# Generating an Explorable World

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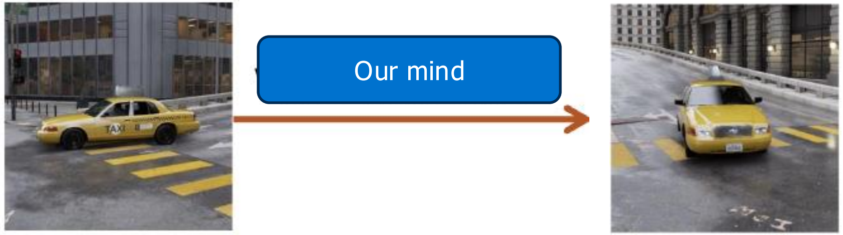
Invited Talk at ICLR Workshop on Embodied Intelligence with Large Language Models In Open City Environment

# Generating a car

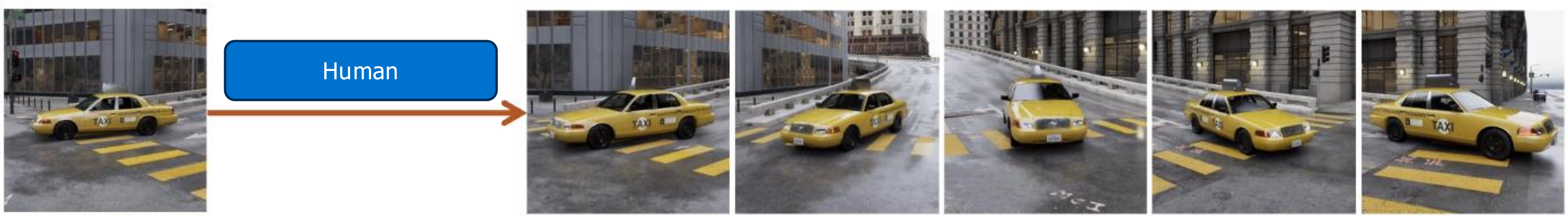
Close your eyes and generate an car in your mind (mental imagery test).

# Generating the novel views



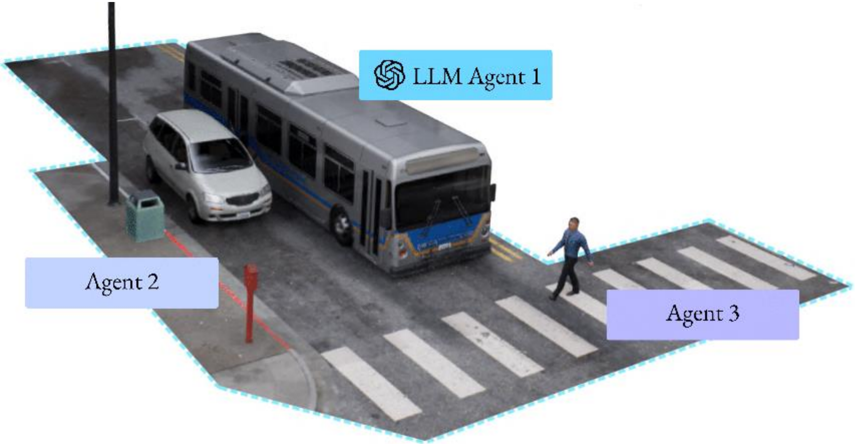
Our mind

# Generating the surroundings

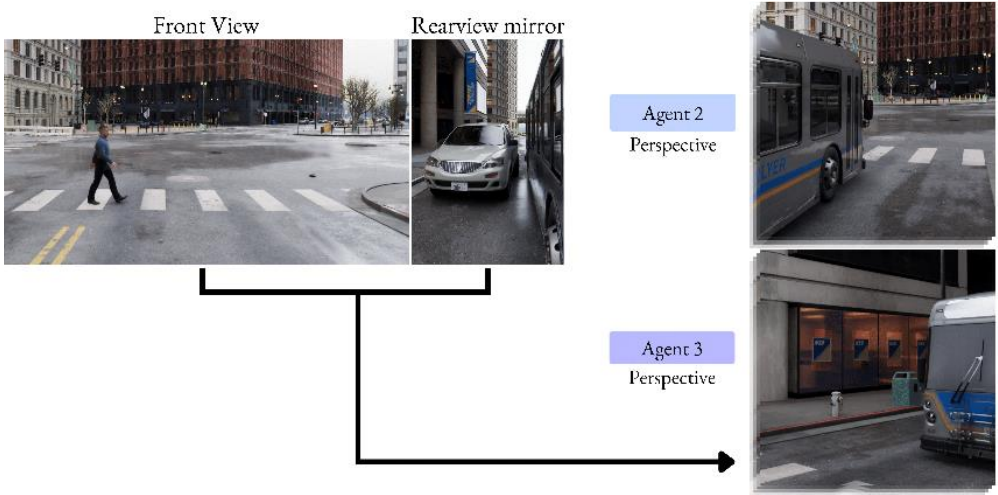


# Generating an explorable world

The bus blocks the line of sight between the sedan and the pedestrian.



The bus driver can mentally **explore** the viewpoints of other agents.



# Are we ready for human-like world generation?

GAN
2014

Diffusion
2020

LDM
2022

Sora
2024

Going from generating one object to producing a realistic video is a decade-long journey.

✗ 3D/4D Consistency

✗ (Interactive) Action Control

✗ Physical Commonsense

# Are we ready for human-like world generation?

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What is the next decade?

Going from generating one object to producing a realistic video
is a decade-long journey.

# My bet is on the physical world

GAN
2014

Diffusion
2020

LDM
2022

Sora
2024

**Physical World**

Going from generating one object to producing a realistic video
is a decade-long journey.

