Using Cognitive Models to Transfer the Strengths of Computer Games into Human Computer Interfaces

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This paper extends techniques from affective psychology to show how cognitive models can be used to represent and reason about interaction with computer games. It is argued that this modeling activity provides insights into the motivational appeal that often distinguishes computer games from other forms of human computer interaction. The long-term aim behind this research is to use our improved understanding of interaction with computer games to inform the subsequent development of more general classes of interactive systems. Barnard's Interacting Cognitive Subsystems (ICS) is used throughout this paper. This decision is justified by the fact that ICS has already been applied to analyze the negative emotions surrounding clinical depression. This previous work provides a useful starting point for our investigation of the more positive emotions evoked during interaction with computer games. A further justification is that ICS has also been successfully used to represent and reason about the design of human computer interfaces.

Keywords: computer games; user modeling; fun; human computer interaction.

1. Introduction

The last decade has seen a considerable amount of research into the psychology of play and the motivational appeal of computer games [1, 2]. For instance, Neal identifies factors that contribute to successful computer games: a sense of control; the opportunity for strategy; the discovery of information [3]. This research is significant for interface designers because motivation and play are becoming increasingly important aspects of human computer interaction. For example, desktopVR interfaces help to motivate users through exploration and discovery [4]. Microsoft Channel technology has created a range of Internet services that are intended both to entertain and to inform. Unfortunately, the work of Neal and others into the successful features of computer games has had relatively little impact upon interface development [5]. This paper, therefore, uses cognitive models as a means of applying recent research into motivation and play to support the development of human computer interfaces. This is appropriate because cognitive models have been used to explain empirical studies of emotion [6]. They have also been used to support the design of human computer interfaces [7].

2. Computer Games and Interface Design

This section identifies a number of different techniques that designers have exploited to transfer the strengths of computer games into other forms of interaction. It is argued that there are limits to the benefits that can be gained from simply copying surface level features of arcade or home systems.

2.1 Copying Surface Level Features

A number of researchers have argued that interface designers can apply successful features of computer games to support other forms of human computer interaction [8]. For example, Figure 1 shows an interface that was designed to provide users with access to a range of web pages about exhibits in the Hunterian Museum, Glasgow. The map on the left shows the user standing in front of the exhibit that is pictured in the photograph on the right. Both views are updated after each movement. This combination of a map and a direct image is based on successful features of id Software's Doom interface.

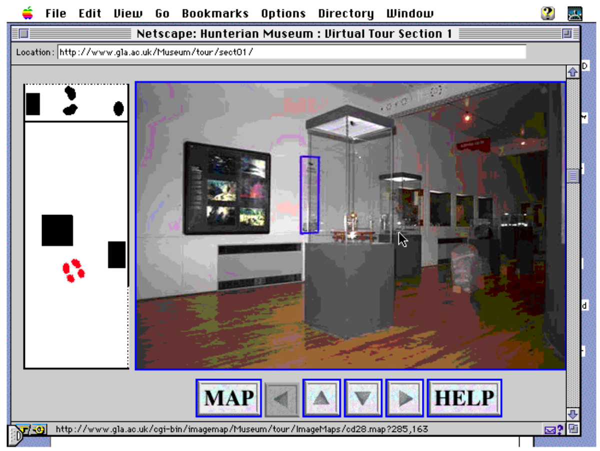

Figure 1: Learning From Successful Games

A number of problems prevent interface designers from exploiting surface level features of computer games. For example, numerical scores often provide users with direct information about their progress with a game. It is difficult to see how this approach might be extended to text editors or spreadsheets [2].

2.2 Heuristics from the Design of Games

High level heuristics provide a more generic means of transferring the strengths of computer games into other domains of human computer interaction [9]. For instance, Neal's guidelines encourage designers to support "a sense of control" or provide an "opportunity for discovery" rather than exploit surface level features, such as numerical scores for a user's performance [3]. This approach is illustrated by the two interfaces to a CAL system that are illustrated in Figure 2. The system on the left uses a slide show metaphor to provide users with information in a pre-determined order. This has been shown to limit the sense of discovery, often associated with computer games, because the system orders the users path through the information. The interface on the left, in contrast, is intended to increase the users' sense of control and discovery by enabling them to choose their path through multiple, redundant sources of information.

