How Far Can a 1-Pixel Camera Go? Solving Vision Tasks using Photoreceptors and Computationally Designed Morphology

visual-morphology.epfl.c



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Inspiration from Nature

Nature displays a wide variety of eyes, including many simple, low-resolution ones.

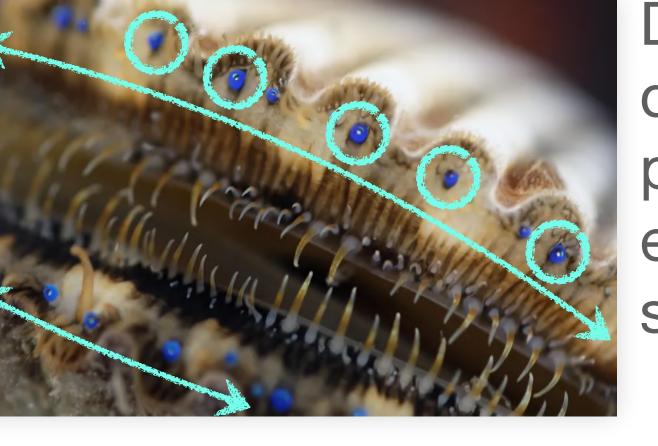
 Simple eyes enable a large variety of complex behaviors.

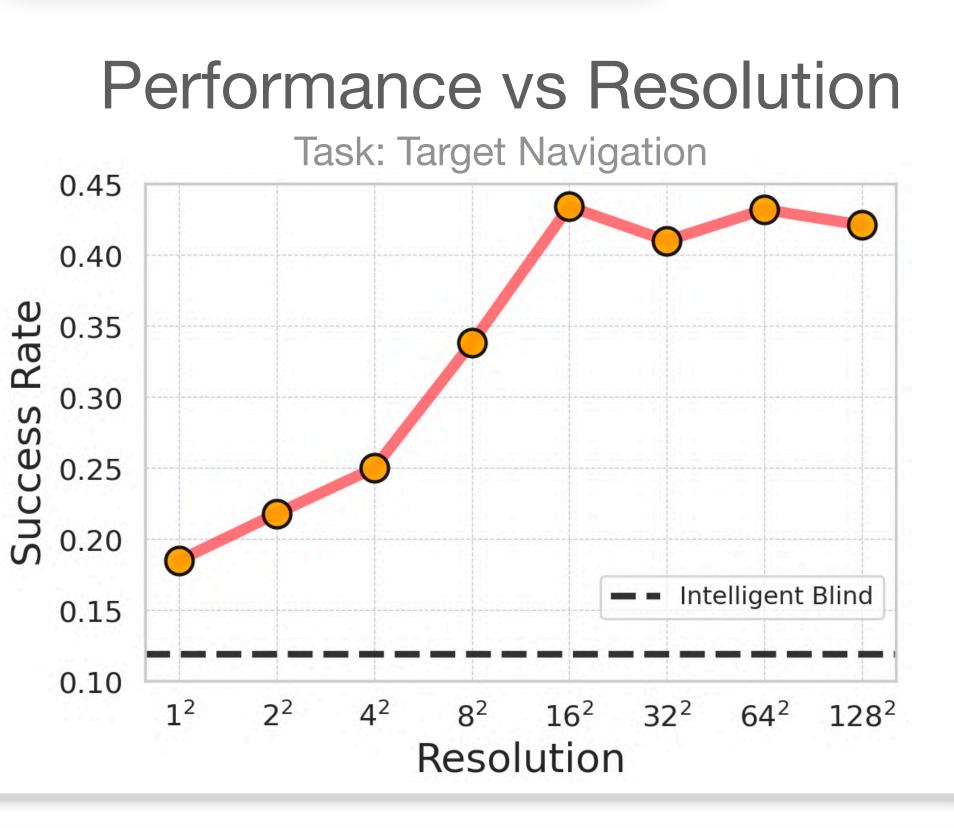


Do we need high-resolution sensing in computer vision?

- Agents with low-resolution visual sensors (4x4 / 8x8) can achieve good performance.
- ◆ In this example, the performance saturates at a resolution of 16x16.

The design of simple eyes has been optimized by evolution.



