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Executive Summary of the Thesis

Cicero Reloaded: A Mixed Reality Tool for Enhancing Memorization with the Ciceronian Loci Method

Laurea Magistrale in Computer Science and Engineering - Ingegneria Informatica

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1. Introduction

This thesis focuses on adapting the Ciceronian loci, a powerful memorization technique also known as the memory palace, to mixed reality.
Originating in ancient Greece around 500 BC, the Ciceronian loci method was thoroughly described by Cicero in De Oratore, from which it takes its name. This technique involves selecting a familiar path or environment and mentally distributing concepts along it in a specific order. When recalling information, one mentally walks this path to retrieve the associated ideas.
The Ciceronian loci technique has been used for centuries. Research indicates that using this method activates specific brain areas, like the hippocampus, crucial for spatial navigation [4]. Ordinary people can learn and significantly improve their memory with this method, developing specific brain connections after training [2]. This technique is particularly effective compared to other techniques, as recall relies on locations rather than strict sequential order, preventing a single forgotten element from compromising subsequent information recall [6].
This study aims to modernize the loci technique by integrating it into mixed reality. The technique is particularly well-suited for this transposition, as it enables the materialization of virtual content within the real world, thereby enhancing the sense of immersion. This research seeks to address gaps existing in custom-made applications developed for past studies, offering a more immersive and effective solution. We particularly target the educational field. The thesis was developed with the technical collaboration of FifthIngenium, a company specialized in mixed reality, which provided essential equipment and support.

2. State of the Art

In this section, we take a broad perspective and review how the method of loci has been transposed into "Extended Reality" (XR), that is, any kind of virtual environment, in order to identify the key approaches and the gaps our work aims to fill. It is important to first clarify the terminology related to extended reality in order to better understand the current work: AR (augmented reality) overlays digital elements onto the real world, MR (mixed reality) allows digital elements to interact with real objects, and VR (virtual reality) creates a fully immersive digital environment. The literature shows that there are applications and studies related to the loci technique in both VR and AR environments, although the latter remains less developed compared to VR, while no existing studies currently adopt a truly mixed reality approach.

2.1. Current Research

Let us begin by examining applications of the method of loci in VR. Some studies focus on creating virtual memory palaces to enhance the classic loci technique, optimizing design and immersion for better memorization; often involving users to actively place elements while physically walking around (in VR) through specific sensors and sometimes allowing personalization by selecting content from predefined sets. These studies have shown promise in leading to improved memory outcomes and faster learning [5]. Other studies in VR have proposed the use of virtual reconstructions of real-world environments, obtained through dedicated scanning technologies, based on the premise that the loci technique is most effective when applied in familiar settings, thus, paradoxically, aiming to recreate a mixed reality scenario within a virtual context [7]. Additionally, some applications allow importing 3D models, i.e., the information to be memorized, from online repositories [7].
In the AR domain, one study, for example, focuses on an application that supports language learning, where users place virtual notes along a selected route in the real world. However, the study does not draw any conclusions regarding the effectiveness of the approach [1]. Other AR works explore collaborative mechanics through gamification elements, such as games involving multiple users reconstructing knowledge by combining distributed information, with preliminary trials suggesting the presence of a potential cognitive benefit from this gamification approach [3].
These studies use different devices, from dedicated headsets (VR and AR) to smartphone-based solutions. Development primarily relies on Unity, often complemented by specific SDKs (like ARCore) and high-level interaction frameworks (like MRTK).

2.2. Review and Critical Reflections

Based on the literature review, it emerges that there are applications in virtual reality, which are relatively advanced, and in augmented reality, which are more rudimentary. In fact, VR applications typically offer greater interaction with virtual content and higher levels of customization, although not always in a fully satisfactory way. On the other hand, AR allows users to build memory palaces within familiar environments. As noted earlier, some VR studies attempt to replicate this approach, but the process is often tedious and suboptimal.
There appear to be no applications in mixed reality.
The literature review highlights the following limitations of existing applications in both VR and AR:

- **Experience personalization:** Remains underdeveloped. While some VR applications allow selection from predefined content sets [5] or even importing models from online repositories like Google Poly [7], this often implies dependence on third-party services.
- **Content persistence:** A technical challenge in AR involves the use of anchors (e.g., ARCore anchors [1]), which, if correctly implemented, enable virtual content to be persistently placed in the real world across different sessions. However, current implementations are limited to mobile devices, single environments, and are subject to time constraints.
- **Interaction and physical engagement:** Extremely limited, often reduced to object placement.
- **Advanced features (gamification and sharing):** Scarce [3], despite known benefits for motivation and learning. Sharing memory palaces, useful for education, is non-existent.

3. Application Design

In this section our developed mixed reality application is presented.

