incidental interaction

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Abstract. This paper identifies a class of ubiquitous phenomena, incidental interactions, that are not focused on users' deliberate purposeful acts, but are incidental to the user's main activity. Examples are discussed and a definition used to explore the relationship with purposeful interaction, awareness, ambient interfaces and surveillance. The implementation of incidental interactions requires an open underlying event infrastructure. This should influence the emerging protocols in this area, but also raises issues of security and privacy. Incidental interactions also elicit particular user behaviours as users explicitly or implicitly interpret the phenomena and the paper uses an evolutionary psychology perspective to explicate this.

1. Introduction

rationale

Our environments are being filled with sensors and devices and if the work in the ubicomp field reaches fruition these will invade even more parts of our lives. Some of these devices will be used as alternative ways to perform familiar types of computer-based activities – for example, watching a film on your wristwatch TV, or setting your oven timer through a voice operated interface in your car. Even these relatively straightforward changes raise a range of new problems and issues [[BBEGHL02]]. However, the ubiquity of sensors, actuators and devices also gives rise to completely different kinds of human–computer interactions. We will need a corresponding vocabulary and models of interaction to address these emerging issues and we already see new terms emerging: tangible bits [[IU97]], roomware [[SGH98]], the invisible computer [[N98]], physiological computing [[AW02]]; to make sense of these new modes of interaction.

This paper introduces incidental interaction, a way of viewing a class of existing and emerging phenomena in the physical and electronic world. By identifying this class of interaction we are able to see the common issues of analysis, implementation, software architecture and effective design.

new styles of interaction: purposeful vs. incidental

In the context of smart home technology for the elderly, Dewsbury and Edge describe a scenario based on infra-red sensors and pressure sensors under the bed [[DE01]]. The system has rules such as "when the householder gets up in the night the hall lights come on at 50% intensity, gradually getting brighter over 1 minute and the bathroom light comes on at 100%". At a system level this is still "somebody does something and the computer does something back" – just like clicking a mouse on a menu item, or typing at a keyboard. However, there is clearly something about the intentionality of the interaction and the user's model that is different.

Traditional human–computer interfaces are designed to be purposeful - the user wants to do something and uses the computer to do it. This is even true of games – the player wants to fly the aircraft or make Lara jump and so presses the relevant buttons.

In many experimental and proposed systems the interaction is far less direct. A person walks into a room and the smart house, sensing their presence, adjusts the air conditioning and lighting to their normal preference. The person doesn't intend to dim the light or turn up the heat it just happens because she entered the room.

One aspect of this is the richer set of sensors in ubiquitous computing and mobile applications: sensing where objects and people are, perhaps what they say, may be even their physiological state, but that is not the whole story.

Tangible computing also makes use of the sensors in the environment allowing the user to control virtual entities as they manipulate physical artefacts. However, the focus in tangible computing is again purposeful – the user moves the block representing a house because he wants the house in the virtual plan to move also.

In the smart house this is different – the occupant's purpose is to go into the room and incidentally, as a side-effect. the light and heating changes ... this is incidental interaction.

this paper

In the next section we will look at a number of examples of incidental interaction before giving a detailed definition in section 3. This analysis is continued in section 4, where we will look at a number of related phenomena. One of the strengths of identifying incidental interaction is that it enables us to see common features in quite disparate areas and technologies. One example, discussed in section 5, is the way users are able to co-opt the interactions to behave as they want once they have figured out the behaviour. We will then move on to design with section 6 looking at implementation issues and section 7 looking at evolutionary psychology as a way of understanding users conscious and unconscious models of incidental interaction.

2. Everywhere ...

When we look for incidental interaction we begin to see examples everywhere, both in existing systems and in proposed or experimental systems:

- car lights that go on when the door is opened
- room lights that go on and stay on so long as there is movement
- auto-flush toilets
- mediacup as a sensor [[BGS01,GBK99]]
- bio-sensors used for dynamic function allocation [[S96,HH02]]
- active-badges (e.g. Xerox Pepys project's automatic diaries) [[NEL91]]

We can also see examples that are purely within the computer domain (that is where the sensed activity is purely electronic):

- adaptive interfaces
- automatic 'help' systems such as the Microsoft paper clip!
- other forms of 'auto-completion' or automatic macro creation interfaces (e.g. Eager [[C91]])
- e-shopping systems that recommend alternative purchases based on your previous shopping basket (e.g. Amazon)

Strangely it was only after considering these examples that I also realised that onCue [[DBW00]], on which I worked for some time, is exactly taking advantage of incidental interaction – it watches the clipboard and when the user cuts or copies anything it analyses the type of data and adjusts its toolbar to suggest potential things to do with the copied data.

