COMPUTER SCIENCE
DEPARTMENT

ANDRÉ TOMÁS RIBEIRO
Bachelor in Computer Science

# PROCEDURAL GENERATION OF INTERIORS IN VIRTUAL REALITY(VR)

## EXPLORING NEW NAVIGATION PARADIGMS

MASTER IN COMPUTER SCIENCE
SPECIALIZATION IN SPECIALIZATION NAME

NOVA University Lisbon
***Draft:*** *December 5, 2024*

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# Abstract

Regardless of the language in which the dissertation is written, usually there are at least two abstracts: one abstract in the same language as the main text, and another abstract in some other language.

The abstracts' order varies with the school. If your school has specific regulations concerning the abstracts' order, the NOVAthesis LaTeX (novathesis) (LaTeX) template will respect them. Otherwise, the default rule in the novathesis template is to have in first place the abstract in *the same language as main text*, and then the abstract in *the other language*. For example, if the dissertation is written in Portuguese, the abstracts' order will be first Portuguese and then English, followed by the main text in Portuguese. If the dissertation is written in English, the abstracts' order will be first English and then Portuguese, followed by the main text in English. However, this order can be customized by adding one of the following to the file `5_packages.tex`.

```
\ntsetup{abstractorder={<LANG_1>,...,<LANG_N>}}
\ntsetup{abstractorder={<MAIN_LANG>={<LANG_1>,...,<LANG_N>}}}
```

For example, for a main document written in German with abstracts written in German, English and Italian (by this order) use:

```
\ntsetup{abstractorder={de={de,en,it}}}
```

Concerning its contents, the abstracts should not exceed one page and may answer the following questions (it is essential to adapt to the usual practices of your scientific area):

1. What is the problem?
2. Why is this problem interesting/challenging?
3. What is the proposed approach/solution/contribution?
4. What results (implications/consequences) from the solution?

**Keywords:** One keyword, Another keyword, Yet another keyword, One keyword more, The last keyword

# Resumo

Independentemente da língua em que a dissertação está escrita, geralmente esta contém pelo menos dois resumos: um resumo na mesma língua do texto principal e outro resumo numa outra língua.

A ordem dos resumos varia de acordo com a escola. Se a sua escola tiver regulamentos específicos sobre a ordem dos resumos, o template (LaTeX) novathesis irá respeitá-los. Caso contrário, a regra padrão no template novathesis é ter em primeiro lugar o resumo *no mesmo idioma do texto principal* e depois o resumo *no outro idioma*. Por exemplo, se a dissertação for escrita em português, a ordem dos resumos será primeiro o português e depois o inglês, seguido do texto principal em português. Se a dissertação for escrita em inglês, a ordem dos resumos será primeiro em inglês e depois em português, seguida do texto principal em inglês. No entanto, esse pedido pode ser personalizado adicionando um dos seguintes ao arquivo `5_packages.tex`.

```
\abstractorder(<MAIN_LANG>):={<LANG_1>,...,<LANG_N>}
```

Por exemplo, para um documento escrito em Alemão com resumos em Alemão, Inglês e Italiano (por esta ordem), pode usar-se:

```
\ntsetup{abstractorder={de={de,en,it}}}
```

Relativamente ao seu conteúdo, os resumos não devem ultrapassar uma página e frequentemente tentam responder às seguintes questões (é imprescindível a adaptação às práticas habituais da sua área científica):

1. Qual é o problema?
2. Porque é que é um problema interessante/desafiante?
3. Qual é a proposta de abordagem/solução?
4. Quais são as consequências/resultados da solução proposta?

**Palavras-chave:** Primeira palavra-chave, Outra palavra-chave, Mais uma palavra-chave, A última palavra-chave

# Contents

# List of Figures

# Acronyms

| | |
|---|---|
| novathesis | NOVAthesis LaTeX *(pp. i, ii)* |
| **VE** | Virtual Environment *(p. 1)* |
| **VR** | Virtual Reality *(p. 1)* |

# 1 Introduction

The implementation and exploration of safe, expansive and immersive Virtual Environments (VEs) has evolved with the development of Virtual Reality (VR) and its wide range of navigation techniques. These techniques influence several dimensions of User Experience (UX), such as efficiency, usability, immersion, comfort, and accessibility, and are, therefore, used in different contexts and situations.

In small physical spaces, the most commonly used navigation techniques rely on joystick-based movement and teleportation, due to the physical contraints of the environment. By cutting the use of Natural Walking, these techniques prove to be less immersive and unrealistic, as they trade the realism of walking elements for ease-of-use.

To address these limitations, new navigation paradigms have been developed. Some of these resource to the use of Impossible Spaces and Non-Euclidean Geometry to provide users the ability to naturally walk through extensive VEs, even whithin restricted physical spaces. By manipulating spatial perception and geometry, these techniques create the illusion of larger virtual spaces, enabling more intuitive and immersive navigation experiences.

It's through User Testing that the distinct advantages and disadavantage of each of these techniques are evaluated, making it easier to pinpoint which paradigms fit best into different contexts or situations.