# Adding 360° physical world to generation

- Scaling data via 3D physical engine.

- High-quality world generator.

**Physical World**

# Adding 360° physical world to generation

- Scaling data via 3D physical engine.
    - World dynamics.
    - Physical exploration and interaction.

- High-quality world generator.
    - 360° world exploration.
    - Strong 3D consistency.

[1] Genie 2: A large-scale foundation world model

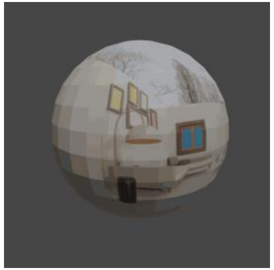
[2] Generative object movement with video prior

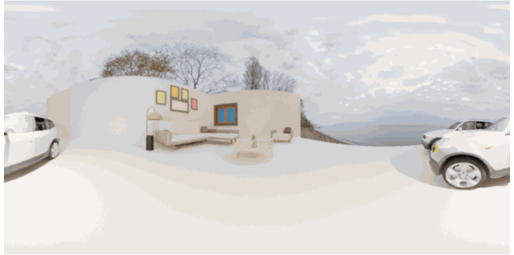
# Adding 360° physical world to generation

- Scaling data via 3D physical engine.
  - World dynamics.
  - Physical exploration and interaction.

High-quality open-source video generation
(e.g., SVD, Cosmos)

- High-quality world generator.
  - 360° world representation.
  - 3D/4D consistency.





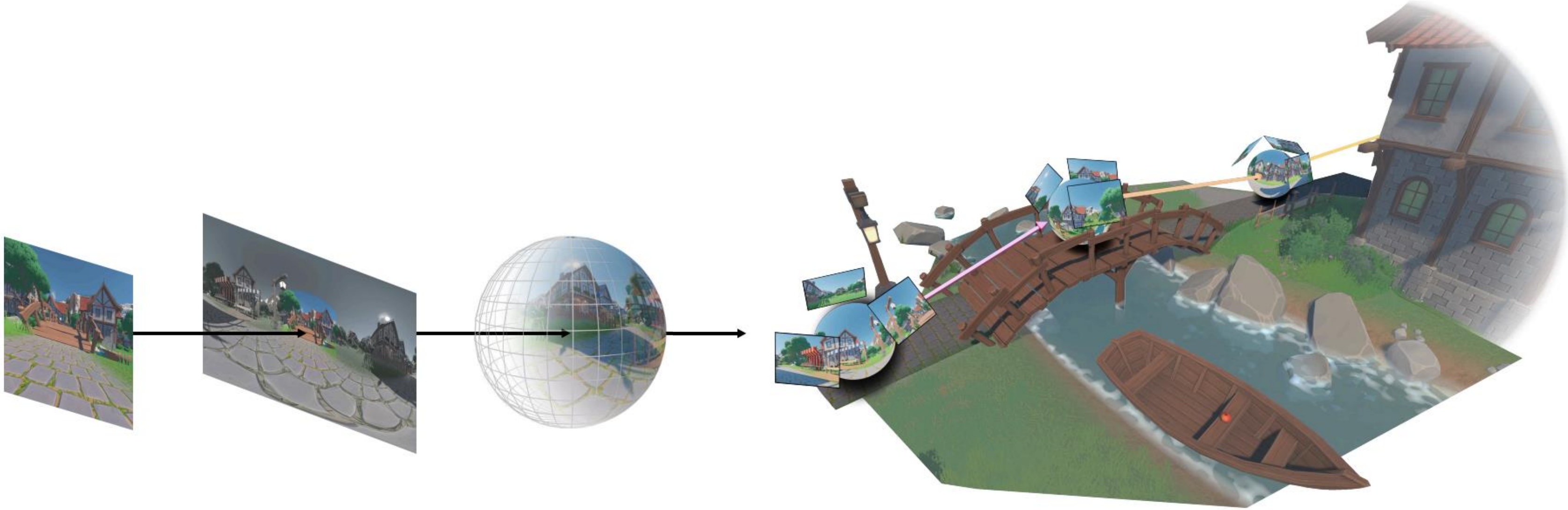
[1] GenEx: generating an explorable world

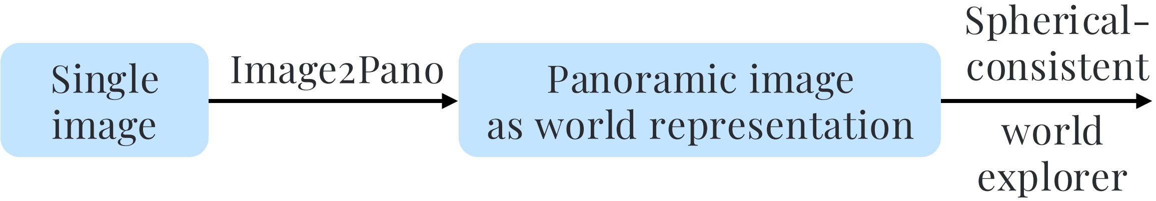
# More than a generated world

**GenEx**: a type of **world model** that offer a predictive distribution over "changes" in the world.

- $\boldsymbol{x_{t-1}}$: the past world observation / state
- $\boldsymbol{x_t}$: the predicted future world observation / state
- $\boldsymbol{a_t}$: the action