We'll look now at a few examples in a little more detail to see the variety and ubiquity of incidental interaction. However, examples of incidental interaction are literally everywhere in the ubicomp literature and these examples are meant to be illustrative not exhaustive.

courtesy lights

In many cars an the interior light turns on triggered by various events: the opening of the doors, unlocking the car, stopping the engine. These car-related events are chosen to correspond with likely times the interior lights are likely to be required – whilst getting in or out of the car. Other car-related events may turn the lights off: locking the car, starting the engine.

The lights are also typically turned off by some timer – I think to stop the battery running down. Because the sensors that are available (doors opening) are only loosely correlated with the actual desired status (people in care) – it would be possible to open the door, then not get in and the lights stay on overnight. Perhaps a more sophisticated sensor, perhaps tied into the car-alarm's infra-red sensor, could turn the lights on only when and so long as people were in the car and isn't actually in motion.

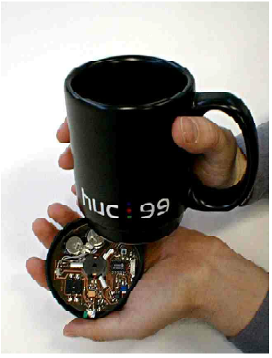
The driver's *purpose* in opening the door is to get in the car; *incidentally* the lights go on making it easier to get settled.

onCue

aQtive onCue is a sort of 'intelligent toolbar', it sits at the side of the screen and 'watches' the clipboard [[DBW00]],. Whenever anything is cut or copied to the clipboard onCue looks at it and tries to recognise what kind of thing it is: ordinary text, a table of numbers, a post code (zip code), a person's name. Depending on the type of the object onCue adds icons to its toolbar window that suggest things you can do with the text in the clipboard: for example a search engines for plain text, graphing tools or spreadsheet for a table, mapping tools for post codes, directory services for names.

The user's *purpose* in copying the data is to paste it somewhere else; *incidentally* onCue offers alternative things to do with it.

mediacup



The mediacup is an ordinary coffee mug, but with an added electronic base unit [[GBK99,BGS01]]. In the base unit are temperature sensors, switches to detect tilt and movement and small infra-red unit broadcasting the cup's state every few seconds. Infra-red receivers around the office building pick up the infra-red signals and then interpret the measurements as indications of user activity and location. This can then be used to give both explicit information and general awareness information to colleagues.

Hans's *purpose* in filling and lifting the cup is to drink some coffee; *incidentally* his colleagues become aware that he is taking a mid-morning break.

shopping cart

As you move around the Amazon site and look at books, perhaps choosing to buy some, the web site records your choices and behaviour. This is used partly to build a model of overall user behaviour and preferences (people who like book X also like book Y). It is also used to suggest other books you might like based partly on special promotions and partly on previous users' observed behaviour.

My *purpose* in navigating the site is to find Gregory's 'Geographical Imaginations'; *incidentally* Soja's 'Post-modern Geography' is suggested to me (and I buy it!).

Xerox Pepys

In Xerox's Cambridge laboratories a few years ago, everyone was issued with 'active badges'. These used small infra-red transmitters to broadcast their location to receivers throughout the office building [[WHFG92]]. At the end of each day the Pepys system analysed the location data to produce personalised diaries for each person [[NEL91]]. Pepys knew about the office layout so it could say "went to Paul's office", but also could use the fact that, say, several people were in a room together to say "had meeting with Allan and Victoria".

Victoria's *purpose* in walking round the building is to visit Paul's office; *incidentally* a diary entry is produced for both of them as a record of the meeting.

3. A definition ...

> **incidental interaction**
> where actions performed for some other purpose or unconscious signs
> are interpreted in order to influence/improve/facilitate
> the actors' future interaction or day-to-day life

Let's look closely at the parts of this definition ...

First "for some other purpose" distinguishing incidental interaction from purposeful interaction such as switching on a light, or selecting an option from an on-screen menu. This does not mean that the actor is unaware that the action may have secondary effects, but it is not <u>why</u> the action is performed.

Second "or unconscious signs" is to include physiological signs such as body temperature, unconscious reactions such as blink rate, or unconscious aspects of activities such as typing rate, vocabulary shifts (e.g. modal verbs). For example, in a speech-based game, Tsukahara and Ward use gaps in speech and prosody to infer the user's emotional state and thus the nature of acceptable responses [[TW01]] and Allanson discusses a variety of physiological sensors to create 'electrophysiological interactive computer systems [[A02]]. The word 'unconscious' emphasises it is still a (human) actor or group of actors who are being directly or indirectly sensed, in contrast, say, to a thermostat which is responding to purely environmental conditions (although using room temperature to detect number of participants would be included).