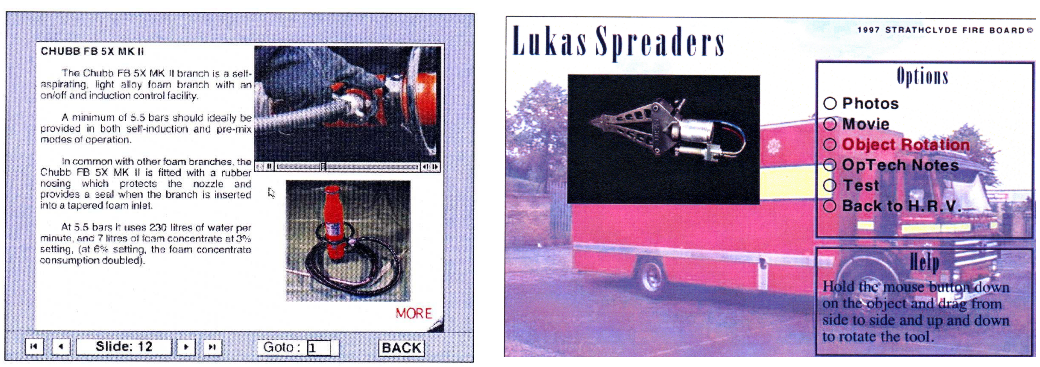

Figure 2: Applying Neal's Heuristics from Computer Games

A number of problems limit the utility of heuristics as a means of transferring successful features of computer games into other forms of user interface. They can be difficult to apply. Requiring that interfaces support a "sense of control" is of little benefit if designers cannot identify the means of satisfying such a requirement. Similarly, there are often situations in which the benefits of applying an heuristic must be balanced against other interface requirements. For example, the interface on the left reduces user control by imposing a sequence upon the information presented. On the one hand, this breaks Neal's heuristic from game design. On the other had, it provides the ordered presentation of material that can determine successful concept acquisition in many areas of Computer Aided Learning [10].

Further problems complicate the use of heuristics to guide interface development. High-level guidelines can obscure the underlying psychological factors that influence the success of a computer game [1]. Stating that an interface should provide a "sense of control" tells us little about the cognitive and perceptual factors that encourage such feelings about an interactive system.

3. The Psychology of Play

Psychological theories of affection help designers to understand the contribution that certain attributes, such as a "sense of control", make to the success of a game. For instance, the embodiment of the user as a character in a game has direct links to laboratory studies of mood congruence [6]. By analogy, a positive feeling of control is determined not only by the users' task and expertise but also by their own view of the character that they are playing. This analysis supports the informal observations that motivated Brenda Laurel and Purple Moon's development of computer games for girls between the ages of 8 and 12. Male adolescents dominate the games market because they empathize with the characters in those games. This empathy, in turn, increases their sense of control. Such results have strong implications for commercial interface development. Microsoft, IBM and British Telecom are all developing desktop interfaces that "embody" their user in a virtual office environment [4]. The empirical work on reflection and mood congruence suggests that these embodiments must be carefully chosen if they are not to have an adverse effect on many users.

A number of problems prevent designers from applying affective psychology to directly inform interface development. In particular, there are several distinct approaches to the role of affection in play. The behaviorist perspective cannot easily be reconciled with more direct neuro-physiological explanations. Such distinctions remain the subject of considerable debate [11]. In anticipation of the products of this research, this paper adopts what has become known as the cognitive-appraisal theory of emotion. In simple terms, a user's subjective state is the result of some internally evoking stimulus, a set of accompanying physiological changes and a cognitive appraisal or interpretation of the situation as beneficial or harmful to the individual. A key idea in this approach is that a single arousal state can yield different emotions depending on how the individual interprets this state. This is useful from an HCI perspective because it has obvious parallels with Norman's gulfs of evaluation and execution. Unfortunately, grounding observations about successful games in psychological theories of affection is insufficient as a constructive tool for interface development. There must be some means of applying the products of affective psychology to support design, implementation and evaluation.

4 From Affective Psychology to Cognitive Models

Cognitive modeling techniques provide means of propagating the successful features of computer games, as indicated by recent work in affective psychology [1], into other forms of human computer interaction. Teasdale and Barnard have used cognitive models to analyze the symptoms and causes of depression [6]. This work is relevant because the same Interacting Cognitive Subsystems (ICS) techniques can also be used to analyze the more positive emotions that contribute towards successful games. This approach is also justified because ICS has been widely advocated as a constructive tool for interface development [7, 12].

4.1 Interacting Cognitive Subsystems (ICS)

Cognition is represented in ICS as the flow of information between a number of different subsystems. Each of the subsystems has associated with it a unique mental code in which it represents the information it receives and processes. Each subsystem transforms its data output into the corresponding mental code of the subsequently receiving subsystems. The nine subsystems can be grouped into four categories.

Sensory subsystems:
visual: hue, contour etc. from the eyes
acoustic: pitch, rhythm etc. from the ears
body-state: proprioceptive feedback

Effector subsystems:
articulatory: subvocal rehearsal & speech
limb: motion of limbs, eyes etc.