3.1. Vision and Goals

This thesis project focused on the development of a Mixed Reality application designed to support the Ciceronian method of loci. The vision is to enhance the memorization of concepts within the context of formal education, specifically for at-home review of school subjects.

To achieve this vision, we defined the following key goals:

- **Personalization**: The application should allow users to freely choose the concepts to be memorized, ensuring adaptability across various school subjects and enabling a tailored learning experience.
- **Content persistence**: The system must ensure content remains available over time, allowing learners to pause and resume their memorization sessions across multiple uses.
- **Gamification**: The application should integrate basic gamification elements to boost user motivation and engagement throughout the memorization process.
- **Collaboration and sharing**: The system should support content sharing and comparison of results, fostering peer interaction and community-based learning.
- **Ease of use**: The user interface and overall interaction should be simple and intuitive, ensuring accessibility for all students.
- **Learner autonomy**: The system must support self-directed learning, allowing students to engage with the content independently, without the need for continuous teacher supervision.

3.2. Functionality Overview

Please note that some functionalities rely on the Tinalp platform developed by FifthIngenium, which serves as the foundation for the application. The focus of this thesis was the development of the application itself, not the underlying platform.

3.2.1 Preparation of the Experience

Users select and upload content (in the form of videos, images, audios and 3D models) via FifthIngenium's "Tinalp" portal, a web editor used to create "decks" (experience containers). The user does not have to worry about the size or other aspects of the contents as they will be adjusted by the application on the headset. Tinalp supports decks' sharing, allowing multiple users to download the same experience. Once a deck is created, users access its content via the headset.

3.2.2 Experience Startup

Upon launching, users log in via Tinalp and select an experience (Tinalp deck). The application requires the room to be spatially scanned by the headset beforehand. After successful setup, a welcome message appears, and a command table spawns nearby.

3.2.3 Core of the Experience

The command table menu provides access to key functionalities:

Magnet Distribution: The first phase involves placing virtual magnets (on which the items to memorize will be later placed) in chosen room locations. Each magnet represents a locus, ideally near a real object to facilitate recollection. The number of magnets matches the uploaded content. This phase can be accessed at any time, resetting (if already in this phase) or restoring magnets.

Concept Distribution: In this second phase, users attach "concepts" (i.e., materials uploaded to Tinalp) to the placed magnets. Concepts appear one at a time on the table for attachment. 3D models can be rotated for optimal orientation. This process continues until all magnets are occupied, completing the memory palace. This phase is accessible after all magnets are placed and can be reset (if selected when already in this mode) or restored.

Play: This phase offers a mini-game for memorization and it's accessible after the completion of the memory palace. Concepts detach from magnets and appear on the ground; users reassociate them to the correct magnet. Points are awarded for correct matches, deducted for errors. Difficulty dynamically adapts, varying the number and order of concepts. This active, repetition-based approach reinforces loci memory more effectively than passive observation. After a timed period, a final timed matching round occurs in the original order. A final score is displayed, with an option to publish to a leaderboard, fostering competition.

Memorize Concepts: This function hides magnets for better immersion. It is accessible only after all concepts are distributed and not during the playing mode.

See standings: This function displays the leaderboard for the current shared experience (deck), it's not accessible while playing.

3.2.4 Additional information

The application features an essential auto-save system for magnet and concept positions (excluding the playing phase), allowing users to resume their memory palace. Saves are linked to Tinalp accounts. Experiences are tied to the physical room where they are used, but it is possible to re-arrange the same experience in different rooms.

4. Technical Implementation

The application was developed in Unity using C# for Meta Quest 3/3S. It combines Unity's native features with Microsoft's MRTK (Mixed Reality Toolkit) for spatial interactions and UI, alongside specific Meta SDKs to enable mixed reality functionalities like spatial anchors, scene model, and passthrough.

4.1. Anchors and Scene

Our application heavily relies on Meta's Spatial Anchors to save and restore the positions of virtual objects in the real world across sessions, ensuring the persistence of built memory palaces. Each anchor is identified by a unique UUID. Users can create, save, load, and delete these anchors, each of which has a pose in the real world. Developers must create a data structure to keep track of the necessary information, like the objects to which the anchors are attached. This data structure can be saved for future sessions. Note that objects with an OVRSpatialAnchor component cannot be moved, and most anchor methods are asynchronous, requiring extra care, especially since they only work in the built application on the headset, which makes debugging more difficult.
The system also leverages the Scene Model, a representation of the physical environment created by the headset's space setup, providing a basic understanding of the room's layout.

