

World Models and Human-like Reasoning

Visual Generation Unlocks Human-Like Reasoning through
Multimodal World Models

thuml.github.io/Reasoning-Visual-World

Jialong Wu

Tsinghua University & ByteDance Seed

February 13rd, 2026

About Our Work

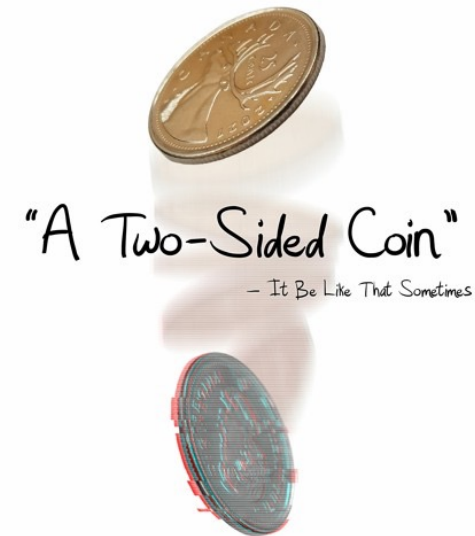


Tsinghua University



Visual Generation Unlocks Human-Like Reasoning through Multimodal World Models

Jialong Wu^{1,2,*}, Xiaoying Zhang^{2,†}, Hongyi Yuan², Xiangcheng Zhang^{1,2,*}, Tianhao Huang¹, Changjing He¹, Chaoyi Deng^{1,2,*}, Renrui Zhang², Youbin Wu², Mingsheng Long^{1,†}



A perspective on:

1. What is **multimodal world models** and why do we need it?
2. When and how does **visual generation benefit reasoning**?

Contents

- **A Brief History of World Models**
- Reasoning with World Models
- Multimodal World Models and Human-like Reasoning

World Models in AI Applications



Content Creation

OpenAI Sora. 2024.

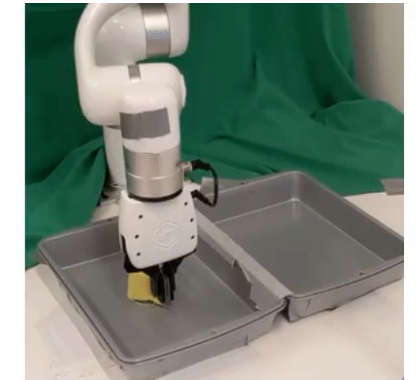
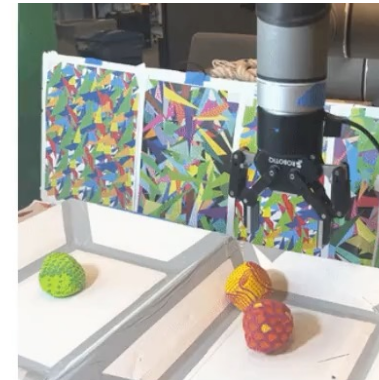
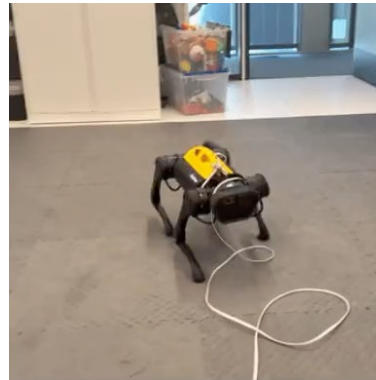
Genie 3. 2025.

World Labs Marble. 2025.



Autonomous Driving

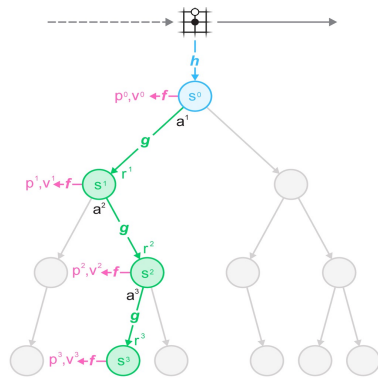
Alex Kendall. CVPR 2023 E2EAD Workshop.



Robotics

Philipp Wu, et al. CoRL 2022.

World Models in AI Applications



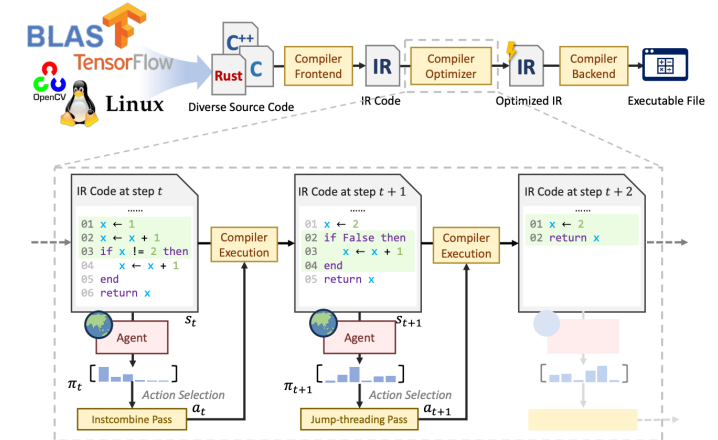
Games

Julian Schrittwieser, et al. Nature 2020.



Code Generation

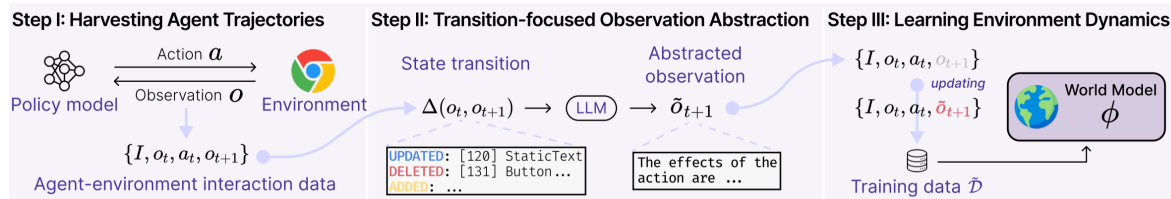
FAIR CodeGen Team. 2025.



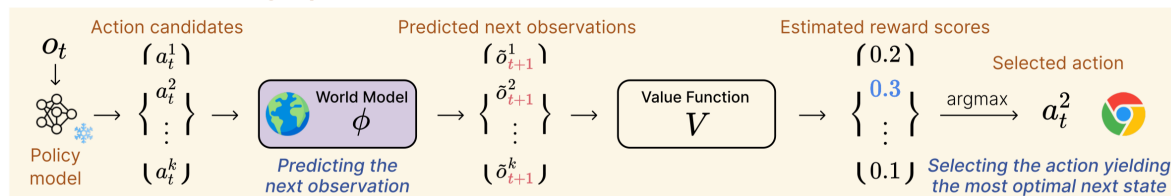
Compiler Optimization

Chaoyi Deng, et al. KDD 2025.

World Model Training



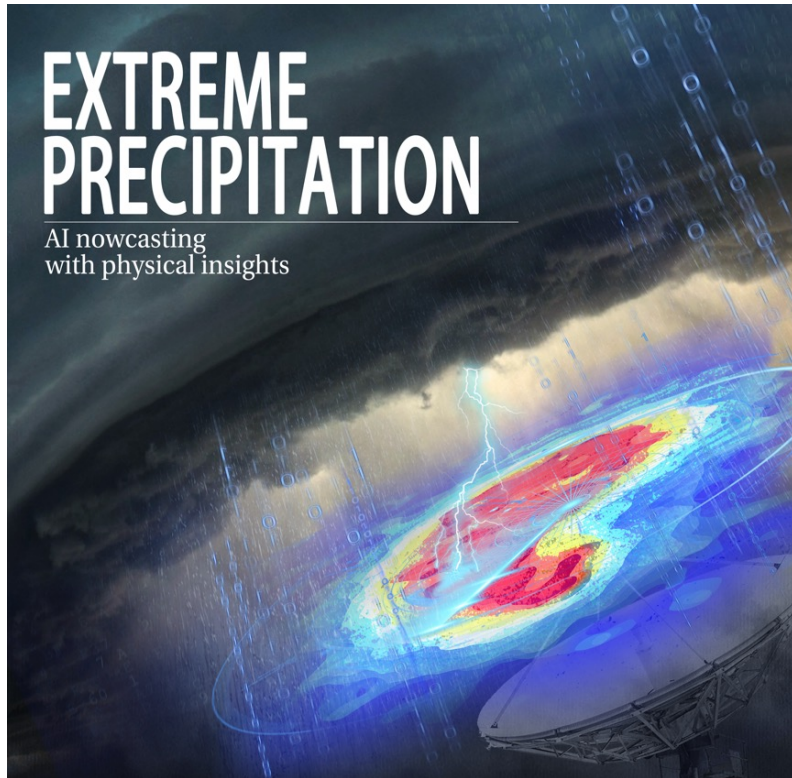
Inference-time Policy Optimization via the World Model



Web Agents

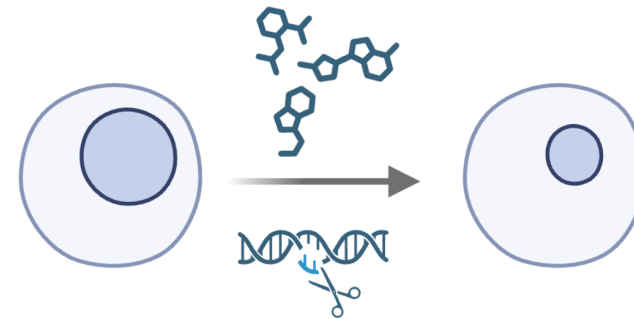
Hyungjoo Chae, et al. ICLR 2025.

World Models in AI Applications



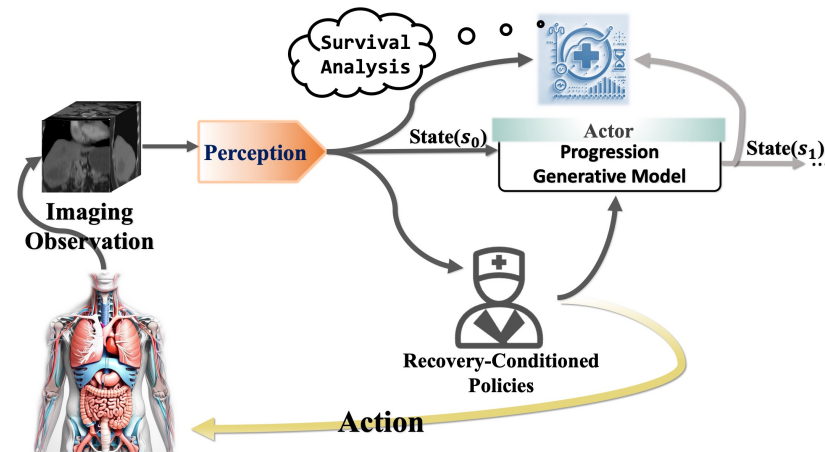
Weather Prediction

Yuchen Zhang, et al. Nature 2023.



Cell Morphology

Yuhui Zhang, et al. ICML 2025.



Clinical Medicine

Yijun Yang, et al. 2025.

Interdisciplinary Nature of World Models

Dudes showing up at the first conference for World Models...



<https://github.com/knightnemo/Awesome-World-Models>

Back to the Origin: Mental Models of Human



Kenneth Craik
Psychologist
(1943)

Reasoning and Planning:

“If the organism carries a “small-scale model” of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future, and in every way react in a much fuller, safer, and more competent manner to the emergencies which face it.”



