Game Space Design Foundations for Trans-Reality Games

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ABSTRACT
Trans-reality games are games that take advantage of pervasive, mobile, ubiquitous, location-based and mixed reality technical infrastructures to create game spaces that can include physical reality together with one or more virtual realities. Creating these games requires basic design decisions about the relationships between the large scale game spaces involved. In particular, the different game spaces can be related by general 3D coordinate system transforms, together with decisions regarding isomorphism at different levels of spatial scale. The result is a large space of possibilities for trans-reality game space design supporting very different forms of game mechanics.

Categories and Subject Descriptors
D.3.3 [**Design**]: Mixed/Augmented/Trans-Reality Games – *trans-reality game space design.*

General Terms
Design.

Keywords
Trans-reality games, mixed reality games, game space design.

1. INTRODUCTION
Massive Multiplayer Reaching Out (MMRO) is a research subproject of the EU Integrated Project on Pervasive Games (IPerG, http://iperg.sics.se/). MMRO is specifically concerned with the development of demonstrators for a new game form involving the integration of mobile and location-based game play with a persistent, massively-multiplayer on-line game accessed via personal computers. The MMRO game involves two distinct but interconnected game spaces, one being the physical world and the other being an interactive 3D virtual world. This is quite different from mixed and augmented reality games (eg. [2], [5], [6], [7], [9]) that seek to create a single game space integrating both physical and virtual elements. The MMRO approach to the structure of the game space raises a number of general options for game space design where player actions within different game subspaces have a simultaneous influence upon other game subspaces. These issues can be referred to as questions of *trans-spatial* game space design. Games having multiple perceptual game spaces of which one is the physical world and the others are computer synthesized, or virtual, worlds can be referred to as 'trans-reality' games. This paper defines trans-reality games in relation to other forms of pervasive games. The options for large scale game space design within trans-reality games are then described in detail. The question of game object position and motion within game subspaces is briefly considered. Finally, the impact of trans-spatial game space design upon game play is discussed.

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2. TRANS-REALITY GAMES
Pervasive games are a broad class of games lacking a strict definition but generally based upon the integration of technologies with physical game experiences (see http://iperg.sics.se/)). The term derives from the concept of pervasive computing, or computing 'anywhere, anytime', and refers to gaming within a pervasive computing environment. For a pervasive game, the physical world has a greater impact upon game experience than in the case of conventional computer or console games, while the computational infrastructure facilitates game play in ways atypical for conventional physically staged and manually manipulated games such as board games, table-top games or live-action role-playing games. Attempts to develop a more precise definition of pervasive gaming, and the various subtypes of games falling within the broad category of pervasive games, are ongoing. However, a well-established and clear definition is not as interesting as the ongoing exploration of the many new games forms suggested by the term and the possibilities of gaming experiences that are not limited in time and space by technical constraints.

Pervasive games vary in their reliance upon computer and communications technologies, the presence or not of virtual (ie. computer-generated) game spaces, and their use of the physical environment in game play. Technology enhanced live-action role-playing games [8] may have a strong foundation in physically staged game play, while commercial location-based games like BotFighters (http://www.botfighters.com/) use location for competitor selection while most game play is staged within a virtual space viewed on the screen of a mobile device. Within the endless scope of possible pervasive games, the term *trans-reality games* can be used to refer to a subset of pervasive games that may simultaneously include physical, virtual and mixed reality game staging spaces.

Within this class of games there is also a distinction to be made between diegetically monolithic and diegetically polymorphous trans-reality games. The diegesis of a game can be understood as the things represented in the game world including game objects, events and cause/effect interactions. A *diegetically monolithic* game can be understood as a game set in a world perceived by players as being a single world by virtue of having continuous time and motion within a Euclidean (or similarly uniform) geometrical space. For a diegetically monolithic game to also be a trans-reality game, the media staging approach used for game play may include primarily virtual staging scenarios, primarily physical staging scenarios and mixed reality staging scenarios. An example of this would be a role-playing game in which some players are acting out their game characters by live-action role-playing, perhaps using costumes, props and an appropriate physical setting, while other players are controlling virtual characters via computer interfaces. Physical play in this case must take place within an environment including mechanisms for transferring game information into the virtual world, and for representing virtual characters within the physical world. Techniques for doing this are explored in more detail in [4].

