Geogames: A Conceptual Framework and Tool for the Design of Location-Based Games from Classic Board Games

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Abstract. Location-based games introduce an element that is missing in interactive console games: movements of players involving locomotion and thereby the physical effort characteristic of any sportive activity. The paper explores how to design location-based games combining locomotion with strategic reasoning by using classical board games as templates. It is shown that the straightforward approach to "spatialize" such games fails. A generic approach to spatialization is presented and described within a conceptual framework that defines a large class of geogames. The framework is complemented by a software tool allowing the game designer to find the critical parameter values which determine the game's balance of reasoning skills and motoric skills. In order to illustrate the design method, a location-based version of the game TicTacToe is defined and analyzed.

1 Introduction

The traditional image of home entertainment based on game consoles that confine physical involvement to letting the player move a joy stick is certainly obsolete. Currently, the integration of bodily action into games receives much attention from research in academia and industry. Examples of commercial products which allow the player to interact via more or less complex movements are *Donkey Konga* (Nintendo), *EyeToy* (Sony) and *Dancing Stage* (Konami). The motions of the player that are taken into account can be as simple as hitting a drum or stepping on a dancing mat. More intricate forms of movement without physical sensor contact, e.g. waving gestures, are captured by video or IR. All these games involve movement of parts of the body but only very limited displacement of the body as a whole.

In contrast, locomotion of players – and the physical effort it implies – has been a major motivation for developing location-based games. A classification of spatial scales from cognitive psychology proves useful to clarify the issue. Montello (1993) distinguishes *figural space* which is smaller than the body and accessible to haptic manipulation or close visual inspection, *vista space* which is as large or larger than the body but which can be visually apprehended from a single place without locomotion, and *environmental space* which is larger than the body and cannot be

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experienced without considerable locomotion. Using these terms, we can say that location-based games consider body movements beyond figural space, i.e. beyond the space of computer screens and small 3D-objects, and that they focus on locomotion in vista space, typically the space of a single room or a sports ground, or locomotion in environmental space such as the space of a neighbourhood or a city.

Many location-based games have been designed for environmental space with GPS as localization technology. Some of them are just adaptations of popular computer games such as *ARQuake* (Thomas & al. 2000) or *Pirates!* (Björk & al. 2001); others are rather straight forward chase games like *Can You See Me Now* (Flintham & al. 2003). A totally different type of game is obtained by combining the intellectual appeal of classic board or card games with the physical involvement of location-based games, that is, by merging strategic elements from the former with real-time locomotion from the latter. A typical example of this type of game design is *CityPoker* (Kiefer & al. 2005). Although the idea to directly map classic board games to the real world is not entirely new, see Nicklas & al. (2001) for another example, to our knowledge no general framework for location-based games with strategic elements has been presented yet.

The contribution of this paper consists in defining and implementing a framework which helps a game designer to create a challenging location-based game. A game is considered *challenging* if it addresses both, the player's reasoning skills and the player's motoric skills. Neither a chess tournament nor a 100 m sprint would constitute a balanced challenge in this sense. We are looking for games blending chess-style and sprint-style elements. The main body of the paper is structured as follows. In section 2 we show that a straight-forward spatialization of a board game leads only to trivial non-challenging location-based games. A general solution to the problem of spatialization is proposed. Section 3 introduces the conceptual framework which defines a large class of geogames. The geogame analysis tool allows the game designer to find the critical parameter values which determine the game's balance of reasoning skills and motoric skills. As an illustration of the design method, a location-based version of the game TicTacToe is analyzed in section 4. Finally, related work and future research directions are discussed (section 5).

2 Synchronization as Problem in Spatial Versions of Board Games

Board games come in many variants not all of which are intellectually as demanding as chess or Go. These two games belong to a large class of games that game theory describes, namely two-person games which are deterministic (no random element such as a dice exists) and provide full information about the game's state to each player (no hidden elements such as cards in the hand of the opponent exist). In the following we concentrate on this rich class of games as a source of inspiration for strategic elements for location-based games. Throughout the paper the term *board game* is used in this narrow sense. A well known and structurally simple instance of this class serves as our running example. In *TicTacToe* two players move alternately placing marks – the first player to move uses *X*, the second *O* as mark – on a game board consisting of 3×3 squares. The player who first places three marks in a row, a column or one of the two diagonals wins the game. If neither player wins, the game ends in a draw.