Structural subsystems:
object: mental imagery, shapes etc.
morphonolexical: words, lexical forms

Meaning subsystems:
propositional: semantic relationships

implicational: holistic meaning

One of the key motivations for using ICS is that it considers both the physiological and cognitive state of the user. This is important because computer games, typically, impose both physiological and cognitive demands on their users. They, typically, require good hand-eye coordination as well as strategic thinking in order to obtain high scores. ICS, therefore, provides an appropriate vocabulary with which to represent and reason about such dynamic and highly interactive systems. These same characteristics also make the ICS model well suited to transfer the strengths of computer games into many of the emerging technologies of human computer interaction. Desktop virtual reality systems, such as those supported by VRML and QuicktimeVR, are imposing new demands upon a user's ability to navigate through three-dimensional space. These demands include a high degree of hand-eye coordination. Similarly, distributed information systems often require users to think tactically if they are to avoid the overheads of retrieval delays over slow networks.

A number of alternative cognitive modeling techniques can be used to represent and reason about interaction with computer games. For instance, Bonnie John and Alonso Vera used GOMS to analyze interaction with a number of video games [13]. However, this approach neglects the physiological factors that were mentioned as a particular strength of ICS. GOMS also takes a functional view of interaction. It ignores the role of affect and emotion which are important factors during interaction with computer games. Finally, the focus upon expert performance in GOMS also prevents an effective analysis of why many users do not like computer games. In contrast, the previous work on affect in ICS provides good clues about the negative emotions that can arise when users become disillusioned with role playing applications, shoot-em up systems and simulated environments.

4.2 Using ICS to Model Depression

ICS provides a link between cognitive modeling and recent research into affection. It, therefore, provides useful analytical tools for understanding the motivational benefits that computer games provide for other forms of human computer interaction. Figure 3 shows how Teasdale and Barnard have used ICS to model the negative mode of thought that leads to the internal self-regeneration of depressive thoughts. The links between the user's body state and their implicational subsystem suggest that inactivity and a beaten posture may lead to thoughts about previous failures which, in turn, further affect the individual's body state. Expectations of failure increase the likelihood of viewing oneself as a failure and this, in turn, increases an expectation of failure.

Teasdale and Barnard's work on depression can be used to explain the unsuccessful attributes of computer games. In particular, Figure 2 corresponds to a breakdown in the sense of flow identified by Csikszentmihalyi as a critical aspect of game playing activity [14]. Flow theory provides an account of the state of happiness and satisfaction that people experience when they are "carried" by an activity that is automatic and spontaneous. This sense of flow is a frequent, everyday occurrence. It does, however, require deliberate effort and attention. It shares many common characteristics with Neal's analysis of computer games [1]. It is characterized by optimal levels of challenge, feelings of complete control, attention focused so strongly on the activity that feelings of self-consciousness and awareness of time disappear. As levels of skill increase, users look to maintain this sense of flow by increasing the level of difficulty associated with their task. If this level of difficulty and absorbtion cannot be increased then users may quickly become bored and disillusioned with the game. Figure 2 describes a further way in which this sense of flow can be broken. In particular, computer games can have negative effect upon the body-state and arousal of a user who fails to control their interaction. This, in turn, can lead to the internal self-regeneration of negative thoughts through the links that Teasdale and Barnard identify between the user's body state and the implicational cognitive subsystem. Users who perform badly with a computer game will expect to perform badly with other games and this in turn can make it more likely that they will, indeed, perform badly during further interaction.