A *diegetically polymorphous* trans-reality game is one in which the game world has significant discontinuities or departures from being perceived as a single, continuous game space on a large scale. More specifically, the game space is perceived and understood as consisting of more than one world. The different worlds represent simultaneous and interactive game play zones, where players may be represented in one or both game spaces, and game actions in one space can have consequences in the other. This might include games that use a virtual model or map of the physical world, but only if the physical world and the virtual map each support simultaneous, interacting but not identical game moves; the map and the world must represent separate game spaces.

The MMRO demonstrator project involves a diegetically polymorphous game world within which the virtual game space is an interactive 3D world and the initial physical game space is the city of Stockholm. A trans-reality game of this kind is a game that can be played by players in a primarily physical staging, or in a primarily (or completely) virtual staging, or moving between the different staging contexts. In all cases the players have a strong sense of playing the *same* game, even though interaction modes and play functions may be different in the different staging contexts.

The question of game space design for trans-reality games concerns the design not just of each of the separate game spaces involved, but also of their interrelationship within an integrated overall spatial concept. For convenience this may be referred to as the sphere of *trans-spatial* game space design. This paper concentrates upon principles for the trans-spatial design of diegetically polymorphous trans-reality games. Similar principles apply to the design of diegetically monolithic trans-reality games, but are localized to specific staging and play instances, and address the mapping between each specific staging and a canonical representation of the larger scale world upon which all local play instances and their stages are mapped.

3. PARAMETERS FOR TRANS-SPATIAL GAME SPACE DESIGN

A basic question for the design of a diegetically polymorphous trans-reality game is that of how any two particular simultaneous game spaces are to be interrelated. This includes the example of the MMRO game and other pervasive games in which a virtual game space is used simultaneously with a physical game space. Having the physical world as one game space has many implications for the integration of physical game objects, interface design, compatible game mechanics, etc.. However, the overall principles of trans-spatial design apply not just to trans-reality games including the physical world, but also to trans-reality games including, or even limited to, an arbitrary number of simultaneously active virtual worlds. In all cases, trans-spatial design is intimately associated with game mechanics and also requires a consistent game scenario or story; trans-spatial design can begin with a spatial concept that may inspire compatible and interesting game mechanics and scenarios.

Basic parameters for the design of the interrelationships between simultaneous game spaces include isomorphism together with general operations of transform geometry: scaling, dimensionality, translation and orientation. These parameters are explored in detail in the following sections. The basic mathematics of transform geometry are well established (eg. [10]) and can be readily applied to trans-spatial design. For simplicity, Euclidean geometry, a maximum of three spatial dimensions within a single game world and linear transformations are assumed throughout this paper.

4. ISOMORPHISM

Isomorphic mappings result in the adjacency relationships between game subspaces in one world being the same as those of the subspaces to which they are mapped in another world, such as subspaces of the physical world and subspaces in a virtual world. That is, in an isomorphic mapping, if one location is next to another in the virtual world, the corresponding locations will be next to each other in the physical world (Figure 1). This has an impact upon positions, motions and game actions, and also allows game objects in one world to have an interpretation, representation or meaning in the other. For example, in the MMRO design, the subway station of the Royal Technical College (KTH) might correspond with the Tree of Knowledge in the Forest of Wisdom within the virtual 'mirror world' of the MMRO scenario, providing a convenient meeting point for mobile players wishing to gather under the branches of the virtual tree.

Non-isomorphic mappings can have different adjacency relationships, so that, for example, a player can be in a zone next to the zone of a team member in the physical world (or another virtual world) where those zones in one world represent zones between which there are other intermediate zones (mapped onto other physical spaces) in the other (eg. virtual) world (Figure 2).