Jay Wright Forrester
Father of system dynamics
(1971)

Abstract Representations:

“The image of the world around us, which we carry in our head, is just a model. Nobody in his head imagines all the world, government or country. He has only selected concepts, and relationships between them, and uses those to represent the real system”

Mental Models in Daily Life

Observation A glass of water is spilled on the table



Mental Simulation The water spreading across the surface, and potentially dripping onto the floor



Mental Evaluation Broken valuable items are unacceptable



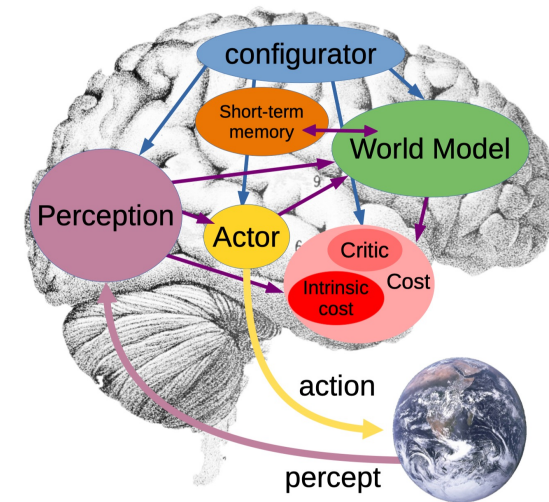
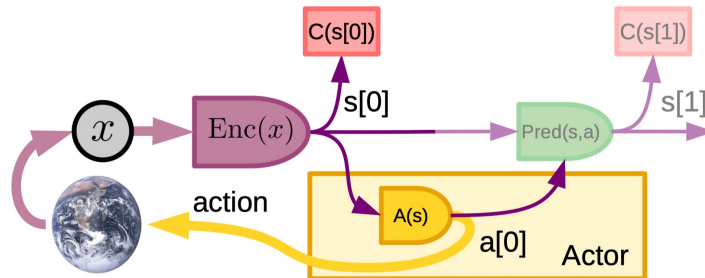
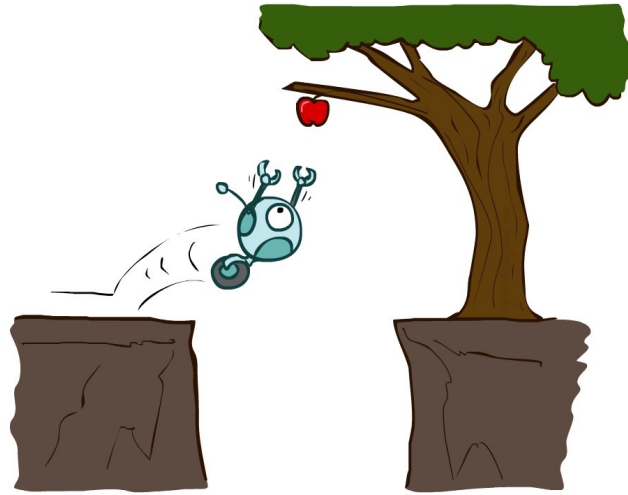
Action Quickly move valuable items away or reach for a towel



World Models for AI: From System-1 to System-2

System-1 Agent (Reflex):

Not utilize
the world model
nor the cost.



World Models:

How the world transits under interventions

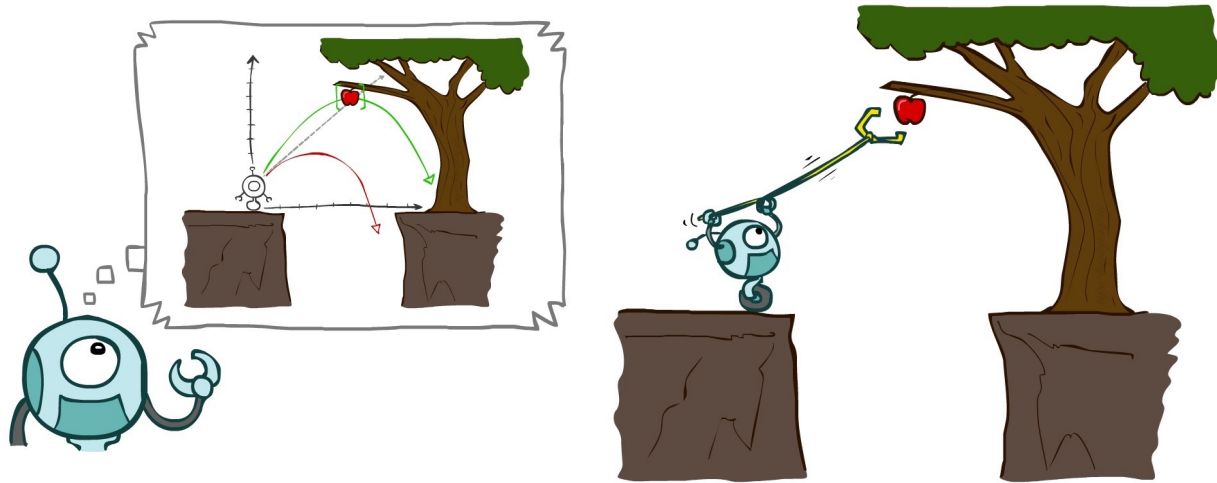
$f: \text{State} \times \text{Action} \rightarrow \text{Next State}$

Interventions

Yann LeCun. A path towards autonomous machine intelligence. 2022.

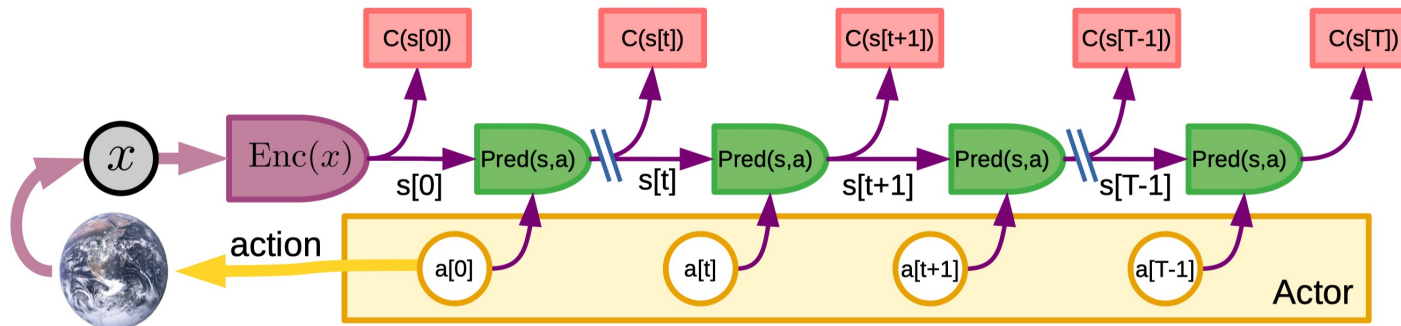
Dan Klein and Pieter Abbeel. Introduction to Artificial Intelligence.

World Models for AI: From System-1 to System-2



System-2 Agent (Planning/Model Predictive Control):

Act through an optimization procedure running the **world model**.



Amortized Inference (Model-based RL):

A **policy** module mimicking (distilling) the planned optimal actions

Yann LeCun. A path towards autonomous machine intelligence. 2022.

Dan Klein and Pieter Abbeel. Introduction to Artificial Intelligence.

What to Predict?



**Abandon
generative models!**

"Modeling the world for action by **generating pixel is as wasteful** and doomed to failure..."

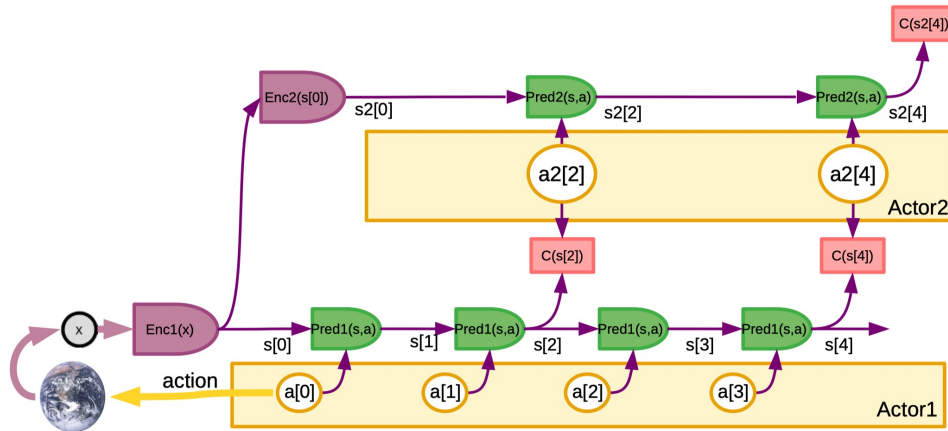
"It's much more desirable to generate **abstract representations** of those continuations that **eliminate details in the scene that are irrelevant** to any action we might want to take."

Raw Pixels vs. Abstraction

OpenAI. <https://openai.com/research/video-generation-models-as-world-simulators>

Yann LeCun. <https://twitter.com/ylecun/status/1758740106955952191>

Different Levels of Abstraction



We have no objective signals in the wild!
How to learn **abstract latent embedding**
at scale?

~~JPEA?~~



Approximate by

Visuals (concrete) + Languages (abstract)



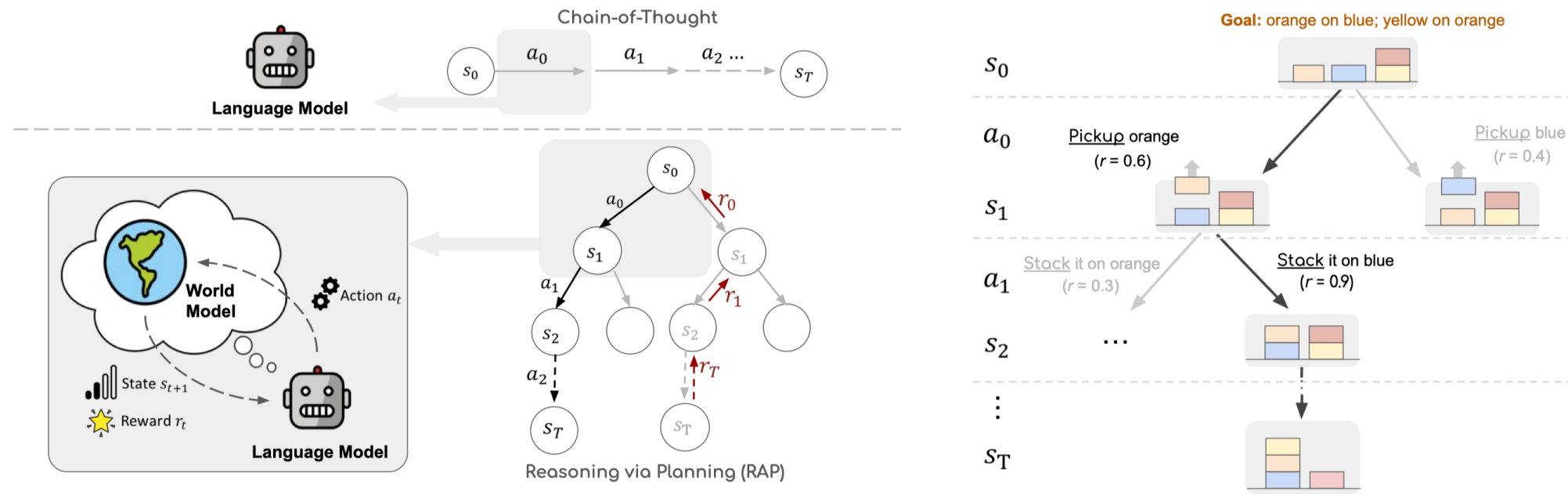
Question 1: What is **multimodal world models** and why do we need it?

Contents

- A Brief History of World Models
- **Reasoning with World Models**
- Multimodal World Models and Human-like Reasoning

Planning with Verbal World Models

Language as abstract representation of world states



Reasoning with Language Model is Planning with World Model. EMNLP 2023.

Chain-of-Thought Reasoning with Verbal World Models

World modeling as an inherent capability rather than a separate model.

During CoT reasoning, LLM/VLMs **explore, reflect, and backtrack** within the structured solution space, guided by their world knowledge.

Mathematical Reasoning

Question: If $a > 1$, then the sum of the real solutions of $\sqrt{a - \sqrt{a + x}} = x$ is equal to

Response: <think>

To solve the equation $\sqrt{a - \sqrt{a + x}} = x$, let's start by squaring both ...

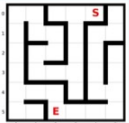
$$(\sqrt{a - \sqrt{a + x}})^2 = x^2 \Rightarrow a - \sqrt{a + x} = x^2.$$

Rearrange to isolate the inner square root term:

$$(a - x^2)^2 = a + x \Rightarrow a^2 - 2ax^2 + (x^2)^2 = a + x \Rightarrow x^4 - 2ax^2 - x + (a^2 - a) = 0$$

...

