Semiotics & Syringe Pumps

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Abstract

Semiotics can be a useful paradigm in HCI research and yet the cognitive process of semiosis is difficult to uncover and empirically study. Thus in the domain of HCI semiotics has largely remained a descriptive theory, able to provide a theoretical basis for the study of interfaces and interaction, but unable to produce empirical data and generative research.

This work, made up of several studies, aims to investigates human errors motivated by the problems of medical interfaces. It takes an empirical approach to investigate the interplay between semiotic signs and human error, attempting to uncover how signs in the interface may affect the use of interactive devices.

Interfaces are created from signs, collections of symbols, icons and indices which form a semiotic scene, a meaningful whole through which the user may interact with the underlying system. Therefore interaction with an interface relies heavily on the process of semiosis.

The first study in this thesis was a questionnaire study looking at number pads as indurate signs for calculators and telephones. The questionnaire was designed to ascertain how users interpreted number-pads and what features of the number-pad influenced this interpretation. We found that the layout of the numerical buttons on a number-pad had little to do with how the number-pad was perceived, and that the users based their assumptions about the use of the interface based entirely upon the extra contextualizing non-numerical buttons.

The wish to use a semiotic paradigm in an empirical study demanded the exploration of a novel experimental methodology. The next set of studies were experiments to see whether the interpretation of indurate signs could be overcome under pressure. Thus we used a computer game based experiments as it was thought that they would allow for the complete control and manipulation of signs within the experimental environment, and encourage more natural semiosis that one might expect from participants in a real life task based explicit experiment. In these studies it was found that under pressure participants fell back upon the culturally fossilized meanings of the indurate signs they encountered, suggesting that indurate signs may cause misinterpretation in human-machine interaction if used ineffectively.

Overall this thesis makes a contribution to semiotics by exploring the notion of indurate signs and how they are interpreted, by investigating what features of common interfaces affect semiosis, and by attempting to further the course of empirical semiotic studies. This thesis also contributes towards the use of computer games as a research tool by charting the evolution of the game based experimental methodology over the course of this thesis.

A note on writing style

Writing style of academic work varies widely throughout the various scholarly disciplines, and between the authors which work within them. This MSc is written in a first person perspective and contains some informal language, a potentially controversial choice. Although use of the first person is somewhat rare in the field of computer science and human-computer interaction, it is more common within humanities based fields such as sociolinguistics, semiotics and philosophy. The renowned semiotician Umberto Eco often uses the first person and an informal style of language throughout his writing [36]. The use of the first person is also perhaps more relevant within an MSc by research than in other academic texts as this thesis plots not only the findings of a study but a learning process of the author.

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Author's Declaration

I hereby declare that I am the sole author of MSc by Research.

1 Introduction

Semiotics is no stranger to the world of computer science ([6][41][50] [93][94][102]) and has been applied to the discipline with mixed results. One of the most influential semioticians in the field of human-machine interaction is Andersen [1]. Andersen states that, like any other theoretical framework, semiotics has strengths and weaknesses and argues that semiotics is really only useful at dealing with things which deal primarily in semiosis, such as media, language and computer systems. These examples intrinsically contain signs, representations of concepts. Therefore semiotics can be expected to reveal more about the basic and important properties of computer systems than other artefacts in society which do not primarily deal in semiosis [1] such as helicopters, shipping lanes, etc. Andersen goes on to argue that computer systems are sign-vehicles and thus non-semiotic approaches in computer science will have to deal with the same phenomena as semiotics do, therefore semiotic concepts can be found in other approaches to HCI [1]. This may be observed in the conceptual similarities found between semiotics and activity theory[11], situated action[122], blend theory[88], affordance[133], appropriation[30], etc. Tanaka-Ishii echoed this sentiment, stating that the development of computer languages has simply been an effort to transform a mere mechanical command chain into more human-friendly expressions by rediscovering ways to exploit the sign using mind of humans[123]. In other worlds, creating programming languages and developing ways in which humans may interact with computers is simply an exercise in semiotics.

The hypothesis of this thesis is that a knowledge of semiotics can measurably improve the design of an interface. To test this hypothesis this thesis will move away from the purely descriptive nature of most semiotic approaches and use empirical data to explore semiotic issues in human-computer interaction. As will be discussed further in Chapter 2, semiotics has provided insights into the many areas of academia including the domain of human-computer interaction (HCI). However, its application within HCI has been mostly limited to that of a purely descriptive tool, used to simply label rather than producing valuable generative research. Therefore, this thesis will use semiotics as more than just a descriptive theory and attempt to use it to create insights into HCI which can be used to practically guide design. To accomplish this, this thesis will explore the semiotic concepts which are at work within HCI and attempt to develop a novel experimental methodology, based on computer games, to test these concepts. Thus it is hoped that this thesis will also contribute to the use of video games as experimental tools, as well as to the understanding of the adoption and reinterpretation of signs present within interfaces.

One of the main focuses of this thesis will be problems with real interfaces, specifically those of medical devices. Gaining insights into how people interpret the interfaces of critical devices such as syringe pumps is an important part of reducing human errors in critical environments, but what of the importance of a semiotic perspective on the matter? In the literature review of this thesis some of the studies relating to the dangers of these devices are discussed, but what becomes clear from this discussion is that there are still many issues which are not understood about what causes many errors. Therefore the importance of this thesis centres around gaining new insights into errors in critical devices via the use of a novel paradigm in this area of research.

This thesis begins with a review of the relevant literature, starting with sections on general semiotic theory and how context affects semiosis. Next previous semiotic studies within the domain of HCI are discussed along with an exploration of empirical semiotics. The literature review also contains a section which discusses the use of syringe/infusion pumps and the risk of errors inherent to their use. Chapters 3, 4 and 5 of this thesis centre around the gathering and analysis of data. Chapters 3 investigated of the concept of the *indurate* signs, a central theme throughout this thesis. The concept is discussed in detail and a questionnaire based study is used to gain empirical data on the subject. Chapters 4 is devoted to the design and evolution of the game based experimental methodology, culminating with the analysis of the results from the final game experiment.

This thesis does not simply hope to investigate one rather novel area of study, but sets out to investigate and test a number of relatively sparsely explored areas. While it is hoped that this will provide a number of insights into each of these areas, the scope of this thesis will be limited by its predominantly exploratory nature. Thus, though a definite solution to all the problems raised in this thesis can not be reached, this thesis should provide insights into empirical semiotics, using games as experimental tools, semiotics in games, the nature of culturally indurate signs, and the interplay between signs and errors. In summary then, this is an exploratory study, cutting a path through a number of areas to provide a base for further investigation, the main research questions for this thesis are as follows.

- What is the interplay between signs and errors in human-computer interaction?
- How are culturally indurate signs interpreted in situated use with interfaces?
- Can 3D gaming provide a suitable environment in which to test semiotic theories?

2 Background

2.1 Semiotics

Levinson states that the human mind contains an '*interaction engine*'[76][77], a ramshackle but adaptive system cobbled together from scraps of motivational tendencies: our desire to be understood and to understand, temporal sensitivities: how we react to the incidences of our perceptions, the Schelling mirror-world: the capacity to analyse others' actions through mental simulation, simulating other minds simulating our minds[77], cognitive phenomena, semi-cooperative instincts, ancient ethological facial displays and so forth. Levinson's interaction engine allows us to communicate and interpret the intended actions of others, and goes far beyond language.

Broadly speaking, semiotics is a theory of signs and meaning, it is the study of signs and their life in society [1] and it is a useful theory for design and human-computer interaction as it acknowledges the compulsive nature of human interpretation. The sign using brain of the human allows us to use a system made up of arbitrary sounds and shapes to communicate meaning in language, and it looks for meaning in human action, and it allows us to form meaning from the artefacts of societies. Eco states that signs are not only words and images but may be any artefact including social behaviour, political acts, or artificial landscapes [35]. In this thesis a wide range of semiotic ideas will be drawn upon to form the theoretical basis, however the particular flavour of semiotics shall steer clear of pansemiotics, the theory that "all environmental phenomena are semiotic in their essence" and that "the relationship between humans and their non-human environment, nature is semiotic throughout, and the signs which we perceive in our natural environment are messages emitted by God or some other supernatural power" [99]. In doing so this study maintains the view that signs are limited to artefacts of a human origin and that the only way we may attribute meaning to nature is to anthropomorphise our observations of elements within it, or by assuming that all existence works by the standards of our own fragile consciousness.
Although this thesis does not hope or need to adequately critique pansemiotics, the main argument I have with the theory is that natural landscapes communicate very little to us, we may see a tree or a valley and muse upon how it came to be there but the artefact holds no real meaning. This is because nature, in all its beauty, is meaningless. When the leaves turn brown in autumn it is not for the sake of meaning, but a simple biological act, and though we as humans may ascribe the meaning of 'autumn and winter are coming'to this change, the meaning is entirely centred around our arbitrary labels for these things, the tree all the while, meant nothing. It is only our natural obsession with the weather and the seasons which imbues cold innocent meteorological and biological phenomena with meaning.
Standing stones are a good example of the distinction between natural and human artefacts. They have sat, lichen patched, weathering in the fields for such a time that they could be considered more part of the landscape than some of the surrounding flora. However, when we see a standing stone atop a hillock, we do not wonder at the meaning of the hillock or the distant trees or the curious cow, but we *do* wonder at the meaning of the stones. The standing stones *must* hold meaning, a meaning we can only blindly guess in our ignorance but meaning nonetheless. Why? Simply because we know a human decided to put them there and that they would mean something if we had put them there. These ancient artefacts and ones like them [113] often bring the use of signs to the forefront of our minds as we struggle to unlock the meaning within them.

Humans are compulsive interpreters [2] and when a human sees an artefact they attempt to create meaning from it. This meaning is usually formed from previous experiences with similar concepts but is never pure guesswork as, will be discussed later, meaning does not happen in a vacuum, and thus there is always context to interpretation. For example, if a person has never experienced a particular artefact before, such as coming across a new word, they will unwittingly attribute meaning to that artefact based upon their current world knowledge [20], the information they have at hand [74] and the context in which it is found [75]. This interpretive nature of humans is not limited to language or ancient monoliths. A user who is unsure about how a computer system works may construct their own mental model of the machine [9], and according to the 'paradox of active user' theory [14], a user will create ad-hoc theories about an interface if it is not *transparent*.
So humans compulsively create meaning. Humans are also fallible, even in interpreting their own actions, and this trait can lead to problems if meaning is interpreted in an unintended way. Misinterpretation of signs within the sign system of language can lead to problems in a social environment, while the misinterpretation of signs within

a machine interface may cause errors during the use of the machine. In critical devices, such as syringe pumps, mistakes can often result in fatalities [127] and so, understanding interpretation may help to make these devices safer by designing with semiotics in mind. Designing for consistent semiosis.

Semiotics was primarily created by Peirce [107] and Saussure [62][114]. A sign is *anything that is taken by someone to mean something else* or as Peirce stated, a semiotic sign can serve as the theoretical basis for any perceptual phenomenon, internal or external [107]. For example, the stop sign is a sign which prescribes an action. The shape, colour and word on this sign are arbitrary ways of communicating the thing it represents.

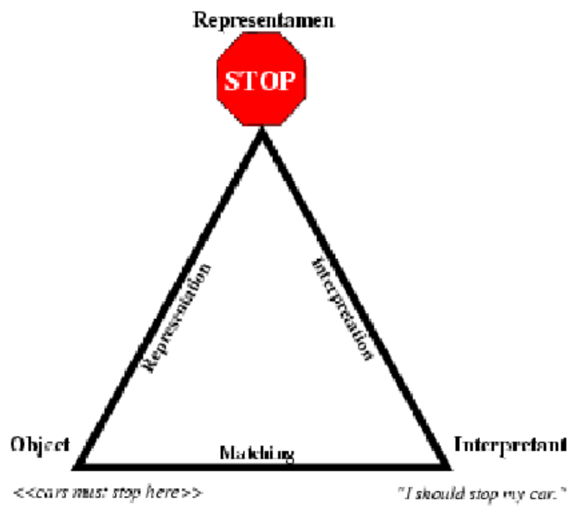


Figure 1: The Semiotic Triangle[6]

Signs have three main properties (Figure 1), the *representamen* (representation), the *referent* (object) and the *interpretant* (the sense made of the sign). The representamen is the form the sign takes (e.g. the word 'stop' written on a red octagon), the referent is the concept to which the form refers (the action of stopping) and the interpretant is the meaning extracted from the sign in the mental model of the operator. The process of forming and revising meanings from a sign is known as *semiosis*.
Some signs rely heavily on context to convey meaning, others hold cultural significance, and in other cases the meaning of a sign arises purely from the difference between it and other signs. *Signifier* is another term for the form of a sign while the *signified* is the concept to which the sign refers. Figure 1 is an example of the sign process of a *culturally indurate sign*. Like an idiom this sign is so common to members of the specific culture that, in a mundane context, its meaning is transparent and immutable. In everyday cognition of familiar signs, there is no distinction made between signs and referents [111]. For example, when faced with a traffic light which is showing a red light, a culturally acclimatized actor will simply stop rather than going through a cognitive sequence that involves remembering the rules of traffic lights, interpreting the light, thinking "This means I have to stop"and then deciding to step on the brakes [111]. The information that the driver must stop is mediated through the traffic lights and, through its ubiquitous nature in western culture, this meaning has become embedded in society and is therefore totally transparent [86]. The sign (red light) and the referent (blocked right of way) have become aspects of a singular concept (stop) [111], it has become an culturally *indurate* sign.

Peirce [107] established that there are three kinds of sign, icons, indices and symbols. Iconic representamen are linked to their referent simply by imitating them, examples of icons are classical statues, the shapes prescribing sex on toilet doors and most desktop icons. An icon relies on likeness, there is no dynamic connection to the thing which it represents, it simply has qualities which resemble the object[107]. Indices indicate something and are physically connected with the referent. Some examples of indices are, sign posts pointing towards a town thus indicating to what they refer, exclamation marks, which refer to the word/sentence to which they are attached, a knock at the door which indicates a person being at the door, and a flag causally linked to the wind. Symbols

are associated with the referent purely by use, examples of symbols are the arbitrary words and symbols used in language and maths. Peirce [107] states that symbols are connected with their objects by the virtue of the symbol-using mind, and without the sign based mind of humans no connection could be made.
As symbols are not causally or analogously linked to the thing which they represent, they behave differently and are mutable within the individual semiotic space in which they exist. This semiotic space is known as a semiosphere, outside of which semiosis itself cannot exist [80]. It is a conceptual space containing a specific user base, text, culture, etc. the borders of which are defined by language use, cultural knowledge and perceived reality. A hospital ward, a pub, or a control room are all a combination of physical, conceptual and virtual constructs, semiospheres which are governed and defined by their own rules and laws of existence [63]. Through use and experience within the semiosphere, the meaning of symbols grows and develops, symbols evolve with society, changing and enveloping other signs.

Semiotics is not only a theory to be pontificated from atop an ivory tower but has practical uses within design and engineering. In a study of the semiotics of control room situation awareness, Hugo [63] explored the semiosis in industrial human-system interfaces. Using concepts from the broad field of semiotics Hugo, introduced how information representation and communication could be optimized if control rooms were considered as semiotic spaces. Spaces home to perceptual or cognitive stimuli which are interpreted by actors, leading to interactive tasks which in turn produce other stimuli, giving rise to an endless process. Interwoven in this process is semiosis which has an inescapable effect of performance [63]. In other words, by understanding the relationship between a sign, its meaning and the context, we will have a clearer understanding of the reasons why different representational modalities are better than others to convey operational information in specific contexts, thereby improving the chances of achieving the required performance.
Semiotics is not a science but can be used as a powerful tool when used to inform science and engineering as those disciplines are inevitably applied to humans and society. In this vein semiotics has already been applied to many different disciplines, to form and inform such lines of enquiry as artificial intelligence[82][119], biosemiotics [39], cognitive semiotics [3], media studies [61][92], art & theatre studies [5][37], organizational semiotics [47], information management & knowledge representation [85], and so on. Due to the interoperability of semiotics, it has also been used in conjunction with various other disciplines and theories of action and interaction to create combined methods of analysis, theories such as activity theory [11] and metaphor [6]. Semiotics has even been suggested as the great peace maker between the qualitative and quantitative disciplines [116] an issue which we shall not dare to dive into here.

2.2 Semiosis does not happen in a vacuum

The physical and conceptual context in which we find a sign is a critical factor in semiosis. Hodge et al.[61] argue that meaning is constructed through the interaction of a number of signs with an overall code. This code can be thought of as a set of expected rules that may be explicit, such as the audience expectation of a film, or more transparent such as Grician maxims in speech.
These codes are analogous to coloured lenses, they affect how we perceive the world and when one views an artefact using different codes, one may see the artefact differently. In other words different codes can create different meaning from the same 'text'[61]. For example, in Discourse Analysis one may read a text *against the grain* to find implicit meaning, when watching a film one may enjoy it less if it was expected to be of a different genre, and if a computer user sees a program as a game they are likely to use it differently. People use these different codes or *cultural frames*[88], as a grounding for interpretation within the larger context of their reality, and use conventional frames of interpretation to stabilize[59] an environment so that the semiosis may be closer to the cultural norm. This process is much like the concepts of *common knowledge* and *common ground* [21][75] in interpersonal interaction, in which people *grease* the interlocution by establishing the accordance and consistency of their joint reality. To make life easier people generally interpret things in a way that they assume they were designed to be interpreted. de Fornel et al. state that what makes individual thoughts possible is the existence of this stable environment of thoughts, conceptions, and signs that are nobody's, that are shared by society and form reality [23]. This conceptual reality together with all we can perceive forms our *Umwelt*, the basis for all context in which a sign may be interpreted. Jakob von Uexkll's Umwelt [81] refers to that which an organism can perceive, and everything has its own Umwelt according to its own specific measures [130]. Emmeche states that the "umwelt may be defined as the phenomenal aspect of the parts of the environment of a subject (an animal

organism), that is, the parts that it selects with its species-specific sense organs according to its organization and its biological needs"[38]. In applying Umwelt to non-organic systems Gudwin defines the concept as "the phenomenal aspect of the parts of the environment surrounding a system, that is, the parts the system is able to interface with, by means of its sensory and actuative devices, according to its internal organization and its internal objectives"[57]. Thus, the interpretation of signs is the product of the human mind, and therefore the product of our cognitive evolution operating within a our knowledge and experience, within a set of cultural rules.

To expand the traffic light example, if we pull up to a red traffic light we know it means 'stop', if there is a white line across the road close to the traffic lights we know it means 'stop here', and if we see a traffic light from a distance it communicates the possibility of having to stop. Context changes and creates meaning, and the meaning of even simple signs such as traffic lights are in flux as operators move through the semiotic space in which they occur. In real world semiosis a sign cannot exist as a single entity and is always a part of a bigger system which inherently includes other signs [70] which are all part of the semiosphere [80]. Lotman stresses the importance of considering context in the analysis of signs with his calf metaphor. This metaphor states that though you may split a calf up into pieces of delicious veal, you cannot take many pieces of veal and make from them a calf. The calf to veal process is non-commutable and so in splitting it into pieces something is lost which cannot be recovered. One must look at the whole scene rather than the individual components to understand meaning [34]. Meaning is, to use an old adage, greater than the sum of its parts. Individual signs may affect the meaning of a scene, and thus must be analysed in terms of the entire scene when investigating their potential to communicate misinformation. This inaccurate encoding of meaning is discussed in terms of information presentation by Tutfe [129]. Tufte argues that when pictures are used to represent numbers, the disproportionate nature of elements within the graphical representation can create a different interpretation of the issue, in the case of Figure 2, making the issue of the '*shrinking family doctor*'seem more drastic.

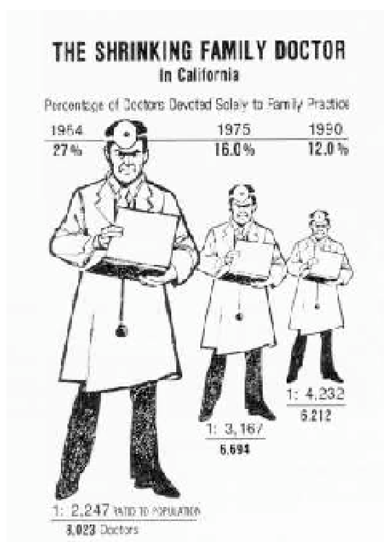


Figure 2: How pictures can mislead[129]

In an industrial or medical setting signs which do not accurately match the numerical data which they accompany or represent could cause problems with situation awareness and the perceived relevance of information presented. Signs within an interface may not be *lying* with their form or size, but they may not be communicating as effectively at they might, or worse, not communicating the right message. For example, a small icon showing critical information may be perceived as less important than a larger icon displaying mundane information. An example of such ill-considered semiotics can be seen in the syringe pump below (Figure 3).

Figure 3: Alaris Syringe Pump

In the syringe pump interface the large dosage rate is actually irrelevant if the person who set the rate believes it to be true. What may really highlight any programming errors to the care worker is the time of infusion left, the volume of drug left, volume infused and the battery life, and yet this information is either missing or given less screen space. Tufte, speaking about graphical representations of quantitative data, states that behind a bad graphic is a lack of judgement about quantitative evidence [129]. If we carry this idea over to instrument design, a lack of judgement about how signs are interpreted may cause an the interface designer to ignore issues concerning relevance of information.

In HCI *context* can refer to several concepts. Dourish [32] states that there are two main types of context, the first is the technical notion, one which allows developers to conceptualise human action and the interaction between that action and computational systems, a mesh of social structure, affordances and material properties [18]. The second type is the social sciences notion, which consists of drawing analytical attention to the social setting. He goes on to argue that context is phenomenological and proposes a model in which context and activity are mutually constitutive called *embodied-interaction*. In this model the context is not simply made up of the physical reality but from the availability for engagement, the way in which the meaningfulness of artefacts arises out of their use within systems of practice [32]. In semiotics studies, it is important to consider physical and conceptual reality in which we act, action can shape our physical surroundings but more often it shapes our thoughts, concepts and perceptions of reality. Following Dourish this thesis does not aim or need to define what context *is*, only to be aware of what the concept does in terms of interaction and semiosis, and that all interaction takes place within a broad context. Medical devices in particular are situated within a complex web of information, people, systems and cultural frames [10].

2.3 Errors with Syringe Pumps

In this thesis one of the issues we are exploring is how signs present in medical devices such as syringe & infusion pumps may influence their use. A syringe pump is a dangerous device, it can kill with the simplest of slips or planning errors in the steps leading up to the device being programmed and the causes of medication errors involving syringe pumps are not limited to the care giver who programs the pump. Several nurses who use syringe pumps regularly, several times a week and often daily, were informally questioned for this study about the amount of training they received to operate these devices and their thoughts and experiences of them. Most nurses I spoke to stated that they had to use various different models of syringe pump throughout the hospital and that they received full training on each of these devices. They went on to state that they trusted syringe pumps and regarded them as safe devices with the only real potential for error stemming from the user, to quote one of the nurses "in safe hands they are safe". However, mistakes and slips such as capture, keying, and calculation errors are more common than one would like, and it seems that the various errors which may occur in the process of drug infusion are related to the number of steps which must be taken in the process of using a syringe pump to deliver drugs a patient (Figure 4). This suggestion is based upon the literature discussed below, in which the various potential errors at each stage of the infusion process are explored.

