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Designing Information Feedback within Hybrid Physical/Digital Interactions

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Abstract: Whilst digital and physical interactions were once treated as separate design challenges, there is a growing need for them to be considered together to allow the creation of hybrid digital/physical experiences. For example, digital games can now include physical objects (with digital properties) or digital objects (with physical properties), both of which may be used to provide input, output, or in-game information in various combinations. In this paper we consider how users perceive and understand interactions that include physical/digital objects through the design of a novel game which allows us to consider: i) the character of the space/spaces in which we interact; ii) how users perceive their operation; and iii) how we can design such objects to extend the bandwidth of information we provide to the user/player. The prototype is used as the focus of a participatory design workshop in which players experimented with, and discussed physical ways of representing the virtual in-game information. The results have been used to provide a framing for designers approaching information feedback in this domain, and highlight the requirement for further design research.

Keywords: Interaction, Feedback, Information Bandwidth, Prototyping

1. Introduction

Until relatively recently, most people would consider a video game as being confined to the virtual area represented on the screen, as this is predominantly the point of focus for players of the game. However, technologies such as the Microsoft Kinect, Nintendo Wiimote, and PlayStation Move have effectively made the space in front of the screen a significant part of the overall game experience particularly for co-located multiplayer games (Juul 2012). Whilst co-located players have previously used this space during play it has been principally been within the context of 'Trash Talking' (Voida, Carpendale, and Greenberg 2010) between players, in a similar vein to that seen in on-line games (Wright, Boria, and Breidenbach 2002), and players' focus is still primarily on the screen. However, as the Kinect, Wiimote, and Move are all designed to encourage greater physicality in the way the player interacts with the game this physicality turns the interaction into a performative act as was initially seen in the arcade game Dance Dance Revolution (Behrenshausen 2007).

In recent years we have seen the emergence of physical game objects such as Activision Skylanders, Disney Infinity, and, more recently, the Nintendo Amiibo which places the physical game objects at the centre of the activity by using them to control the characters and activities within a digital game running on a console (Coulton 2012) or tablet.

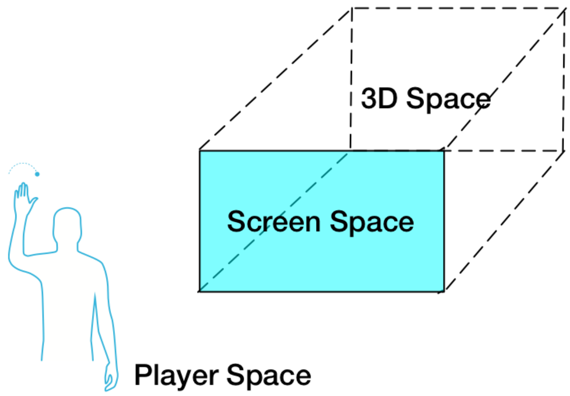

Figure 1. Game spaces as characterised by Jesper Juul in Casual Revolution.

One of the unique aspects of the Skylanders game objects is that a character type, name and abilities are stored on the physical game piece along with the players accrued experience of playing the game rather than on the console (Coulton 2012). While Skylanders, Disney Infinity, and Amiibo are arguably the most notable examples of game objects, there are also a number of 'app toys' appearing such as LEGO's Life of George, Disney's App Mates and the YetYet from Totoya Creatures. This focus on the object produces a number of very interesting effects such as: blurring the boundary between toys and games; expanding existing modes of game play to the physical world; providing the opportunity for physical play outside the game (Coulton, Burnett, Gradinar, Gullick, and Murphy 2014). Thus while these objects have a control element, they have value beyond being simply a game controller. Although some of these physical game objects provide some feedback to the player within the physical space, it is very limited, which leads us on to our main research question: 'How do we best feedback information to the player in both the physical and virtual spaces of the game?'

In order to answer this question we must first consider the space in which the interaction takes place, which is the subject of the following section.