Physically, board games are played in figural space. To obtain a location-based version of the game, the game should be mapped onto vista or environmental space in a way that each move requires locomotion of the player introducing time as a new dimension in the game. We call the result a *spatial version of the board game* and refer to the process of producing a spatial version as *spatialization*. The straightforward approach to spatialization consists in mapping the game board to vista or environmental space by assigning a geographic footprint to each of the board's positions. To simplify matters, points are used as geographic footprints for *TicTacToe* board positions, that is, spatialization assigns a geographic coordinate to each of the 9 squares of the board. Players need to physically move to a board position in order to place a mark. The time it takes to complete a move therefore depends on the distance of the board positions in vista or environmental space. Note that it is not necessary that the geographic footprints of the *TicTacToe* board positions are arranged in form of a regular 3×3 array of points (left in Fig.1). In general, spatialization does not preserve the distance relationships that hold on the game board in figural space because this gives game designers an important additional degree of freedom (right in Fig. 1).

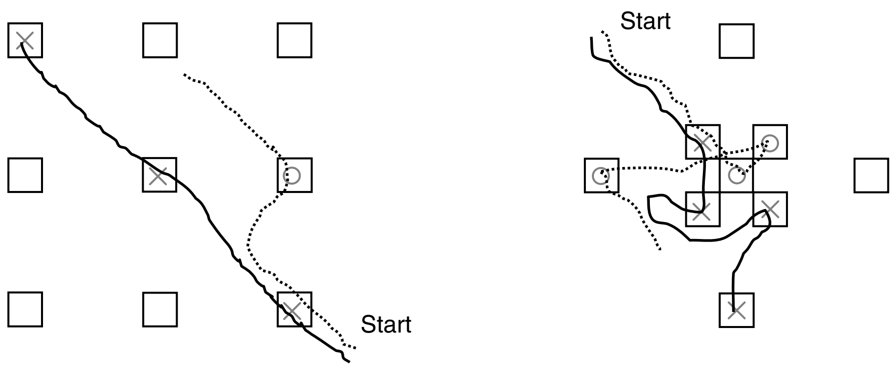

Fig. 1. Spatial version of TicTacToe played in vista or environmental space

Unfortunately, the straightforward approach to spatialization results in location-based games that are not challenging in the sense defined in section 1. The problem is due to the fact that the logical appeal of board games is linked to the complexity of the state space of the game which is altered drastically if the two players do not move in alternation. Consider the game illustrated by the left graph in Fig. 1. The traces of the two players' locomotion reveal that the X-player moves significantly faster than the O-player. Obviously, in this case there is a simple winning strategy for the player who moves faster: be the first to reach the lower right square, proceed to the central square and move to the upper left square at which point the game is won. This spatial version of *TicTacToe* amounts to a race between the two players which lacks any elements of strategic reasoning and therefore cannot be considered a challenging location-based game. In a game with strictly alternating moves, on the other hand, the players' speed has no impact at all resulting in a non-challenging board game.

The type of game one would like to see is illustrated by the right graph in Fig. 1. In such a game, moves are very often – but not always – played in alternation. To put it differently, the challenge of designing a location-based game from a board game consists in limiting the occurrence of multiple moves from the faster player. We call this the *synchronization problem* because it levels to a certain extent differences between the two players' speed resulting in a deliberately non-perfect synchrony of moves. We propose a surprisingly simple solution to the synchronization problem which is inspired by a strategy to resolve timing problems in computer hardware. After reaching a board position and placing the mark, a player is required to spend a certain pre-defined synchronization time at the position before moving on. It is to the game designer how to build this synchronization time into the game: Either the player might be forced to wait idle, or he could be obliged to perform some time-consuming tasks like solving a puzzle or searching an item. As we will show in section 5, the length of the *synchronization time interval* constitutes the parameter that determines whether the spatial version of a board game becomes a challenging location-based game or whether it deteriorates into a race-style game or classic board game respectively. For now, we just note that the synchronization problem is not a problem of the specific choice of geographic footprints and the starting position in the left graph of Fig. 1. It appears as an effect of speed difference between players in pretty much the same way in the right graph of Fig. 1.