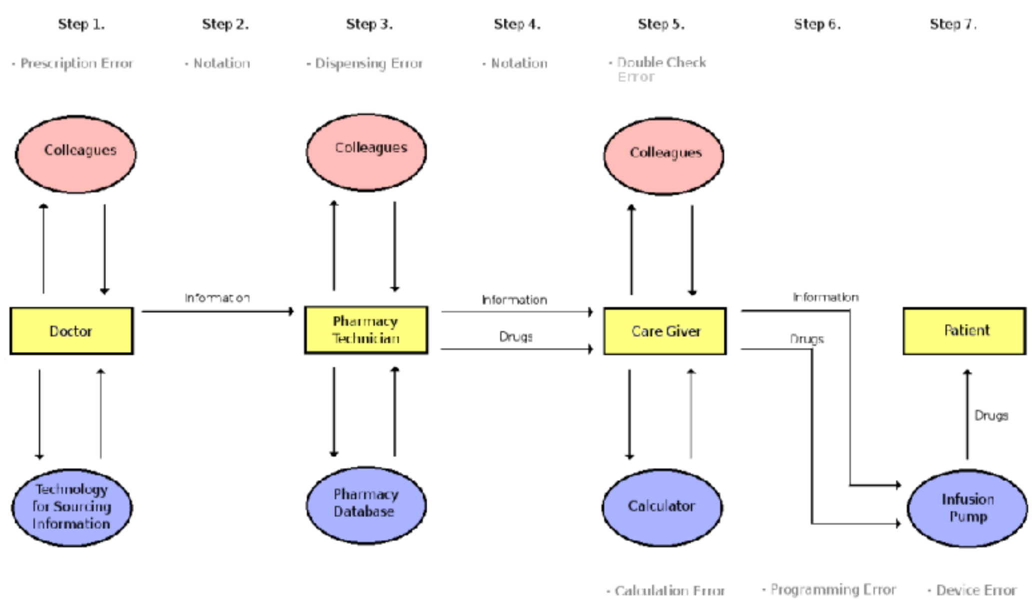


Figure 4: Stages and possible errors in the transfer of information and drugs

Step 1: Prescription Error - Doctor
Apart from mistakes, in which the prescribed drug or dosage are simply incorrect, there are many opportunities for prescription errors which are not due to lack of knowledge or incorrect assessment of a situation. Doctors use computers and handheld devices for reference to drug and medical information, patient tracking, checking guidelines and access to online databases [71]. This creates situations in which slips and mistakes when using these technologies may lead to prescription error, and any increased reliance on this external memory can only lead to a greater potential for errors.

Step 2: Information Transfer - Prescription Notation Error
Notation error is when a prescription is written in a way which is incorrect or, more often, difficult to interpret. These errors often occur due to the prescription being noted down using a mixture of acronyms, numbers and other non-standardised language using barely legible freehand. This has the potential to cause the incorrect semiosis of symbols and thus misinterpretation of the prescription information which may lead to errors in the drug type and

dosage [46].

Step 3: Pharmacy - Drug Dispensing Error
An unsuitable dosage or drug may be sent from the pharmacy. Common mistakes include the dispensing of an incorrect drug or an incorrect strength, dosage or quantity of the intended drug [66]. The causes of these errors include semiotic issues such as look-alike sound-alike drugs and misidentification of drugs, and working conditions such as overly high or low workload, distraction, work patterns, lack of breaks, software and inadequate lighting [108] [66] [54]. One way to combat these problems is the barcode system, in which barcodes are placed upon drug containers which, when scanned, reveal all the details of the drug within. If medical devices such as syringe pumps can read these barcodes then risk of medication errors is greatly reduced as incorrectly dispensed drugs would be flagged by the device.

Step 4: Information & Drugs Transfer - Drug Label or Direction Label Error
In much the same way as the prescription notation error, labels or directions for use which have been supplied with the drug may be written in a way which encourage misinterpretation and therefore cause errors.

Step 5a: Care Giver - Calculation Error
The calculation of the dosage and duration of drug infusion often involves using a calculator to complete a calculation which is simple yet very easily completed incorrectly. Thus cognitive slips and mistakes can lead to error. In a medical environment calculators, and their inherent problems, which have been extensively explored in many papers by Thimbleby [127], are directly linked to syringe pumps. Errors may occur if a care giver does not know the most effective way to complete the dosage calculation or suffers a slip, such as a decimal point error which may occur if proper number entry procedure is not followed.

Step 5b: Care Giver - Double Checking Error
The double checking of drug dispensing information, calculations and device input can be used to detect medication errors. However, in some situations double checking can be rendered ineffective. If a double check is not done by a second individual then the usefulness is reduced, this is because it is more difficult to find ones own errors due to confirmation bias, seeing what we are most familiar with rather than what is actually there [55]. Similar errors may occur if the double checking is done by another person but is not done independently, as people may be swayed by the opinion of others [55] or assume that their colleague is correct.
One example of a double checking error was a check which did not discover a fatal calculation error. This occurred when the person doing the double check was on their way to complete another task and could not find a calculator. The person was both distracted and had to do the calculation in their head, this lead to the failure of the double check [101]. Another example of a double check error occurred when a care giver was unable to open a device to check if the concentration of the drug matched the concentration which had been entered into the device. The patient had been moved to another ward and for the lack of a special key, the inaccurate programming of the device was undetectable [132].

Step 6: Information & Drug Transfer - Programming Error
Now we come to the subject of this thesis. Errors may be caused by the syringe pump itself, not by a hardware or software fault but by bad design. One problem with the user interface of most infusion devices is that they contain unhelpful or inappropriate manipulatable and non-manipulatable elements. We have already seen in Figure 3 that the size of on-screen artefacts bear little relation to their critical importance and the safest type of number entry system is still entirely debatable though work on the subject is essential[128].
Another problem with the interfaces of these devices is that design guidelines [95] for the interface of infusion devices seem to be produced heuristically, with little or no evidence of empirical research forming the basis for the guidelines. One of the aims of this thesis to empirically investigate how signs within the interface of syringe pumps may lead to cognitive slips, mistakes and misinterpretations. This in turn will hopefully contribute to the understanding of safe number entry.
Devices may also have opaque software, mode problems, illogical temporal attributes or lack fail-safes. These and numerous other problems may cause errors in the programming of the device. An example of such a design error is explored in a report by Grissinger [56], in which a feature of a syringe pump caused the death of a patient. The feature was that the pump would default back to any previous settings if the current settings were not properly confirmed, this feature was unknown to the care-givers who programmed the device, leading to the incorrect dosage being given to a patient. As well as problems with the software, the interface as a whole may also cause errors. This is because while the prescription, drugs and calculation of the dosage may be correct, this information

must be transferred to the device. In this critical step of drug infusion it is the interface of the device and the user's interpretation of that interface which is all important to prevent programming errors. Errors which are caused by simple slips such as key-stroke errors, the lack of training or upkeep of skills on a particular device, or by inherently unintuitive, misleading or dangerous design [128]. It is worth noting that even when an interface does not cause a problem, cognitive slips, capture errors and mistakes can still cause fatal errors which could only be avoided through multiple fail-safes. In a situation explored by Vincente et al.[132] a nurse originally wanted a drug cassette containing 1 mg.mL solution of morphine when there was only cassettes of 5 mg.mL available. A 5 mg.mL cassette was used however, 1 mg.mL was entered into the pump. Even with dosage fail safes used in 'smart pumps' [112] the device cannot know that the concentration entered is inaccurate. This sort of cognitive slip is difficult to prevent without the barcode system.

Step 7: Drug Infusion - Device Fault
Finally, the device may suffer a hardware or software error which causes problems in the delivery of medication. However, as stated by the nurses mentioned previously, technical problems are rare and most faulty devices are identified before they can harm a patient. Many devices are recalled by manufacturers due to software errors such as inconsistent dosage rate, alarms failing to sound, display values error, system crashes, unexpected actions, data lost, missing functions and internal calculation error [134]. These problems can only be combated through good engineering and vigilant medical staff.

► The Stopped Buck
From this chain of action, we can see that the process of drug infusion is a complex manipulation and transfer of both information and drugs, two things which must remain accurately linked throughout the process. It is also apparent that though the cause of an error may originate far from patient, the error will be manifest within the syringe pump. So although the responsibility ultimately rests with humans, technology could be used to safe guard against many potential errors, to create more conceptual slices of Reason's swiss cheese [110] to block more errors. Safe guards such as bar coded drugs and software dosage limits in syringe pumps have already been mentioned. However, unsafe practices can render these safe guards useless. Unsafe practices including failure to comply with standard IV drug dilutions, inappropriate use of the device, use of potent medications without physician orders, overriding drug rate limits, and incorrect programming of patient weights for medications with weight-based dosing protocols [112]. In these examples 'smart pumps' may only log these unsafe practices [112], a feature reminiscent of a certain horse and closed stable door, and one which lacks the contextual information that would make it useful in avoiding future errors as infusion device logs are not black boxes for medical safety [7]. This situation demonstrates how the implementation of technology cannot alone influence change in human practice [84], and so technology's role in the safe infusion of drugs should be to guide the safe practice of health care workers while providing a number of fail safes. This thesis considers two things, can safer interfaces and prompts be made through a heightened use of semiotic principals in design and by understanding what semiotics are going on in the situations which cause capture errors and similar cognitive slips?

There have been many studies into the design of, and procedures surrounding, infusion and syringe pumps, using task analysis [100], qualitative data gathering of their situated use [10], and numerous other methods to try to solve the various problems with these critical devices. Many of these studies have made contributions to our understanding of these devices and the errors which occur in their use, yet more analysis is clearly needed as these errors continue to happen.

2.4 Semiotic Studies in HCI

In the following section the two semiotic approaches which have the greatest impact on HCI will be explored in greater detail, these approaches are the work of Andersen and de Souza. Andersen was one of the first to thoroughly address the issue of semiotics in relation to computers and interfaces. Andersen views a computer interface as a sign vehicle, they are the mediators of communication, not the direct communicators [1]. In Andersen's view semiotics can be used for [2] exploiting insights from old media which have been used to construct new texts, defining the characteristic properties of the new computer medium and situating HCI systems in a broader context. However, Andersen warns that semiotics is limited in its ability to provide insights in to HCI and states that to provide useful analysis, semiotics must be used constructively (i.e. used to explain how complex interfaces can be created from simple semiotic elements), rather than simply in a traditionally analytical way, and with an in-depth awareness of the technical possibilities and limitations of computer systems [2].

More recently Andersen has developed a semiotic methodology for the analysis of instruments such as wind-speed/direction displays on sea going vessels. This conceptual analysis of instruments aims to develop a systematic approach to design options, to analyse the efficiency, consistency or coherence of design choices in a given work context. The object of this approach is the physical and conceptual decomposition of interface elements into a set of the smallest building blocks and then the practical assemblage of instruments by means of these blocks [89]. This process discovers the basic features, components and operations of an interface and provide a core of background knowledge which allows the interface to be better understood, modified and redesigned based on the user's changing need for information [89].

Thus, to use a Hacking-esque [58] analogy, if we consider the broad field of HCI semiotics as a lens through which we may view an interface, Andersen's instrument semiotics uses this lens as a conceptual microscope. Instruments are broken up into their separate parts (for example a standard speedometer would consist of a pointer, annotation of speed and a frame) which are defined according to their modality and media type i.e. how they are perceived by the user and how they behave temporally (through time). Media and modality types combine to form the schemata for the object, this schemata is shaped into 'prototype schemata'by the purpose of the instrument which in-turn combine to form components. Components are spatially co-ordinated to form scenes.

By stripping down instruments to their component parts, each having its own properties and constraints, complex objects in an interface can be analytically understood in terms of how it may be interpreted and how well it may convey meaning in a much deeper way than might be achieved by simply referring design guidelines [89]. Andersen states that this could be important for research into flexible and intelligent interfaces, where these tailorable interfaces could display information in a more dynamic and useful way depending on its relevance to the current situation. For example, in Figure 3 we can see that there are multiple components which are arranged together, with the spatial co-ordination contributing to interpretation, to create the scene. This scene is framed to group these instruments into a topical whole which is, in-turn, framed and therefore subordinated as part of the larger interface. The juxtaposition of the screen and the keypad within the blue background also serves to create a sense of direct relation between the two interfaces.

The semiotic engineering of de Souza grew largely independently from that of Andersen, starting with a paper on semiotic interface design [24]. The semiotic foundations of de Souza come primarily from the work of semiotician Eco [34] and have developed into the concept of semiotic engineering, becoming a theory of HCI with its own research methodology. The concepts which provide the foundation for semiotic engineering are metacommunication and the 'one shot message'. Metacommunication is communication about communication. In semiotic engineering metacommunication represents the signs an interface uses to communicate to the user, how they should communicate with the interface. An outline of what the designers are communicating to users through a metacommunication template could be thought of as the following.

> "*Here is my understanding of who you are, what I have learned you want or need to do, in which preferred ways, and why. This is the system that I have, therefore, designed for you, and this is the way you can or should use it in order to fulfill a range of purposes that fall within this vision.*" [25].

In other words, metacommunication could be considered as signs which help the user decode the sign system of an interface. The concept of a 'one shot message'between the designer of the interface and the user centres around the concept that the designer is communicating to the user by proxy via the system [27]. The designer may communicate via the interface to the user, but the user cannot communicate with the designer. Therefore the designer only gets one message to send to the user in which there is no room for the negotiation of meaning. The two investigative methodologies developed by de Souza [27] as part of semiotic engineering are SIM (semiotic inspection method) and CEM (communicability evaluation method), which aim to analyse designer-user metacommunication to evaluate communicability. In simple terms, SIM explores the emission (encoding) of metacommunication, while CEM explores the reception (decoding) of metacommunication [27]. In SIM the metacommunication of an interface is semiotically explored to establish what it is communicating to the user, this is done in much the same as Discourse Analysis, using informed critical analysis to explore media and text. CEM uses video data to explore the user's reaction to the metacommunication present in an interface and uses a Conversation Analysis (CA) style of analysis.

Semiotic engineering and Andersen's computer and instrument semiotics share some fundamental theoretical concepts. Both consider the interface as a medium for communication rather than a communicator and both acknowledge that semiotics has specific uses and limitations in the field of HCI [2] [27]. The main differences between the two methodologies are the core ontologies of each. As noted above, de Souza's semiotic engineering focuses its analysis on the metacommunication of the interface, an analysis aimed squarely at the sending and receiving of this communication within GUIs and the manipulation of GUIs. The focus of Andersen's semiotics on the other hand, is on a multilayered decompartmentalising of each component in the interface, a focus which is directed towards data display and situation awareness[89].In broad terms we may characterise de Souza's semiotic engineering as most effective at providing an analysis which we may term wide-shallow, while Andersen's instrument semiotics best provides a narrow-deep analysis. However, neither of these methodologies has been used to gather quantitative data for an empirical study reflecting the rarity of empirical semiotic study.

2.5 Empirical Semiotics

Most semiotic studies simply use semiotics as a base for the study, using the terminology and succinct theory to explore their subject, label and describe elements within it and sometimes create a new model for design.
Empirical semiotic studies however, use semiotics as a paradigm through which they can interpret data. One of the largest studies which used empirical semiotics was *Children and Television* by Hodge and Tripp [61], the results of which gave great insight into how children interpret television. The study was based upon showing children cartoons and then gathering their interpretations through interviews, it took around 3 years and around 600 subjects were involved. Hodge et al. stated that, although large numbers of participants were used to provide statistical data, their studies did not constitute proof of their conclusions. Their study was based upon discovery over proof, exploration rather than demonstration, suggestion rather than certainty and aimed to show the diversity of children's responses to television rather than the statistical probability of an effect or phenomenon [61]. This study used statistics to highlight trends and observations rather than as a claim of proof. This treatment of quantitative data is most likely due to the reliance that some social science studies have on dubious statistics, and although statistical methods can be useful, anything can be mapped against anything to *prove* anything [61][129]. Therefore in *Children and Television* all *counting* is done in relation to the complex nature of meaning and there is no insistence of proof.
A semiotic experiment by Lui et al. [79] in HCI used the interview technique to gather the descriptions of three interfaces from participants. These descriptions were then subjected to a semiotic interpretation. The study attempted to examine whether semiotic concepts provided greater precision in interpreting the vague language of users and how design guidelines might be created from the evaluation of user feedback. The study found that semiotics was indeed useful for decoding user descriptions into a common form and could be used to develop heuristic principles to assist design but not hard design rules.

In the field of HCI there have been numerous studies in testing interpretation of icons [33][42][52][90] to name but a few, using various methods including cognitive psychology, design guidelines and heuristic aesthetics, with many doffing their cap to semiotics [29]. One such study of icons took the form of the 'Icon Intuitiveness Test' (IIT) [42] which was used to gain an understanding about whether users interpret icons ironically or symbolically. The IIT was a simple questionnaire which presented a group of users with a set of icons, to which they had to ascribe the meaning they had interpreted from them. The icons were placed in groups according to what type of program they came from (word processor, spreadsheet, etc.) and icons used for ubiquitous functions with conventional representations such as 'copy', 'paste', 'save', etc. were omitted.
The study found that users generally assumed icons they were unfamiliar with to be iconic in nature, associating functionality with what the icon resembles rather than assuming a purely symbolic relationship between form and function. One interesting exception to this rule was when the icon represented movement, in this case that movement was the rotation of an on-screen artefact. In the study a simple circular arrow was interpreted accurately by 100% of the participants in the experiment while an iconic representation of rotation was only interpreted correctly by one participant.
The questionnaire presented the participants with a group of icons with only the most basic contextualization, making apparent the type of program in which the icons would be found. However, this information created two main problems with the study. The first problem was caused by the lack of information, the icons being

interpreted were not in their usual context and therefore could not be interpreted, as they would be in actual use, in relation to other icons and signs present in the interface [42]. Conversely the next problem came from too much information and a concept akin to *audience expectation*. In this study it was found that many users were able to accurately guess the functionality of an icon based upon their previous experience with the type of program [42]. Therefore the users where interpreting some icons in terms of what they expected to find within a specific program and only partially in terms of the form the icon took. This is an example of the creation of meaning purely from the user's world knowledge. The tentative nature of the study resulted in the interpretations being neither usefully context based nor based entirely upon the form of the icon. It is a common view in most fields of study which deal with meaning that context is fundamental to the creation of meaning and therefore any experiment in which we are observing semiosis should be relevantly contextualized.

> "*If we put together many branches and great quantity of leaves, we still cannot understand the forest. But if we know how to walk through the forest of culture with our eyes open, confidently following the numerous paths which criss-cross it, not only shall we be able to understand better the vastness and complexity of the forest, but we shall also be able to discover the nature of the leaves and branches of every single tree.*" U Eco [34].

In another study designed to both design and evaluate unfamiliar icons, the method above was advanced to include a confirmation of interpretation [33]. The study was done in three parts consisting of three questionnaires containing icons. On the first questionnaire participants were asked to choose a preferred style from six groups of icons (Figure 5), this established the general graphical style or theme of the icons which would be used in the project.

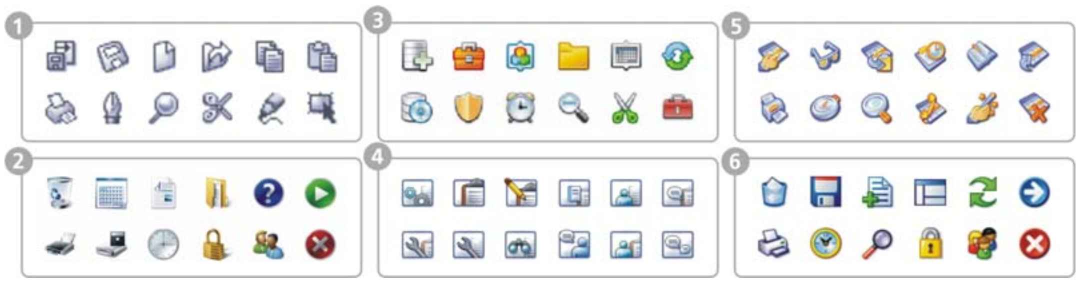


Figure 5: Icons Sets for the Icon Set Preference Test[33]

Three weeks later participants were then sent a second questionnaire which contained a number of icons which were designed to represent a certain concept (Figure 6). Participants were asked to choose the icon they thought best represented that concept.

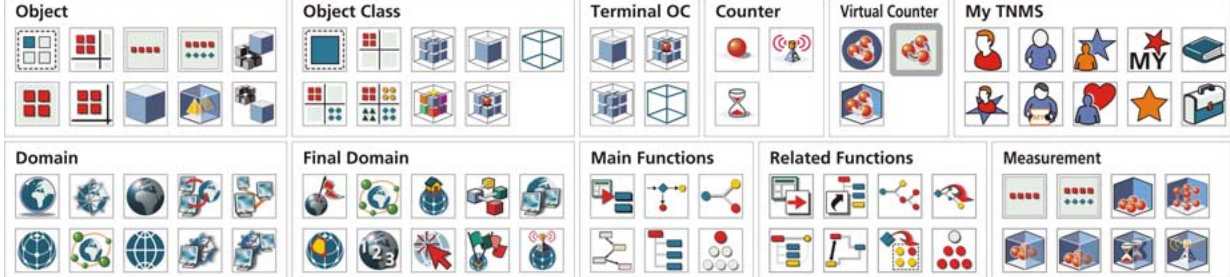
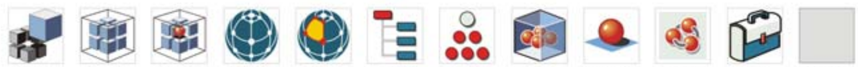


Figure 6: Icons Sets for the Icon Preference Test[33]

Three months later, the preferred icons where shown to the participants along with the set of concepts which they represented. This stage of the study could be considered as confirmation of the original semiosis. The icons and concepts (representamen and the referents) were presented in no particular order to prevent spatial association and the participants were then requested match the icons to the assumed function [33]. The results of the 'associativeness test' (Figure 7) clearly show which icons produced consistent interpretation with the majority of participants and which were less intuitive or more subject to idiosyncratic influence.



	Object	Object Class	Terminal OC	Domain	Final Domain	Main Functions	Related Functions	Measu- -rement	Counter	Virtual Counter	My TNMS	Others	Errors	Missing
Object	6	1	5	1	2	1	0	1	6	3	0	7	27	1
Object Class	6	4	4	0	2	6	3	7	1	1	0	0	30	0
Terminal Object Class	11	0	4	0	0	0	2	2	12	0	0	0	27	3
Domain	2	4	0	9	10	3	1	1	0	0	0	2	23	2
Final Domain	0	2	1	6	11	2	1	0	0	3	0	3	18	5
Main Functions	0	1	0	7	0	19	0	1	1	1	4	0	15	0
Related Functions	2	0	1	0	1	9	4	1	0	7	0	5	26	4
Measurements	2	6	5	0	1	1	1	5	1	3	1	5	26	3
Counter	4	0	7	0	1	0	1	2	10	1	0	3	19	5
Virtual Counter	0	0	0	1	2	0	1	8	4	9	0	3	19	6
My TNMS	0	0	1	1	2	0	0	1	0	0	25	1	6	3
Hits	6	4	4	9	11	19	4	5	10	9	25			
False alarms	27	14	24	16	21	22	10	24	25	19	5			

Figure 7: Associativeness Test Results[33]

By displaying the results of the study using accessible graphs and tables such as Figure 7, the study was able to produce a representation of how users interpreted icons in an simple and effective way. Icons which produced incorrect interpretations or were ambiguous were able to be flagged and so the designers could establish which icons needed to be reconsidered and redesigned. This study also suffered from a similar context problem to the previous example, of which Duarte et al.[33] were fully aware, stating that contextualized comprehension tests needed to be carried out as real use situations provide situations which limit the number of reasonable interpretations of icons [33].

Although these studies may show what a small icon may or may not mean to a user, there is a doubt as to whether such simple approaches could ever shed light upon semiotic processes which would occur in the situated use of the icons. Hodge et al.[61] (along with such as Piaget, Bruner, Kelly and Vygotsky) argue that the creation of meaning is so complex and subtle that the mental operations involved might be missed by crude survey or lab conditions [61].