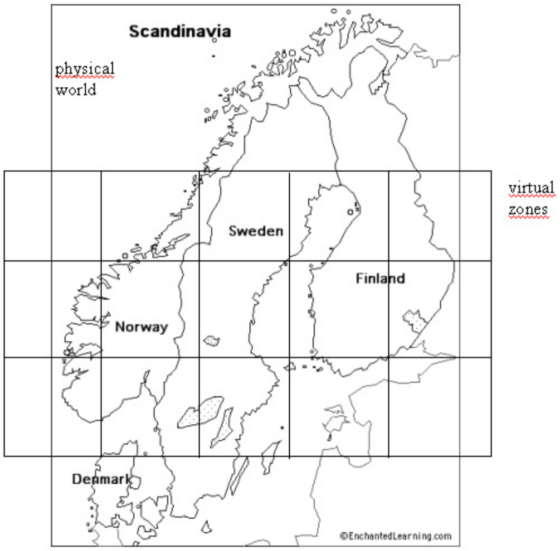

Figure 1. A simple isomorphic mapping from virtual to physical game spaces.

Isomorphic and non-isomorphic mappings may occur in nested structures. For example, if a grid is used to partition the game spaces at some level, positions within a grid square may be isomorphic between the two game spaces (eg. the physical and virtual spaces), while adjacent grid squares are not isomorphic: a player moving from one square to the next in the physical space may be instantly transported many squares away within the virtual space, although within the two squares smaller scale relative positions are the same.

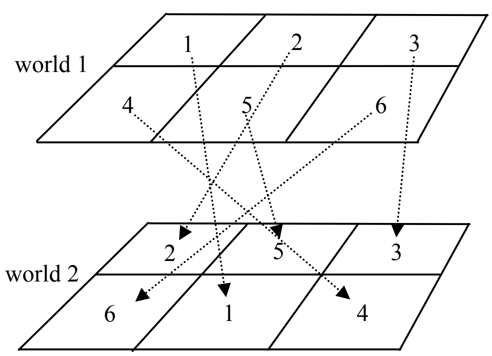

Figure 2. Example of non-isomorphic mapping between 2-dimensional coordinate systems of two separate worlds.

Non-isomorphic mappings provide the possibility of creating maze or spatial puzzle structures involving both worlds. For example, suppose a particular game goal requires a player character to move from one location to another along a particular path within a virtual world, and the virtual character or game object is moved by having the player move within the physical world but only by traversing map subspaces corresponding with adjacent spaces within the virtual world, as shown on Figure 3. The non-isomorphic mapping of physical world grid squares to virtual world grid squares results in the physical path to be traversed being quite different from the virtual path to be traversed, resulting in a spatial puzzle to be solved by exploration within the physical world (a task greatly aided by players working together!). The puzzle is constituted by the non-isomorphic mapping of the game spaces (together with the need to navigation around objects within the game spaces).

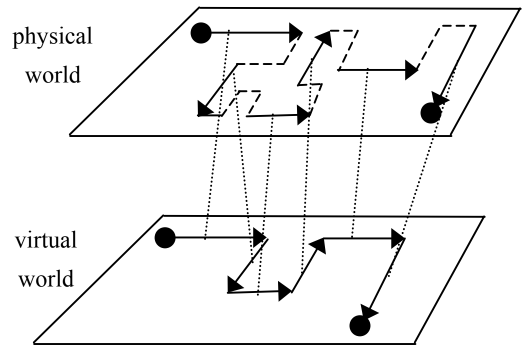

Figure 3. Relationship between two game worlds creating a trans-spatial puzzle.

Non-isomorphic mappings also include the case of worlds connected together via arbitrary *portals* (essentially, small scale connection points), where the connections are made from point to point between worlds, and the relationships between the distances and locations of all portals within one world have no general relationship to those within another. Comparison of this case with the case of isomorphic mappings shows the strong connotation of isomorphically mapped spaces as existing simultaneously at the same location within a perhaps unspecified meta-space, generally autonomously but with some principle for moving between one space and another. Worlds linked only by portals do not have this connotation. Here it is proposed that this implied metaspace should be explicitly modeled as a global coordinate system, both for isomorphically mapped and non-isomorphically mapped spaces, supporting a generic principled approach to spatial design and for the (automatic) inter-location of game objects across worlds. This is elaborated below.

An extreme case of a non-isomorphic mapping is to have no mapping at all, in which case position within one space can have no intrinsic significance for spatial location within another.

