Supporting Wayfinding through Patterns within Procedurally Generated Virtual Environments

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ABSTRACT

Procedurally generated 3D worlds pose their own problems in terms of user's navigation. The rules for supporting wayfinding through specific world generation have to be categorized and implemented in the generative algorithms. Our answer to this problem is based on a combination of the architectural theories by Lynch and Alexander. We adjusted a procedural world generator to include selected patterns as suggested by these theorists. Unlike other research, we put our main focus not on an arrangement of obvious landmarks but instead on the organization of objects that form patterns of much smaller scale in their spatial combination to trace how players structure and comprehend these environmental patterns. Our hypothesis was that these small-scale patterns would assist player navigation in procedural worlds. We tested our model in the procedural world generator *Charbitat*. Statistical analyses showed no significant effect of environmental patterns on player navigation. However, post-experiment questionnaires indicated that users were aware of the patterns and had used them for orientation. This suggests that while patterns were sought after, they alone apparently were not sufficient to improve user navigation in the 3D world.

Keywords

Gaming, navigation, procedural, virtual space

1. INTRODUCTION

Procedural world generation is emerging as a new way of content generation in video games. On the one hand, it supports traditional game features such as automated level generators. On the other hand, it provides high level detail environments for next generation game engines with relative ease and allows for new game concepts that explore the feature of content generation at their very core. During our own work with procedurally generated 3D worlds in the *Charbitat* project we noticed that the generation of the world itself – although challenging – was not the main and certainly not the final problem in this area. Instead, the question how to use, read, and comprehend these worlds became central the moment players started to actually interact with them.

Charbitat is an experimental game project that investigates procedurally generated, navigable, 3D virtual environments. Terrain is created during runtime and objects in the landscape are positioned and selected based on generative algorithms. This 3D world is implemented in a case study designing procedural game spaces. The algorithms used to manipulate the terrain and to position objects accept parameters that can be affected by the user's actions. Actions that the user performs change these underlying seed values and cause the environment to be generated differently. The result is a user-driven 3D space that combines to an infinite game world that grows larger as the player continues to play in it [Nitsche et al. 2006]. Like any other 3D virtual world, this environment has to support a number of functions to remain accessible and comprehensible; one of them is to support a player's navigation of the world.

Figure 1 Screenshot of the original version of *Charbitat*

In order to facilitate user navigation within *Charbitat*, we experimented with the generative algorithms to take guidelines for supporting wayfinding into account. The aim was to implement and test a procedural method for structuring 3D spaces. This paper will discuss how users' wayfinding ability within *Charbitat* changed in relation to specific spatial configurations placed in the environment. The data gathered may be used to find new techniques of object placement and orientation within a procedurally generated environment and inform future 3D world design.

It is largely accepted that players navigate virtual worlds by making sense of the space in a manner very closely related to the way they read physical "real" space. Consequently, spatial design patterns for real and virtual environments are often connected. For example, Parish and Müller generate cityscapes procedurally from road layout to building assemblies and facades [Parish/ Muller 2001]. Norman Vinson suggests higher level frameworks for designing virtual environments based on studies of human navigation within real environments [Vinson 1999]. Darken has tested multiple facets of navigation in virtual work, and found that users recognize a landmark in relation to their presence within the virtual environment which, in turn, impacts their orientation skills [Darken et al. 1999]. However, most of these studies of wayfinding within virtual environments focus on static spaces. They were not designed, implemented, or tested in procedural worlds. Environments that algorithmically create spatial elements

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lack the conscious (or sub-conscious) arrangement of terrain and objects by a level designer. Instead, they are the result of a given rule system that operates precisely, can be replicated, and adjusted to new conditions. This paper reports on the findings regarding our implementation of rules we adopted from Alexander's pattern language and Lynch's model for cognitive mapping in this world generation.