Pearson [106] argues that the problem with semiotic measurement arises from the fact that the operator constitutes a full third of a sign's construction. A sign is made up of one third form, one third referent and one third interpreted meaning [106]. Thus the operator's cultural identity, goals, motivations, values, etc. all become part of the semiosis and therefore must be considered in semiotic measurement. If questionnaires with 'open'questions are used in experiments, accumulated data may be fuzzy and hard to interpret due to the participants' idiosyncrasies. If the issue of fuzzy language is addressed by giving participants a questionnaire with multiple choice questions, answers will always be led by the available choices and so guide unnatural semiosis. Of course the benefits and problems associated with questionnaires are well known[135], so apart from questionnaires, what other methods of data gathering and analysis could be employed in an empirical semiotic study?

de Souza's SIM methodology is akin to discourse analysis, using informed analysis to come to conclusions about what the 'text'is communicating. The semiotic analysis and concepts of SIM may be used to help designers organize the metacommunication to explicitly formulate what the design elements will mean to users[26]. It may be possible to employ empirical methods with SIM based upon finding patterns and variety, detecting the various shapes of features of signs within an interface and the number of times they are repeated [43]. This 'content analysis'[61] could be employed using a combination of SIM and Andersen's instrument semiotic, breaking up the interfaces into countable units which can then be analysed qualitatively and quantitatively. Hodge et al. argue against this method of analysis, stating that simple content analysis and counting cannot get to the heart of semiosis as meaning is not at all a simple, surface matter but refers to the result of immensely complex operations that take place out of view, inside minds, sometimes outside consciousness [61].

Another method of data gathering is via observation of situated action. Suchman states that the problem with subjective interpretation of observed actions may be remedied by the use of video or audio recordings such as those used in enthographical and linguistic studies [122]. Data gathered in this manner can be re-analysed, used in data sessions, etc. so that it may be explored repeatably in a more objective manner. de Souza also recommends video recordings in CEM studies so, could this method be used to produce qualitative data? As CEM is fundamentally conversation analysis for HCI, we must consider if CA is able to produce meaningful quantitative data.
In CEM, data is collected via observation and then interpreted and analysed, as with SIM, via informed qualitative analysis. In principal CEM tells us how people react to the signs in an interface but not exactly what they make of them. CEM is clearly inspired by the linguistic analytical method of conversation analysis (CA) and it is not the first time CA has been consider as an alternative methodology for HCI [83][109][121][136]. The early work of Suchman [121], in which interaction in collaborative technology use and interaction problems with that technology were explored is an example of a CA inspired HCI study. In this case, general CA perspectives are refined to consider situational interaction, including specific work settings in which there are pre-allocations of turn types and specific agendas in speech. From this perspective a number of cases of 'trouble'in interaction between human and machine were analysed, troubles were classed as misunderstandings between the human and machine, which were hard to detect for either party and therefore hard to repair.

CA uses audio or video recordings and transcripts of linguistic data, features of this data are then analysed within the context of the conversation in a qualitative, narrow-deep and exhaustive way. CA is primarily a qualitative methodology, however data gathered from multiple discourses and studies can be used to quantitatively build models of language use. For example, through wide study of a specific discourse situation (repair, face threatening acts, etc.), familiar patterns of language use regularly emerge. Therefore, by gathering data and observing these patterns in language, empirical evidence of sociolinguistic phenomena accumulates. Using this accumulated data, researchers can then build models of language use and identify the cause, intention and affect of that language use. Many CA studies include quantitative data, usually consisting of many examples of a specific interactional phenomena, however this data gathering is often used to simply strengthen an argument rather than as an analytical technique. Hutchby and Wooffit [64] argue that conversation analysts are reluctant to use quantitative data as the ultimate aim or even a preliminary stage in analysis because, although CA does gather data, develop categories and classify data extracts [124], CA uses exemplars as a basis on which a generalization is built. It is this difference between inductive and deductive analysis which means CA does not treat phenomena as statistical variables but as unique cases of interactional data, even if they occur regularly across a number of cases [124].
Schegloff [117] describes quantitative analysis in CA as the study of multiples or aggregates of single instances, built upon the back of single cases of analysis, while ten Have argues, with a note of ethnomethodological caution, that collectable or classifiable interactional phenomenon can be sensibly collected and used to reveal how frequent many patterns in interaction are, giving a wider relevance to an exemplary case [124]. In other words, the bulk of analysis in CA occurs before, and not after, quantitative analysis takes place.
Considering the above, it could be argued that a CEM study imbued with a greater affinity for CA, could be used to collect and analyse interactional data to look for recurring behavioural and cognitive patterns and phenomena in relation to signs within an interface. However, there are a number of issues which would make a CA based HCI study unsuitable for investigating the interplay between signs and errors. Some minor issues include the lengthy process of data collection and transcription required, and because the data from any CEM study would primarily show user behaviour, it may be argued that a more suitable approach to video data analysis would be behavioural analysis techniques such as activity theory, situated action or distributed cognition. The major issue however is that CA is simply too ontologically removed from the aims of this study to be suitable. CA is indulgently narrow and deep in its relentless attack on the finest details of language use, and at the core it is focused on individual phenomena over quantitative data. In this thesis, both qualitative analysis and quantitative data will be used to draw conclusions about the nature of semiosis, this will require behavioural or cognitive experiments along with semiotic analysis of interface elements. To use CA in this study would require the effacing of the principles of the methodology or changing the focus of the study.

2.6 Concluding Thoughts

The discussion of the literature above has shown that human interpretation is an persistent process, is based upon cognition, culture, knowledge and context, all of which are in flux. Interfaces include signs, and these signs and the flux of these concepts can contribute towards misinterpretation and human error.

The literature also highlighted the main methodologies for gathering empirical data in semiotics. These methods include exposing users to signs and gathering their interpretations via questionnaire and/or interview, observation and video recordings of users reactions to signs, possibly asking the user to think out loud to make their interpretations more explicit, and statistical content analysis. The literature showed that interpretation of uncontextualized signs may be accurately studied, however this may provide limited insight into the mental operations of semiotics, while the study of contextualized signs in HCI is currently based upon ethnographical, behaviour focused approaches.

Although no single methodology has thus far provided a perfect solution to the study of semiotics, this is probably because meaning is such a fuzzy concept. Pearson introduces the concept of Garner's operational convergence into empirical semiotics, a concept which was inspired by the Peircian multi-filament approach to reasoning. In this multi-filament approach, unlike the Cartesian single-chain model of deductive reasoning, "a single fact that records and summarizes the data from many different observations gains more empirical reality with each new observation that justifies it"[106]. In other words, the results from many observations are converged to form an empirical reality, for example, showing that the results from a number of experiments are correlated [106]. Pearson goes on to argue that this multi-filament approach with converging observation may build to form facts, laws about facts and overarching theories of these laws of semiosis.

I feel this is a good idea, taken too far. Converging data from many different sources seems like the only logical way to tackle the fuzzy concept of meaning, however this fuzzy attribute entails that there can be no immutable laws of meaning and thus semiotics. This leaves us with the questions of whether there can ever be laws or even generalisations of semiosis which can be used in the process of design or whether we can only explore semiosis on a case by case basis.

I share the view of Hodge and Tripp [61] in that semiotics can only be used as a lens through which the world can be viewed, it is a powerful theory which can be used to inform design and analysis but not to create concrete rules of interpretation or strict models for design.

Now, one may well look at semiotics in HCI and liken it to the concept of metaphor and in many situations metaphorical issues are semiotic issues. However, while the concept of metaphor in language and thought is fascinating, in HCI the debate on metaphor is largely something of a *toy* issue, the limits of which have been thoroughly mapped out by Blackwell[8][9]. In other words the concept of metaphor has never been of great importance and usually never strays past the bounds of the GUI. For example, some interfaces contain *broken* or nonsensical metaphor, icons which do not look like anything in particular, desktops which are no longer metaphors but still cling to the fossilized concept, etc. Once these interfaces have been used, their quirks learnt and their ideomatic structures decoded, the user knows what was actually meant and so the problem is solved.

Thus unless one is feeling particularly pedantic there is no need to create a perfect metaphor when designing a standard interface, and in the same way there is no need to create an interface or system which is designed to encourage consistent and accurate semiosis. Though it may be useful, there is no real *need*. This author is well aware that there are few things in the world less important than the interface on an *i-pod* and that doing a semiotic analysis of such a device would be little more than self appeasement. However, when dealing with the interactive properties of a medical or industrial device it is essential to understand and create devices which encourage careful practice, and if a semiotically informed look at these devices can reveal anything, it is not so bad to give it a go.

3 Indurate Signs

3.1 Indurate Signs in Design

Society renders some signs inured to change. The power of a million minds maintains a conceptual vault to protect these signs from the normal flux of meaning which haunts and twists signification throughout the semiosphere. Some indurate signs are protected from mutability through necessity, the meaning of road signs or warning signs for example, are enshrined in this stillness of meaning to allow society to flow more easily. Religious symbols are warded from change by those who give them power and hold them dear, while other signs, much like fossilized metaphors, simply become indurate over time and perpetual indistinguishable reoccurrence.
This study introduced the novel term of an *indurate* sign, the term is used in this study to distinguish the signs talked about from other signs in an environment and to distinguish the semiotic phenomena from other similar but different concepts such as fossilized metaphor and idiom. In the world of design we may see thousands of examples of the latter, things which look as they do because all previous objects of their kind have looked this way. From cars to kettles we see these indurate signs as they sit and tell us exactly what they are. Of course the slight differences entice us on an aesthetic level, perhaps I wish my kettle to be chrome, perhaps I wish my car to be small and aggressive looking, but whatever the insignificant aesthetic properties, the thing which still sits in my driveway, and will always sit in my driveway, is a slightly aerodynamic box with 4 wheels and a few windows. These tawdry dull artefacts litter the landscape and are so well anchored, so embedded into the fabric of our reality, that any shift is painfully slow and prone to falter.
One such of these seemingly immortal signs can be seen in the humble calculator.

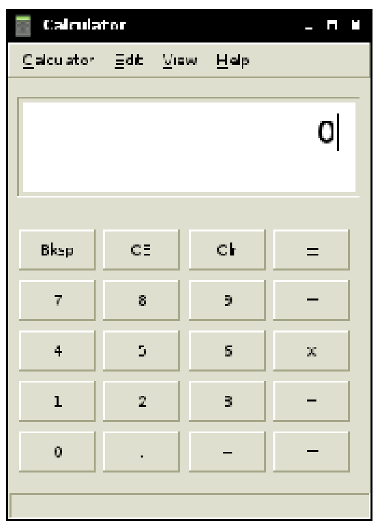


Figure 8: A typical calculator

► A semiotic look at the Calculator
The appearance of most modern calculators (Figure 8) follows an established convention, the design may vary but the overall form of a calculator is usually the same. The form of the calculator has become a sign, it represents the concept of what a calculator is and does. This calculator sign is so embedded in our culture that almost all electronic calculators, both real and virtual, (Figure 9) still follow the design pattern of the standard calculator.

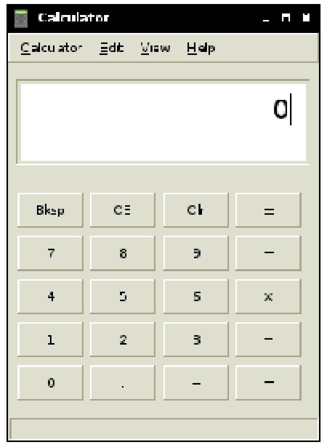


Figure 9: gcalctool

Designing a calculator to look like a calculator is the greatest piece of metacommunication available to calculator interface designers. It establishes the rules of use for the a calculator, defining what the device is for and the expected relationship a user may have with it. The benefit of this metacommunication strategy is that little effort is needed to communicate how a user should interact with a calculator and that users will know what the device is for and is capable of at a glance. The calculator, like many other complex indurate signs, can communicate large amounts of information and an entire sign system while using very few resources.
The cost of relying on conventional design is that the calculator is only as usable as it has ever been, which means errors which occurred on the first digital calculators may still occur to this day. Thus the calculator is caught in a troublesome semiotic situation, Thimbleby[125] has well established the need for improvement in both the hardware and software of calculators, but advancing the usability or communicability of a calculator interface may inadvertently create a device which does not appear to be a calculator to users and consumers.
A good example of how embedded the the convention of calculators is in the culture is highlighted by Nadin [93] on the subject of calculators within a GUI. Nadin observes that in an interface, calculators are usually in the form of a standard pocket calculator, using the conventional display, button layout, etc. as shown in Figure 9. Nadin describes this phenomenon as a 'convention over convention'.

▶ Under the Bonnet
So usually when examining an interface, one may assume that the designer is trying to communicate how the user may complete their task on the device. However, as previously discussed, the form and function of a calculator is now so embedded in society that this assumption may be, at least partially, incorrect. The symbols on a calculator's buttons are, of course, there to show people what number or function will be entered when the button is pressed. However, as calculators have such an established sign system, the layout of the buttons may, debatably, be making no attempt to communicate the encoding of the unique sign system of the particular device. Instead the metacommunication presented in the interface may be simply to communicate to users what features the calculator has rather than how the features may be implemented effectively and efficiently.

Unlike other computation devices a calculator is not expected to be able to do anything not explicitly displayed on the interface. For example we may expect our phones to be able to play music, or our games console to play DVDs, but we do not expect to be able to peruse *Wikipiedia* on our calculators. Therefore what the interface initially communicates to a user is the complete extent of the device's functionality, each button being both the evidence of, and the means of implementing, a function.
The buttons and symbols present on the Casio in Figure 8 are typical of a calculator interface and though they do communicate to users about how to communicate with the system, they do not communicate the sign system in full. That is to say, they tell the users which buttons to press to enter specific symbols but they do not communicate how the calculator will manipulate those symbols or in what form calculations can be done more efficiently and effectively. This is the reason why there are so many ways to do the same calculation on a calculator.
Semiotically speaking all buttons have an underlying referent, push and something happens. The close proximity

of buttons to a display of any kind signifies that the two artefacts are linked and users will assume the manipulation of the buttons will result in some sort of feedback on the screen. All buttons are signs, where-ever they are placed and whatever their form may be, they represent some perceptual phenomena. For example, in basic numeracy the + symbol represents the addition of two values, one on each side of the symbol. The button on a calculator which carries the sign of + instead represents the concept that this symbol will be added to the equation visible on the display screen of the calculator.
The objects manipulated by calculators and which appear on a calculator screen are "neither concrete objects nor objects from the formal mathematical world: they are virtual objects in the interface that separate the conceptual world of mathematics, from the concrete objects world. Therefore themselves are knowledge instruments, and not knowledge itself"[51]. In other words, symbols on a calculator must be manipulated and interpreted by users correctly, there is no margin for error once a calculation has been entered because the calculator does not know what a user needs or intends to mean and can only return a *knowledge instrument* based upon its own internal rules. Calculators are created as a general purpose, context free calculation tool, the device has no knowledge of the world and so, all the calculations it processes cannot be contextualized. For example, when working out a drug dosage of a syringe pump, a nurse may enter numbers representing the volume, concentration and duration of a drug infusion, in this case the calculator makes no distinction between the numbers and so can make no attempt to appropriately parse the calculation. Infusion and syringe pumps on the other hand, are entirely contextualized for use within a very specific scenario.

▶ The Forgery of a Fossil

Figure 10: Graseby 3400

This handsome character is the Graseby 3400 (Figure 10) and as we can plainly see, to "facilitate ease of setting up, the keys are arranged in the same format as an electronic calculator"[91]. Interestingly enough in previous models such as the 3100, "the buttons are arranged in pairs of up and down keys for hundreds, tens, units and tenths of the ml/hr infusion rate" to "facilitate ease of setting up"[91].
It is not the first time this pump has been targeted for an academic bludgeoning. Thimbleby and Cairns [128] have exposed the false promises advertised by the interface of this devise and insinuated within the pages of its instruction manual, pointing out that though the device's calculator style number-pad may look the part, it enters numbers into the device in a way which is nothing like any standard calculator.
So to put it simply, the interface is telling the user that it is a simple number pad entry system, one similar to calculators, cash machines, etc. and even the manufacturer is telling the user the interface is that of a calculator. But, as Thimbleby and Cairns [128][126] have suggested, the number entry on this syringe pump works nothing like a calculator, and what is worse, the pump displays no warnings when this un-calculator-like system of number entry causes errors.

So is there *really* a problem here? After-all nurses are trained to use these devices and thus are expected to know the idiosyncrasies of each device and adapt their use of the number-pad accordingly. All well and good, but as we shall see from the experiments in Chapter 3 even experts in the field, in this case Gamers in games, can make semiotic slips. Even a slight chance of a semiotic slip in a medical setting is incredibly serious and unlike mistakes in our sign-maze experiment, there is a possibility that the users of the devices will not be aware that any semiotic slips have occurred. In the experiments in this study, when a participant made an error, they were met with a dead-end or longer route which allowed them to reaffirm the reinterpreted meaning of the signs in their mind. If a semiotic slip causes a user to improperly use the number-entry system on a syringe pump, specifically the Graseby 3400, the evidence of the error may not appear until it is too late and as mentioned, they are unlikely to be warned by the device about any such errors [128].

Number-pads are troublesome in a number of operations, whether it is calculators, cash-machine, or any number of other interactive devices. But what semiotic slips are actually likely while using a number pad? Do we always think number-pads work like calculators? Are people more familiar with telephone number-pads than those found on a calculator as an NHS design manual [95] suggests?
This is important because it may be expected that hardware instinctively takes precedent over software in the human mind. In other words, what we can touch and manipulate will have more influence over how we interpret a device than the internal sign system. This can be observed in the way we temperamental humans hit out keyboards, slam our mice and even kick our computer cases when the software refuses to work. Of course this could simply be that we have a primal urge to hit things when we are frustrated, and software is rather difficult to attack with more than a barrage of verbal abuse. Even so, despite our primitive urges, when a computer locks up, I wager that most people initially go for *the claw* (ctrl+alt+del) or some other hardware based solution rather than trying to find a software based solution. We can also see the hardware precedent in all areas of design, most electronic devices still have a hardware power button to turn them off (rather than simply in *standby mode*), in cars we still have hard buttons and knobs and in automatic cars arguably no longer require gear sticks, some watches have both hard and soft controls, and many other electrical devices which do not require hard elements but still have them. They are all there for a reason, people like hardware, something to grab, twist, twiddle and position.

So to find out what the number-pads *say* to users and thus to find out exactly what semiotic slips are possible when using the number-pad on a syringe pumps, we need to investigate how their interfaces are interpreted.

3.2 Testing Induration

Pilot Questionnaire

Aim

The aim of this questionnaire is to find out what people assume various number-pads and interfaces are used for according to their layout, to find out what, if any, indurate signs are tied to specific configurations of buttons on number entry systems. In this questionnaire, and any that follow, the interface from the Graseby 3400 will be used to gauge how the interface mentioned throughout this thesis will actually be interpreted.

Method

To find out what the number-pad hardware is communicating to users I developed a simple online questionnaire, showing participants a number of pictures of various number-pad based interfaces and devices and asking them what they thought the device was for, an example question is shown below (Figure 11). This questionnaire can be seen in full in Appendix 6.3

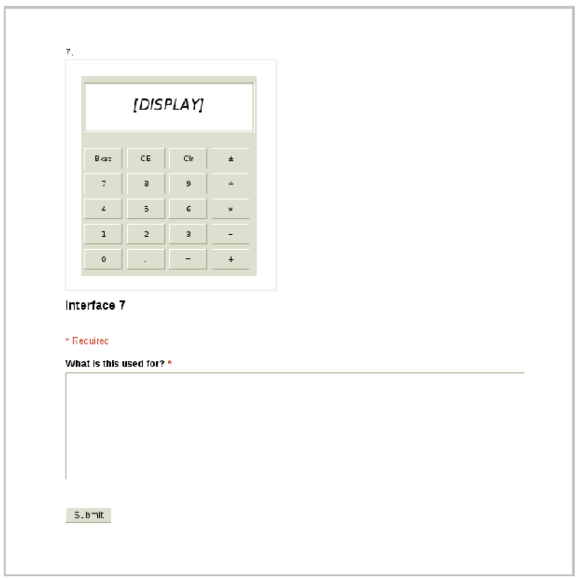


Figure 11: An example question

The pictures were gathered from a Google Image search using terms just as *number-pad*, *number entry*, *number interface*, and images were chosen which represented various number entry devices. It was hoped that the results of this questionnaire may show what the initial assumption is when faced with a number-pad, do people assume number-pads work like calculators or do they assume they work more like phones or elevator controls, etc?
The questionnaire was distributed over the internet by posting a request for participants on the *Ubuntu Forums*, a popular Linux community forum. This request for participants produced 15 respondents, a number deemed sufficient for this pilot, who consisted primarily of young adults.
It was hoped that this pilot questionnaire will give some insight into whether the number-pad is a sign which is conceptually as static as the interface of a calculator or, whether the aesthetic properties of the number-pad will offer contextualization and in turn, accurate interpretation. This pilot was produced as an exploratory study, with fruitful and interesting results leading to a second, more refined questionnaire which would aim to gather a larger amount of data on the subject.

Expected Results

I expect the results of this questionnaire study to reveal that people do indeed have indurate interpretations of number-pad based interfaces, and I expect that people will easily and consistently interpret phone and calculator interfaces accordingly.

Results & Discussion

The results of this questionnaire are best discussed in relation to the three major interface designs, which consisted of two forms of number-pad and the other non-number-pad designs. The number-pad based interfaces fall into two categories, telephone layout and calculator layout.

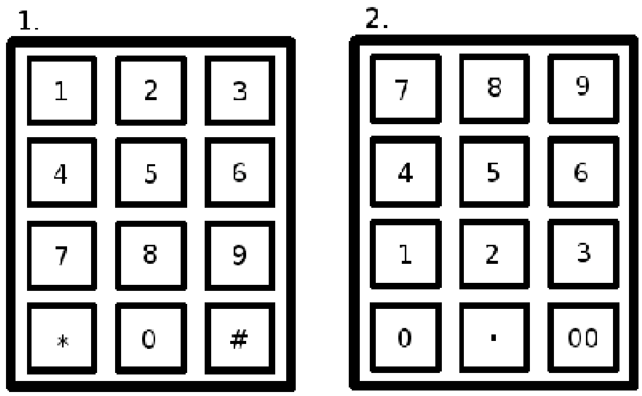


Figure 12: 1. Telephone layout, 2. Calculator layout. The '00'symbol on layout 2. is often a different symbol such as '=', etc.

In the questionnaire there were twelve number-pad interfaces with the phone layout, of these five had extra of alternative buttons not usually found on standard telephone hardware. The results of the questionnaire showed that all the standard phone number pads were identified, by an 83% majority, as phone interfaces. In fact most were used for other purposes, electronic locks, etc. but the layout of the numbers coupled with the '#'and '∗'symbols made people assume that they were phone interfaces.
However, interfaces with the phone layout and other buttons not found on standard telephones such as letters and symbols (interfaces 2, 11, 13, 20 and 21) produced a variety of assumptions about their use, few of which being that of a telephone interface. This suggests that the complex sign which is the telephone number-pad is a fairly fragile entity, with the addition of any heterodox symbols or additional buttons breaking the sign.
Like the calculator, the phone layout seems to communicate function by an established form, however this complex sign seems to be defined more by what it does not contain rather than by what it does. In the case of this sign, extra buttons and symbols create an assumption that the interface is not that of a phone. One interesting exception to the rule were two number-pads which only contained the standard telephone buttons as shown in Figure 12. However these particular interfaces were on a metallic surface with single red, green and amber LEDs above the buttons. This context made almost 70% of the respondents to the questionnaire assume that this interfaces were that of an electric door lock/alarm system rather than that of a phone. In this case, it was not the addition of any buttons or a change to the standard symbols, but simply the addition of LEDs to form a traffic-light-esque sign above the number-pad, which created a shift in interpretation.

Each of the standard calculator interfaces were correctly assumed to be calculators, however the number-pads which shared the calculator style number layout but did not include mathematical symbols (interfaces 10, 16 and 19) were not assumed to be calculators. This supports the concept already discussed, that all buttons on a calculator interface show the functionality of that device, thus no mathematical symbols means no mathematical capability. One interface which did include a small number of mathematical symbols ($*$,$+$, $-$,$/$) but was not assumed to be a calculator by a single respondent was an interface which contained buttons labelled 'Ctrl', 'Alt', 'Tab', etc. as well as a number of '*F*'buttons such as 'F11', 'F12', etc. These button labels are common to computer keyboards and are rarely found upon standard calculators, therefore we may argue that the complex sign of a calculator number-pad is, unsurprisingly, dependent upon the presence of mathematical symbols, yet seems to break when buttons from another more complex technology are added to it. In this case the interface was actually that of a complex television remote, but most assumed it was the number-pad section from a computer keyboard due to keyboards often containing similar buttons to calculators along with the ubiquitous 'Ctrl', 'Alt', etc.