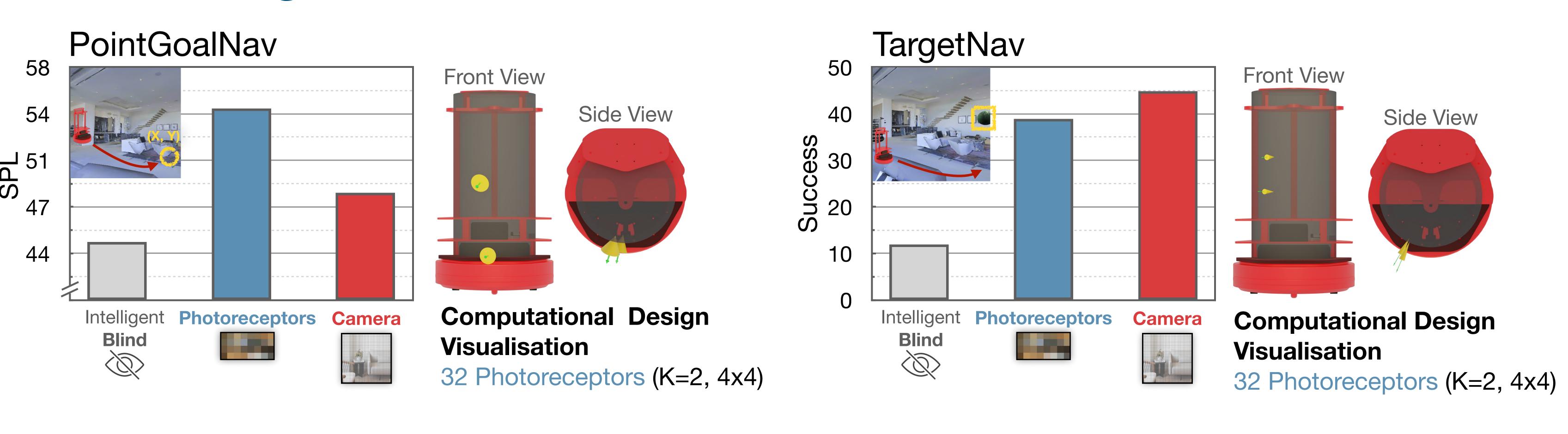


Photoreceptors vs. Camera: Performance

Photoreceptors are Effective Visual Sensors

Well-placed photoreceptors can solve vision tasks with good performance, significantly outperforming a blind agent and comparable to a camera agent.

Visual Navigation: Habitat MatterPort3D



PointGoalNav

Photoreceptor agents find efficient trajectories with fewer collisions.

TargetNav

Photoreceptor

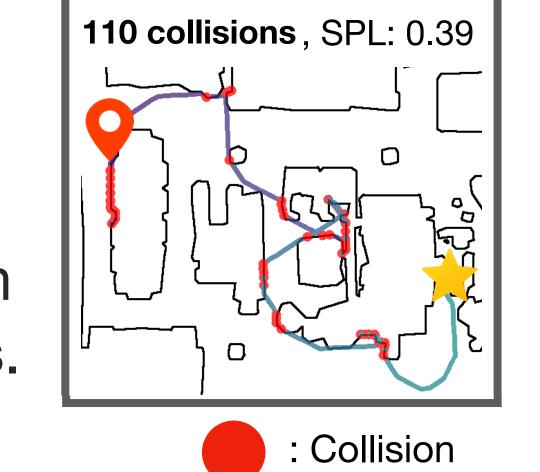
to locate a

target.