5. SCALE

The question of scale is quite independent of the question of isomorphism. Whatever morphological strategy is used, some convention is needed for translating between physical world distances and virtual world distances, or between different virtual worlds. Virtual worlds have coordinate systems with arbitrary dimensional units. Game implementation requires establishing conventions for how dimensional units are to be interpreted for establishing the scale of synthesised game objects and their motion. For example, 1 unit could be conventionally understood to represent 1 m, so a medium height human-sized character might be 1.7 units tall. Once such a convention has been established, the question arises of how this should be mapped to units within another game space, such as the physical world. MMRO uses a horizontal expansion of virtual scale, so a horizontal distance within the virtual world represents a larger distance within the physical world. For MMRO scale is around

1:13, based upon the physical world map being 1600 km across, characters 'walking' at a running speed of 10 km/h and designing the virtual world to allow characters to traverse the whole world in 12 hours by walking [3]. This does not affect the isomorphism between worlds, however, since all adjacency relationships are preserved. Additional motivations for choosing this rescaling in the case of the MMRO game include reducing the impact of positional uncertainty in the physical world and increasing the spatial density of players within the virtual world. Simple rescaling is depicted in Figure 4 in relation to the implied meta-world coordinate system of the graphical space used in this paper.

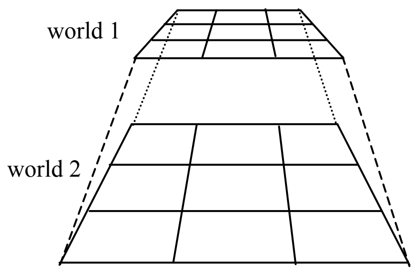

Figure 4. Inter-scaling of 2D world dimensions.

If a point in a game space is represented by it's x, y and z coordinate systems in the form P (x, y, z), this can be represented by a matrix and the scaling to obtain the scaled position of an isomorphically corresponding point in another world can be represented as a matrix multiplication operation:

$$\mathbf{P}_2 = \mathbf{S}\,\mathbf{P}_1$$

or

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \\ 1 \end{bmatrix} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \\ 1 \end{bmatrix}$$

6. DIMENSIONALITY

Dimensionality concerns how many dimensions of the respective game spaces are involved in their inter-mapping. This is generally a matter of choosing between one, two or three dimensions of one space to map onto one, two or three dimensions of another (greater dimensionality risks confusing both designers and players). The most common design cases are likely to use the same dimensionality in both of two inter-mapped game spaces, so the same spatial metaphor can be used within both. However, varying from this can again result in puzzle-like game spaces, or game designs for which it would be impractical to use the same dimensionality. An example of the latter would be a game involving a large virtual construct, such as a tower or a dungeon, that it is not possible to map directly to a three-dimensional physical structure (eg. it may be too large, or a weird shape); this can be solved by mapping different levels of one world, such as a 3D virtual structure, to different zones of another world, such as horizontal (2D) space within the physical world, as shown on Figure 5. This example follows the general principle of representing multi-level 3D spaces as 2D plan views on maps.

Isomorphism and scaling can be treated separately for each inter-mapped dimension pair. For example, MMRO uses large horizontal distances in the physical world to represent smaller horizontal distances within the virtual world, but heights (the third dimension) may have a 1:1 relationship.

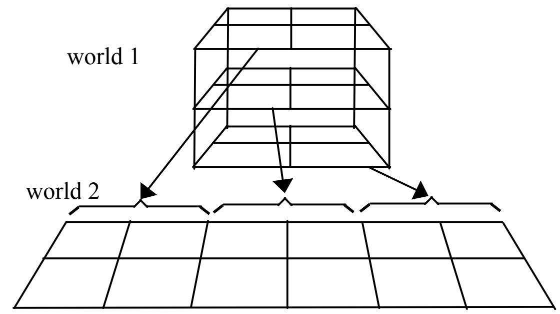

Figure 5. Inter-mapping of world dimensions.

7. TRANSLATION

Translation of one game (sub-)world with respect to another immediately raises the need for a reference coordinate system. Each world can be modelled (or fabricated) as having its own world coordinate system with its own origin. Isomorphism does not in itself establish the relationship between these coordinate systems, since the coordinate systems themselves may be used to specify an isomorphic mapping. Possible strategies for interrelating the coordinate systems include: 1. define one coordinate system as the base coordinate system and define translations of the other coordinate system in relation to that base coordinate system, or 2. adopt a global coordinate system with respect to which the local coordinate systems of both of the game subspaces can be translated. For a trans-reality game including the physical world it is useful to adopt the physical world coordinate system as the global coordinate system, since this world will be present for a large class of games, and any number of virtual worlds can be built into a single game without having to rely upon existential dependencies between their respective coordinate systems (although this can also be done if the coordinate systems are arranged hierarchically as a kind of trans-reality scene graph).