The non-number-pad interfaces in the questionnaire got some interesting responses, which give some insight into interfaces which do not rely on indurate signs. One of the interfaces in question was the interface from an adjustable hospital bed as shown in Figure 13. I do not consider this interface to be indurate, though it does use indurate iconic signs such at the stick-man to represent a human and a battery icon to communicate concepts. Four fifths of the respondents correctly guessed the use of this interface, considering the respondents could not see the bed this interface was attached to, this suggests that simple buttons employing simple icons can be an effective communicator.

Figure 13: Adjustable hospital bed.

The other non-number-pad interfaces consisted of the two interfaces shown in Figure 14. As you can see, these interfaces contain input methods which are completely different to number-pads and, although they too contain indurate signs as part of the interface, are not indurate signs as a whole.

1. 2.

Figure 14: 1. Syringe pump, 2. Electronic blood pressure tester.

These interfaces caused much confusion in the respondents created some of the greatest variation in assumptions. As these were specialist medical devices it was not expected for respondents to correctly guess their use, though the great variation of unsure responses suggests to me that once a user had learnt what the interface was for, they are so unlike any other interface that they are unlikely to be mistaken for an interface of another type of device.

One of the interfaces I entered into the questionnaire was the interface of our old friend, the Graseby 3400. For the questionnaire I edited an image of Graseby 3400's interface to remove any clues to its use which the screen gave and also removed everything surrounding the interface panel (Figure 15).

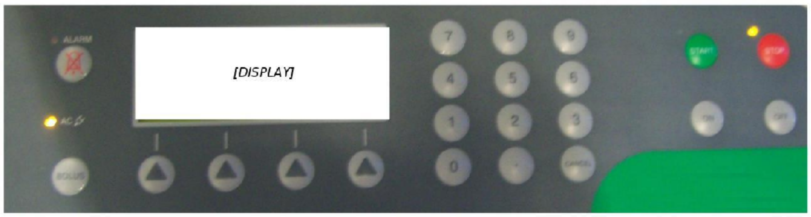


Figure 15: Graseby 3400 edited for the questionnaire.

This interface contained a number-pad with the calculator style layout of numbers, yet due to the lack of mathematical symbols, no respondent assumed this was the interface of a calculation device. Due to the strange long shape of this device, most assumed this interface was that of an alarm clock, with others guessing such things as fax machines or running machines.

► Concluding Thoughts

This result suggests that either the interface of the Graseby 3400 is either not as calculator-like as its operational manual states or that the aesthetic properties of the interface are creating a different interpretation of what the interface as a whole is for. To test which of these it is, in the next questionnaire I shall separate the number-pad of the Graseby 3400 away from its surrounding and test what people's assumptions are when it is in isolation. It is interesting to note that the Graseby 3400 interface caused just as much confusion and varied responses as the other syringe pump interface (Figure 14.1) which does not attempt to resemble any indurate sign.

3.3 Indurate Questionnaire

As the rough and ready pilot questionnaire seemed to provide some interesting ideas, it was decided that another more considered questionnaire would be developed to gather a larger amount of responses.

Aim

The aim of this questionnaire was much the same as that of the pilot, to find out what people assume various number-pads are used for according to their layout, to find out what, if any, indurate signs are tied to specific configurations of buttons on number entry systems. However, this study shall aim to improve the questionnaire and gain a larger number of respondents to provide more insightful data.

Method

In this new questionnaire the images would be more standardized with all the images containing only a number-pad with little or none of the surrounding interface to provide context. This was done to try to make sure that it is the form of the number-pad that is being interpreted rather than the context. As we have already established, context is critical for interpretation and whatever people think a number-pad is used for, this assumption will no doubt alter if it is situated within a larger context. The reduction in surrounding context will not only provide participants with a more focused target of semiosis but will also allow the results to be compared more usefully. For example in this questionnaire I will again be using the interface of the Graseby 3400, but this time only using the number-pad section of the interface.

Another reason for standardizing the images in this questionnaire was that it allowed for the interfaces to be manipulated more easily and poignantly, with a smaller number of external influences to colour the resulting interpretation of these manipulated interfaces. For example, as in the pilot questionnaire, the interfaces a broadly split into two distinct layouts, the calculator and the phone configurations. In this questionnaire one of the interfaces will be altered so that it contains the calculator layout, but with buttons which usually denote telephone functionality such as '#'and '∗', another of the interfaces has been altered so that it contains the telephone layout but with buttons which are usually found on a calculator such as '×', '+', '÷', etc.
This was manipulation was done primarily to investigate how the layout of a number-pad and extra function buttons create a complex sign and how non-standard variations of the number-pad configurations affect semiosis. The pictures were altered from the pilot questionnaire or gathered from a Google Image search using terms just as *number-pad*, *number entry*, *number interface*. Three of the images were manipulated to test to what extent the number layout of number-pads affected the interpretation of their use (Figure 16). This was done by altering the interfaces using simple image manipulation software to change the number layout from that of a calculator, on Interfaces 10 and 14, to that of a telephone, and doing the opposite to Interface 8. The questionnaire can be seen in full in Appendix 6.4.

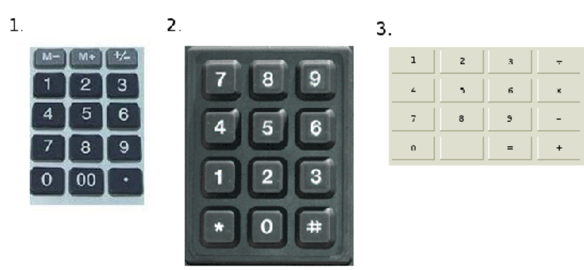


Figure 16: 1. Interface 8, 2. Interface 10, 3. Interface 14

It was hoped that the results of this questionnaire may show what the initial assumption is when faced with a number-pad, do people assume number-pads work like calculators or do they assume they work more like phones

or elevator controls, etc?
The questionnaire was distributed over the internet by posting a request for participants to a number of mailing lists and student groups including the computer science post-graduates at the University of York, the York Linux User Group mailing list, a HCI based mailing list, and a number of post-graduate students at the University College London's Interaction Centre. This request for participants produced 66 anonymous respondents.

Expected Results

So what was expected of this questionnaire? One thing that must be considered in the analysis of the results of this questionnaire is that it uses pictures of real devices, therefore aesthetics will always be a factor in interpretation, with buttons of different sizes, shapes and materials providing semiotic fodder for the minds of our respondents.

I expected most of the images to be interpreted much like the first questionnaire, with number-pads displaying the '#'and '$*$'symbols being interpreted as phones, but with the addition of any heterodox symbols or additional buttons causing a non-telephone interpretation. I expected interfaces with mathematical symbols are likely to be interpreted as calculators. It is also expected that the manipulated interfaces will be interpreted according to their additional buttons rather than their button layout, this is because, as discussed, simple devices such as the calculator wear their functionality on their sleeve, with all their potential uses displayed by their buttons.

Results

The answers given by the 66 separate respondents in the online questionnaire were, of course, expressed in different ways, for example answers such as '*pocket calculator*', '*calculator device*', etc. will all fall under the collective answer of '*Calculator*'.
In the case of some interfaces there were many varied answers which alluded to the same concept, in particular the concept of an interface giving access to a door. In these results any answer which represents the concept of a key code door lock, key code entry system, flat door buzzer, etc. will all fall under the answer heading of '*Door Lock*'. Similarly the answer '*Security Software*'covers a multitude of software/online situations which require a number based password, pin number, etc.

Here are examples of the coding used for some of the 66 answers for Interface 4:

Code	**Answers**
Part of a Keyboard	a number pad on computer keyboard, because of the F keys
	computer keyboard
	Part of PC keyboard. Can be used for calculator functions
	computer keyboard
	Keyboard because it has the control, alt and enter bottom
	Numeric Keypad on computer
	number pad on the side of a computer keyboard
Mobile Device	Mobile Computer
	laptop
	A laptop keyboard or a keyboard for a small device
	Laptop
Separate Number-pad	num pad
	Add on keypad
Public Terminal	Entry of ID numbers. For example, my high school cafeteria
	Some public interface
	A kiosk
Unknown	not totally sure
	don't know
Calculator	Calculator
Other	Game
	navigator device
	dvd remote

space shuttle cockpit

To ensure the coding of these various answers was logical I found an external assistant, who was supplied with the answers and the the codes which I had assigned to them, and then asked to sought the answers into the codes they deemed suitable. This process produced an 92% overlap, with most differences in coding occurring within the more obscure '*other*'answers in the data.

► Calculator Layout

Interface 2 was almost entirely identified as the interface from a calculator, with respondents describing how the mathematical symbols and AC button made this clear.

Figure 17: Interface 2. Actual use: A calculator interface

Interface 2		
Answer	Number	Percentage
Calculator	65	98
Alarm	1	2

Table 1: Interface 2

Figure 18: Interface 4. Actual use: A TV remote

Interface 4		
Answer	Number	Percentage
Part of Keyboard	31	47
Mobile Device	12	18
Separate Number-pad	9	14
Public Terminal	4	6
Unknown	3	5
Calculator	1	2
Other	6	9

Table 2: Interface 4

Interface 4 was identified as a keyboard of some sort, whether that was as part of a whole standard keyboard, as a separate number-pad or as a miniature keyboard for mobile devices and small netbooks. Respondents stated that this interpretation was due to the arrows keys as well as other conventional buttons associated with personal computers such as Ctrl, Alt and 'F'keys. Interface 6 on the other hand was assumed to be a cash machine (ATM) by most participants due to the '*Cancel*'button, but also could not be identified by a large proportion of the respondents. This may have been due to the atypical appearance of the buttons or the lack of identifying keys, however those respondents which did answer 'unknown'to this interface did not give a reason for this answer.

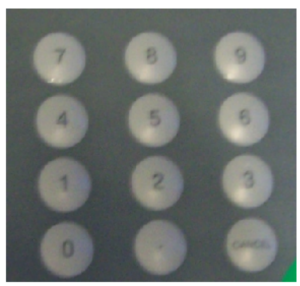


Figure 19: Interface 6. Actual use: An infusion pump interface

Interface 6		
Answer	Number	Percentage
Cash Machine	23	34
Unknown	15	23
Door Lock	10	15
Phone	7	11
Calculator	3	5
Other	8	12

Table 3: Interface 6

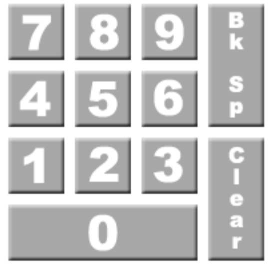


Figure 20: Interface 13. Actual use: An online race horse search interface based on the horse's number

Interface 13		
Answer	Number	Percentage
Unknown	31	47
Security Software	7	11
Phone	6	9
Calculator	5	8
Data Entry Device	5	8
Other	12	18

Table 4: Interface 13

Interface 13 produced a range of answers with the highest percentage of the respondents stating that they did not know what the interface was for due to a lack of identifying keys.

▶ Telephone Layout

Interface 1 was identified by the majority of respondents as the interface of a telephone who stated that this interpretations was due to the '#'and '∗'symbols and the rubber buttons.

Figure 21: Interface 1. Actual use: A digital safe interface

Answer	Number	Percentage
Interface 1		
Phone	64	97
Door Lock	1	2
Unknown	1	2

Table 5: Interface 1

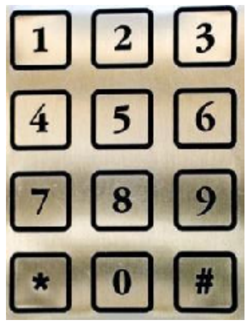


Figure 22: Interface 11. Actual use: A telephone interface

Interface 11		
Answer	Number	Percentage
Phone	36	55
Unknown	18	27
Door Lock	8	12
Calculator	2	3
Elevator	2	3

Table 6: Interface 11

Most of the respondents assumed that Interface 11 was that of a telephone. However, despite Interface 11 being very similar to Interface 1 and including the '#'and '∗'symbols, around 40% less of the respondents thought the interface was that of a phone.
The majority of the answers for Interface 3 were split between the interpretations of a telephone and a door lock, with most respondents citing the non-numeric buttons as the reason for this interpretation.

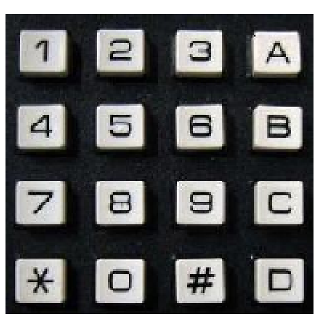


Figure 23: Interface 3. Actual use: A general purpose number entry interface for embedded systems

Interface 3		
Answer	Number	Percentage
Phone	27	41
Door Lock	20	30
Unknown	9	14
Vending Machine	4	6
Calculator	2	3
Other	4	6

Table 7: Interface 3

Figure 24: Interface 5. Actual use: An elevator interface

Interface 5		
Answer	Number	Percentage
Door Lock	42	64
Elevator	10	15
Phone	4	6
Vending Machine	3	5
Calculator	1	2
Game Controller	1	2
Unknown	5	8

Table 8: Interface 5

Interface 5 was assumed by the majority of respondents to be a some sort of door access interface as described in the introduction to this section. The majority of respondents did not know what Interface 7 would have been used for, with its non-standard buttons and strange symbols confusing respondents.

Figure 25: Interface 7. Actual use: A household alarm interface

Interface 7		
Answer	Number	Percentage
Unknown	23	35
Home Control	10	15
Phone	7	11
Door Lock	7	11
Personal Organizer	4	6
Other	15	23

Table 9: Interface 7

Figure 26: Interface 9. Actual use: A cash machine interface

Interface 9		
Answer	Number	Percentage
Cash Machine	59	89
Phone	4	6
Unknown	2	3
Petrol Pump	1	2

Table 10: Interface 9

Interface 9 was identified as a cash machine (ATM) by the majority of the participants, with the most common reason for this being the amount of dirt on the interface.
Most respondents did not know what Interface 12 would be used for, stating that like Interface 13, the lack of identifying buttons made its intended use unclear.

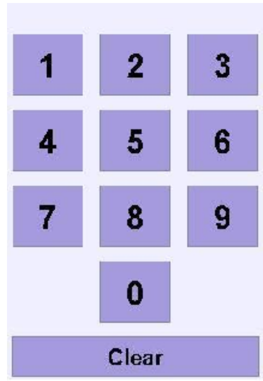


Figure 27: Interface 12. Actual use: An online hearing test

Interface 12		
Answer	Number	Percentage
Unknown	22	33
Security Software	11	17
Phone	9	14
Calculator	6	9
Cash Machine	6	9
Other	12	18

Table 11: Interface 12

► Manipulated Number-Pads

The following three interfaces were manipulated to help investigate what features of an interface most influence interpretation, whether it be layout, extra buttons, aesthetic properties or otherwise. Interface 8 was a standard calculator interface which has had the number layout changed to that of a phone, and with most buttons containing mathematical symbols removed, save the memory buttons. Interface 14 started its life as a GUI for piece of simple calculator software and has had similar layout treatment but in this case keeps the mathematical symbols. Despite the changed to these two interfaces, both were interpreted as calculator interfaces by the vast majority of respondents.

Figure 28: Interface 8. Actual use: A calculator interface

Interface 8		
Answer	Number	Percentage
Calculator	60	91
Cash Register	3	5
Unknown	3	5

Table 12: Interface 8

Figure 29: Interface 14. Actual use: A software calculator interface

Interface 14		
Answer	Number	Percentage
Calculator	60	91
Unknown	6	9

Table 13: Interface 14

Figure 30: Interface 10. Actual use: A general purpose number entry interface for embedded systems

Interface 10		
Answer	Number	Percentage
Phone	42	64
Unknown	12	18
Door Lock	9	14
Calculator	2	3
Radio	1	2

Table 14: Interface 10

Interface 10 was manipulated in the opposite way to the previous two examples. This interface has had the button layout changed from the telephone style to that of a calculator, but keeps the '#'and '∗'symbols so ubiquitous to phones. Table 17 clearly shows that most respondents assumed that this interface was indeed belonging to a phone, and stated that this was due to the symbols mentioned above.

Discussion

As expected most interfaces were interpreted according to their additional buttons, with interfaces containing mathematical symbols being identified as calculators and '#'and '∗'symbols denoting telephones. This is especially notable with the answers gained from the manipulated interfaces which were interpreted by the vast majority of respondents according to these additional buttons.
An interesting feature of the questionnaire data is what happened when there were additional buttons along side these standard calculator and telephone buttons. Interfaces 3 and 5 both contained buttons labelled with letters as well as numbers in the telephone layout, an addition which caused these interfaces to be interpreted as various types of door entry systems by many of the respondents. Interface 7 contained so many extra buttons labelled with strange symbols that most participants did not know what the interface would be used for, with the next most popular answer being that of a *home control system* (thermostat, alarm device, media/lighting control, etc.). This result seems to suggest that extra buttons upon a standard number-pad interface are a referent to extra functionality, or at the very least, alternative functionality to the devices upon which standard number-pads can be found. It is likely that this is due to the experience of the respondents and the indurate nature of the phone interface, virtually all phones contain a standard interface, therefore a device with a similar but non-standard interface is not a phone. Similarly, Interface 4 was interpreted as a computer keyboard of some sort by the majority of the respondents due to the arrow, Ctrl, Alt and 'F'keys. This occurrence is also likely to be due in part to the indurate nature of both calculator interfaces and computer keyboards, both of which almost always contain certain buttons/keys and while omitting others. In this case the interface contained a number of mathematical symbols but crucially contained indurate keys found upon all standard keyboards leading to the semiosis that the interface had to be some sort of keyboard.

As well as extra buttons, the lack of buttons also created an interesting result in the respondents' answers. Interfaces 12 had the telephone number layout and 13 had the calculator layout, yet neither contained mathematical or standard phone symbols. This led to most of the respondents stating that they did not know what the interface was used for and to many stating that the lack of identifying buttons had lead to this inability to guess. Thus it seems that many of the respondents where fully aware that it was these extra buttons that was allowing them to form their interpretations of these interfaces. This strengthens the argument that button layout has little to do with how a number-pad is interpreted, but it is the accompanying buttons which contextualize the interface and allow semiosis to occur smoothly.
Interface 6 is the interface belonging to the Graseby 3400, whose manufacturers claim its interface is "arranged in the same format as an electronic calculator"[91] to "facilitate ease of use". However, according to the discussion above, one may expect this interface to be interpreted according to what buttons surround the number-pad rather than the number layout, and this is indeed the case. Instead of interpreting this interface as a calculator, the majority of respondents gave the answers of Cash Machine, Door Lock and Unknown, with only a tiny 5% of respondents assuming that this interface was that of a calculator. According to the respondents, the interpretation of this interface as that of a Cash Machine was due entirely to the *Cancel* button.

One final issue which requires discussion is that of aesthetics. One concern of using pictures of real interfaces for this questionnaire was that the aesthetic properties of the interfaces may seriously affect semiosis. As few answers from the respondents contained any comment on aesthetics, this leads me to conclude that this worry has been proved to be mostly unfounded, however there was one interface in particular which seemed to sway respondents with its appearance. Interface 9 was identified as a cash machine by the majority of the participants, with the most respondents commenting that the amount of dirt on the interface was the main reason for this interpretation.

► Concluding Thoughts

The aim of this short questionnaire based study was to find out what number-pads were *saying* to users, how these types of interfaces were interpreted, and to use this information to explore what semiotic slips are possible when using the interface of critical devices such as the Graseby 3400. A number-pad containing only numeric symbols represents an uncontextualized number entry function. Although the three-by-three button layout of most number-pads might be seen as a design convention, this type of interface does not alone communicate any specific fossilized conventions about what number-pads are used for. In other words, number-pads containing only numeric symbols do not really *tell* users anything other than that they can be used for number entry.

It is the extra buttons of any number-pad which creates any strong communication to the user about what underlying sign system interface will manipulate, these extra buttons and labels contextualize the number-pad, and create the complex indurate signs that are ingrained into the minds of users. These indurate signs are strange in that they have both flexible and brittle elements. As we have seen in this questionnaire study, the layout of the numbers within a interface does little to affect the interpretation of its function, however the addition of any heterodox buttons to an indurate sign often results in a complete change in semiosis. For example, Interface 3 contains all the components which are requisite for the indurate sign which is recognised as the interface of a telephone, however the addition of the extra alphabetic buttons breaks this indurate phone sign and requires the interface to be reinterpreted.

So what does this mean for a device like the Graseby 3400? Because the Graseby 3400 has few contextualizing buttons it may be argued that this interface is less likely to encourage users to think the device works differently than it actually does. The number-pad on the Graseby 3400 is fairly uncontextualized interface and is thus free from indurate concepts and the assumptions which accompany them. Therefore one may expect users to contextualize the device using only the device it is attached to, linking the unconventional interface to the underlying sign system of the specific device. However, the manufacturers make the mistake of claiming that the interface of the device is in fact an indurate sign, in this case using the familiarity people have with calculator interfaces as a selling point. As we have seen, it is not the layout of an number-pad but the buttons which accompany it which determine the interpretation it provokes. Therefore it is doubtful that the layout alone of a number-pad could really *facilitate ease of use* and implying to users that the interface is in some way similar to a calculator is needlessly breeding potential confusion about the underlying sign system of the device. It makes about as much sense and me claiming that my oven facilitates ease of use by mimicking the knob layout of my PC speakers, they look very similar but control vastly different systems. It would have been more appropriate perhaps for the Graseby 3400 to be advertised by highlighting the fact that the interface will probably *not* be mistaken for a calculator, given that the device's sign system bares little resemblance to that of a pocket calculator. This study was, of course imperfect and could have been improved in a number of ways, such as including a greater variation of number-pads with a greater variation of aesthetic properties, and of course including more participants. However, due to the issues arising from this study, I do conclude that it has given some insight into number-pads and the process of semiosis, revealing that context is indeed one of the most important factors in interpretation.

4 Experiments

4.1 A World of Signs

In the previous chapter, indurate signs were explored, along with the semiosis of these signs. In this chapter the investigation will be taken one step further, the investigation of how indurate signs are interpreted in context and under cognitive pressure. The paradigm for data gathering in this study is in part inspired by Hodge and Tripp's [61] thoughts on using semiotics in a broad sense, giving quantitative and qualitative analysis equal precedent and Pearson's ideas of converging data[106]. The errors characteristic in the use of syringe pumps will be explored using this broad scope of semiotic enquiry, to describe, test, investigate and empirically analyse the issues at work. One type of data needed for this study will be experimental data. The problem is, how does one test or accurately observe semiosis? In the time frame of this project I could not have hoped to complete an interview based study on the scale of Hodge and Tripp [61], therefore another methodology was considered for this study, one which would hopefully show semiosis in action. And so in this study I will test an experimental tool which is novel to the study of semiotics, computer games.

▶ Why Computer Games?
One of the problems with some theories in HCI, such as Activity Theory or Distributed Cognition, is that the signs involved cannot be removed from the action. There is also a problem that in task-based experiments the task and the test environment will colour the results. It is hoped that using games will partially solve these problems, first because players know that in a game environment everything is an artificial artefact and therefore specific signs are not *special*. Second, because games are perceived differently from experimental tasks, participants may be more predisposed to think more *freely* and, it is hoped, interpret signs in a more *natural* way.
Games environments are worlds constructed from signs, made up only of representations of things, games are syntagms, a combination signifiers that are put together within a text to produce form a meaningful whole [102]. Yet signs in games are not simply used for mundane construction but for explicit and implicit communication and scene setting within the game environments. One genre of gaming which often uses very simple semiotic concepts to communicate ideas are real-time strategy (RTS) games. The following screen shots from various RTS games (Figure 31) show how primary colours and relatively simple shapes and textures are used to communicate such concepts as team affiliation, natural and man-made terrain and various military units.