2. PROCEDURAL OBJECT PLACEMENT

2.1 Alexander's Patterns

In "A Pattern Language" [Alexander/ Ishikawa/ Silverstein 1977], Christopher Alexander, Sara Ishikawa, and Murray Silverstein describe 253 architectural patterns they derived from existing real world structures. The patterns comprise an archetypical language for what Alexander has termed the "one timeless way of building" [Alexander 1979] which emphasizes the liveliness of architectural structures. "Liveliness" relates to the degree in which these patterns reflect and support the human use of architectural structures. Based on existing arrangements, these patterns present a valuable bridge into the real world architecture when applied to virtual environments. The patterns vary in scale and context and range from the materials that should be used when developing a building to the differences between tree arrangements. For instance *Pattern 1 'Independent Regions'* describes regional arrangements in large urban areas while *Pattern 253 'Things from Your Life'* suggests wall hangings for individual rooms. While the majority of Alexander's patterns are germane to the architecture of urban environments, some can be applied to game worlds to create designs familiar to users.

Alexander's patterns can be used when procedurally generating individual cities or a series of towns. Out of the 253 patterns listed within Alexander's work, the first 94 patterns deal with the way whole towns and communities can be organized. The parameters listed in the pattern *Distribution of Towns* (2) describe how far apart towns of certain sizes are from one another. They can be used within an algorithm determining the layout of a series of towns. If one was to procedurally generate the roads within a city by a body of water, the pattern *Access to Water* (25) would provide useful advice stating that roads are typically orientated in right angles of the water.

Patterns that describe room lay-outs within different types of buildings can be used to provide variety when procedurally generating buildings within a city. The *Holy Ground* (66) pattern describes buildings that are used for religious purposes. They are typically made up of a number of nested precincts that gradually get smaller, ending in a room that can be referred to as the innermost sanctum. This room can only be reached by passing through each gateway of the outer precincts. In the *Intimacy Gradient* (127) pattern, Alexander describes how all buildings should have rooms that are more public near their entrances. These public areas should lead to slightly more private areas which lead to the most private rooms in the building.

Pattern 120 'Paths and Goals' specifies that landmarks have to be sufficiently separated from one other to facilitate walking between them, but they have to be within line of sight so that the player can know how to get to the next landmark. Ljungström provides examples of this pattern in *World of Warcraft* [Ljungström 2005]. *High Places* (62): There should be occasional high places within a city. Increased elevation in a procedurally generated world would allow a player to survey the area that he or she has covered. *Tree Places* (171), Alexander lists three main types of tree arrangements that have different meanings to a person in the space. An umbrella arrangement serves as a place for someone to sit or rest. A pair of trees serves as a gateway. A grove is a circle of trees with space in the center that separates the inner space from the outside. An avenue is a double row of trees that serves a path to another location.

For this study, we concentrated on the patterns that were listed in the *Tree Places* section as it related most directly to the world generations in *Charbitat* that generate mainly virtual outdoor scenarios. Alexander believes that trees have "a very deep and crucial meaning to human beings." [Alexander/ Ishikawa/ Silverstein 1977] He goes on to state that there is an "indication that trees, along with houses and other people, constitute one of the three most basic parts of the human environment." [ibid.] We attempt to utilize this fundamental aspect of an environment by populating the test world with basic objects and textures that map to tree structures. We modified the world generator to spawn objects in Alexander-like patterns. The first question was, whether players would recognize these patterns during play testing. A single pattern provides for orientation only in its immediate vicinity, not covering the necessary breadth needed for a navigation exercise. Thus, we spawned these patterns all over the 3D world in the hope that players would start to assemble them into more complex cognitive patterns as suggested by Kevin Lynch.

2.2 Lynch's Elements

In "Image of the City", Kevin Lynch describes five types of elements that people use to form cognitive maps of urban environments [Lynch 1960]. These five elements are:

- Landmarks: that often have some unique feature that lets them stand out as singularities in the environment
- Paths: that indicate a direction and might be channels that an observer travels
- Edges: that provide a form of (not necessarily impenetrable) border
- Nodes: that can include junction points or a strategic point for decision
- Districts: that often use homogeneous elements in, for example, façade, material, or skyline which distinguish them from other zones

His model has been applied to virtual environments in numerous projects as analytical tool (as seen in Darken) and as design guideline. For an early example, see Strohecker, Barros, and Slaughter's *Placeholder* project [Strohecker/ Barros/ Slaughter 1998]. Its value for the design and comprehension of virtual spaces is widely discussed and generally accepted. *Charbitat* features multiple structural characteristics that Lynch describes in his work as supportive of a player's ability to form cognitive maps.