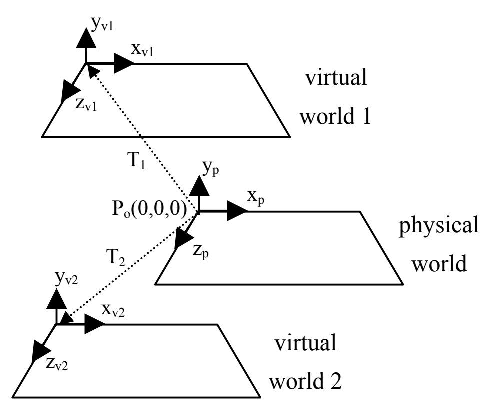

Figure 6. Relative translation of worlds.

In this case one or more virtual worlds can then have their translational relationship to the coordinate system of the physical world specified, thereby implicitly characterising the translational relationships between multiple virtual worlds, as shown on Figure 6. A translation can also be represented as a vector operation of the form:

$$\mathbf{P}_2 = \mathbf{T}\,\mathbf{P}_1$$

or

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & T_x \\ 0 & 1 & 0 & T_y \\ 0 & 0 & 1 & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_2 \\ y_2 \\ z_2 \\ 1 \end{bmatrix}$$

where T_x, T_y and T_z are the translation values along the x, y and z coordinate axes, respectively. If **P**1 is the origin of one world and **P**2 is the origin of another world, then the translation matrix gives the shift in coordinate origin of the second world in relation to the origin of the first.

For the MMRO game, the origins of the coordinate systems of the physical game world/space and the virtual game world/space are conventionally taken to be co-located, so no translation of the virtual world is involved.

8. ORIENTATION

Orientation can be defined in terms of rotations of the coordinate system of one game space around the axes of another. The same general considerations of transform geometry apply as in the case of translation, including the need to specify either a base or a global reference coordinate system, as shown on Figure 7. For games including physical staging it may again be most convenient to take the physical world coordinate system as the global coordinate system. The interesting consequences from a game mechanics and play perspective include the impact, for example, of inter-mapping heights and horizontal distances between worlds, while consequences from the perspective of the scenario and diegesis include exploring virtual worlds that may be tilted or rotated in relation to the physical world.

A rotation around a specific axis can be expressed by a rotation matrix, eg.

$$\mathbf{P}_2 = \mathbf{R}_x\,\mathbf{P}_1$$

where $\mathbf{R}_x$ is a matrix representing a rotation around the x-axis. Rotation matrices for the x, y and z axes are:

$$\mathbf{R}_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{R}_y = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{R}_z = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotations around more than one axis can be (non-commutatively) multiplied together into a single overall transform matrix.

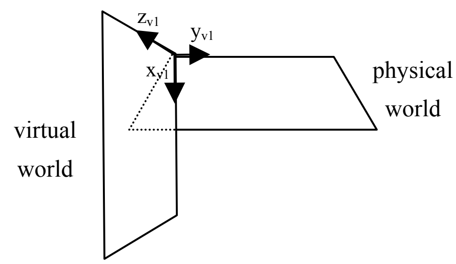

Figure 7. Rotating one world in relation to another.

As for general 3D rotations, if a 3D world is translated in relation to a coordinate system in relation to which it is also to be rotated, the world must be translated back to the origin of the coordinate system in relation to which the rotation is to be made, then rotated, and then translated back into the original position of its origin.

9. COMBINING WORLD TRANSFORMS

Multiple scaling, translation and rotation matrices can be concatenated to create a net transformation matrix for any linear transformation. Of course, general techniques for 3D modeling can be applied to systems of worlds, and this includes the possibility of scene-graph style structures for interrelating multiple world locations. A scene graph is a modeling technique in which a graph structure is used to represent positional dependencies between the parts of a 3D model. Hence a model of a hand can be connected to the model of an upper arm, an upper arm to the shoulder of a torso, a torso to a hip, etc.. Each submodel representing a node of the resulting tree structure can have a net transformation matrix associated with it (or any arbitrary series of transforms) defining its position in relation to the origin of its parent node within the tree. The relationship of the submodel to the overall model origin can then be determined by traversing the tree from the root to the nodes and concatenating the net transform matrixes along the way, so that lower submodels within the tree effectively inherit the transforms applied to all of their parent nodes.