Figure 31: 1. & 2. *Command & Conquer: Tiberian Sun*[120], 3. *Command & Conquer 4: Tiberian Twilight*[4], 4. *Supreme Commander 2*[44]

Games with a more immersive first person narrative often use complex and subtle semiotics to contribute to the mise-en-scene. A good example of this scene setting is the first environment of *Half-Life 2*[131]. Public spaces in the city through which you walk are filled with ominous looking guards, prison-esque fencing and citizens dressed in clothes which make them appear as if they have arrived from the watchful oppressors of *1984* [103] (Figure 32).

Figure 32: *Half Life 2*[131]

Most signs in games serve a dual purpose, both representing a simple concept such as the edge of the gaming environment, and using aesthetics to create a more enrapturing experience. In *Half Life 2* bare metal is used to represent the encroaching presence of otherworldly invaders while practically steering the player through the environment by blocking their path or representing inaccessible doors (Figure 33).

Figure 33: *Half life 2*[131]

Of course all gaming artefacts, beyond those present in most graphically simple games, are charged with a dual purpose of serving both the practical game mechanics and providing a sense of aesthetic continuity (Figure 34).

Figure 34: The 2D side scroller *Braid*[65]

Most gaming research is used to either explore how gaming experience can be improved [67], find new ways of acquiring and measuring player feedback [53], or studying how playing games affects behaviour and cognition in the real world[49]. They investigate how games and simulations can be used to train people for dangerous situations [72], how they can make games educational *and* fun, or how games can improve cognitive abilities such as improving visual search skills [15] and spatial cognition [40]. Yet, little work has been done looking in the other direction, looking to games as a tool for behavioural or cognitive experimentation rather than as the focus of the research. Some studies on using games as experimental environments include fire drill simulators [17] [118] designed to test if games can be used to train players in evacuation procedures.

This thesis aims to use games in a similar way, to reveal more about the nature of signs in technology by observing how players interpret signs within gaming environments, environments designed specifically to test semiosis. By using abstract forms of semiotic issues within the use of syringe pumps, the results of the observations can be converged with data from the other research conducted for this study to form a greater insight into the semiotic issues afoot. In summary then, it is theorised that because a computer game is a *world of signs*, by using games as an experimental methodology, complete control over the signs involved in each experiment can be achieved. As stated the main aims of this Chapter of this study are to gather data which will contribute towards answering the research questions, but to put the rest of the data in context, we must first explore the question of whether semiotic concepts work the same in the games as they do in real life.

There are, of course, other foreseeable problems with using games to study semiosis, the main issue being one of gaming experience. Background knowledge of a user can have an effect on their interpretation of signs within a computer system[52] and people who play computer games of a regular basis are become more game literate, that is able to read and decode the content of games [48]. This suggests that those with gaming experience may interpret signs present within games at greater speed or quite differently than people with little experience. This coupled with the unfamiliarity non-gamers may have with the control system has the potent of colouring the results of any gaming experiment which uses non-gamers and gamers. Thus the results of Gamers, and non-Gamers will be observed within this study. In this study the terms gamer and Gamer will both be used, with gamer being used to describe a person who occasionally plays games, and Gamer being used to describe the social label and identity to which people who use the label subscribe. E.g. One may play games and thus be a gamer but not be a Gamer, but one must be a gamer to be a Gamer. This distinction is common within the gaming community.

4.2 Abstracting from Reality

The aim of this section is to discuss the issue of whether semiosis within a game environment can hope to give insights into real world semiosis. To explore this issue we shall consider if similar semiotic situations within virtual environments produce similar behavioural and cognitive results as in real life. The outcome of this exploration should allow for a more insightful analysis of the data collected in the proceeding experiments which will use 3D gaming environments to test semiosis.
3D first person shooter (FPS) games were chosen as an experimental platform for this study for a number of reasons. Most game based experiments use simple games which may not encourage players to interpret signs from a real world perspective or in a real world setting, FPS games arguably give the player the most hominal perspective on a game environment. Many FPS games also have readily available level editors in which game environments can be quickly produced. As stated, this methodology is quite novel and exploring whether it is suitable for this subject area and in this experimental context will be an integral part of this study.
First let us look at an example of that rarest of beasts, a real life experiment to test semiotic principals. The experiment chosen for consideration is an experiment mentioned earlier by Markussen and Krogh[88]. It is an example of an explicitly semiotic experiment in which the concepts of cultural frames and blend theory are explored by introducing a foreign artefact into a location in which the artefact is not considered to be part of the cultural frame. Thus participants had to make a cultural frame shift in order to interpret how to use the artefact, using blending theory to unpack its internal configurations and governing principles and thus use the artefact successfully [88].

Figure 35: The movable mixed reality *Hydroscope* used in Markussen and Krogh's[88] experiment

In this observation based semiotic study by Markussen and Krogh[88], the concepts of cultural frames and blend theory were tested by watching the actions of children when encountering a novel artefact within a familiar cultural frame. In this case the novel artefact was an large tangible interactive visual device which revealed a virtual underwater world when pushed around the floor (Figure 35), while the cultural frame was that on an aquarium. It was found that even though the artefact did not *afford* any action within his particular cultural frame, the children still worked out that pushing the device around created an interactional phenomenon by blending the conventions and rules from different cultural frames. Perhaps the results would have been different if the participants of the experiment would have been adult but this study was a good example of a real life semiotic experiment.

► Outside the Frame
So do similar concepts work the same way within computer games? What is not within the cultural frame of a game? And do players of computer games adapt to foreign artefacts in the same way as Markussen and Krogh describe? Games are a special kind of media, which present us with fictional realities, some of which would be unpalatably ridiculous would they be in a film of television program. The reality within games is often in flux, changing from realistic to fantastical, with narratives starting with *normal* events familiar within the genre before then introducing some strange happenstance with little warning. We think nothing of stalking the streets as a vampire [45], or being told the Russians have travelled back in time to win world war three before it has begun [105], going on a killing spree and being forgotten by police after a nights sleep [98], and so on. If we play an FPS, throughout which we battle humans in a realistic world, when a monster jumps out from a bush we shoot it all the same. We may willingly sell ourselves strangeness in games, just as we willingly experience fear as we watch silly horror movies, but little strikes the average gamer as truly odd. Thus games appear to have almost infinite elasticity when it comes to their cultural frame.

However, over the years there have been a few games which do contain artefacts which exist outside the cultural frame of some gamers, included artefacts such as the narrative, graphics, dimensions, hardware use, control systems and game mechanics. Whether these artefacts are in or out of the cultural frame of gaming is in flux depending on the target audience, the release date of the game, and the hardware it is released on. For example during the time of the proliferation of 3D gaming consoles, starting from the release of the Playstation, the N64 and the Sega Saturn, 2D games for these platforms were almost unheard of. This is because, even though the 3D graphics were basic, is was considered the status quo in console gaming at that time, it was expected that all games for these platforms would be 3D and to do otherwise would have been like releasing a monochrome game for the Super Nintendo.
It is only in handheld consoles, which have always held a special place in gaming, in which 2D games could flourish as there was no audience expectation to the contrary. It is only now in what we may consider the *post-next-gen* console era, that mainstream 2D games are being produced once more as a stylistic choice.
Hand held gaming is both a curse and a blessing to the consoles which inhabit it, and some games released for the Nintendo DS were a victim of the device's success and the cultural frame which it came to inhabit. The DS was released with few *Gamer's* games, and as the years rolled on both Nintendo and producers of third party games began to target a different sort of audience. Games were produced to attract mothers, daughters, the elderly, they promised to improve your mind, to tell you what to eat, to let you have a virtual horse or to let you play sudoku on your lunch break. These casual, self help and aspirational games coupled with the release of pink and baby blue versions of the console is why we now see our aunties and grandmothers playing DS at family gatherings rather than pursuing more traditional pastimes such as watching Ernest Saves Christmas. It is also arguably the reason why many *serious* games for the platform have failed to attract widespread appeal. Games such as *Hotel Dusk: Room 215*[19] and *Grand Theft Auto: Chinatown Wars*[73], created as serious adventure games or mature action games, were outside the cultural frame of the DS gaming community. And so due to the aggressive marketing tactics of Nintendo, such games largely failed to capture the imagination of the majority of the DS audience.

As well as hardware, the control system or game mechanics can also be considered outside the cultural frame of gaming to some players. Games such as *Killer 7*[87] which was a unique *on-rails* shooter was unpopular with many gamers used to more freedom of movement within 3D environments. In research by Calvillo-Gamez [12][13] it was found that if game controls are changed from the standard set up, the degree of *puppetry* between the player and the game was reduced and thus immersion would decrease. However, research by Cheng et al. [16] explored how players would react to changing in-game physics, finding that if a player is immersed in the first place, they are likely to ignore any changes. This suggests that, in terms of immersion, the control mechanism for a game is more critical than consistent game mechanics.

Figure 36: A screenshot from *Killer 7*[87]

In fact the ability to change how a game reacts to player input is used in a number of games in an attempt to increase immersion. For example, players in games from the Grand Theft Auto series [97][98] may experience drastic changes to their view of the game world and to their character's ability to drive while the game simulates being under the influence of illicit substances. The Metal Gear series is well known for using techniques from outside the standard cultural frame of gaming including its often surreal 'breaking of the fourth wall', in game characters addressing the player, and meta-reference. Games like *Metal Gear Solid*[68] require the player to physically interact with their console, changing which port their controller was plugged into to beat an enemy that purports to read the player's mind. *Metal Gear Solid 2: Sons of Liberty*[69] (*MGS2*) is particularly rich in these features.

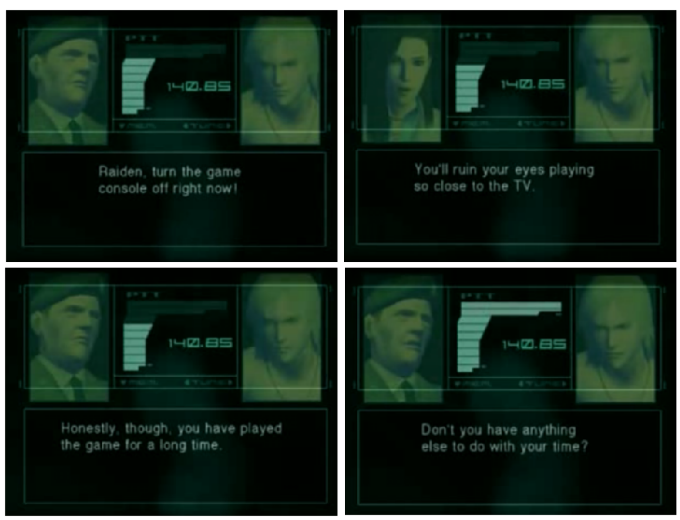


Figure 37: Screenshots from *MGS2*[69]

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Of course most games break the fourth wall from time to time, addressing the player or player character and telling them which buttons to press to perform an action, but this is usually overlooked in terms of the narrative of the game. In *MGS2* however, the metareference becomes part of the story, with some of the characters even instructing the player to turn off the games console, and advising the player that they have been playing too long and it will damage their eyes, all in a bid to save themselves from the player (Figure 37). The messages from player character's commanding officer and spouse proceed to get ever creepier turning the ending of the game into metaphysically challenging adventure, something which divided the gaming community with some fans hating being told that they were playing a game, with others loving the oddness. In summary then, it would appear that there are indeed artefacts which lie outside of the cultural frames of various games, foreign artefacts that do not render the game unplayable but require players to make a frame shift to be able to navigate or manipulate the artefact, just as in the Markussen and Krogh experiment. Therefore I tentatively conclude that, in terms of cultural frame blending at least, humans do react to semiotic concepts in a similar way in both virtual and real environments. Though, of course, the nature of what constitutes as a foreign artefact does differ between the two environments, the main types of foreign artefact one may find in games consisting of, in game oddness such as meta-referencing and fourth wall breaking, physical real-world action beyond standard gaming controls being required to play the game, perceived inappropriate game genre for the device or controls, and perceived discord between game mechanics and game aesthetics.

4.3 The Pilot Experiments

Aim

The following section charts the first tentative pilot experiments using the game based experimental methodology to investigate the interplay between signs and errors. During this pilot phase in the study, three variants of the same experiment were run, with each variant testing different in-game scenarios which will be discussed in greater detail below. The aim these experiments is to investigate how signs are interpreted in various situations, if reinterpreted signs are interpreted consistently throughout these situations and to what extent counter-cultural uses of indurate signs can cause errors.

Experimental Design

These experiment each use a single sample of participants from which the suitability of this experimental methodology may be determined. This will be decided by analysing what insights this experiment can give us into the interplay between signs and errors.

Designing the Experimental Environment

Each experiment in the pilot phase uses essentially the same virtual environment. The participants in these experiments were asked to navigate a virtual maze from a first person perspective. The maze was presented to participants as a game in which they must reach the end of the maze as quickly as they could. The virtual maze was constructed using the Value Hammer Editor which is used to create maps for games which use the Source game engine such as Half Life 2, Portal, Counter Strike, etc. This was used for a number of reasons, first the map editor provides an effective means of creating rapid prototype levels which can be altered and tested very easily and quickly [118]. Secondly the Source engine's realistic physics, lighting and simple in-game item manipulation provide many possibilities for more advanced gaming scenarios in the future. In this experiment, the environment contained no music, no special lighting effects and no weapons/means of attack for the player to use.

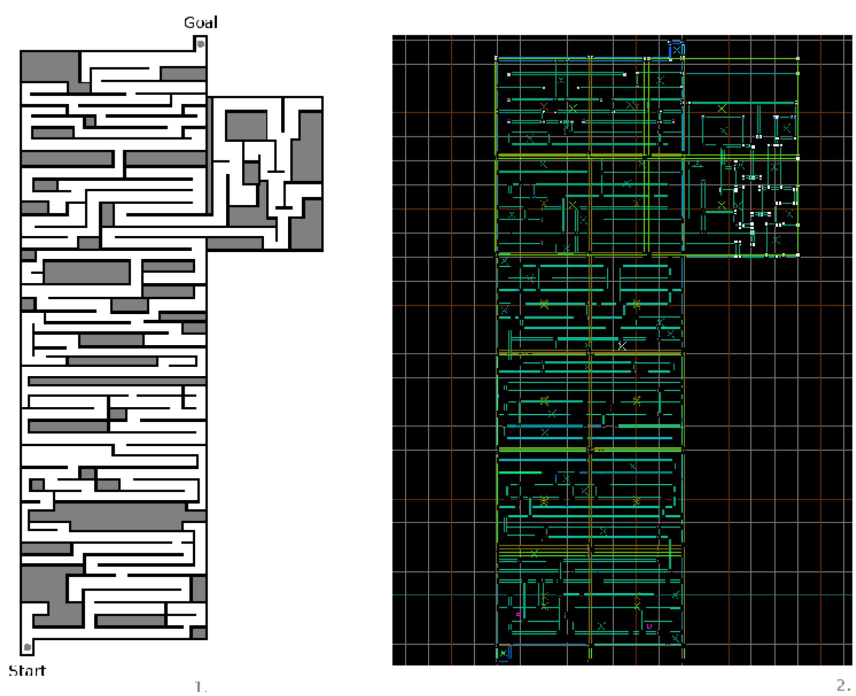


Figure 38: 1. A plan of the maze. 2. The maze as seen from the top-down view in the Valve Hammer Editor.

The passages of the maze were bias towards the x-axis, thus creating a set of parallel bars containing a series of dead-ends and false doors. The walls of the maze are textured in a simple grid pattern which makes doors and corners easily visible from a distance and creates a gaming environment with a reduced sense of genre (Figure 39).

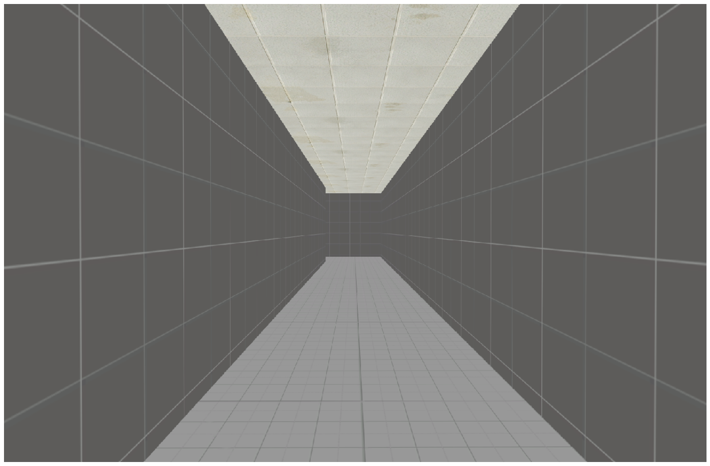


Figure 39: A screenshot from the pilot maze

In these experiments, the indurate signs used were arrows. Arrows were used as they are one of the simplest indurate signs, used throughout society and thus they should be recognisable anyone taking part in the experiment. The arrows were to be placed at various points within the maze and always pointed towards a dead-end or false door. This was intended to test how these well known signs are interpreted when used counter to their common usage of denoting a direction. In other words, these experiments will investigate if signs can be easily reinterpreted and if this reinterpretation remains consistent throughout a number of scenarios.

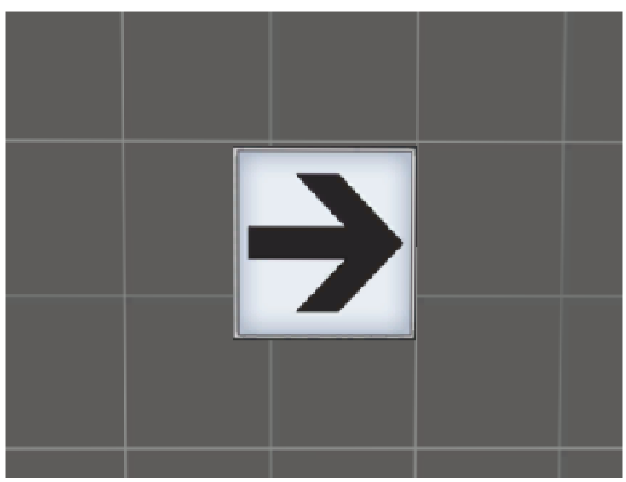


Figure 40: The indurate arrow sign

Scenarios:
Each scenario will use a different sample of participants, in each scenario participants will be asked to complete a maze.

Scenario 1 ► *Boring*: In this first experiment the maze was simply the maze as described above.

Scenario 2 ▶ *Static Danger*: In this second experiment some of the dead-ends and false doors to which the arrows pointed contained a static danger which may 'damage' the player character. In this case the danger was in the form of turrets from the Valve game 'Portal' [22]. As shown in Figure 41 the turrets emit a laser beam which is used to aim at the player character, this beam can be seen from around corners and so once a player has learned this, the laser alone should be enough to convince them they are heading for danger. In the game 'Portal' these turrets were used as obstacles rather than adversaries and as such they only 'kill' the player if they are able to shoot them directly for around 5 seconds. This should be enough for a player to get 'shot', learn the danger and retreat back behind a corner.

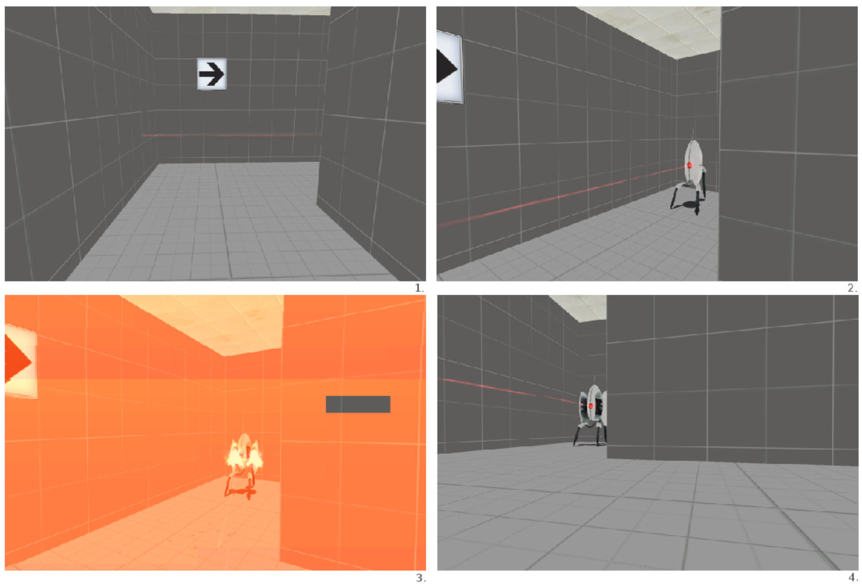


Figure 41: The *Portal* turrets

Scenario 3 ▶ *Approaching Threat*: In the third pilot experiment imminent threats to the player were introduced to the maze, giving the player a time limit to their advance through the maze. The threat which creates the time limit was the introduction of 'poison gas' (Figure 42 1/2) which spewed forth from vents in the walls. As the player advanced through the maze their character would take damage to represent the air being more saturated with poison, this damage would occur more frequently as the player progressed. The player character will eventually 'die'from the gas close to the end of the maze. For this scenario the use of non-player characters (NPC) which would chase the player (Figure 42 3/4) and cause damage to them, were considered as a means of heightening the perceived threat. Although the NPC would not have the power to 'kill' the player character, the actions of chasing and striking the character may have provided a perceived threat to the player's ability to complete the maze. However, while testing this facility it became clear that NPCs were prone to trapping the player character in corners and blocking doorways and thus the poison gas alone would be a more controllable and predictable danger.

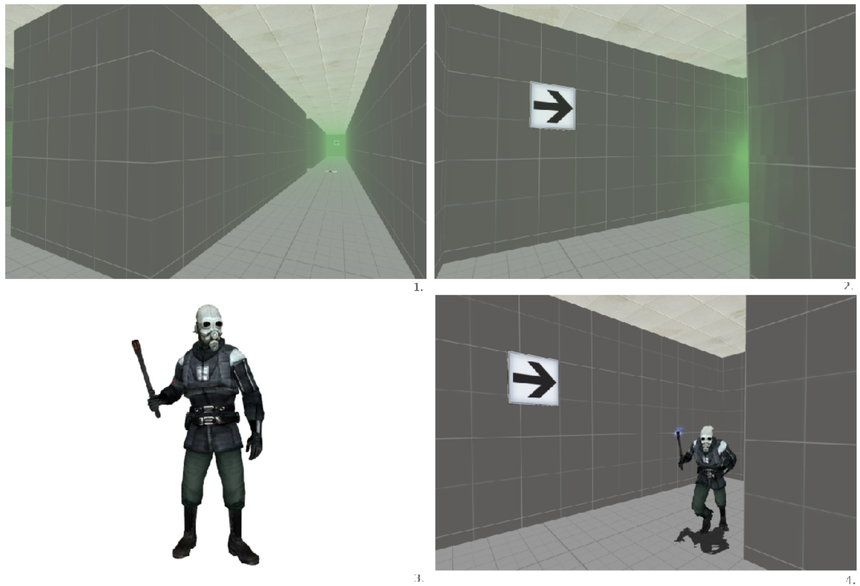


Figure 42: Approaching Threats

Null hypothesis and expected results

1. Culturally indurate signs can be interpreted differently with little chance of error.

2. The meaning of indurate signs is freely cognitively mutable. The proving or disproving of this null-hypothesis may provide insights into how uninformed use of indurate signs may affect interpretation in unbefitting situations.

In these experiments using indurate signs it was expected that in the first experiment, the mundane situation would cause the direction of the arrows to be followed by the player according to their culturally conventional meaning rather than their new learned meaning. This may be due to a capture error brought on by monotony. In a situation where an arrow points to a dead-end, the arrow may be assumed to point to 'nothing in particular'and thus not be re-interpreted as quickly as if it pointed to 'something'.
In the static danger scenario of Experiment 2, it was expected that because the arrow points now towards 'something' rather than simply an incorrect path, the sign will be subject to a more permanent reinterpretation, with the referent of the sign being danger. The reinterpreted meaning will be remembered and thus there will be less 'incorrect' interpretation of the signs.
In the imminent danger scenario of the third pilot experiment, in which there is danger which is unrelated to the sign, it was expected that the meaning of the signs will become less critical in the player's mind as they race to escape the gas, thus causing capture errors.