$$\boldsymbol{p(x_t|x_{t-1}, a_t)}$$





Single image

Image2Pano

Panoramic image as world representation

Spherical-consistent world explorer

Action Control

Generating future observations

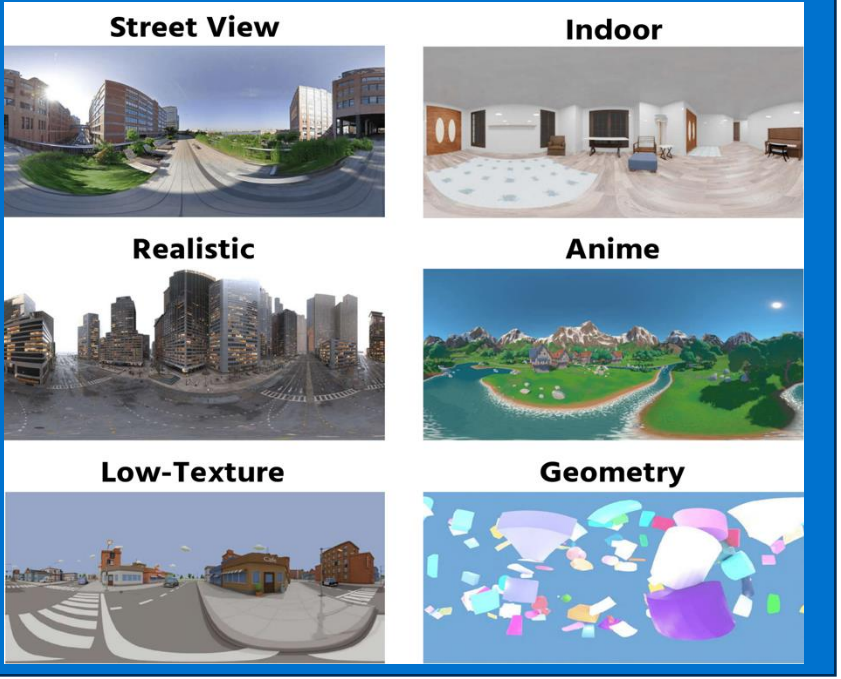
[1] GenEx: generating an explorable world

