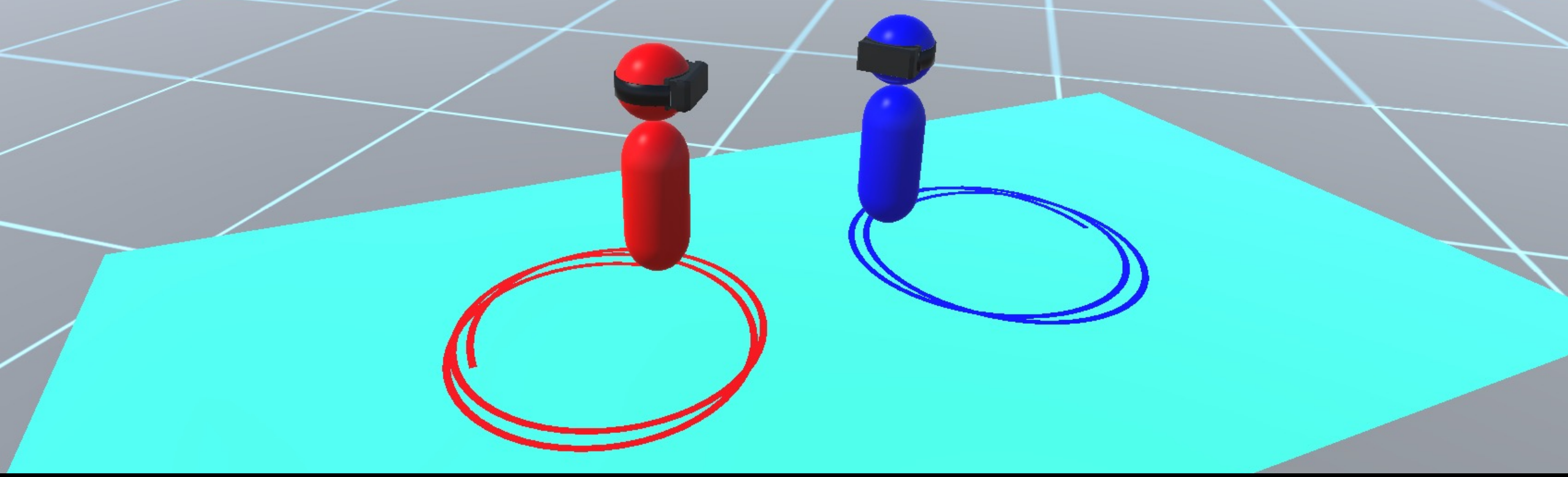


# Redirected Walking

Reading: *15 Years of Research on Redirected Walking in Immersive Virtual Environments*

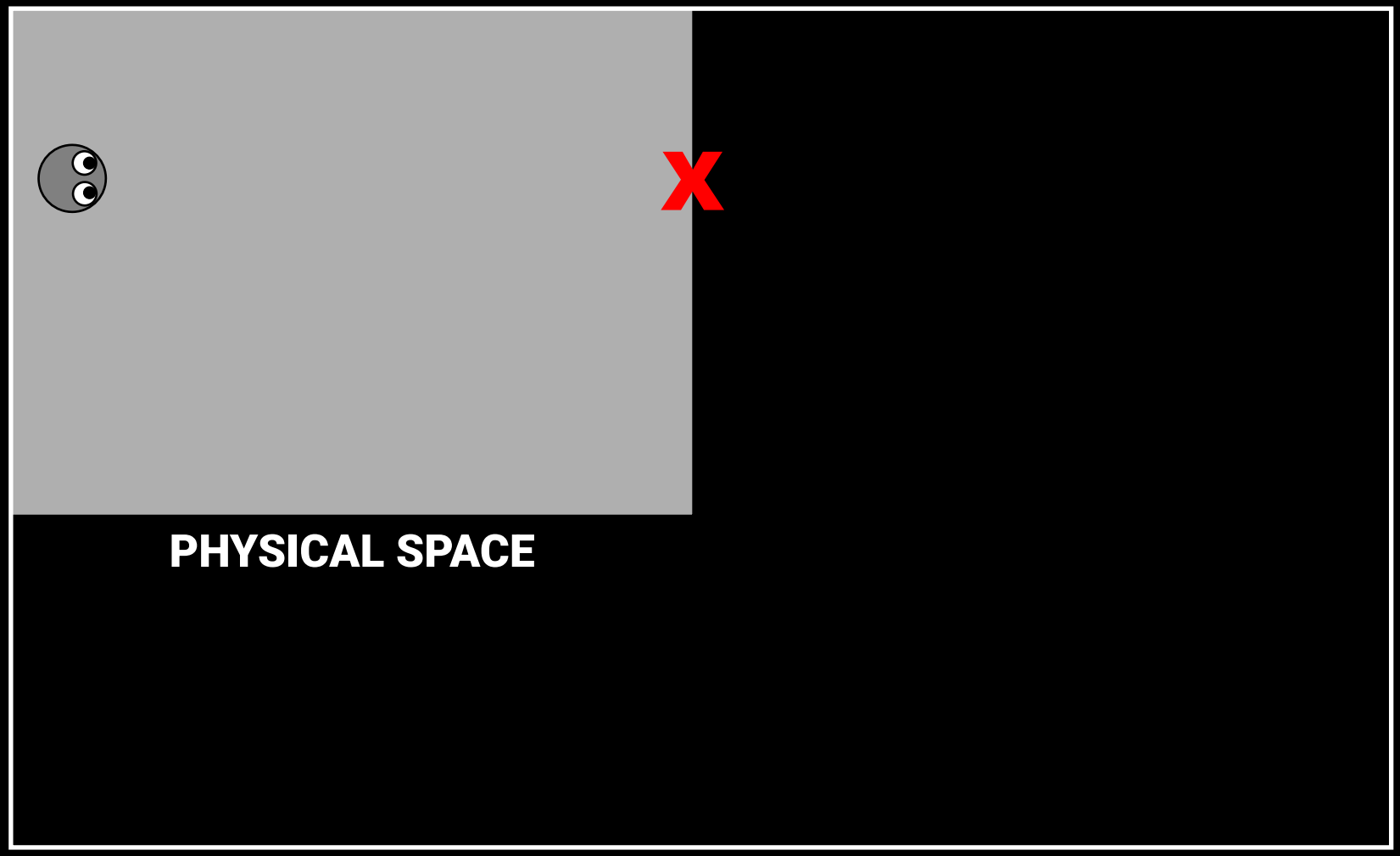
**Slides adapted from Evan Suma Rosenberg's material**


STRESS LEVEL ZERO

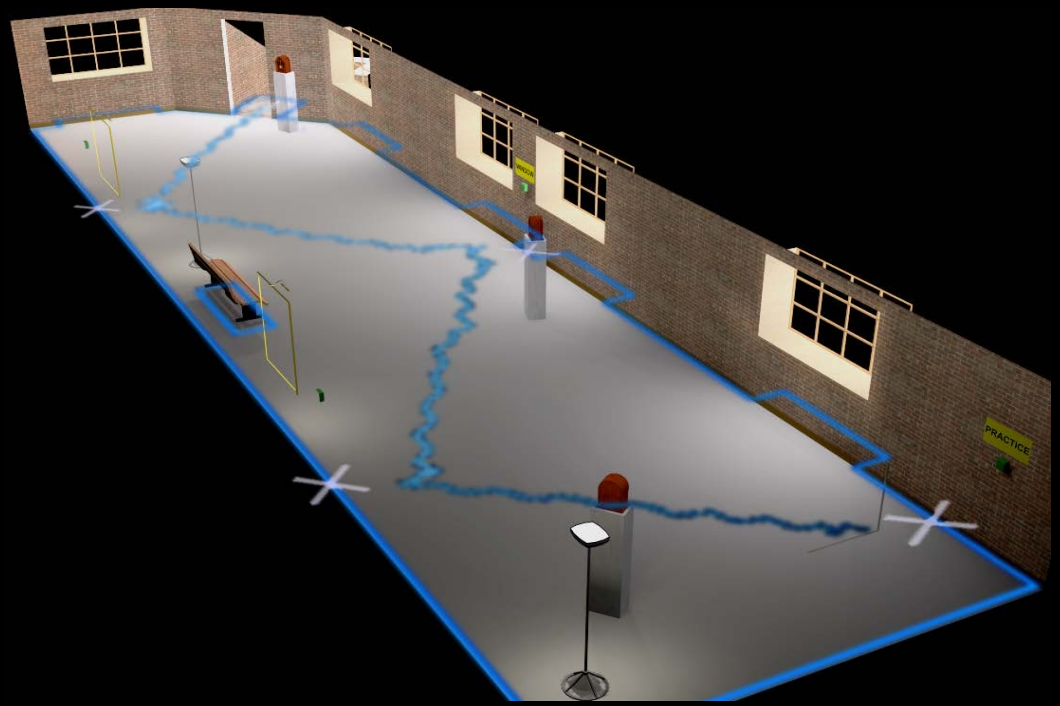
Every controller position is still being tracked

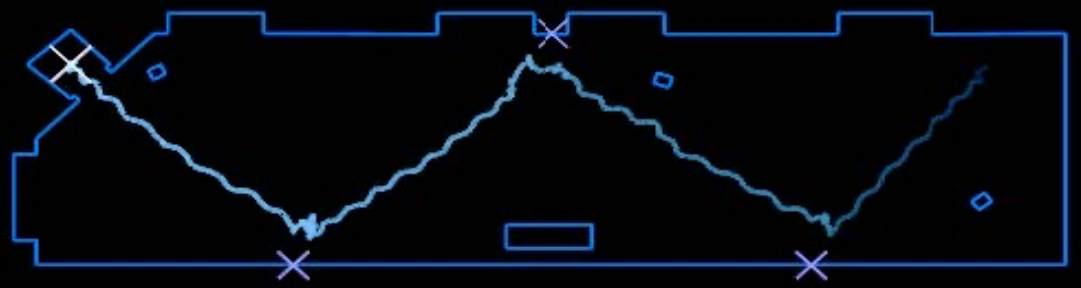
orange volume is our Primary hard bounds