Most of the projects dealing with Lynch's model operate on the level of landmarks and large-scale orientation and navigation helpers. In addition to these (often obvious) arrangements, we wanted to examine how the less obvious pattern structures suggested by Alexander can serve as navigational helpers and support the generation of a cognitive map of the virtual world as proposed by Lynch. Thus, our approach differs in two significant ways from past research:

1) rather than concentrating on navigation along clearly marked "unique" and "singular" landmarks, we investigate small-scale patterns;

2) instead of fixed virtual environments that often include conscious or sub-conscious design patterns, we present and test a system in a procedural setting.

Two questions motivated our research: First, we wanted to determine whether the patterns are indeed recognized by players. An affirmative answer would prove the functionality of our procedural generation and the value of patterns as such. Second, we wanted to find out whether players can use these patterns alone to effectively navigate the 3D world.

Our hypothesis was that a procedural implementation of a selection of Alexander's patterns will assist players' navigation of a virtual world as players will recognize these patterns and use them for spatial reasoning in the way suggested by Lynch even in the absence of other markers.

3. STUDY OF PLAYER NAVIGATION

3.1 Approach

In previous *Charbitat* installments a number of Lynch-like structures were actively supported. Procedurally generated rivers and sea shores referred to possible edges, roads to paths, extremely rare 3D objects or especially high ones could be seen as unique landmarks. Numerous clearly distinguishable objects of varying size, color, and texture were positioned in the generated game world (see fig. 1). A random noise function was used as the main factor in positioning the environmental objects and algorithms controlled consistency of larger scale objects (e.g. a river would run continuously through multiple sections of the environment). Instead of random placement, the pattern-infused version applied certain patterns established by Alexander to the arrangement and spatial relationship between the visible objects in the 3D world. The selected patterns were:

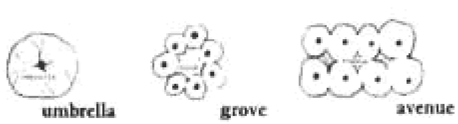

Figure 2 Picture from "A Pattern Language" showing three tree patterns

The project deliberately concentrated on the recognition of these patterns as opposed to singular objects and elements. That meant that individual objects forming these patterns could not have any unique traits. To avoid possible unintended recognition of individual objects as landmarks in the testing environment, we replaced the descriptive geometry of the original *Charbitat* environment with abstract shapes called geons.

Geons are basic geometric shapes that have been proposed, within the recognition-by-component theory [Biederman 1987], as a way people segment their viewing of complex objects.

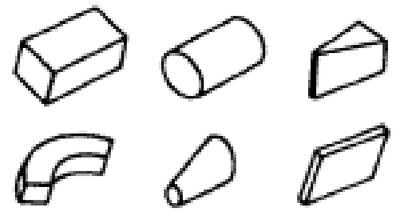

Figure 3. A subset of geons from Biederman's Recognition by Component Theory

The theory proposes that people map basic shapes such as rectangular blocks or curved cylinders onto certain portions of the object they are viewing depending on how close the components of the viewed object match the basic shapes. Although geons are abstract, they remain recognizable and distinct. That means that while the individual geon does not appear as a single unique landmark object, it is sufficiently distinct to help the user distinguish between each type of environmental object.

The user's avatar will be unable to move or see through these environmental objects. They act as obstacles as well as visual cues for the user. We used four different types of geons to construct the objects within the 3D environment: the rectangle, cylinder, rectangular pyramid and the cylindrical pyramid.

Figure 4. Example of a geon next to the avatar in the 3D environment

At the same time, the detailed texturing at work in the original *Charbitat* project was reduced to minimal differences in the texturing of the geons. This additional graphical limitation was applied to prevent that individual outstanding objects could be defined by their material and used for orientation. Ultimately, geons provided the necessary variety of objects but care was taken to avoid the generation of obvious singular landmark objects. This design feature of the Charbitat world was intended to make recognition of individual objects more difficult, and instead to direct a user's attention to the spatial relationships between them. Alexander's patterns were included into the world generating algorithms of *Charbitat* and realized as spatial patterns formed by geon objects in the 3D world.

Our hypothesis was that this kind of micro-structured landscape will facilitate players' navigation through the 3D world.

3.2 Design of Experiment

To test this hypothesis, players were assigned to one of two groups: One group navigated through a procedurally generated environment with geon objects placed according to Alexander's patterns; the control group navigated through a procedurally generated environment with randomly placed geon objects.