Applying this principle to relative world positions within a multi-world game space can result in similar hierarchical tree structures defining the relative positions of worlds and points within them. Of course the tree structure merely represents the dependencies between the positions of subworlds, where the actual relative and potentially overlapping positions of those subworlds can have many resulting overall forms. This opens the possibility of many puzzle-like or even paradoxical arrangements of game worlds within a game's meta-space.

One example of a game mechanic (or potential game design pattern) that can take advantage of this is what might be called the 'Halloween principle'. Halloween derives from a Celtic tradition of belief in one night of the year upon which all laws of space and time are suspended, allowing the spirit world to intermingle with the living. The Halloween principle is the principle of having some particular time and or place in which the boundaries between two worlds are weakened, making it possible to pass from one of those worlds to the other. The Halloween principle can be applied within a trans-reality game based upon dynamic transform relationships between the worlds of the game. An example of applying the principle within a game rule might be: 'when two worlds within this game intersect, then a player character may pass from one intersecting world to the other at any point along the line of intersection of the respective horizontal planes of those worlds' (eg. by using an in-game key, a spell or whatever). Game quests and challenges might then be defined that require not only moving within one game world or from one to another, but working out the time and space patterns involved in the formation of opportunities ('Halloweens') for passing from one world to another (ie. players must determine when and where such passages might be possible). Such time and space relationships can be arbitrarily complex and derived from hierarchically organized and dynamic transform relationships between the worlds of a game. While many kinds of functions could be used for varying the scale, translation or rotation relationships between game worlds to create Halloween events, cyclic functions may be the most interesting since they are the most amenable to being learnt by the kinds of trial-and-error learning processes typical of games, as well as providing recurrent events that can be written into the histories, tutorials, advice and mythologies of player communities.

10. GAME OBJECT POSITIONS AND MOTION

While the above discussion has explored basic design parameters for the relationship between simultaneously existing game spaces within a single game, this is an issue of general world design independent of the question of positional representation of game objects and characters. For trans-reality games, the positions of some game objects or characters may be determined or influenced by positions within the physical world. For example, in MMRO, in some game play modes mobile players are represented in the virtual world in positions determined by their known position within the physical world together with the mapping between the physical and virtual worlds. Virtual game objects are synthesised and therefore fully determinable in their (virtual) positions. Physical game objects may have various forms of inaccuracy and instability in their position as known to the game system. This has a strong impact on game mechanics, but is not in itself an issue of global game space design; physical position inaccuracies may be directly translated into virtual world position inaccuracies.

The degree of inaccuracy in the positions of mobile players can vary according to the form and implementation of positioning technologies used. For example, positioning based upon mobile cell id can vary between, for example, 150 m and 35 km, while positioning by time advance can result in accuracies from approximately 50 m to 500 m [1]. GPS positioning may vary from better than 3 m to around 15 m, but can only be used outdoors, while virtual and augmented reality tracking systems may have high accuracies, eg. up to 0.01 m, but within a limited area of about 5 m. Position data is also is subject to device dropouts, radio shadowing and long propagation delays.

As [1] note, there are four broad strategies for dealing with these uncertainties: 1. try to reduce uncertainty, 2. try to hide uncertainty, 3. reveal uncertainty and 4. exploit uncertainty. Strategies 1 and 2 may stem from introducing concepts from other games having continuous and predictable spatial positions into the new media form of pervasive games. Strategy 3 is a step towards strategy 4, which represents embracing the true nature of pervasive game forms and reflecting this in the design of game mechanics unique to those forms.