2. Game Spaces

In considering the role of space when playing games, it was Jesper Juul in his book 'The Casual Revolution' (Juul 2012) that provided arguably the most useful framing when he divided game space into: player space; screen space; and 3D space as shown in Figure 1. Juul's aim with this framing was to highlight that in many casual games, such as those using Wii Sports, the player space has a much more significant role than in many of the more traditional console games (Juul 2012). This division of space allows us to address how physical/digital game objects can be designed to act in various ways, thus allowing designers to consider: where and how the interaction takes place; and where and how feedback on that interaction should be presented to the player.

In Figure 2 we highlight four possible interaction scenarios and, unlike the casual games explored by Juul, the question whether the games are either single or multiplayer does not dominate the discussion, as it is anticipated that all scenarios could support both single or multiple players.

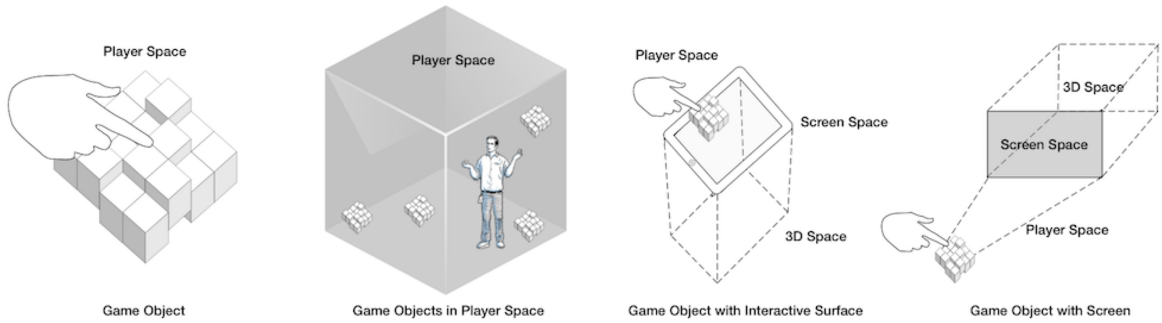

Figure 2. Potential Hybrid Physical/Digital Games Spaces.

- *Game Object:* In this scenario the game is the focus of the user's interaction and all the affordances that would be associated with the object. It is worth noting that as the object may exist both physically and virtually the affordances need to be considered in this context.
- *Game Objects in Player Space:* In this scenario we expect multiple game objects to be used to enhance the physical space. Whilst a screen might form part of this scenario, the game objects would not operate with it directly.
- *Game Object with Interactive Surface:* In this scenario the interactive surface provides both a screen and a means through which the physical objects interact with a virtual game which could be represented as either 2D or 3D space (Burnett, Coulton, and Lewis 2012).
- *Game Object with Screen:* In this scenario movements of the physical object are transferred to the screen via a wired/wireless link and, as with the previous case, the virtual game can be represented as either 2D or 3D space (Coulton et.al 2014).

It is important to note that these scenarios are representative of just some of the current possible game implementations involving objects and they should not be considered the only possibilities as designers may be free to configure the interaction within spaces as part of the overall game design. Further these scenarios are applicable beyond game and can be used to represent many forms of hybrid physical/digital interactions with connected devices.

Having highlighted possible scenarios we can now consider how information relating to the game can be provided to the player in such a space.

3. Information Bandwidth

Games often manipulate how much of information is presented to a player to create the overall game play. Salen and Zimmermann describe it thus:

> "When you create information in your game, its value for the player emerges from both its objective and perceived status: its structural position within a larger information economy and the players knowledge about that economy" (Salen and Zimmerman 2004).

In other words, information can be used as a primary game mechanic. In this research we are primarily concerned with how such information is represented to the user, i.e providing feedback associated with either players' interactions or events occurring within the game as this is generalisable to interactions beyond games. The focus here is to investigate in what way information can be made available to users, and what scenarios are best suited to which techniques.

We can consider the combination of channels that a system uses to communicate between player and system as the 'Information Bandwidth' of that system (Gullick, Coulton, and Lau 2015). For example, if the player's focus is only on the screen we are primarily using the visual and audio channels. However, if we are playing Wii Tennis, we are using visual, audio, and touch (through vibration) channels to convey game information. This concept of bandwidth is based partially upon the work of the physicist Tor Norretranders who characterised each sense by its data rate, in bits per second (bps), and differentiates between the amount of data we physically sense compared to the amount we consciously perceive (Nørretranders 1991).