## 1.1 Motivation

## 1.2 Related Questions

Q1-Is it worthwhile to explore navigation through non-Stride techniques whilst in a constricted physical space?

Q2-Does using hyperbolic strides instead of linear ones lead to increased disorientation and cybersickness?

Q3-Do hyperbolic spaces effectively convey more control to the user compared to spaces with linear strides?

# 2

# Related Work

## 2.1 Non-Euclidean and Impossible Spaces

### 2.1.1 Non-Euclidean Geometry

Rita, Rebelo, O. (2020). VR LAB: USER INTERACTION IN VIRTUAL ENVIRONMENTS USING SPACE AND TIME MORPHING.

Warren, W. H. (2019). Non-Euclidean navigation. In Journal of Experimental Biology (Vol. 222). Company of Biologists Ltd. https://doi.org/10.1242/jeb.187971

Hart, V., Hawksley, A., Matsumoto, E. A., & Segerman, H. (2017). Non-euclidean Virtual Reality I: Explorations of H 3. In Conference Proceedings (Vol. 33).

Muryy, A., & Glennerster, A. (2021). Route selection in non-Euclidean virtual environments. PLoS ONE, 16(4 April). https://doi.org/10.1371/journal.pone.0247818

### 2.1.2 Impossible Spaces

Suma, E. A., Lipps, Z., Finkelstein, S., Krum, D. M., & Bolas, M. (2012). Impossible Spaces: Maximizing Natural Walking in Virtual Environments with Self-Overlapping Architecture.

## 2.2 VR Locomotion Techniques

Boletsis, C., & Cedergren, J. E. (2019). VR Locomotion in the New Era of Virtual Reality: An Empirical Comparison of Prevalent Techniques. Advances in Human-Computer Interaction, 2019. https://doi.org/10.1155/2019/7420781

Boletsis, C. (2017). The new era of virtual reality locomotion: A systematic literature review of techniques and a proposed typology. In Multimodal Technologies and Interaction (Vol. 1, Issue 4). MDPI AG. https://doi.org/10.3390/mti1040024

### 2.2.1 Joysticks and Teleportation

Langbehn, E., Lubos, P., & Steinicke, F. (2018, April 4). Evaluation of locomotion techniques for room-scale VR: Joystick, teleportation, and redirected walking. ACM International Conference Proceeding Series. https://doi.org/10.1145/3234253.3234291

### 2.2.2 Natural Walking

Cao, A., Wang, L., Liu, Y., & Popescu, V. (2020). Feature Guided Path Redirection for VR Navigation. 137–145. https://doi.org/10.1109/vr46266.2020.00032

Exploring Large Virtual Environments with an HMD when Physical Space is Limited (2007)

Flexible Spaces: Dynamic Layout Generation for Infinite Walking in Virtual Environments . (2013). IEEE.

Suma, E. A., Lipps, Z., Finkelstein, S., Krum, D. M., & Bolas, M. (2012). Impossible Spaces: Maximizing Natural Walking in Virtual Environments with Self-Overlapping Architecture.

Nakatsu, Ryohei., Klinker, Gudrun., & Lok, Benjamin. (2010)

#### 2.2.2.1 Through Redirection

15 Years of Research on Redirected Walking in Immersive Virtual Environments. (2018). www.computer.org/cga

#### 2.2.2.2 Through Adaptable Spaces

Simeone, A. L., Christian Nilsson, N., Zenner, A., Speicher, M., & Daiber, F. (2020). The Space Bender: Supporting Natural Walking via Overt Manipulation of the Virtual Environment. 598–606. https://doi.org/10.1109/vr46266.2020.00082

Suma, E. A., Lipps, Z., Finkelstein, S., Krum, D. M., & Bolas, M. (2012). Impossible Spaces: Maximizing Natural Walking in Virtual Environments with Self-Overlapping Architecture.

## 2.3 Space Modification Techniques

### 2.3.1 Procedural Content Generation

Dong, Z. C., Fu, X. M., Zhang, C., Kang, W. U., & Ligang, L. I. U. (2017). Smooth assembled mappings for large-scale real walking. ACM Transactions on Graphics, 36(6). https://doi.org/10.1145/3130800.3130893

Sra, M., Garrido-Jurado, S., & Maes, P. (2018). Oasis: Procedurally Generated Social Virtual Spaces from 3D Scanned Real Spaces. IEEE Transactions on Visualization and Computer Graphics, 24(12), 3174–3187. https://doi.org/10.1109/TVCG.2017.2762691

### 2.3.2 Spatial Compression

Simeone, A. L., Christian Nilsson, N., Zenner, A., Speicher, M., & Daiber, F. (2020). The Space Bender: Supporting Natural Walking via Overt Manipulation of the Virtual Environment. 598–606. https://doi.org/10.1109/vr46266.2020.00082

Towards Efficient Spatial Compression in Self-Overlapping Virtual Environments (2017)

# 3

# Plan and Analysis

# 4

# Conclusion