Note also the use of the plural for both 'actions' and 'signs'. This is because many forms of incidental interaction will involve time series and sensor fusion – using many actions or environmental readings over a period of time to generate a model of user activity.

Third "are interpreted in order to ..." distinguishing incidental interaction from undesigned influences. For example, if you repeatedly take the same route through a wood you will wear down a path through the undergrowth, which will then make the journey easier. Of course, noticing how the environment unintentionally and accidentally moulds itself to us can be and has been a fruitful inspiration for designed systems. Similarly the computer environment may have unintentional interactions, for example, in a small network you may be aware if one of your colleagues is transferring a large file as it slows down the network.

The fourth part "to influence/improve/facilitate" is a little problematic. For example, a criminal under a curfew order may have a sensor fitted to a bracelet that administers a small electric shock if it detects infringements. Hence the use of the inclusive word 'influence'. However, on the assumption that most uses will not be so coercive the definition also includes alternative more benign wording!

Fifth "the actors' ..." again focusing on human actors and the effects on them. Note that this is phrased in the plural so as to allow either a single actor, or where, say, a system that notices that a group of people are doing something (perhaps just being together) and reacts accordingly. However, very significant is that it is the actors' own lives/interactions that are being affected. This is to distinguish incidental interaction from surveillance or other forms of monitoring (e.g. security video, recording transaction details for data mining).

		intention	
		purposeful	accidental
who it affects	the actor	purposeful interaction	incidental interaction
	someone else	control / messaging	monitoring / surveillance

In the case of a group, the effect may be on the group as a whole (e.g. the system detects a particular project group in the meeting room and the wall screen opens the group workspace) or may be more inter-personal (e.g. one member's mediacup movements mean that another member of the group gets a 'person X is in the office' message). Another example of this is the proposed 'presence lamp' [[HMLHB01]]. A pair of context-aware lamps in two locations are linked so that activity in one location increases the brightness in the other. There is of course no hard boundary between these inter-personal incidental interactions and surveillance, except that the former tend to be symmetric and indirectly impinge back on the primary actor through the enhanced group interaction. We will return later to the relationship between incidental interaction and awareness.

Finally, the last clause says "future interaction or day-to-day life". This is to include things like menus that change their defaults depending on assumed tasks (future interaction) and physical things such as the room temperature control (day-to-day life).

Although not emphasised earlier, this is also true of the actions and signs being sensed and interpreted. Valid sensors for incidental interaction may include:

- watching the users own computer interactions (e.g. screen saver notices inactivity),
- watching the system state which has been affected by the user (e.g. keeping a diary of altered files),
- watching the users own body (e.g. bio-sensors or recognition of body gestures), or
- watching the environment that has been affected by the user (e.g. fridge light comes on when the door is opened).

4. Related phenomena

awareness and ambience ... incidental perception

Issues of awareness and also ambient interfaces obviously share a lot with incidental interaction. Whereas incidental interaction is about things happening to you incidental to your main locus of activity, awareness is about what you perceive of others incidental to your main focus of perception. Of course, gathering the information to give awareness may be explicit (e.g. launching an instant messaging window), but as often may be implicit (e.g. mediacup), so awareness may be a result of incidental interaction.

		intention	
		purposeful	accidental
modality	sensing actor	conventional input	incidental interaction
	influencing actor	conventional output	awareness / ambient

A lot of the awareness literature is focused on other people's actions whereas ambient interfaces are typically focused on giving awareness of things in the environment (e.g. network traffic). In incidental interaction a sensor may detect the effects of your actions on the physical environment and reflect this in some way in the computer system. In ambient interfaces the system reflects some aspect of the computer system in the physical environment.

ambient interface:	computer system state	→	physical environment of user
incidental interaction:	physical environment of user	→	computer system state

physiological computing

Physiological computing [[AW02]] is the use of bio-sensing in computer applications. This involves some applications that are very clearly purposeful interaction – for example a physically disabled user controlling a mouse pointer using direct brain activity sensing. Others are very clearly incidental interaction – for example, releasing stimulating smells if the car driver appears to becoming sleepy. Other uses start to impinge on the medical domain, however we exclude standard use of monitoring in medical applications as it is clearly not an interaction in the same sense – the patients are beneficiaries of the monitoring but they are the objects not the subjects of interaction.

incidental human–human interaction ...