Measurements

Our unit of measurement during these tests was the number of path-errors made by the player. A path-error was classed as any decision made to take an incorrect path.
Also to be measured was the time taken for participants to complete the game and, as part of the debriefing process, measure engagement/immersion levels in the player using a questionnaire taken from a study by Jennet et al. (Appendix 6.1) [67]. The results of a debriefing questionnaire should also help determine if errors were explicitly due to the interpretation of signs, asking participants if they noticed the signs, what they thought the signs denoted, if they used the signs, etc.
To be able to get an accurate idea of how many errors occurred the participant's progress through the maze will be recorded so that the video record can be separately timed and analysed for observable errors.

Materials

The virtual maze was made using the Valve Hammer Editor and will run using the Valve Source Engine. To conduct the experiment there will be one PC for the player to use which will run the game and screen capture software (Fraps) so that the video of game play can be analysed in detail.
One concern which may arise from using a gaming environment is that Gamers and gamers may react differently to non-gamers. However, this is not a concern for a number of reasons. First of all the game the participants will play is not a prototypical first person perspective game. There will be no heads-up display (HUD) on screen, no weapons or methods of attack in game, the person will progress at walking pace, and simple maze traversing games are not common in today's gaming community.

More fundamentally, this experiment is testing semiosis in a controlled abstract environment and thus whether the player reads the signs in the environment in a 'gaming'cultural frame should not change the reading of the signs. However, it is expected that Gamers may be more proficient with the controls and thus complete the game quicker. Participants will, of course, be asked if they are Gamers to observe any results which dispute these expectations but it is not a concern at this time.

Pilot Results

Pilot Experiment 1 ► The Boring Scenario

► Participants
In this first pilot experiment, two participants were recruited to take part. The first was a 28 year old female student who played computer games around once a week but did not class herself as a Gamer. The second was a 21 year old male metalworker who plays games in any spare time he has and is a self labelled Gamer.
► Semiosis
Both participants noticed the symbols in the maze. The first participant stated that they assumed the arrows pointed to the correct path but then realized they were "pointing the wrong way" and so made a decision to go in the opposite direction. The second participant stated that they thought the symbols "pointed to a direction" but did not trust it to be the correct one. The video data showed that the first participant followed the first few arrows before becoming wary of the meaning of the arrows. After twice taking the incorrect path denoted by the arrows the participant then went in the opposite direction, making only one mistake throughout the rest of the maze. However it may be interesting to note that the participant took the time to *glance* in the direction in which the arrows pointed as if to double check her assumptions about the meaning of the arrow. It is of course, difficult to interpret the exact reason for this checking, a situation which highlights the value of post completion commentary [53]. This situation shows that video data alone can be used to count phenomena but not accurately interpret the semiosis behind these phenomena.
The second participant followed the first few symbols to the dead ends. After following the arrows twice the participant then began to go in the opposite direction. However, after a short time the participant stated that they had become annoyed with the maze and that to navigate the maze they would "just follow the left wall all the way". This strategy rendered the maze experiment fruitless and highlighted some fundamental problems with the experimental methodology. The construction of the virtual environment used with game based experiments would have to be reconsidered for future experiments and although this was a concern, I endeavoured to pilot the other scenarios before taking drastic action.
► Immersion
The results from the questionnaire showed that the first participant was engaged and somewhat immersed but not in deep immersion, the second participant showed engagement but was in no way immersed in the game. The game environment was not intended to be a particularly immersive environment, focusing on simple navigation and sign interpretation. This does however raise several questions, is immersion is needed for realistic interpretation of signs? Do Gamers, gamers and non-gamers have different requirements for immersion or perceive immersive environments differently?

Pilot Experiment 2 ► The Static Danger Scenario

► Participants
In the pilot one participant was recruited to test the experimental scenario. The participant was 25 year old female, a self defined *casual* Gamer and has had plenty of experience with FPS games.

► Semiosis

As they travelled through the maze they dutifully followed the path along which the arrow had directed them and so were led around a corner to where a turret fired upon them. The participant stated "Ah so the arrows point towards turrets,"and from then on they went in the opposite direction to which the arrows pointed. This suggests that a palpable phenomenon can be quickly linked to a sign, the semiosis and subsequent careful advance through the maze seemed to be caused by this reinterpretation of the arrows and once a sign had been attached to an explicit danger the meaning became more salient in the participant's mind.

Pilot Experiment 3 ► The Approaching Threat Scenario

Out of the three pilot experiments I was most concerned with the effectiveness of the *approaching threat*. This scenario was designed to make participants feel as if they had very little time to escape the maze, and thus put them under more pressure in the hope that this would stimulate a different reaction to the signs. The semiosis of signs under pressure is an important phenomenon to better understand how signs in medical devices might be interpreted, therefore to test this concept this pilot was tested more thoroughly and with a greater number of participants.

► Participants

A request for participants was made on an online forum dedicated to the game 'Portal'. Volunteers were sent the maze map, installation instructions and a link to an online version of the questionnaire via email. A Portal forum was chosen as the maze had been designed using textures and objects from the Portal game, therefore it would be easy for anyone with Portal installed to to quickly install and play the map, and who are more likely to have Portal installed than members of a Portal forum. Another reason for choosing a forum used by people who enjoy gaming was that many of the people in this community are also actively involved in the modding community, an online community which modifies (mods) and customizes games in various ways including creating new levels, textures, weapons, etc. by either creating or testing new mods. It was purported that this active involvement would create a critically minded group of enthusiastic participants which were fully game literate [48] and so could give insightful feedback about how the approaching threat affects game play and meaning making. Of course, using a gaming community as a pool for participants means that the majority are young male gamers. In this small study all but 2 of the 8 participants classed themselves as *Gamers* and all but one (a 25 year old female) were male and between 17-36 years old.

► Semiosis

The results of the pilot study showed that the approaching threat of death did not have a notable effect on the semiosis. Participants generally reinterpreted the meaning of the arrows to mean that they pointed toward the incorrect path and then followed this reinterpretation throughout the remainder of the maze. In response to the question of whether or not they noticed the arrow symbols in the maze, all but one participant not only noticed the signs but quickly deduced their meaning. The exception to this was the one participant who, like one of the participants in the pilot of the *boring* maze, has a system. They stated that "[...]*in a maze I always turn right at intersections, does not matter how long it takes, you will get there*" and thus assumed the arrows pointed the correct direction but never checked or paid much attention to these symbols. The pilot has highlighted this 'maze beating system'problem and thus measures can be taken in proceeding experiments so that such systems cannot be used. The remainder of the participants however had more to say about the meaning of the arrows.

"*I thought they meant the direction I should take at first, but then that theory was blown out of the water when I was cruelly led into a dead end. Then I vowed never to follow the arrows again, and jumped on them every time I saw one on the floor.*"

"*The symbols were lies, you had to* [...] *go the opposite way to what they said. I gathered this after about 1/8 of the map.*"

"*I thought the arrows were consistently pointing at dead ends. However, since after a while I stopped checking, I may have been wrong*!"

"*Confuse the gamer, obviously the right way is not follow the symbols*"

"*After following the first few arrows, which lead straight to a vent spewing poisonous gas, it was very obvious to me that they showed the direction not to go*."

"*The symbols depicts a commonly known indicator, an arrow, at first leading me to believe that they would guide me along a safe route; however, after running into a dead end after following the first arrow, I realized they pointed in the direction of false paths or dead ends and avoided the directions indicated.*"

Participants where also asked if they felt the arrows in the maze were counter productive or trying to *trick* them, something to which all but the anomalous participant agreed was the case.

"*The arrows definitely felt like they were purposefully placed such that if you follow them, you will be going the wrong way*."

"*Yes. After a few attempts to 'follow' the arrows, I realised they were usually leading to dead ends. However, I didn't check every arrow I came to*."

"*They trick me, later I don't care about them, my way was always the other direction*."

When asked if they had ever gone the wrong way by unconsciously following the direction of the arrow, some participants stated that they made a very small number of slips showing that the poison gas had little effect on their ability to proceed through the maze. Other participants paid very close attention, stating that they learnt that the arrows pointed to dead ends and thus made a conscious effort to go opposite direction.

"*No, I purposefully paid attention to the direction of the arrow and went in the opposite direction*."

"*I did, but this was up to 1/8 of the map, then I decided to test if you had to go the opposite way of the arrow, I found myself to be right*."

From the results of this experiment it is clear that the participants quickly and accurately reinterpreted the signs, giving them new meaning within this particular cultural frame. The small number of mistakes made by the participants tells us that in the design of this scenario failed to produce the desired mental state and thus did not show semiosis under pressure. I expect that this is due to a number of factors. Primarily the speed of the player character and the design of the maze. Although the players sustained damage from the poison gas and would wish to avoid this, they could only traverse the maze at walking pace and thus could not hurry. This meant that even though the players may have wished to rush through the maze, a process which may have caused more impulsive semiosis, they were unable to and so had more time to process the signs they passed. One solution to this would be to allow the player character to sprint, however for consistency this ability would then have to be applied to the other scenarios which were designed with walking speed in mind. The problem with the design of the maze was that a large proportion of it also allowed players a cognitive rest between signs, in the first two scenarios this was designed to create sense of boredom and mundanity to test if this state of mind created slips. In this scenario I hypothesize that this uneventful resting space, although filled with spewing gas vents and green smog, allowed the players to keep focused on the new meaning of the arrows.

I conclude from this pilot study that testing semiosis under pressure requires a very different experimental design to testing semiosis in mundane scenarios or environments which contain static dangers. If I was to reconsider this scenario as a separate experiment I would completely redesign the map to include more turns, doors and intersections which would subject the player to a higher number of signs in quick succession. The player character would also be able to move at a higher speed to better simulate quick decision making.

▶ Immersion

The data from the questionnaire showed that participants were *engaged* [67] with the game but not *immersed*. This is not surprising as the maze was designed to be a simple digital environment rather than an engrossing game. The environment contained few of the conventions of FPS gaming, there were no weapons, no interactive objects, simple textures and no dynamic objectives. This lack or immersion, although not a concern when designing the experiment, may have contributed to the ease with which the participants dealt with the reinterpreted signs mentioned above. A lack of immersion is likely to have allowed the players to focus more of their attention on the task of remembering rather than concentrating on the game environment and events within. As the gamers stated, they did not find the maze enjoyable, immersive or challenging but were still motivated to finish the maze and still wished to *win* and thus held the new meaning of the arrows in their mind.

By designing a maze with few of the beguilements present in games it was hoped that a more pure form of semiosis would occur, in some ways this may be the case but in stripping away distraction there is little context left in which *natural* semiosis could occur. In real life semiosis we are ever situated in a cultural frame, within a complex and dynamic context. For experiments in virtual environments to tell us anything more than how signs work in the individual study, a more contextualized immersive experience will be necessary, an environment with distractions, goals and objectives in which signs are not the focus but are interpreted *on the fly* as part of the virtual reality.

This pilot study also showed that using game engines and level editors for the rapid prototyping of virtual environments for experiments is both useful and practical. It also suggests that the gaming community is a good place to rapidly acquire participants for game based experiments. This rough and ready methodology of piloting an experiment has many potential flaws but is useful in that it quickly highlights the problems in a study, from posting the request for participants to receiving the final questionnaire submission took just 3 days, with most of the results appearing within 48 hours.

Discussion

Back to the cheese board

When creating the maze for these three experiments I play tested them throughout the development to ensure they gave the gaming experience I desired. Once the maze had been completed and the counter cultural signs added I ran through the *boring* maze for one last check, with the intention of simply following the correct path. During this test I found myself at a dead end, I knew that the arrows in the maze pointed to the incorrect path, I had designed and built the maze my self and yet there I *stood* feeling not a little foolish. Hoisted by my own petard and not even recalling mentally processing the arrow, I set to musing on the cause of this incredible feat of absent mindedness. Was my maze so deft that the human mind could do naught but fall into the trap? Somehow I doubted it. I realised that as I made my way through the maze my aim was to simply traverse the maze, to test that no walls seemed out of place, that no alley was too narrow, etc. and the only point at which I took notice of the signs were if I thought them to be in an imperfect position. I would argue that due to the mundane nature of my test run and the fact that my mind was not focused on the counter intuitive nature of the arrows, the signs were being processed by my subconscious and not by my critically aware mind. The indurate meaning of '*this way*' caused physical responses as my mind wandered from the task at hand.

However, the participants of the experiment were focused entirely upon the maze of which the signs were a part. To the participants who reinterpreted the meaning of the arrows they served as a tool for navigation, a tool which, in an environment with little distraction or other goals, could be the focus of their attention.

A fundamental flaw in the experiment seemed to be the unanticipated *systems* which people employed to beat mazes, this problem could be solved by changing the environment from a maze to a less primitive game environment. I conclude that my assumptions about a genreless, plain game environment giving a more pure and readable sense of semiosis was completely misguided. I fell into the trap of the icon interpretation investigators by providing too little context, an unnatural environment for semiosis and thus created a flawed experiment. Perhaps this experimental design could have been more successful in testing semiosis under extreme cognitive load, in which context may be secondary to the mental processes of the participants, but in testing simple semiosis it fails. Although the experiment failed in its aim of providing any useful data, some interesting things can still be taken from the whole exercise. The sparse data collected from these pilot studies seems to suggest that, in simple situations, indurate signs can be reinterpreted accurately and consistently applied throughout a cultural frame. In other words, once the players had learnt that the arrows pointed to the incorrect path they assumed that this rule was the same for all arrows throughout the maze. Therefore I conclude that, in virtual environments at least, in situations which give the participant time to learn and apply newly acquired rules, indurate signs can be interpreted differently with little chance of error. However, the responses of the participants would also suggest that the meaning of indurate signs are not entirely freely mutable. This is because although the participants reinterpreted the arrows to mean *incorrect way* instead of *correct way*, they still interpreted the arrows as signifying some sort of path or direction. The arrows still *pointed*.

Of course in a maze there is little else to signify but *the way*, however it can be seen that the choice of words used to describe the reinterpretation of the arrows suggest that the core meaning in the participant's mind was always one of 'pointing'. If nothing else I conclude this experiment has shown that the nature of indurate signs and their semiosis requires further empirical research.

This naive study also revealed that semiotic issues in game based experiments, although abstracted from the real world, must be considered in relation to their original context. Though it might be useful for a gaming environment need be realistic in a graphical or atmospheric sense, what is more important is that the game contains realistic and relevant phenomena, distractions and dynamic tasks. This is because situations in which signs are experienced in the real world are not often simple, and so neither should they be in a semiotic experiment within a virtual environment.

In terms of game related research methods I conclude this experiment has raised some interesting points and questions. Building game environments using level editors does seem to be an effective way to create rapid virtual behavioural experiments, yet creating a virtual environment must be coupled with effective data gathering methodology. Questions for the future include, is deep immersion a requirement for virtual behavioural and cognitive experiments? Do gamers and non-gamers have different requirements for immersion? Is immersion needed to create realistic in-game semiosis?

4.4 Experiment 1: The Enriched Environment

Aim

As in the pilot, this experiment attempts to investigate the interplay between signs and errors, but aims to vastly improve upon the experimental methodology of the pilot experiment.

Experimental Design

In this experiment a single sample of participants will be taken from which I will observe how participants reinterpret the meaning of arrows and then apply the new rule throughout the rest of the maze.

Designing the Experimental Environment

In the last experiment there were several problems with the virtual maze and game environment. These included such issues as walking speed, maze beating *systems* (wall hugging), and a lack of immersion stemming from a lack of context and uninteresting objectives. For the new experiment a completely new game environment and maze were created using the Valve Hammer Editor.

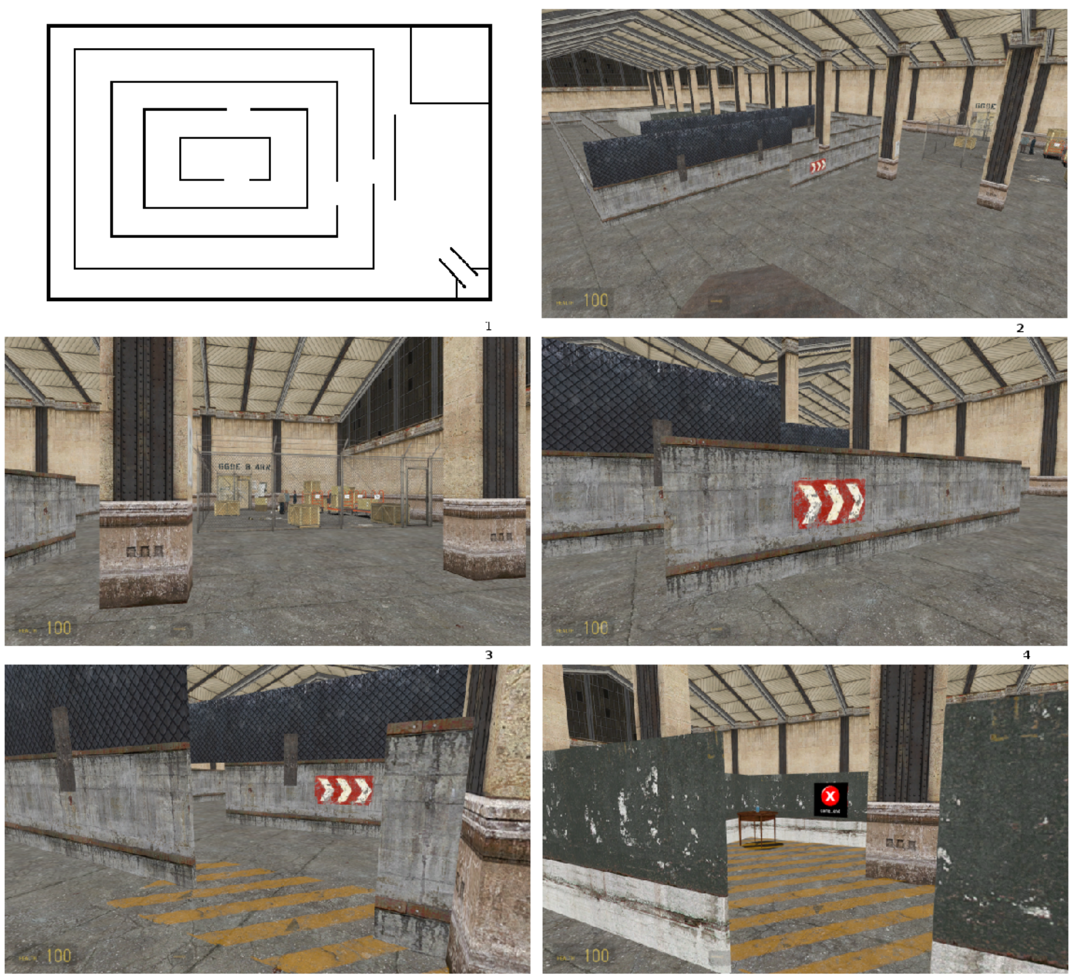


Figure 43: Screenshots from the virtual environment

Participants were asked to make their way to the inside of a number of concentric rectangles (Figure 43 1) as quickly as possible. The participants will be informed that if they reach the centre within a specific time they will win a small prize (chocolate bar) and if they are the fastest participant overall they will win a more substantial prize (Amazon gift voucher).
As in the pilot, the maze contains arrow symbols which point in an undesirable direction, however in this environment there are no dead-ends and thus no truly *incorrect* directions. The walls of the concentric rectangles each have one opening, this opening is placed so that going in one direction will take longer than the other. For participants to reach the centre of the maze quickly, they will have to choose their direction carefully while still moving at a fast pace. This creates a more dynamic objective than simply reaching the end of a linear maze and it is also hoped that the concentric rectangles will solve the problem of the *wall huggers*. To allow participants a chance to reinterpret the symbols the timer will only be started once they have entered the maze. This means that the participant may explore the environment and even look into the maze before attempting to set a time (Figure 43 5). To make the experiment seem more like a game, player characters will have a health score, the ability to sprint, and the game environment contains far more stylistic features. Using elements from the game Half Life 2, the environment has been designed to resemble the interior of a large warehouse or train station. The environment contains a small inaccessible area containing NPCs, props, etc. and more realistic and interesting textures were used throughout (Figure 43 2-4). It is hoped than the while the improved graphics, the dynamic objective, time pressure and chance of a physical prize should create a greater sense of immersion.
In summary the main changes made in this experiment are:

- A more salient objective.
- A more immersive environment.
- More explicit time pressure.

Null hypothesis and expected results

1. Culturally indurate signs can be interpreted differently with little chance of error.

2. The meaning of indurate signs is freely cognitively mutable.

The null-hypotheses of this experiment are the same as in the pilot, however the expected results are somewhat different. Participants will be made aware of the nature of the maze, a set of concentric rectangles with a short and a longer path to the center. In this maze the arrows explicitly point to a particular path, they neither point to a dead-end nor a danger of any kind. It is expected that participants will successfully reinterpret the arrow symbols but will still make some mistakes as they rush to the center of the maze. It is also expected that participants who use the sprint ability will make more mistakes.

Measurements

As in the pilot the measurements of this experiment were the number of times a participant takes an incorrect path and the time it took them to reach the center of the maze, although the timing is really just to add a little pressure to the player. Errors were counted even if the participant takes the incorrect path for a moment before turning back. After the experiment participants were debriefed, this consisted of a short interview about their general experience of the game environment and the maze task while a questionnaire is filled out to measure the level of immersion and their thoughts towards the symbols in the maze. The questionnaire is the same as in the first sign-maze experiment. The only difference in this experiment is that video data will not be used, as the maze is so short I feel it would be far more simple to note down the number and nature of any errors made by the participant next to their time score.

Participants

In this study participants were recruited via word of mouth and consisted of 7 male and 3 female participants between the ages of 18 and 30. Six of the participants defined them selves as Gamers.

Materials

The virtual maze was made using the Valve Hammer Editor and will run using the Valve Source Engine. To conduct the experiment there will be one PC for the player to use which will run the game and a stop watch.

Procedure

In this experiment, participants were given a general briefing about what was required from them and were then placed in control of the player character within the game environment.

Results

The following table shows the gaming habits, time, number of errors and level of immersion for each participant. The immersion levels are scored between 31 and 155, with 155 being the highest level of immersion.

Participant	Gamer?	Time/Errors	Immersion
1	No	0:12/0	82
2	No	0:14/0	100
3	Yes	0:41/1	89
4	Yes	0:18/1	99
5	Yes	0:28/1	95
6	Yes	0:19/0	84
7	Yes	0:30/1	77
8	Yes	0:36/1	96
9	No	0:21/1	79
10	No	0:24/0	81

Table 15: Immersion, Time and Errors

To reach the center of the maze a time of 8 seconds can be achieved by seamlessly sprinting along the correct path, and a time of 12 seconds can be achieved without sprinting. As we can see the times that the participants scored are an eclectic mix with few taking over 20 seconds. This reflects the varying styles of play which were observed during the experiment with some participants using the sprint feature, some content to wander at a gentle pace, some proceeded cautiously taking in their in-game surroundings, while others had their heads down charging toward the center.

What is interesting about these results is the number of errors which occurred. Participants who proceeded straight into the maze generally followed the first arrow they saw which took them toward the incorrect path, some participants suspected their error upon turning a corner to be faced with a long featureless corridor and turned back, while others continued upon their longer route. However, all 6 participants who made an error, usually as they entered the maze, realised their mistake and promptly reinterpreted the arrows, applying their new rule to the rest of the maze. Those participants who explored the environment and cautiously checked inside the maze before venturing in did not make errors.

For example, participants 1 and 2 spent a lot of time exploring the environment and looking into the maze through the first door before proceeding over the yellow lines. As a result they learnt the rules of the arrows before entering the maze and thus made no mistakes but always went in the opposite directing to the way the arrows indicated. On the other hand, participant 3 entered the maze from a direction which did not allow the player to see the opening in the first wall. He did see the first arrow and *followed* the direction it was pointing around the longer route. After taking this long route the participant then went the opposite way to the direction the arrows were pointing for the remainder of the maze. On the questionnaire he stated that the arrows were "lies". Therefore we might deduce that to this player, the arrows were assumed to be communicating the message of *go this way*, and instead of reinterpreting the arrows to be communicating *this is the long way* as the some other players did, they regarded them as communicating an intentionally untrue meaning.