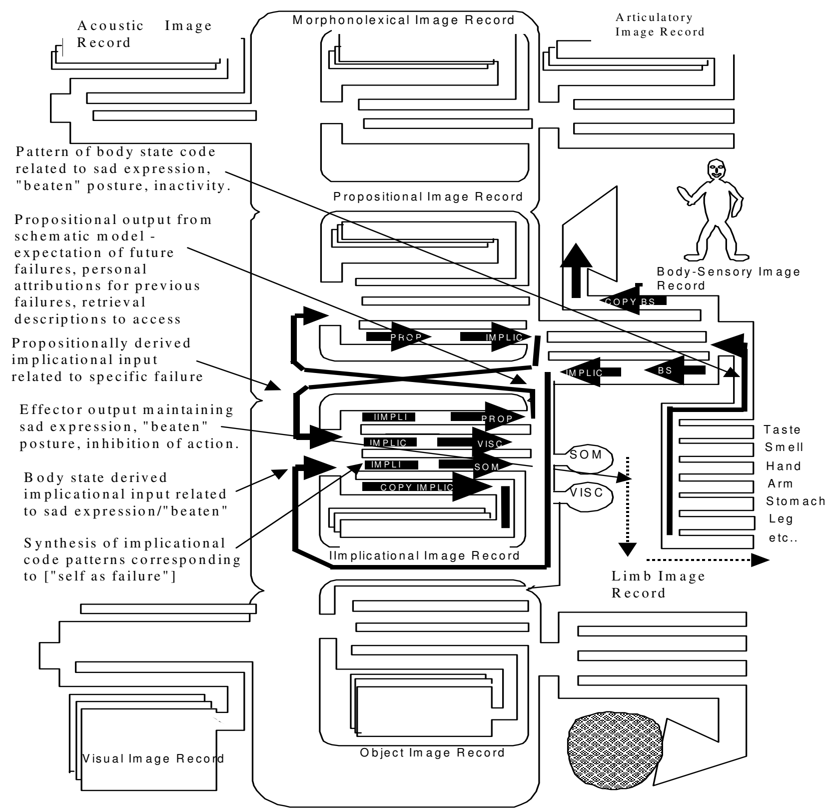

Figure 3: Modelling depression in ICS (Teasdale and Barnard [6])

The previous paragraphs have shown how work in affective psychology can be used to represent and reason about the negative aspects of interaction with computer games. Work on the self-regenerative nature of depression can be used by analogy to model the cycle of interaction between low expectations and poor performance with computer games. The following paragraphs build on this analysis and move away from Teasdale and Barnard's work to analyse the more positive emotions that arise when people play with these applications.

5. Using ICS to Model Successful Interaction with Computer Games

This section demonstrates that ICS can be used to model three different cognitive aspects of successful interaction with computer games: maintenance of mood by external sensory input; mood maintenance by internal body state and the interaction of anticipation, imagination and tactical thought. This is not intended to be an exhaustive taxonomy. However, these examples do illustrate the potential power of ICS in this area. For instance, maintenance of mood by external sensory input describes the ways in which games designers exploit audio and visual feedback to maintain a sense of excitement during interaction. In contrast, mood maintenance by internal body state describes the ways in which the users' previous experiences with computer games can generate a sense of enjoyment during interaction with new applications. Finally, the interaction between anticipation, imagination and tactical thought describes the way in which skilled games players exhibit more sophisticated tactics by anticipating or "imagining" the potential consequences of their actions, and those of the game in response to their actions.

5.1 Maintenance of Mood by External Sensory Input

In the ICS model, emotions and moods are principally explained in terms of the implicational subsystem. Users form schematic representations that represent general characteristics of situations that elicit particular emotions. These situations are formed from the visual and acoustic information available in the environment, for example, when a user plays a game. They also include internal sensory input about the users' body-state; for example an alert posture may be associated with feelings of excitement. Over time, the occurrence of similar sensory inputs in similar emotion provoking situations will lead to a reinforcement of these schematic representations. Within the implicational subsystem, propositional codes will be developed to reflect the underlying interpretation or "meaning" of situations that elicit a particular emotional response. This propositional encoding enables users to find the same emotive "theme" behind situations that share very few sensory features. In other words, the same emotional response may be evoked in different contexts not because there are any sensory similarities between those contexts but because they share a similar implicational or thematic encoding.

ICS model can explain why games designers are so successful at affecting users' emotional state. In simplistic terms, designers exploit visual and auditory feedback to create a direct relationship between sensory input and the implicational representations that determine the meaning of those signals. Rewards are clearly indicated and penalties are presented in a manner that is difficult to avoid. Progress is indicated by numerical scores but also through the pitch and rhythm of music and even the color of the background display. These presentation techniques have a direct effect on the emotional state of the player, increasing excitement; communicating feelings of success or failure etc, only if the users have an appropriate propositional encoding. As the previous paragraphs suggested, the interpretation of external stimuli depends upon the repeated association of those stimuli with particular moods. However, similar moods can be associated with different stimuli. This explains why players may obtain the same emotional reaction in very different situations. It also explains why some people completely fail to achieve an emotional reaction to the same set of stimuli that enthrall other players.

The previous paragraph also help to explain particular feelings of success and failure during interaction with computer games. For instance, an experienced player would, over time, develop a schematic representation of the various feedback mechanisms that indicate the successful completion of a stage or level in a game. These changes in the display help to trigger the extraction of the implicational encoding whenever the user moves on to the next level. This implicational schema can lead to an associated proposition reflecting "arrival at goal". Processing of this implicational pattern will be associated with "being successful". Such feelings have profound effects upon the user's subsequent interaction through the continuation of moods.