Whilst it is possible to use only one channel to convey information, we believe that multiple channels are beneficial in a number of ways, of which two of the most important are:

- To avoid what we term 'Channel Saturation' - by conveying too much information to the user in one channel potentially overloading the amount of information the player can consciously perceive. For example while Nørretranders estimates we process visual data at 10 Mbps (Mega bits per second), but we are only able to consciously perceive 40 bps. Thus complex visual interfaces that change rapidly may cause the user to 'miss' information.
- When discussing Ambient Media [9], Ishii differentiates between media in the 'Foreground' (centre) or 'Background' (periphery). By combining foreground

and background channels we allow more utilisation of a player's attention. Norstranders' division of sensed and perceived information supports this idea.

This consideration of attention is also analogous to what Marshall McLuhan categorised as 'hot' and 'cool' in relation to media, whereby a hot media, such as print, is one that dominates one particular sense, absorbing our attention and leaving little room for participation, while a cool media (sometimes described as fuzzy) is one that engages across our senses and leaves space for participation (McLuhan and Fiore 1967). This suggests that when a player needs to act quickly within a game setting the feedback of information should be primarily provided through fewer channels than for slower, more explorative games that may need to give the player time for reflection. Arguably this feedback should additionally be provided through channels that can accommodate information with the needed immediacy for example: visual for immediate 'hot' or 'foreground' information and audio and touch for 'cool' or 'background' information. Given the emergence of physical/digital games there appears an opportunity of providing information in a greater number of ways relating the feedback to physical objects. It is important to note that we are not suggesting that these senses be divided into two discrete categories of foreground or background, but instead they should be considered as existing on a spectrum from entirely foreground to entirely background, and it can in fact be a mixture of both. A sense can exist on multiple points on this spectrum: sound can be foreground (a loud distinct beep for example), or background (a softly building ambient sound).

As an example of expanding the Information Bandwidth consider Table 1, which provides a limited selection of possible ways of representing different in-game information to the player.

Table 1   Alternative Representations of In-Game information

Information	Representation	Main Sensory Channel
Character Position	Projected Image	Visual (foreground)
Character Health	Heat/Cold	Touch (background)
Game Progress	Inflation/Expansion	Touch (background)
Game Event	Audio	Audio (foreground)
Weather	Mist/Vapour + Heat/Cold	Touch (background)

4. Expanding the Information Bandwidth

In order to help evaluate the effects of expanding the interaction using physical/digital objects, we designed and implemented a two-player tabletop game, known as Antus, focused around players controlling two rival ant colonies. In essence, Antus is a 'God Game', in that the player controls the game on a large scale, as if they are an entity with divine/supernatural powers. In this particular case each player takes control of an ant colony and must control the activities of that colony in order to survive. Integral to colony survival is keeping the queen ant happy with the winner being the controller of the ant colony that survives the longest.

The game contains both physical and digital elements as shown in Figure 3 and thus can be considered as a form of augmented tabletop game. This game has been designed in such a way that it has both information that could be characterised as 'hot' and considered to be available in the players 'foreground' of attention and information that could be characterised as 'cool' and suited to display in the users' periphery. Our aim was to use this game as a design stimulus for a workshop focused on presenting the information in the game space in a physical way.