The study involved three different phases. In the first phase, floating key objects surrounded a player's avatar (see fig. 5). The keys were placed in the world slightly above the avatar, so a player-avatar had to jump to make contact with a key. Once the player had made contact with a key, it disappeared permanently from the world. Players were asked to have their avatar touch all 5 keys in order to familiarize them with the controls of the system. All necessary control options had to be performed by a player to succeed in this phase: movement of the avatar, jumping, and camera control. Data collected from this portion of the study were not included in assessing players' navigation performance.

The second phase started with a navigation task that required players to explore the world. Players were informed that there was another key (just like the ones used in the first stage) hidden in the game world and that they had to find it. Data collected from this portion of the study were used to examine whether experimental and control groups exhibited different movement patterns while searching the 3D environment. We hypothesized that environmental patterns will help players to better structure their search.

The third stage was initiated once players found the last key. At that point, players were asked to find their way back to the place where they had started their search. Data collected from their return trip was used to determine whether players had created a cognitive map during the search phase that aided them to find their way back.

Upon completion of the game, players received a questionnaire. Two demographic questions concerned players' gender – as research has shown that male and females use different strategies to navigate within an environment [Lawton/ Kallai 2002] – and familiarity with virtual 3D environments (rated as either "very familiar," "familiar," "less familiar", or "entirely unfamiliar"). Three questions probed players' game experience. Players were asked to indicate how difficult it had been to find the way back to the origin. Answers for that question range from Very Easy to Normal to Very Hard. An open-ended question probed players to describe any strategy they had used to navigate back to the starting point. Lastly, players were asked to provide an adjective that described the game world and whether they would have navigated through the world longer if given the opportunity.

3.3 Setup and Configuration

The *Charbitat* modification used for this test runs on consumer level PCs using keyboard and mouse as input devices. It is based on a modification of the *Unreal Tournament 2004* game engine. The world generation is computed in an independent Java program, which also tracked the user behavior in-world.

At the beginning of each game players were presented with their avatar inside the *Charbitat* world. The avatar's control scheme followed established conventions of 3D games and virtual worlds. Players could move their avatars forwards, backwards, and strife left and right by using the 'w', 's', 'a' and 'd' keys respectively (or the up, down, left and right arrow keys). The camera was consistent with game conventions: it was a following camera positioned behind and above the main avatar. The mouse controlled the orientation of the camera which in turn re-oriented the avatar in the world.

As players navigated through the game world (the pattern-infused, or the randomly arranged environment), our system automatically traced the position of their avatars and stored this information to a file along with a time-stamp (see Figure 6). This allowed us to re-trace and interpret the movements of a player in the game world.

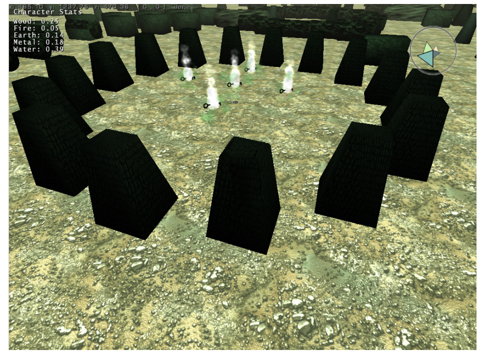

Figure 5. The starting location of a user within the patterned 3D environment

Finally, we had users fill out the aforementioned questionnaire to provide additional feedback on their overall experience. In-game data and questionnaires were stored along with random ID numbers to allow for correct cross-referencing of player responses while assuring participants' anonymity.

3.5 Participants

50 individuals, mostly students, took part in the study. Participants were randomly assigned to the experimental or control condition. Eighteen males and seven females were in the control group. The experimental group consisted of fifteen male and ten female players.

4. RESULTS AND DISCUSSION

4.1 Measurement of Player Movement

Data collection started with the second phase, i.e., the search for the final missing key. An alpha level of .05 was used for all statistical tests. Significance testing involved Analysis of Variance with game condition (control versus experimental) as independent variable, or when the assumption of normality was violated, the two-sample Kolmogorov-Smirnov (K-S) Test, or where appropriate the Spearman rank correlation (r_S).