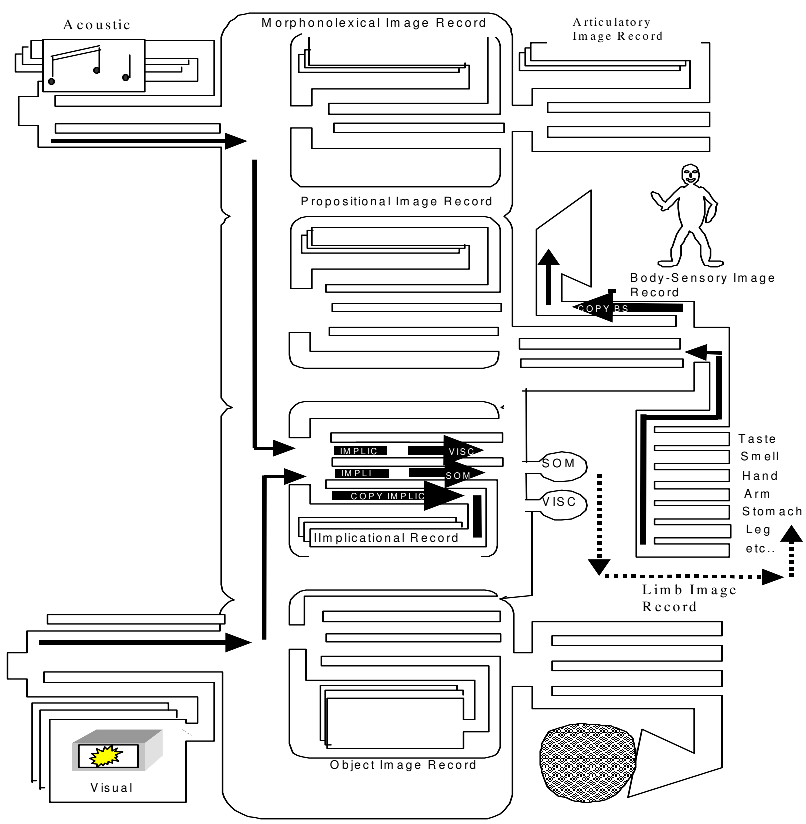

Figure 4: Maintenance of mood by visual and auditory input.

Moods are important for any emotional analysis of games because they persist longer than the emotional reaction to specific events. A sense of success must continue beyond the individual setbacks and failures that provide the challenge and motivation for many games players. If this sense of success does not continue beyond the periodic setbacks then users may simply stop playing the game and may stop buying subsequent titles in the same series. This style of analysis creates problems for the ICS model developed up to this point. The implicational subsystem processes the propositional meaning of particular schemas. These schemas are characterized by particular patterns of external and internal sensation. This does not account for the persistence of moods across particular patterns of sensory input. In order for a mood to continue, therefore, the schematic models related to that affect have to be "regenerated" over time. In effect, there has to be some form of feed-forward between previous emotional states and the future interpretation of internal and external sensations.

Figure 4 illustrates one way in which moods persist over time. Visual and auditory inputs can be sustained to continue the stimuli associated with particular emotions. For example, music can be used to indicate the level that a user has currently reached. If this theme continues playing during interaction then the user is presented with a continuing reminder of their achievement in having reached a particular point. Location and setting are used in a similar manner within most adventure games. Reaching a higher level is continually indicated by the environment, city, jungle or sea, that the user interacts with. Conversely, if the player is returned to some lower level then the external will change. The feeling of success may diminish as the player's mood changes.

5.2 Maintenance of Mood by Internal Body State

In ICS, the body-state encodes types of stimulation such as cutaneous pressure, temperature, muscle tension. It also encodes the location and intensity of these stimulants. This subsystem can, therefore, be used to represent and reason about bodily sensations of pain, pleasure, positions of parts of the body, as well as tastes and smells. Teasdale and Barnard note that this "proprioceptive sensory input is not as dependent on continuing environmental sensory input [6]. In addition to any external taste, smell or pain stimuli, implicational elements derived from Body-state sources within the person can contribute to the internal regeneration of mood states". This regeneration is sketched in Figure 5.