# The Locomotion Problem



# Redirected Walking



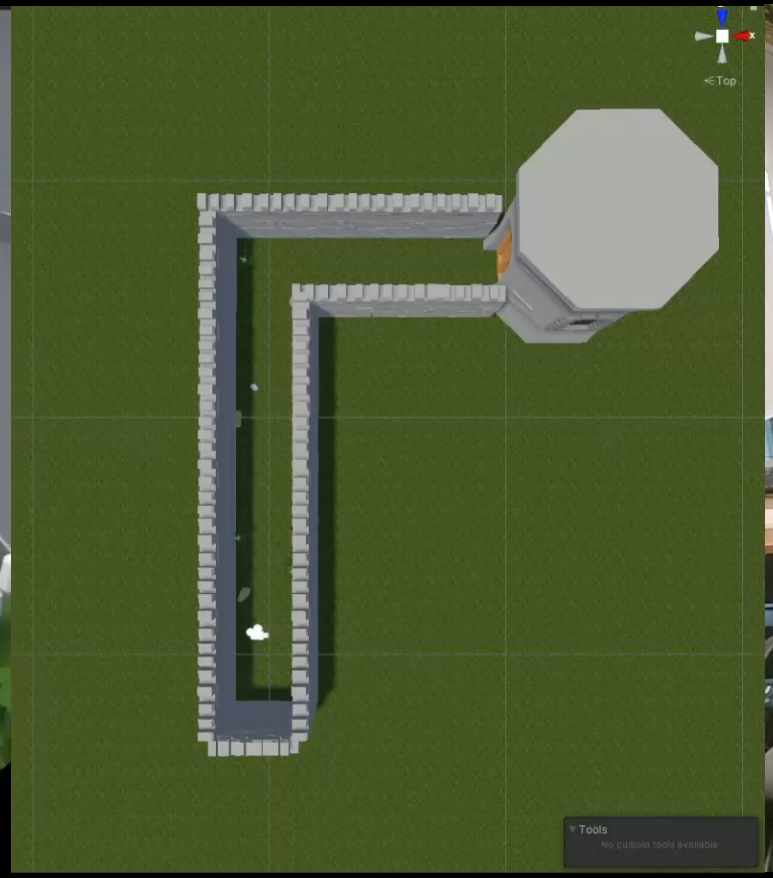



Virtual World Path

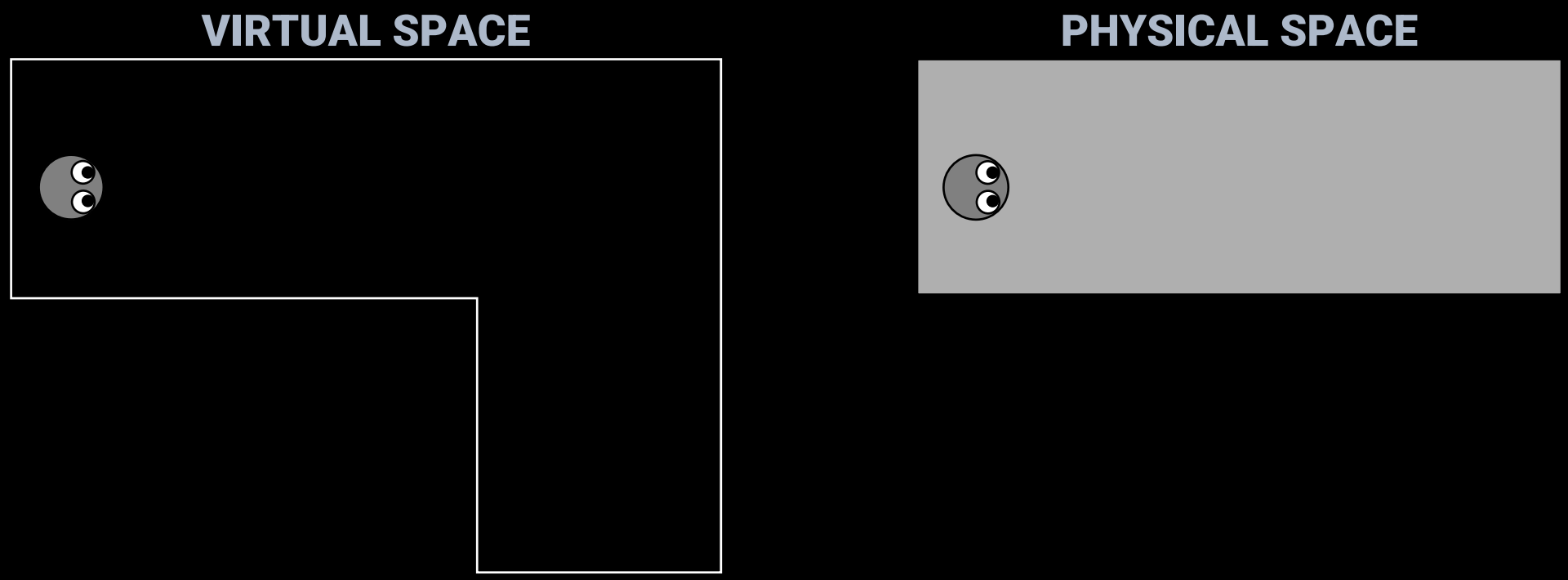
Real World Path

S. Razzaque, Z. Kohn, and M. Whitton. Redirected Walking, Eurographics 2001.

# Redirected Walking

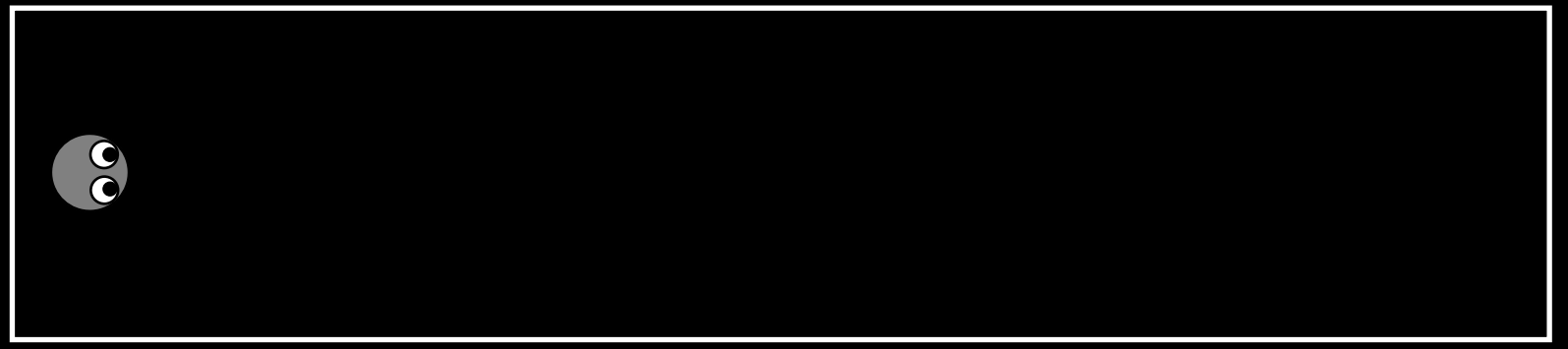



# Rotation Gain



# Translation Gain

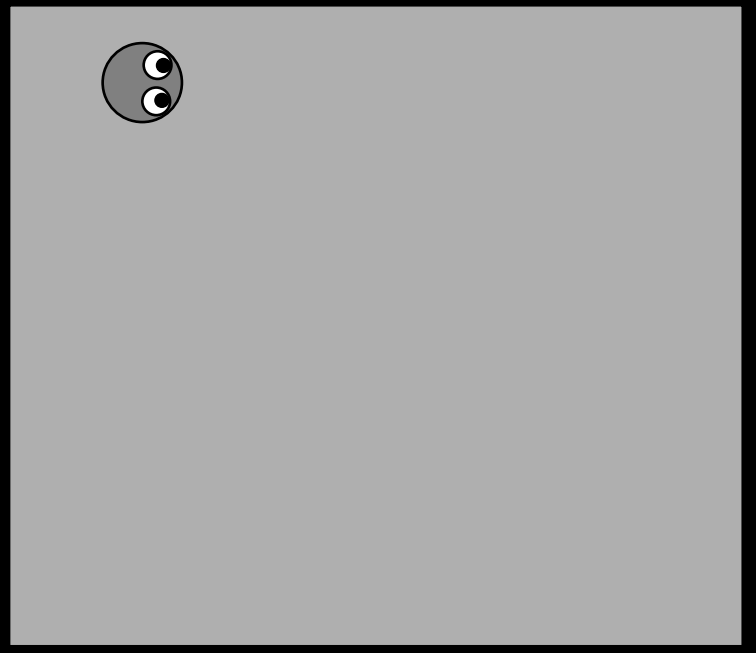
PHYSICAL SPACE



VIRTUAL SPACE

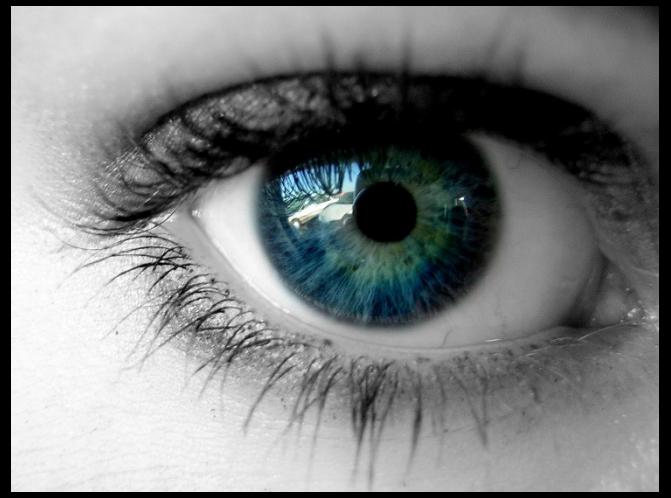
# Curvature Gain

VIRTUAL SPACE



PHYSICAL SPACE

# Why does redirection work?



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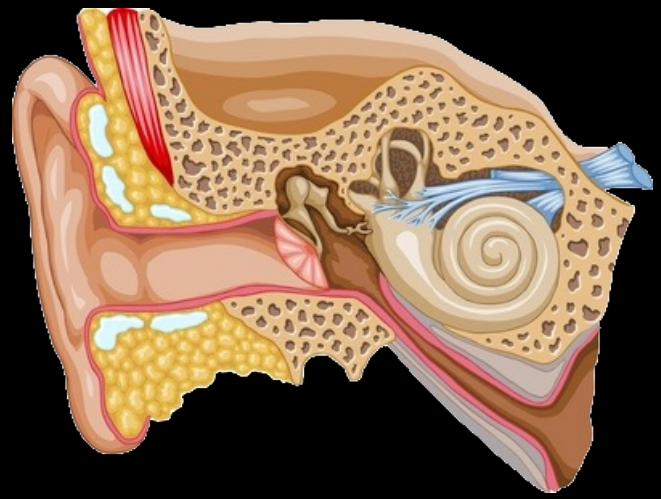
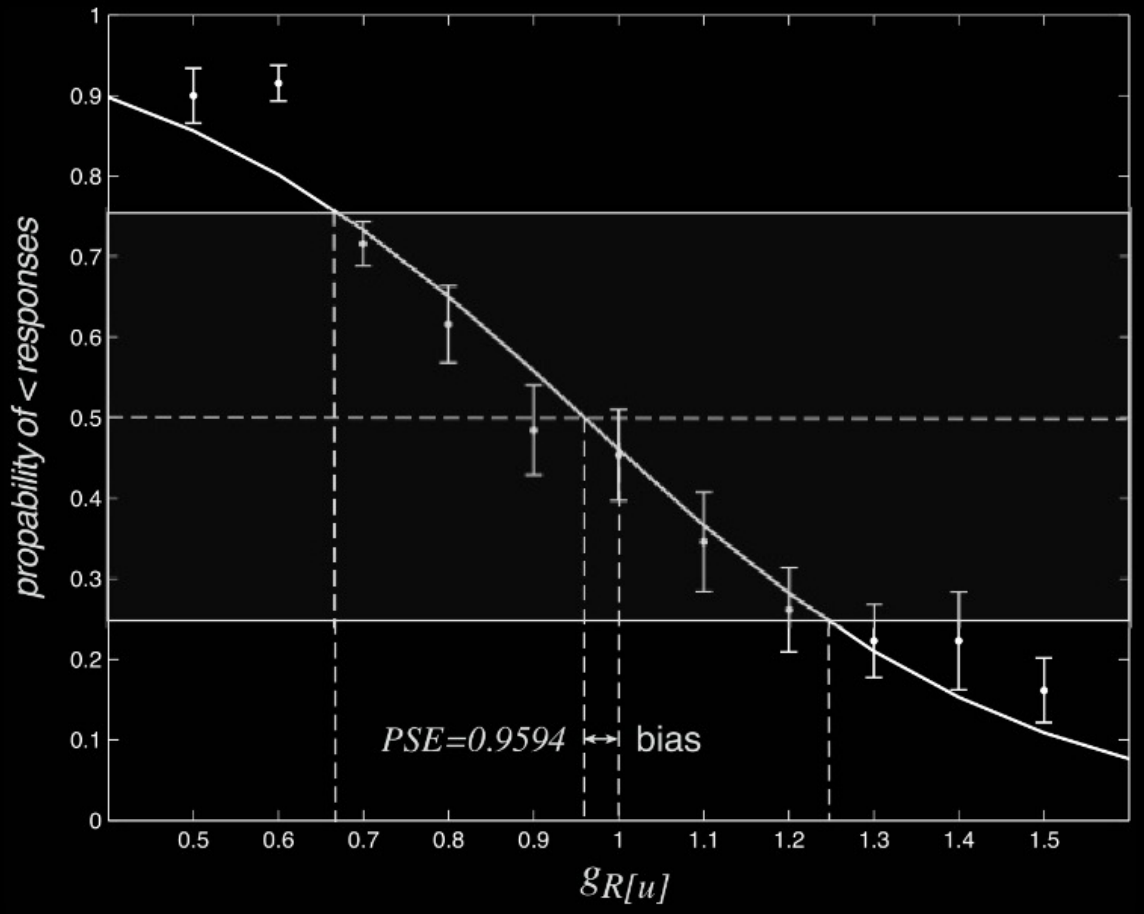


**Vision** tends to dominate over **vestibular** sensation.

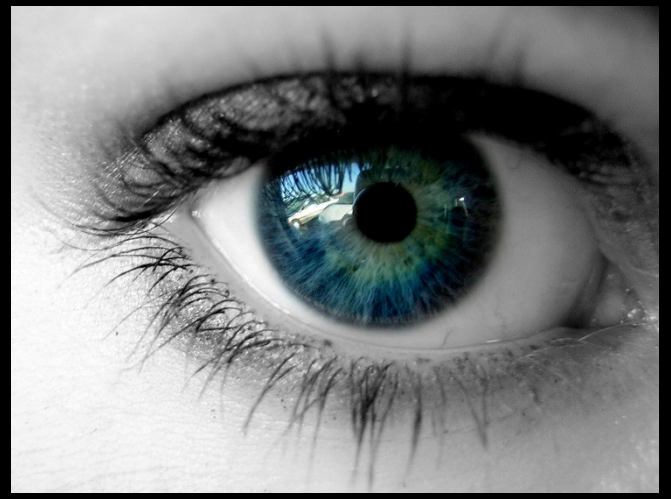
# Measuring Detection Thresholds

- Two alternative forced choice task (2AFC)
- User repeatedly presented with a stimulus of varying level and asked to detect it
- Compute pooled probability of response (forced choice, no neutral option)
- Fit a psychometric function (sigmoid)
- Point of subjective equality (PSE) at 50%
- Detection thresholds at 25% and 75%




F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe. Estimation of Detection Thresholds for Redirected Walking Techniques, IEEE TVCG 2010.

# Detection Thresholds for Redirected Walking



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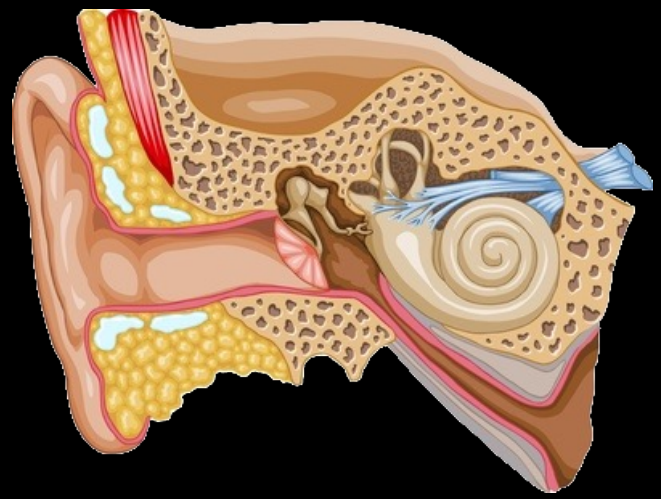
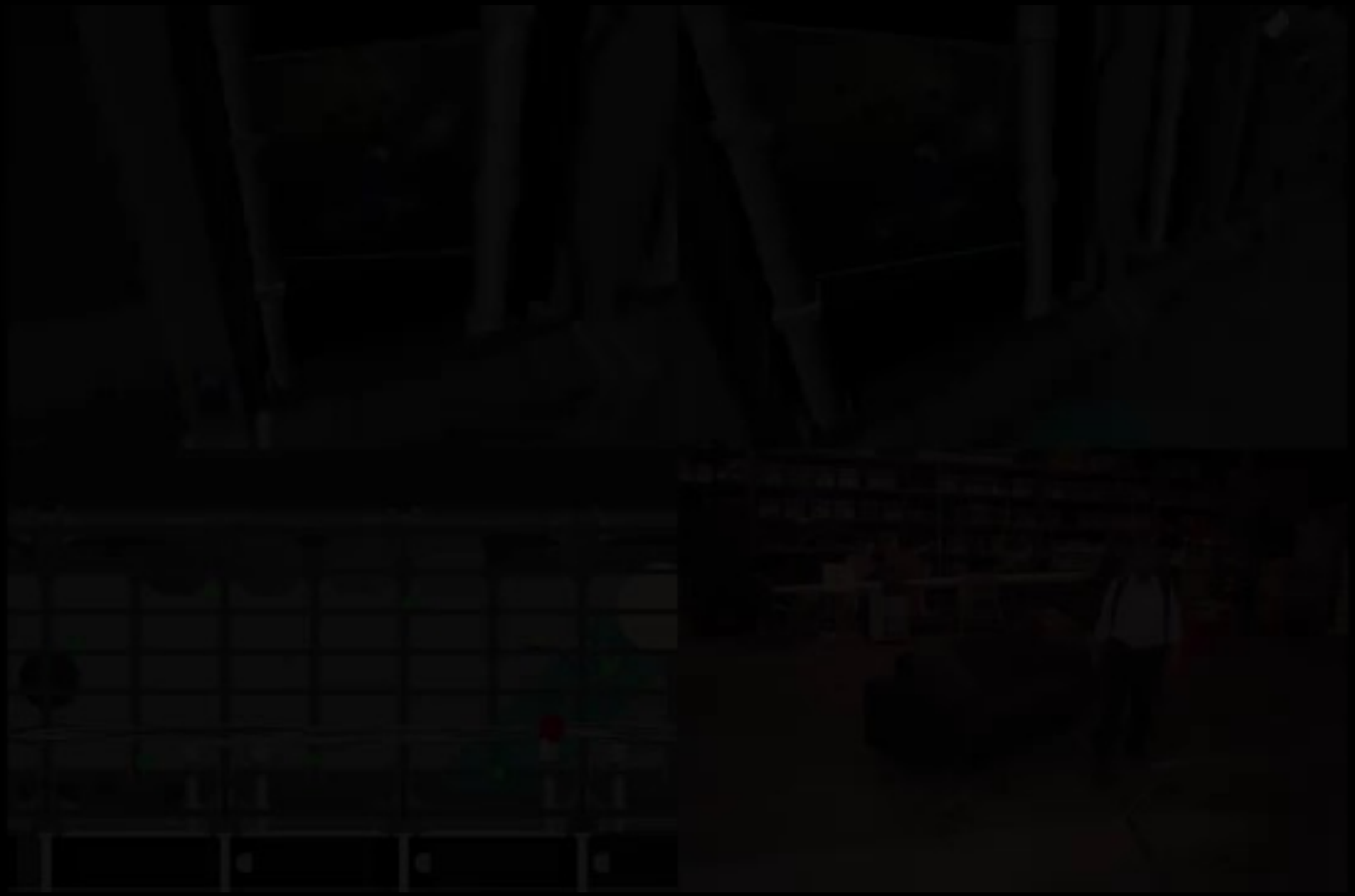


**Rotation Gains**
49% amplification
20% dampening

**Curvature Gains**
arc radius >= 20 meters

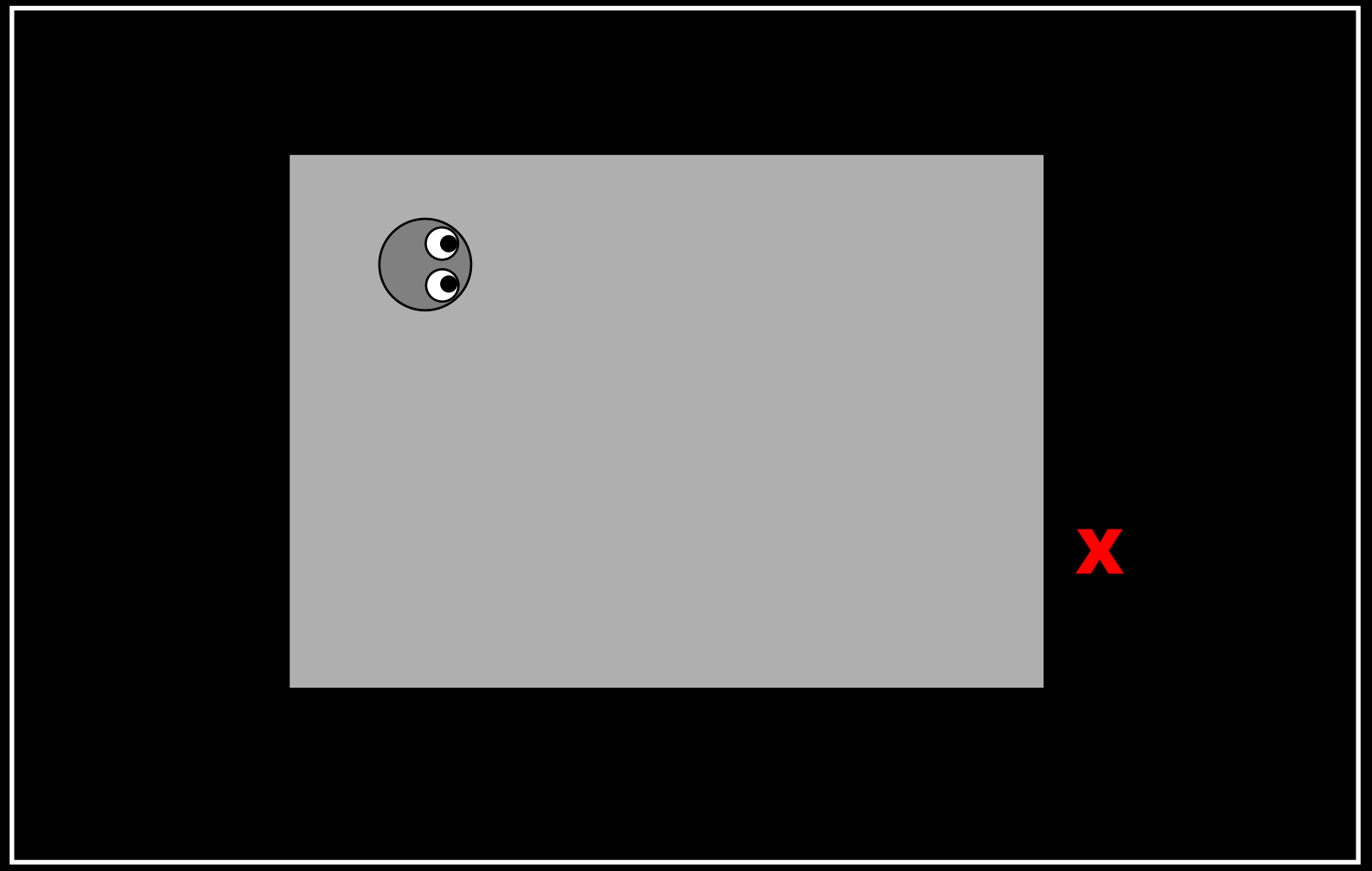
**Translation Gains**
26% upscale
14% downscale

F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe. Estimation of Detection Thresholds for Redirected Walking Techniques, IEEE TVCG 2010.

