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Executive Summary of the Thesis

Situated Visualization in Motion for Video games

Laurea Magistrale in Computer Science Engineering - Ingegneria Informatica

Author: Federica Bucchieri

Advisor: Prof. Franca Garzotto

External advisors: Petra Isenberg, Lijie Yao

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1. Introduction

Video games produce rich dynamic datasets during gameplay that are often visualized to help players succeed in a game and make important decisions about how to act in the game. Examples include health bars, navigation aids, ammunition count, or team affiliation (see Figure 1). As such, visualizations play an important role in how effective a player can be but they also pose a number of interesting design challenges. Visualizations need to be read at a glance while the player is focused on a primary task such as fulfilling a game mission. They also often need to be small, match the aesthetics of the game, or be closely embedded next to game elements [1]. Frequently, those data visualizations are in motion on the screen due to camera changes or because the visualizations are attached to moving game elements such as game characters. My thesis aims to explore how contextual factors in video games affect the readability of visualizations in motion. Designing visualizations subject to motion factors is challenging because compared to standard desktop visualizations many contextual factors are introduced such as speed, direction and trajectory of motion, size of the visualizations and background changes. Understanding how motion factors influence the readability of visualizations in motion in the context of video games can help game designers improve data visualization and subsequently player performance and enjoyment in their games. Previous research on visualization techniques in the context of video games analyzed how data is presented to players. This thesis extends this past work in that it concentrates on the motion of visualizations related to contextual factors of the game itself which have not yet been explored.

Figure 1: Examples of situated visualizations in motion in the context of video games. Left: Navigation aids and objective location in *Watch Dogs: Legend*. Middle: Ammunition count embedded in the weapon display in *Halo Infinite*. Right: Objectives' team affiliation and soldiers' death positions in *Call of Duty: Black Ops II*.

2. Research Goals and Contributions

Within this thesis I pursue three research goals. My first goal is to acquire a general understanding of the existing practices of situated visualization in motion for video games. Second, I want to explore embedded visualization and their effect on video game players, with the goal of deriving a study design about the design choices in embedding visualizations with game elements in motion. Last, I pursue to implement an evaluation program to evaluate different visualizations with respect to the aforementioned research goals. To achieve the those goals, I contribute:

- **A systematic review of situated visualizations in motion in the context of video games** Through a survey of 160 visualizations in motion and their embeddings in the game world I provide an analysis and categorization of these visualizations. The categorization comprises several dimensions related to situated visualization and motion factors.

- **An analysis of situated visualizations in motion in video games for different types of data**
  In addition to the systematic review, I contribute an analysis on how different types of data are represented in games. Specifically, I focused on quantitative and categorical data by analyzing two prominent examples of the information displayed in video games: character's health and game element types.
- **A video game for the evaluation of situated visualization in motion for video games**
  I designed and implemented a First Person Shooter (FPS) video game called RobotLife to conduct an empirical evaluation of different visualizations in motion. RobotLife is implemented in Unity and deployed for PC. I developed the game design, level design, gameplay design, visualization design, implementation and game testing.
- **A study on visualization in motion in video games**
  Relying on the video game I implemented, I contribute a study on three different visualizations in motion embedded with the game characters. The study evaluates different embedding locations with visualizations and how they affected players' experience.

3. Background

Yao et al. [5] proposed a first design space for *visualization in motion* that included the motion relationship between viewer and visualization. When playing video games this motion relationship involves a stationary player sitting in front of a monitor, seeing visualizations moving on the screen. Visualizations are *situated* in the game context and as such my work related to the research area of situated visualization. Willett et al. [4] formalized the difference between situated and embedded visualization, analyzing the relationship among data and the referents to which the data refers. My work focuses on embedded visualizations that have a close connection between data and referent; for example where data about a game character is displayed directly next to the character's representation. My work is of course, also related to past work on visualization for video games. Zammitto [6] was the first one to tackle the topic and analyze the principles of visualizations used in games. Her analysis focused on determining how video games provide the player with important visual information like the use of silhouettes, mini-maps, HUDs, Fog of war etc. Some theories and design spaces have been proposed, based on a systematic review of existing games that incorporate some sort of visualization. Peacocke et al. [3] studied players' performances with different types of displays to find the best way to represent different types of data. Their work shows that there is no universally best display type for every information. Different representations worked well for specific types of information (e.g. players performed better with information about ammo displayed with spatial displays). My research deviates from this past work in that I concentrate on the motion of visualizations related to contextual factors of the game itself.