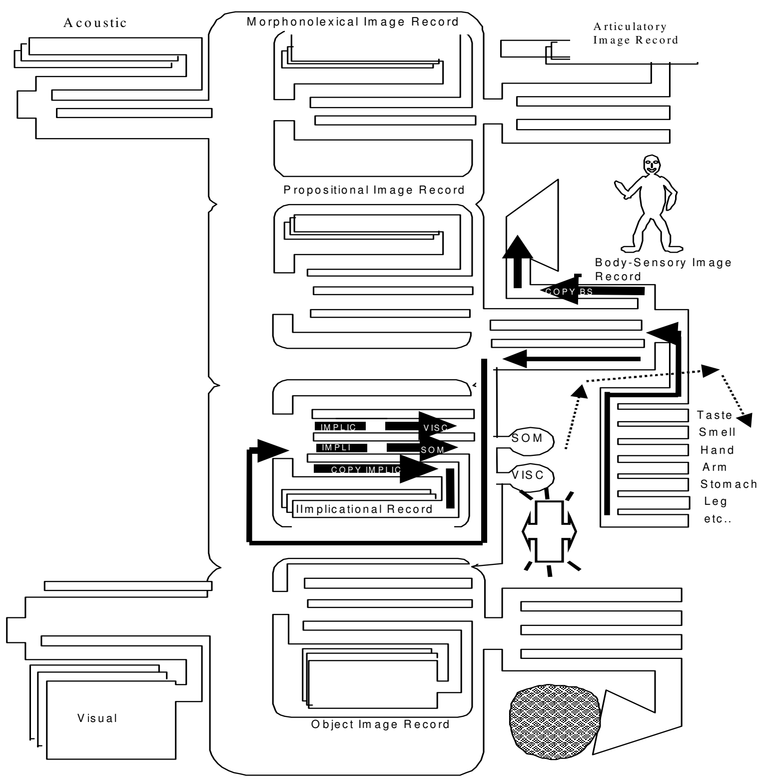

Figure 5: Using ICS to Model Mood Maintenance through a Body-State Feedback Loop

The users' body state can affect the implicational subsystem and its interpretation of external and internal stimuli. The interpretive processes within the propositional subsystem, mentioned above, will in tun affect the body-state of the user. This feedback loop depends upon repeated and sustained exposure to similar affect-related schemas. In other words, the transformation process that links the body-state to the implicational subsystem must learn to generate codes that affect the future interpretation of external and internal stimuli. In particular, for moods to be sustained, this transformation process must "guide" the implicational subsystem towards interpretations that produce the same emotional responses that originally led to the proprioceptive feedback. This can be illustrated by an example from game playing. If a user were faced with multiple hazards on their display and the game emitted rapid rhythmic sounds then this would result in an implicational schema that relates to excitement. The propositional interpretation of these sensations would be one of approaching danger or threat. All of this would result in a range of proprioceptive effects including increased heart rate, a possible rise in temperature, tightening of the facial muscles and changes in the user's posture. These proprioceptive changes, in turn, make it more likely that any further changes to the display will sustain the users' feeling of excitement as their body state makes it more likely that subsequent changes to a display will be regarded as a continued threat. A common observation amongst games players is that tension is sustained for some period even after they have avoided an immediate threat or achieved a short-term goal.

Figure 5 also illustrates the key role that the VISC and SOM "codes" have in the ICS account of emotion in game playing. SOM represents the somatic output of the implicational subsystem. It captures the motor-expressive elements of emotional reaction including both facial orientation and body posture. Given an appropriate pattern for the Implicational code, ICS describes a transformation process that will produce a coordinated pattern of responses for the somatic musculature. . VISC represents the visceral output of the implication subsystem. This represents the autonomic and physiological components of an emotional response. Given an appropriate input pattern from the Implicational code, this process produces instructions for a coordinated pattern of autonomic response. Brevity prevents a detailed analysis of both of these aspects of games playing. It is important to note, however, that successful interaction with many computer games depends not only on the well considered application of strategic and tactical planning but also on the visceral reactions to perceived threats and opportunities. Similarly, initial field-studies of computer games players have shown a much higher frequency of extreme somatic effects than can be witnessed in more conventional forms of game playing. In team sports, such as football or hockey, these effects are typically concentrated around relatively infrequent attempts on goal. In games, such as chess or bridge, users may even attempt to mask any changes in facial muscles or posture during critical sections of play. If our analysis is correct then the high frequency of somatic changes in computer games both reflects the emotional impact of many of these applications and also helps to sustain those effects during more prolonged interaction.

5.3 The Role of Anticipation, Imagination and Tactical Thought

The ICS model is built around two basic types of operation. The first of these transforms the mental encoding of information. Previous paragraphs have already provided several examples of this form of operation. Figure 4 shows how external and internal sensory information is transformed into schematic representations within the implicational subsystem. These schematic representations may be transformed within the propositional subsystem to determine the meaning or interpretation of such schematic representations. In this way, a user's physical experience of interacting with a game may be "transformed" into a propositional representation that encodes danger or threat. This feeling of threat, in turn, may be transformed or associated with schemas that encode excitement at an implicational level.