3 Geogames

3.1 A Framework for Describing Location-Based Games

Although a spatial version of *TicTacToe* has some interest in its own, the aim of the designer is to possess a general method permitting to reuse board games as templates for location-based games. The descriptive framework for location-based games should handle other spatial versions of board games or games that could be considered such games as, for instance, *CityPoker*. Common traits of these games are: a fixed number (often but not always two) of *players* move between a fixed number of board positions called *locations* taking up and putting down resources when they reach a new position. A *resource* is anything that can be transported by players and deposed in locations, e.g. an *X*-mark or *O*-mark in *TicTacToe* or a playing card in *CityPoker*. The state of a game is defined by the locations of the players and by how the resources are distributed over players and locations. Actions are described as transitions between states. They describe the combined effect of moving from a location to new one and of taking up and/or putting down resources there.

Definition: Let P denote a set of players, L a set of locations and R a set of resources. A *state* $s = (location, resources)$ is a tuple of two mappings, $location: P \rightarrow L$ and $resources: R \rightarrow L \cup P$. By S we denote a set of states, usually the states of a game. An *action* a *on* S is a mapping $a: S \rightarrow S$. A set of actions is denoted by A.

The first basic constraint for actions is *spatial coherence*: a player can pick up or dispose of a resource only at the player's current location, and no resource may appear or disappear at a location without involvement of a player. To describe the temporal aspect that differentiates location-based games from board games, a duration is assigned to all actions. Game states are assigned a value which expresses the interest of the state for the players. In *TicTacToe* the values of interest are {*open*, *X-wins*, *O-wins*, *draw*} with the intuitive semantics that *open* is assigned to non-end states of the game. The length of the synchronization interval is specified by a constant. The second basic constraint for actions is *temporal coherence*: every action consumes time equivalent to the sum of its duration and the synchronization interval.

Definition: Let *S* denote a set of states and *A* a suitable set of spatio-temporally coherent actions. A *geogame* $G = (S, A, time, value, sync)$ consists of two mappings, $time: A \rightarrow \mathbf{R}^+$ and $value: S \rightarrow V$ where V denotes the value space for state evaluation, and a constant $sync \in \mathbf{R}^+$.

Although the definition describes a large class of games, not all location-based games are geogames. Most important, games that do not satisfy the spatio-temporal coherence constraints – in which resources magically jump around the board – are not geogames. A spatial version of *TicTacToe* which we call *GeoTicTacToe* can easily be described in a way that fits with the above definitions. The game is played by two players, $P = \{P_X, P_O\}$ on a board with locations $L = \{L_{11}, \ldots, L_{33}, Start\}$ where *X* and *O* are used as marks, $R = \{X_1, \ldots, X_6, O_1, \ldots, O_6$. The states of the game are described by their distribution of resources, for instance *start* = (*locationStart*, *resourcesStart*) with $locationStart(P_X) = locationStart(P_O) = Start$ and $resourcesStart(X_1) = \ldots = resourcesStart(X_5) = P_X$, and similarly for the resources denoting the *O*-marks. In practice, only the starting state is described explicitely while other states are constructed from applying actions to the starting state.

3.2 Geogame Analysis Tool

The synchronization time interval specified by the *sync* constant of a geogame has already received some attention. In principle, it would be possible to find suitable values for the parameter by playing and evaluating a large number of games in reality with different parameter settings. Although some successful games such as *CityPoker* were developed that way, it is hardly satisfactory as a general method for game design. The geogame analysis tool supports the designer to determine the *sync* parameter by systematically exploring the game's state space. As geogames are defined as a rather generic concept, the state space analysis must handle significantly more special cases than the analysis described by Kiefer et al. (2005) for *CityPoker*.