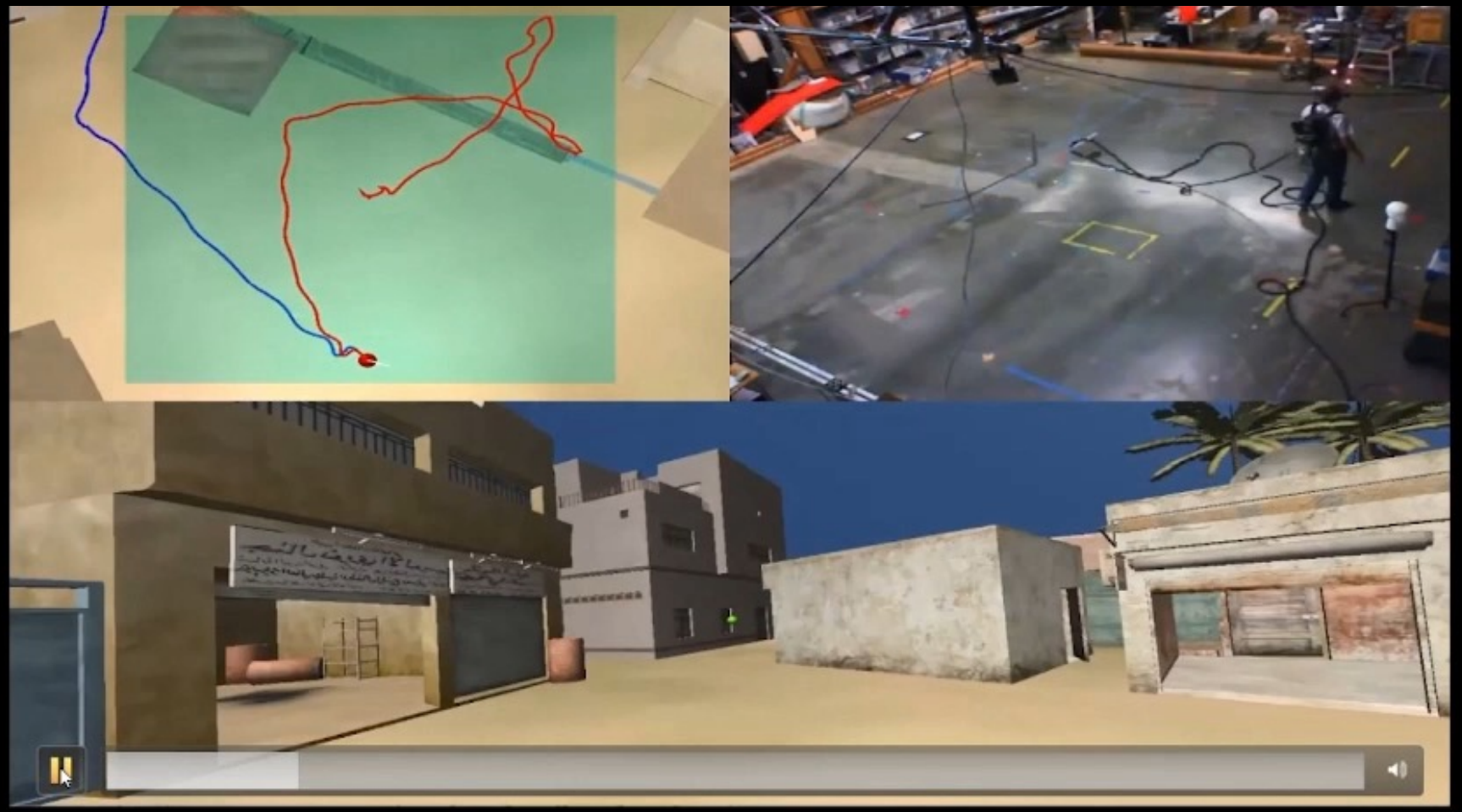


Discovering Near-Field VR: Stop Motion with a Touch of Light-Fields and a Dash of Redirection, 2015 SIGGRAPH AR/VR Contest Winner

# Reorientation Events (Resets)

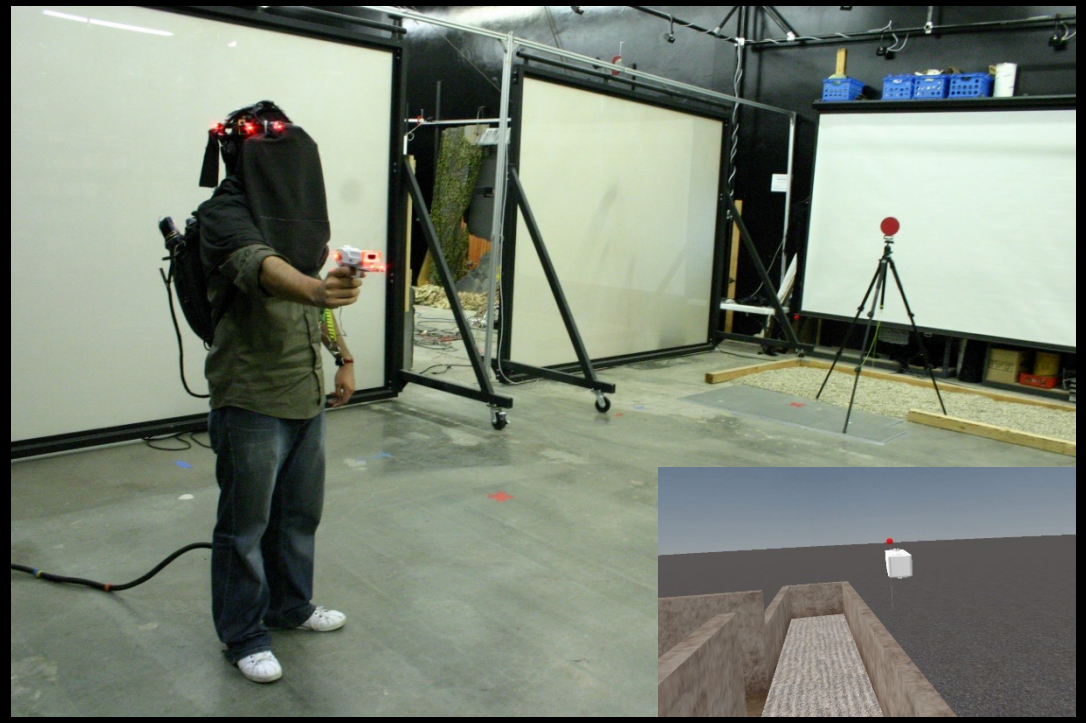


# Reorientation Events (Resets)



T. Grechkin, M. Azmandian, M. Bolas, and E. Suma. Towards Context-Sensitive Reorientation for Real Walking in Virtual Reality, IEEE VR 2015.

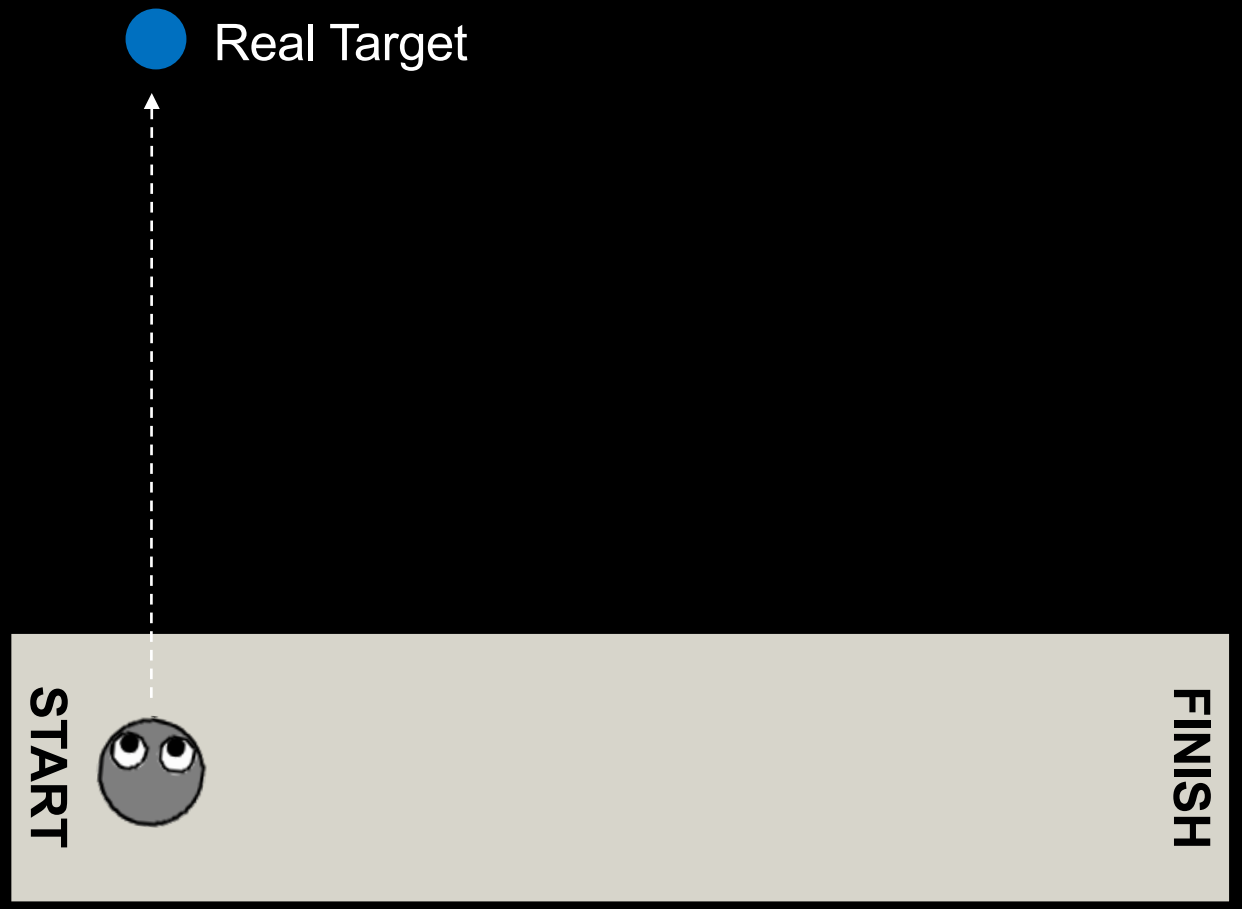
# Spatial Orientation Experiment

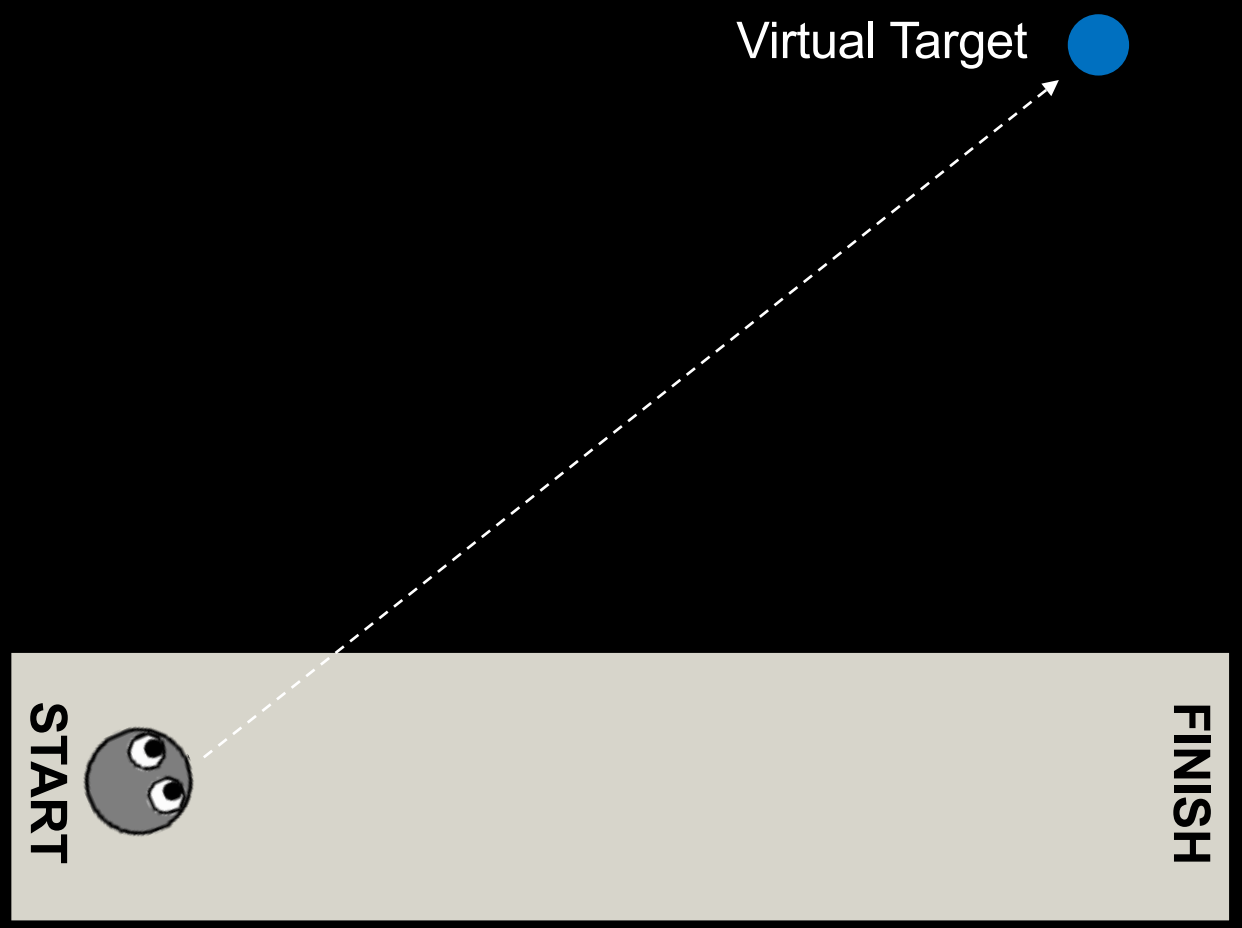


E. Suma, D. Krum, S. Finkelstein, and M. Bolas. Effects of Redirection on Spatial Orientation in Real and Virtual Environments, IEEE 3DUI 2011.

How does redirection influence the user’s **real world** orientation?

Can we maintain both spatial **reference frames** at the same time?