4. A Systematic Review of Visualizations in Motion in Video Games

To ground our work in existing practices of moving visualizations in video games we[1] conducted a systematic review. To cover a diverse selection of video games we made use of a commercial ranking website called *Metacritic*. For 17 game genres we selected the top 3 games from 2011 to 2022 sorted by the Metacritic relevance score. In total, we reviewed 50 games and collected 160 examples of visualization in motion. We categorized these examples according to multiple dimensions related to situated visualization and motion characteristics. Here I present the most relevant ones:

Visual Representations: describes how data was represented. Signs were the most prevalent representation (36/160), followed by bar charts (28/160), labels with numbers (21/160) and labels with texts (19/160). The remaining 56/160 visualizations included silhouettes, pictographs and more (see Figure 2).

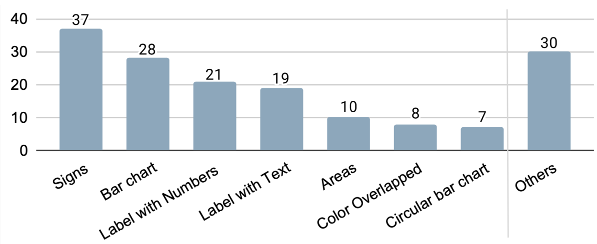

Figure 2: Number of occurrences of visualizations with different visual representations based on our systematic review.

Data referents: are the entities that the data refers to. Most referents are game characters, locations, or an object in the game. In our sample collection, 114/160 data referents were game characters, 30/160 were locations, and 16/160 were objects (see Figure 4: Left).

[1] I was solely responsible for the data collection and analysis of the work presented in this section which resulted in a publication with my supervisors [1] whose text I use in this section. Thus any use of "we" in this chapter refers to all

Figure 3: Examples of visualizations in motion embedded in different locations with respect to the data referent. Left: Stamina bars and player's name embedded below the feet of the players in *NBA 2K21*. Middle: Heath map overlapping the game environment in *Civilization VI*. Right: Health counter integrated with the character's design in *Nintendo Land*.

Embedding locations: refers to the spatial relationship of the visualization and the data referent. We found three different types of embedding locations (see Figure 4: Middle). 121/160 examples embedded visualizations *around the data referent*. Visualizations were close to the referent for example above an object (see Figure 3: Left), under the feet of a character, or above a checkpoint (a location). 26/160 visualizations showed full or partial *overlap with the data referent* as shown for example in Figure 3: Middle. Finally, 13/160 visualizations were *integrated with the data referent* permanently for example in the material color of the referent (see Figure 3: Right). Although visualizations integrated or overlapped with the referent might look similar, integrated visualizations cannot be separated from the referent while overlays may be temporary.

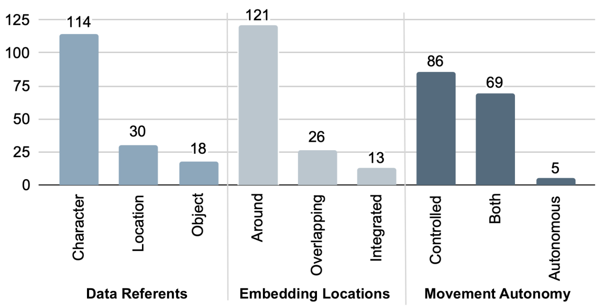

Figure 4: Numbers of visualizations collected and analyzed according to their data referent, embedding location and movement autonomy.

Movement autonomy: considers if the visualization was moving autonomously or was controlled by a player. For example, a player can induce motion of a static enemy's health bar on the screen by moving his or her camera, for example via one's character. Autonomous movement of a visualization was not prevalent in video games, only 5/160 samples moved autonomously, while 86/160 were consistently controlled in some way only by the player and 69/160 depended on autonomous movement and the player's control (see Figure 4: Right).

co-authors: Federica Bucchieri, Lijie Yao and Petra Isenberg.