Of course incidental interaction is not just a feature of human–computer interaction. Again and again ethnographic studies have exposed the importance of subtle unintentional interactions within workgroups. For example, in the studies of the London Underground control centre, the large size of the main display screen (showing the locations of trains) means that controllers have some awareness of where other controllers are looking on the screen. The same studies also showed the importance of overhearing. As one controller is talking on the telephone and discovering, the neighbouring controller starts to act in response to the problem even before the first controller has passed on the information [[HL92]].

Of course, the controllers are at some level aware of this potential and may emphasise their actions speak louder etc. to facilitate third-party 'over hearing'. So, third party incidental interactions have become co-opted and become, at least subconsciously (if this is not an oxymoron), intentional.

5. Co-opted interactions

stage whispers

This management of incidental interaction is not confined to human–human interactions. In a hotel room the guest is sitting quietly in bed reading a book – the lights go out – "not again" she thinks and waves her arms – the sensor detects the movement and the lights come back on. Similarly auto-flush toilets are designed to detect a person sitting and then standing up and moving away. If you want to flush the toilet deliberately it is possible to deliberately 'fool' the sensor by moving a hand back and forth in front of the sensor. Automatic interior car courtesy lights can also be controlled in this way. You have just got into the car and are checking your route on the map when the light goes out. You could switch the interior light on, but might simply partly open and close the car door re-triggering the courtesy light.

We can do these things because human beings are 'natural' scientists constantly analysing, theorising and modelling our environment, then using this knowledge to predict and control (natural engineers as well). It is interesting to note that Seay et al. in their 'meditation chamber' are interested in unconscious responses and so deliberately seek to discourage users from building models of the chamber in order to stop them 'playing' the environment [[SGHS02]].

In onCue we also noticed users co-opting the incidental behaviour for purposeful activity. In the early versions of onCue there was no way to explicitly address it. All interaction was incidental through the clipboard. Enthusiastic users of onCue who wanted it to do something for them could not simply enter it into onCue. Instead they would deliberately type a word or phrase into a word-processor window – that was not intended to be part of the document – and then copy it knowing that onCue would react to it. In later versions of onCue we added a type-in box that would appear if someone selected the onCue window to allow users to directly address it.

failures of co-option ...

Of course, part of our design of incidental interaction must be a recognition of model making and co-option by our users. In onCue we got this wrong initially.

If the rules are complex or non-deterministic (perhaps relying on statistical algorithms or spare resources) then there are many possibilities for confusion. At one extreme the user may not be able to understand the relationship between what they do and the effects they cause. This magic model of the interface may be the safest form of failure.

More problematic are times when the user comes to rely on incidental behaviour either not realising it is probabilistic or unreliable, or not understanding completely the circumstances in which it operates. For example, in a Java development environment I use, the system notices when you are about to type a method name and suggests possibilities based on the class of the variable. This is very useful and I come to rely on it, but occasionally, and annoyingly doesn't work. Over time I've come to understand some of the reasons, but still sometimes find myself waiting for a prompt that never appears.

Even more confusing are coincidental interactions where two potential causes are often coincident and the user infers the wrong relationship. For example, you might assume that the lobby lights turn on because of some movement sensor when in fact they are on a timer triggered by opening office doors. This may only become apparent of you stood talking in the corridor for a long time.

These issues of magic, unreliability and co-incidence are potential problems in all interfaces, but perhaps especially so in incidental interaction because the algorithms used are more likely to be non-deterministic and also because they are incidental they are more likely to be undocumented. Indeed, Erickson believes that correctly interpreting human contexts is so problematic that context information should be used primarily, or perhaps only, to inform other users actions [[E02]]. Alternatively, issues of privacy might suggest that context information should only used by automatic agents acting on your behalf.

6. Building incidental interactions ...

Most ubiquitous systems, wearables and bio-sensors involve bespoke architectures. For smart homes there are bus standards, but still quite diverse. For closed systems involving incidental interaction, such as the hotel room lights, standardisation doesn't matter. However, if we want one application to eavesdrop on sensors intended for some other application it is essential that architectures are open both in terms of the ability to listen-in on events and also in the interpretation of events. This is true of both electronic domains and physical sensors.

Let's look first at onCue as an example in the electronic domain. When designing onCue one of the few events that we were able to reliably listen-in to was copy/cut to the clipboard. This was partly because we were intending to eventually target multiple platforms and looking for commonality across platforms. If we had been targeting MacOS we would have found this easier as 'good' MacOS applications are supposed to be factored so that the user interface and back-end communicate via AppleEvents. This is partly to allow external scripting, but has the effect of making incidental interaction easier to implement. On Windows it was possible to get some interactions on an application-by-application basis using COM, but not at this level of generality.