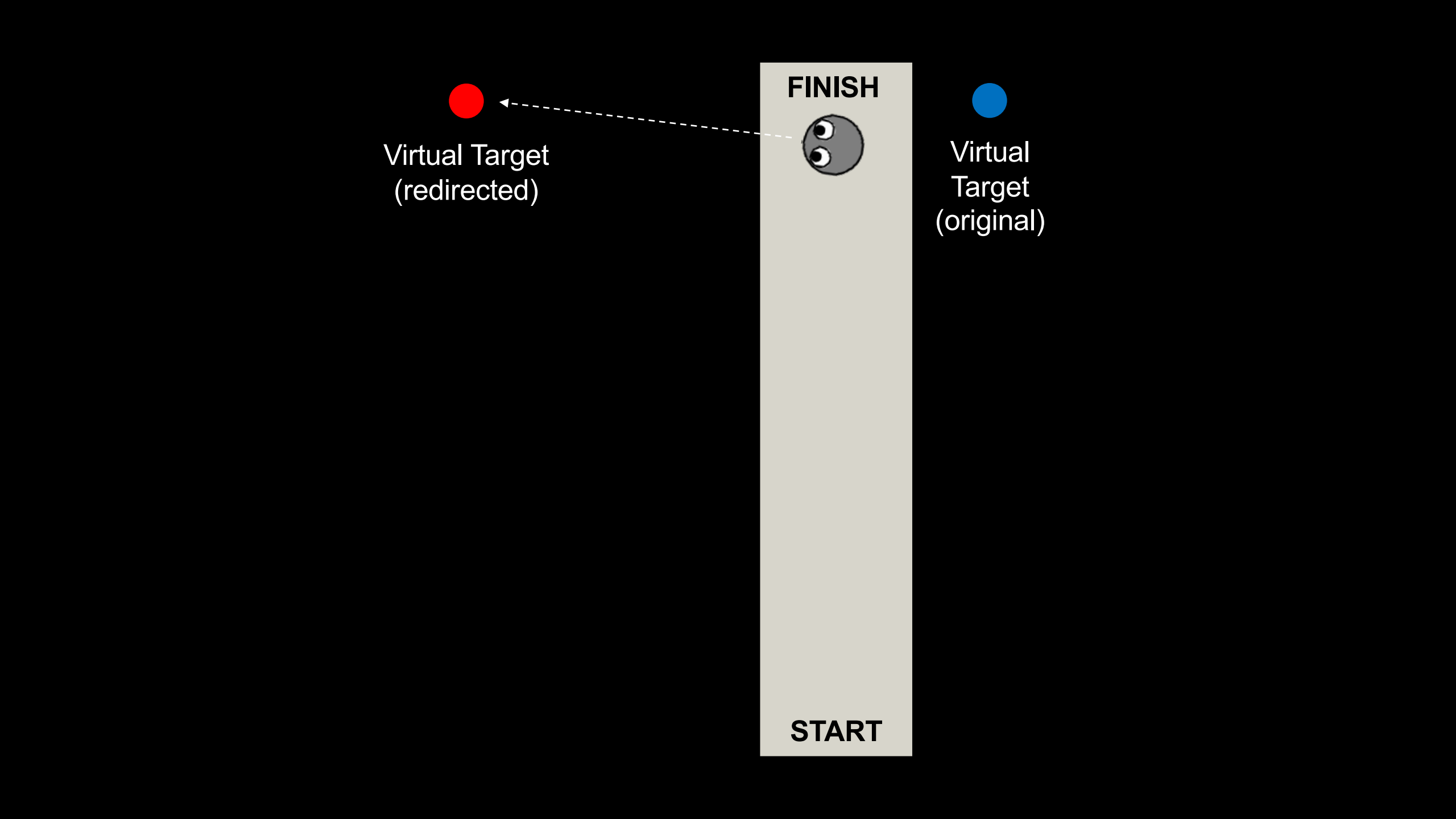

Real Target
START
FINISH


Virtual Target
START
FINISH

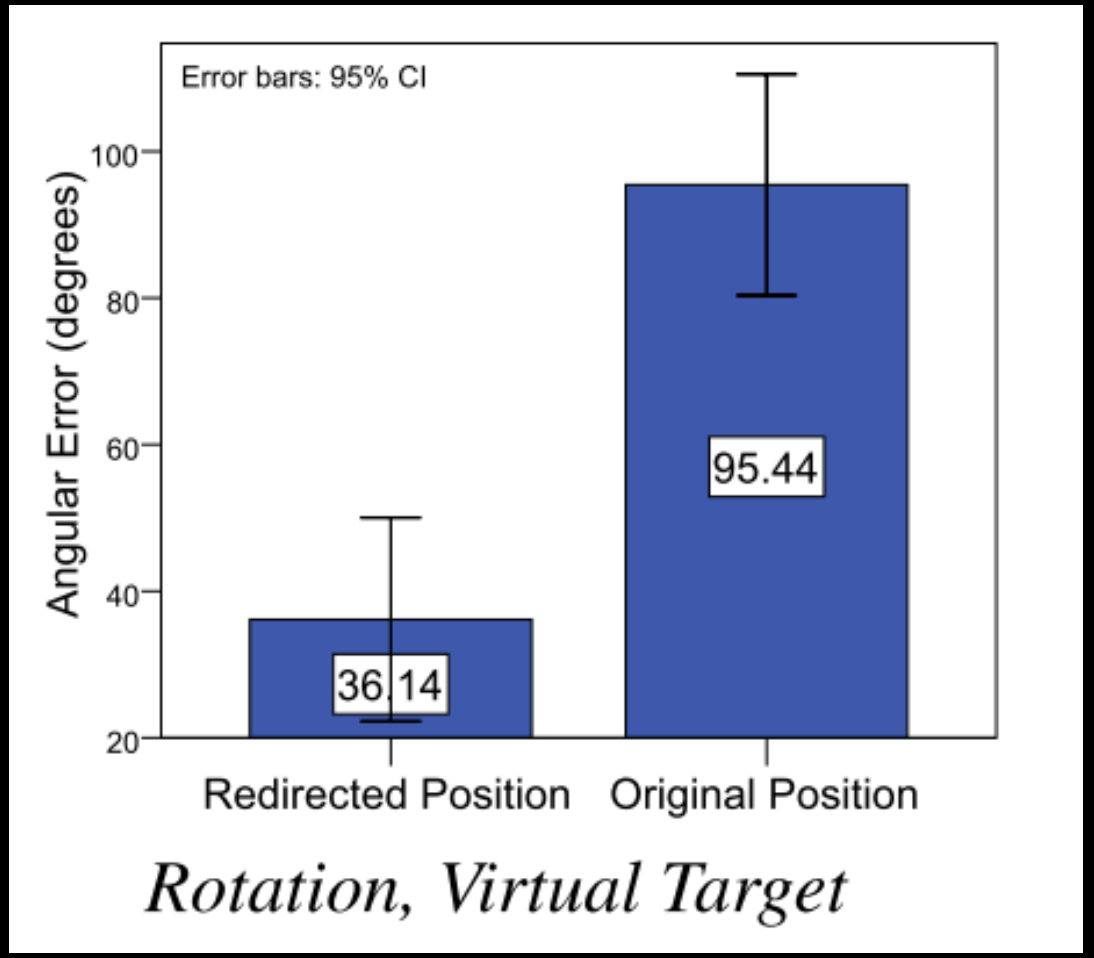
FINISH

START

Virtual
Target
(original)
START
FINISH


FINISH
Virtual Target
(redirected)
Virtual
Target
(original)
START

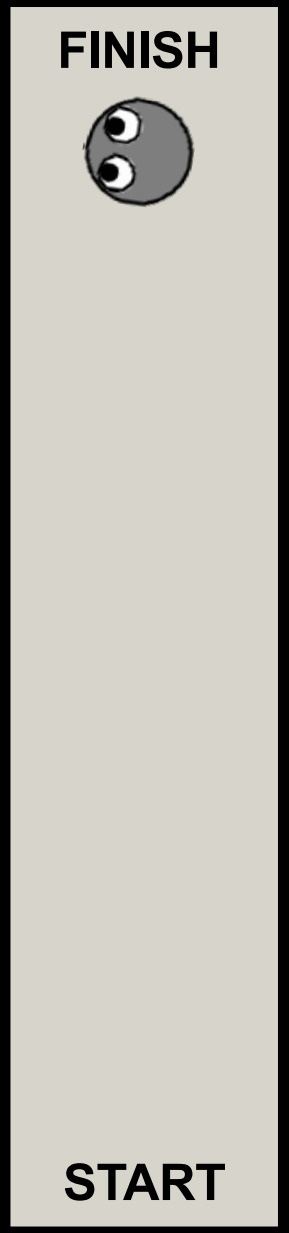
# Angular Pointing Error

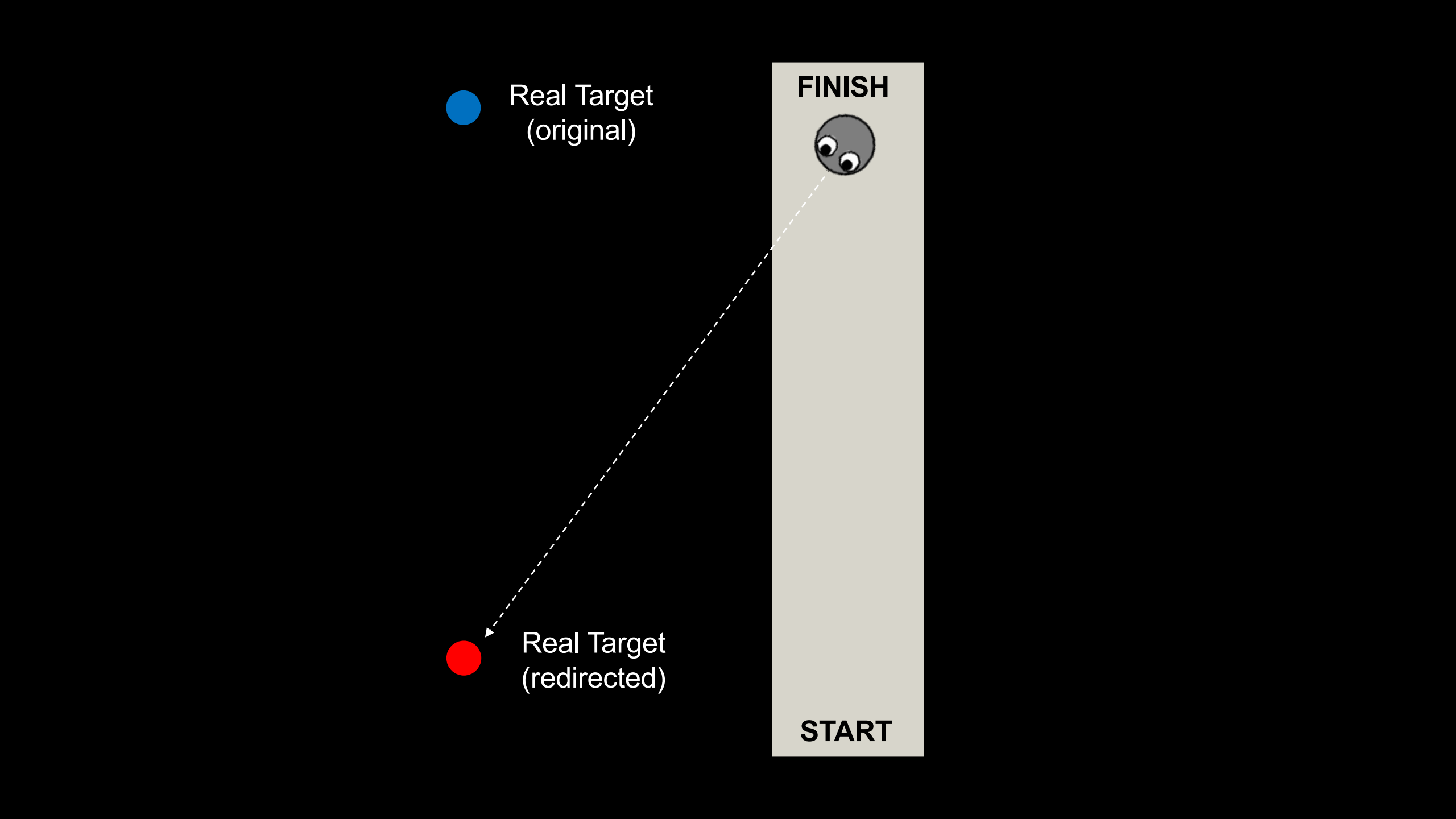


FINISH

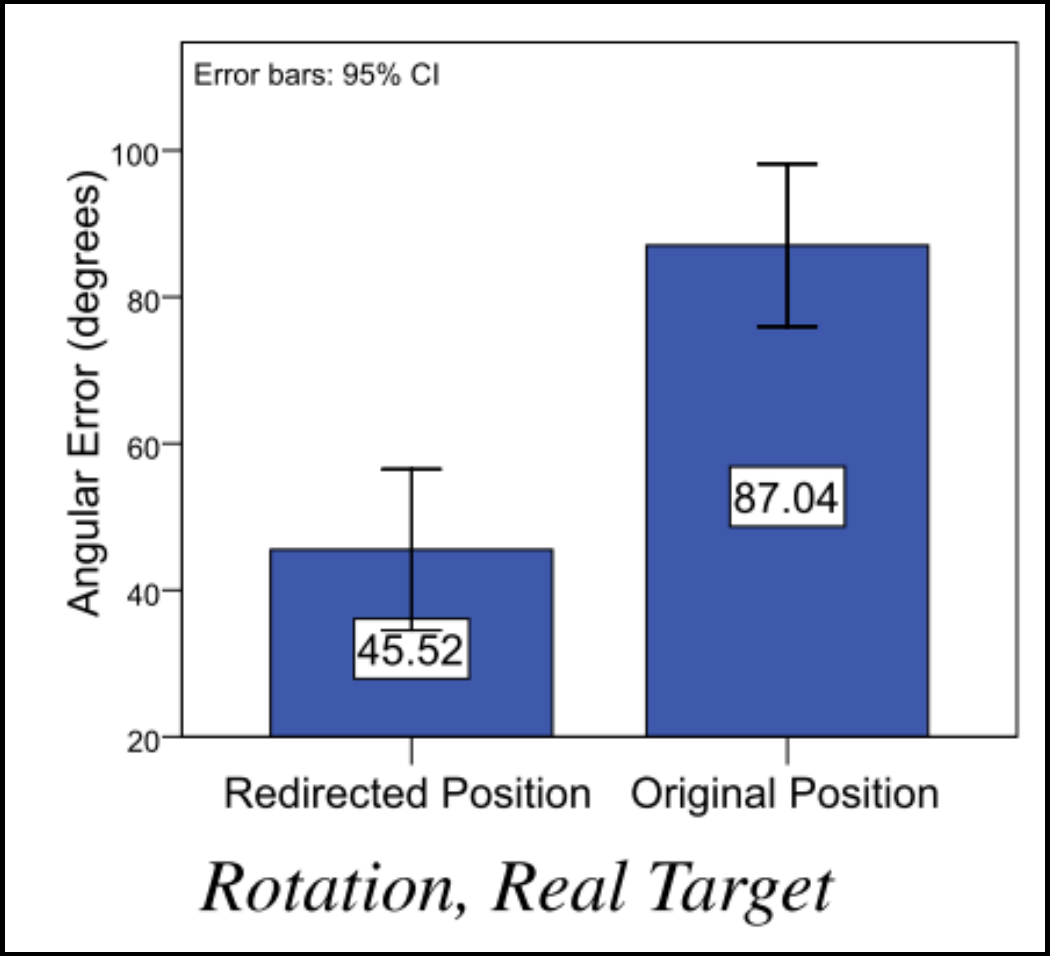
START

Real Target
(original)




Real Target
(original)
FINISH
Real Target
(redirected)
START

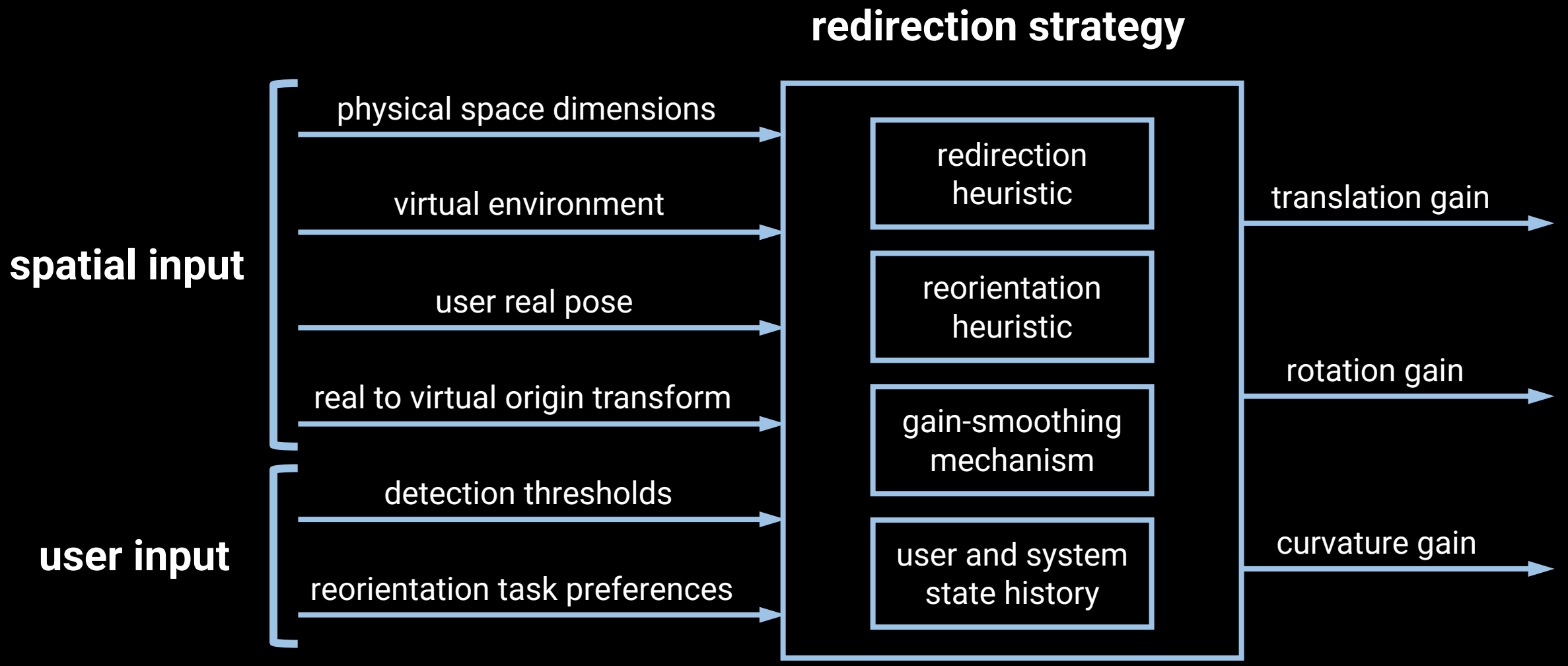
# Angular Pointing Error



# Research Questions

- How much redirection can we apply before it becomes **perceptible?**
  - *Answer: quite a bit!*
- How much redirection can we apply before it becomes **noticeable?**
  - *Answer: even more!*
- How does redirection impact the **user experience?**
  - spatial cognition
  - user behavior
  - task performance
- **Optimal steering direction** that minimizes # of resets?

# Redirected Walking Systems



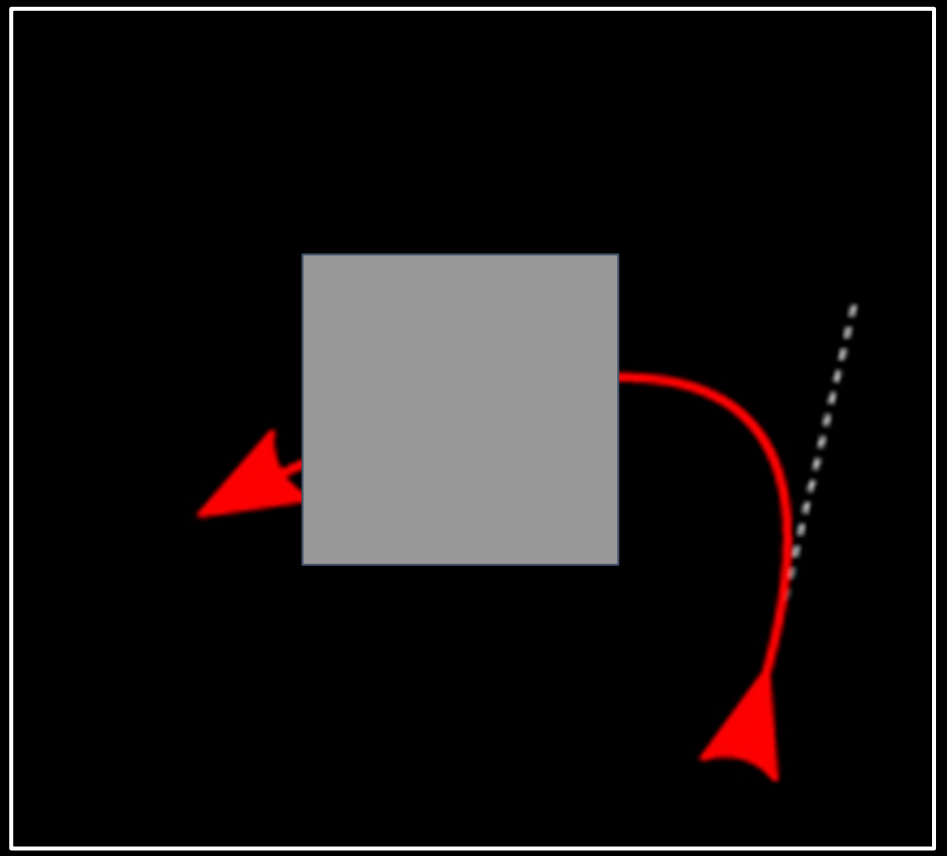
# How much can we predict the user?


| Linear Route | Branching Pathways | Open World |
| --- | --- | --- |
| **Static Planning** | **Dynamic Planning** | **Reactive Algorithms** |

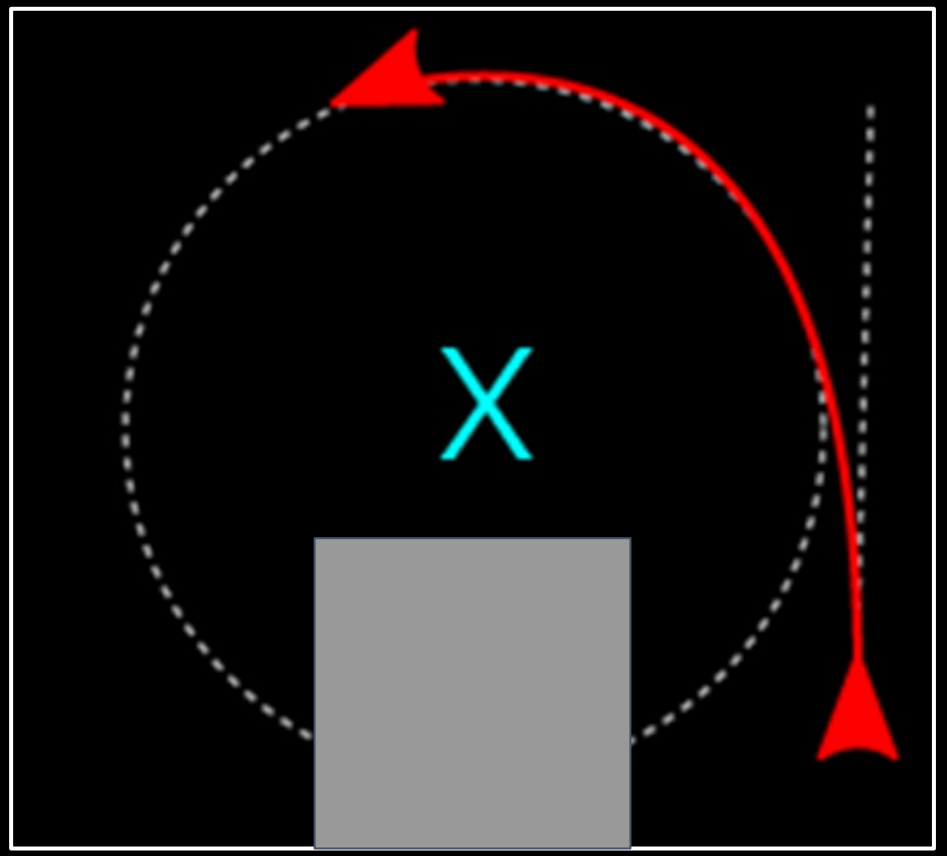
# How much can we predict the user?