We assume that the players in a geogame always behave in the following way: They first decide which location to move next (several possibilities), then they move towards that location and arrive after some time. Now they select which resources to change, before they finally have to wait synctime and move on to the next location. The geogame analysis tool makes a number of additional assumptions, for instance, that players move as fast as they can and that they don't waste time by waiting longer than the synchronization interval. Finally, rational players are assumed who try to win the game. With these assumptions, the geogame analysis tool explores the state space using a generalization of the minmax algorithm (see Russell and Norvig (2003) for a description of standard minmax). The generalization handles multiple players and determines the next player to move by the time units players need for their actions. The modifications of minmax are not trivial. Consider, for example, two or more players arriving at a location in the same instance of time, i.e. with remaining time units 0 (concurrent resource change), necessitating the incorporation of randomized elements (see Kovarsky and Buro (2005) as an example). Furthermore, appropriate pruning strategies become essential for state spaces larger than the one of *GeoTicTacToe*.

A geogame ends when an end-of-game condition becomes true. End states are evaluated using an evaluation function that is derived from the *value* mapping of the geogame. The result is propagated through the tree similar to standard minmax until the starting state is reached. Finally, the values at the starting state induce a ranking of the players and thus represent the outcome of the game under the assumption that all players act optimal. This ranking gives the game designer a first idea about the fairness of the game he has created: a completely fair game ends with all players having the same rank. Note that fair games are not necessarily challenging in the sense of the definition of section 1.

The geogame analysis tool is implemented using a flexible architecture with the four layers *search mechanism*, *geogames engine*, *concrete geogame* and *parametrized geogame*. This architecture allows to easily model and analyze any geogame and to experiment with different search mechanism with only little effort.

4 GeoTicTacToe: A Case Study

With the help of the geogame analysis tool an appropriate value for the synchronization time interval *sync* can be found. We describe the analysis of *GeoTicTacToe* for the case where the *X*-player is 10% faster than the *O*-player. Keeping this speed ratio fixed, synchronization time was varied between 0 and 12 in steps of 0.1. Three types of results were logged for each set of parameters. (1) The *ranking of the players* for which there are two possible outcomes as the slower *O*-player is not able to win: *X*-player wins and the game ends with a draw. (2) The *depth of the game*, that is, the number of *X*- and *O*-marks that have been made when the game finishes. Each end state has a depth value between 3 (one player could set three marks) and 9 (all marks have been set) which is propagated through the tree along with the corresponding evaluations. Having the choice between two winning successor states, a player would prefer the one with lower depth. Obviously, depth correlates with the ranking: A depth of smaller than 9 always comes along with a win for the *X*-player. On the other hand, a depth of 9 could result in either a win or a draw; nevertheless, we did not have any win situation at depth 9 in our study. (3) An *optimal path* through the game tree which corresponds to the game in which both players act optimally. Usually, more than one optimal path exists.

Fig. 2 shows the results for *GeoTicTacToe* played with the geographic footprint configuration illustrated in the inset which is the same as the one shown in the left graph of Fig. 1. Note that the grey square denotes the common starting point of both players. The result very clearly shows the effect of the length of the synchronization interval. For small values of *sync* (*synctime* in Fig. 2), the depth of the game does not exceed 4 or 5 respectively. These are games which the faster *X*-player wins by racing. The *O*-player cannot prevent the *X*-player from setting the *X*-marks in the diagonal.