Whatever the interpretation of the signs, the participants still applied their new readings of the arrows to the rest of the maze once they had deduced their meaning and thus created the new situational rule in their minds.

The immersion of this virtual environment proved to be far higher than that of the first experiment and the more interesting surrounding provided this more immersive environment. The realistic textures and *scenic features*, artefacts which cannot be interacted with nor add anything to the mechanics of the gameplay but are simply there to add to the mise-en-scene of the virtual environment, seemed to provide a level of immersion far deeper than the engagement experienced in the first experiment. See Appendix 6.2 for the full results.

Participants felt the game was more interactive and more like the game was something they were experiencing rather than just doing, even though the maze navigation task was essentially the same. The participant's views on immersion only differed substantially on two issues, how much suspense they were in about whether they would *win*, and how much they lost track of time during the game. Unsurprisingly players neither became emotionally attached to the game or had a sense of being detached from real world. These results I attribute to the extremely short amount of time the players spent in the game environment (a few minutes at maximum) and the lack of interaction opportunities with NPCs.

Discussion

In terms of questionnaires, the problems encountered in this study show that in experiments which deal with gaming the questions must be carefully constructed so that they are both relevant to the game and environment while clearly distinguishing between questions about in-game and out-of-game experiences. However, the problem with the questionnaire did suggest that different games do indeed have different requirements to be immersive. In a short maze based FPS, emotional attachment was deemed a ridiculous idea by the participants in this experiment, whereas in the testing of a Role Playing Game (RPG) or a dating simulator I would expect it would be quite a mundane question. Similarly, as participants knew the game was to be a short maze within an enclosed environment, suspense and narrative were not expected.

The debrief interviews showed that the participants enjoyed the environment, stating that it had enjoyable graphics, and was "realistic but still cool and dystopian", a trait which I can attribute to the use of textures from Half-Life 2 which is a set in a dystopian near future. This highlights the importance of in-game textures to the mise-en-scene of a virtual environment. In this scenario this issue did not present a problem but if I were attempting to create a truly realistic virtual environment the Half-Life 2 textures would have been detrimental to that charge. Smith et al.[118] acknowledged this issue when using textures from Half-Life 2 to create a replica of a real world office interior. When asked about possible improvements to the game the participants both indicated that they would have preferred a bigger gaming area, a more dynamic challenge and that they greatly desired to gain access to the inaccessible area and the NPCs within. This suggests that immersion could be deepened if NPCs were used more, perhaps to give the participants instructions, and that using access to inaccessible areas as a reward for completing a task would provide a great amount of motivation for participants in a game.
Other features which almost all participants would have liked in the game were the addition of guns, things to shoot and tasks which involved the in-game physics, specifically *"throwing things at people"*. The request for the latter features was spawned from the object placed at the center of the maze, an old table and a drinks can. Around half the participants realised the can could be picked up by the player character and thrown using the fire key, leading to the usual conclusion of games community that if a game has a feature, that feature should be utilised throughout. This mentality probably due to the way in which every artefact within a game is artificial and therefore had to be placed within the game for a reason, and rarely is this reason limited to pure aesthetics or whimsy. In other words, if the player can throw a can, they want to have a reason that they can throw it.

In this experiment I expected that participants would successfully reinterpret the arrow symbols but will still make some mistakes as they rush to the center of the maze. Although the participants did indeed reinterpret the signs accurately, few mistakes were made. It may be that this was due to the extremely short nature of the maze and so, in any future experiments the maze would have to be longer, exposing the participants to a greater number of reinterpreted signs.
I conclude the second experiment was a marked improvement on the first and that with more time, testing and experimentation with different game engines, this experimental methodology could be used to further explore practical semiotic issues. Therefore, in response to the original research questions of *can 3D gaming provide*

a suitable environment in which to test semiotic theories? To this questions I must answer in the affirmative but accept that far more work is needed to perfect this process. In the introduction to Chapter 4 I noted a concern that the use of Gamers, gamers and non-gamers as participants may create a problem for this type of experiment. However, we can see that the times and number of errors varied greatly with no real pattern emerging, this is probably due to the novel map which the participants were exposed to, the unfamiliar objective and type of gameplay present in a maze game, thus I feel that these fears were unfounded in this particular experiment.

▶ Concluding Thoughts

I designed this experiment to reveal something of the relationship between signs and errors, specifically capture errors. However, this experiment has revealed more about cultural frame shifting in the interpretation of symbols. Both the pilot and this experiment have shown that, in these situation at least, people can quickly reinterpret indurate signs but that the meaning of these signs is not entirely mutable. In both experiments the arrows still *pointed* and whether the arrows were reinterpreted to mean *wrong way* instead of *right way* or were thought simply to be *lying*, the concept of pointing remained constant. I suggest that this is due to the conceptual tension which arrows carry in western society, this tension is such that while an arrow may communicate many concepts, the core semantics of an arrow is always one of pointing.

What is perhaps more interesting is the way in which people apply this new meaning throughout a cultural frame. In most cases, participants would reinterpret a sign after one or two exposures to its new meaning and this new meaning would then be applied to all subsequent signs. In other words, people expect regularity within cultural frames and once a new rule has been created it is assumed that this rule remains consistent throughout the entire frame. Of course these experiments only show that this is the case in virtual environments and in young members of western society, however the expectation of regularity is inherent to concepts throughout society. For Language and all its dependants to remain useful, the assumed consistency of the signs within them are essential. In fact one could argue that western society is dependent upon the assumption of its members that it is consistent. The idea that people use stable cultural frames to conceptually grease thought and interaction was touched upon in Chapter 2 and I conclude that these experiments have shown that people are extremely quick to create and abide by rules which serve to stabilize an environment. In this case the new rule was formed from a conceptual blend triggered by the conceptual tension of the indurate meaning of arrows and their new meaning within the context of the virtual environment. In other words, the difference between two meanings caused participants to form a conceptual blend, allowing them to use the arrows to navigate through the maze.

Although these experiments have thus far created more questions than they have answered, they have opened up many new lines of enquiry for future study. The experiments have driven me to explore the nature of immersion and its effect on behaviour and cognition while also considering challenging some simple but fundamental semiotic problems, such as can conceptual tension be *snapped*? Is there a point at which the tension between an indurate meaning of a sign and its intended use are so different that a conceptual blend is implausible?

4.5 Experiment 2: Making a Game

Aim

As in the pilot and experiment 1, this experiment attempts to investigate the interplay between signs and errors, aiming to explore how errors may be caused by the misinterpretation of indurate signs. It also aims, once again, to vastly improve upon the experimental methodology to provide a more immersive environment and thus more insightful results.

Experimental Design

In this experiment a single sample of participants was taken from which I looked for a systematicity in the frequency of errors, any correlations between the number of errors and immersion scores, and under what circumstances any errors occurred. To see if the errors in this experiment were indeed systematic and not purely down to chance, the systematicity limit will be at 5% of the total potential errors. This number was chosen due to the previous experimental work on human error by of Li et al.[78]. Therefore if the frequency of errors exceeded 5% it suggests that the errors which should occur in this experiment are indeed systematic.

Designing the Experimental Environment

This experiment will use a similar design to Experiment 1, but will consist of a larger more interactive level, and will include many of the suggestions requested by the participants of Experiment 1 such as dynamic objectives, interactive elements, guns and enemies. This experiment will again be using arrows as the indurate signs that participants will be required to reinterpret to successfully complete the game. In the last experiment, the amount of time that the participant was exposed to signs was insufficient to measure capture errors. Therefore, in this experiment the participant will be exposed to a greater number of signs at a greater frequency. For the new experiment a completely new game environment and maze were created using the Valve Hammer Editor.

Figure 44: 1. The location of the Rocket Launcher.

The participant's goal is to find a weapon which is at the center of maze (Figure 44) located somewhere in a large non-linear gaming environment. In this environment the participant started in a small building which served to teach them the new arrow rules, in this case, that the arrows on the walls always point to dead ends. Once the players escape this building they find themselves in a large area containing many other buildings, enemies, and interactive props such as explosive barrels, breakable boxes, new weapons, etc. (Figure 45). There is no single correct path to the player's goal and therefore the player must explore the environment to complete the game. It is hoped that this need to explore and interact with the environment, coupled with the ambient sound effects and music which were added, will greatly increase the level of immersion.

Figure 45: Screenshots from the virtual environment

Figure 46: Screenshots from the virtual environment

To create a more dynamic objective, there were a number of enemies which must be disposed of before entering the maze and throughout the maze there are explosive barrels and other interactive props which must be negotiated (Figure 46). On reaching the center of the maze the participant would then be required to escape the environment, by first escaping the maze and then finding their way to a large door at the edge of the environment. During this escape phase, alarms sound, a helicopter can be heard swooping in overhead, and more enemies spawn to fire upon the participant as they attempt to make their get away. This escape phase allowed observation of the participants as they are exposed to signs during both their entrance and assailed escape of the maze. It was hoped that the interactive props and enemies attacking the participant will also render any ponderous *maze beating* strategies, as seen in the pilot study, unworkable as the player character will inevitably die if the participant does not escape quickly from the maze.

In Experiment 1 the more graphically enhanced surroundings seemed to improve immersion and thus this progress was continued in the construction of the gaming environment for Experiment 2. In this experiment the environment featured dynamic lighting effects, and more interesting and varied textures in an attempt to improve immersion further.

In summary, similar to Experiment 1, the main changes made in this experiment are:

- More dynamic objectives and interesting tasks.
- A more immersive environment.
- A more complex experimental manipulation.

Hypothesis and expected results

I hypothesized that the participants of the experiments would have problems maintaining the reinterpreted meaning of the culturally indurate signs present in the virtual environment, especially while under in-game pressure. Thus the null-hypotheses of this experiment was as follows:

1. Culturally indurate signs can be interpreted differently with little chance of error.

2. The meaning of indurate signs is freely cognitively mutable, even under pressure.

The null-hypotheses of this experiment were much the same as in the pilot and experiment 1, however the expected results were somewhat different. It is expected that participants would, as in the previous experiment, successfully reinterpret the arrow symbols. However, in this experiment it is expected that participants will make more errors when they are escaping the maze under fire, this prediction is based on the assumption that a higher level of immersion would create a more empathetic link between the player and the player character. In other words the player would be more concerned with their life and thus feel under more pressure while escaping. Therefore we may also expect to see a higher number of errors in participants with a higher immersion score.

Participants

Sixteen people were recruited by opportunity sample to take part in the experiment. There were 4 women and 12 men. The average age was 24. Seven of them described themselves as gamers and nine as non-gamers. One participant was excluded as she failed to complete the task and also during the task constantly commented on her inability to play the game.

Measurements

In this experiment the primary method of measurement was the number of errors made by the participants as they traverse the maze to find and escape with the rocket launcher. The location and circumstances of these errors was also noted so that we may see if situations in which actual errors occur correlate with where errors are expected. Errors were not recorded while the players were in the building in which they begin, the interior of which is designed as a small maze which allowed them to reinterpret the meaning of arrows throughout this game. Time was not measured in this experiment as it was be expected that participants would explore the large gaming environment at their own leisure. It was also felt that the in-game sound effects and attacking enemies will give the participant ample cause to wish to exit the maze as quickly as possible.

Procedure

As stated in the description of the virtual environment, participants were instructed to find a *rocket launcher* weapon within the virtual environment. Once the participants found their way to the maze within the virtual environment the number of errors made by them as they enter and exit the maze was noted down. After the experiment participants was debriefed, this consisted of a short interview about their general experience of the signs, objectives and game environment, while a questionnaire was filled out to measure the level of immersion and their thoughts towards the symbols in the maze. The questionnaire was the same questionnaire as used in previous experiments (Appendix 6.1).

Materials

The virtual environment was again made using the Valve Hammer Editor and will run using the Valve Source Engine. To conduct the experiment there will be one PC for the participant to use to complete the experiment.

Results

As in Experiment 1, participants were given a general briefing about what was required from them and were then placed in control of the player character within the game environment. The following table shows level of immersion, the total number of errors made my each participant, as well as showing whether those errors occurred on the way in or out of the maze.

Participant	Gamer?	Total Errors	Errors In	Errors Out	Immersion
1	No	3	1	2	124
2	Yes	1	0	1	104
3	No	4	1	3	114
4	No	5	0	5	119
5	No	3	0	3	112
6	Yes	0	0	0	100
7	Yes	1	0	1	104
8	No	5	1	4	124
9	No	4	2	2	113
10	No	7	2	5	96
11	No	5	0	5	118
12	Yes	2	1	1	111
13	Yes	6	2	4	111
14	Yes	4	3	1	111
15*	No	15	-	-	90
16	Yes	2	0	2	98

Table 16: Immersion, Time and Errors 2: *Participant 15 was excluded from the results.

The average number of errors the participants made while entering and exiting the maze in this experiment was 3.4, this is 21.25% of the total potential number of errors of 16. As we can see from *Table 2*, apart from the participant who made no errors, the error percentage ranges from 6% to around 43% giving us plenty of evidence of systematicity within this experiment.

Unlike Experiment 1 and the pilot, the design of this experiment seemed to produce the effect I was looking for, while maintaining the observations made in the previous experiments. As in these previous experiments, participants quickly reinterpreted the meaning of the arrow symbol and then applied this new meaning throughout the rest of gaming environment. The participants then followed their new rule, usually without checking where the other opposite direction led, however unlike previous experiments, this virtual environment was able to create a situation in which most participants made errors when under pressure. As predicted, most of the errors took place during the participants assailed escape from the maze, in which participants rushed to avoid the gunfire and the probably death of their game character. For example, participant 1 made one mistake while entering the maze at the centre of the gaming environment and two more as she rushed to avoid the gunfire when the alarms went off, participant 5 made no errors while entering the maze and three as he attempted to escape, and so on. Errors were noted by the experimenter as they occurred together with any other points of interest, though the latter were not systematic, because the notes were not systematic, and thus not sufficient to give a definitive account, it gives an accurate account of our perception of when errors were made.
So in this experiment, what did the participants think the arrows *meant*?

"*They showed opposite direction from where you should go*."

"*I felt tricked only on the first few ones, after that I realized that they show the opposite direction of the correct path*."

"*They pointed to dead ends mostly*."

"*I followed* [the arrows] *to start with but i think they were pointing the wrong way so i started going the opposite way*."

"I thought I should follow them, I think? But I don't know, some seemed to point to dead ends."

These quotes from a few of the participants are a fare representation of the thoughts of all the participants in this experiments. The arrows were reinterpreted to represent a direction which should not be travelled and still, as in previous experiments, *pointed*. This is unsurprising given the circumstances in which the arrows were encountered, pointing as they did towards an incorrect path. However it is interesting to note that no participant simply stated that the arrows were *meaningless*.

This experiment was conducted in the most *game-like* virtual environment in this study so far and it was these tried and tested conventions of 3D FPS games which allowed participants to become more immersed in the task. However, was this experiment *too gamey*? So much so that non-Gamers were always going to fair worse than Gamers? The table below shows the differing results between the Gamer and non-Gamer participants.

	Gamers	Non-Gamers
Number	7	8
Average Errors	2.2	4.5
Average Immersion	105	115

Average Scores

Unlike the previous experiment and the pilot, in this experiment the differences between Gamers and non-Gamers is apparent, with a clear divide in error frequency and immersion level. A Mann-Whitney test showed that the difference between the spread of errors was indeed statistically significant, with significant difference among the mean ranks of Gamers (5.4) and non-Gamers (10.3), and a P2 value of 0.0424.
But is the increased error rate in non-Gamers due to a reduced ability to deal with counter-intuitive signs, or is it simply that non-Gamers are less proficient at using gaming controls? I would argue that the latter is not the case for a number of reasons.

- The non-Gamers spent a substantial amount of time exploring the virtual environment and getting used to the control system before they entered the maze.
- Most non-Gamers made far more errors exiting the maze than entering it.
- Non-Gamers made no complaints about the controls being tricky or difficult.
- While observing the experiment there were very few instances of keystroke errors and/or participants forgetting the control keys.

Although there are differences in the number of errors between the two groups, the location of the bulk of those errors remains the same, the assailed exit from the centre of the maze. Therefore it would seems that, although Gamers appear to be more proficient at dealing with counter-intuitive rules within gaming environments, the same semiotic processes are still happening.
I conclude this means that we can still use both non-Gamers and Gamers in game based experiments and evaluate the results of Gamers and non-Gamers together, as long as we factor in how adept Gamers are at dealing with rules within the cultural frame of gaming into our evaluation.
Apart from the difference between Gamers and non-Gamers there were few other differences between the demographic divides. All participants were aged between 18-35 and had a variety of occupations and gaming preferences. The results varied greatly within this group of participants.

Throughout the experiments in this study the level of immersion of the participants has been followed and this has thus far helped to improve the experimental methodology, by increasing the immersive properties of the virtual environments and thus allowing participants to engage with the experiments more freely. In this experiment it was hoped that we might observe any relationship between immersion and the number of errors made by the participants.

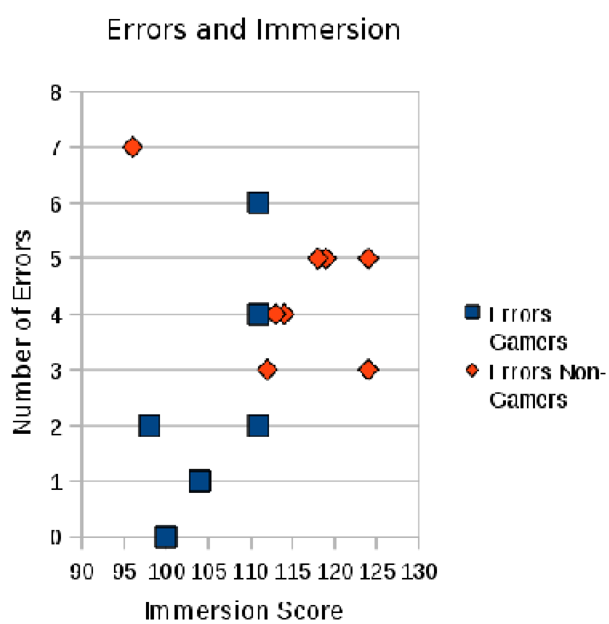


Figure 47: Immersion scores and the number of errors

As this graph (Figure 47) shows the relationship between immersion and number of errors is negligible, but what it does show is the almost universal divide of the immersion scores between Gamers and Non-Gamers. The only Non-Gamer to have a lower immersion score than the most highly immersed Gamer was a participant who never plays any games and does not particularly like gaming at all. So although we cannot say for certain that a higher degree of immersion causes more errors in this game based experiment, we can safely say that Gamers were generally less immersed by this type of virtual environment than non-Gamers. A Mann-Whitney test does show some statistical significance between the immersion levels of Gamers (5) and non-Gamers (10.6), with a P2 value of 0.0178. So why, as Table 3 and Figure 47 show, might gamers be less immersed than non-Gamers?

It may be that the answer to this lies in how challenging the participants found the game, and that the game environment was designed so that participants of all skill levels could complete it. Therefore the level was not made too difficult for novice gamers, thus making it quite easy for experienced gamers. I also suspect that the Gamer participants found the 3D graphics and weapons they could obtain on the level very mundane as they are standard to most modern FPS games. One interesting question that this issue does throw up is, *do Gamers and non-Gamers have different requirements for immersion*? The differing immersion results from this experiment, though subtle, may suggest that more investigation into this question may be useful in the study of immersion.

Discussion

In this experiment the null-hypotheses were also shown, in this situation, not to be entirely true. Culturally indurate signs were indeed reinterpreted with little effort on the part of the participants, showing that the meaning of these indurate signs is, to some extent, cognitively mutable. However in this immersive environment the chance of error increased with the addition of in-game pressure on the participants, with this increase in urgency causing the meaning of the indurate signs to *snap* back into their original meaning in moments of distraction within the minds of the participants. Thus we may conclude that in this experiment at least, the meaning of indurate signs is not entirely freely cognitively mutable, and will always be strongly linked to its static meaning within society. In this experiment it was expected that more errors would occur on the participants way out of the maze, when it was thought that the arrows would be encountered in a more hasty way while the participant's mind was busy dealing with avoiding attack. This prediction seemed correct and the semiotic process by which participants reverted back to the indurate meaning of the arrow did indeed occur more frequently while the participant was under in-game pressure. A Mann-Whitney test does show statistical significance between the number of errors on the way into the maze (10.9) and on the way out of the maze (20.1), with a p2 value of 0.0048. In terms of experimental methodology it was also expected that more dynamic tasks and interactive elements would increase immersion in this game based experiment. This also seemed to be an accurate prediction as the increased amount of conventional *gamey* content (enemies, weapons, etc.) and interactive features of the game environment correlated with the increased immersion scored for this experiment. The increased immersion also seemed to improve the quality of the experiment, with a higher amount of immersion allowing participants to really think *in game*, and it is to this heighten immersion that I attribute the relative success of this experiment. I would also argue that it appears that making a virtual environment more immersive is of great importance when using them to test cognitive and behavioural theories such as semiotics, and that in any future experiments of this nature, I will endeavour to make the environment as immersive as possible.

This experiment succeeded in its aims of providing a more dynamic goal for participants, being more immersive and being a more effective experiment over all. The improved immersion and dynamic properties are shown in the immersion scores of participants and the comments made in the de-briefing interviews and it is likely that these improvement were due to the enhanced level design in this experiment.
In this experiment the average immersion score was 110, a great improvement compared to an average of 88 in Experiment 1. Not only did the numbers show a greater amount of immersion, but the interviews after the experiment showed that the participants were more enraptured with the game, enjoyed the features suggested by the participants of Experiment 1 but were still hungry for more interaction.

"*I like the addition of weaponry and things and people to shoot. It would have been nice to make it harder to reach the final white door, ie, a barrier of troops. Maybe even a small vehicle section but I think I'm just nitpicking*."

"*Enemies and attacking makes it more immersive, but it should be a longer level because it feels like it is going somewhere. Also more interactive NPC's and technology would be good*."

"*The large number of props, barrels and other breakables made the level feel more like real half-life and the enemies shooting for all round kept me aware. The hidden vehicle was also a nice touch but I would have liked to use it to escape*."

"*The music made the game feel like a film, and the areas you didn't need to be were more interesting than the main area.*."

This seems to suggest that interactive features, a steady stream of attention grabbing elements, and an environment which is designed as much for its stylistic and aesthetic appeal as for its role in the game mechanics, are all important to immersion in 3D gaming. The feedback from the debriefing interviews also suggest that participants enjoy and explicitly praise the features which were designed to immerse them in the game, suggesting that players are aware that games are creations while they are playing them, and enjoy them as such. In other words when people play a 3D game, or I would predict any game where the visuals plays a more than purely practical role in the game-play, they are both playing and watching the game, and thus can enjoy the game in both an active and passive sense. In this way I suggest that players can become more immersed in the interactive

elements of a game if they appreciate the effort put into constructing the game, primarily the visual elements of that game.
This idea is nothing new of course, simply an old idea in a new situation, the idea that beauty is often perceived as *goodness* has been studied for a number of years in the field of usability [28][60]. For example, work by Overbeeke, Djajadiningrat and others [31][104] argues that HCI should not simply focus on cognitive aspects of interaction but should consider what people perceive and feel when using technology. They argue that we are emotional beings and thus design of interactive devices should reflect this with their mantra of; *don't think affordances, think temptations, don't think products, think experiences, don't think beauty in appearance, think beauty in interaction, don't think ease of use, think enjoyment in interaction, don't think buttons, think rich actions, don't think labels, think expressiveness and identity*, and so on. This then is something else to consider in regard to immersion and enjoyment of virtual environments and will be discussed further later in this study.

This experiment could have been improved in a number of ways, both in terms of methodology and immersion. In terms of methodology the it would have been fruitful to have multiple tasks throughout the level in which the participants were exposed to the reinterpreted arrows. In the virtual environment used for this experiment there were only two such tasks, the first in the player character spawn area, which served to teach the participants to reinterpret the arrows, and the second, the main maze in which the main observations of the participant's errors took place. With more of these tasks throughout the experiment, perhaps the rewarding the participant with better weapons or vehicles, etc. more observations of the players under differing circumstances, these observations could provide more data and give possible insights into errors in different situations.
In terms of immersion, what participants commented on was the lack of a narrative throughout the game. This was because the virtual environment had been improved to such an extent that it felt for the players like a game, however, because most games have some sort of narrative structure to their levels, this was now expected from this more *game-like* virtual environment. Simple additions such as communicative player-friendly NPCs (allies), more dramatic enemy encounters and a more eventful scenic escape would have created this narrative which, is seems, very *game-like* games require for player satisfaction.