Puzzle Solving



<think>From S at [452, 59], the only available move is West to [359, 59]

Travel Planning

Task: Plan a trip with a budget of \$1,700.

<think>STATE: Initial Budget: \$1700, Spent: \$0.

Day 1: transportation: PENDING...Available:

Flight F3573659: \$474

ACTION: Plan day 1 transportation. Select Flight F3573659.

NEXT STATE: After this action, you've spent \$474, leaving \$1226 from your \$1700 budget...

State/Observation

Action

Everyday Activity Planning

Goal: Cooking tomato and eggs



<think>... ACTION: Cook the eggs in the pan
STATE: This action changes the state of the eggs from liquid to a partially cooked state. The eggs are now partially cooked and are being transformed into curds. The heat from the pan cooks the eggs, and the stirring action ensures even cooking...

Planning with reasoning using vision language world model.

Revisiting the necessity of lengthy chain-of-thought in vision-centric reasoning generalization.

DeepSeek-R1 incentivizes reasoning in LLMs through reinforcement learning.

Agent learning via early experience.

Chain-of-Thought Reasoning with **Verbal** World Models

World modeling as an inherent capability rather than a separate model.

During CoT reasoning, LLM/VLMs **explore, reflect, and backtrack** within the structured solution space, guided by their world knowledge.

```
<|trace_context_start|>

def count(s, t):
    n = 0
    for c in s:
        n += int(c == t)
    return n

count("strawberry", "r") # << START_OF_TRACE

<|frame_sep|>
<|call_sep|> {"s": "'strawberry'", "t": "'r'"} <|action_sep|> def count(s, t):
<|frame_sep|>
<|line_sep|> {"s": "..", "t": ".."} <|action_sep|> n = 0
<|frame_sep|>
<|line_sep|> {"s": "..", "t": "..", "n": "0"} <|action_sep|> for c in s:
<|frame_sep|>
<|line_sep|> {"s": "..", "t": "..", "n": "..", "c": "'s'"} <|action_sep|> n += int(c == t)
...
<|frame_sep|>
<|return_sep|> <|action_sep|> return n <|arg_sep|> "3"
<|frame_sep|>
```

Inference

Agentic (baseline) P T O T O T O T

Agentic reasoning P T_R T O T O T_R T O T

WM-based agentic reasoning (future research) P T_R T O T O T O T O T_R T O T O T

Unrolling plan with world model

Submitted answer

Types of data

T Text / code / tool call
T_R Text / code with reasoning
O Observations

P Prompt (or context) text / code
T_A Human annotated text / code
R Rewards

World modeling type of data

T O T O T O

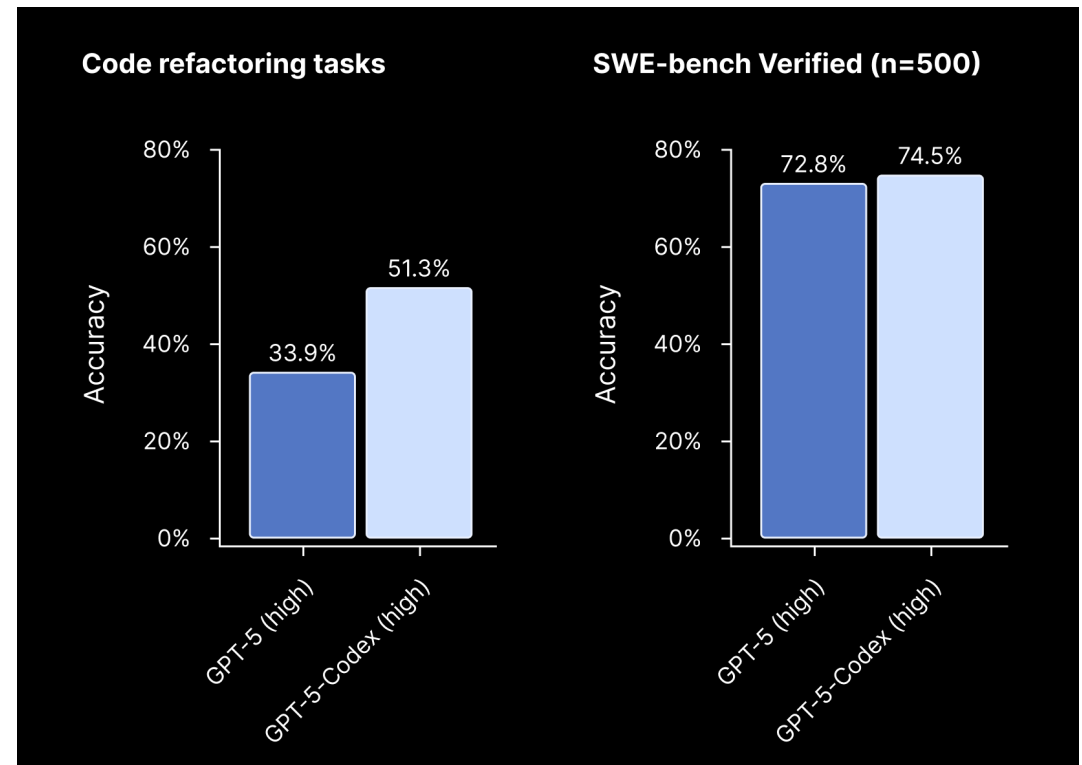
Expert Performance in Formal and Abstract Domains

Article | [Open access](#) | Published: 17 September 2025

DeepSeek-R1 incentivizes reasoning in LLMs through reinforcement learning

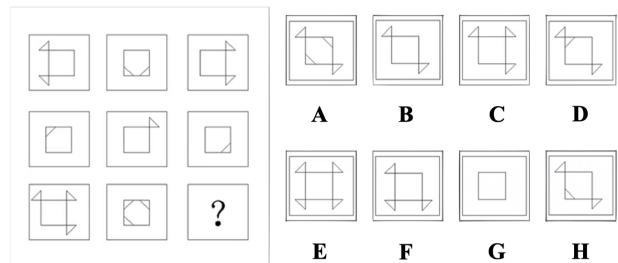


Mathematics and Coding



Baby Performance in Physical and Spatial Reasoning

Struggle with tasks grounded in basic physical and spatial intuition that even young children naturally master



Question: Based on the sequence and position of the other shapes, identify the pattern and determine the correct option for the question mark grid.



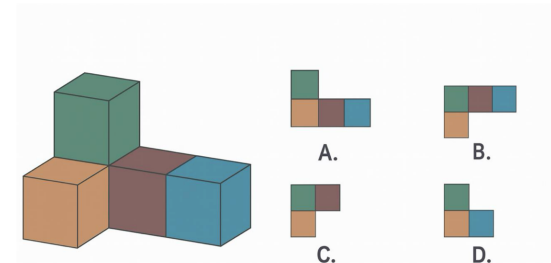
GPT-5

Answer: F. ✓



Human

Answer: F. ✓



Question: Which option is the correct top-down view of the object?



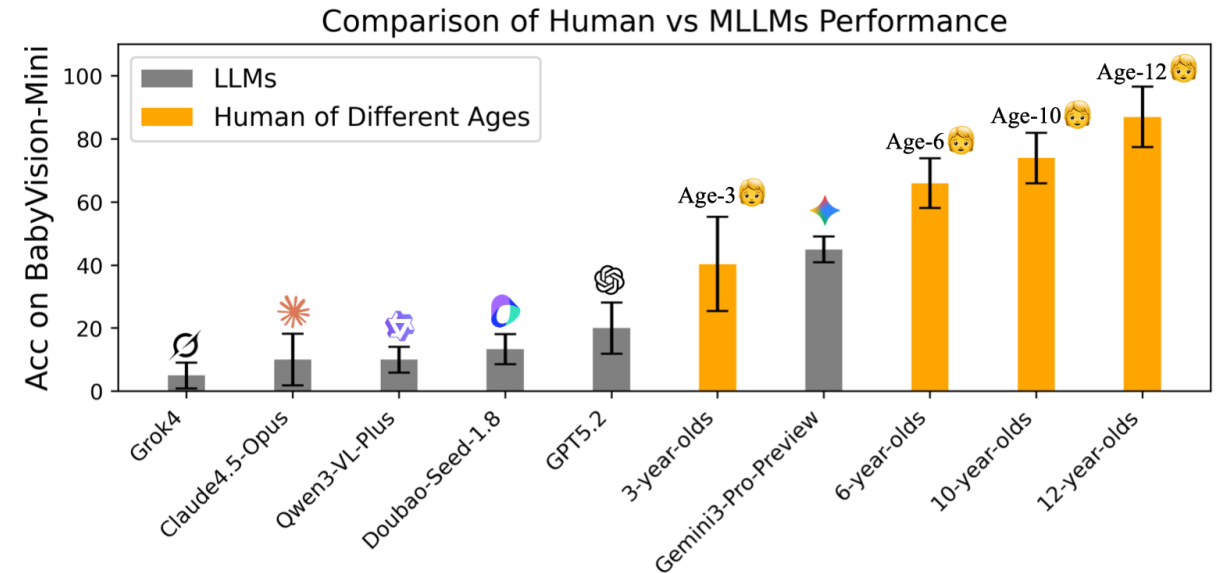
GPT-5

Answer: A. ✗



Human

Answer: B. ✓

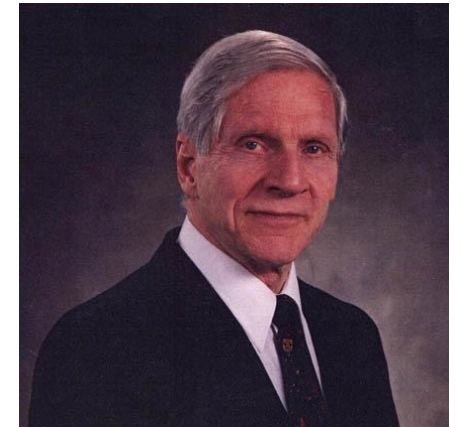
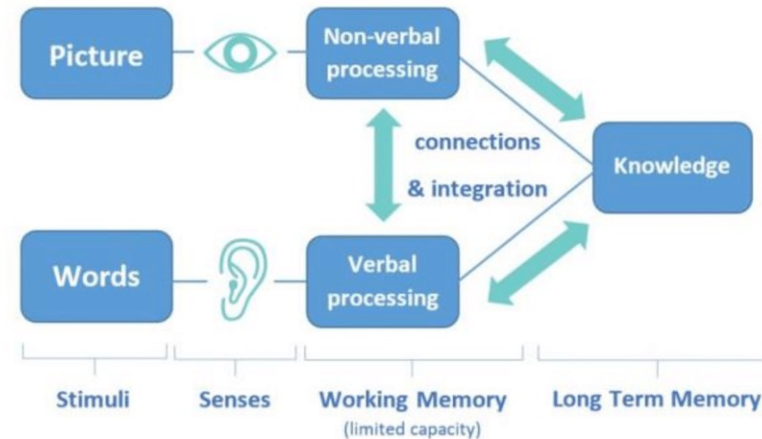


Has GPT-5 Achieved Spatial Intelligence? An Empirical Study
BabyVision: Visual Reasoning Beyond Language

Dual-Coding Theory of Human Cognition

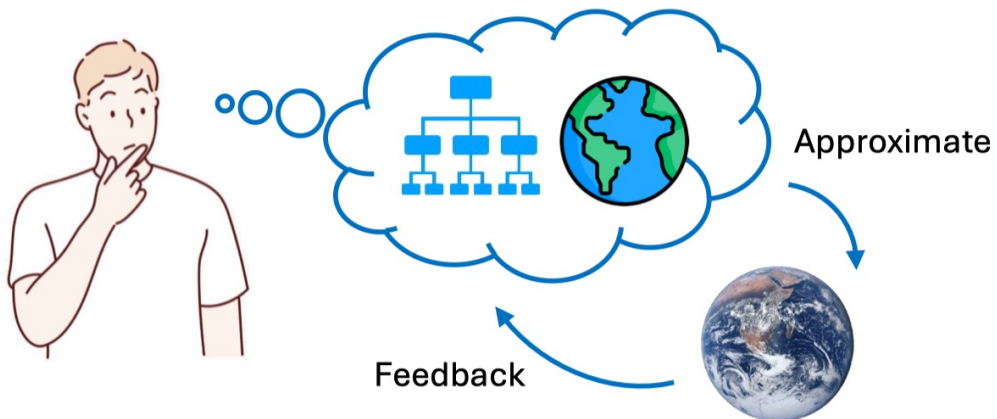
Mind processes information along two different channels: verbal and nonverbal.