agents efficiently

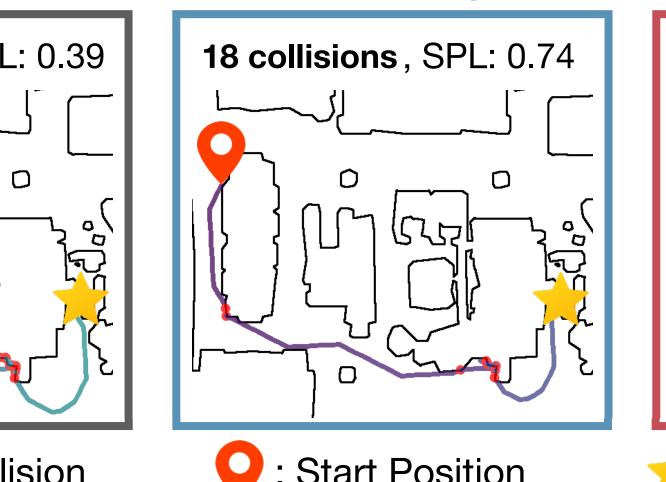
explore a scene

randomly placed

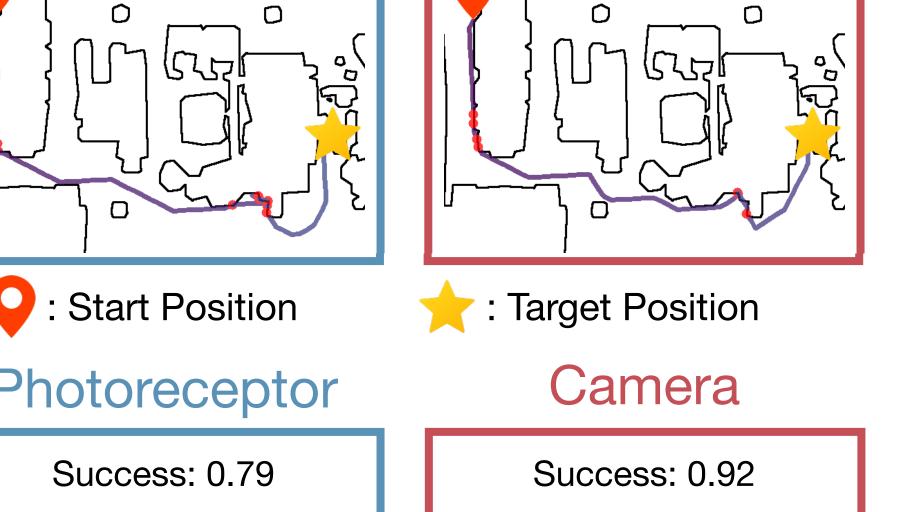


Success: 0.08

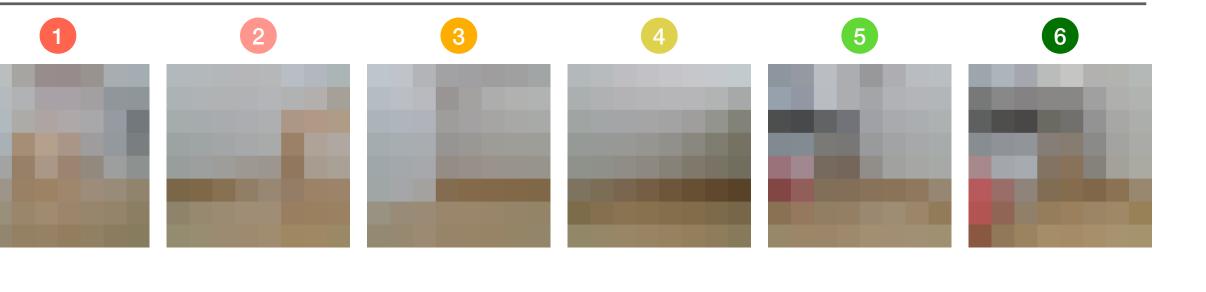
Percentage of Max Episode Length



Continuous Control: DeepMind Control Suite







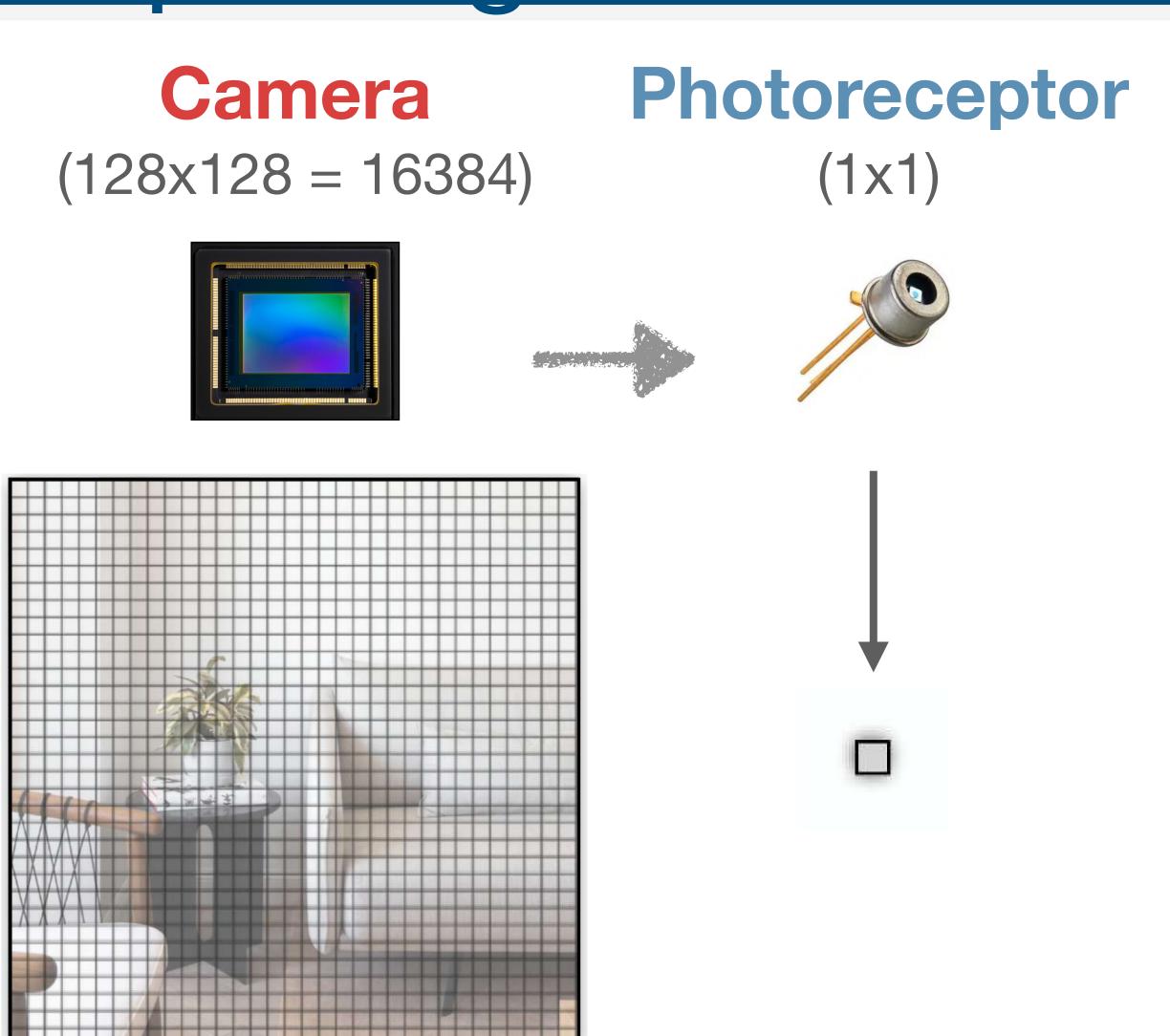
Photoreceptors in the Wild

◆ Target navigation in the real world in a

novel room without additional training.

External (Third-person) View

Replacing Camera with Photoreceptors

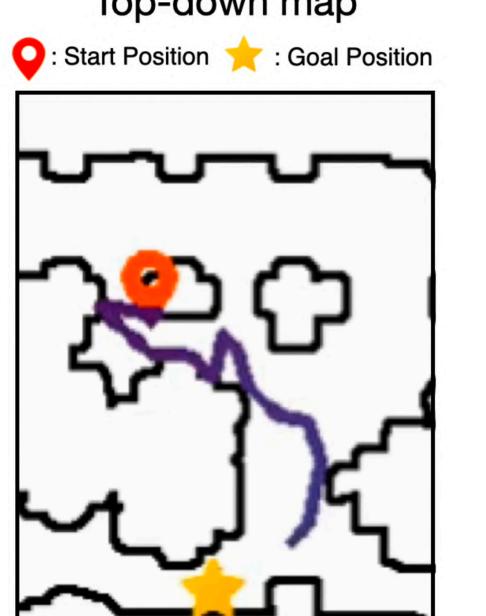


Io make computer vision systems more effective and simplified, we:

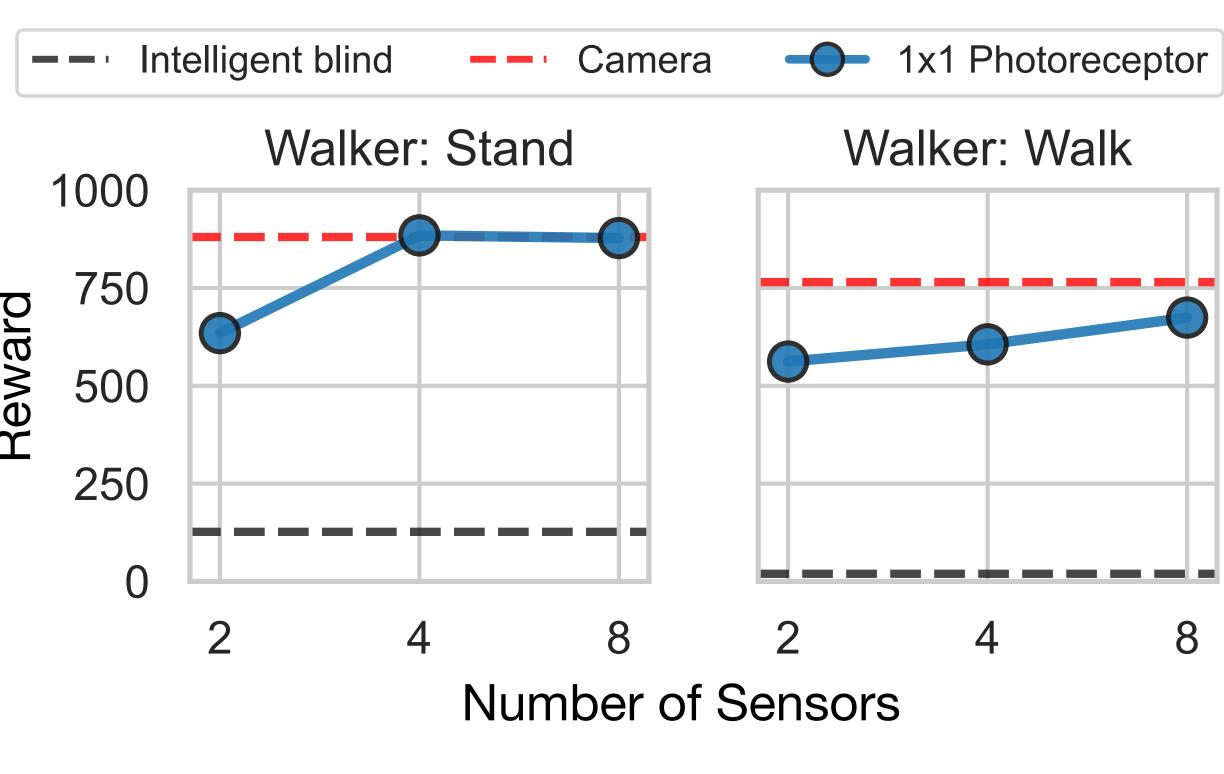
- Show that simple photoreceptor sensors can <u>solve vision tasks</u>.
- Demonstrate the importance of design of visual sensors.
- * Develop a computational design optimization method.