| Linear Route | Branching Pathways | Open World |
| --- | --- | --- |
| **Static Planning** | **Dynamic Planning** | **Reactive Algorithms** |

# Reactive Algorithms

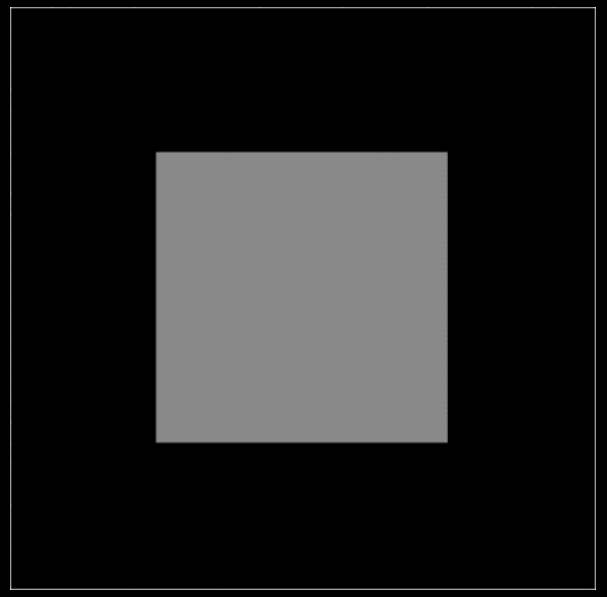


Steer to Center (S2C)

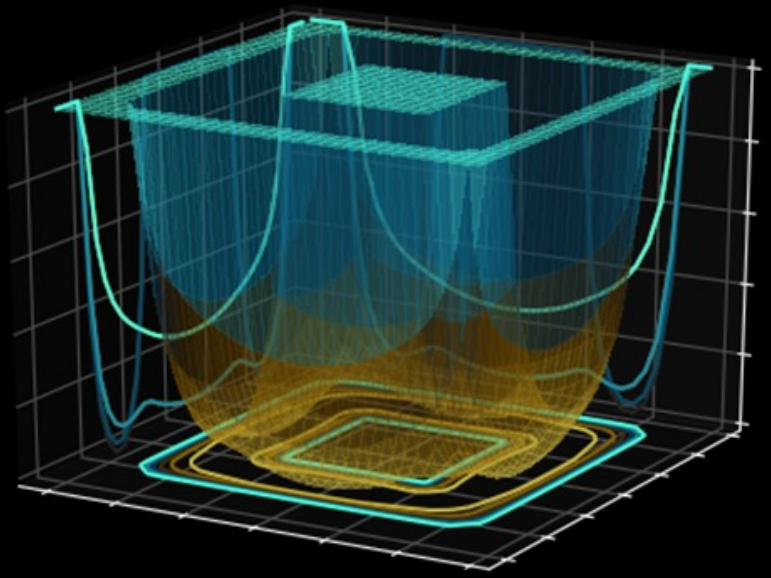



Steer to Orbit (S2O)

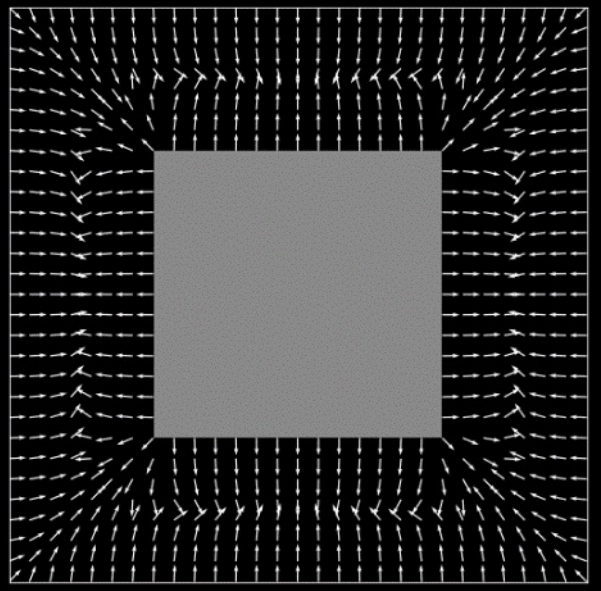
# Push / Pull Reactive (P2R) Algorithm



Physical Environment



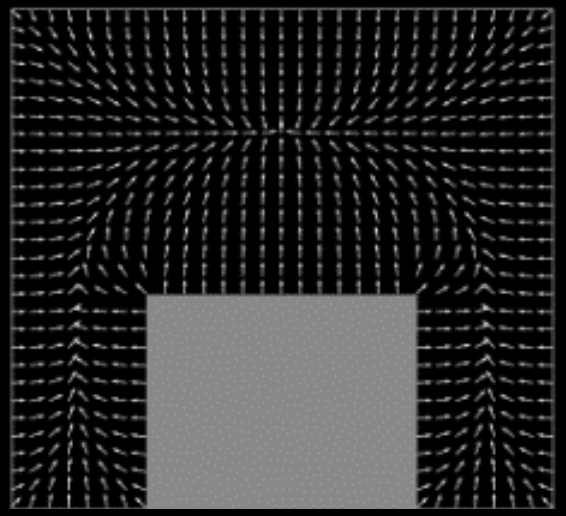
Artificial Potential Function

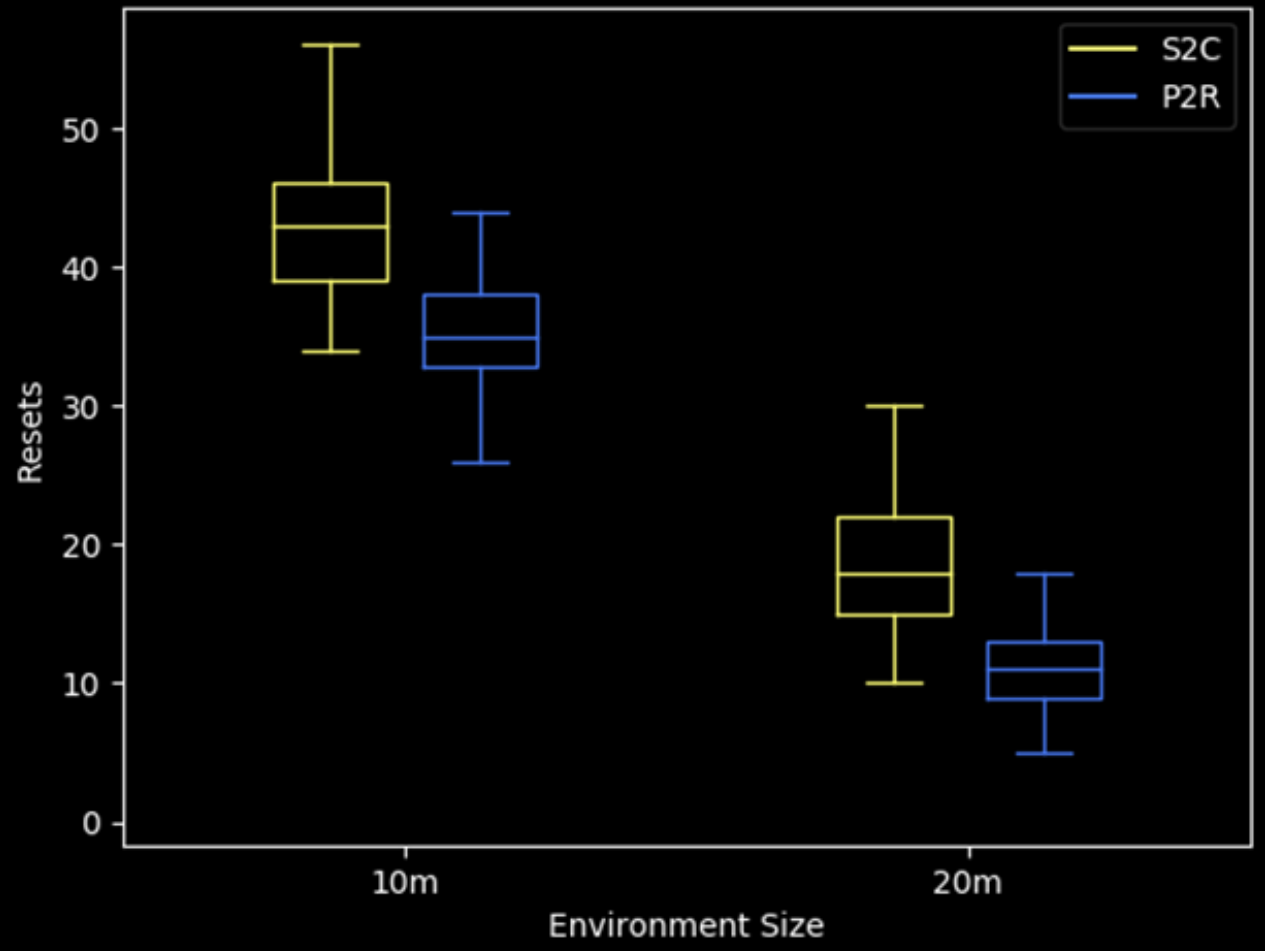


Gradient Field

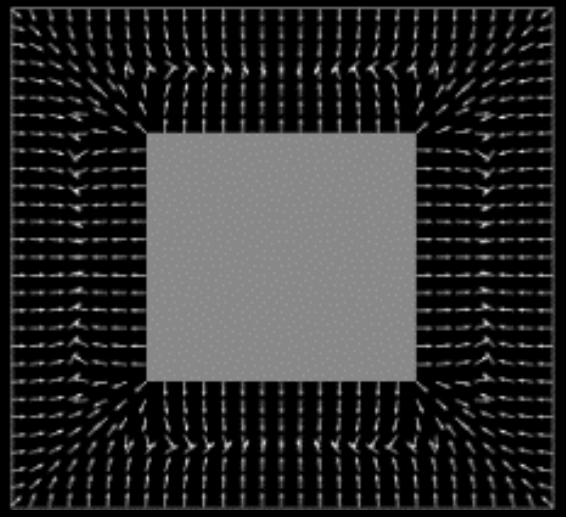
J. Thomas and E. Suma Rosenberg. A General Reactive Algorithm for Redirected Walking using Artificial Potential Functions, IEEE VR 2019.