5. Visualization in Motion for Different Types of Data

After conducting the systematic review of visualization in motion, we[2] specifically concentrated on how different types of data are represented in video games. Video games produce a wide range of types of data, defined by the values they can express. 67 out of the 160 visualizations we analyzed represented *quantitative data*. This data concerned health points of a character, the number of resources crafted, or the distance from a location. *Categorical data* were the second most common category, with 64 out of 160 representatives. Categorical data concerned team identification and resource type. Furthermore, 49 out of the 160 visualizations showed *spatial data* of the data referent's position. Meanwhile, *ordered data* were the least frequent with 8 out of 160 representatives and were only present in racing games. In the next two sections we focus on the two most frequent quantitative and categorical data displays: character health and game element types.

5.1. Character's health

Out of 67 *quantitative data* visualizations, 24 represented the character's health. A typical way to represent health were horizontal bar charts (18/24 visualizations; see Fig. 5: Left). Only 3 out of 24 representatives were radial bar charts (see Fig. 5: Middle), and the remaining three were a pie chart, a label with numbers, and a pictorial fraction chart (see Fig. 5: Right). Health was sometimes represented with single-color horizontal bar charts that encoded data only by bar length. Some examples showed a dual encoding with the use of color, usually in gradients from green (healthy) to red (critical). As stated by Zammitto [6], to be color-blind friendly, applying length as the unique method is already sufficient. 16/24 visualizations in our collection had an opaque background, while the remaining 8 had a transparent background. Having a transparent background also meant that these bars lacked a reference frame that could help to judge the length of the bar.

[2]I was solely responsible for the data collection and analysis of the work presented in this section which resulted in a publication with my supervisors [2] whose text I use in this chapter. Thus any use of "we" in this section refers to all co-authors: Federica Bucchieri, Lijie Yao and Petra Isenberg.

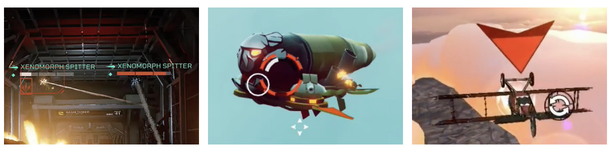

Figure 5: Different types of character's health's visualizations. Left: Bar chart in *Aliens: Fireteam Elite*. Middle: Radial bar chart in *The Falconeer*. Right: Pictorial fraction chart in *Skies of Fury DX*.

5.2. Game element types

To succeed in certain games, finding the right resource or correctly identifying enemies is important. This type of information is usually represented by *categorical data*. We found 26/160 visualizations that represented the type of game elements, such as interactive objects and characters. Signs were the most common visual representation, with 13/26 visualizations. Signs used shape and color encodings to distinguish different categories of game elements, such as mission targets (see Fig. 6: Left). Those encodings aimed to help players differentiate between other players, objects, and objectives. Another prevalent method to identify character types is the use of color in the character's health bar charts (see Fig. 6: Middle). In fact, when categorizing the 26 visualizations found by the type of encoding used, it's possible to notice that the majority used color-only with 12 out of 26 representatives, while 8 out of 26 visualizations used both shape and color, and 5 used only shape (see Fig. 6: Right). The last representative (1/26) displayed information by using text.

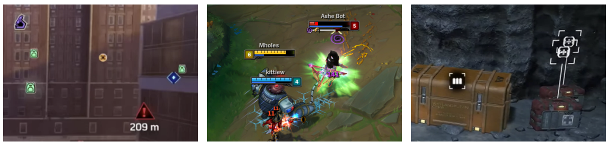

Figure 6: Different game element's type visualizations. Left: missions' icons in *Spider-Man*. Middle: color coded health bar charts in *League of Legends*. Right: Resource's type signs in *Aliens: Fireteam Elite*.