Target Navigation by an agent equipped with photoreceptors

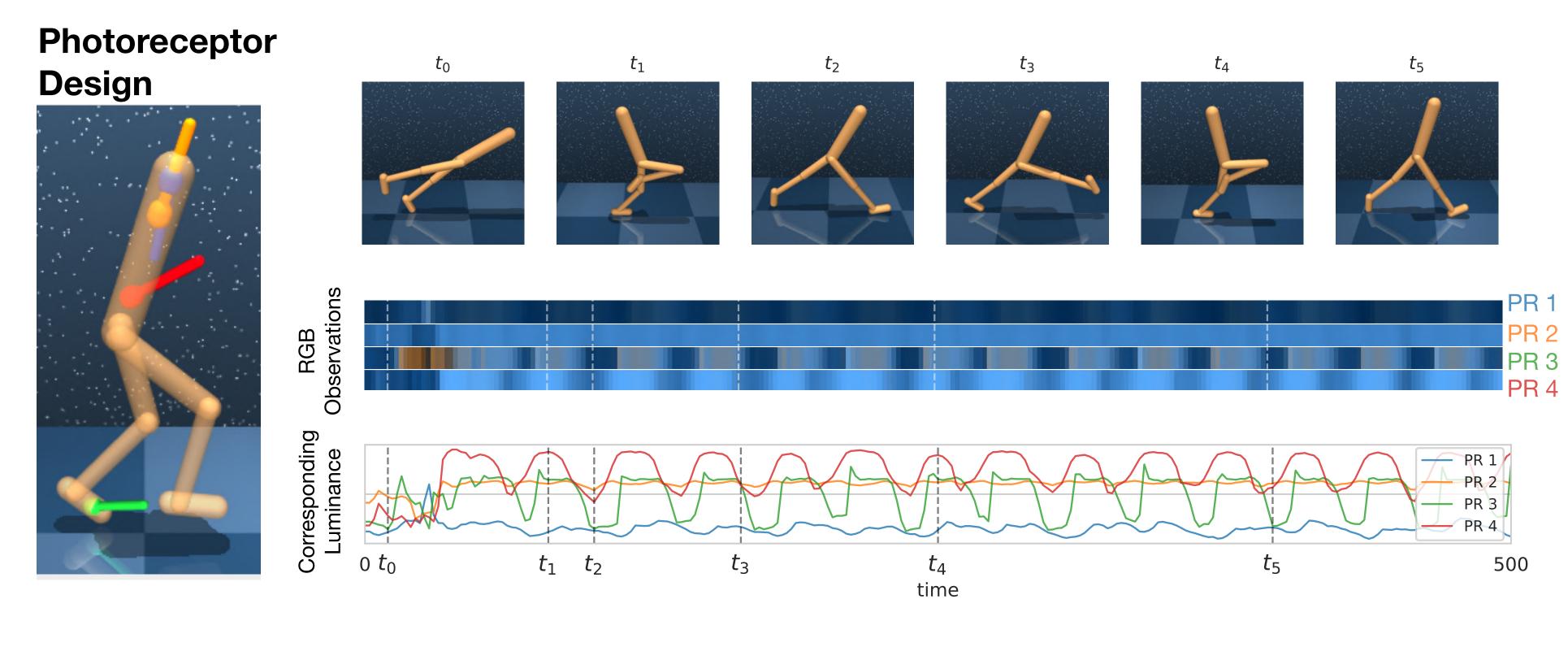




a high-resolution camera sensor.



 A few photoreceptors perform on par with
Exemplar episode for the Walker: Walk task: Only 4 photoreceptors enable stable bipedal locomotion.

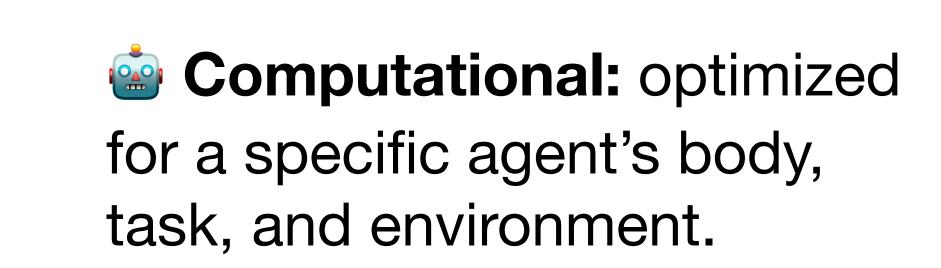


See more results and analyses on the project page and in the paper.

The Design Problem

Design Space:

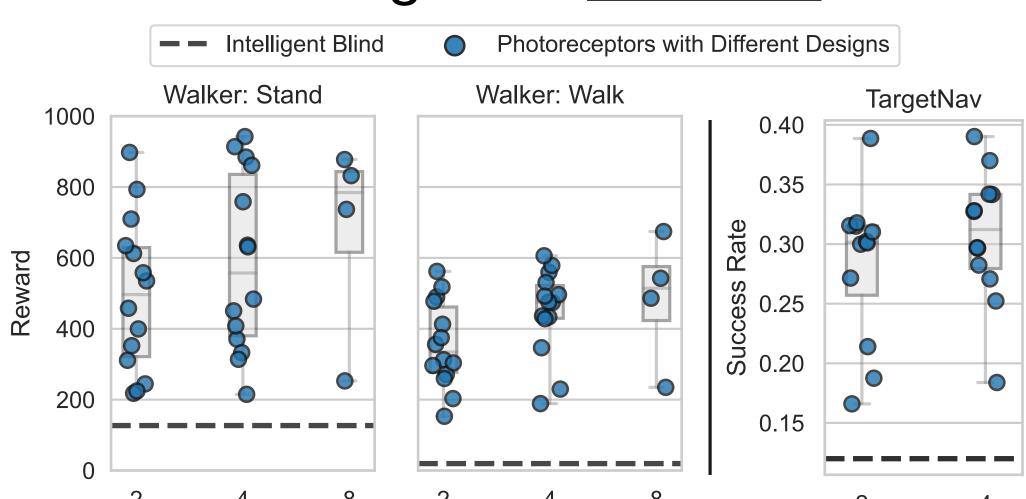
Design Types: Random: sampled uniformly from design space.



Intuitive: engineered by humans (collected via survey).