Architectures for ubiquitous applications are still in their infancy and the need for extensible mechanisms for incidental interaction should be one of the drivers. Happily, the implementation mechanisms being used often do involve fairly open eventing mechanisms.

Of course, having an open event infrastructure within a computer is one thing, but having this within the home poses new problems of privacy and security. What if the new net-enabled toaster you have recently bought from the door-to-door salesman is surreptitiously using the open event architecture of your in-house domus-net to monitor your behaviour and transmit your comings-and-goings to the salesman's burglar brother. If that sounds far fetched how about the information your internet fridge sends to the supermarket about your eating preferences?

As well as security issues, open architectures could cause performance problems. Some eventing systems force all event listeners to act synchronously and serially – the model is that an event listener is given the event and can either do something or pass the event on for further processing.

In the design of onCue we found the Windows clipboard listener interface particularly problematic. Individual applications are given a link to the next application's handler and expected to pass it on. Badly written applications loaded after onCue could unintentionally 'consume' the event. The underlying model for this form of event chain comes from GUI component chains where different levels get a chance to 'consume' events before passing them on to other levels either top down (application → window → widget) or bottom up (widget → window → application).

This sounds as though it would only be an issue for within PC event notification systems, but in fact distributed event systems sometimes 'inherit' this model. This means that before an event can produce its intended effect the system has to pass the event to any remote agents that have registered an interest in the event.

It is clear that event architectures allowing incidental interaction should always allow asynchronous event listening – "tell me sometime after". Furthermore, the rate of event notification should ideally be more flexible. In GtK (Getting-to-Know) an experimental notification server, Devina Ramduny-Ellis and I have experimented with pace impedance – allowing applications to select rates of event notification appropriate for the user's tasks [[RDT98,RD02]]. For example, a background window may elect to only be sent events bundled every 15 seconds rather than exactly as they happen. In the existing GtK, this rate is determined by the application registering interest.

For incidental interaction it would be ideal if the listening application could also register weak interests "tell me *when* you have time" allowing the notification server to prioritise event notification central to the users' purposeful interaction, queuing up incidental event notification until a gap in activity. At the extreme listeners should be able to register "tell me *if* you have time" allowing the notification service to optionally drop events altogether or flush pending event queues when they get too full.

Many incidental interactions as well as more purposeful context-aware applications involve forms of signal processing and inference. Techniques being used include traditional statistical clustering and various forms of neural network [[CP98,L01]]. This inevitably leads to the potential for errors and Edwards and Grinter list this amongst their 'seven challenges' for ubiquitous technology in the home [[EG01]].

One of the design principles behind onCue is *appropriate intelligence* – using simple heuristics within a framework of interaction that makes errors in interpretation of minimal cost to the user [[DBW00]] . The crucial things are that the interaction should

(a) be useful when it is right
(b) be right often enough to be useful
(c) not cause problems when it is wrong

The Microsoft paperclip clearly violates (c) as it interrupts your work. In contrast, the Excel sum (Σ) button 'intelligently' chooses a default selection for the sum formula and satisfies all three (a) when it works you don't have to select the range by hand just confirm it, (b) using very simple heuristics it is often right about what you want to add up (usually the line of figures immediately above), and (c) if you want a different selection the act of performing the selection overrides the default so the only cost is the mental recognition of whether it is correct.

Much of this sensor data is of a continuous nature both in terms of its values and in that it is continually available: e.g. temperature, voice pitch (whilst speaking). There has been some study of hybrid systems incorporating continuous and discrete phenomena in formal computing community [[G93]] and of course this is the norm in engineering. However, there has been very little investigation of such phenomena within HCI with most cognitive, task, dialogue and system models being strongly event oriented. This is, however, the central issue in status–event analysis, which studies the common issues that arise when you take seriously both events (that occur at particular moments) from status phenomena (that always have a value). This has been an area of concern for me for many years [[D91]], working especially with Abowd (in formal modelling, e.g. [[DA96]]) and with Brewster (for audio interfaces, e.g. [[BWDE95]]).Recently the European TACIT project [[TCT]] has also looked at these continuous interactions including using models from hybrid systems theory [[MDS99]].

7. Understanding users understanding incidental interactions

We have already discussed some problems that users face as they attempt to understand and to co-opt incidental interactions. Now we shall look a little more closely. Some forms of incidental interaction may be so subtle that users simply never notice that they happen and so never need to build a model. These are not a problem. However, if users do become aware (or are told) that changes in the electronic or physical environment are influenced by their actions, then we need to understand the sorts of mental models they may construct.