6. RobotLife

With the aim of exploring how different contextual factors influence visualizations in motion in games, I designed and implemented a video game called *RobotLife*. The goal was to exploit the data produced by the gameplay and visualize it to study the impact of contextual factors on situated visualizations embedded in game elements subject to motion. RobotLife is a First Person Shooter (FPS) game set inside a robot factory. A virus infiltrated inside the factory and altered some robots. The altered robots became evil and started damaging the electric system of the factory. The player acts as the guardian of the factory and has the duty to eliminate all the evil robots without damaging the good ones. RobotLife was implemented using Unity (C#) and due to the time constraints of this project I decided to start my implementation from an open-source Unity Template called *FPS Microgame*. My main goal while designing RobotLife was to create specific game mechanics that would push users to mainly focus on the situated visualizations inside the game, while maintaining the classical gaming experience of a FPS game. The robots came with easily accessible data such as their position in the scenario, their status and their health level. I decided to focus more on the health level and build the main objective of the game around this piece of information. Therefore, I implemented the division of the enemies in two "teams", good and evil robots. The division is made considering the starting health level of the robots. Good robots have a health level lower than 66% while evil robots have a health level higher than 66%. This division allowed to force the players to focus on visualizations. Moreover, each robot is programmed to move freely around the factory in order to ensure the presence of motion factors influencing the readability of the visualizations. The player wins the game if eliminates all the evil robots in the scenario (8 robots) without damaging more than 2 good robots. Since the goal of the study was to experiment inside a real case scenario, the level map and game aesthetics are designed to reach the standards of a real video game.

Figure 7: Screenshot of the gameplay of RobotLife. The player is holding his weapon and approaching a good robot with the health level integrated in the robot design.

7. Study on Visualization in Motion in Video games

As final contribution of my thesis, I propose a pilot study on situated visualization in motion in video games. The study aimed at evaluating how different embedding locations affects the readability of visualizations in motion in the context of video games.

7.1. Visualizations evaluated

To conduct the study I designed three visualizations with different embedding locations representing the health level of the RobotLife's robots. The first visualization (Figure 8: Left) is a bar chart embedded *around the character*, specifically above the robot's head. This design is the mainstream design for health representations. The second visualization (Figure 8: Middle) is instead *embedded in the character design*. The health level is embedded with the texture of the robot that will change color according to health value itself. The higher the health value, the more the robot will be colored in red. Lastly, the third design (Figure 8: Right) is a donut chart *overlapping the hover bot*. This visualization rotates accordingly to the robot to be always visible such as the other two designs. In order to reduce the number of influencing variables and design an experiment as much controlled as possible, I used length encoding only in all the three visualizations. Moreover, the visualizations had red as unique color to reduce biases arising from color contrast differences.

Figure 8: Evaluated visualizations of the robot's health. Each visualization shows an health value of 66%. Left: Bar chart embedded around the character. Middle: Colored texture integrated with the character design. Right: Donut chart overlapping the character.

7.2. Participants

For the pilot study I recruited 12 participants. Participation was voluntary and the study was anonymous, no personal data have been asked or recorded. I recruited 5 female and 7 male participants, with an average age of 25 years. Their familiarity with video games was below average, since they self reported their level of ability in playing games on a scale from 1 to 7 and on average the level was around 3,8. Their frequency of playing video games was on average once or twice every three months. Instead, their familiarity with FPS games specifically was also below average (3,3/7) and their frequency of playing those kind of games was once or twice in a year. Each participant conducted the experiment on a MacBook Pro 16-inch (2019) with a 2,6 GHz Intel Core i7 6 core processor. Participants were asked to complete some questionnaires on Google Forms and then play RobotLife with keyboard+mouse input.

7.3. Study procedure

Firstly, participants had to agreed to a consent form. Secondly they completed a demographic and gaming habits pre-questionnaire. After completing the pre-questionnaire, RobotLife was launched and the software guided the participants through the experiment under my constant supervision. Participants had to complete a tutorial level to learn the basic commands of RobotLife. Once the tutorial was completed, RobotLife proposed three blocks, one per each condition, including a training session, a 5 minute gameplay and an in-game questionnaire. While playing, a logging system recorded all the in-game events producing a log file. On average each participant played RobotLife for 27 minutes. At the end of each block, participants had to complete an in-game questionnaire comprising 2 likert scales with 4 and 5 items each. After completing the gameplay of RobotLife, participants completed a post-questionnaire asking them to rank the three visualizations according to different aspects. Lastly, participants took part in an interview to gather qualitative data, feedback and insights about their strategies while playing RobotLife and general comments about the visualizations.

