SQUARELAND 2.0: A flexible and realistic virtual environment for investigating cognitive processes in human wayfinding

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Abstract

We introduce the new version of our virtual environment (VE) SQUARELAND. As its predecessor it enables researchers to create human wayfinding experiments with variations in route length and complexity, as well as in the availability of route information and landmarks. A newly developed aspect is that test participants can be given active movement control. Now it also is much easier to create experiments in which participants are passively moved through the virtual environment. SQUARELAND 2.0 comes as a standalone executable file with easy setup controls. It was programmed in the game engine Unity (Unity Technologies©) and is licensed under the General Public License (GNU). It is highly adjustable and usable for many research questions in spatial cognition science.

Keywords: virtual environment, wayfinding, landmarks, salience, spatial cognition, spatial information processing, spatial learning, memory

Introduction

In spatial cognition research human navigation and spatial orientation are two of the core topics. According to Montello (2005) navigation can be divided into two components: locomotion and wayfinding. Locomotion is the pure active or passive (i.e., to which amount a person can control the speed and direction) movement through an environment. Wayfinding is the related but planned movement to a certain destination (cognitive component).

Without the help of any means (e.g., maps and/or navigation systems) it is unlikely to reach distant goals if no mental representations of route knowledge can be retrieved from memory. By definition, such route knowledge

> "describes the path that one must walk to reach the goal by telling the individual what to do at the decision points on the route, e.g. turn right at the church, then the second street to the left. It is one-dimensional or 'string-like' and it does not necessarily involve the knowledge of the exact location of the goal." (Meilinger & Knauff, 2008, p. 14).

Since route knowledge includes a sequence of landmarks (Siegel & White, 1975) it becomes clear why landmarks are necessary for its acquisition (e.g., Daniel & Denis, 1998).

In general, a *landmark* can be any object that stands out from the surroundings and aids navigation (Lynch, 1960; Presson & Montello, 1988; Janzen & van Turennout, 2004; Caduff & Timpf, 2008). Landmarks are often used in route descriptions and increase their quality (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999).

However, what makes a certain landmark "useful" or "good" in comparison to other objects? Previous research found that landmarks at street intersections with a change of direction are better remembered (Lee, Tappe, & Klippel, 2002; Lee, Klippel, & Tappe, 2003). At most decision points, however, there is more than just one object (e.g., building) that may be used as a landmark. For instance, at a prototypical cross intersection (figure 1) there are four possible landmark positions next to the pathway (Röser, Krumnack, & Hamburger, 2013) and some landmarks probably possess a higher quality (salience) than others.

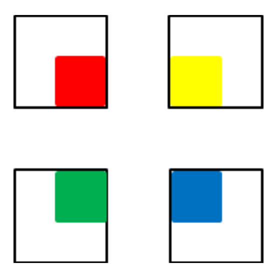

Figure 1. A prototypical cross intersection with four possible landmark positions represented by different colours.

To specify the quality of a landmark, several different theories were introduced in the past (e.g., Sorrows & Hirtle, 1999, Klippel & Winter, 2005; Caduff & Timpf, 2008; Röser, Krumnack, Hamburger, & Knauff, 2012). In these theories the term *landmark salience* is of central importance. This salience is often described as how much an object stands out from its immediate surroundings (Presson & Montello, 1988). Commonly, the salience of a landmark is divided into three dimensions:

- *Visual* or *perceptual salience* refers to colour, size, shape, etc. (Caduff & Timpf, 2008; Hamburger & Knauff, 2011; Röser, Krumnack, et al., 2012).

- *Semantic* or *cognitive salience* refers to knowledge-related features of a landmark like its meaning, function and name (Caduff & Timpf, 2008; Hamburger & Röser, 2011).
- *Structural salience* refers to a landmark's position along a route (Hamburger & Knauff, 2011). It can be either close to the route or more distant (for a detailed overview see Klippel & Winter, 2005). Further, the structural salience can be defined as "a preference of a wayfinder for a landmark to be located at a specific position at an intersection." (Röser et al., 2013, p. 3315).

Caduff and Timpf (2008) postulated a trilateral relationship between a potential landmark, its surroundings and the observer. This implies that the landmark's salience strongly depends on the context and on the perceiver (e.g., in an environment with black houses a red house is highly salient). To investigate each component of the trilateral relationship during a wayfinding task, as well as the landmark saliences in detail, a 3D virtual environment (VE) can have various advantages (e.g., higher controllability, replicability, etc.).