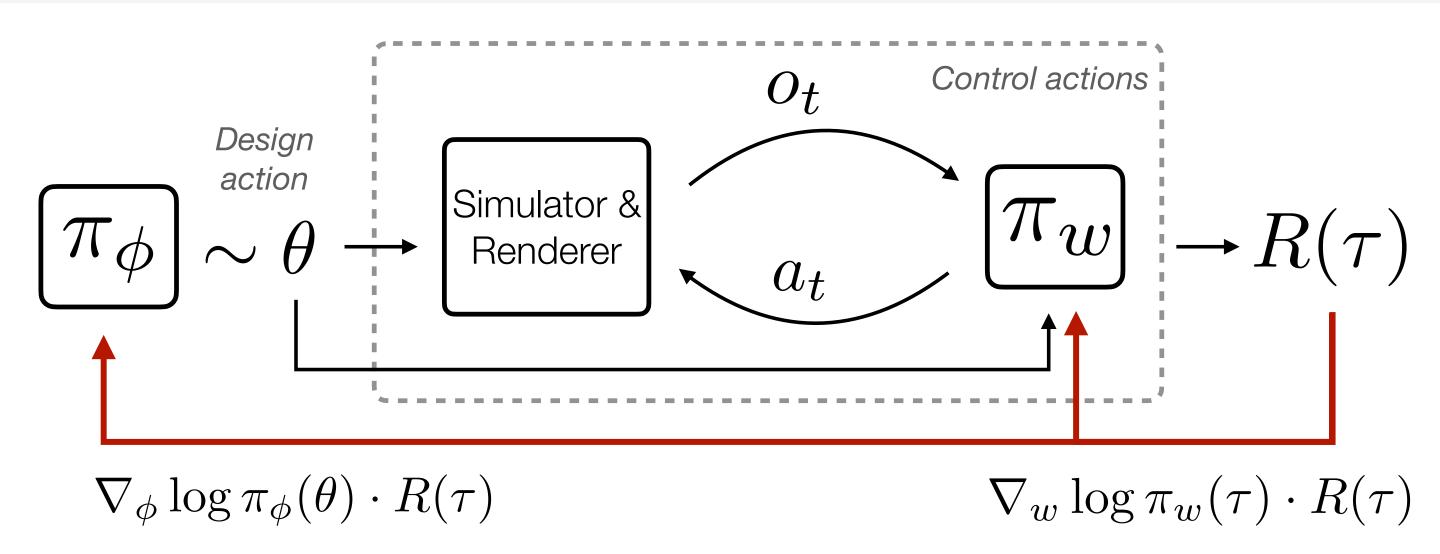
Design importance:

◆ There is a <u>large variance</u> across various designs on <u>all tasks</u>.

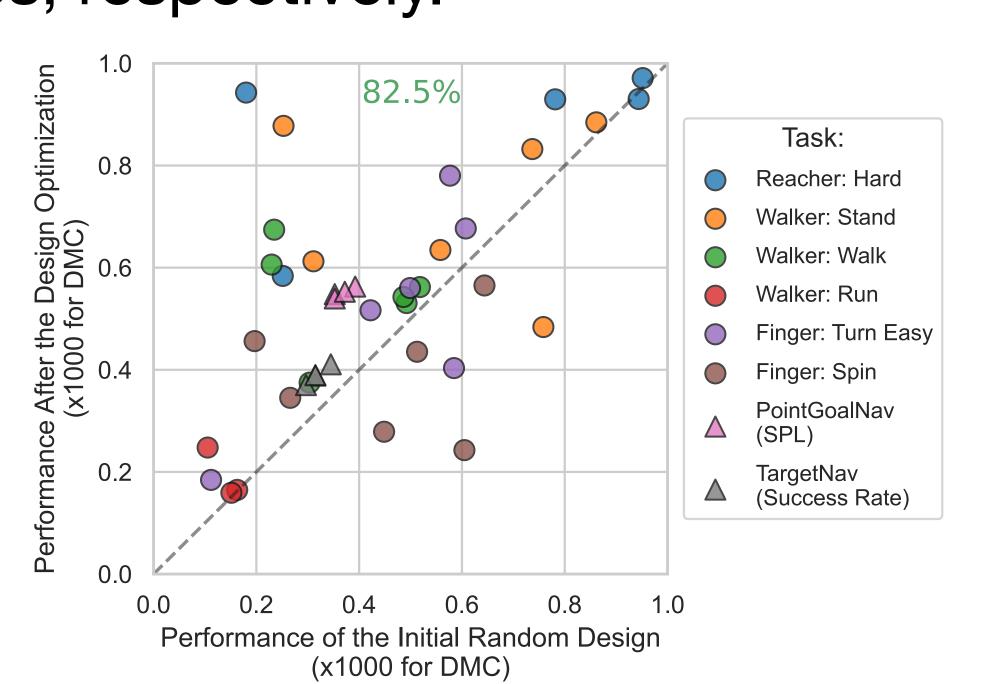


A computational method for finding well-performing designs is necessary.