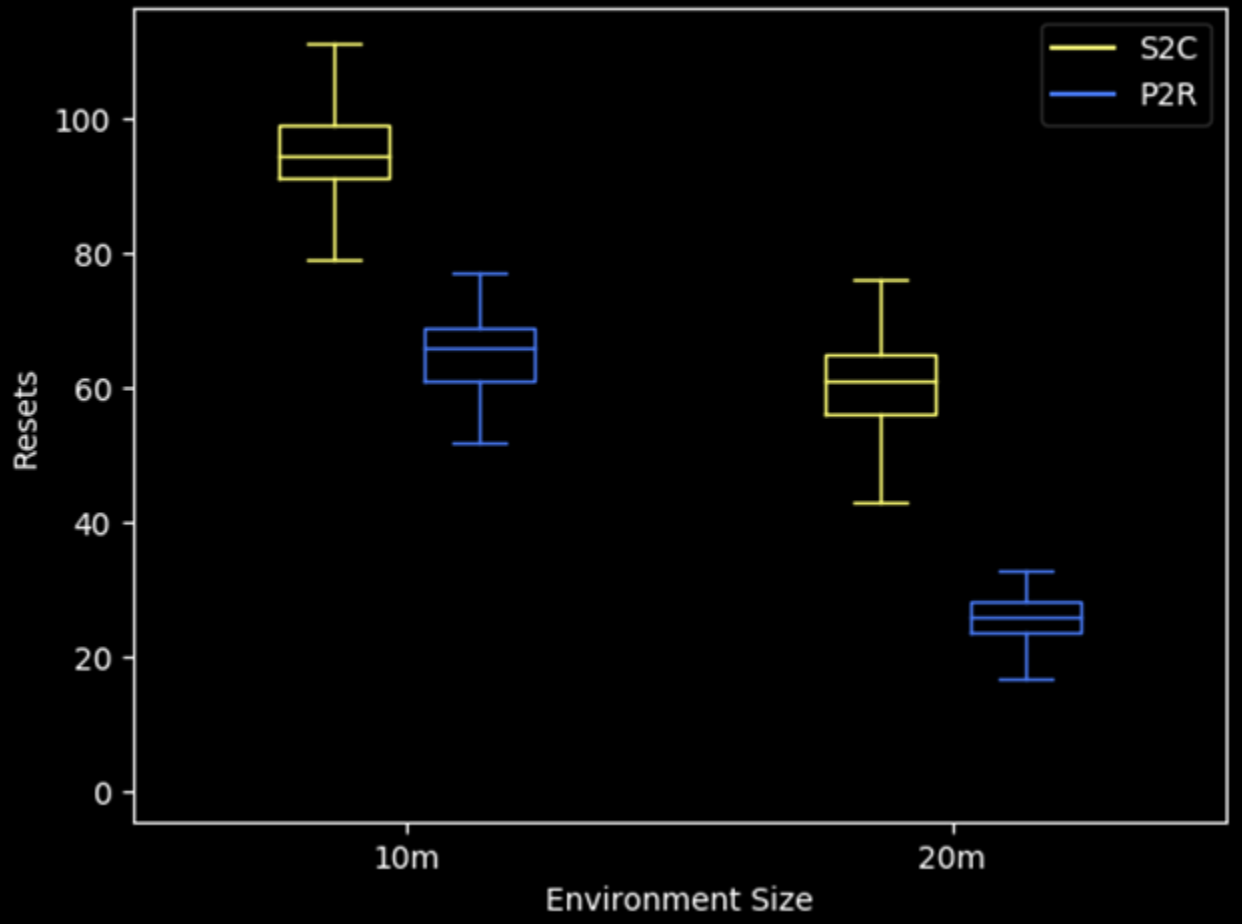
# P2R Results: Non-Convex Boundaries





# P2R Results: Interior Obstacles





# How much can we predict the user?


Linear Route

Branching Pathways

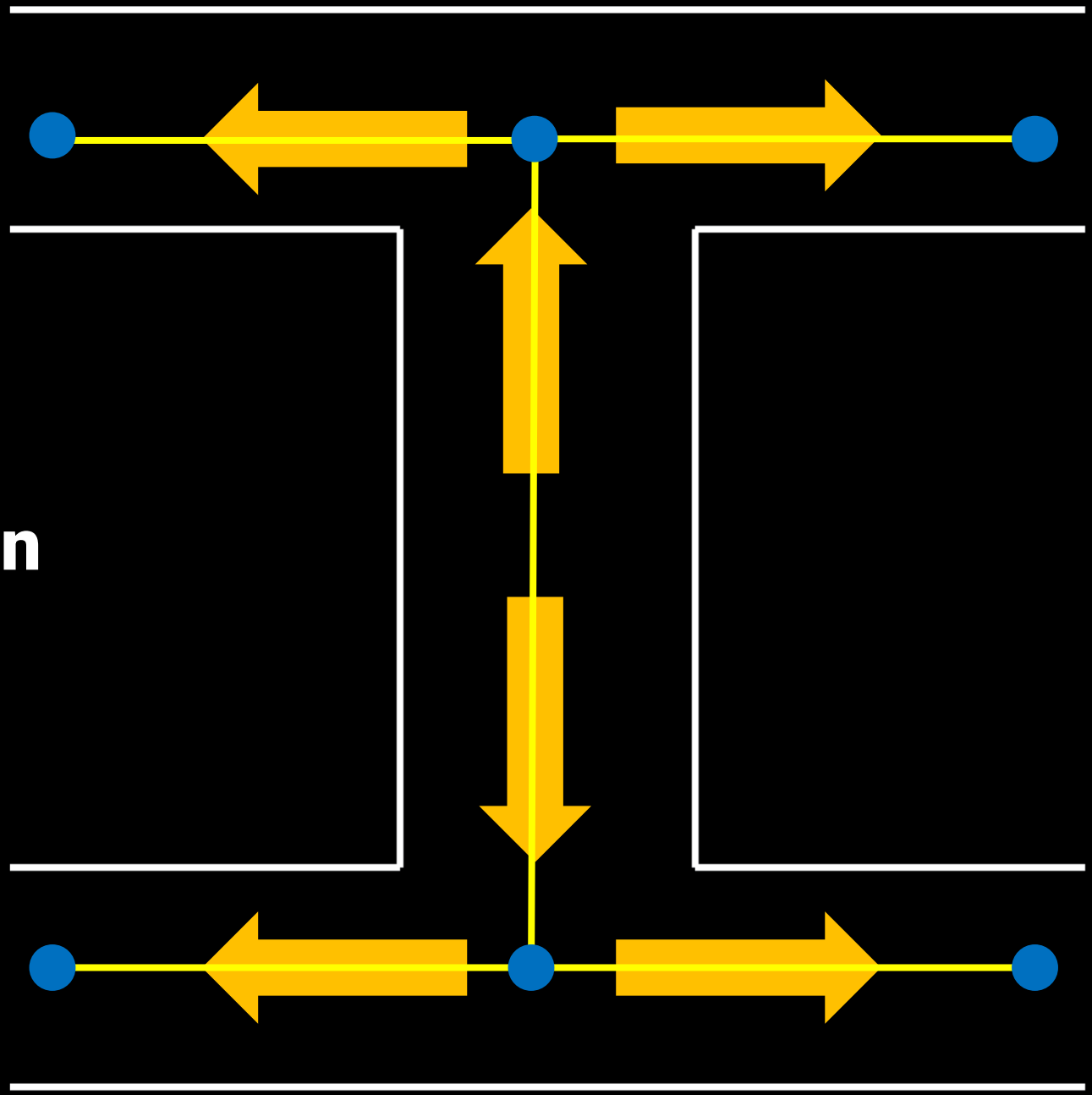
Open World

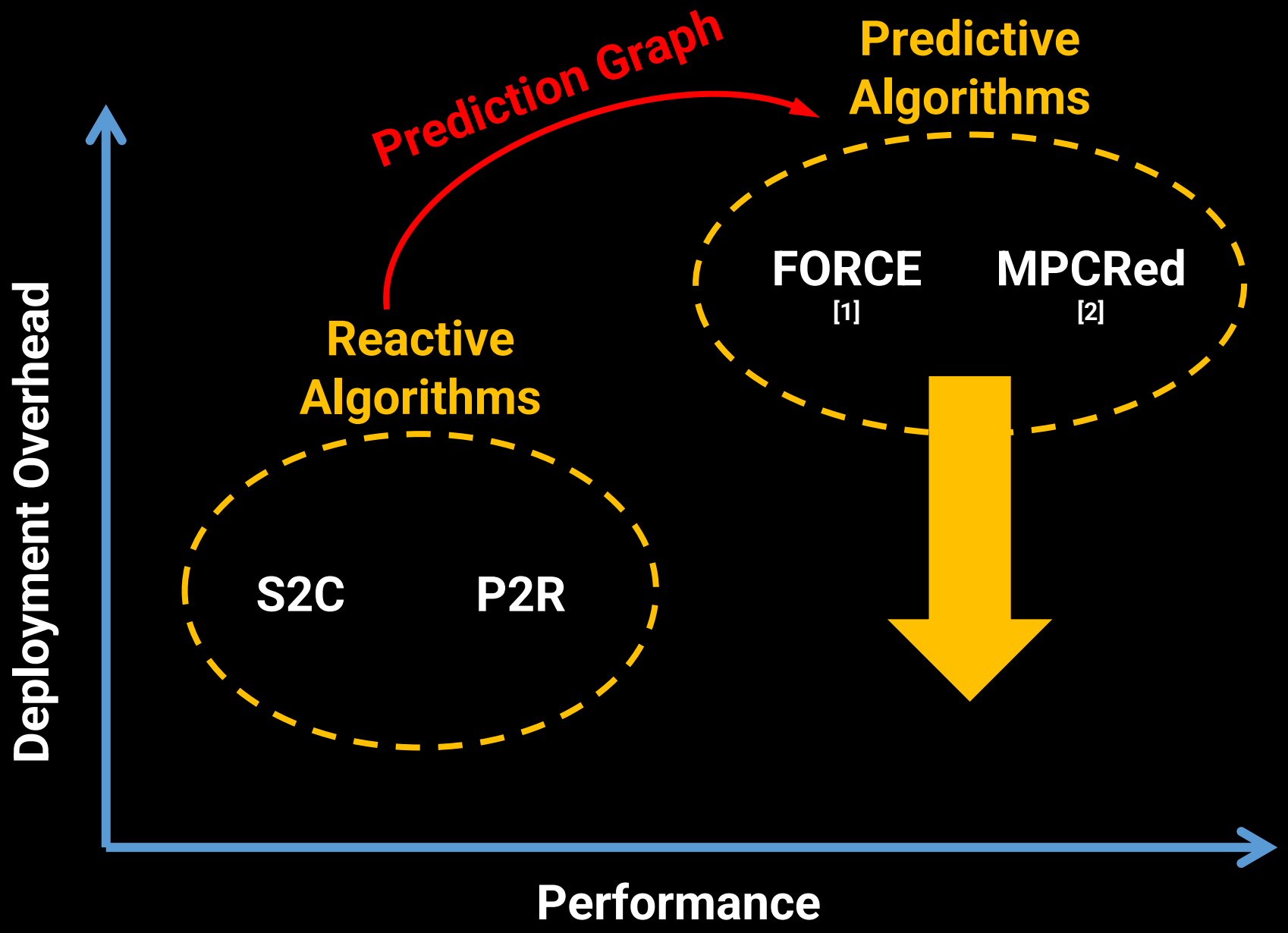
**Static Planning**

**Dynamic Planning**

**Reactive Algorithms**

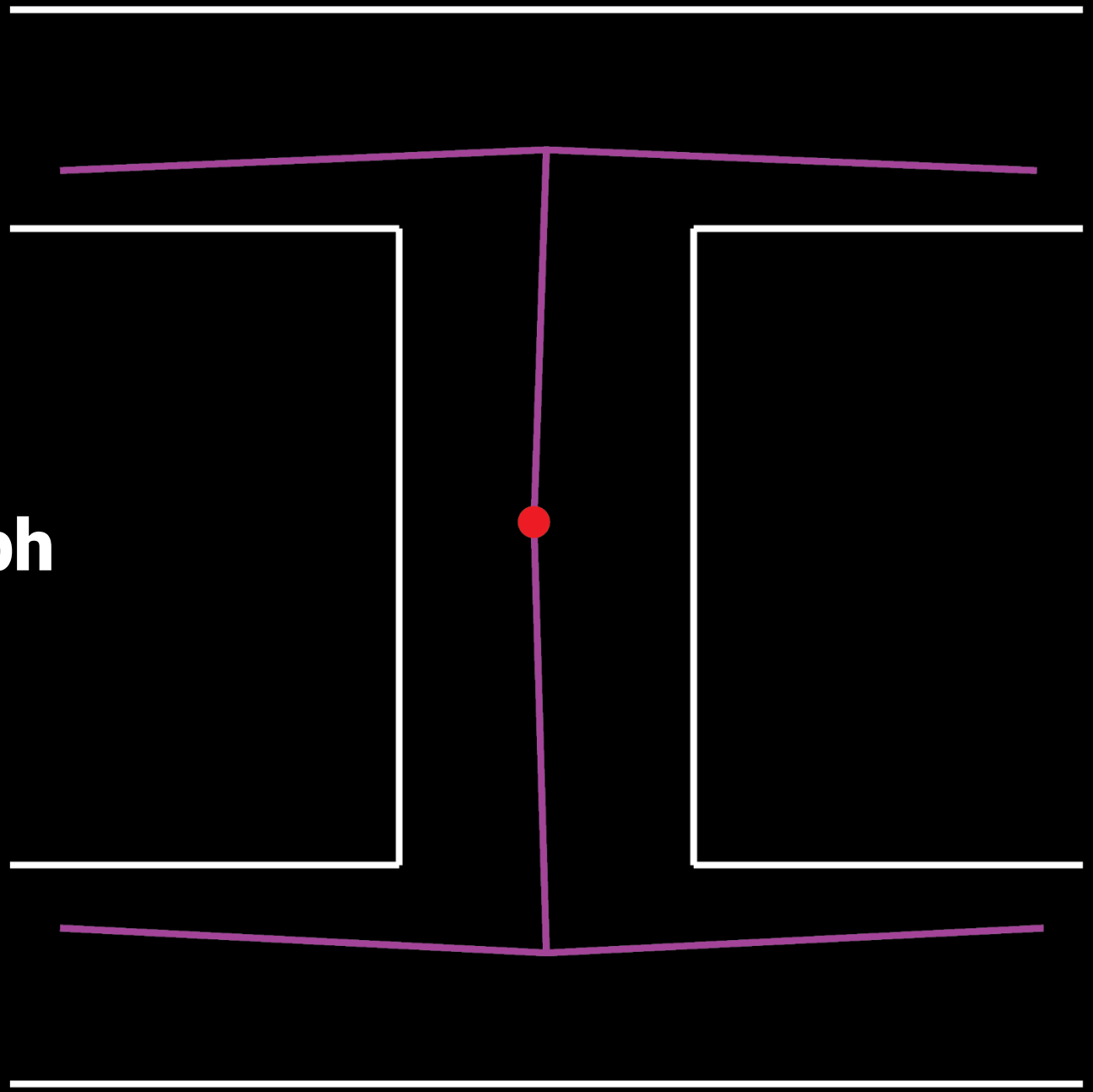
user prediction



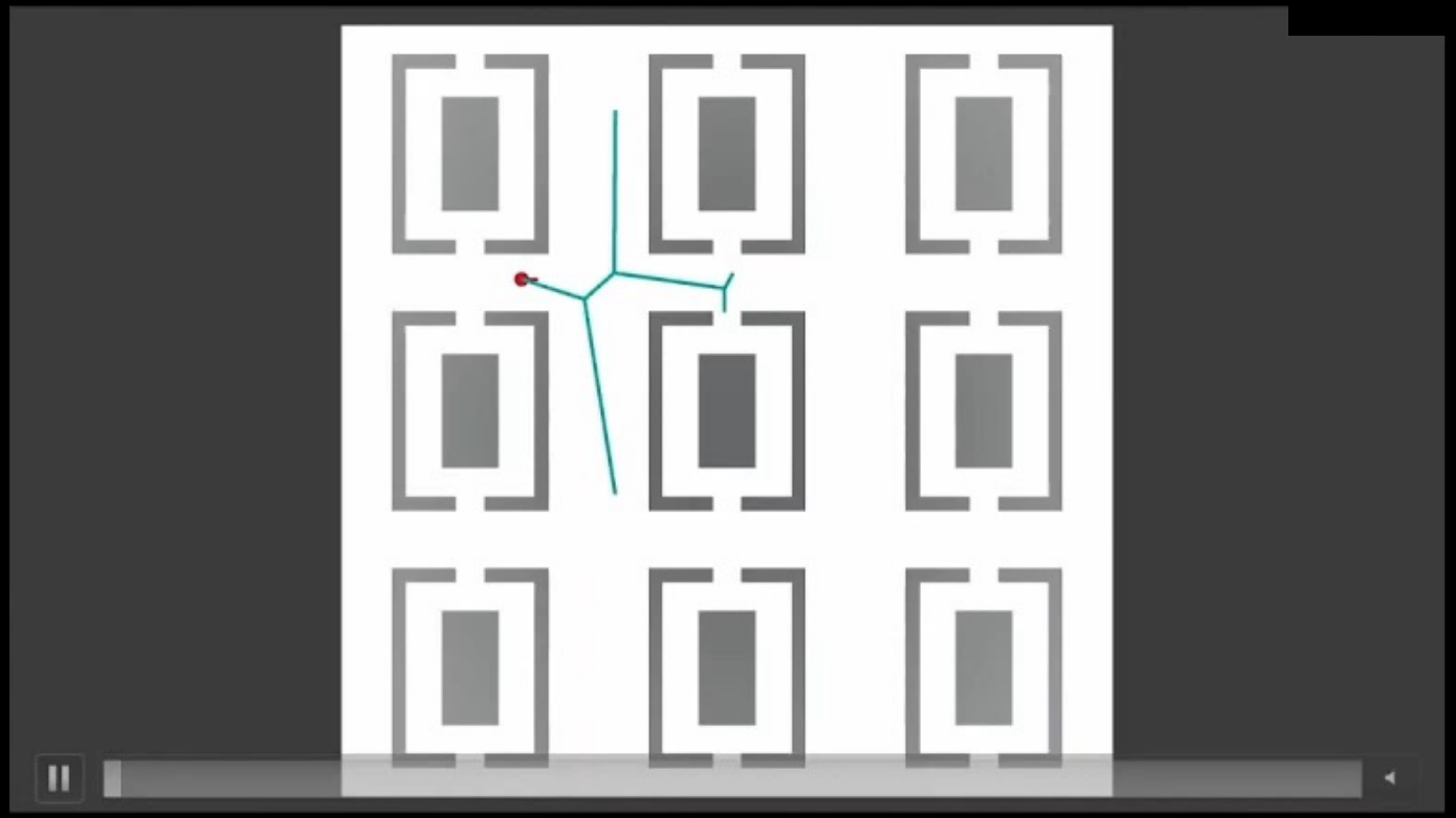



[1] M. Zmuda, J. Wonser, E. Bachmann, and E. Hodgson. Optimizing constrained-environment redirected walking instructions using search techniques, IEEE TVCG 2013.
[2] T. Nescher, Y. Huang, and A. Kunz. Planning Redirection Techniques for Optimal Free Walking Experience Using Model Predictive Control, IEEE 3DUI 2014.

# prediction graph



# Prediction Graph Generation

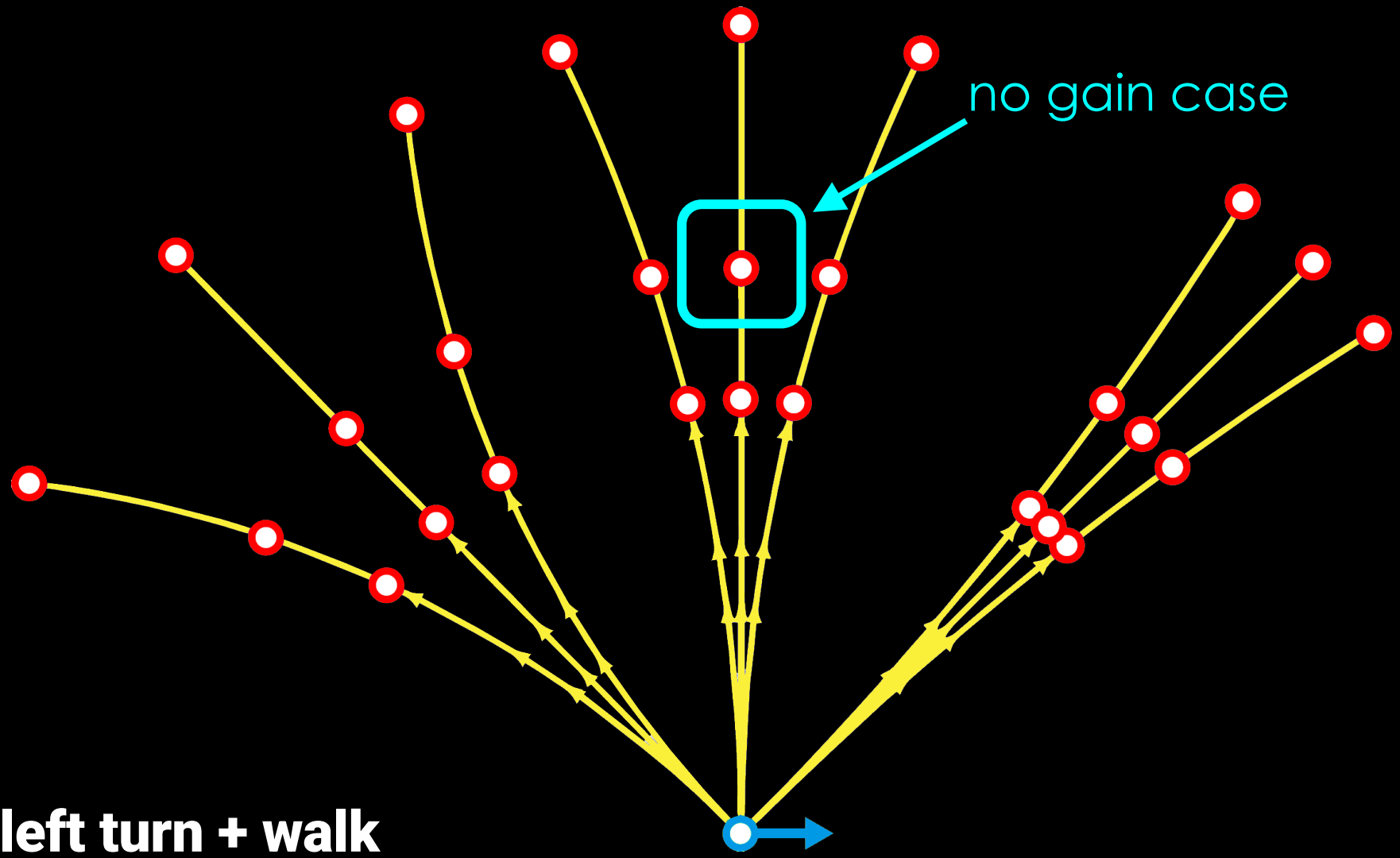


M. Azmandian, T. Grechkin, M. Bolas, and E. Suma. Automated path prediction for redirected walking using navigation meshes, IEEE 3DUI 2016.

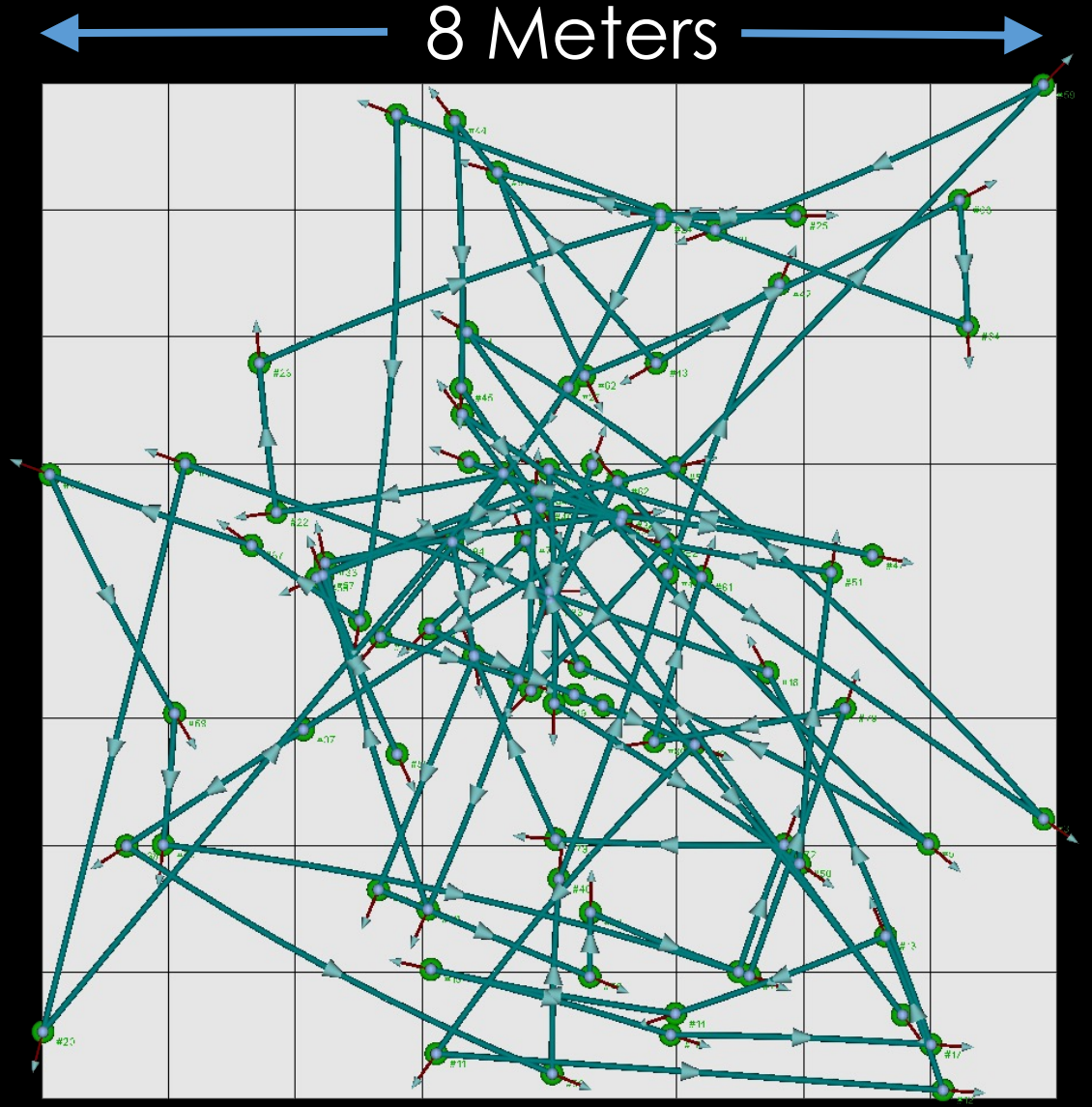
# How much can we predict the user?