# Training recipe: purely synthetic physical engine

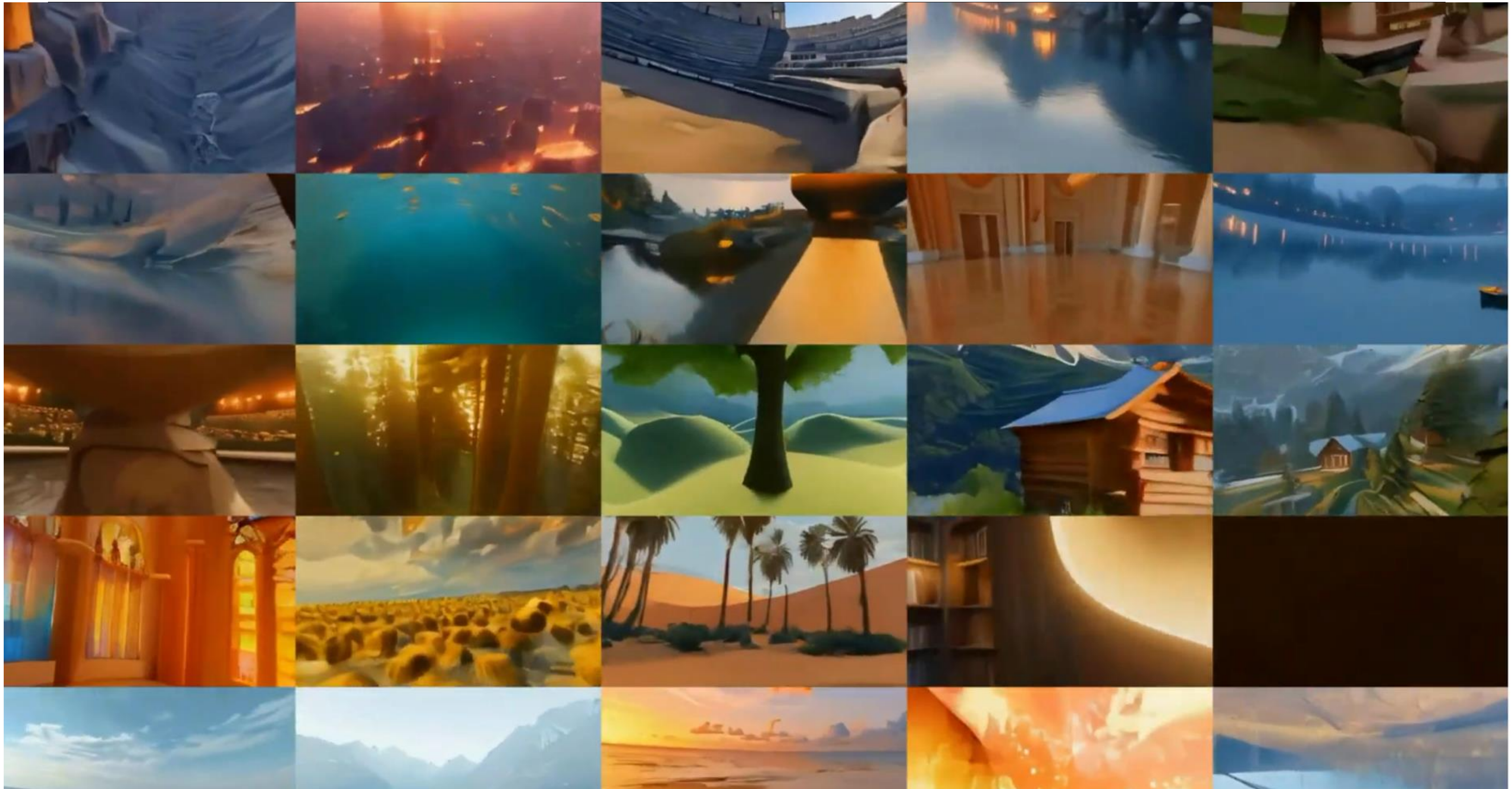
UNREAL ENGINE

Unity

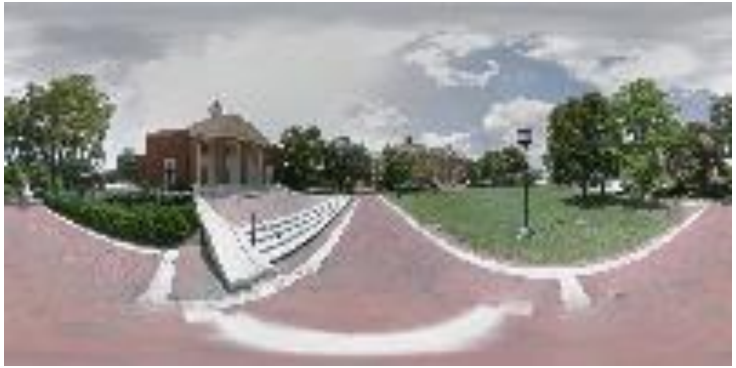
One million meters of data



# Inference on unseen diverse scene

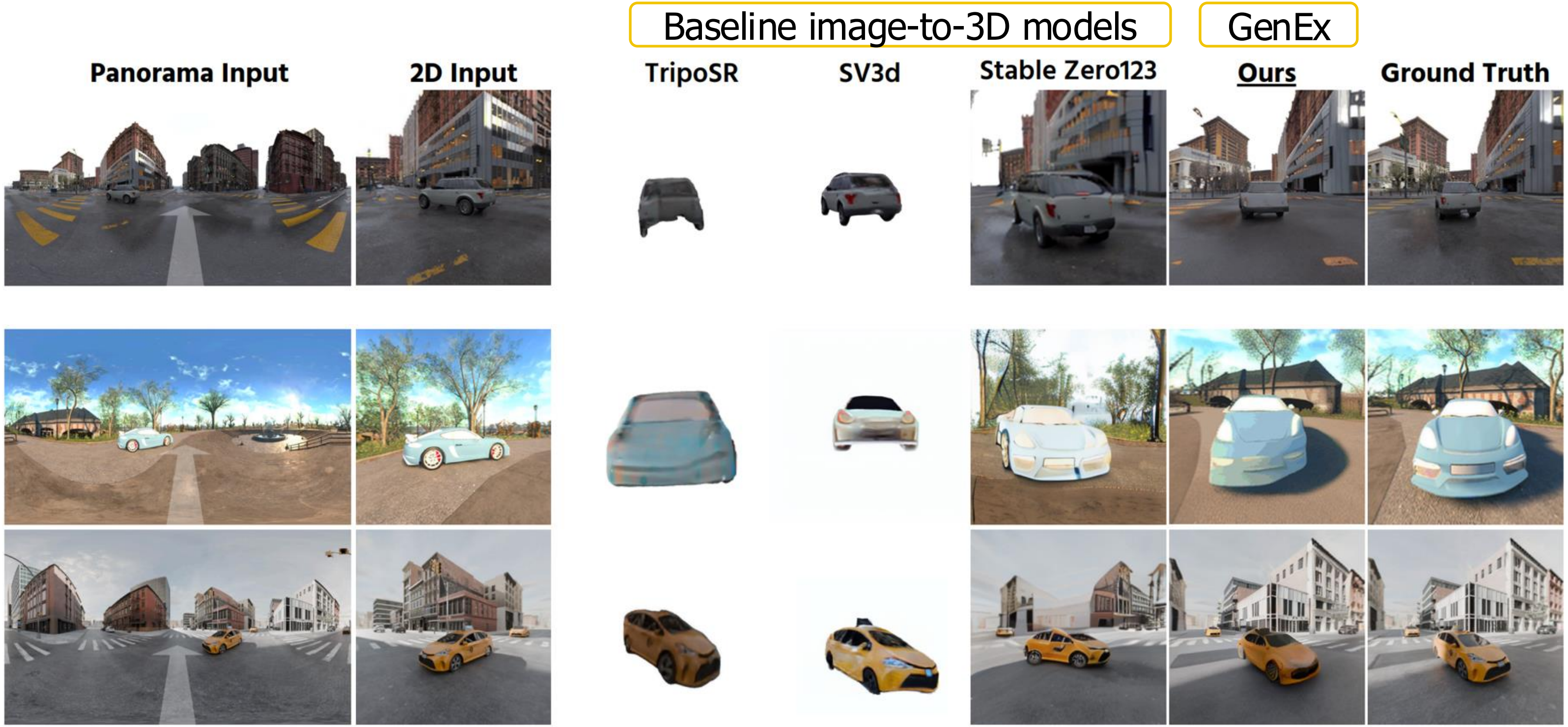


# Inference on unseen real world (JHU campus in left)



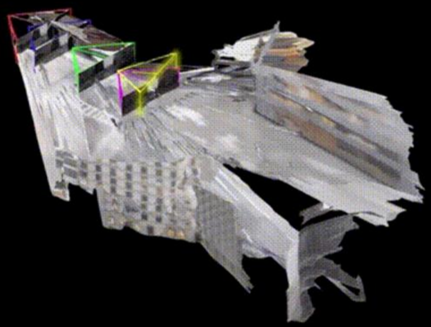
Different to prior world models focusing on AI gaming, this is one of the first to show the real-world generalizability.

