Applying GIS Concepts to a Pervasive Game: Spatiotemporal Modeling and Analysis Using the Triad Representational Framework

Kim J.L. Nevelsteen

DSV, Stockholm University,
164 40 Kista, Sweden

Abstract
Given pervasive games that maintain a virtual spatiotemporal model of the physical world, game designers must contend with space and time in the virtual and physical. Previous works on pervasive games have partially contended with these representations, but an integrated conceptual model is lacking. Because they both make use of the Earth’s geography, the problem domains of GIS and pervasive games overlap. The goal here is twofold: (1) to help designers contend with the spatiotemporal representations and the analysis thereof, and (2) to show that Peuquet’s Triad Representational Framework from the domain of GIS is applicable to specifically the sub-domain of pervasive games that maintain a virtual model of physical space and time. By borrowing the Triad framework, space and time can be conceptualized in an integrated model as the WHAT, WHEN and WHERE, allowing for spatiotemporal analysis. The framework is evaluated and validated by applying it to the pervasive game called Codename: Heroes.

Keywords: Pervasive Games, GIS, Triad, physical, virtual, spatiotemporal.

1. Introduction
The focus of this article is on pervasive games [1], which model physical space and time inside a computer system i.e., virtual; where at least some of the correlations between the physical and the virtual model is maintained. To maintain a correlation with moving entities, pervasive games can make use of positioning technologies [2], which provides for both a spatial reference to the Earth’s surface and a timestamp when it was measured. An elaborate example of virtual georeferenced1 modeling in pervasive games, is Uncle Roy All Around You [4], where a section of the environment, including buildings, were modeled virtually and positioning technologies were used to track moving game entities. Given pervasive games that maintain a virtual spatiotemporal model of the physical world, game designers must contend with space and time in the virtual and physical.

Current research pertaining to pervasive games does not provide an integrated model for dealing with space and time in the virtual and physical. Geographical Information Systems (GIS) research is centered on applications using Earth’s geography. Because they both make use of the Earth’s geography, the problem domains of GIS and pervasive games overlap i.e., research found in GIS, on how to model the physical world, can be used in pervasive games. The usefulness and application of GIS to pervasive games has been suggested in literature [5] and GIS implementations have already been used in pervasive games [6], but no literature was found applying GIS modeling concepts to pervasive games. A reason for this could be that the domain of GIS modeling is extensive and far from the domain of game design, so GIS information is simply taken at face value and applied. If a designer aims to design a pervasive game that maintains a spatiotemporal model of the physical, how can space and time in the virtual and physical be usefully (e.g., for spatiotemporal analysis) related into an integrated model; and, if the problem domains of GIS and pervasive games overlap, are there concepts from GIS that can be applied to pervasive games?

The goal here is twofold: (1) to help designers contend with spatiotemporal representations and the analysis thereof e.g., space-time paths or the detection of a zone being entered; and (2) to show that Peuquet’s Triad Representational Framework [7], from the domain of GIS, is applicable to specifically the sub-domain of pervasive games that maintain a virtual model of physical space and time. By borrowing the Triad framework, space and time can be conceptualized in an integrated model as the WHAT, WHEN and WHERE, corresponding to an object-based, time-based and location-based representation, respectively [7]. The WHAT, WHEN and WHERE can then be used for spatiotemporal analysis. To evaluate and validate that the Triad framework is indeed applicable, the framework is applied to the pervasive game called Codename: Heroes.

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1 When virtual locations use the Earth’s surface as a spatial reference, locations can be referred to as ‘georeferenced’ [3].
(CN:H) [8], which maintains a spatiotemporal model of the physical world. CN:H has been successfully implemented and staged twice.

By adding GIS to their arsenal of tools, the aim is that a designer might reach a better understanding of the relationships between the different representations used in the pervasive games they create. And, how the conceptual model can lend itself to be queried effectively.