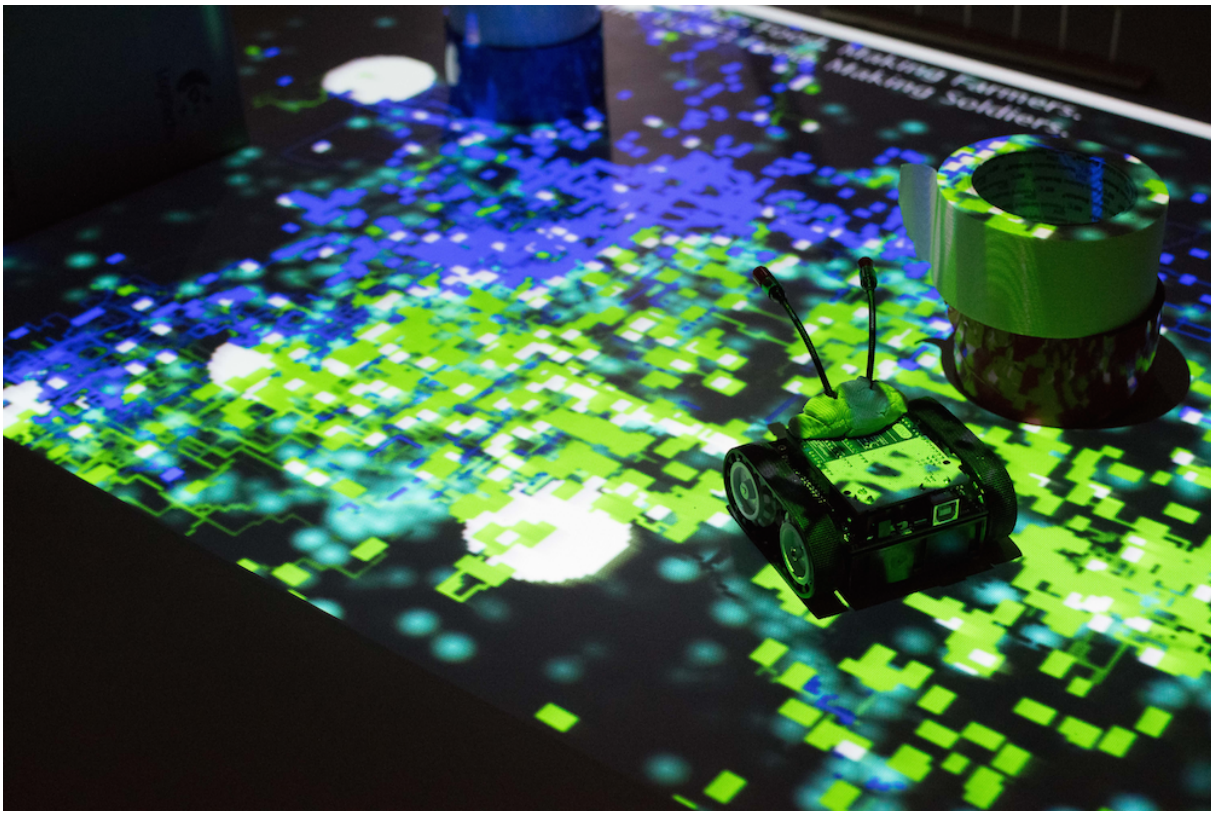

Figure 3. Antus Game (Robot Queen in Foreground).

Augmented tabletop games have been the subject of much research (Kojima, Sugimoto, Nakamura, Tomita, Inami, and Hideaki 2006, Leitner, Haller, Yun, Woo, Sugimoto, Inami, Cheok, and Been-Lin 2009 , Magerkurth, Memisoglu, Engelke, and Streitz, N. 2004) although the majority have largely been used to highlight novel technological interactions and they have not considered the information the object may be required to represent. While Baker et al. identified that players generally preferred physical objects over virtual ones (Bakker, Vorstenbosch, van den Hoven, Hollemans, and Bergman 2007) the issue highlighted by Magerkurth et al. of understanding whether feedback should be physical or digital within the context of augmented tabletop games (Magerkurth et al. 2004) or whether players prefer digital or physical representation remains unanswered. Additionally, there exists very little in the way of guidelines to help in designing physical feedback in games for different types of information, especially when focusing on the immediacy, and overall nature of the data represented.

5. Hybrid Physical/Digital Game Design

The game is situated on a tabletop scenario and uses a ceiling mounted projector that allows the system to augment the game space with visual information, and a ceiling mounted colour/depth camera allows the system to process the state of the game space system using image processing techniques. Figure 4 shows the system configuration, which provides a game space which conforms with the third scenario discussed in Figure 2 (game object with interactive surface).