7.4. Analysis approach

First, I implemented a logging system that recorded every salient action occurred during the gameplay. Log files were processed using a Python script to extract aggregated data and then analyzed to generate statistics about the participants' performances in the experiment. Second, I gathered ordinal data from the in-game questionnaire at the end of each block of RobotLife. The in-game questionnaire comprised two Likert scales of 4 and 5 likert-type items respectively. The first likert scale evaluated the visualizations' readability and the second one the visualizations' aesthetics. Furthermore, I collected ordered data from the post-questionnaire. Participants were asked to rank the three visualizations in terms of readability, aesthetic, and support towards achieving the game goal and for the overall game experience. Last, I gathered qualitative data by interviewing participants at the end of the experiment. Particularly, I asked about the influence of motion factors, the impact of the different embedding locations and the influence of other contextual factors on the visualizations' readability. Examples of other factors were the game mechanics, the player's experience or the visualizations occlusion due to other game objects. The data gathered during the interviews was subsequently thematically coded and divided in six categories. Those categories derived directly from the topics of the questions asked. My goal was to understand the overall perceived readability, how well those visualizations matched the aesthetic of the game and how much motion factors (both depending on the robots' movements and on the player's control) impacted the visualizations' readability.

8. Results

The bar chart embedded around the character resulted the most readable visualization under motion. Other than because of the shape of the bar chart it self, the visualization resulted familiar to the participant. The embedding location around the character allowed to avoid occlusion due to most of the objects in the game environment, resulting in a good readability from the distance. Also, this visualization was not particularly altered by motion factors. On the other hand this visualization was not particularly appreciated in terms of aesthetics. The bar chart was considered too mainstream and the around embedding location criticized because it occupied extra space other than the character itself and is not directly integrated with it. Instead, the colored texture integrated in the character design resulted the most beautiful visualization. The integrated design was particularly appreciated because it enhanced the game immersion and was considered more challenging and therefore more fun. This particular visualization was also criticized because the rendering effect of the red color on the robot body endeared the color contrast between the gray and the red. Therefore, the visualization resulted less visible and difficult to read. The donut chart visualization overlapping the character body seemed to be a good trade-off between readability and aesthetics. Dividing a donut chart in quarters helped participants to read the visualization while under motion. Furthermore, the particular robot design and the similarity between the donut shape and the hover bot eye-ball resulted in a aesthetically pleasing design. Regarding the impact of motion factors, they generally had a negative impact on the visualizations readability. The autonomous movement of the robots impacted particularly the visualizations integrated and overlapping the game characters due to occlusions caused by the robot moving behind other game objects. Finally, all the participants declared that the game was fun and easy. Also the less experienced players learned very easily the game commands and mechanism, proving that the game design is consistent and adaptable to different level of expertise.

8.1. Limitations

A main limitation of this research is that, as a pilot study, I did not have a large number of participants. Although my result may vary from a future formal experiment it is still sufficient and able to give a prediction of the real experiment. Another limitation is, that due to the limited time, I did not have a chance to recruit experienced game players. The lack of experience in video games may have influenced the gaming performance as well as the overall gaming experience. Another limitation of the study is that we have to bind visual representations with embedded locations. While the main goal of the study was studying the impact of embedding locations, in the context of video game, it is unrealistic to take into account only the embedding position without considering the aesthetics and rationality of the visual representation. Many participants appreciated one visualization more than the other not only because of the embedding location but because a good visual representation is displayed at a suitable position. Therefore, embedding locations and visual representations should not be discussed separately but combined to provide more practical results.

9. Future Work

Since the study presented in this thesis was conducted in the form of an extensive pilot, a formal experiment is required to gather more informative data. Moreover, the topic of visualizations in motion in video games can be furtherly explored by taking into account other design factors, such as different visual representations for the same type of data, or the use of specific colors to draw the attention of the players. Finally, while implementing RobotLife I started creating another game framework to evaluate different visual representations for game element types. Thus, an other empirical study will come soon.

10. Acknowledgements

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