Allan Paivio's Dual-Coding Theory



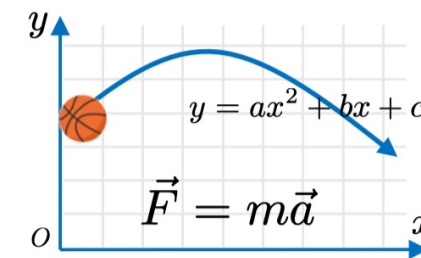
Allan Paivio
Professor of psychology

World Model: Mental Model of the World



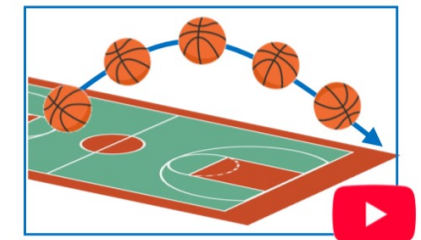
Dual Representations of World Knowledge

Verbal/Symbolic Knowledge



Dislike in Daily Life

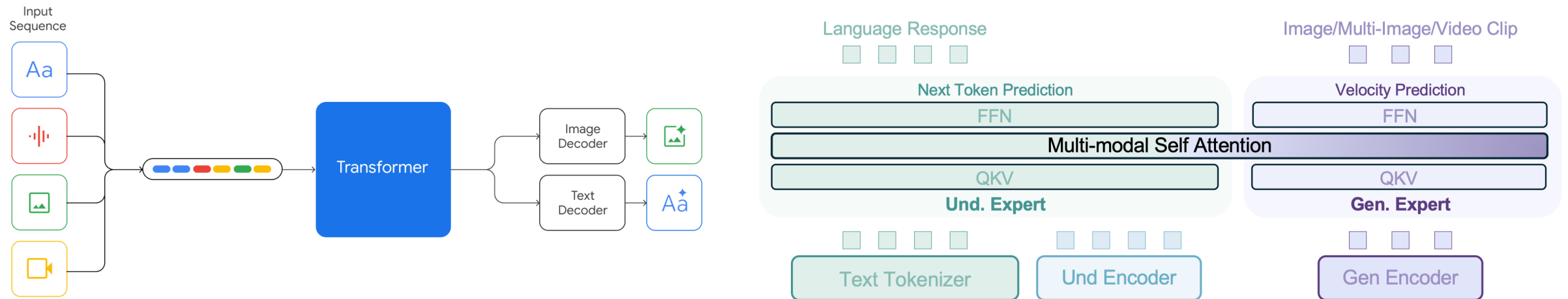
Visual/Imagery Knowledge



Prefer in Daily Life

Unified Multimodal Models

Unified multimodal models (UMMs) seamlessly integrate both **verbal and visual generation** capabilities, opening a new paradigm of **verbal-visual interleaved reasoning**.



Gemini: A Family of Highly Capable Multimodal Models
Emerging Properties in Unified Multimodal Pretraining

Inconclusive Investigations

× Heuristic task design

| Model | Understanding Enhances Generation | | | | | | | Generation Enhances Understanding | | | | | Total |
|----------------------------|-----------------------------------|---------|---------|---------|---------|---------|-------------|-----------------------------------|---------|---------|---------|-------------|-------------|
| | WK | CR | MR-I | LR | SR | C2I | Avg | MR-II | MT | AF | CN | Avg | |
| Proprietary Models | | | | | | | | | | | | | |
| Nano Banana | 89 / - | 86 / - | 34 / - | 65 / - | 48 / - | 56 / - | 63.0 / - | 34 / - | 27 / - | 36 / - | 30 / - | 31.8 / - | 50.5 / - |
| Open-Source Unified Models | | | | | | | | | | | | | |
| MIO | 24 / 35 | 26 / 33 | 18 / 13 | 9 / 10 | 10 / 11 | 0 / 8 | 14.5 / 18.3 | 26 / 23 | 19 / 18 | 35 / 19 | 23 / 21 | 25.8 / 20.3 | 19.0 / 19.1 |
| Janus-Pro | 25 / 26 | 77 / 71 | 16 / 7 | 13 / 17 | 16 / 20 | 3 / 10 | 25.0 / 25.2 | 21 / - | 23 / - | 28 / - | 29 / - | 25.3 / - | 25.1 / - |
| ILLUME+ | 44 / 52 | 62 / 62 | 22 / 22 | 23 / 25 | 26 / 26 | 1 / 7 | 29.7 / 32.3 | 27 / 27 | 19 / 20 | 35 / 38 | 30 / 25 | 27.8 / 27.5 | 28.9 / 30.4 |
| Show-o2 | 30 / 42 | 56 / 50 | 25 / 25 | 21 / 21 | 18 / 20 | 18 / 19 | 28.0 / 29.5 | 36 / - | 28 / - | 36 / - | 21 / - | 30.3 / - | 28.9 / - |
| OmniGen2 | 36 / 55 | 61 / 60 | 21 / 26 | 29 / 28 | 16 / 20 | 19 / 6 | 30.3 / 32.5 | 30 / 42 | 21 / 24 | 51 / 38 | 28 / 19 | 32.5 / 30.8 | 31.2 / 31.8 |
| UniPic2 | 61 / 62 | 73 / 72 | 31 / 30 | 28 / 38 | 25 / 26 | 7 / 15 | 37.5 / 40.5 | 26 / 28 | 20 / 24 | 27 / 27 | 23 / 16 | 24.0 / 23.8 | 32.1 / 33.8 |
| UniWorld-V1 | 51 / 56 | 64 / 59 | 26 / 26 | 33 / 37 | 21 / 24 | 15 / 9 | 35.0 / 35.2 | 29 / 33 | 19 / 25 | 57 / 36 | 24 / 20 | 32.3 / 28.5 | 33.9 / 32.5 |
| Ovis-U1 | 37 / 59 | 72 / 71 | 28 / 30 | 23 / 34 | 15 / 17 | 12 / 25 | 31.2 / 39.3 | 32 / 38 | 28 / 25 | 60 / 31 | 36 / 24 | 39.0 / 29.5 | 34.3 / 35.4 |
| BLIP3-o | 57 / 62 | 71 / 74 | 21 / 24 | 19 / 25 | 28 / 22 | 2 / 9 | 33.0 / 36.0 | 36 / - | 25 / - | 57 / - | 32 / - | 37.5 / - | 34.8 / - |
| OneCAT | 61 / 64 | 70 / 65 | 32 / 20 | 29 / 27 | 24 / 31 | 9 / 27 | 37.5 / 39.0 | 26 / 29 | 25 / 26 | 43 / 26 | 31 / 36 | 31.3 / 29.3 | 35.0 / 35.1 |
| BAGEL | 46 / 74 | 70 / 80 | 23 / 26 | 29 / 37 | 21 / 29 | 7 / 40 | 32.7 / 47.7 | 37 / 38 | 31 / 25 | 50 / 52 | 39 / 28 | 39.3 / 35.8 | 35.3 / 42.9 |



Question 2: When and how does **visual generation**, enabled by UMMs, **benefit reasoning**?

Realunify: Do unified models truly benefit from unification? a comprehensive benchmark.

Rover: Benchmarking reciprocal cross-modal reasoning for omnimodal generation.

× Mixed empirical results

| Verb.+Vis. Reasoning for Verbal Generation | Reasoning Modalities | World Model | | | Logic & Math | | | Visual Perception | | | Overall | | |
|---|-------------------------|-------------|--------|------|--------------|--------|------|-------------------|--------|------|---------|--------|------|
| | | IR | Align. | Acc. | IR | Align. | Acc. | IR | Align. | Acc. | IR | Align. | Acc. |
| Closed-source Unified Models | | | | | | | | | | | | | |
| Nano Banana (Comanici et al., 2025) | Verb.+Vis. | 35.3 | 62.0 | 40.6 | 14.8 | 61.2 | 44.9 | 66.5 | 56.8 | 50.0 | 38.8 | 60.0 | 43.6 |
| | Verb. | - | - | 36.9 | - | - | 42.0 | - | - | 43.7 | - | - | 40.8 |
| Gemini 2.0 Flash (Comanici et al., 2025) | Verb.+Vis. | 27.1 | 46.7 | 35.6 | 11.4 | 47.9 | 30.4 | 49.5 | 46.8 | 43.0 | 29.3 | 47.1 | 36.3 |
| | Verb. | - | - | 33.2 | - | - | 32.6 | - | - | 39.8 | - | - | 35.2 |
| GPT-5 (Hurst et al., 2024) | Verb.+Vis. | 32.8 | 61.5 | 39.2 | 13.2 | 58.7 | 45.6 | 62.7 | 54.9 | 45.5 | 36.2 | 60.9 | 43.4 |
| | Verb. | - | - | 39.2 | - | - | 45.6 | - | - | 43.6 | - | - | 42.8 |
| Open-source Unified Models | | | | | | | | | | | | | |
| BAGEL-Think (Deng et al., 2025) | Verb.+Vis. | 22.3 | 34.7 | 26.6 | 10.8 | 36.9 | 24.6 | 31.2 | 44.3 | 34.1 | 21.4 | 38.6 | 28.4 |
| | Verb. | - | - | 24.9 | - | - | 23.1 | - | - | 32.2 | - | - | 26.7 |
| UniCoT (Liu et al., 2025b) | Verb.+Vis. | 22.1 | 35.4 | 26.7 | 10.6 | 38.8 | 21.7 | 34.2 | 42.3 | 34.1 | 22.3 | 38.8 | 27.5 |
| | Verb. | - | - | 24.6 | - | - | 21.7 | - | - | 33.5 | - | - | 26.7 |
| Qwen-2.5-VL-7B (Bai et al., 2025) | Verb. | - | - | 24.2 | - | - | 22.4 | - | - | 32.9 | - | - | 26.5 |
| Reasoning Language Models | | | | | | | | | | | | | |
| GPT-4.1 (Liu et al., 2025b) | Verb. | - | - | 37.8 | - | - | 31.8 | - | - | 37.9 | - | - | 35.8 |

Contents

- A Brief History of World Models
- Reasoning with World Models
- **Multimodal World Models and Human-like Reasoning**

Our Work

Formulation



We formalize:

- ✓ **Multimodal** world models
- ✓ **Atomic capabilities** of world models
- ✓ World model-based **CoTs**

Analysis



We analyze distinctions among different forms of world models from both **informativeness** and **knowledge** aspects.



The Visual Superiority Hypothesis

Task Suite



VisWorld-Eval

- ✓ **Necessitate** interleaved CoT
- ✓ **Isolate** specific atomic capabilities
- ✓ Spanning **synthetic** and **real** world

Empirical Evaluation -

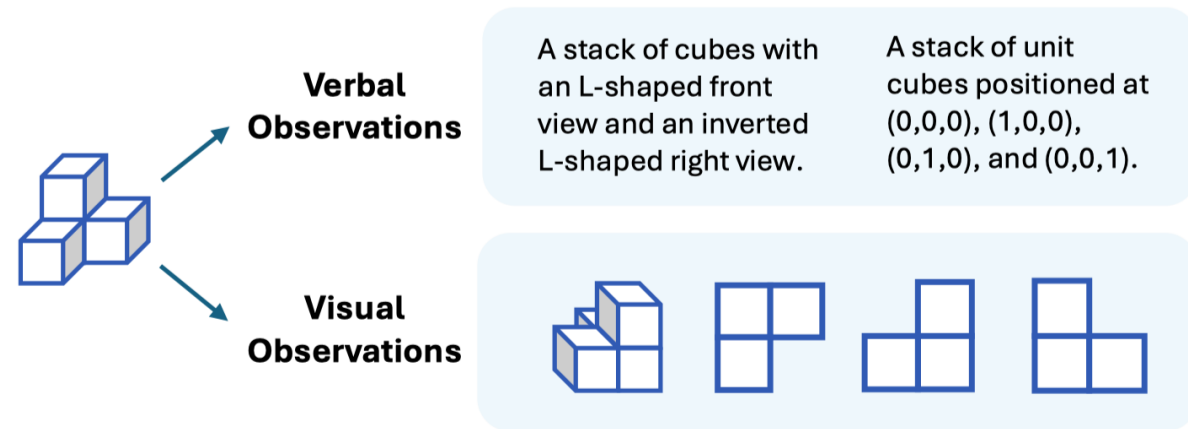


Controlled experiments on BAGEL

whose results are well explained by
and strongly support
the proposed insights

Formulation: Multiple Observations of the World

Underlying world states can be observed through **multiple modalities with different focus**.