# Result 1: 3D Consistency



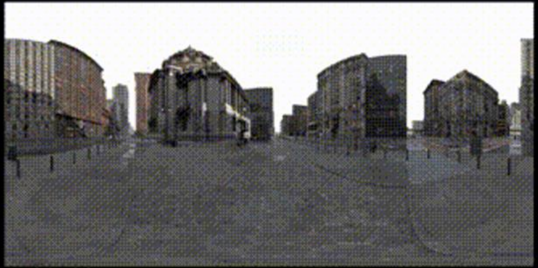
# Result 2: Reconstructing 3D World

Generating the World

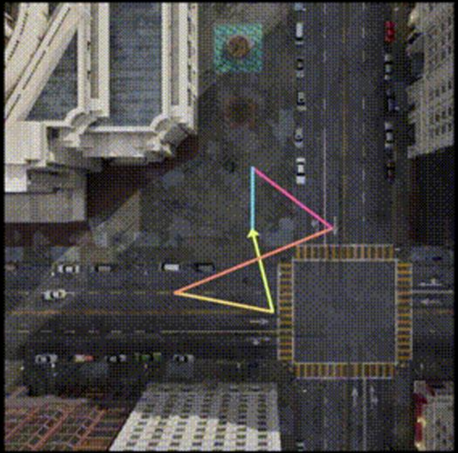


Reconstructing the World

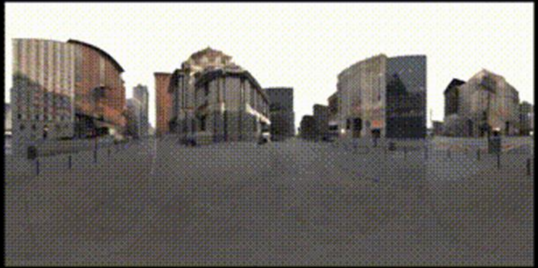
# Result 3:  Loop Closure in the Generated World



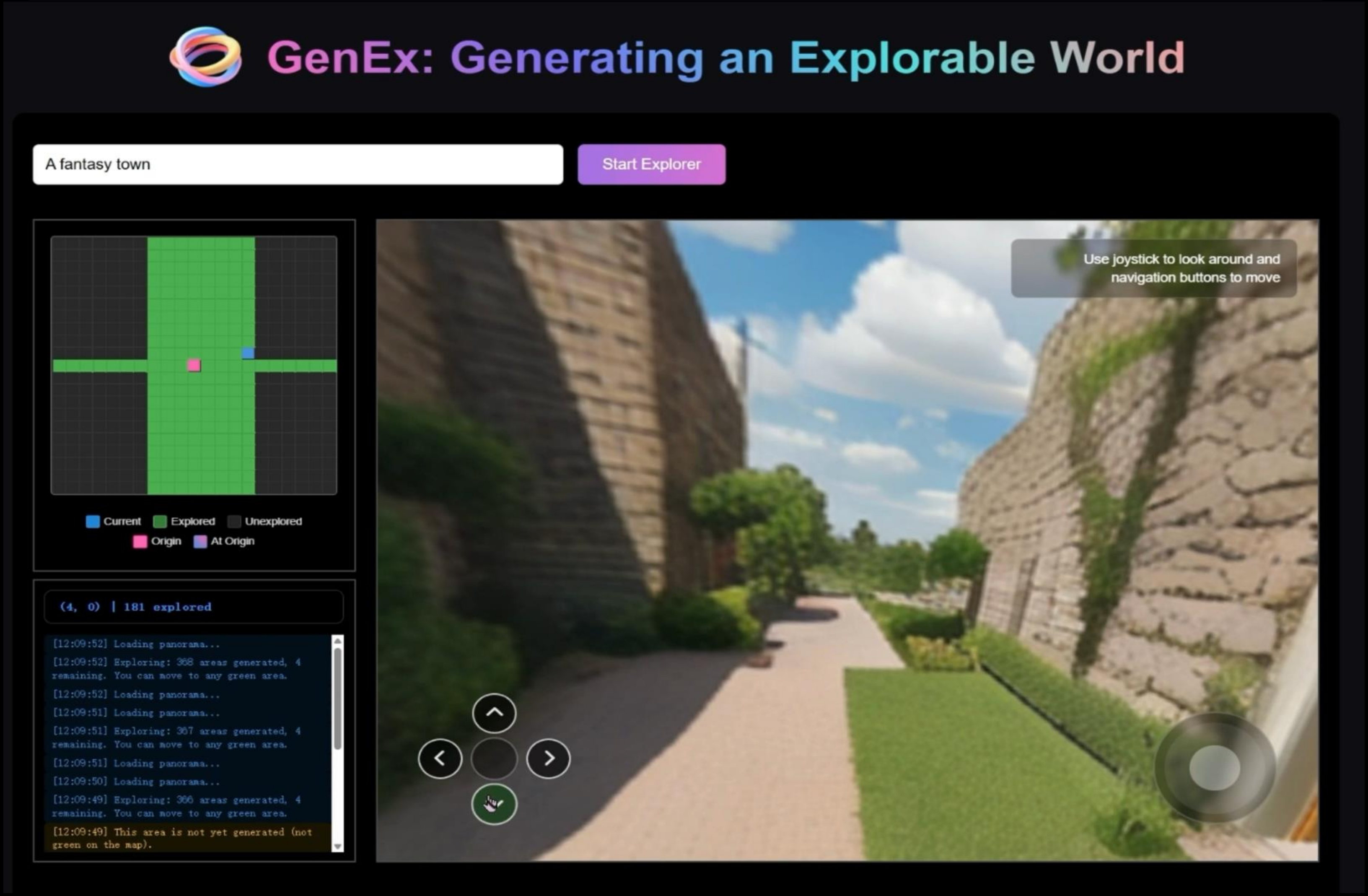
Initial



Path



Navigated



GenEx: Generating an Explorable World

Use joystick to look around and navigation buttons to move

```
(4, 0) | 181 explored

[12:09:52] Loading panorama...
[12:09:52] Exploring: 368 areas generated, 4
remaining. You can move to any green area.
[12:09:52] Loading panorama...
[12:09:51] Loading panorama...
[12:09:51] Exploring: 367 areas generated, 4
remaining. You can move to any green area.
[12:09:51] Loading panorama...
[12:09:50] Loading panorama...
[12:09:49] Exploring: 366 areas generated, 4
remaining. You can move to any green area.
[12:09:49] This area is not yet generated (not
green on the map).
```

