor on the dragonfly was perhaps a bit too loud). We remained peripherally aware of each other's presence, and we found ourselves using that awareness to move smoothly and naturally into conversation at opportune moments. In contrast, the iconic indicator running in parallel on the computer display (seen in Fig. 1) was rarely used.

Surrogate position: Both of us positioned the surrogate and Active Hydra just to the side of where we normally sat. While typically out of our direct line of sight, it was within our peripheral vision. Its position meant that we could look directly at it by turning our head to the side, and we could move close to the Active Hydra by swivelling our chairs and leaning forward. The consequence of this positioning was that we could easily maintain peripheral awareness of the surrogate state, glance at the video displayed in the Hydra unit when desired, e.g. after a change in surrogate state; and move towards the surrogate to initiate communication. Of course, other surrogate positions are possible. On reflection, what struck us was that we unconsciously situated the apparatus in a place that suited the type of intimate awareness and collaboration we desired.

Surrogate to balance privacy and awareness: The Active Hydra we used was controlled using a simpler version of the state diagram illustrated in Table 2. We found that this naturally provided a reasonable balance between awareness distraction, and privacy. For example, author Greenberg often conversed with students within his office, which Kuzuoka could potentially overhear and/or find distracting. This did not prove problematic for two reasons. First, the natural way chairs were positioned in the office meant that visitors were seated far enough away from the Active Hydra to disable the audio. Consequently, Kuzuoka could not overhear the conversation. When people did stray close to the surrogate, the Active Hydra would produce a slight humming sound, thus providing ambient feedback that audio had turned on. Second, if the conversation become very sensitive, Greenberg could tip the responding surrogate over to limit what went through the channel (Table 2). This explicit act was needed only occasionally, as the mediation offered by implicit acts – proximity – sufficed for most situations.

One final experience we should mention is that visitors to our offices found this media space both interesting and natural. They grasped its concept after a brief explanation, and were able to use it immediately.

7. Issues and Next Steps

The advantages of digital but physical surrogates are many when compared to their computer counterparts. Windows cannot cover them. They can be positioned anywhere within a room to take advantage of the way the physical space is used [13]. They do not depend on the person using or attending the computer. Finally, surrogates can embody some or even the entire communication channel, and the contents of the channel can be mediated seamlessly by how people interact (either explicitly or implicitly) with the surrogate.

However, we recognise that the surrogates as presented here are limited. Various issues suggest a research agenda.

Issue 1: We do not understand how activity estimates availability. We need to further understand how people's activities really equate to availability, and how these activities can be captured and displayed effectively by surrogates. This requires us to understand the human factors of how people perceive another person's availability as one looks into the other's space. While there is some work in this area, e.g. [29], most researchers (including ourselves) use hunches and educated guesses as to what information should be captured and portrayed to remote people.

Issue 2: We need to design surrogate appearances and behaviours to be appropriate to particular audiences. Acceptance of these surrogates will depend greatly on their external appearances. The whimsical and playful appearance and behaviours of the surrogates presented here may appeal only to a sub-group of collaborators. Business associates may prefer a more institutional style. For example, we envision a wireless Active Hydra with a form factor similar to a PDA that can be positioned around the office. Instead of having add-on surrogates such as a dragonfly, the device itself will animate, e.g. by rotating in a cradle, or by slight motions. In contrast, children may prefer familiar characters, and other researchers are already exploiting toys such as Microsoft Barneys to embody information [30]. Adult friends may desire a contemporary and aesthetic style that will fit within their homes. On a related point, we also need to know how these surrogates can be situated and integrated effectively in the office and home architecture. Quite simply, there is plenty of room remaining for invention, art, architecture, and industrial design!

Issue 3: We need better ways to mediate privacy on the communication channel, perhaps by altering the quality of service. We need to create and experiment with methods that manipulate the "quality of service" of the communication channel in order to automatically reveal some information over the channel for awareness purposes while preserving a sense of privacy. A third collaborator to this project, Michael Boyle, is now experimenting with several digital methods that alter the video appearance, including automatic blurring, resolution reduction through pixelation,