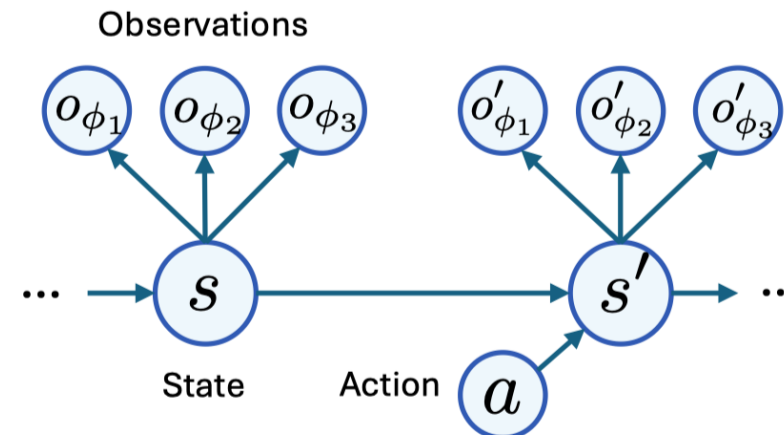


Multimodal world models
approximate MOMDP:

$$\mathcal{M} = (\mathcal{S}, \mathcal{A}, p, \Phi, \mathcal{O}_\phi, e_\phi)$$

different observations (views)
parameterized by ϕ

Multi-Observable Markov Decision Process



Formulation: Atomic Capabilities of World Models

World Reconstruction: reconstructing the environment structure from a few observations

Perception: $\hat{s} = \text{enc}(o_{\phi_1}, \dots, o_{\phi_n}) \approx s$

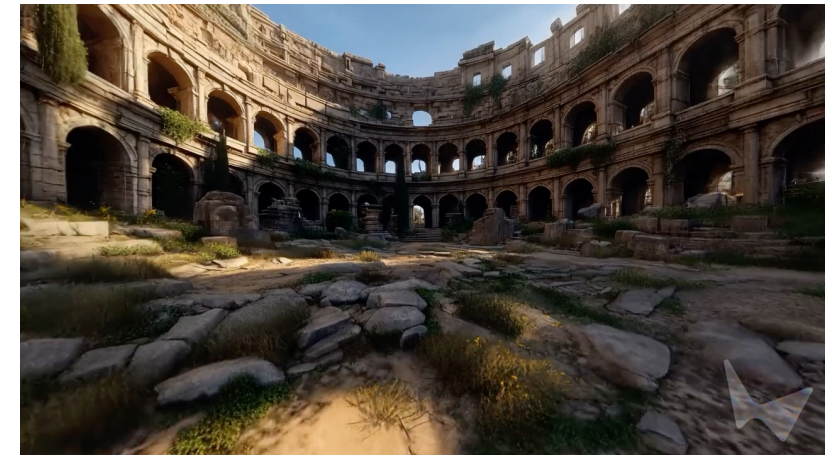
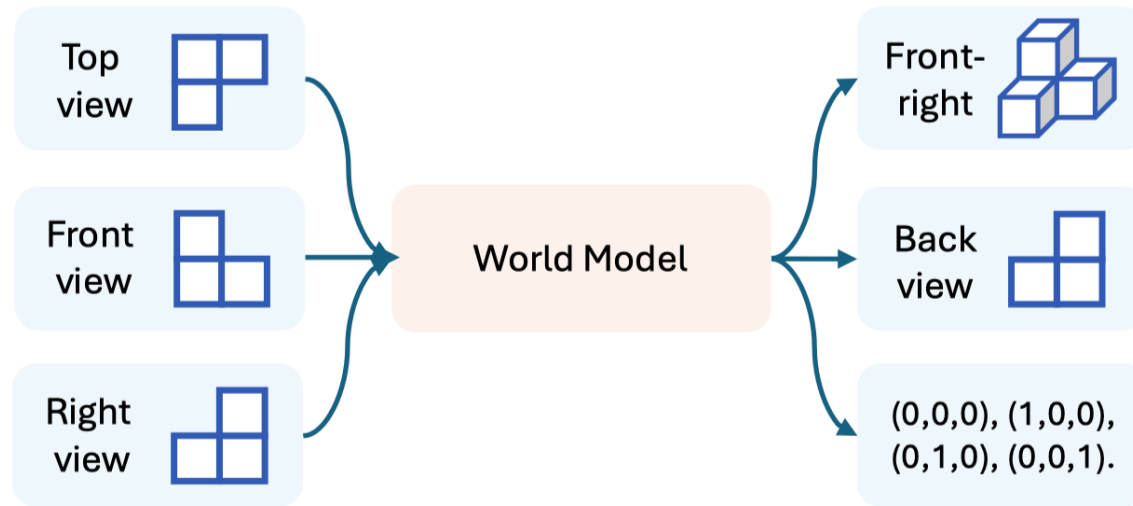
Decoding: $\hat{o}_{\phi_{n+1}} = \text{dec}(\hat{s}, \phi_{n+1}) \approx e_{\phi_{n+1}}(s)$

End-to-end



Novel view synthesis

$$p_{\theta}(o_{\phi_{n+1}} \mid o_{\phi_1}, \dots, o_{\phi_n})$$



Experience of **navigating** the world

Formulation: Atomic Capabilities of World Models

World Simulation: simulating how the world evolves into the future

Perception: $\hat{s} = \text{enc}(o_{\phi_1}, \dots, o_{\phi_n}) \approx s$

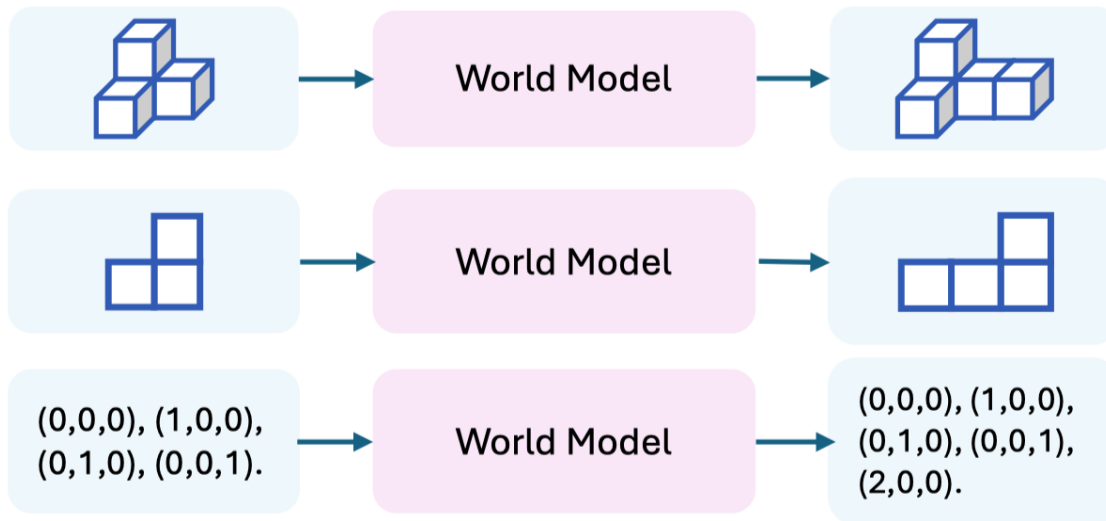
Prediction: $\hat{s}' \sim \text{pred}(\hat{s}, a)$

End-to-end



Future observation prediction

$$p_{\theta}(o_{t+1} \mid o_{\leq t}, a_{\leq t})$$



Experience of **interacting** with the world

Formulation: Reasoning with World Modeling

Chain-of-thought reasoning

$$R = \tau_1, \tau_2, \dots, \tau_H$$

Intermediate steps

Refine




Explicitly maintain **evolving observations**,
generated by **world modeling** capabilities,
as **evidence of reasoning**

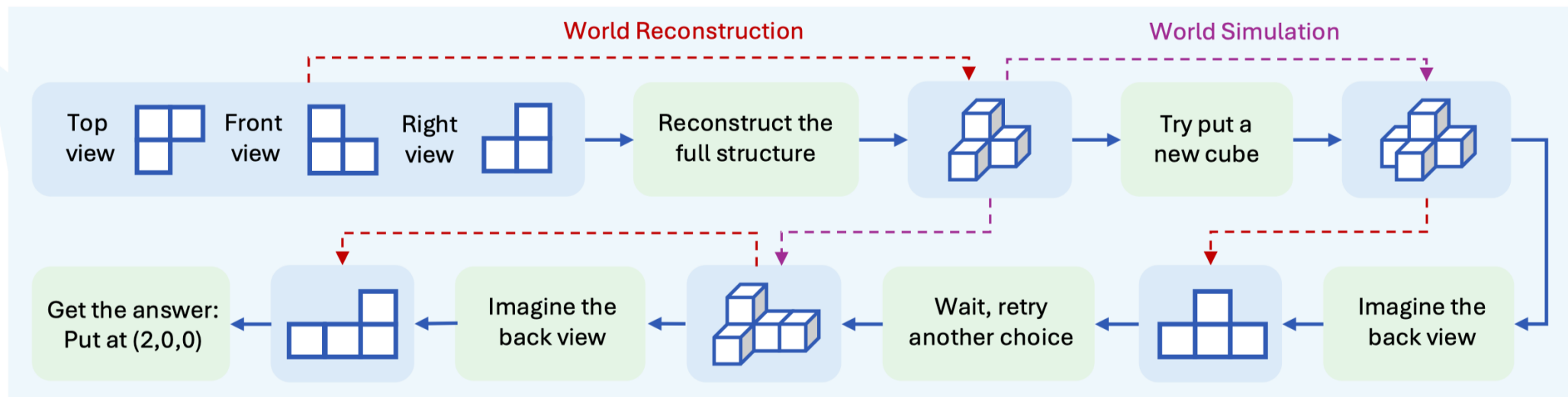
$$R = (\tau_1, o_1), (\tau_2, o_2), \dots, (\tau_H, o_H)$$

Logical reasoning step
(Not reward!)

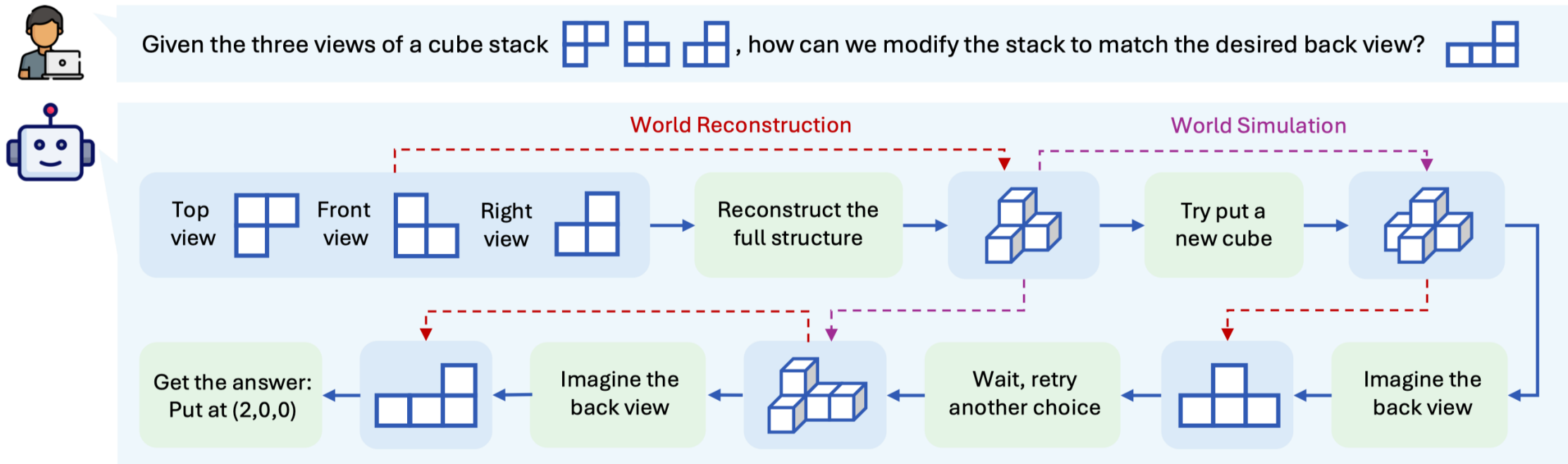
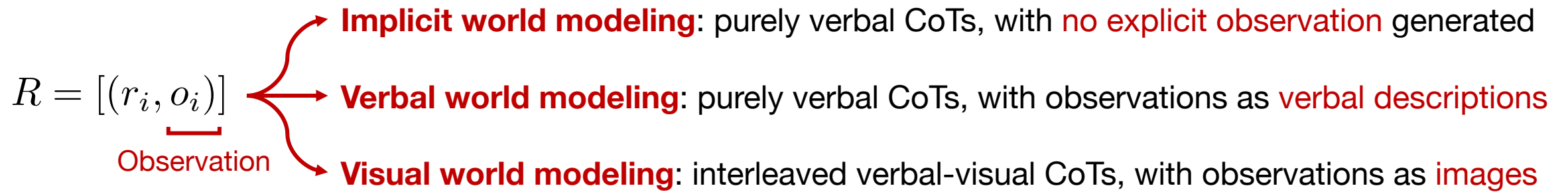
Observation



Given the three views of a cube stack   , how can we modify the stack to match the desired back view? 