The COPY operation is the second basic process in ICS. This replicates the encoding within a subsystem and stores it for future recall within that system. There is one of these specialized stores for each of the nine subsystems within ICS. The COPY operation is fundamental because it provides an episodic record of recent patterns encountered within a subsystem. It also supports specific databases of patterns that recur within each subsystem. For example, the COPY operation provides a means of storing the implicational schemas that are associated with recurring patterns of sensory input. This is the critical stage in the mechanism by which users "learn" to associate particular display characteristics with a sense of progress or achievement, see Section 5.1. The COPY processes, therefore, form the basis of subjective experience. They record the mental codes that were derived from previous experiences. These records can, in turn, be retrieved to influence and "inform" subsequent transformations within the various subsystems.

The COPY operation provides a means of buffering the input that is provided to the transformation process within a particular subsystem. The impact of this buffering depends upon the particular subsystem in question. For example, Figure 6 uses a black triangle to denote the use of the buffered transformations within the Object subsystem. The Object subsystem encodes abstract structural descriptions of entities and relationships in visual space. The introduction of this subsystem has important consequences for the propositional-implicational feedback loops that were discussed in previous sections. Its inclusion enables the configuration to draw upon specialized information processing skills that the Object subsystem has acquired over successive interactions.

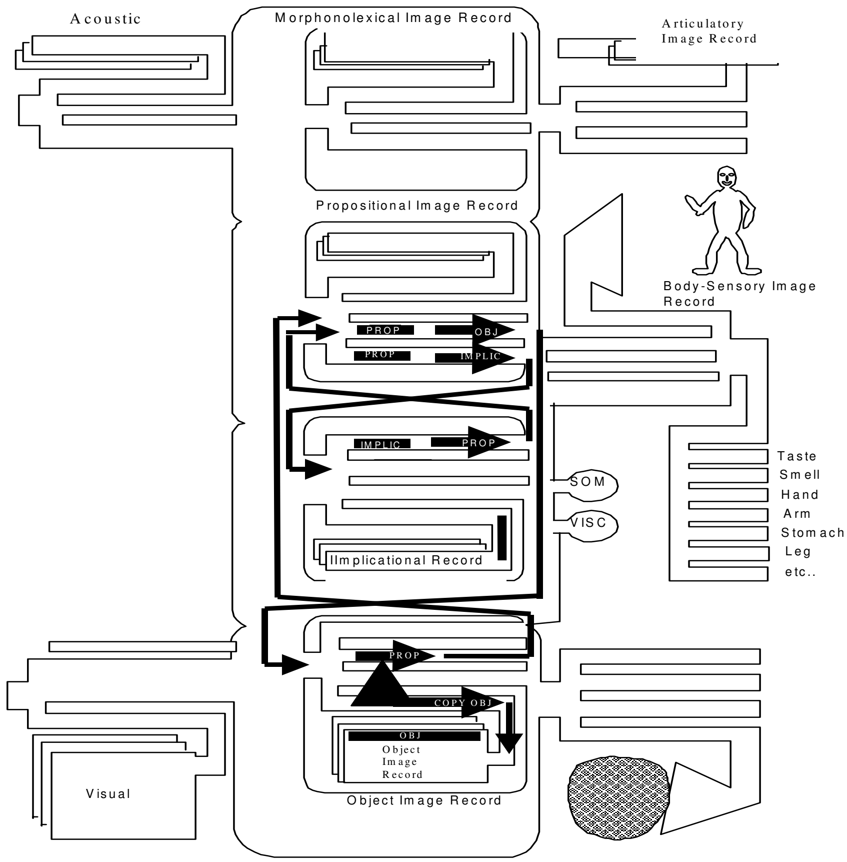

Figure 6: Heightened Awareness of Visual-Object Based Imagery

The COPY operation in the OBJ-PROP transformation of Figure 6 represents particular skills that the user may have developed in the extraction of meaning from complex patterns of spatial information. In many game-playing situations, these skills provide more effective means of transforming sensory input than the information processing of the implicational and propositional subsystems, described in previous sections. For instance, if an expert user were interacting with a game of strategy, such as SimCity, then they might anticipate the consequences of their intervention by transforming the relevant propositional information into patterns of the Object code. These encodings together with the image of the existing situation can be used as input to a propositional transformation that will yield the meaning of these potential future states in the context of the existing situation. In other words, the object subsystem helps to explain why expert users are better at "envisioning" the consequences of their interaction than novice games players.

6 Using ICS to Support Design

ICS not only provides means of modeling interaction with computer games, it also provides constructive tools for interface design. For example, a cognitive model of interaction with a computer game can be compared with a similar model for a proposed interface to determine whether the interface preserves the successful features of the game. The previous analysis in the paper has identified a number of these successful feature.