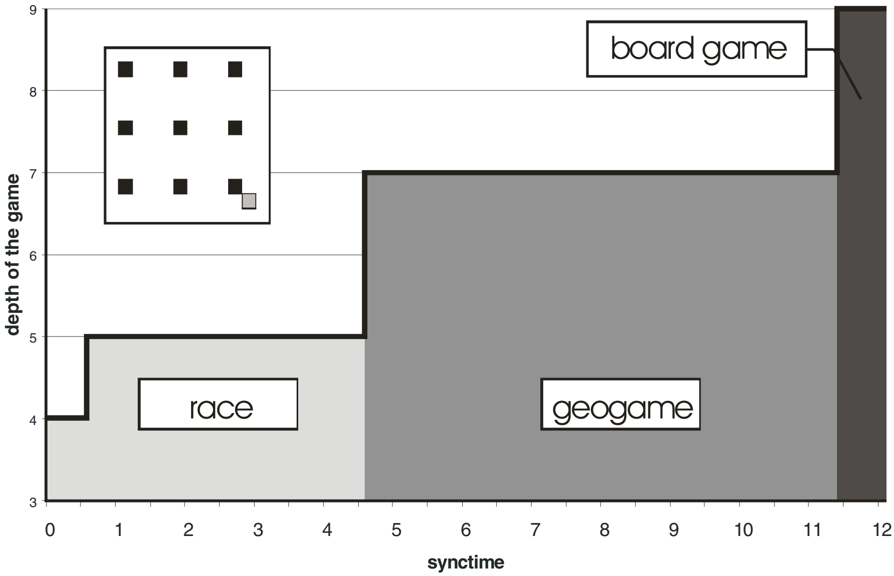

Fig. 2. Depth of the game for varying synchronization intervals for *GeoTicTacToe*

On the other hand, high values for sync (synctime in Fig. 2) lead to alternating moves of the two players as in the board version of TicTacToe. We conclude that the interesting range for the parameter sync lies between 4.6 and 11.3 and leads to games that end at depth 7.

Fig. 3 illustrates an optimal path (course of the game) for sync=10. Here, the *X*-player has to wait long enough at the first location to allow the *O*-player to set an *O*-mark in the centre. With the next move, the *X*-player forces the *O*-player to move to the top right corner which opens up the possibility to fill in the missing *X*-marks in the bottom row with the *O*-player being too far away to reach the lower left corner in time. This type of move sequence which blends logical reasoning with physical locomotion is generally found at depths between 6 and 8 and creates just the kind of game that can be considered a challenging geogame.

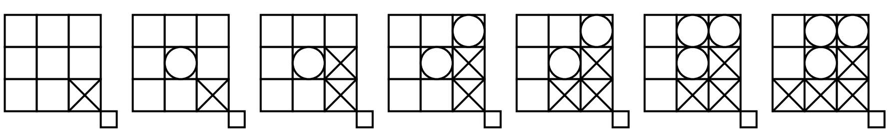

Fig. 3. Challenging geogame (optimal path) at *sync*=10.0

With the geogame analysis tool also the effect of different choices of geographic footprints is easily studied. Fig. 4 shows a depth versus *sync* plot comparable to that of Fig. 2 but for the geographic footprint configuration shown in the right graph of Fig. 1.

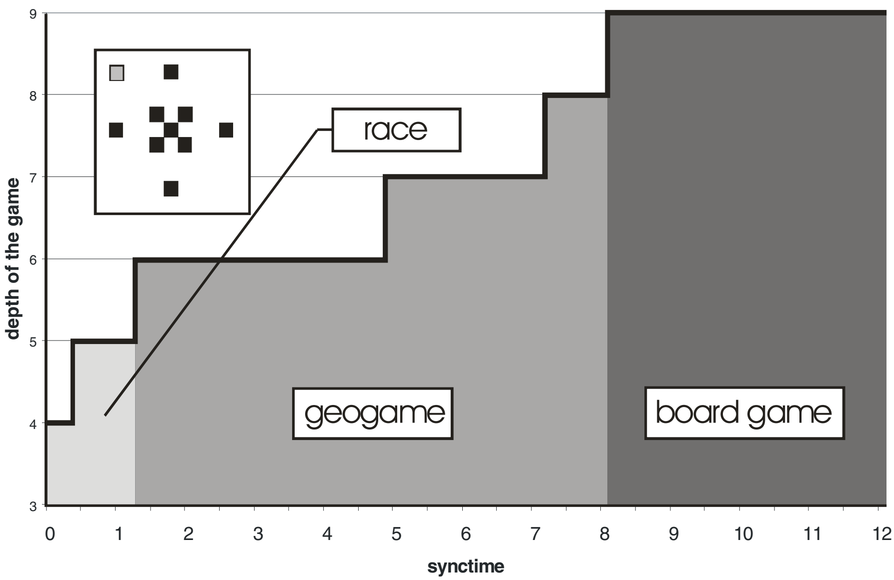

Fig. 4. Depth of the game for varying synchronization intervals for *GeoTicTacToe*