Formulation: Reasoning with World Modeling



The Visual Superiority Hypothesis

Informativeness

(Information theoretical analysis)



Prior Knowledge

(Transfer learning analysis)



Verbal representations suffer from **ambiguity** and **representational bottlenecks**



Humans naturally **represent and communicate** certain knowledge visually



The Visual Superiority Hypothesis

In multimodal reasoning tasks grounded in the **physical world**, visual generation as a world model yields representations that are more **informative** and **knowledge-rich** than those produced by verbal world models.

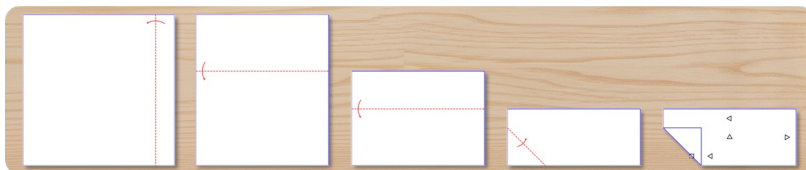
VisWorld-Eval Suite

VisWorld-Eval: Task Suite for Reasoning with Visual World Modeling

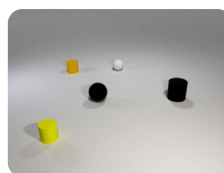
World Simulation

Paper Folding

Q: How many cutouts are there in the unfolded paper? A: 15

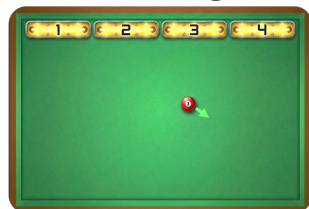


Multi-Hop Manipulation



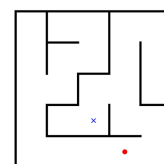
Q: Starting with the initial arrangement, perform the following:
1. Place a red cylinder to the left of the black cylinder.
2. Swap the colors of the orange cylinder and the black cylinder.
After these operations, what is to the left of the orange cylinder?
A. black sphere, B. white sphere, C. yellow cylinder, D. red cylinder.

Ball Tracking



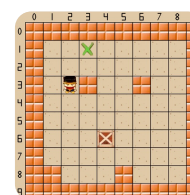
Q: Given a red point-mass ball that moves at constant speed, reflects perfectly off solid walls, and follows the initial direction indicated by a green arrow, determine which numbered hole at the top it will enter first. A: 1

Maze



Q: Navigate the maze from the red dot to the blue X.
A: (4, 5), (5, 5), (5, 4) ...

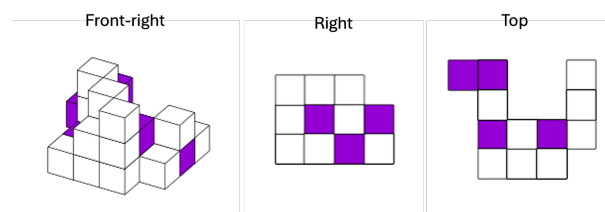
Sokoban



Q: Guide the player to push the box onto the goal position.
A: Down, Right, Down, ...

World Reconstruction

Cube 3-View Projection



Q: How many cubes in dark violet can possibly be seen from the back view?
A. 0, B. 2, C. 3, D. 9.

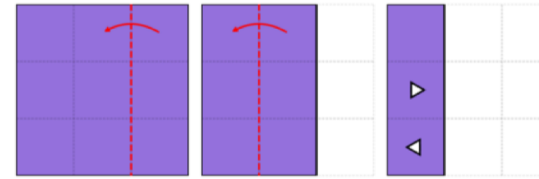
Real-World Spatial Reasoning



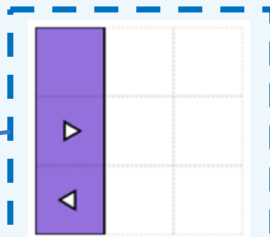
Q: Which direction is the black door relative to me when I am taking Image 2?
A. Behind, B. Left, C. Front, D. Right

SFT Data for Controlled Comparative Evaluations

Question: An image shows a sheet of paper that has been folded, with some shapes cut out in its final folded state. Unfold the paper step by step to determine the final pattern when fully opened. Then, answer the question: how many triangle_left cutouts are there in the unfolded paper?



Response: <think> Let's first enlarge the top-rightmost image that shows the cutting pattern on the folded paper.



```
[[0, -1, -1],  
[1, -1, -1],  
[1, -1, -1]]  
  
[['', '', ''],  
['triangle_right', '', ''],  
['triangle_left', '', '']]  
...
```

Verbal World Modeling

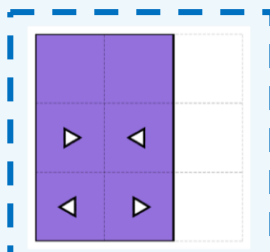
Implicit World Modeling

Let's systematically, step by step, to reveal the final appearance of the completely unfolded paper. And then answer the question accordingly. Let's trace the process of unfolding the paper step by step, beginning with the most recent fold.

First, we will reverse the second fold. This was a vertical fold where the right side of the paper was folded over the left. To undo this, we unfold the paper from left to right, using the vertical line between column 0 and column 1 as the axis of reflection. Any shapes on the top folded layer (column 0) will be mirrored into the newly revealed column 1. Let's trace this reflection:

- The 'triangle_right' at position (1, 0) is reflected across the vertical axis. This creates a mirrored shape at (1, 1). The horizontal flip inherent in this reflection transforms the 'triangle_right' into a 'triangle_left'.
- Likewise, the 'triangle_left' at (2, 0) is reflected to position (2, 1). The horizontal flip transforms this 'triangle_left' into a 'triangle_right'.

After this step, the original shapes remain in column 0, and their mirror images now occupy column 1.



```
[[0, 0, -1],  
[1, 1, -1],  
[1, 1, -1]]  
  
[['', '', ''],  
['triangle_right', 'triangle_left', ''],  
['triangle_left', 'triangle_right', '']]  
...
```

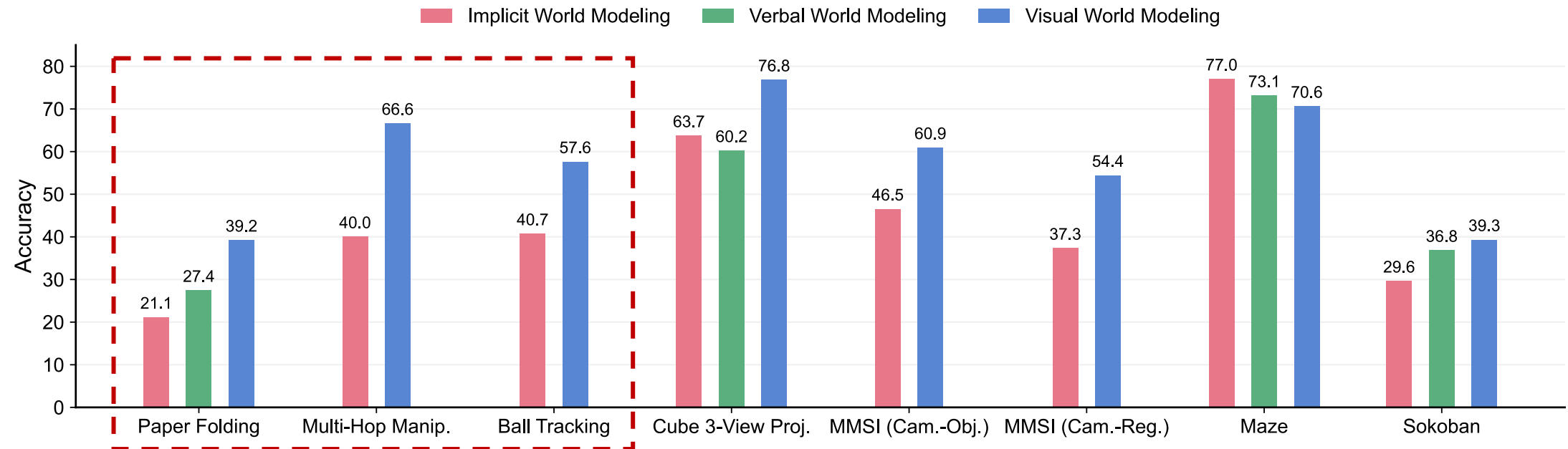
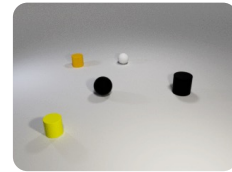
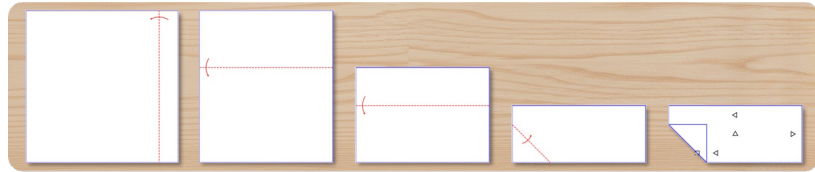
Visual World Modeling