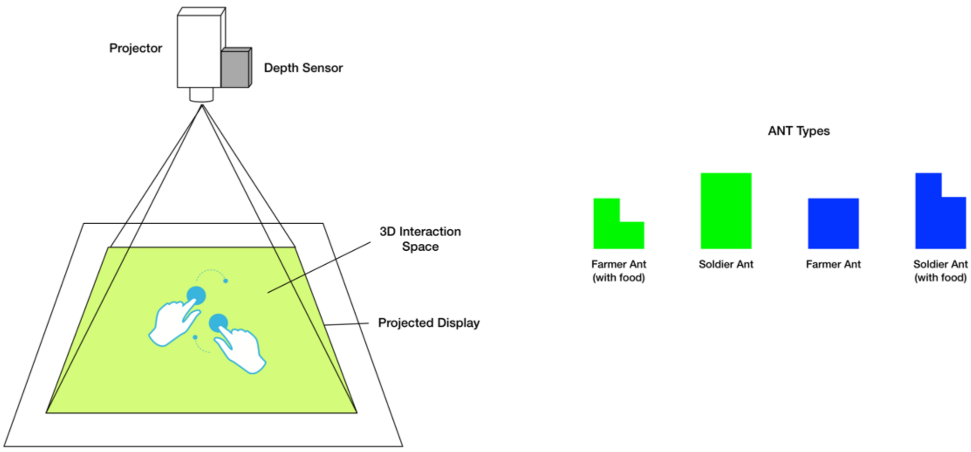

Figure 4. Hybrid Physical/Digital Game System and Ant Types

Initially, players are positioned at either side of the table and given control of a virtual ant nest (differentiated by colour) that is projected onto the table. Whilst a number of parameters that affect the colony can be controlled by the user and the main goal of this ant colony is to collect the 'food' resource and use it to produce more ants.

Using similar depth sensing techniques as 'Zune Buggies' (Wilson 2007), Illuminating Clay (Piper, Ratti, and Ishii 2002) and 'Efecto Mariposa' (Vivo 2011), the system can detect the changes within the terrain of the game space and react in such a way that the virtual elements in the game space react as they would if they were physical, much like in IncreTable (Leitner 2009). This means that players can place objects on to the table that result in the virtual ants treating the objects as obstacles and thus they seek to find an alternative route around the obstacle. In addition to detecting the shape of the terrain, the system can detect the presence and location of predefined physical objects, which can then be used as a tools using Holmquist et al's classification (Holmquist, Redström, and Ljungstrand 1999). In this case we detect the objects using fiducial markers (as used in camera based augmented reality systems) attached to objects, and detected via the overhead camera. Although other object tracking techniques are possible we felt that this is the easiest to explain and implement for the purposes of the participatory design workshop considered in a later section.

5.1 Game Avatars (Ants)

The are three types of ant present within the Antus game which are characterised by the following behaviours:

- T*he Farmer Ant:* This ant requires the smallest amount of food to be newly created within the colony. The farmer ant can collect food from a food source situated on the tabletop and take it back to their nest. On its way back to the nest the ant leaves a virtual pheromone trail to help other members of its colony find the food. This ant has no physical presence within the game space but will respond to physical changes (obstacles and food blocks) and other player interactions in the game space.
- *The Soldier Ant:* A new soldier ant requires more food to be created within the colony than a farmer ant. Whilst it cannot directly carry food back to the nest from a food source, it can attack ants from the rival colony and carry them back to the nest as food. Like the 'Farmer Ant', the 'Soldier Ant' has no physical presence within the game space but does respond to physical changes in the space.
- *The Queen Ant:* There is only one queen ant per colony and she sits on the users nest and uses food to create new ants. This ant has a physical presence in the form of a robot that is capable of moving around the tabletop game space. The queen ant will remain static as long as the colony is keeping her supplied with food but will grow agitated and eventually move to a new location if not supplied with sufficient food by the colony. The green queen ant can be seen in the right of Figure 3.

As discussed, the soldier and farmer ants are represented virtually within the game and in the current prototype as the simple abstract shapes, shown in Figures 4 and 3, in order to reduce the computational overhead when generating lots of ants within the game.

The virtual ants navigate around the game using the pheromone trails. Ants that have found food leave a 'food' pheromone trail on their way back to the nest, and ants leaving the nest in search of food leave a 'home' pheromone trail. Ants looking for home or food can then follow a trail of the desired type to navigate their way around the game space. These trails can be seen by the players and used to anticipate the reaction of an ant to a specific game scenario.