**Scalability**

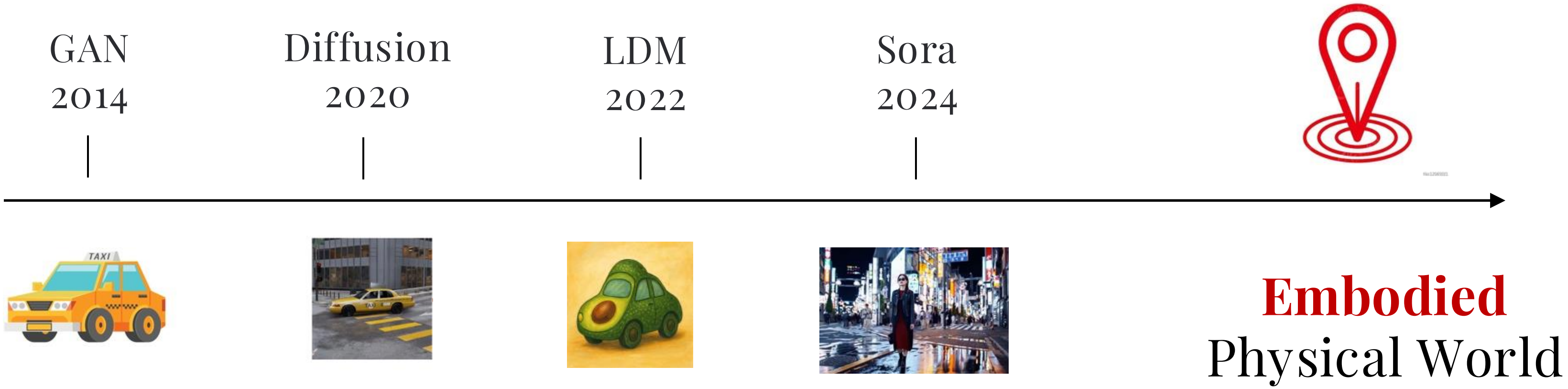
**Scalability**

# Scalability

Aim: turn **any** single image/text into a fully explorable world.

# More than a generated world

# A step further for human-like world exploration



GAN
2014

Diffusion
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**Embodied**
Physical World

# Embodied intelligence amplification with generated world

$$A = \arg\max_{A} \pi_{\theta}(A \mid \text{instruct}, \text{observation}, \text{goal})$$

$$\Big\downarrow \quad \text{Intelligence amplification}$$

$$A = \arg\max_{A} \pi_{\theta}(A \mid \text{instruct}, \text{observation in generated world}, \text{goal})$$

# Embodied question answering benchmark

200 scenarios for EQAs

Single-agent

**Scene:** I arrive at an intersection and want to turn left. The front path is clear, there is no car. … I see another car at the intersection, on the left view moving slowly.

**Question:** What should I make the turn?

**Choices:**
- **(A)** Stop in place to wait for the car to make the turn first.
- **(B)** Honk to warn other cars to avoid collision.
- **(C)** Pull over and wait for traffic to clear.
- **(D)** Carefully continue the turn to avoid traffic congestion.

**Scene:** I arrive at an intersection and want to drive forward. … I see the car opposite to myself suddenly stop. Also, I hear what seems to be an alarm, possibly from an emergency vehicle."

**Question:** What should I do?

**Choices:**
- **(A)** Change lanes to bypass the car carefully.
- **(B)** Stop passing the intersection and move a little bit left to clear the way.
- **(C)** Stop in place to observe the environment.
- **(D)** Continue to proceed through the intersection since the traffic light is green.

**Scene:** I am driving down a street. Ahead, there is a car stopped in my lane. I can't see what is in front of this car because it is blocking my view. The traffic is light, …

**Question:** How should I proceed?

**Choices:**
- **(A)** Change lanes to pass the stopped car quickly, since there is no visible obstruction.
- **(B)** Honk to signal the stopped car to move.
- **(C)** Slow down and keep to my lane, proceeding with caution.
- **(D)** Wait for the car ahead to start moving.

**Scene:** I am approaching an intersection with a "Do Not Enter" sign. … Ahead, there is a police car in view, but it is unclear whether the police car is waiting or needs to move.

**Question:** How should I respond to this situation?

**Choices:**
- **(A)** Wait at the intersection for the police car to move first.
- **(B)** Change lanes to pass through.
- **(C)** Honk to signal the police car to move.
- **(D)** Slow down and proceed cautiously, assuming the police car will stay in place.

Multi-agent

**Scene:** I arrive at an intersection to proceed forward. The intersection does not have a traffic light and is busy. There is a pedestrian on my right side crossing the road fast …

**Question:** What should I do now?

**Choices:**
- **(A)** Drive forward as normal.
- **(B)** Block the pedestrian for a few seconds to avoid hitting by other cars.
- **(C)** Accelerate to avoid collision with other cars.
- **(D)** Pull over and wait for traffic to clear.

