A Virtual Reality Game to Explore Hyperbolic Geometry

Joris Rijsdijk - jarijsdijk@tudelft.nl

Responsible Professor: M. Skrodzki, Supervisor: R. Bidarra

TU Delft

1. Background

- **Hyperbolic space** is a type of geometry that is different from the **Euclidean geometry** we experience in the real world
- This research builds upon a software project called **Holonomy**, in which players explored a hyperbolic world in VR by walking in real life.
- In particular, the space is tiled using 5-order square tiling, as seen in **Figure 1.**
  - This means the space is tiled by squares, but each corner is connected to 5 squares instead of 4.

2. Problem Description

- Without the objective on screen, the space appeared to be Euclidean as Holonomy's environment was **empty**.
- It is impossible to design an infinite level beforehand, which is required as Holonomy does not restrict the player in where they move.

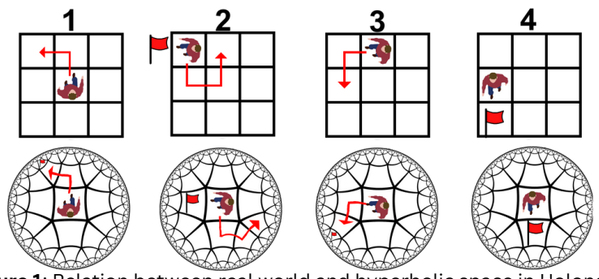

Figure 1: Relation between real world and hyperbolic space in Holonomy

3. Research Question

- Does **procedurally generating** an environment **immerse** players more compared to an empty environment in a virtual hyperbolic world?

4. Proposed Solution

- The **Wave Function Collapse** (WFC) Algorithm can be used to populate the environment.
  - WFC is a constraint solver, that builds a solution to a problem by repeatedly propagating constraints, as seen in **Algorithm 1**.
- **Hierarchy** can be introduced to group tiles.
  - A cell first is assigned a biomes or tileset, then WFC tries to only use those tiles if they are compatible with its neighbours.
- We made the environment represent a **park** instead of a haunted house to feel more inviting, like in **Figure 2**.
- Constraints can also dictate per direction what edge can connect to it. This allows WFC to generate seemingly multi-tiled objects, such as ponds. We call these **orientational constraints**, as seen in **Figure 3**.

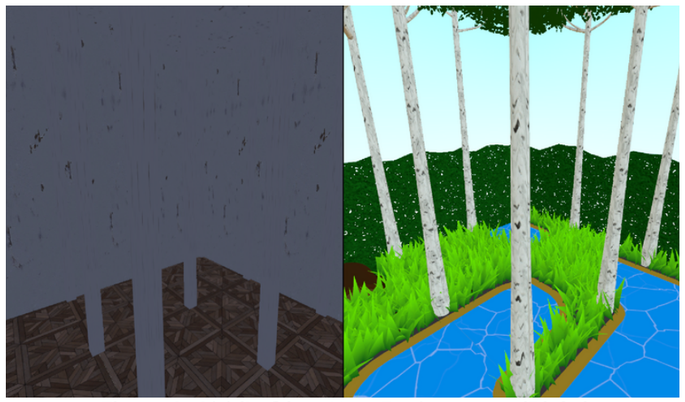

Figure 2: Old **(Left)** vs New Environment **(Right)**

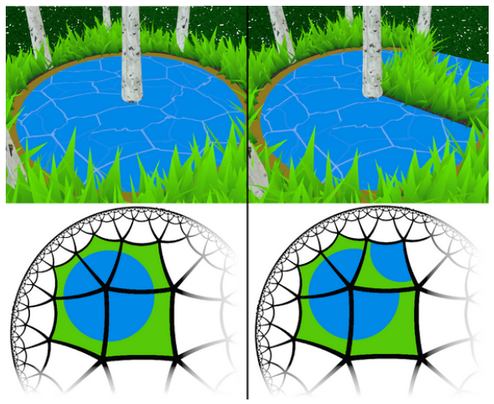

Figure 3: Orientational Constraints

5. Evaluation

- Two groups of players **completed three levels** in Holonomy, where they had to navigate to an objective.
  - 15 people in Group A completed the levels in the old environment.
  - 8 people in Group B completed the levels in the procedurally generated environment.
  - As seen in **Figure 4**, Group A and B required mostly the **same time**, but Group B required **fewer steps**.
- Both groups answered an evaluation form at the end, the results are seen in **Figure 5**.
  - None of the questions were **statistically significant**, although one came close.
  - Group B **thought they did worse** than Group A, even though this is false.
    - It could be that players were getting distracted by the environment.
- Players also gave feedback after the experiment.
  - Players from Group A reported **completely ignoring the environment**, or even being confused by it.
  - Players from Group B were sometimes **hesitant to walk on rivers** or followed them to try to reach the objective.
- Both groups reported being over-reliant on the minimap for navigation.

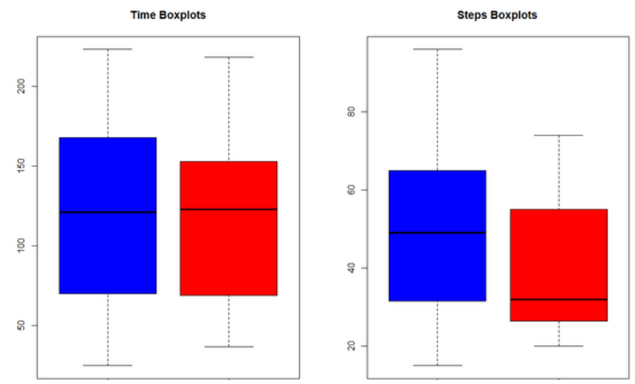

Figure 4: Performance measured in Time **(Left)** and steps **(Right)**, for Group A **(Blue)** and Group B **(Red)**

Survey Question	Group A Med	Group B Med	p-value
My navigation towards the objective went well.	4	2.5	0.102
The minimap was very helpful with finding the objective.	6	6	0.969
The minimap was easy to read and understand.	5	4	0.404
I have a good understanding of hyperbolic geometry.	3	3	0.895
I felt comfortable in the environment.	4	3.5	0.767
The environment helped me orientate.	4	2.5	0.322
The environment helped me navigate towards the objective.	2	2	0.557

Figure 5: Results of evaluation form, p-value calculated using Wilcoxon rank sum test

6. Conclusion

- We can conclude that a procedurally generated environment **immerses players more** compared to an empty environment in a virtual hyperbolic world.
  - Players from group B interact more with the environment compared to group A.
- Group B takes fewer steps to complete the objective, so we infer players in a populated environment are **better at building an intuition** for the space.

Algorithm 1 Wave Function Collapse

```
while an uncollapsed cell exists do
    Cell C ← GET any cell with lowest entropy
    Tile T ← Collapse C into any of its possible tiles
    for all neighbours of C do
        Remove possible tiles that are not compatible with T
```

Algorithm 1: High level Implementation of Wave Function Collapse

7. Future Work

- Further user tests are needed to reach statistical significance.
- Additional tests without minimap could be conducted, to make sure both groups solely rely on the environment.