11. THE INFLUENCE OF TRANS-SPATIAL DESIGN UPON GAME PLAY

The impact of trans-spatial design upon game play may be manifested in: 1. the perceptual presence of one world and the game objects that it contains within another world, 2. the behaviour of game objects and characters as influenced in one world by virtual of their presence and actions in another, 3. player interactions facilitated by game mechanics as influenced by the presence or behaviour of game objects/characters in one world, the other, or both, and 4. the ability of players (or their characters/avatars) to pass from one world to another. Overlaying different worlds immediately creates possibilities for designing puzzle and maze structures formed by the interaction of the topologies of the different worlds, supporting game challenges based upon solving problems of location and movement that must take into account more than one layer of obstacles and access opportunities. These factors interact with the existence of game objects and characters in either or both worlds. Further complexity can be added in the form of temporal variations created by allowing the trans-spatial design to change over time. Examples of this are not limited to changes in transform values, as described above, but might include changes to non-isomorphic mappings.

Game play modalities allowed by a trans-spatial game space design include three play models for mobile location-based players according to their relationship with the virtual game space: 1. game interaction limited to other mobile players and based only upon physical location, 2. game interaction within the virtual world using the mobile device without location data, in which case the player is represented as an avatar similarly to fixed location (eg. PC) players, and 3. location-based game play where the movements of the player within the physical world are 'shadowed' by a player avatar within the virtual world, allowing interaction with other players in both worlds.

In the MMRO game, this leads to players having the following modes of game play, depending on how they are connected to the game [3]:

- *Dreaming*. This mode is achieved whenever the player is logged in with a PC client. All virtual player functions are available to players in this mode, including movement, performing magic (except for being the lead spell-caster of invokation spells), and all social functions (ie. guild and group management and communication).
- *Dormant*. This mode is achieved whenever the player is logged in with a mobile client, and the player character is not in the astral projection state. In this mode offline alerts are available, allowing a player to be notified of specific in-game events even though they are not actively immersed in playing.

All other game play functions (movement, social interaction and performing magic) are disabled unless another mode is entered,

- *Astral projection*. This mode allows the player to log in with a mobile client, and to move a particular kind of avatar referred to as an 'aura ball' arbitrarily within the virtual game space in a way not associated with the player's physical game space. In this mode, however, the player cannot be the lead spell caster for invocation spells.
- *Mirror*. In this mode the player is logged in with a mobile client and their position in the virtual world is based upon their position within the physical world and the mapping of the physical world to the virtual world. This is the only state in which a player may be the lead spell caster of an invocation spell. Invocation spells are an important mechanic in the game since they allow players to invoke game creatures that may attack enemy players, providing positive game play value to this play mode and making location-based play a core mechanic for the whole game.
- *Off Line*. This mode is achieved whenever the player is not logged in with either the PC- or the mobile client, and is not actively playing the game in any way.

MMRO deals with positional uncertainty in the mirror mode of mobile play by adopting the strategy of revealing and exploiting uncertainty in game play. A 'shadowed' mobile player is represented in the virtual world by a simplified avatar in the form of an 'aura ball'. The aura ball is located in the virtual world according to the best available information about the position of the player within the physical world. Motion is tracked as a best estimate of the player's position. In cases where there is high positional uncertainty, the aura ball may make a series of discrete jumps through the game space to reflect movement, eg. corresponding with the relationship between neighbouring cells of the cellular network. This mode of movement supports unique challenges in game play including: mobile players searching for physical world movements and paths that allow the player to catch or escape from enemies or to meet up with friends, virtual world players having to coordinate their actions quickly to attack an opposing player before the target aura ball unpredictably moves, and virtual world players trying to infer what the movement possibilities might be for the aura balls of mobile opponents by taking into account their physical world location for the purpose of, for example, ambushes or other tactical plays.

12. CONCLUSION

Trans-reality games are a new game form that has barely begun to be explored. Considering the parameters of trans-spatial design for trans-reality games suggests a vast space of possible spatial concepts to explore, along with unique modes of game play based upon those spatial designs. This paper has considered many possibilities for the trans-spatial design of diegetically polymorphous trans-reality games. These possibilities have included issues of isomorphism in mapping between game worlds, dimensionality, and general linear transforms for interrelating the relative positions of game worlds. Adding dynamism to these parameters increases their interest in terms of creating unique game mechanics within trans-reality games. Further design possibilities can be facilitated by changing some of the basic assumptions of this paper. Examples of this might include the use of non-Euclidean spaces and non-linear spatial transforms within and between game worlds.

13. ACKNOWLEDGMENTS

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