To address this I will use a form of naïve evolutionary psychology. Because evolutionary psychology is not a widely known area I will give a very brief introduction here as well as summarising my own approach.

evolutionary psychology

Evolutionary psychology is an approach to understanding areas of psychology associated particularly with the work of Leda Cosmides (a psychologist) and John Tooby (an anthropologist) at University of California Santa Barbara [[C89,BCT92,TC97]] and popularised in Steven Pinker's books [[P94,P98]]. Evolutionary psychology works from the premise that the fundamental cognitive architecture of our brains must have developed through evolutionary adaptation and that these effects are strong determinants of many aspects of our modern mental life.

The area is surprisingly controversial given the first part at least of the above premise is pretty self-evident. The controversy seems to be related to several aspects. First the intentional or unintentional breadth of claims about the second part of the premise – just how much can be explained/understood in this area – in particular in relation to nature vs. nurture debates. Second, the topic areas studied are often themselves controversial including aspects of altruism and social behaviour. Third, the methodology of evolutionary psychology, although involving some traditional psychological experiments, also involves imaginative thinking about the process of adaptation – what would life have been like two million years go, what cognitive processes would have been needed for survival?

One of the most interesting and well evidenced results of this work has been the discovery that, just as we have specialised areas for visual processing, we also have specialised forms of reasoning. For example, experiments involving Wason's cards show that people are far better at 'solving' the card puzzle if the problem is phrased in terms of people attempting to renege on social contracts [[C89]]. This is despite the fact that all previous attempts to make the problem 'easier' by relating it to everyday life have failed [[ME79,W83]].

In adopting a naïve evolutionary psychology approach this should not be taken to imply a belief that low-level evolved cognitive processes are pre-eminent (and I don't think the main players in the area would make this claim). Indeed probably the most interesting aspects of being human relate to the last 40-60,000 years of human development, which is outside the evolutionary timeframe (for all but the most limited adaptations). It is merely an acceptance that our social, cultural and cognitive processes are built upon older foundations. Furthermore the use of an 'evolutionary' label is not intended to suggest a blind acceptance of the arguments of neo-religious evolutionary fundamentalists such as Dawkins. Although I use the model of evolutionary process this is as a scientific working hypothesis and a practical tool, not a world-view. For the purposes of the arguments in this paper, it is sufficient to accept that we are 'designed' for a hunter-gatherer lifestyle not technological life.

naïve evolutionary psychology for design

I deliberately use the word naïve as the adoption of evolutionary psychology here is naïve in the same way as we use naïve psychology and sociology in traditional interface. In most HCI papers and books you will find simplified models and psychological results stretched beyond their empirical basis and generally very problematic methodology. This is because in shifting from science to design we need broader results than are available. An applied discipline is academically shaky but potentially useful! In a similar way evolutionary psychology is used here to inform design and hence used in ways those more qualified would wince at.

The approach is also naïve in the sense that we all use naïve physics – if I drop this apple it will fall. Common sense understanding of everyday life. Evolutionary psychology has been part of my own thinking for as long as I can remember, certainly before the discipline had a name, because, if you accept an evolutionary process model, common sense can be used to generate tentative hypothesis in day-to-day understanding of the world.

In my own work I have used this naïve evolutionary psychology in a variety of areas including predicting human temporal behaviour [[D96]] and understanding the extended nature of self in cyborg experiments [[D02]]. It was in the former work that I first formulated the design principle:

design computers for cavemen

This does not mean that a random Neanderthal should be able to use a computer system, but that if a computer system demands any "cognitive or motor facilities that a hunter gatherer would not need to possess, then users are likely to have problems".

It is of course common in psychology to experiment on animals under the assumption that there are similarities in certain kinds of mental function. The extra step we make in applying this to design is the heuristic that older/lower cognitive behaviours are easier to learn and less effort to apply. This design assumption can be seen in other areas such as in Dehaene's treatment of number acquisition [[De97]].

types of real-world interaction

Having established this perspective, let's look at some types real world interactions and how they may relate to incidental interaction. First we have several fairly primitive ways in which we can interact with inanimate objects:

physical – I knock a rock and it moves. This innate knowledge (not the formal reasoning) must date back hundreds of millions of years to the earliest animals. Without this you cannot tell that you can move through grass, but *over* rocks. Note that these are direct effects – the thing being moved is the thing I touch.

instrumental – "If I move this end of the stick and I can get the other end to move". This tool use was once seen as a defining human characteristic, but various examples have been found (albeit rare) throughout the animal kingdom. For example, some birds use small sticks to dig grubs out of holes in tree trunks (saves wear on their beak!). In contrast to simple physical behaviours tool use involves indirect apprehension – by interacting with one object I affect something else .

mechanical – This includes toolmaking – "I break this bit of stone it will cut better" – and other forms of complex physical interactions involving multiple indirections and/or extended over time. The flint tool is perhaps the symbol defining of early hominids, although the first hominids actually predated the first known stone tools (about 2 million years old) by perhaps 1.5 million years [[A79]]. Even this is not a uniquely human characteristic as some chimps clean and trim twigs for probing termite mounds [[L81]].