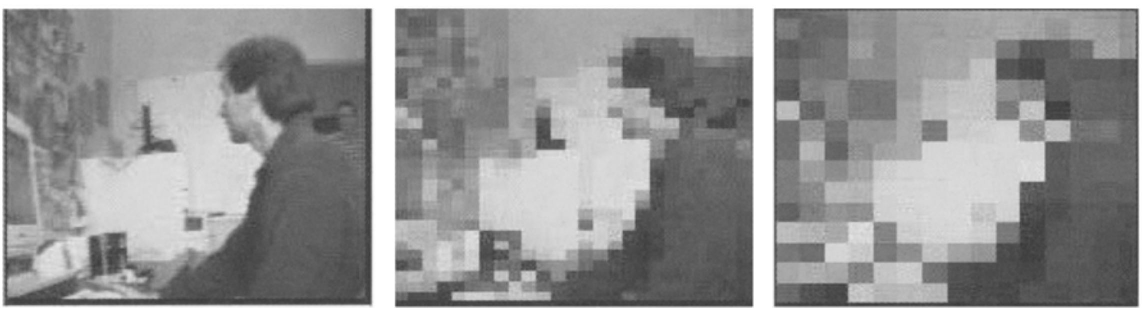


Fig. 7. Progressive distortion effects as a function of proximity, using a pixelisation algorithm [31].

the refresh rate, and contrast [31]. Figure 7, for example, illustrates how our second version of the Active Hydra distorts the running digital video image as a function of distance using pixelisation. We are testing the various distortion techniques with users to:

- determine which ones are effective,
- measure how particular levels of distortion mask and reveal information, and
- understand how these levels should be mapped onto a proximity function.

This is an ambitious extension to work that others have done to mitigate privacy by distorting what appears in periodic video snapshots [8,32]. Similarly, we are experimenting with methods that alter the audio, including volume adjustment, distortion, and so on.

Issue 4: We need to scale surrogates to work with larger groups. The system we built is currently point to point (the system architecture is actually multipoint – we just haven't taken advantage of this yet). We can easily envision the surrogates being extended to (say) a group of three or four, as done in related work on Hydra units [14]. This number is probably on the edge of what people would accept in an office (however, we should remember that surrogates are designed for intimate collaborators, implying small groups). Beyond three or four, we probably need a switching mechanism. To this end, we are currently working on a matrix of compact ambient and tangible devices that show availability status of a slightly larger group (e.g. eight people), where particular people or subgroups can be selected by (say) touching the device. This causes the video on the Hydra unit to switch to that person. One of our prototypes is illustrated in Fig. 8. We rewired and modified the behaviours of a children's game to act as a multi-user surrogate device. Each alligator represents a different remote person, where the alligator moves out of its cave by an amount that reflects the remote person's presence and activity level. If the local person wants to move into conversation, he "hits" the desired alligator with a hammer (Fig. 8 left), and a video connection between the two people is established on the desktop (Fig. 8 right: future versions would make it appear on the Hydra unit instead). Note that no video connection can be made to alligators that are in their caves as they cannot be hit, which means that people cannot peer into an unoccupied office. We should also emphasise that this type of playful interaction (getting a response by trying to hit alligators as they appear) keeps the persona of the original game [30].

Issue 5: We need to extend surrogates to facilitate how people move easily into work as well as conversation. We have already experimented linking the surrogates to GroupKit's groupware applications [27], such as a shared whiteboard, where it automatically appears on the computer display when people are in close proximity. For example,

Fig. 8. A multi-user awareness surrogate, where each alligator represents a different person, and their movement in and out of the cave indicates that person's availability. Hitting the alligator with a hammer establishes a video connection between the two.

Table 2 could be extended to make groupware "ready to hand" as a function of proximity.

Issue 6. Surrogate-based systems need thorough evaluation. While our own usage experiences have been positive, we do not know how well surrogates will be accepted and used by different groups in different environments.

Issue 7: We have to judge whether surrogates really do ensure reasonable levels of privacy. We recognise that all awareness devices present a risk of being subverted as surveillance devices, and we need more knowledge of their possible abuses as well as uses if we are to design them with appropriate built-in safeguards.

8. Summary

Previous systems have demonstrated the notion that physical devices can be used as awareness indicators. In this paper, we have tried to reflect on the role of these devices in these situations, particularly how they can act as surrogates for remote people. As part of this reflection, we discussed how surrogates must support or facilitate both awareness and the smooth transition to interpersonal interaction. This included showing how surrogates can indicate activity and availability, how they can be used to indicate interest in others, and how they can embody the communication channel by acting as an integral part of the media space. We also discussed how surrogates can balance awareness and privacy by limiting and abstracting how activities are portrayed, and by offering different levels of salience.

As implementers, we needed the ability to explore different surrogate designs and how they worked together. We argued that this can be straightforward if a good infrastructure is in place. We described how an awareness server based on a distributed model-view-controller architecture can automatically capture, store and distribute events. We also argued that it is important to package surrogates as physical widgets or phidgets with a well-defined interface, for this will make it easy for a programmer to plug a surrogate into the awareness server as a controller (to generate awareness events), or view (to display events that others have produced), or both.

Of course, there is much left to do. This paper is just a small step in a large research agenda that will help us understand the role of physical devices as mediators of awareness, communication and privacy in media spaces.

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