4.2. How the Code Works

The application is organized in different classes, an extremely brief explanation is provided here. **LociActivityController** is the class that is used for the startup of the experience. The controller holds a reference to **FILociActivity**, which acts as a bridge for retrieving data uploaded to Tinalp. Moreover **ActivityRoomController** is used for downloading the content uploaded to the web platform. The latter two classes leverage FifthIngenium's functionalities. **ObjectManager** is responsible for instantiating the downloaded resources and managing them.
After initial preparations, **LociActivityController** is called, invoking a method that leads to obtaining current scene information, and if it is valid, to identifying a unique code for the experience. Experiences are managed in **ExperienceData**, a structure that tracks and saves on the device information, related to each experience, necessary for future sessions, such as the rotation of 3D concepts and spatial anchors.
SpatialAnchorManager is then initialized. This class is the controller of anchors, its functionalities are used to restore and save the virtual content placed in the real world. Main structure here is *Dictionary<string, Dictionary<System.Guid, AnchorType» anchorDictionary*, which stores anchors information, such as their ID, the type of the object they are connected to, and if the object is a concept, its Tinalp ID.
Once all anchors are restored, **LociManager** becomes the main class: it has to reconstruct existing configuration and associations among magnets and concepts, if any. After this step the experience is ready to start: users can select different phases via menu buttons, constructing the memory palace or going back in it. Available phases are *MagnetDistribution*, *ConceptDistribution*, *Memorize*, *PlayingMain*, *PlayingFinal* and *Ended*. The first three phases are accessible directly with menu buttons, while only *PlayingMain* is set with the "Play" button: the other two follow this phase after a certain timer. In order to manage different situations in the various phases, scripts attached to magnets and concepts invoke different methods. These scripts also trigger methods in **SpatialAnchorManager** for achieving a continuously saving of the memory palace.

5. Validation

This section presents the validation of the application, conducted in two rounds: one at Politecnico di Milano's Open Day (larger group) and a second during a class session at the same university (smaller group). In both cases, participants completed the same questionnaire, and a focus group was also conducted in the second round. The evaluation focused on the usability and perceived usefulness of the application.

5.1. Tested Memory Palace

The experience was designed to aid memorization of historical events from the 1929 economic crisis, based on a high school history book. The content used was an extreme synthetic representation of key events: a 3D fridge (industrial expansion), a photo of bank withdrawals (financial crash), a growing snowball (crisis spread to Europe), a video of Roosevelt's speech (New Deal), and a 3D radio (Roosevelt's communication policies).

5.2. Open Day

The "Open Day test" (March 29th, 2025) aimed at gather initial reactions and impressions from as many participants as possible (33 total). The content, specifically chosen for high school students, proved effective as many participants were familiar with the topic, facilitating quicker explanations. Each person received a brief introduction to the loci technique and the application's functionalities, followed by a general questionnaire focused on first impressions.

5.3. Class Test

On May 9th, 2025, we conducted a more in-depth trial during a class session with a small group of master's students (7 participants). The students used the application and then completed the same questionnaire that had been administered during the Open Day. In addition, a focus group was held with the participants to gather qualitative feedback. Students expressed very positive first impressions, highlighting the application's ease of use and functionalities. Students provided constructive feedback for future iterations; they confirmed the solid foundation of the application and understood its suitability for both personal educational use and for comparing/reviewing performance.

5.4. Overall Results

Overall, the experience received very good ratings. With 63% of participants having prior headset experience, comfort scored 4.58/5. Ease and immediacy of use scored 4.45/5. Willingness to use the application scored 3.88/5, which is considerably high given that 60% had never heard of the loci technique and only 7.5% had used it previously. This indicates participants understood the potential and considered using it for self-study. Notably, all 40 testers found the experience positive and worthy of note, often expressing interest in actually using it.

6. Final Considerations

6.1. Future Directions

Future work should focus on a more in-depth evaluation of the application's educational impact, using experimental research methods that were not feasible within the timeframe of this thesis. In addition, functionalities should be expanded, particularly those related to sharing experiences, whether among peers or between the teacher and the student group. While the current application only allows users to access experiences created by others, meaning they can use existing content without having to search for or upload it themselves, a more advanced "shared" version could be implemented in VR, enabling users to virtually explore a memory palace designed by someone else. This could be especially useful, as it allows them to see how the original creator structured and distributed the concepts before organizing their own. Exploring a true multiplayer mode with tailored gamification for simultaneous multi-user experiences is also a valuable direction.

6.2. Conclusions

Our application successfully integrates the Ciceronian method of loci with mixed reality, leveraging virtual elements within the user's familiar real environment.
It provides full immersion, enabling users to walk freely and interact physically with virtual content, supporting deeper learning. A key feature is the system's ability to save and anchor virtual content in the real world, allowing users to build and reload a desired memory palace in a given place at any time. The application offers full customizability (users upload their own content) and supports experience sharing. We also incorporated gamification to boost motiva-

tion and engagement, making the learning process enjoyable.
Tests confirmed our approach was well-received and met its goals. Combining the proven effectiveness of the method of loci with positive testing feedback and achieved objectives, we hope that our application serves as a strong foundation for further research and can help spread this powerful memorization method more widely.

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