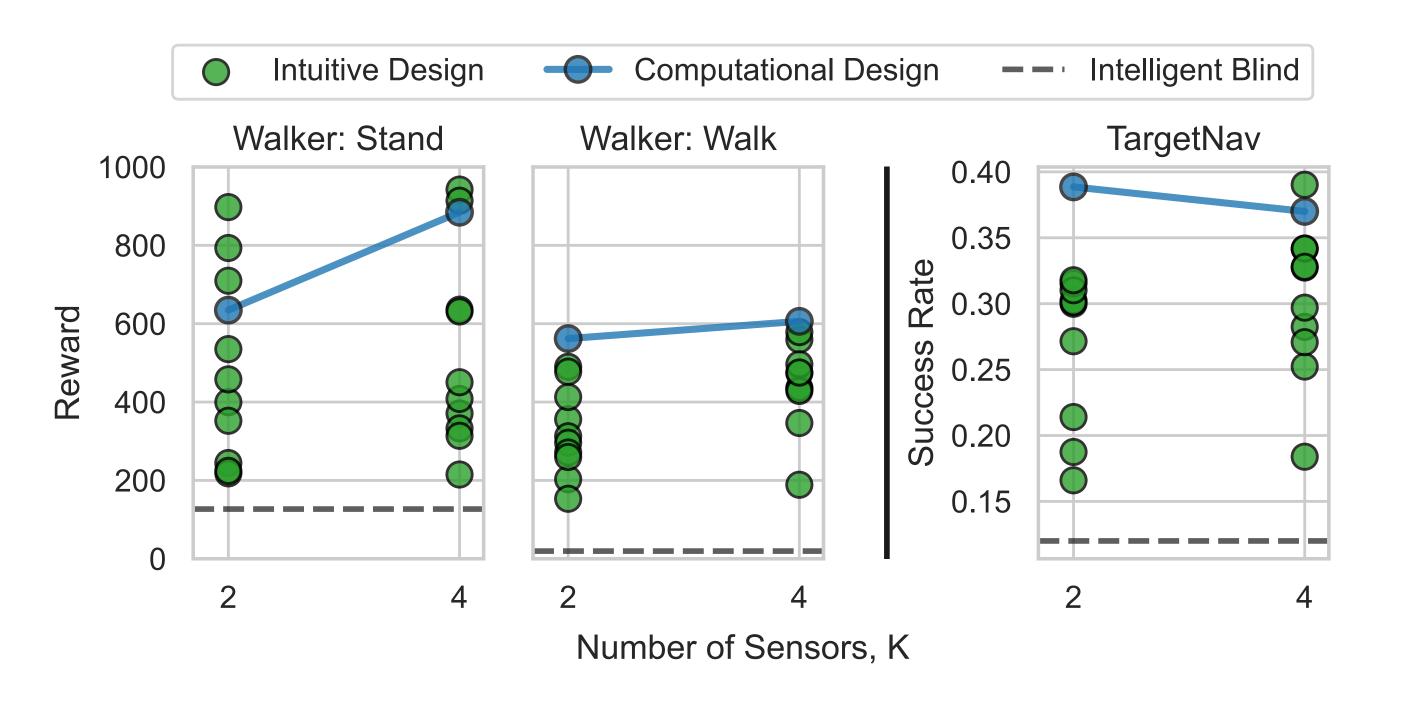
Computational Design via Joint Optimisation



- ullet We jointly train a design policy π_ϕ (generating design θ) and a **design**conditioned control policy π_w .
- Design optimization improves upon the initial random designs. The green and red regions signify success (82.5%) and failure cases, respectively.



 Computational designs are among the best designs in all settings (including intuitive designs collected via survey).



Computational design optimization finds well-performing designs and overcomes anthropomorphic biases.

Summary

- * Simple photoreceptors are effective visual sensors.
- Design is essential for the effectiveness of simple photoreceptors.
- * Computational design optimization finds well-performing designs.

References:

[1] Visual Acuity and the Evolution of Signals, Caves et al. 2018.

[2] Transform2act: Learning a transform-and-control policy for efficient agent design. Yuan et al. 2021