2. Background and Related Work

Literature exists with different techniques for contending with the different representations of space and time in pervasive games: Dix et al. [4] discuss the link between virtual and physical space, define three types of location systems and three types of topologies; Thompson et al. [9] maintain a virtual model of the physical world; Bichard et al. [6] apply GIS objects and spatial data, and imply temporality through the use of prediction; Paelke et al. [5] mention the importance a conceptual model plays in designing a location-based (pervasive) game, but how the GIS conceptual model ties into the game is not discussed. In all cases, an integrated spatiotemporal conceptual model applicable to pervasive games is lacking, especially when taking into account that virtual game entities are also objects with relations. For example, an initial approach to virtually modeling the physical might be to correlate physical location and time directly to virtual location and time, with a one-to-one correspondence; relations between virtual locations and times are evident in the model, but that virtual locations belong to virtual entities and these entities also have relations, is easily left out of the model. In the case where a GIS implementation is combined with a pervasive game implementation (e.g.,), it becomes unclear which implementation maintains the object representation, GIS or the game. This means redundant (one or more in each implementation) representations of the same object are possible. Having a distributed system such as in [9] can exaggerate the redundancy further. Redundancy can be problematic e.g., being the cause for synchronization problems or complex spatiotemporal queries.

Since the physical space being modeled is a geographical phenomena, rather than divide the space using only location, physical space should be divided into spatial objects and their locations [10] i.e., physical spatial objects, physical locations and physical time correlated one-to-one to virtual spatial objects, virtual locations and virtual time, respectively. Peuquet’s Triad Representational Framework integrates these representations as the object-based, time-based and location-based representations [7], hereafter referred to only as the components: WHAT, WHEN and WHERE, respectively. The Triad framework specifies a respective representative modeling object in each component representation, with possible attributes attached to each. Note the different usage of the term ‘object’ between a spatial object and a modeling object. Attributes belonging to the WHAT may contain taxonomic, thematic or membership data; the WHEN may contain a temporal topology, metrics, et cetera; and, the WHERE may contain a spatial topology, metrics, et cetera. Attributes may contain relations to modeling objects in other representations, or alternatively even directly contain objects from other representations (implying a relation).

Both Peuquet [7] and Wachowicz [11] make clear that space and time can be viewed from two different perspectives, objective and subjective views corresponding to absolute and relative space-time, respectively. The objective view focuses on the space and time geometry as the subject matter, while the subjective view focuses on the objects as the subject matter [7]. From Time Geography it is known that the objective and subjective views are complementary, not contradictory [7], and that they are integrated [11]. By treating two representations jointly, certain relationships between objects become more apparent [11]. Through spatiotemporal analysis, enabled by the Triad framework, it is possible to go from an objective view to a subjective view [7].

3. Conceptual Model Using Triad

The following is a general conceptual model using the Triad framework. The WHAT, WHEN and WHERE are first discussed from an objective view, followed by the subjective view thereafter.

3.1 Objective View

Object-Based Representation: Objects in the WHAT and the relations between them constitute a space. A justification for this is clarified by Wachowicz [11], stating that “any relation defined on a set of entities creates a space ... defining a relation automatically defines a space”.

Two spatial relations, that can be used to organize the WHAT, are that of a taxonomic hierarchy or a set of objects. The taxonomy allows for objects to be organized according to their inheritance of attributes [7] or thematics (i.e., thematic modeling [12]) and a set is simply a collection of objects.

Time-Based Representation: The inclusion of a temporal element is required so that change can be represented. Temporal objects laid out on a timeline spanning into the future and past make up the time-based representation of the WHEN. According to Peuquet [7], all temporal

WHERE, respectively. The Triad framework specifies a respective representative modeling object in each component representation, with possible attributes attached to each. Note the different usage of the term ‘object’ between a spatial object and a modeling object. Attributes belonging to the WHAT may contain taxonomic, thematic or membership data; the WHEN may contain a temporal topology, metrics, et cetera; and, the WHERE may contain a spatial topology, metrics, et cetera. Attributes may contain relations to modeling objects in other representations, or alternatively even directly contain objects from other representations (implying a relation).