1. The link between internal and external sources of sensory information and the implicational subsystem will lead to associations being formed between sensory encodings and a particular emotion. Previous experience with computer interfaces, including games, will already have established some of these associations. It, therefore, follows that designers can use interface elements not only to convey information but also to convey mood and emotion (see 2);

2. Games exploit visual and acoustic cues to provide direct indications about the user's progress over time. These progress indicators rely upon users have an appropriate implicational and propositional encoding. Over time, these subsystems may COPY schematic representations of these indicators that may, in turn, become associated with emotions of success or failure. Therefore, the introduction of these indicators into other aspects of a game may be sufficient to trigger the emotional response that has been learnt during previous interaction. The implications for interface development are clear. Feelings of success or failure may be triggered by the presentation of interface features that have become associated with previous successes or failures in other contexts of interaction;
3. Given that the emotional triggers, mentioned in 2, depend upon an appropriate encoding within the implicational and propositional subsystems, these techniques will not produce the same emotional response in all users. In particular, novice users may not have formed the relevant schemas within the implicational subsystem. This has implications for more general aspects of interface design. In particular, some common schemas are acquired from an early age. Fast moving visual cues can communicate a sense of threat. Similarly, certain tones and melodies can be used to evoke more relaxed responses;
4. It is important to emphasize that the COPY operation determines subjective experience. As this operation is available within each of the subsystems, the triggering of an emotional response is more complex than the recollection of information from long term memory. Simply introducing visual and acoustic cues can neglect the other sensory information, such as posture, smell and taste that also affect an individual's response to a particular application. Such insights have strong links with situated approaches to interface design. The emotional response to interaction is not simply a property of particular interface features. It is the product of complex internal sensations that are affected by a myriad of external, contextual factors including heating, lighting and noise levels.
5. Proprioceptive sensory input is determined both by external sensations but also by internal implicational elements. This finding has important consequences for the design of desktopVR interfaces that share many surface features with three dimensional games. However, the initial enthusiasm for such presentation techniques is hardly ever sustained as it is in games. VRML interfaces to information retrieval systems fail to provoke the same emotional response as Doom or Riven. One explanation might be that these more general interfaces lack the feedback loops, for instance between the body state and implicational subsystems, that have been identified as a critical means of mood regeneration in affective psychology.

The elements in this list resemble the heuristics that were cited in Section 2. These were criticized as being too vague. They can also be difficult to apply to constructive interface design. For instance, it can be difficult to establish whether or not a particular interface actually does support "the users' sense of control" as Neale advocates. However, unlike these heuristics, ICS provides a clear means of validating the list given above. In particular, the nine subsystems provide a common vocabulary that can be used to precisely describe the intended effects of particular interface feature.

7. Conclusions and Further Work

This paper has applied techniques from affective psychology to show how cognitive models can be used to represent and reason about interaction with computer games. This modeling provides insights into the emotional appeal that often distinguishes computer games from other forms of human computer interaction. The long-term aim behind this research is to use our improved understanding of interaction with computer games to inform the subsequent development of more general classes of interactive systems.

Barnard's Interacting Cognitive Subsystems (ICS) has used to support the argument in this paper. ICS is an appropriate choice because it has already been applied to analyze the negative emotions surrounding clinical depression. This previous work provides a useful starting point for our investigation of the more positive emotions evoked during interaction with computer games. A further justification is that ICS has also been successfully used to represent and reason about the design of human computer interfaces.

It is important to emphasize, however, that there are some drawbacks with ICS. It is well suited to represent and reason about an individual's interaction with computer games. However, ICS provides little support for analyzing the group interaction that is a growing feature of many team-based computer games. Of course, such distributed interaction could be analyzed in terms of a number of ICS models; each representing a single user's perspective. It is hypothesized, however, that approach would quickly become intractable and may even hide certain aspects of group cognition. This remains a topic for future research.

ICS is a subtle and expressive modeling tool. Unfortunately, it can be too "low level" for many design activities [15]. Similarly, many of the examples in this paper have been grounded by reference to previous laboratory studies into the cognitive psychology of games. These studies, typically, provide insights into the more "holistic" cognitive features of game playing. They provide few clues about the effects of interaction within individual subsystems. On the other hand, it is difficult to construct a coherent account of these disparate studies unless one pitches the level of analysis in terms of the more detailed subsystems within ICS. *Unless we have a detailed vocabulary with which to express and debate the cognitive features of interaction with computer games then we stand little chance of understanding why these artifacts have such appeal.*

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