All three types of ant require food to survive and if left unfed will perish. Normally if an ant is successful in finding food it can restock its reserves and carry any surplus back to the nest in order to keep the queen ant happy, and to help fund any future ants being created.

5.2 Interacting with Game

The following colony parameters can be manipulated by the player by the positioning of designated objects in the game space:

- Stop (to stockpile food) or Start (at the cost of food) producing ants.
- Prioritise the creation of farmer or soldier ants.

Additionally the users can manipulate the game space by:

- Placing physical food blocks onto the table, which the ants can use as a food source (the game imposes a rule where the block has to be a certain distance from the nest).
- Physically manipulating the game space by placing objects as barriers. Ants are programmed to be lazy: they prefer not to go up or down hills preferring to find a route around.

6. Participatory Design Workshop of Physical Feedback

Whilst we could address the previous highlighted questions relating to information by coming up with our own solutions for the problem and then testing them with players, it was decided that a participatory design approach would allow a wider range of options to be considered and facilitate conversation with players about operation of hybrid physical/digital game spaces. The participatory design workshop involved eight participants (6 male and 2 female) who played the previously described version of the game 'Antus' . The players were then invited to comment on the current in-game information and then to consider alternate ways of providing that information. These comments were recorded and participants were also encouraged to build physical prototypes of alternate ways of representing this information along with suggestion of new information that could improve overall game play. Whilst systems have been created that allow prototyping of physical game objects (Marco, Cerezo, and Baldassarri 2012) these were aimed at games designers and offer a limited range of ways in which to represent information. Therefore it was decided that providing players with a range of craft materials would allow them to express their ideas much more freely in the given time (Hare, Gill, Loudon, Ramduny-Ellis, and Dix, 2009). A sample selection of some of the produced prototypes is shown in Figures 5 (general feedback prototypes) and 6 (ant queen based prototypes).

This workshop offered many insights into how players approach the problem of physical data representation, and gave people the opportunity to explain some of the less obvious design decisions. The most interesting and relevant insights are as follows.