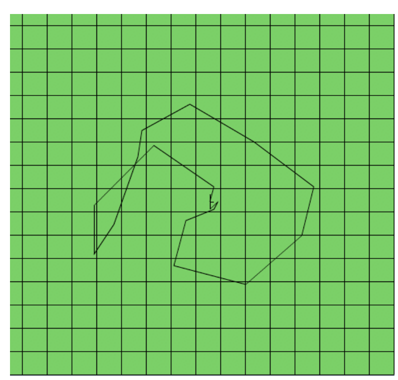

Figure 6 Visualization of one player's path through the 3D world (experimental group)

Players in both groups found the final key and were able to return to the game's starting point. To examine players' navigation and search behavior, we divided the game world into a 16x16 grid of zones and recorded each time a player passed through a zone in the grid, thus tracing his or her path, its length and shape. The same measures were taken during the return phase of the game, in addition to the amount of time players took to get back to the origin.

Contrary to expectations, no significant differences between the control (random) group and the experimental (patterned) group were observed concerning the length of the return trip (*K-S Z*(50) = .707, *p* = .699), nor time needed to navigate back to the starting point (*K-S Z*(50) = -.029, *p* = .98).

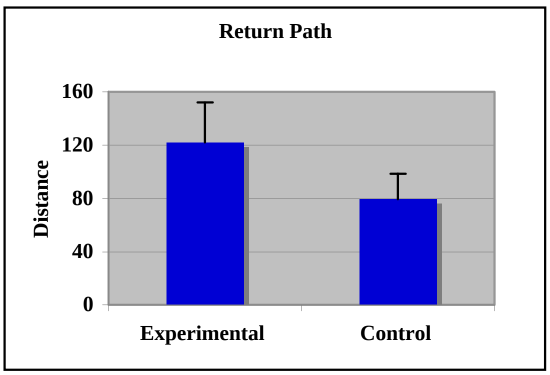

Figure 7. Average length of the path players in experimental and control groups traveled to return to the origin from the location of the key

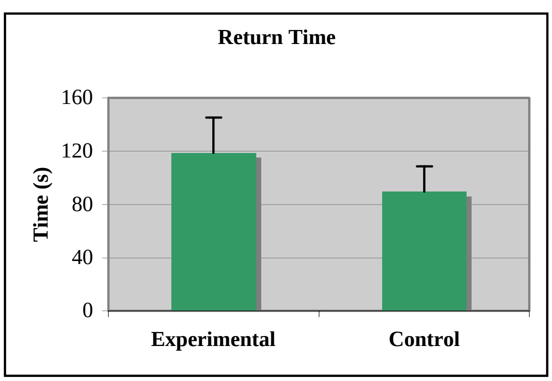

Figure 8. Average time players in experimental and control groups took to return to the game's origin

Experimental and control groups also did not differ significantly in terms of the size of the area (= number of grids) they covered while searching for the final key (*F*(1,48) = .155, *p* = .70).

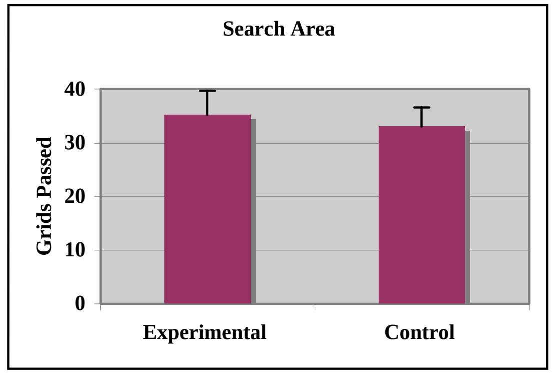

Figure 9. Average number of grids passed by players in experimental and control groups while searching for the key

However, when we examined the paths players took during their search and return trip we noted that the navigation by participants in the experimental (patterned) group tended to have a structure while control subjects showed more random movements. This difference may suggest that subjects in the experimental group who moved through a patterned environment proceeded in a more goal-oriented fashion than the subjects in control group who faced a randomly generated world.

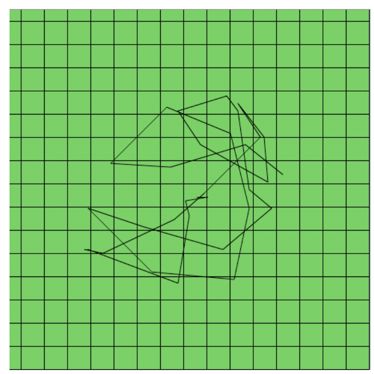

Figure 10. Visualization of a player's path through the 3D world within the control group

Two different navigation behavior characteristic of experimental and control subjects are depicted in Figures 6 and 10, respectively. As can be seen the path taken by experimental subjects appears compact and neat; in contrast the path observed for control subjects seems round-about, with many detours.