| Linear Route | Branching Pathways | Open World |
| --- | --- | --- |
| **Static Planning** | **Dynamic Planning** | **Reactive Algorithms** |

# Combinatorial Optimization

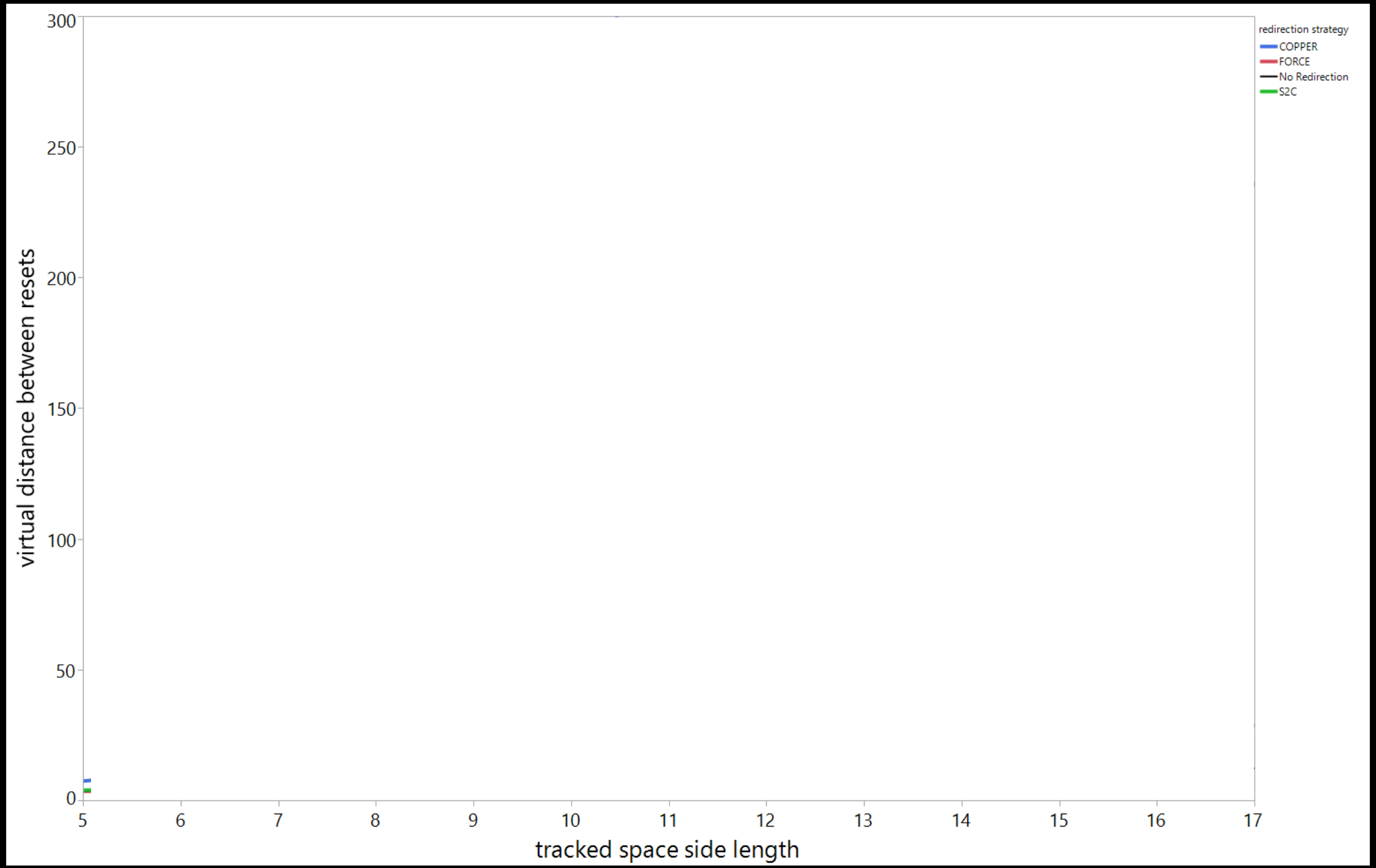



90 degree left turn + walk


M. Azmandian. Design and Evaluation of Adaptive Redirected Walking Systems, Ph.D. Thesis, University of Southern California, 2018.

**IEEE VGTC Virtual Reality Best Dissertation Award Honorable Mention.**

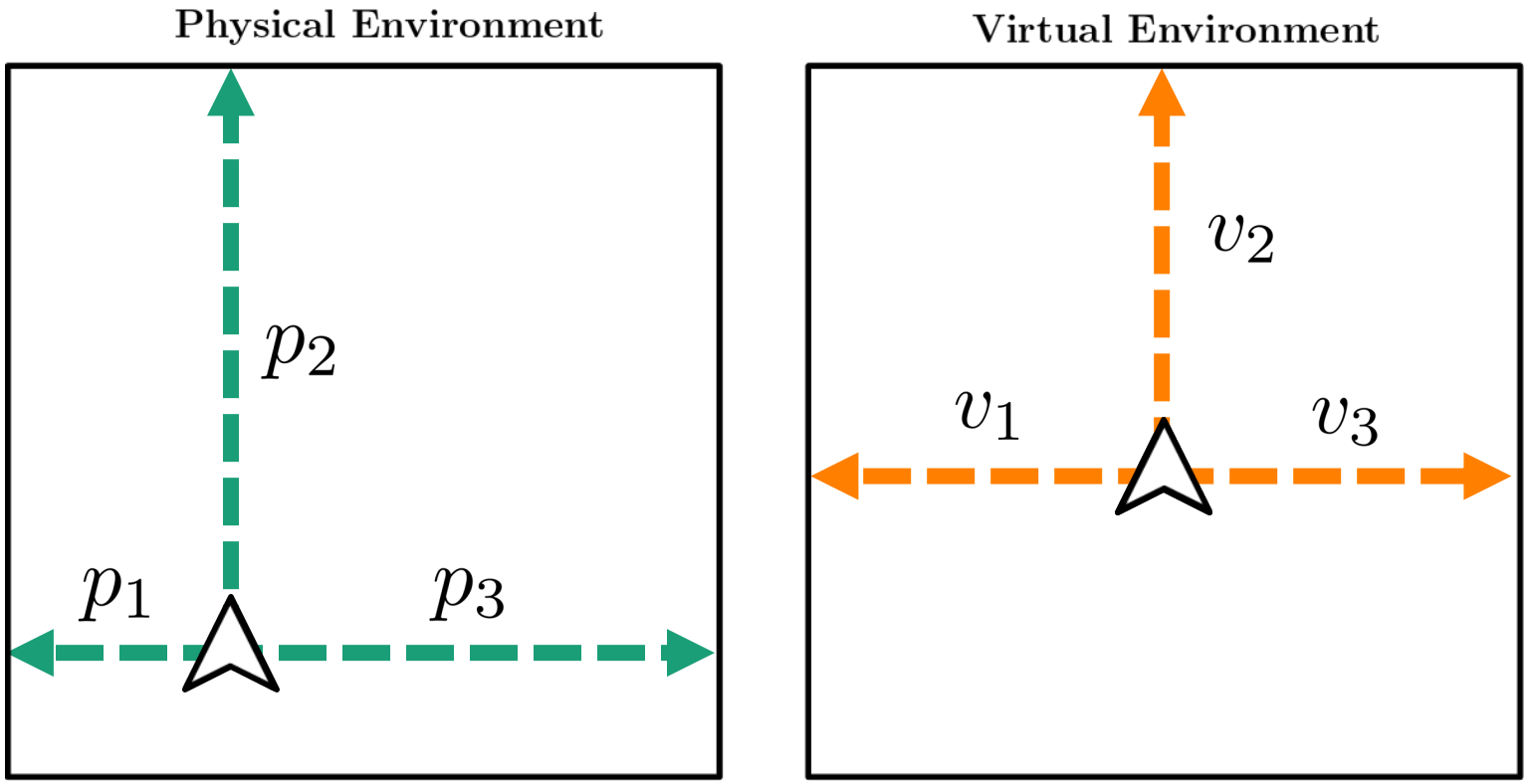

redirection strategy
COPPER
FORCE
No Redirection
S2C
virtual distance between resets
300
250
200
150
100
50
0
5
6
7
8
9
10
11
12
13
14
15
16
17
tracked space side length

# Alignment-based Redirection

Similarity of physical and virtual environments!

# Alignment-based Redirection

How to measure similarity?

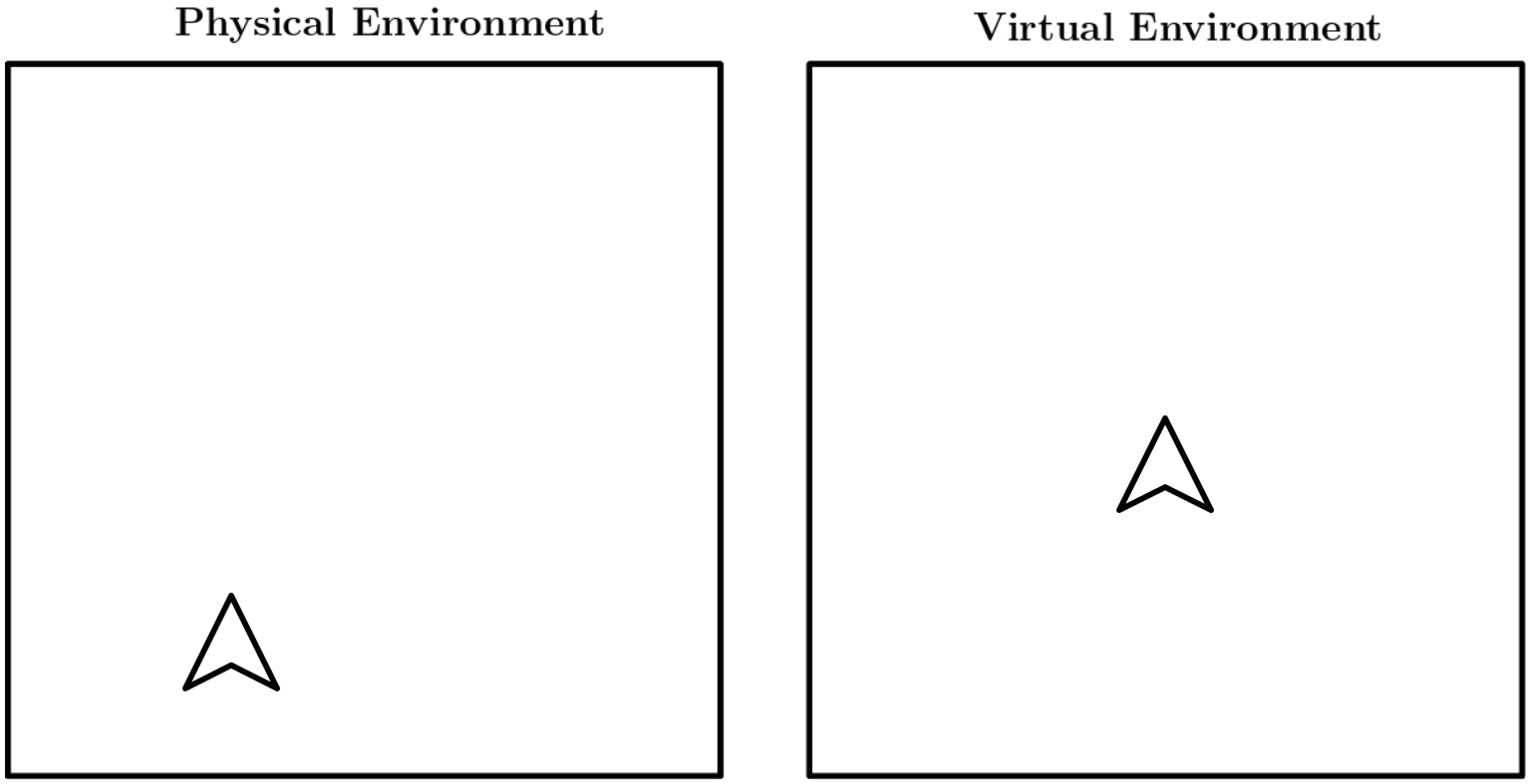



$$\text{similarity} = |v_1 - p_1| + |v_2 - p_2| + |v_3 - p_3|$$


1) J. Thomas, C. Hutton Pospick, and E. Suma Rosenberg. Towards Physically Interactive Virtual Environments: Reactive Alignment with Redirected Walking, ACM VRST 2020.
2) Williams, Niall L., Aniket Bera, and Dinesh Manocha. "Arc: Alignment-based redirection controller for redirected walking in complex environments." *IEEE Transactions on Visualization and Computer Graphics* 27.5 (2021): 2535-2544.
3) Williams, Niall L., Aniket Bera, and Dinesh Manocha. "Redirected walking in static and dynamic scenes using visibility polygons." *IEEE transactions on visualization and computer graphics* 27.11 (2021): 4267-4277.

# Alignment-based Redirection

How to measure similarity?

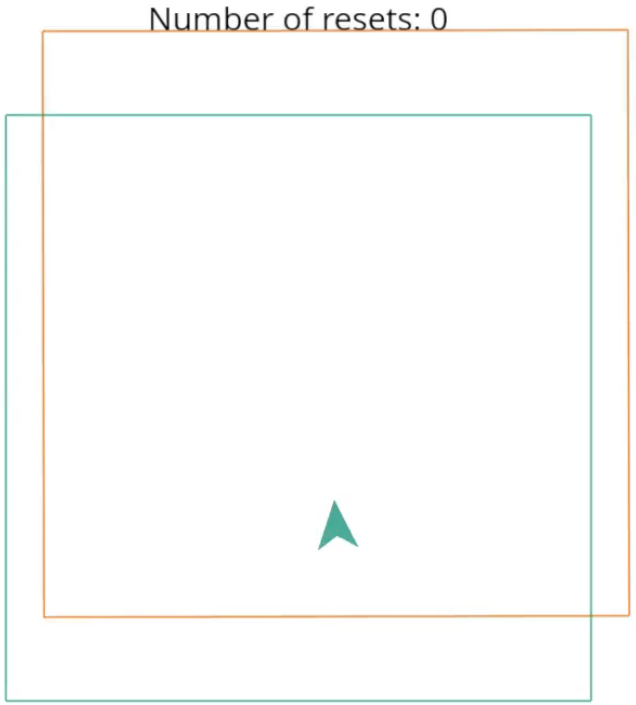



1) J. Thomas, C. Hutton Pospick, and E. Suma Rosenberg. Towards Physically Interactive Virtual Environments: Reactive Alignment with Redirected Walking, ACM VRST 2020.
2) Williams, Niall L., Aniket Bera, and Dinesh Manocha. "Arc: Alignment-based redirection controller for redirected walking in complex environments." *IEEE Transactions on Visualization and Computer Graphics* 27.5 (2021): 2535-2544.
3) Williams, Niall L., Aniket Bera, and Dinesh Manocha. "Redirected walking in static and dynamic scenes using visibility polygons." *IEEE transactions on visualization and computer graphics* 27.11 (2021): 4267-4277.

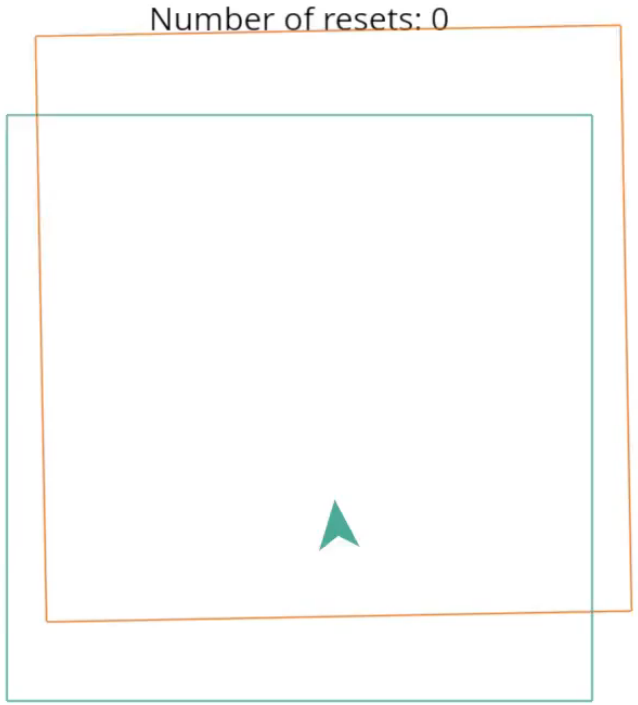
# Alignment-based Redirection

How good is it?