In the context of spatial cognition many researchers have already used virtual environments (e.g., Gillner & Mallot, 1998; Ekstrom et al., 2003; Janzen & van Turennout, 2004; Wolbers, Weiller, & Büchel, 2004; Stankiewicz, Legge, Mansfield, & Schlicht, 2006; Newman et al., 2007; Buchner & Jansen-Osmann, 2008; Hassabis et al., 2009; Wiener, Kmecova, & de Condappa, 2012). For their wayfinding studies Hamburger and colleagues were in the need of a cost-saving VE which is easy to use and consists of orthogonal street intersections. For instance, the VE Hexatown created by Gillner and Mallot (1998) was already used in wayfinding experiments, but is based on a hexagonal street raster (with 120 degree turns) which is suboptimal for at least one of the investigation purposes of Hamburger and colleagues: the structural saliences of landmarks. However, other VEs that consist of orthogonal intersections (e.g., Buchner & Jansen-Osmann, 2008) were created with commercial software or required special programming skills (e.g., Buchner & Jansen-Osmann, 2008).

Thus, Hamburger and Knauff (2011) created a VE called SQUARELAND which should serve for the investigation of landmarks and their salience in human wayfinding, as well as for many other research questions (e.g., route length and complexity, neural correlates of wayfinding, etc.). Their VE was developed in the freeware Google Sketchup 6.0©. It is easy to use, cost-saving, and offers a high standardisation, controllability and comparability. Due to its structure (10x10 block maze) each intersection in this virtual environment is constructed according to the layout depicted in figure 1. The tools in Google Sketchup© allow for placing landmarks at any location in the maze. These characteristics enabled a growing amount of spatial cognition research (e.g., Hamburger & Röser, 2011; Röser, Hamburger, & Knauff, 2011; Röser, Hamburger, Krumnack, & Knauff, 2012; Röser, Krumnack, et al. 2012; Bucher, Röser, Nejasmic, & Hamburger, 2014; Hamburger, Dienelt, Strickrodt, & Röser, 2013).

However, some limitations or difficulties with the use of SQUARELAND occurred. For instance, it is very time consuming to create a video sequence of passive maze walkthroughs, since no programmed coordinates can be used for defining the route. Hence, some of the experiments used a simple sequence of pictures for the presentation of routes (e.g., Hamburger et al., 2013). It can be argued that this type of implementation represents a rather unrealistic setup which may have an impact on an observer's performance. For example, compared to a static presentation of hallways with landmarks, a dynamic learning condition leads to a better recall of landmark information (e.g., sequential learning; Buchner & Jansen-Osmann, 2008). Furthermore, it was recently suggested that video sequences instead of a sequence of decision point pictures lead to significant effects concerning the structural salience of landmarks (Hamburger et al., 2013). These findings imply that the acquisition of route and landmark knowledge highly depends on the type of learning condition.

Another limitation of SQUARELAND lies in the impossibility to give active movement controls to a participant. If for instance, the indication of the direction of turn at a decision point is a subject of investigation, further software is needed. In the past such experiments were often setup using software like SuperLab (Cedrus Corporation©). However, this procedure included other limitations. On the one hand the creation of appropriate video material is even more time consuming (because the video sequences had, first of all, to be prepared and recorded and then to be split into many pieces). On the other hand it is too time-consuming and not very economical to implement full active movement controls. This implies, for example, that it is not possible to enable a participant with control of how fast he or she is moved or moving through a route. Since it was shown that active (self-directed) exploration can play an important role in the acquisition of spatial information (Feldman & Acredolo, 1979) this might be a critical feature of a VE.

Furthermore, some research questions require combining the exposure of a route with textual or even auditory information (e.g., presenting the direction of turn at an intersection). Tasks like the creation of verbal route directions or explaining the used wayfinding strategies could also be a subject of investigation. With SQUARELAND experimental setups like these were possible but limited.

The points mentioned above inspired and motivated us to develop a new, more powerful SQUARELAND. In this second version active as well as passive movement controls are available without the need for complex experimental setups. Moreover, a series of additional, useful tools was implemented. These tools and how SQUARELAND 2.0 was developed is explained in detail in the following.