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relationships can be divided into three distinct classes: (1) metrics and topology; (2) boolean operators; and (3) generalization. With regard to this article, only the first class is of importance. The only temporal metric is temporal distance: “the length of the interval between any two given locations [events] along a time-line”. And, a topology defines how two temporal events relate [7] (also see Langran [13] for details).

Location-Based Representation: A single point is a sufficient georeference and constitutes an object in the location-based representation of the WHERE [7]. By using georeferenced points, bounded areas can be constructed that also adhere to this representation. The spatial relations used are metric and topological; spherical distance with the 9-intersection model [14,12] being sufficient to describe the organization of two objects. A directed graph can be constructed by having location objects serve as nodes, with orientational from-to relations (directed edges) between nodes [12]. The graph being directed, allows for functionality similar to a finite state machine.

3.2 Subjective View

Until now, the discussion of space and time has only been from an objective view, but a subjective view is possible. Focus can be placed on the interactions between different virtual objects, by following their progress through space and time i.e., tracking their space-time paths [11]. To achieve a space-time path for each virtual object, spatiotemporal analysis can be used with the following query: given the WHAT at each progressive time step in the WHEN → WHERE was the object? By tracking the space-time paths of different objects simultaneously, a crossing of paths indicates objects shared space and time. Similar queries can be performed by using the WHEN and WHERE as given, querying for the WHAT or using the WHERE and WHAT as given, querying for the WHEN, revealing different interactions.

4. Using the Conceptual Model in CN:H

To evaluate and validate the conceptual model, it is applied, as a case study, to the pervasive game called Codename: Heroes (the cultural description of which can be found here [8]). Validation of the model was done by: verifying objects, their corresponding relations, and the output of the spatiotemporal analysis. Before discussing the application of the model, a description of a typical scenario in CN:H is provided.

4.1 Scenario in Codename: Heroes

Players or groups of players roam the physical world on a multi-staged quest, directed by the CN:H game client running on a smartphone with GPS and mobile networking. Locations of players in the physical world are recorded through GPS and communicated to the game server using mobile networking, along with a timestamp of when the measurement was made. Players encounter physical artifacts, which have possible virtual counterparts; if the physical object is interacted with, the virtual counterpart can be accessed simultaneously. Each quest stage leads the players from one zone to the next. Each zone is a fictive shape overlaid on the map of the physical world e.g., a polygon or perhaps a point and corresponding radius. Player progression is tracked through the visualizations of trails of moving game objects, including the players, and knowing in which quest stage each player is in. It should be noted that quest stages were not assigned a zone in the physical world, in the design of CN:H, but the implementation supported it none-the-less.

4.2 Objective View

Object-Based Representation: Virtual objects in the WHAT have an identifier, representation specific relations and relations to objects in the WHEN and WHERE. Players and artifacts, present in the physical world, have a corresponding virtual object in the WHAT representation, each storing the WHEN and WHERE representations in attributes, corresponding to a GPS location and timestamp, respectively. A representation specific parent-child relation organizes objects into a taxonomic hierarchy allowing for inheritance. In the hierarchy, one of the objects is specialized as a generic_admin_group, using a member-of relation to organize objects into a set. Each child of the generic_admin_group inherits the functionality to behave as a set and is a unique group in CN:H. Groups of at least one player can be collected in such a unique group. Groups only exist virtually, having no corresponding physical entity, and have a relation to the WHERE, denoting the group’s current quest stage. In Fig. 1, the WHAT hierarchy is depicted contain players, groups, zones, etc., with corresponding relations to the WHEN and WHERE.