We also inherit a range of ways of interacting with animals including our own species:

predatorial – "Those wildebeest are moving towards the water hole, if I sneak round downwind I'll get my supper". Prey as well need to be aware that the movement of grass may signal a predator hiding in the undergrowth.

familial – The desire to feed and protect our children and to stay close to our parents is again very old, but particularly developed in mammals due to live birth and suckling.

societal – This takes the form of pack/herd behaviours – almost as one the herd of gazelle raise their heads to watch for predators, the dog pack in synchrony sweep in to take the weakest. It is also evident in forms of mutual behaviour – if I'm nice to you will you be nice to me.

Of course we are not limited to these primitive behaviours and have the ability to reflect upon our interactions with objects and with one another. Although evidence is sparse there was an apparent flowering around 60-70,000 years ago probably related not to a physiological change but instead the widespread acquisition of language and hence the ability for culture to supplant evolution in human development.

Although this cultural/linguistic Eden is what defines us as modern humans, its is still hard work thinking and acting at this externalised symbolic level. Our natural physical and cognitive responses are still tuned to the deeper more primitive reflexes.

Hence the results for Wason's cards and the difficulty of learning certain sorts of complex physical behaviour in sports.

If interfaces do not conform to these more basic abilities they require explicit thought and are difficult to internalise. For example, as a hunter gather one needs to act straightaway or after some event occurs, but never do something wait 2 seconds and do something else. If we need to learn interactions like these they are very hard to proceduralise and so we have to use 'tricks' such as "jump out of the plane, *count to ten* and then pull the rip cord".

human–computer interactions

Let's see now how various types of human–computer interactions and in particular incidental interaction fit into this picture.

The graphical user interface and desktop model build very solidly on physical and instrumental understanding. The WIMP GUI is a confused metaphor as it also involves menus and dialogue boxes which suggests aspects of linguistic/inter-personal interactions. However moving a mouse on the desk and then seeing a mouse pointer drag an icon is drawing precisely on "I move this end of the stick and then the other end spears grubs".

Virtual reality, by building an imaginary world also allows us to use these very primitive physical and instrumental interactions. Similarly, many forms of tangible interfaces and augmented reality create an artificial world. For example, Urp [[UI99]] allows architects to move physical wire frame buildings around on a table top and see projected shadows of them move also. Although this may involve complex computation, the effect for users is a simulated reality upon which they can exercise their physical instincts. The "parallel world" model inherent in various tour guide systems [[AAHLKP97,CDMFE00]] seems to stretch the bounds of reality, but still seems to be comprehensible. In previous work I've used evidence from various non-digital domains to understand what is essential to our innate models of space and what can be relaxed [[D00]].

Different forms of awareness mechanism draw on several different primitive responses. General situational awareness may be related to physical-level perception – it is getting dark, perhaps it will rain, the plants are changing, winter is coming. However, faster acting awareness is more likely to be connected with the effects of other animate creatures. At a predatorial level we need to be aware that when the grass moves we need to prepare to run from the lion, but may just be a more harmless animal going past. The ARKola experiments probably drew partly on the physical perceptions and partly on these more predatorial ones as the factory is to some extent 'animate' [[GSO91]]. At a pack or herd level each member maintains some background knowledge of the rest of the group and it is these feelings of mutual knowledge that shared office and other forms of group awareness seek to maintain [[DB92]].

Incidental interaction is quiet problematic. Although we may accidentally brush against a glass and knock it over we do not (in the real world) walk into a particular patch of grass and predictably find the sun comes out. Physical interactions involve spatial and temporal proximity whereas action at a distance or delays require a very explicit instrumental relationship (you can see the stick) or perception of dynamic instability (the glass rocks for few seconds and then falls). Action at a distance or with a delay that does not have such a clear cause can only mean one thing – someone or something is out there!