The virtual environment SQUARELAND 2.0

General

SQUARELAND 2.0 was developed with the free version of the software Unity 4.3 (Unity Technologies©). Unity is a cross-platform game engine with integrated development environment (IDE, figure 2).

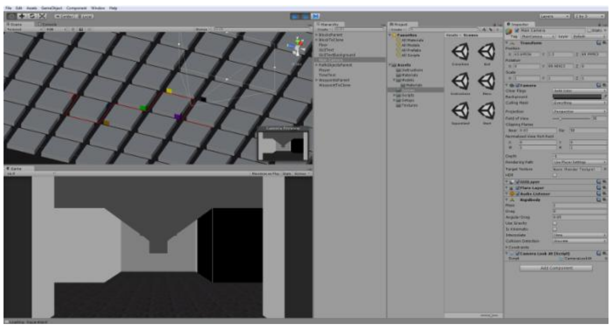

Figure 2. The SQUARELAND 2.0 project in the Unity IDE.

The purpose of SQUARELAND 2.0 is to simplify creating experiments in the field of spatial cognition and human wayfinding. Hence, it comes as a standalone executable file (for Microsoft Windows and Mac OS) with easy setup controls which means that Unity or any other software is not needed if the standard features are sufficient. The VE including an example experiment can be downloaded on the following webpage:

http://www.uni-giessen.de/cms/fbz/fb06/psychologie/abt/kognition/Forschung/weitere/squareland20.

Standard geometrical and textural properties

Like its predecessor SQUARELAND 2.0 consists of a ten by ten raster of cuboids. Each cuboid has a default size of 20 x 20 x 3.5 metres (LxWxH). A section of the facades of these blocks serves as possible landmark surfaces. At an intersection the visible corners of every block have two possible landmark facades resulting in eight surfaces which can be controlled individually. These two-dimensional surfaces have a standard size of 3.5 x 3.5 metres.

Moreover, the paths between the blocks have a default width of four metres and serve as routes in every possible manner. The bottom surface is textured with a brick texture. The blocks are coloured in light grey and the sky in light blue (see also figure 5). If the experiment is meant to be an indoor experiment, a grey ceiling is inserted.

The SQUARELAND 2.0 markup language

For controlling an experiment in SQUARELAND 2.0 (basic settings and the experimental procedure) an extensible markup language (XML) file is used. XML helps to create documents which can be easily analysed using a computer program but simultaneously are human-readable and easy to change. This XML file contains specific elements which, taken together, form the SQUARELAND 2.0 markup language (for an example see figure 3). Some of these elements have the purpose to change or declare basic settings like appearance or routes. Others are commands or actions that are executed at a certain moment of the experiment.

```
<form type="setup" />

<instructions>
    <instruction file="Instruction1.jpg" />
    <instruction file="Instruction2.jpg" />
</instructions>

<crosslines duration="5000" />

<squareland route="1" pause_time="5000" />
```

Figure 3. Excerpt of a SQUARELAND 2.0 markup language file.

However, in this paper we will not disclose the structure of the SQUARELAND 2.0 markup language. For a detailed documentation we refer to the above mentioned web address. Nevertheless, we will now introduce some of the possibilities and functions in SQUARELAND 2.0 which can be controlled by the XML file. This introduction will be split into two topics. The first topic will be about the main settings and properties that can be used and modified to fit individual needs. The second one will address the composition of an experimental procedure which can consist of elements (commands or actions) in various combinations.

Main settings and properties

Routes. In our VE a single route is defined by several intersections. Every intersection in the VE comes with an identifier that refers to the exact position of the intersection in the maze. For instance, the identifier *2;3* refers to the crossroad located in the second row and third column in the maze (figure 4). With the help of these identifiers multiple routes with different lengths and complexities can be created.

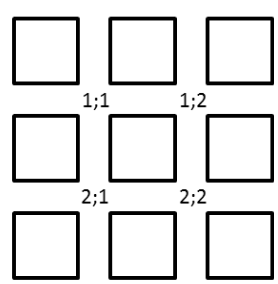

Figure 4. Excerpt of the SQUARELAND 2.0 maze in allocentric view. Each intersection contains its own identifier that refers to the position in the maze (for instance *1;2* for first row and second column). These identifiers are used for defining routes.