SFT



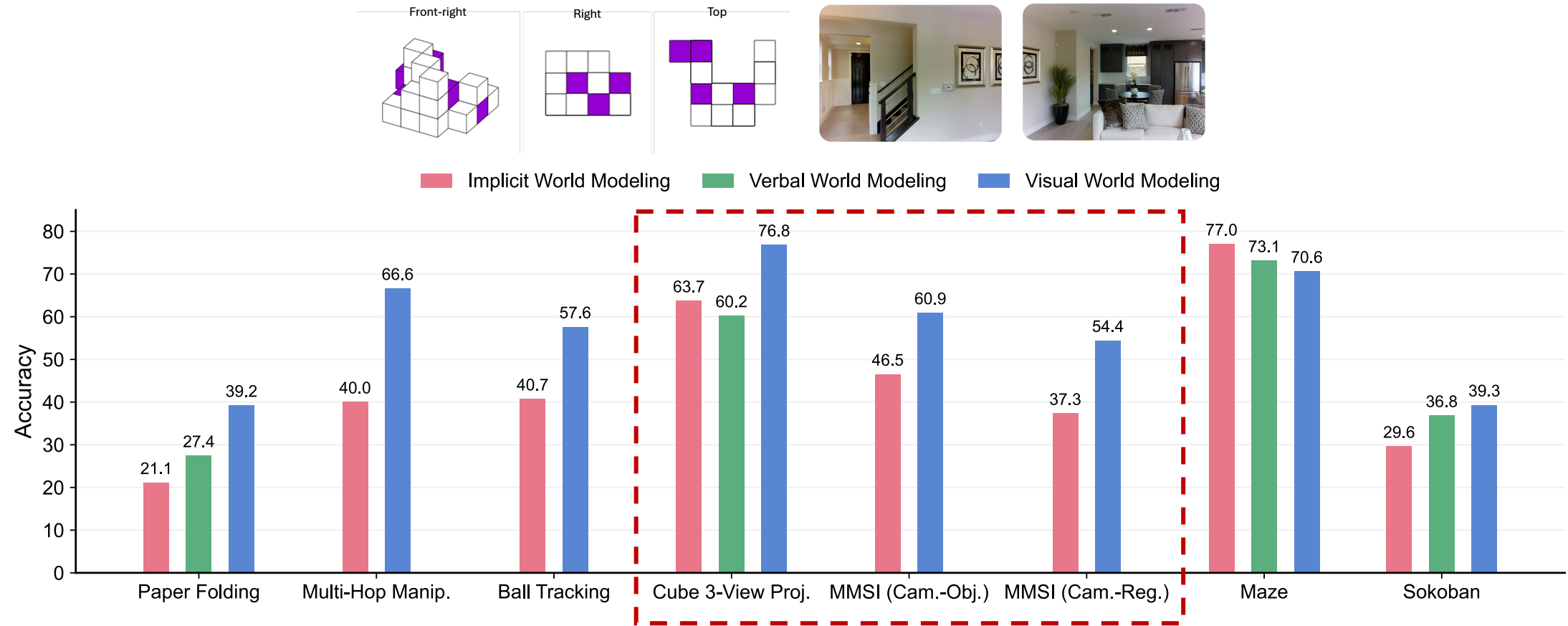
 **BAGEL**

Visual World Modeling Boosts Multimodal Reasoning



**Visual World Simulation
Boosts Multimodal Reasoning**

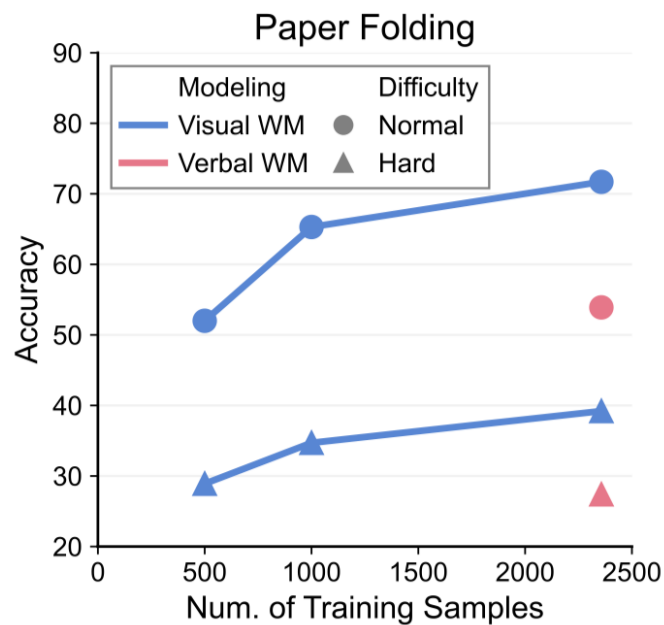
Visual World Modeling Boosts Multimodal Reasoning



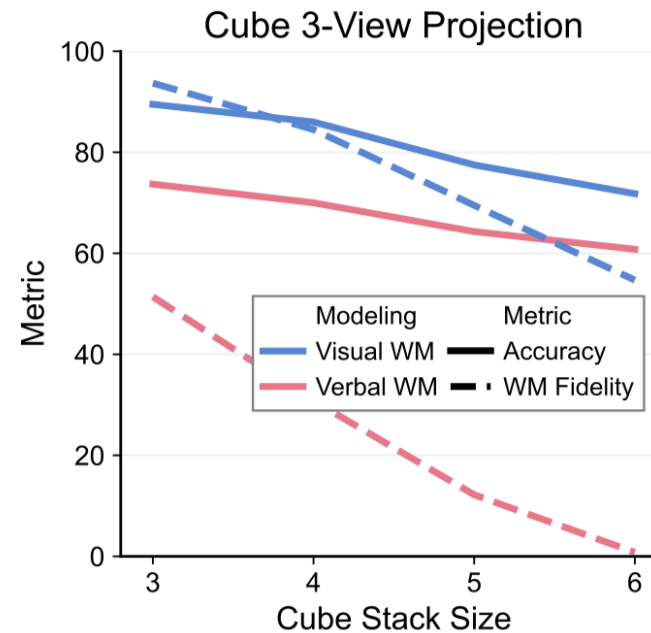
**Visual World Reconstruction
Boosts Multimodal Reasoning**

Visual World Modeling Boosts Multimodal Reasoning

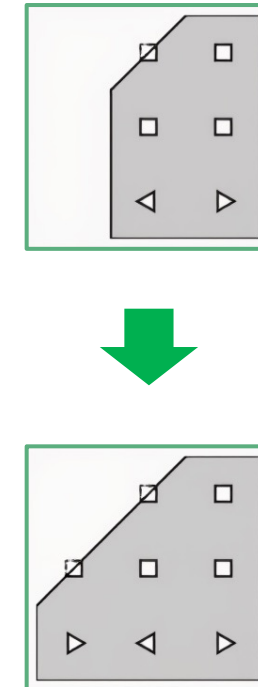
Better Sample Efficiency & World Model Fidelity



(a) Sample efficiency.

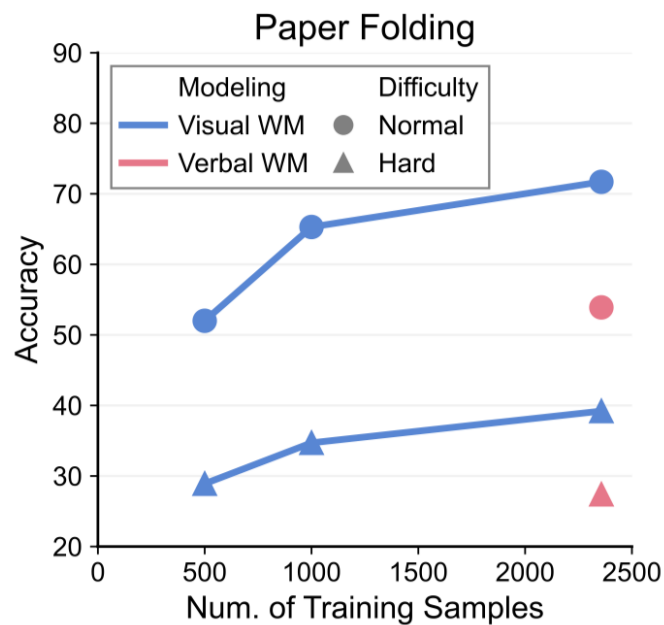


(b) World model fidelity.

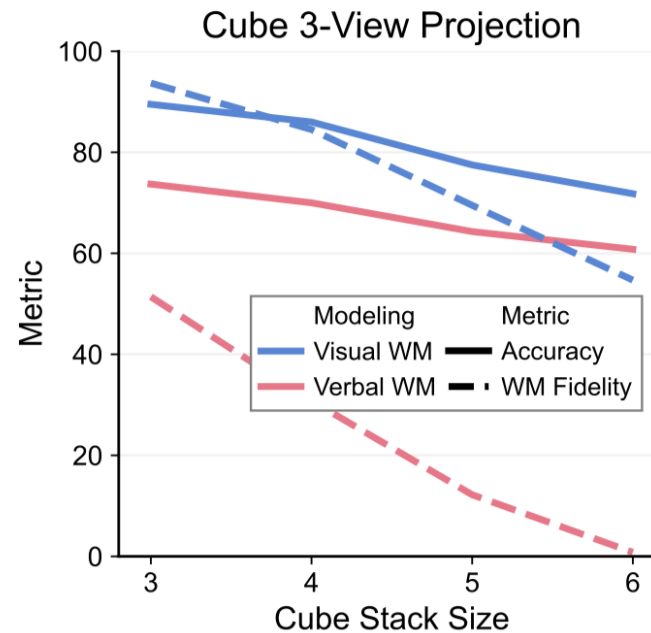


Visual World Modeling Boosts Multimodal Reasoning

Better Sample Efficiency & World Model Fidelity



(a) Sample efficiency.



(b) World model fidelity.

```
...  
[[-1, -1, -1],  
 [-1, 1, 1],  
 [-1, 1, 1]]  
  
[['', '', ''],  
 ['', 'diamond', 'diamond'],  
 ['', 'triangle_left', 'triangle_right']]  
...  
  
...  
[[-1, 1, 1],  
 [-1, 1, 1],  
 [-1, 1, 1]]  
  
[['', 'triangle_down', 'triangle_right'],  
 ['', 'diamond', 'diamond'],  
 ['', 'triangle_left', 'triangle_right']]  
...
```

Showcases: Generated Interleaved CoTs

Real-World Spatial Reasoning

When you took the photo in Figure 1, where was the iron refrigerator located relative to you?



<think>First, let's analyze the images. [...] It's not visible in that initial view, so I need to change my perspective.



The refrigerator is not visible in this 90-degree left turn view, [...] To be thorough, I will also check the view to the right.



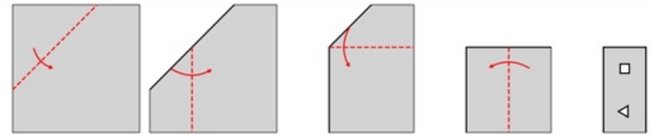
[...] My initial turn was 90 degrees left, but the refrigerator isn't at that exact angle. Let's try a smaller turn to the left.



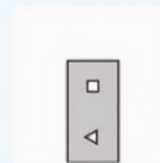
[...]

Paper Folding

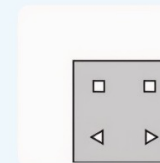
Analyze the image showing a folded paper with cutouts, calculate the number of triangle-left minus the number of triangle-right.



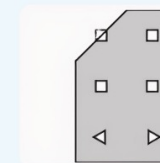
<think>First, zoom into the upper section's rightmost image [...]



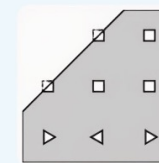
First, we will reverse the fourth and final fold. This was a vertical fold where [...]



Next, we reverse the third fold. [...]



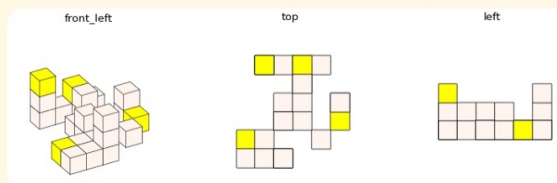
Continuing the process, we now undo the second fold. This was a vertical fold where [...]



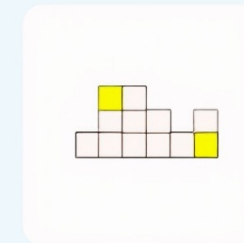
[...]

Cube 3-View Projection

How many cubes in yellow can possibly be seen from the front view? A. 2. B. All three other options are possible. C. 4. D. 1.

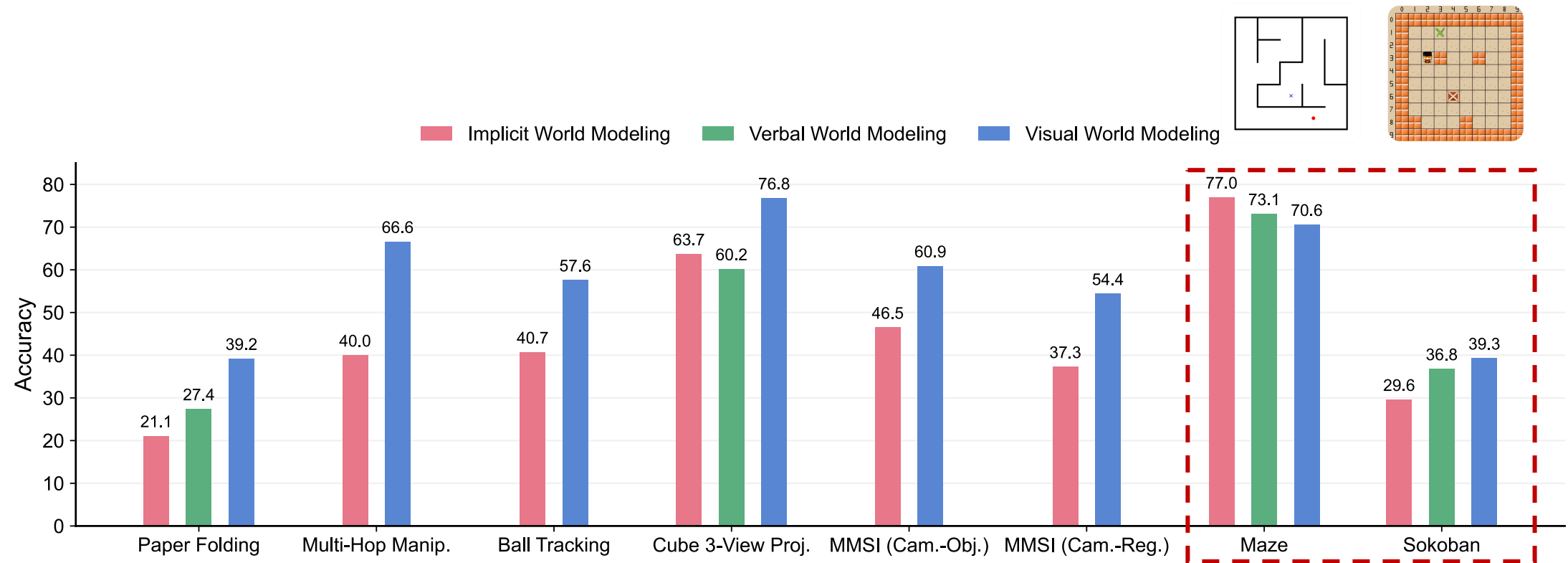


<think>To determine the number of yellow cubes visible from the front, we first need to construct the front view of the stack. By synthesizing the provided isometric, top, and left views, we can generate the required front view.