Across all cultures where physical effects (earthquakes, the blowing of the wind) have no clear cause they are ascribed to animate agents. Such supernatural explanations abound in computing where causal effects are complex or unpredictable. The most primitive animate relations are at a predator prey and not unnaturally the immediate response to 'being watched' is negative. This is a universal reaction: immediate responses to the supernatural are to fear, ward off or propitiate; and still permeates 'modern' thinking from Hardy to Hammer. Colleagues performing ethnographic studies of a half-way house for schizophrenics have to adapt their techniques as their normal practice of 'watching and following around' would not be acceptable for those whose very fear is that they are being watched [[CCHKFPPRR01]]. Although this is a pathological condition it is also very logical reaction – in the wild if something is watching you it probably wants to eat you.

designing metaphors

If we want or expect users to build models of incidental interactions we need to take these primitive responses into account. If we aren't careful the models users infer of the system will be at best magical and capricious and at worst malignant.

One option is to hide the interactions so deeply that users are unaware they are there. For example, the environmental control system in a large office could sense someone come into the office and turn up the air conditioning slightly to counteract the slight increase in human heat output.

Where this is impossible it may be possible to present instrumental or physical models of the behaviour. In science this has been used extensively to model and understand action at a distance. Maxwell imagined space filled with small rotating balls in order to build his electromagnetic field equations and potentials, lines of force and ether are part of the metaphors that have enabled scientific progress (as well as sometimes becoming barriers). Happily many of these metaphors have already been internalised – electricity flowing down wires, radio waves, machines that take a while to 'warm up' – so can be recruited by users to explain incidental interactions and can be encouraged by appropriate design and documentation.

For more complex interactions only more animate or magical understandings may suffice, but run the risk of appearing capricious or sinister. In order to avoid these negative connotations we may need to deliberately introduce 'fun' magical explanations or even tame creatures such as the pussy cat in Eager [[C91]]!

Of course, the more benign familial and social interactions with parents and pack also involve being watched (or watched over) and can be recruited for design. It is interesting to note that the Bible, when describing a good a loving God uses exactly images of fatherhood, motherhood (albeit to a lesser extent) and in the New Testament sibling and friend.

Although there are many dangers in anthropomorphising computers all the evidence is that people will do it anyway! A variety of purposeful interaction techniques make good use of this: eliciting personal information during counselling [[PGA00]], embodied conversational agents in virtual environments and on the web [[CSPC00]], and, at a more mundane level, Ask Jeeves [[AJ]] can elicit more precise search terms by encouraging questions rather than simply keywords.

Again, it is only on reflection that I realise that the although the visual appearance of onCue was deliberately not animate (not another paper clip!), the language we used to describe it was all about watching and doing.

Where incidental interaction is embodied in some way, for example, the Microsoft paperclip, this is an obvious locus for creating a benign persona. People are annoyed and may even hate the paperclip, but they are typically not afraid of it. In contrast, one of the users of Tsukahara and Ward's adaptive speech interface said "... it felt fake, like it has suddenly gotten perfectly in touch with me" [[TW01]] – in other words it felt spooky!

Where the effects of interactions are not embodied but are still apparent we may need to choose language that enhances beneficial models of the system ('watch over' rather than 'watch') and even the names we give systems may be significant ('guardian' as opposed to 'sentry').

8. Discussion

As we move towards more sensing and active environments the old interaction paradigms no longer apply. Focusing on incidental interaction, this paper has identified a particular class of interactions for these emerging systems and in clarifying the design space help move towards better designs.

Others are grappling with similar issues. For example, Button and Dourish's technomethodology seeks to understand how the insights of the rich contextual nature of human activity revealed by ethnographic studies of the workplace can be recruited to help design systems that support rather than constrain work [[BD96]] and this has lead into Dourish's vision of embodied interaction [[D01]]. In my own work and in work with Rodden et al., we have begun to build ontologies of context and location in order to better understand spatially influenced interactions in physical space and cyberspace [[D00,DRDTFP00]]. Also, in a recent paper, Bellotti et al. have tried to unearth crucial issues for 'sensing systems' [[BBEGHL02]] and have produced a framework focused more around interaction as communication rather than the more common instrumental model embodied in Norman's execution evaluation cycle [[N90]]. However, this work is focused solely on purposeful interactions and so starts with issues such as how you and the system knows when you are addressing it. In contrast, by its very nature, an incidental interaction is never 'addressed'. This paper was also inspired by various groups at Lancaster working on the modelling of a variety of mobile, context aware, bio-sensing and wearable interactions.

We have seen that incidental interaction is a significant class of interactive behaviour both in existing environments (such as car courtesy lights), within software systems (such as onCue) and in applications within the unicomp field (such as media-cup). It is important to view it as a phenomena in its own right because there are commonalities between applications in the area in terms of user behaviour (co-opting, common errors) and system architecture. We have also seen that incidental interaction is likely to recruit very different cognitive abilities.

In highlighting incidental interaction this paper aims to give a means to improve understanding and thus improve design.

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