Without going into detail, we note that different boundary values delimiting race-style games, challenging geogames, and classical board games are found. In other words, the choice of the geographic footprints has an effect. We can derive even more from the analysis: the footprint configuration from Fig. 4 promises more interesting games than that from Fig. 2 since all depth values between 3 and 9 actually occur. To sum up, we propose to choose a synchronization interval within the value range corresponding to challenging geogames with game depth between 6 and 8. The exact choice within this range is left to the designer giving him the freedom to put more emphasis on speed or on reasoning. Certainly, any other choice of geographic footprints for GeoTicTacToe or other assumptions about the speed ratio *X*-player and *O*-player may be analyzed the same way.

5 Related Work and Future Research

We have described a conceptual framework defining geogames and a tool for analyzing them, especially with the goal of tuning the game to be challenging. The game designer may now proceed as follows: (1) select a classical board game with interesting strategic elements, (2) choose alternative sets of geographic footprints in vista space or environmental space for the board positions, (3) model the resulting location-based game within the conceptual framework of geogames, (4) use the geogame analysis tool to derive interesting values for the *sync* parameter.

Location-based real-time games abandon the idea of turn-taking of classical board games. Nicklas et al. (2001) observe a consequence, namely that "*lifting turn-based restrictions can make a game unfair*", and propose a solution which is inspired by methods of allocating machine resources to concurrent processes. Similarly, Natkin and Vega (2003) and Vega et al. (2004) show how to assist the game designer in finding dead locks in the game flow using Petri-nets to describe the game. This type of research focuses on concurrency but does not address, yet answer the problem of synchronization that characterizes the difference between race-style games, challenging geogames and classical board games.

AI techniques, like variants of minmax-search, have been applied to board games and are constantly improved to create increasingly smart computer opponents, e.g. for Othello (Buro 1999). This is an interesting line of research; however, the focus of our paper is not the development of optimal search algorithms or pruning strategies.

Although most location-based games have been developed for environmental space, our analysis showed that this is no fundamental limitation. In a vista space version of *GeoTicTacToe* two players are moving each on a dancing mat with the geographic footprints of the game board (Fig. 5). The state of the game is communicated through a wall-mounted display. Synchronization is easily achieved: when a player reaches a board position, a small *X*- or *O*-mark appears on the display which changes to big size when the synchronization interval has passed and the player is free to move on. Note that on a small game of the size of a dancing mat, the synchronization time interval would be very small, e.g. some seconds.

Comparing different spatializations of Geogames starting with *GeoTicTacToe* in vista space and environmental space will be subject of future research. As another location-based game we will map the above-mentioned game *CityPoker* to the Geogames framework. Even a spatialization of chess with modified rules is imaginable and would hold some further interesting synchronization problems. These rule modifications could be inspired by existing modifications of chess which lift turn-based restrictions like “progressive chess” or “double move chess” (see e.g. http://www.chessvariants.org/).

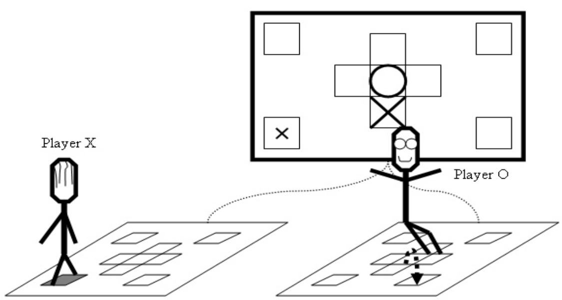

Fig. 5. *GeoTicTacToe* played in vista space at home

Furthermore, we plan to build into our model a parameter for the players’ cleverness. Imagine one player spending much time on reasoning but moving slowly, while the other player is moving fast but does not invest much effort in thinking. Simulating games with this constellation could make up an interesting case for testing the relationship between reasoning time and acting time. By varying one player’s search depth and the other's speed, the balance of speed against reasoning could be emulated. This would also help in the design of a virtual smart opponent as described in Kiefer et al. (2005).

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