Examining the generated front view, we can directly count the number of visible yellow cubes. There are 2 yellow cubes visible. Therefore, the correct answer is 2, which corresponds to option A.</think> A

Visual World Modeling is **Unhelpful** for Certain Tasks



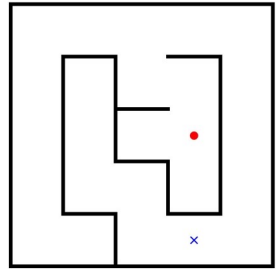
$$\mathbb{I}(o_{1:i-1}; r_i | o_0, r_{0:i-1}) \leq \min(\mathbb{I}(o_{1:i-1}; s_{1:i-1}), \mathbb{I}(r_i; s_{0:i-1}, r_{0:i-1}))$$

**(Un)surprisingly,
How to explain?**

Informativeness: Verbal state tracking alone is sufficient.

Knowledge: Discrete coordinates are commonly adopted.

Visual World Modeling is **Unhelpful** for Certain Tasks

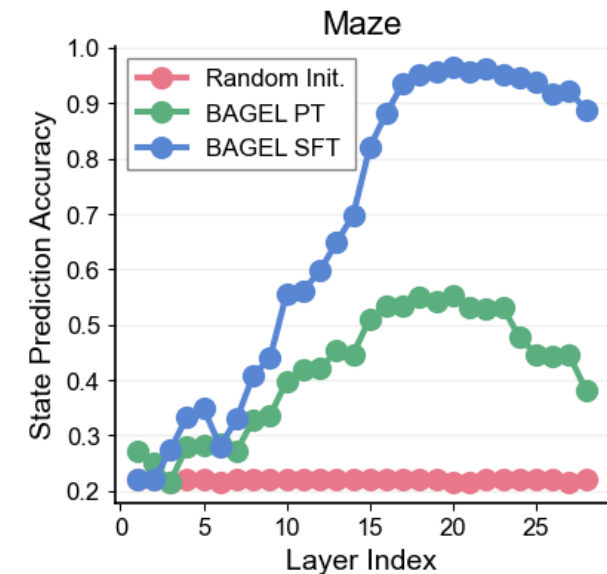
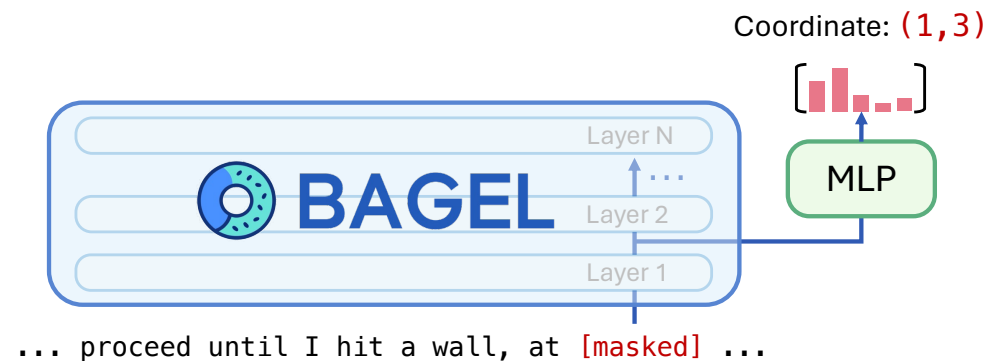


...From my new position at `<point>masked</point>`, the top is the maze boundary, the right is blocked by a wall, and the left is the direction I just came from. My only option is to go down. I will follow this path until I reach `<point>masked</point>`, where another wall blocks further downward movement. ...

SFT
➔

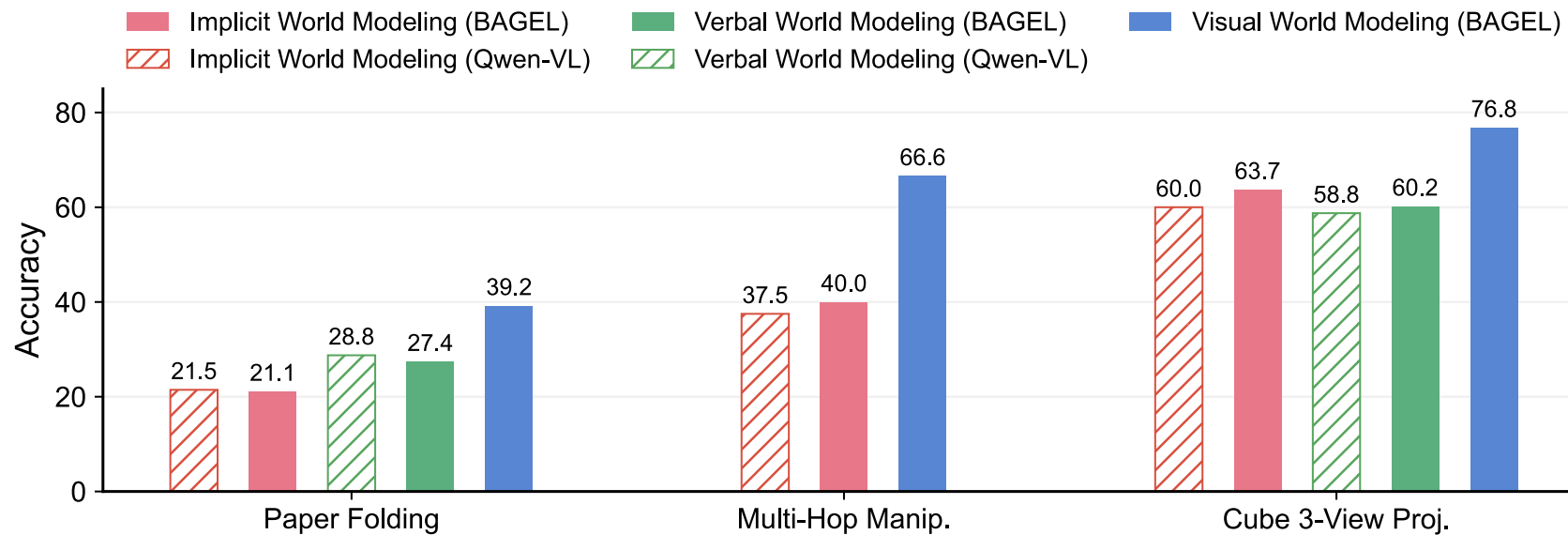


Probing Internal World Representations



Do UMMs Compromise Verbal Reasoning Capabilities?

UMMs are typically trained with a stronger emphasis on visual generation

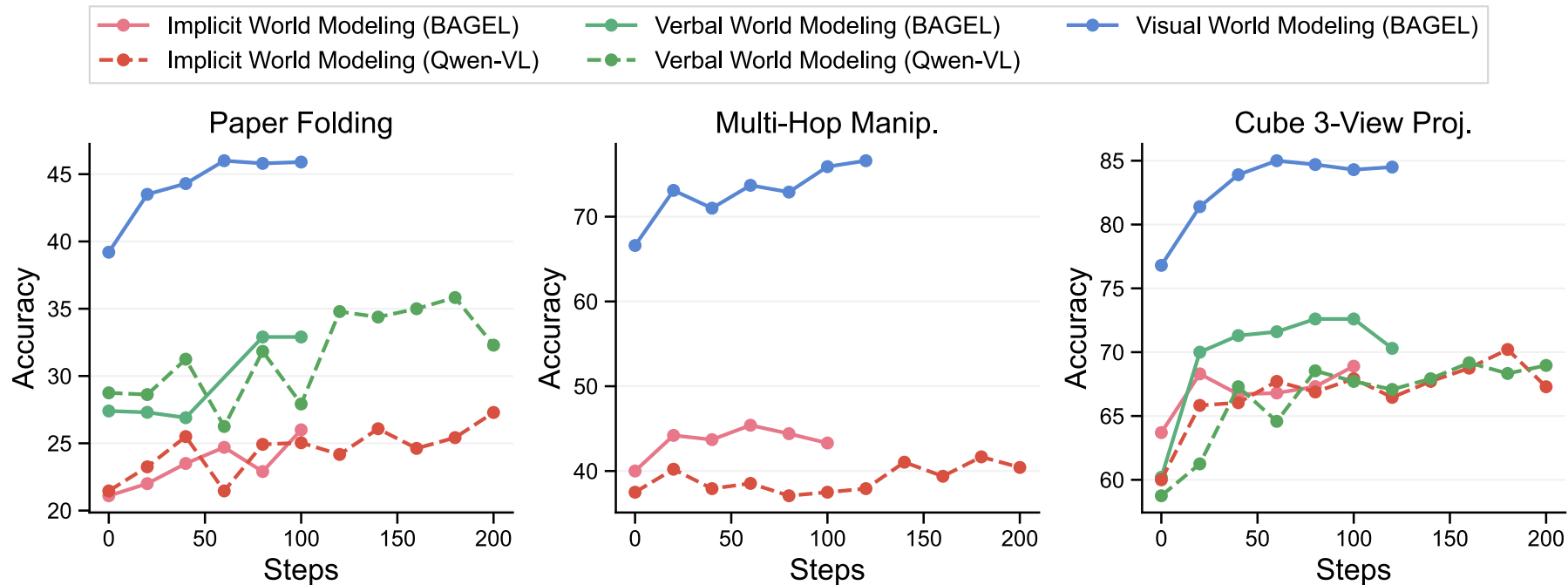


Comparison with Qwen2.5-VL-7B (same Qwen2.5 LLM base with BAGEL):
Still lags behind BAGEL leveraging visual world modeling

RL Enhances Various CoTs, Yet Does Not Close the Gap

$$\mathcal{J}_{\theta}(Q, I) = \mathbb{E}_{o, r \sim p_{\theta_{\text{old}}}} \left[\sum_{i=1}^{H+1} \sum_{j=1}^{|r_i|} \left(\min \left(\frac{p_{\theta}(r_{i,j} \mid r_{i,<j}, R_i)}{p_{\theta_{\text{old}}}(r_{i,j} \mid r_{i,<j}, R_i)} A, \text{clip} \left(\frac{p_{\theta}(r_{i,j} \mid r_{i,<j}, R_i)}{p_{\theta_{\text{old}}}(r_{i,j} \mid r_{i,<j}, R_i)}, 1 - \varepsilon, 1 + \varepsilon \right) A \right) \right. \right. \\ \left. \left. - \sum_{i=1}^H \mathbb{E}_{t, \epsilon} \left\| v_{\theta}(o_i^t, t \mid \tilde{R}_i) - v_{\theta_{\text{ref}}}(o_i^t, t \mid \tilde{R}_i) \right\|_2^2 \right] . \quad (7)$$

Visual generation
are currently not
optimized by RL



Summary

A perspective on:

Q1. What is **multimodal world models** and why do we need it?

A: Inspired by human cognition with dual representations of the world

Q2. When and how does **visual generation benefit reasoning**?

A: Physical AI that thinks and acts in the physical world should be equipped with visual world models.