**Scene:** I'm at an intersection with a red light, where right turns are allowed. … A fast car is approaching to turn right, and a pedestrian is crossing in front of me.

**Question:** What do I need to do?

**Choices:**
- **(A)** Signal the car to stop for the pedestrian.
- **(B)** Stay in place and wait for the green light.
- **(C)** Honk to alert the pedestrian of the approaching car.
- **(D)** Proceed cautiously while monitoring both the car and pedestrian.

**Scene:** I'm driving on a street. The front path is clear. … I see a car in my back try to bypass me. There is also a pedestrain crossing the street on my left side.

**Question:** What would I do?

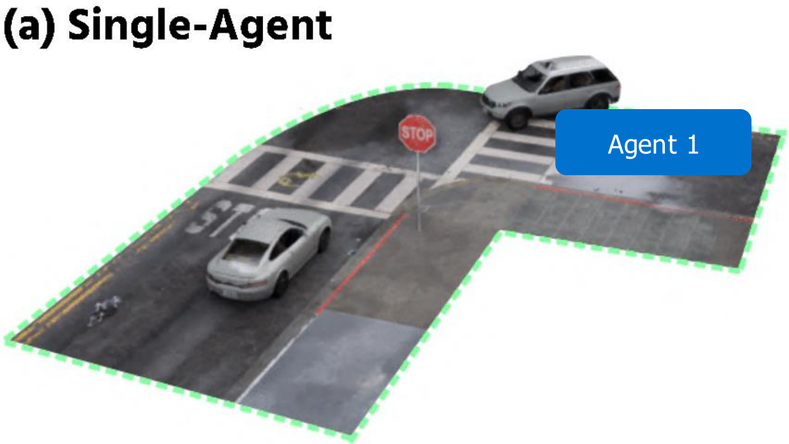
**Choices:**
- **(A)** Move a little bit to the left to allow the other cay to pass.
- **(B)** Continue drive forward fast.
- **(C)** Slow down to avoid the car bypass now to protect the pedestrain.
- **(D)** Suddenly stop in place to block the back car.

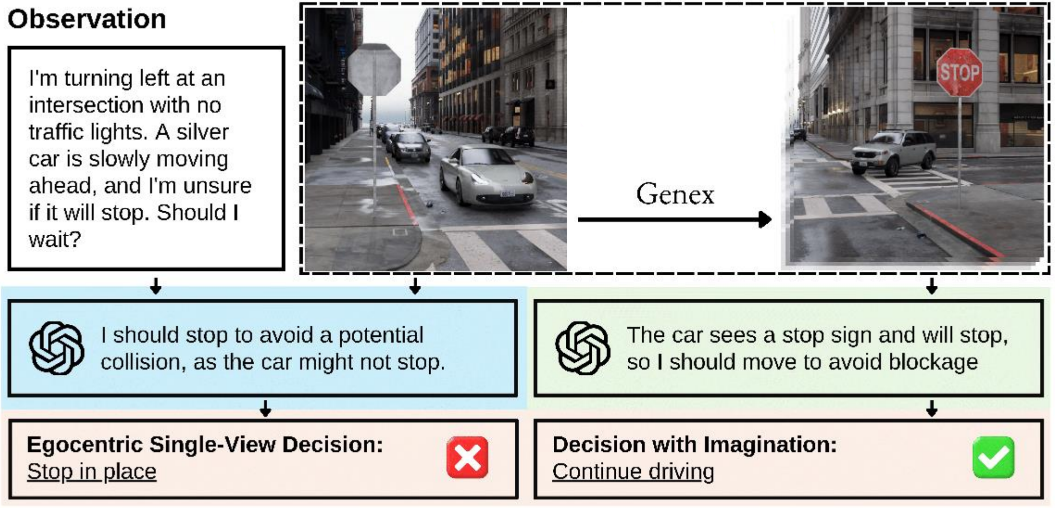
**Scene:** I'm driving on the right lane on a street. On the other lane, there is a car approaching fast. … I can also see a pedestrain on the left side trying to cross the street.

**Question:** What to do now?

**Choices:**
- **(A)** Continue forward as the path is clear.
- **(B)** Honk to signal the front car to avoid collision with me.
- **(C)** Pull over to the right.
- **(D)** Warn both pedestrain and the car for a potentail collision.

# Embodied decision making





**Observation**

I'm turning left at an intersection with no traffic lights. A silver car is slowly moving ahead, and I'm unsure if it will stop. Should I wait?

I should stop to avoid a potential collision, as the car might not stop.

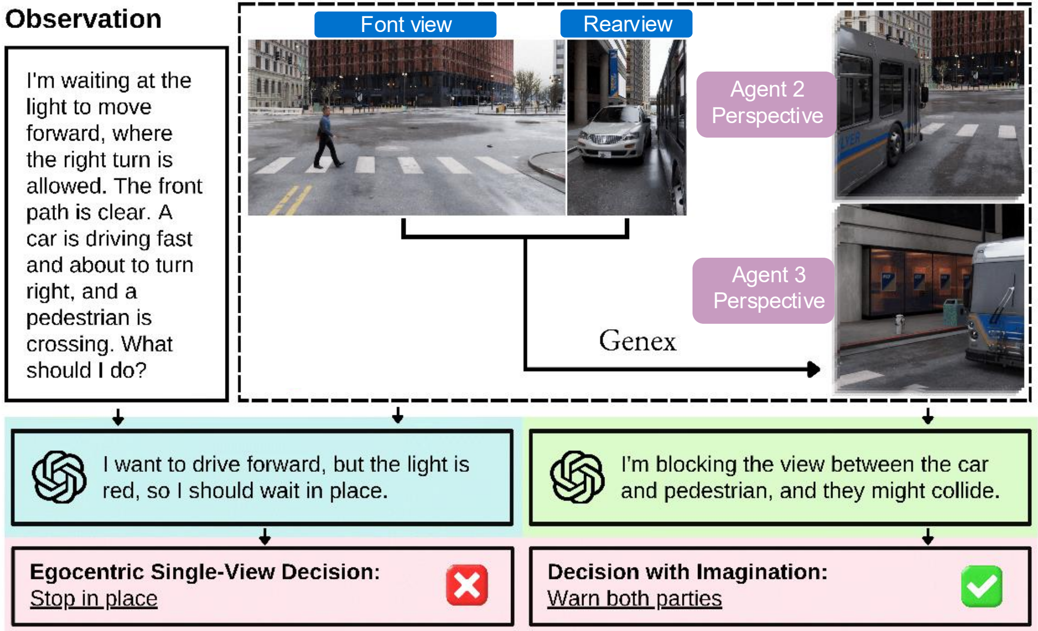
The car sees a stop sign and will stop, so I should move to avoid blockage