Time-Based Representation: Timestamps are temporal objects in the WHEN (also depicted on Fig. 1). A simple “sequent snapshot” [13] method was used to record GPS measurements i.e., a snapshot at regular intervals, recorded on each player’s mobile device and subsequently communicated to the game system.
4.3 Subjective View

To validate usage of the Triad framework, questions relevant to the scenario in CN:H were translated into corresponding spatiotemporal queries [7]. The questions: “Show me the movement trail of Player-1?” and “What is the distance between one game entity and another entity or zone?” both translate into a query of the form: \( \text{WHAT} + \text{WHEN} \rightarrow \text{WHERE} \), a range query, for the first question, and a distance calculation of two subsequent queries, for the second. “What players were in Zone-A at 7pm?” and “Who was playing in the area of Stockholm on Saturday?” translate into form: \( \text{WHEN} + \text{WHERE} \rightarrow \text{WHAT} \). And, lastly, “What time did Player-1 enter Zone-A?” results in a temporal query of the form: \( \text{WHAT} + \text{WHERE} \rightarrow \text{WHEN} \).

Towards the end of the CN:H project, a game master interface was created to specifically visualize results in the form specified by the Triad framework [15]. Space-time paths were visualized using a WebMap in combination with a timeline, although other visualizations were possible e.g., a space-time cube [13]. The spatiotemporal analysis was considered a success, based on the correct game output and correct visualizations thereof.

5. Discussion

Although an adequate validation, it is evident that CN:H does not test the entire problem domain that GIS (and potentially pervasive games) must deal with e.g., CN:H only makes uses of discernible boundaries, when indiscernible boundaries (enclosing an area of a gaseous element) are more difficult [12]. In pervasive games, indiscernible boundaries were reportedly used in [9] through the usage of a fuzziness threshold when modeling team positions. Also, temporal aspects used in regards to CN:H were minimal; many of the complex spatiotemporal changes possible in the physical world were not modeled in the game e.g., changes in landscapes or building architecture. When incorporating temporality into GIS, there is much complexity that must be dealt with (see Langran [13]), so as pervasive games become more advanced, similar complexity might arise. In CN:H, data was recorded in an objective view of space and time. Recording data in a subjective view should have been considered as an optimization [7,13]. Worboys and Duckham [16] discuss a brief history of time, specifying “object lifetimes” and “events, actions and processes” as
In contrast to [6], a GIS implementation was not used in combination with CN:H; all representations had to be dealt with by the CN:H implementation. Before applying the Triad framework to CN:H, space and time in the virtual and physical could be correlated, but virtual objects and their relations to space and time were not accounted for in the model, discounted as implementation details. By applying the Triad framework, the discounted virtual objects and their relations could be incorporated into the model, making it clear to which representation objects (e.g., a quest stage) belonged. The conceptual model assists in the design of spatiotemporal queries, which effect later design stages. Had a GIS implementation been used in combination with the CN:H implementation, all representations would have still needed to be dealt with; the Triad framework could still be applied, highlighting which implementation was responsible for each representation and possible sources of redundancy.

6. Conclusions

This article has attempted to make clear that Peuquet’s Triad Representational Framework can be applied to those pervasive games that maintain a virtual model of physical space and time. And, that by applying the Triad framework, all relations can be incorporated into an integrated model, including those between virtual entities. Because both GIS and pervasive games are dealing with geographical phenomena on Earth, the Triad framework specifies that the physical should consist of objects and their locations. In addition, the Triad framework allows for spatiotemporal queries concerning the WHAT, WHEN and WHERE.

There still much complexity that must be dealt with, when modeling the physical world, but by recognizing that the problem domains of GIS and pervasive games overlap, research can perhaps be applied across the domains. Such as demonstrated herein. Extensions to this work include: applying GIS logical and physical design concepts to pervasive games; equating concepts from GIS with those of pervasive games (e.g., trajectories); or showing how concepts from pervasive games can influence GIS research (e.g., ‘measured space’ by Dix et al. [4]).

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Kim J.L. Nevelsteen is a Doctoral candidate in the Immersive Participation group of DSV, Stockholm University, working on a dissertation pertaining to Mixed Reality and Pervasive Games. He attained his Licentiat in de Informatica from Universiteit Antwerpen in 2008 and his two year Masters from Uppsala University in 2010. In between his academic career he has spent over six years in industry developing medical software.