Moreover, at each intersection of the route, a maximum of eight (potential) landmarks can be implemented via the above mentioned block facades. Therefore, a landmark can only consist of either a RGB colour value or a picture file (e.g., jpeg) which is projected on the block facade.

Movement settings. In SQUARELAND 2.0 it is possible to choose from two different movement modes: active and passive. The active movement mode enables the participants to move self-directed on a given route. This movement, however, follows predefined invisible tracks which prevent participants from walking too close to a block or from bumping into it. As user interface the arrow keys of the keyboard as well as a Joystick or similar devices can be used. If the passive mode is chosen, however, the participants are moved through the maze. For both modes a movement speed can be defined (by default, the movement speed is 5 km/h).

Camera properties. A camera captures and displays the three dimensional virtual world to its observer. Within the SQUARELAND 2.0 markup language it is possible to modify the primary settings of a camera. These are the camera's field of view in its width and length and the distance between the camera and the bottom surface (or eye height). By default, the eye height has got a value of 170 cm which should fit for the majority of participants.

Haze. In order to prevent participants from seeing more than one intersection at once a haze can be implemented (figure 5). While the participant actively or passively moves through the maze, this fog remains in a constant distance in front of the observer at all times. The distance between the fog and the observer is exactly the distance which is necessary to see an intersection in total (with landmarks). If required, the distance of the haze can be modified with help of the XML file.

Overlays. It is possible to present information (e.g., route information like the direction of turn, see figure 5) to the participant while he or she moves through the maze. Such overlays can consist of simple text or pictures. By default, the text overlays consist of a black background and white letters. Because the position of an overlay much depends on the resolution of the used monitor, the exact location on the screen can be modified.

Geometrical and textural settings. It is possible to modify the size of the cuboids and of the landmarks. Also, the path width between the blocks can be changed. Furthermore, the colour of the sky as well as the block, surface and ceiling textures can be specified.

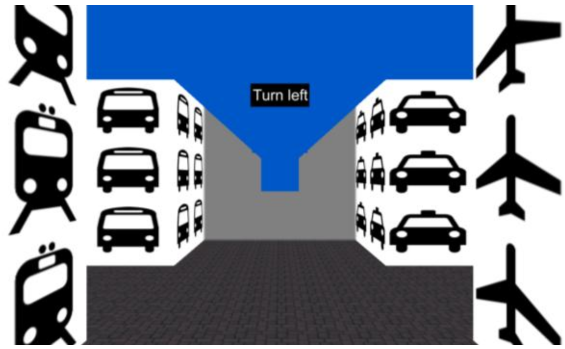

Figure 5. A typical intersection with four different potential landmarks. A haze is preventing from seeing more than one intersection. As the participant approaches the crossroad a text overlay at a predefined position can be displayed (here a route instruction).

The experimental procedure

SQUARELAND. The main feature of SQUARELAND 2.0 is the usage of the maze and the routes. This can be done as often as required and therefore it enables to implement various kinds of learning and retrieval tasks. For instance, it can be specified whether a route should be traced in the initially declared sequence of intersections or in opposite direction. This feature can be useful for experiments which want to systematically investigate the retrace of routes (initial versus return path).

It is also possible to declare whether a walkthrough should stop at intersections or not. If such stops are required, it can be chosen between a simple time stop and a decision stop. With a time stop the walkthrough stops for a given time at all intersections. Such a stop can be useful in combination with a text overlay asking to indicate the direction of the turn. With a decision stop, the participant has to indicate the direction of movement. For this purpose input controls can be specified. By default, the arrow keys of the keyboard are used. In the current version the walkthrough continues in the correct direction independently of what has been entered.

For each trial and participant a data file is created. In these files each keyboard response and the time of the response since the start is recorded as well as any other dependent variable.

Instructions. For almost any kind of research instructions are an important part of the experiment. In SQUARELAND 2.0 there is the possibility to display instructions in form of pictures as well as simple text. Instructions can be presented at any step of the experimental procedure. To prevent participants from accidentally skipping an instruction by pressing the space bar right after the text is shown, a minimum presentation time can be set.