**Egocentric Single-View Decision:** Stop in place ✗

**Decision with Imagination:** Continue driving ✓

[1] GenEx: generating an explorable world

# Embodied decision making



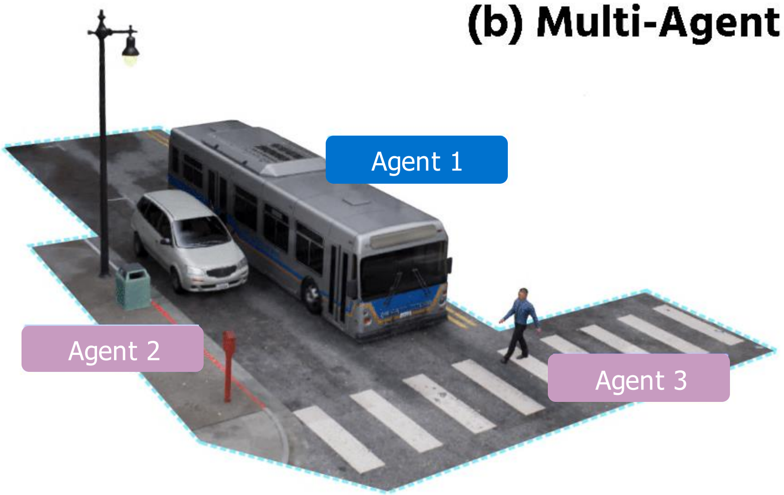
I'm waiting at the light to move forward, where the right turn is allowed. The front path is clear. A car is driving fast and about to turn right, and a pedestrian is crossing. What should I do?

I want to drive forward, but the light is red, so I should wait in place.

I'm blocking the view between the car and pedestrian, and they might collide.

**Egocentric Single-View Decision:** Stop in place ✗

**Decision with Imagination:** Warn both parties ✓

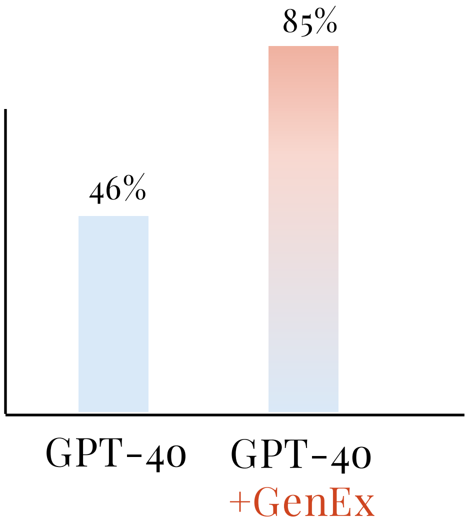


[1] GenEx: generating an explorable world

Collaborative / decentralized world models

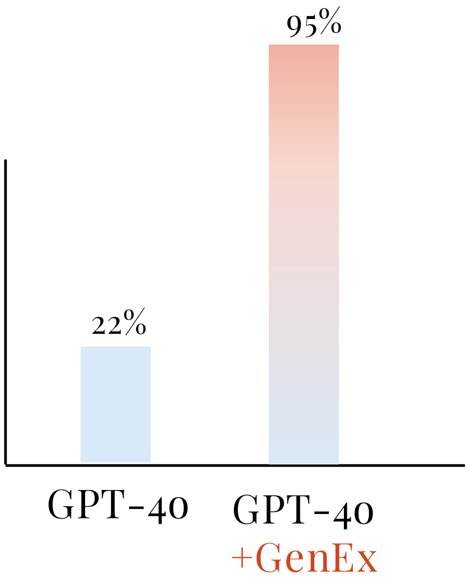
# Boost GPT agent decision making

+ 39% accuracy



Single-Agent Setting

+ 73% accuracy



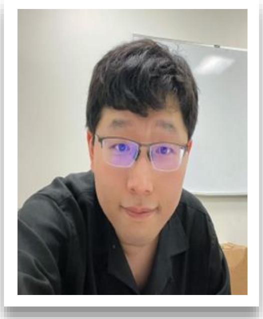
Multi-Agent Setting

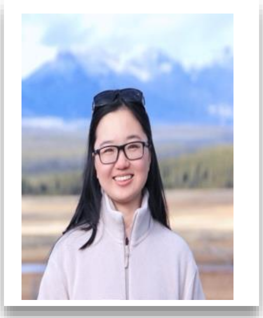
[1] GenEx: generating an explorable world

# Summary

- One of the first models to generate explorable (real) world from a single image.
- Intelligence amplification in the embodied generated world.

# Thanks for wonderful collaborators on these projects!!





# Thank you! Question?