And what of our lost little participant, put out to pasture in the meadow of repudiation? Rather than being simply an outlander, a foreign mind which we may ignore, is this participant simply telling us something about this experimental methodology? Could this participant be suggesting to us that the gaming paradigm by which we conduct these experiments simply does not work with some people? It is certainly a possibility, from the total of 26 participants chosen to take part in the first and second experiment, this participant was the only one to have such an adverse reaction to being asked to play a game but represents almost 4% of the total sample. Of course *there's always one*[115], the question really lies in whether by ignoring the results of these outliers, we are going to miss something about how they do semiosis. Could it be that these participants have little capacity for the world of signs which constitutes a virtual environment? Perhaps it is a simple willing resistance to taking part in a task which they have predetermined them selves to loath and fail at? Either (or neither) way, it would seem that more study into this type of staunch anti-gamer might be fruitful for gaining further insight into using games as experimental environments, although as far as semiotics is concerned we may never know how the truly unwilling interpret signs within this sort of game experiment.

▶ Concluding Thoughts

The aims of this experiment were to investigate the interplay between signs and errors, and to improve upon the experimental methodology. In terms of experimental methodology, lessons learned from the previous experiments guided the design of virtual environment to provide an immersive game space in which participants could act. Over the course of Chapter 3 the evolution of the experimental design and virtual environment has enriched the understanding of using games as experimental tools. The process by which the experimental methodology evolved has shown that, to immersion is key in gathering useful data and that to encourage immersion experimental environments cannot not be cold clinical affairs, but must be resplendent in gaming conventions.
Due to the insights into the nature of immersion that this study has imparted, along with the increased immersion scores in this experiment, I can conclude that this experiment succeeded in the objective of improving the experimental methodology. In terms of the experimental methodology, this this experiment has shown that Gamers will be less immersed than non-Gamers in a game environment designed to be accessible to all skill levels, Gamers are more adept at applying new cultural frame rules in games than non-Gamers, and that the cognitive semiotic processes of Gamers are less phased by in-game pressures than non-Gamers and are better at consistently following reinterpreted rules in game based experiment than non-Gamers. Thus when using games for behavioural

or cognitive experiments, participants who are Gamers and non-Gamers should be identified so that their results can be more insightfully interpreted.

In terms of semiosis, this experiment seems to suggest that, at least in this situation, culturally indurate signs can indeed be reinterpreted and used to convey a new meaning, however people are prone to fall back on the culturally indurate meaning of reinterpreted signs in pressurized situations. Thus it would seem that culturally indurate signs in interfaces could potentially encourage misinterpretation and therefore errors in devices which are used in pressurized environments.

5 Conclusion

What is the interplay between signs and errors in human-computer interaction? This thesis set out to explore the interplay between signs and errors, and develop a novel experimental methodology to test this interplay.

► Signs and Errors

The experiments in Chapter 4 investigated the adoption and potential for re-interpretation of indurate signs and showed that the semiosis of these signs is affected by cognitive pressure. Chapter 3 defined and explored the notion of indurate signs, establishing that some interfaces as a whole are signs, and communicate their use in their entirety, rather than by small pieces of metacommunication. In terms of number-pad interfaces, this study was also able to identify which features of the interface cued particular interpretations and which had little impact on semiosis. As stated in the literature review in Chapter 2, context is key for interpretation, and this was indeed the case in the interpretation of number-pads and the extra buttons which contextualized them.

These findings suggest that the assumptions made by the manufacturers of the Graseby 3400, a device mentioned throughout this thesis, about the interface of their device being similar to that of a calculator were, semiotically speaking, incorrect. This is due to the data showing that the layout of the numbers on a number-pad has little or no effect on the interpretation of the interface, and it is the non-numerical buttons which stimulate semiosis. The findings also provide interface designers with information about what can be included and omitted from an interface to cue certain assumptions about the use of that interface and function of the device to which it is attached.

One of the most important implications for design to come from this research has been the notion of avoiding indurate signs in design. This is because, as we have seen in the experiments of this study, that people revert back to the original interpretation of an indurate sign when under pressure. This is all well and good unless the indurate sign is implemented incorrectly, as in the Graseby 3400. In this case the attempt to copy a conventional design is rather pointless and potentially dangerous as the device does not work like a calculator, and the interface is only tenuously similar to that of a calculator. Therefore if the interface did indeed cue people to interpret it as that of a calculator, this would be bad, as the device does not work like a calculator and this could cause errors. If, as is the case, the device does not cue people to assume it works like a calculator, the attempt by the manufacturers to pass off the standard number-pad as such is pointless and serves only to create potential confusion in the already pressurized environment of medicine.

In short then, the implications for design that this study has produced is that it is generally better for designers to not include any indurate signs within an interface, rather than half heartedly including them for a perceived increase in usability through familiarity.

► Experimental Methodology

One of the aims of this study was to develop a novel methodology to test semiosis, and to this end the thesis explored using computer games as an experimental tool. As mentioned above, the results from the experiments provided insights into the semiosis of indurate signs and thus confirmed that 3D gaming can provide a suitable environment in which to test semiotic theories.

The evolution of the experimental methodology also contributed to the study of games as research tools, finding that immersion is key to gaining useful data from these experiments, and that the use of established gaming metaphors and conventions are a way to achieve heightened immersion. The latter could be considered unsurprising, after all, they are conventions of gaming for a reason. Heightened immersion in the virtual environments made players more focused on the gaming element of the experiment and thus did not seem to *read* the indurate signs much more closely than the other in-game artefacts, as was the case in the pilot experiments.

► Summary

So was the hypothesis of this thesis correct? Can a knowledge of semiotics measurably improve the design on interfaces? I argue this thesis has demonstrated that semiotic theories are at play in human-computer interaction, that the interfaces are interpreted as signs, and that the semiosis is mutable depending on circumstance and context. Therefore a knowledge of the semiotics can do naught but broaden a designer's knowledge about the issues at work in human-computer interaction, imbuing them with an awareness of possible cognitive actions which can result from signs within an interface.

Another objective of this thesis was to use semiotics as more that just a descriptive theory, to use it to gain practical insights into interfaces and provide implications for design. In this study, semiotics guided the evolution of the experimental methodology and the construction of the questionnaire. It was used as an overarching paradigm, a lens through which the whole study was completed, and thus all the contributions stemming from this thesis are part of the empirical flavour of semiotics which was attempted here.

► Further Study

This thesis raised a number of questions for further study in the areas of gaming research and semiotics. In gaming for example, the correlation between high aesthetic appeal and immersion was suggested by some of the experimental results, and will need further study to assess how aesthetics affect immersion in games and game based experiments.

The area of game based experiments has thrown up a number of other potential research questions such as how number entry works from a semiotic perspective, as issue which could be explored using game based experiments with in-game number-pads. However, the most intriguing gaming issue demanding further study, is the cognitive and behavioural differences between people in real and virtual environments.

The differences between human behaviour and cognition in real and virtual environments is a fascinating direction for future study, one which this study has only been able to touch upon and one which is important for evaluating the potential effectiveness of simulations and further game based experiments.

Differences in the type of participant were touched upon within the experimental Chapter of this thesis and more study in this area is required. In the final experiment of Chapter 3 it was found that there was a significant difference between the immersion and error scores of Gamers and non-Gamers, however the results of gamers, that is people who play games occasionally but do not class them selves as a *Gamer*, and non-gamers were not observed. It would be prudent for any further study using computer games as experimental tools to explore the potential differences in immersion and gaming skill between Gamers, gamers and non-gamers (both of which as non-Gamers).

This study built upon the concept of indurate signs which, much like fossilized metaphors or idioms, have become stale and immutable in form and meaning. This concept of indurate signs, though useful, produces many simple but poignant questions, one of which with particular relevance to this thesis being, *do arrows always point*? More indurate sign experiments, perhaps using arrows with different aesthetic properties within the same experimental environment, would be useful to explore both the concept of arrows and indurate signs in general. Arrows in diagrams and mathematical or logical notation, mean things but these are true symbols, their meaning is opaque to layman and their true meaning must be learnt. But even to one who has no idea of their intended meaning may assume that they have as much meaning as any other man-made symbol, in other words arrows always "have the look of meaning"even if they have none [96]. But why is this? Is it simply because arrows look like symbols, and thus must have meaning, and yet they are a funny sort of symbol, always indexical, even to nothingness. Are all arrows symbols that have meaning that must be learnt or do they contain an innate indexical function which stems from our biology? Arrows occur in so many different cultural frames, from road signs to mind maps, and yet they generally are used to mean much the same thing in the vast majority of cultures. With further exploration, this concept is an area which seems to have the potential to reveal much about the semiotic mind of humans.

6 Appendix

6.1 Pilot Experiment Questionnaire

Immersion Questionnaire used in Pilot Experiment [67]
Your Experience of the Game.
Please answer the following questions by circling the relevant number.
In particular, remember that these questions are asking you about how you felt at the end of the game.

To what extent did the game hold your attention?
Not at all 1 2 3 4 5 A lot

To what extent did you feel you were focused on the game?
Not at all 1 2 3 4 5 A lot

How much effort did you put into playing the game?
Very little 1 2 3 4 5 A lot

Did you feel that you were trying you best?
Not at all 1 2 3 4 5 Very Much So

To what extent did you lose track of time?
Not at all 1 2 3 4 5 A lot

To what extent did you feel consciously aware of being in the real world whilst playing?
Not at all 1 2 3 4 5 Very Much So

To what extent did you forget about your everyday concerns?
Not at all 1 2 3 4 5 A lot

To what extent were you aware of yourself in your surroundings?
Not at all 1 2 3 4 5 Very Much So

To what extent did you notice events taking place around you?
Not at all 1 2 3 4 5 A lot

Did you feel the urge at any point to stop playing and see what was happening around you?
Not at all 1 2 3 4 5 Very Much So

To what extent did you feel that you were interacting with the game environment?
Not at all 1 2 3 4 5 Very Much So

To what extent did you feel as though you were separated from your real-world environment?
Not at all 1 2 3 4 5 Very Much So

To what extent did you feel that the game was something you were experiencing, rather than something you were just doing?
Not at all 1 2 3 4 5 Very Much So

To what extent was your sense of being in the game environment stronger than your sense of being in the real world?
Not at all 1 2 3 4 5 Very Much So

At any point did you find yourself become so involved that you were unaware you were even using controls?
Not at all 1 2 3 4 5 Very Much So

To what extent did you feel as though you were moving through the game according to you own will?
Not at all 1 2 3 4 5 Very Much So

To what extent did you find the game challenging?
Not at all 1 2 3 4 5 Very Much So

Were there any times during the game in which you just wanted to give up?
Not at all 1 2 3 4 5 A lot

To what extent did you feel motivated while playing?
Not at all 1 2 3 4 5 A lot

To what extent did you find the game easy?
Not at all 1 2 3 4 5 Very Much So

To what extent did you feel like you were making progress towards the end of the game?
Not at all 1 2 3 4 5 A lot

How well do you think you performed in the game?
Very Poor 1 2 3 4 5 Very Well

To what extent did you feel emotionally attached to the game?
Not at all 1 2 3 4 5 Very Much So

To what extent were you interested in seeing how the games events would progress?
Not at all 1 2 3 4 5 A lot

How much did you want to "win"the game?
Not at all 1 2 3 4 5 Very Much So

Were you in suspense about whether or not you would win or lose the game?
Not at all 1 2 3 4 5 Very Much So

At any point did you find yourself become so involved that you wanted to speak to the game directly?
Not at all 1 2 3 4 5 Very Much So

To what extent did you enjoy the graphics and the imagery?
Not at all 1 2 3 4 5 A lot

How much would you say you enjoyed playing the game?
Not at all 1 2 3 4 5 A lot

When interrupted, were you disappointed that the game was over?
Not at all 1 2 3 4 5 Very Much So

Would you like to play the game again?
Definitely not 1 2 3 4 5 Definitely Yes

6.2 Experimental Data

Participant	Gamer?	Time/Errors	Immersion
1	No	0:12/0	82
2	No	0:14/0	100
3	Yes	0:41/1	89
4	Yes	0:18/1	99
5	Yes	0:28/1	95
6	Yes	0:19/0	84
7	Yes	0:30/1	77
8	Yes	0:36/1	96
9	No	0:21/1	79
10	No	0:24/0	81

Table 1: Experiment 1

Participant	Gamer?	Total Errors	Errors In	Errors Out	Immersion
1	No	3	1	2	124
2	Yes	1	0	1	104
3	No	4	1	3	114
4	No	5	0	5	119
5	No	3	0	3	112
6	Yes	0	0	0	100
7	Yes	1	0	1	104
8	No	5	1	4	124
9	No	4	2	2	113
10	No	7	2	5	96
11	No	5	0	5	118
12	Yes	2	1	1	111
13	Yes	6	2	4	111
14	Yes	4	3	1	111
15	No	15	-	-	90
16	Yes	2	0	2	98

Table 2: Experiment 2

6.3 Pilot Indurate Online Questionnaire

Signs and Buttons

SATURDAY, 3 JULY 2010

Interface Questionnaire

On this page you will find 22 different interfaces, the purpose of the questionnaire if to gauge your first impressions when viewing this type of interface.
Please look at each picture then use the text boxes to state what you think these interfaces are used for.

What device do you think the hardware is used on?

For example, you may think they are used on a calculation device, on digital locks, on the dash-board of a car, etc.

If you have time, we'd also be interested in why you think what you think.

Please enter you first impressions of what you think the interface will be used for **and press Submit on each question separately.**

Some pictures of interfaces contain the text *[DISPLAY]* to confirm the position of any displays linked to the interfaces.

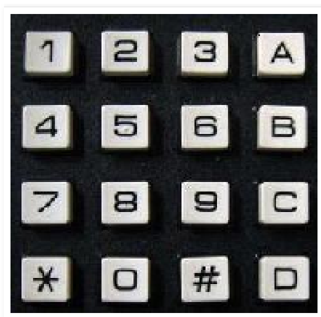
1.

Interface 1

* Required

What is this used for? *

2



Interface 2

* Required

What is this used for? *

3.

Interface 3

* Required

What is this used for? *

Submit

4.

Interface 4

* Required

What is this used for? *

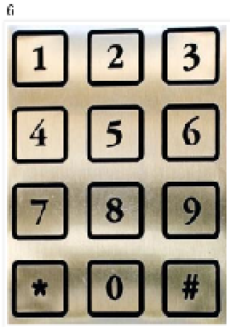
5.

Interface 5

* Required

What is this used for? *

6.



Interface 6

* Required

What is this used for? *

7

Interface 7

* Required

What is this used for? *

8.

Interface 8

* Required

What is this used for? *

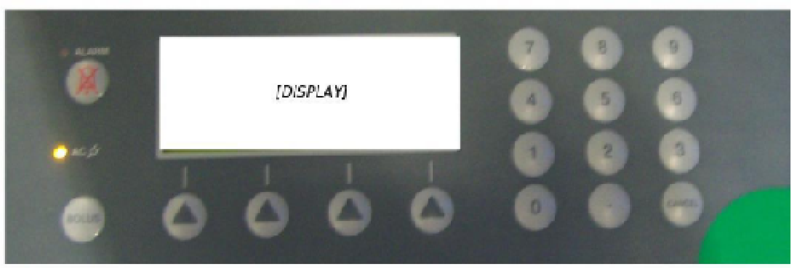
9

Interface 9

* Required

What is this used for? *

10



Interface 10

* Required

What is this used for? *

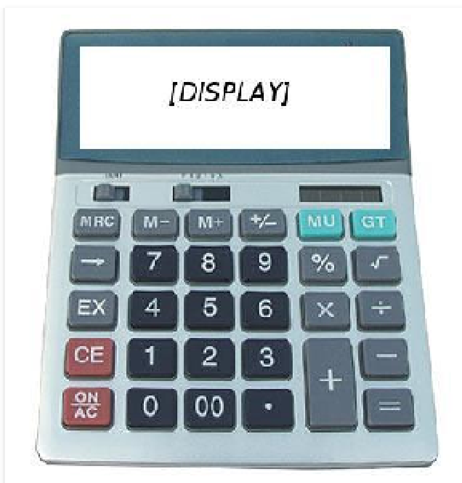
11.

Interface 11

* Required

What is this used for? *

12



Interface **12**

* Required

What is this used for? *

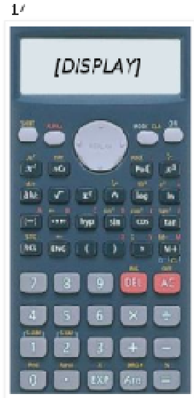
13

Interface 13

* Required

What is this used for? *

14

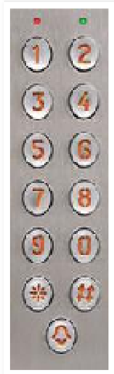


Interface 14

* Required

What is this used for? *

15.



Interface 15

* Required

What is this used for? *

16.

Interface 16

* Required

What is this used for? *

17

Interface 17

* Required

What is this used for? *

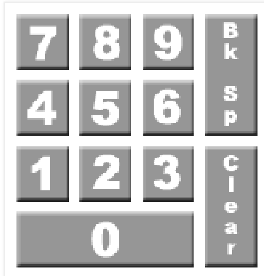
18

Interface 18

* Required

What is this used for? *

19.

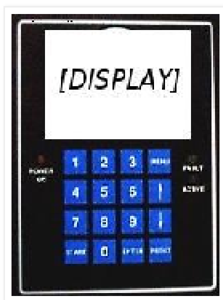


Interface 19

* Required

What is this used for? *

20.



Interface 20

* Required

What is this used for? *

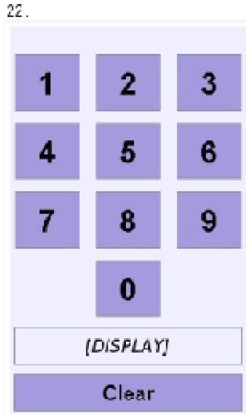
21

Interface 21

* Required

What is this used for? *

22.



Interface 22

* Required

What is this used for? *

6.4 Online Indurate Questionnaire

Number pad

Interface Questionnaire

The purpose of the questionnaire is to gauge your first impressions when viewing this type of interface.

Please look at each picture then use the text boxes beneath each picture to state what you think these interfaces are used for. For example, you may think one interface is used on a telephone, or is part of a car dashboard, etc. There are two types of interface presented: hard ones, that is real physical devices and soft ones, being software representations of physical devices.

On what sort of device do you think the hard interfaces are used? What program might the soft interfaces be used to interact with? Don't think too long about your answers - whatever your first impression is, enter that.

We'd also be interested in why you think what you think, so if you have time, please add anything to indicate why you thought what you did.

Hard Interfaces

Interface 1

1. **Enter Text**

Interface 2

2. **Enter Text**

Interface 3

3. Enter Text

Interface 4

4. Enter Text

Interface 5

5. Enter Text

Interface 6

6. Enter Text

Interface 7

7. Enter Text

Interface 8

8. Enter Text

Interface 9

9. Enter Text

Interface 10

10. Enter Text

Interface 11

11. Enter Text

Soft Interfaces

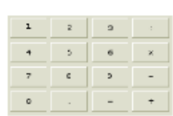
Interface 12

12. Enter Text

Interface 13

13. Enter Text

Interface 14



14. Enter Text

Submit

6.5 Online Indurate Questionnaire Results

Figure 48: Interface 1. Actual use: A digital safe interface

Answer	Number	Percentage
Interface 1		
Phone	64	97
Door Lock	1	2
Unknown	1	2

Table 8

Figure 49: Interface 2. Actual use: A calculator interface

Interface 2		
Answer	Number	Percentage
Calculator	65	98
Alarm	1	2

Table 4

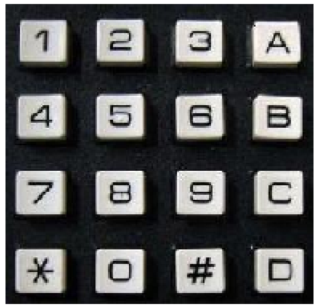


Figure 50: Interface 3. Actual use: A general purpose number entry interface for embedded systems

Interface 3		
Answer	Number	Percentage
Phone	27	41
Door Lock	20	30
Unknown	9	14
Vending Machine	4	6
Calculator	2	3
Other	4	6

Table 10

Figure 51: Interface 4. Actual use: A TV remote

Interface 4		
Answer	Number	Percentage
Part of Keyboard	31	47
Mobile Device	12	18
Separate Number-pad	9	14
Public Terminal	4	6
Unknown	3	5
Calculator	1	2
Other	6	9

Table 5

Figure 52: Interface 5. Actual use: An elevator interface

Interface 5		
Answer	Number	Percentage
Door Lock	42	64
Elevator	10	15
Phone	4	6
Vending Machine	3	5
Calculator	1	2
Game Controller	1	2
Unknown	5	8

Table 11

Figure 53: Interface 6. Actual use: An infusion pump interface

Interface 6		
Answer	Number	Percentage
Cash Machine	23	34
Unknown	15	23
Door Lock	10	15
Phone	7	11
Calculator	3	5
Other	8	12

Table 6

Figure 54: Interface 7. Actual use: A household alarm interface

Interface 7		
Answer	Number	Percentage
Unknown	23	35
Home Control	10	15
Phone	7	11
Door Lock	7	11
Personal Organizer	4	6
Other	15	23

Table 12

Figure 55: Interface 8. Actual use: A calculator interface

Interface 8		
Answer	Number	Percentage
Calculator	60	91
Cash Register	3	5
Unknown	3	5

Table 15

Figure 56: Interface 9. Actual use: A cash machine interface

Interface 9		
Answer	Number	Percentage
Cash Machine	59	89
Phone	4	6
Unknown	2	3
Petrol Pump	1	2

Table 13

Figure 57: Interface 10. Actual use: A general purpose number entry interface for embedded systems

Interface 10		
Answer	Number	Percentage
Phone	42	64
Unknown	12	18
Door Lock	9	14
Calculator	2	3
Radio	1	2

Table 17

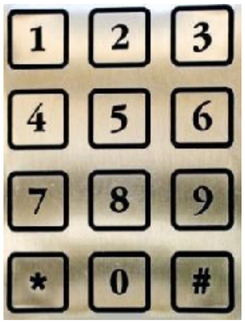


Figure 58: Interface 11. Actual use: A telephone interface

Interface 11		
Answer	Number	Percentage
Phone	36	55
Unknown	18	27
Door Lock	8	12
Calculator	2	3
Elevator	2	3

Table 9

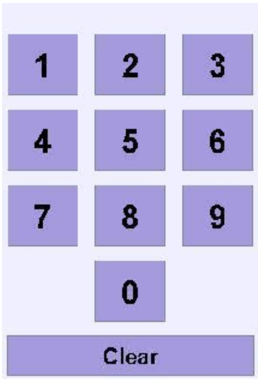


Figure 59: Interface 12. Actual use: An online hearing test

Interface 12		
Answer	Number	Percentage
Unknown	22	33
Security Software	11	17
Phone	9	14
Calculator	6	9
Cash Machine	6	9
Other	12	18

Table 14

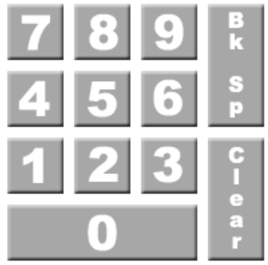


Figure 60: Interface 13. Actual use: An online race horse search interface based on the horse's number

Interface 13		
Answer	Number	Percentage
Unknown	31	47
Security Software	7	11
Phone	6	9
Calculator	5	8
Data Entry Device	5	8
Other	12	18

Table 7

Figure 61: Interface 14. Actual use: A software calculator interface

Interface 14		
Answer	Number	Percentage
Calculator	60	91
Unknown	6	9

Table 16

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