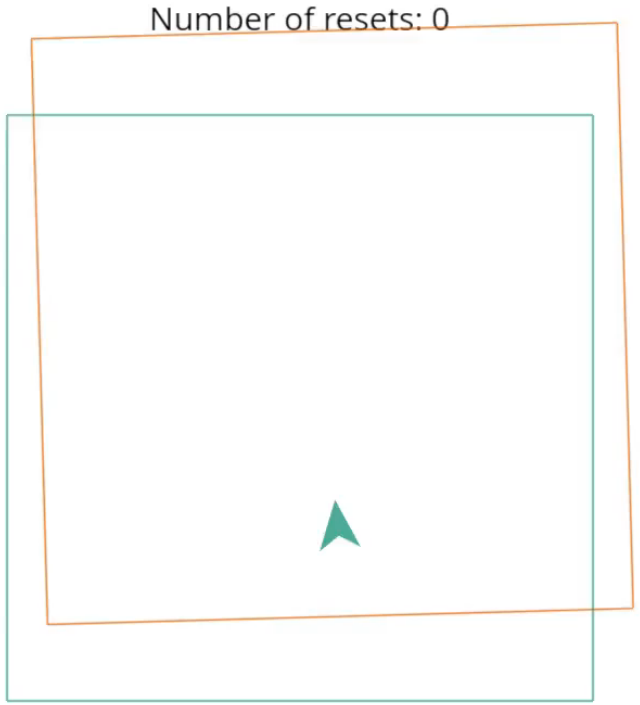
## Alignment




## Potential Fields

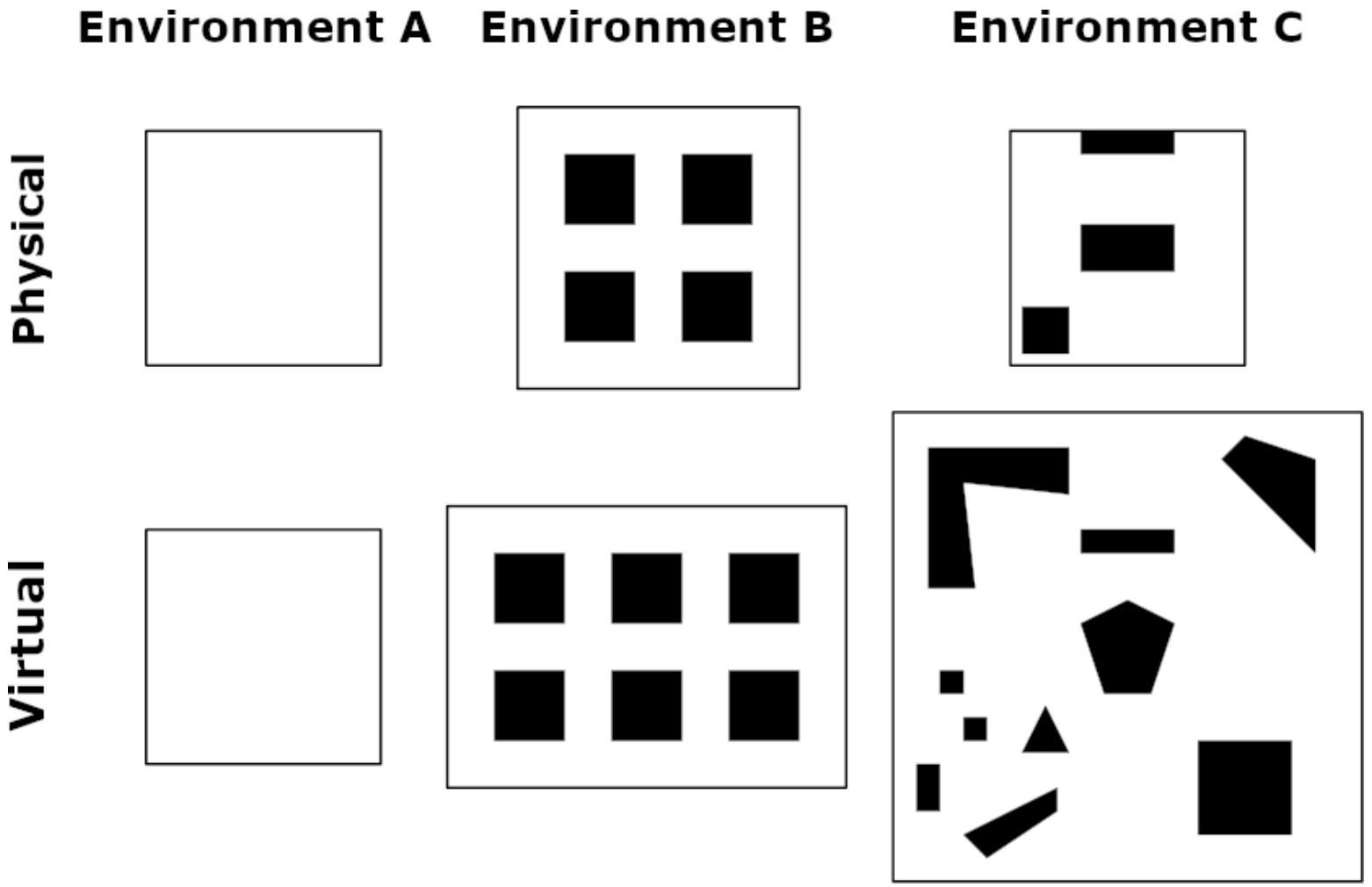



## S2C



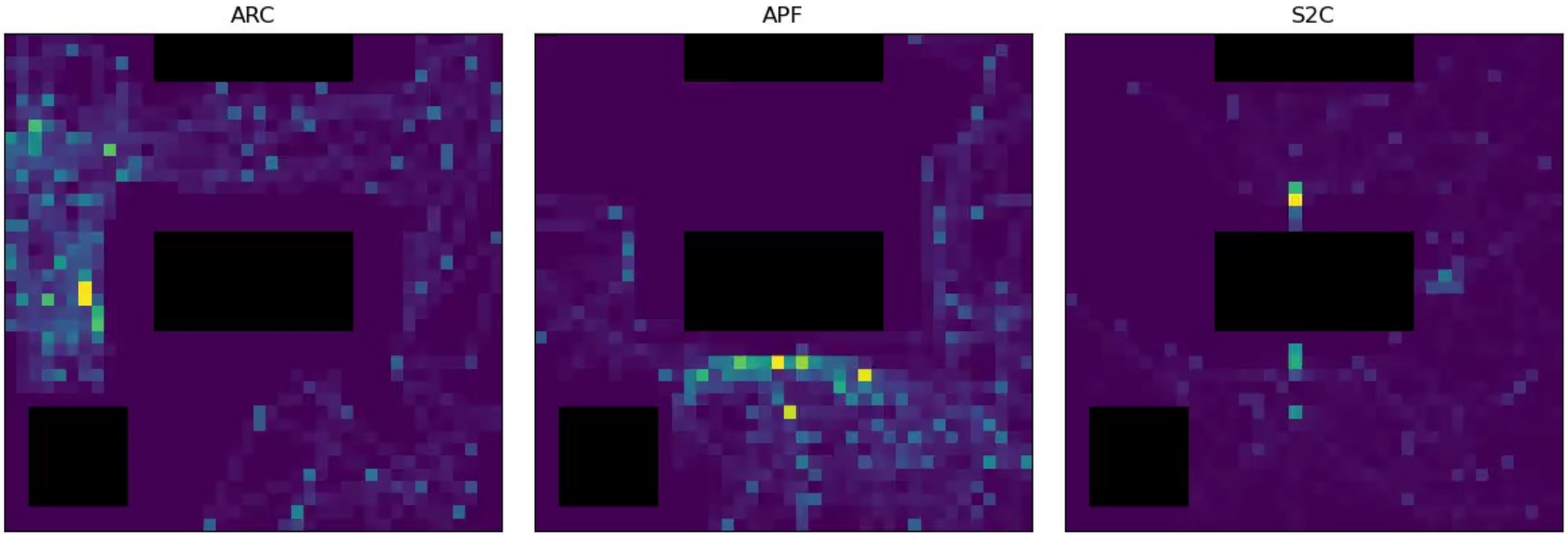
# Alignment-based Redirection

How good is it?

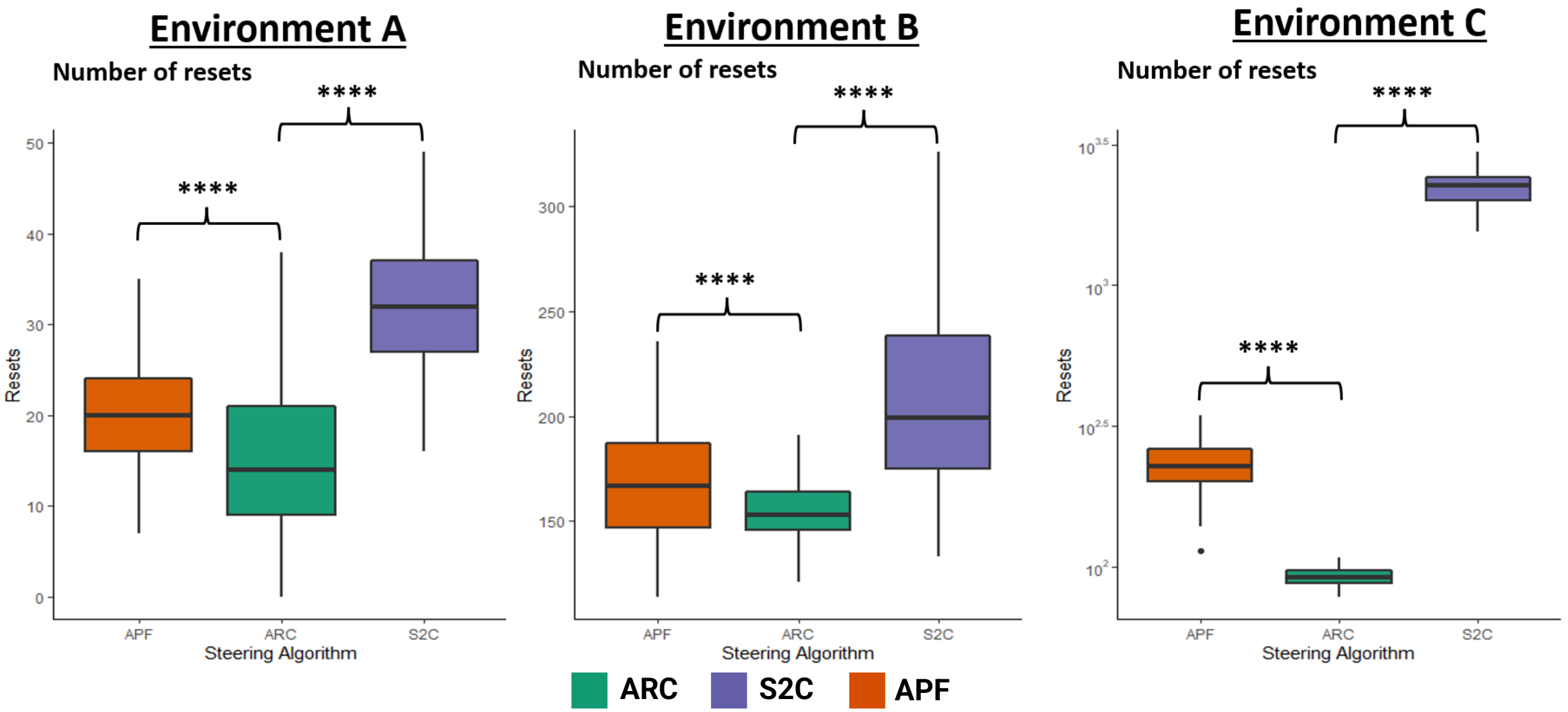


# Alignment-based Redirection

How good is it?

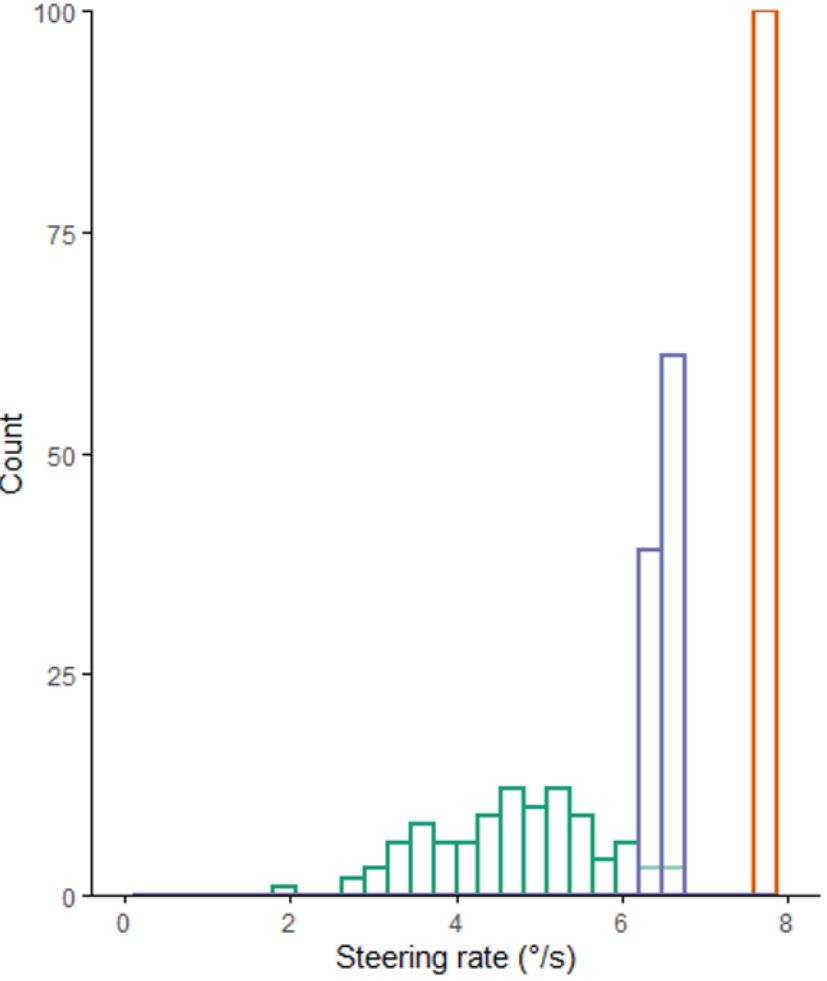


# Alignment-based Redirection

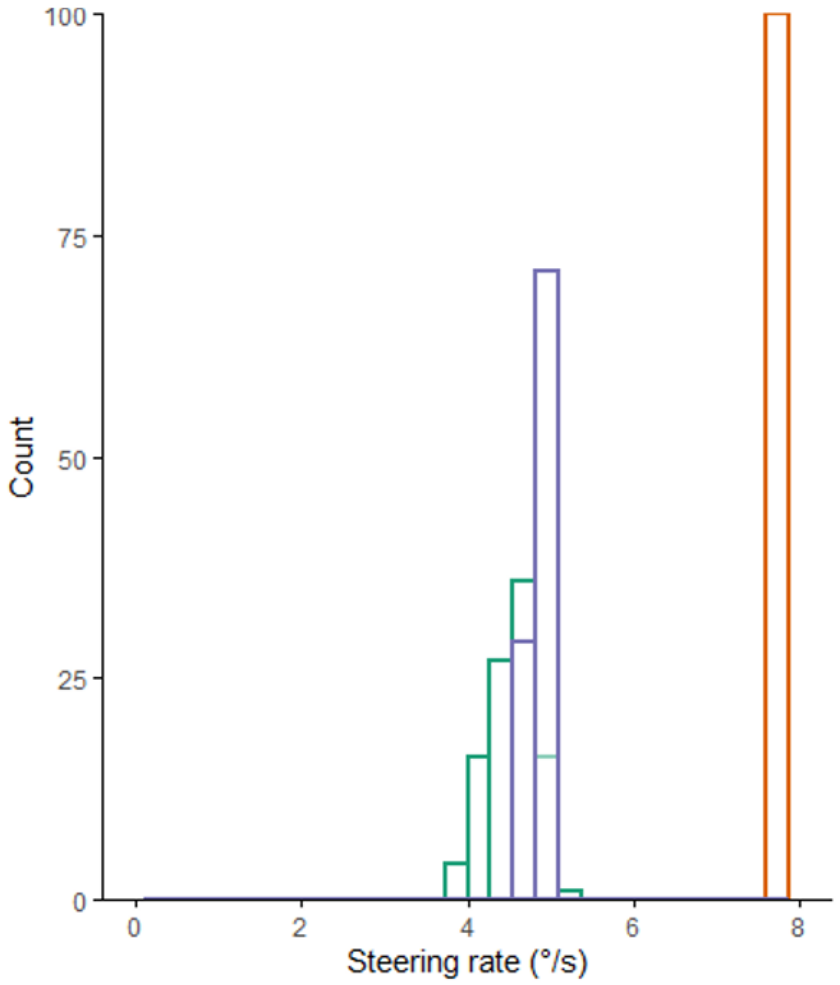


# Alignment-based Redirection

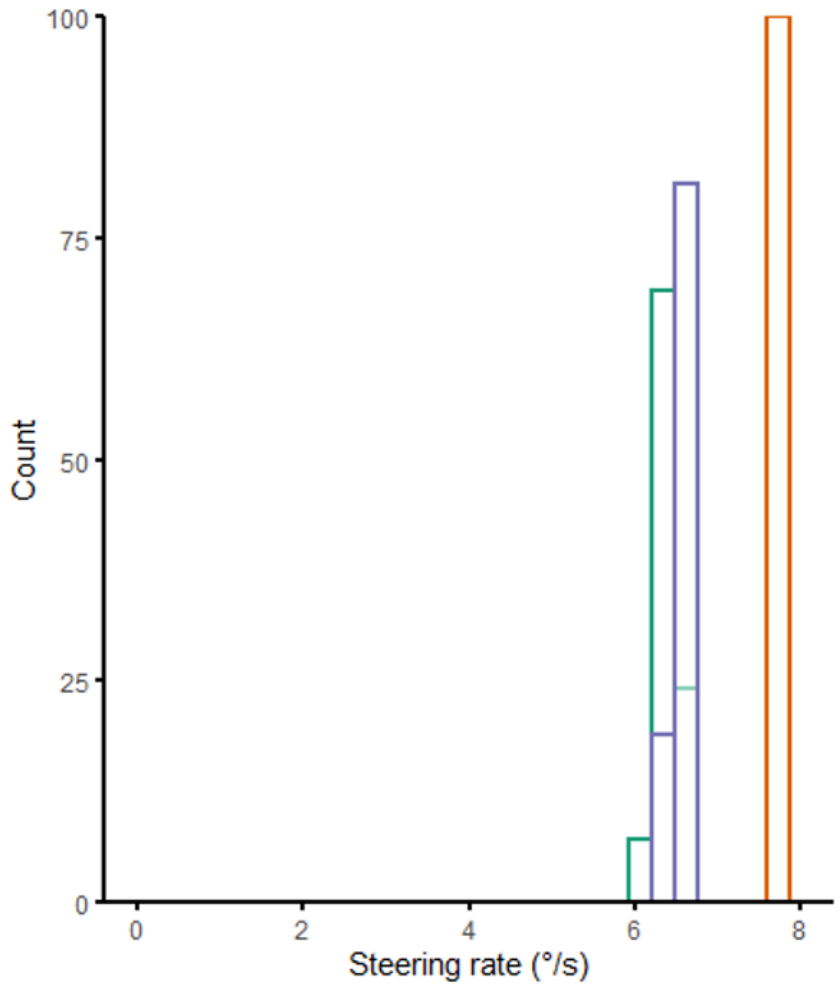
## Environment A




## Environment B




## Environment C




ARC S2C APF