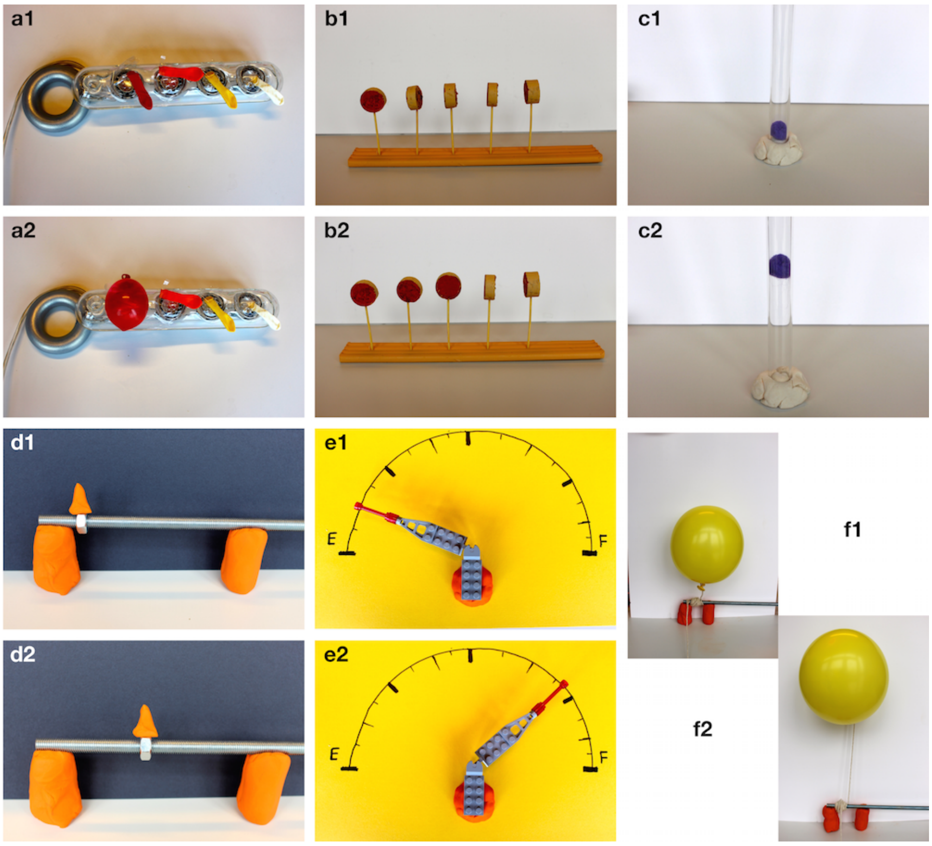

Figure 5. Game Information Prototypes

- Users expected the robot actors to have an emotion and this emotional state has been shown to be important aspect when playing games with them (Barakova and Lourens 2010, Xin and Sharlin 2007) and a number of prototypes built supports this result. Additionally, texture and sound are often related to a state of emotion when used with robotic actors. Most participants chose to use a rough textures and fast noises to represent a negative mood and a smooth textures and slow noises to represent a positive mood.
- The relative difference of information is often more important to users than specific value of the data. Many of the prototypes were designed in such a way that it represented relative concepts such as 'more than my opponent' or 'doing well' rather than to represent specific values to the users. When questioned about this, one participant explained: "the amount isn't important, it's being able to easily see your relative position to your opponent that is important".

Figure 6. Ant Queen Information Prototypes

- 'Glanceable' feedback was important to a number of participants as they wanted to spend more time considering their strategy and playing the game rather than exerting effort to decode the information. Additionally many of the feedback mechanisms were designed as background information – participants did not want to be interrupted to be told the state of the game, and instead want to choose when to get feedback by looking or touching, or have feedback which is more ambient so that they can get a sense for the state of the game. The creator of prototype (5b) said they wanted to recreate "those mechanical displays you used to see in train stations or bus stations" because "you don't have to keep watching them as the noise tells you when something has

changed". This noise is effectively an ambient alert that helps bring the information from background to foreground.
- Multiple senses can be used simultaneously to perceive information. For example one participant designed a feedback system that utilised a speaker, LED lights and an inflating balloon to represent different aspect of the game, within one feedback device. The creator explained it was easier to understand than a purely visual feedback device. Often one sense was used as a cue to let the user know that new information is available.
- A scale on a feedback device is not always necessary as some participants chose to not include a scale, and just to represent a state change and a direction.

Whilst some of these prototypes may be used within some of the other game spaces characterised in Figure 2, it does not necessarily follow that they will perceived as the most applicable by players and further prototyping sessions will be needed to explore these alternate spaces. Additionally, it was noticeable that participants were focused on what could be more easily seen, touched or heard as the main channels for feedback, although in later discussions additional senses such as smell were described as possibilities to indicate certain types of information. This may be due to the physical crafting nature of the design workshop - it is hard to represent something as abstract as a smell with a physical prototype.

7. Conclusions

One of the challenges for game designers creating hybrid physical/digital games how they understand the space in which the interactions take place. Starting from the work of Juul we produced four characterisations for physical/digital games spaces described as: Game object; Game objects in player space; Game objects with an interactive surface; and Game objects with screen. We believe these characterisations are a useful way for designers to consider where the focus of the users attention may be, and how feedback is presented to the user. We recognise that these characterisations are by no means a definitive list but as a starting point for designers not only to consider games, but more general interactions in hybrid physical/digital spaces.

The physical prototyping workshop proved an extremely useful way of gaining insights into how players might best be presented with information. One of the main findings of this study is that participants already understood the concept of treating attention as a resource, and were happy experimenting with different senses in order to achieve this. During the course of the workshop, it was often mentioned how many modern designs ignore these physical properties in favour of digital displays.

Not only must a designer consider what kind of information they need to provide, they must also decide whether it is quantitative or qualitative, fixed or relative, a single value or a range. Additionally they must consider what way this information should be conveyed to the user; virtually or physically, visually or kinesthetically.

Whilst this initial study in to the area shows promise, we hope that this and future work in the area produce a 'data representation toolkit' for physical/digital game spaces, something that will aid designers to decide how to represent certain data types, taking in to consideration their data type, urgency and their preferred information bandwidth channel, whilst minimising wastage of users attention. Future work will look into more in depth studies using multiple senses, specifically the more abstract senses such as smell, and testing the viability of the produced toolkit.

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