Forms. In many cases different forms are needed to collect data from participants. In SQUARELAND 2.0 it is possible to build forms that consist of input fields for text as well as checkboxes (figure 6). This offers the opportunity to retrieve data from the participant without interrupting the experimental procedure.

Again, forms can be used at any step of the experiment. The data of each form (the inputs of the participant and the time needed for completion) is saved into a separate text file which can be analysed easily (e.g., with Microsoft Excel).

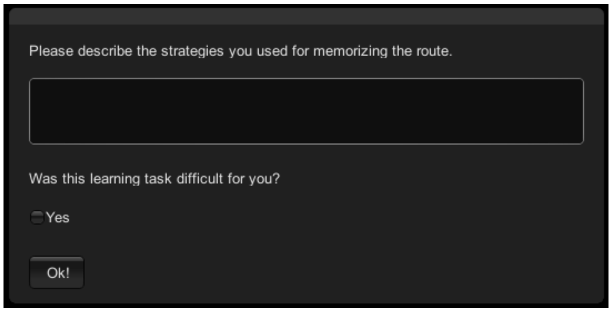

Figure 6. An example form in SQUARELAND 2.0 with a text area and a checkbox.

Fixation cross. Between a series of intersections or between instructions it is often required to display a fixation cross for a certain amount of time. This can be done in SQUARELAND 2.0 very easily.

Possible features in the future

The development of SQUARELAND 2.0 will be continued steadily, and, more features will be implemented in the future.

For instance, it might be of use to be able to present objects as landmarks for example in the middle of an intersection (e.g., Hamburger et al., 2012; Wiener et al., 2012) or somewhere along the route (e.g., Janzen & van Turennout, 2004). In the current version this was not a central issue because it was the purpose to create a tool for investigating the structural salience of landmarks at an intersection in the first place (see figure 1). However, if one is able to import and place objects in Unity, any kind of landmarks and landmark positions (also distant or global landmarks) can be implemented. In future versions of our VE objects might also be positioned with the help of the SQUARELAND 2.0 XML file, which would simplify creating experiments with any kind of landmark position.

Some might argue that the appearance of the SQUARELAND 2.0 maze is not quite a realistic setup. As in its predecessor the benefit of the chosen structure can be seen in its satisfying variable control (Hamburger & Knauff, 2011). As done in a study by Bucher et al. (2014) the blocks in the Google Sketchup© version of SQUARELAND may be substituted by another object (e.g., building), leading to a more realistic environment. The Unity game engine allows researchers to implement complex worlds (e.g., worlds with buildings, lakes, trees, mountains, cars, etc.). In such environments the current SQUARELAND 2.0 functions may be integrated, if orthogonal cross intersections are used. A goal for future versions could be to as well allow routes with non-orthogonal crossings or even curved paths.

Beside the overlays it could be interesting to present auditory stimuli while the participant moves through the maze (e.g., Hamburger & Röser, 2011). This could simulate commands of a navigation system or could serve to further investigate the role of different modalities (e.g., acoustic versus visual stimuli) in human wayfinding (see Hamburger & Röser, 2011 for further details).

It might also be of interest that a participant's decision while exploring a route leads to adaptations in the maze (e.g., changes in landmarks and their position, etc.). With such a feature the participant could be left uninformed about his or her wrong decisions concerning the direction of turn (adaptive testing).

Possible research questions

According to Hamburger and Knauff (2011) the major aim of the first version of SQUARELAND was to develop a "*neuro-cognitive theory of landmark salience in human wayfinding*" (p. 152). This aim was divided into the following subgoals:

- What determines a landmark's salience in human wayfinding?
- Can the salience of a landmark be defined solely by the three mentioned forms (visual, semantic and structural)? And if so, which one is most important?
- How can the different forms of salience be measured quantitatively?
- What are the neural processes and representations behind wayfinding with landmarks?

These goals may also be addressed with SQUARELAND 2.0. Some of these questions were already examined empirically with its predecessor (e.g., Röser et al., 2011; Röser, Krumnack, et al. 2012, Röser et al., 2013). However, the new version of our VE can now be used to investigate whether the results in these studies also occur if active movement controls or a dynamic presentation of the routes are used (if this was not the case). The VE can also be used to investigate new research questions and again we would like to invite the community to use this tool for future empirical studies on human spatial cognition.

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