This difference suggests that the patterned environment influenced how experimental subjects navigated the game world; however, the impact of the patterns apparently was not sufficiently strong to build an accurate cognitive map of the game space as experimental subjects were not more effective or faster to return to the point of origin than control subjects. Factors that may have moderated the effect of environmental patterns, will be addressed in the next section.

4.2 Player Variables and Perceptions

Control and experimental subjects differed in terms of their experience with 3D games (X^2(N=50; df=2) = 9.441, *p* = .009). Specifically, as can be seen in Figure 11, control subjects indicated higher familiarity with 3D virtual environments than experimental subjects. Moreover, participants' familiarity with

3D games was negatively correlated with their judgments of how difficult it was to navigate back to the game's starting point ($r_S(50) = -.51$, $p = .000$). That is, participants who thought the return trip was "very easy" or "easy" were predominantly (88.9%) those reporting high familiarity with 3D games. This finding suggests that players' game literacy may have influenced their navigation behavior and may have moderated the effect of the visual appearance (patterned or random) of the game world.

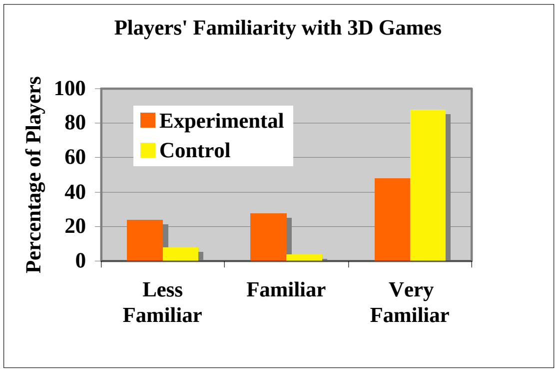

Figure 11. Levels of game familiarity reported by players in experimental and control groups

Participants' descriptions of the game world revealed that we had succeeded in generating a world devoid of singular landmarks. Participants in both groups perceived the game world as nondescript (22% of respondents), maze-like (16%), barren (14%), intimidating (6%), or cluttered (6%). Despite the plain appearance of the game environment, players tried to find visual cues that could guide them on their way back to the game's starting point. While experimental and control subjects mentioned strategies in the post-experiment questionnaire, they did so with different frequencies (X^2(N=50; df=3) = 19.84, p = .000) and, more importantly, referred to different cues. Most (60%) experimental subjects stated they had identified certain patterns in the environment and had looked for them during their return trip. The remaining experimental subjects indicated that they had focused on some significant landmark (12%), or had relied on the outer edges of the 3D space as reference (4%). This latter strategy was the dominant strategy reported by control subjects (32%); others mentioned landmarks (16%), or some pattern (4%).

This finding suggests that a majority of players in both groups attempted to construct a cognitive map of their game environment utilizing whatever visual clues the game world afforded them. Control subjects navigating a randomly generated world used the edges of their world as their only available marker. While this behavior is consistent with Lynch's typology of cognitive map elements, the edges in our game world were too uninformative as to facilitate spatial orientation. For participants in the experimental group, in contrast, outer edges were apparently less salient than the patterns of objects present in their virtual environment. Consistent with our hypothesis, experimental subjects were sensitive to the Alexander patterns; yet their pattern recognition did not improve their spatial understanding. One possible explanation is that experimental subjects failed to appreciate the spatial relationships between patterns. Thus, the 3D world remained a puzzle to them. While individual chunks were discerned, they could not be integrated into a coherent overall picture.

5. FURTHER RESEARCH

Local patterning seems to be a useful design feature of procedural worlds because players are able to recognize even highly abstracted implementations of these spatial structures. However, our research suggests that players may not be able to construct an accurate cognitive map of a game world on the basis of these patterns alone. One possibility is that players may also need a certain amount of more unique landmarks to support cognitive maps, either in the form of special texturing or in the form of dominant patterns, such as Alexanders "high places."

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