What good is the world in your head?

Readings for today

- Ha, D., & Schmidhuber, J. (2018). World models. arXiv preprint arXiv:1803.10122.

Topics

- World models
- The utility of dreaming

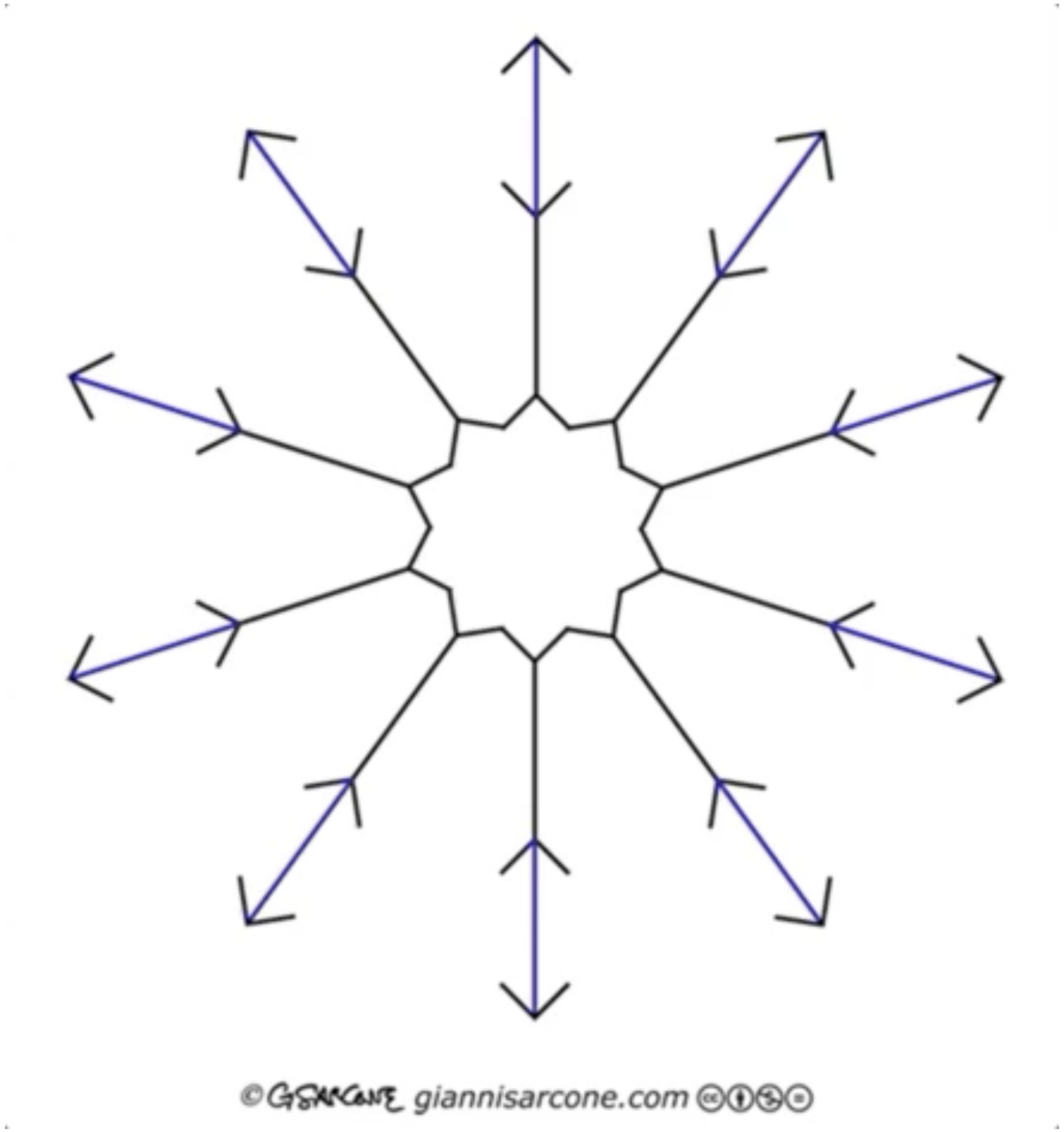
World models

Is seeing really believing

Question: Do we perceive the world as it is?

Illusion: Müller-Lyer Illusion

- The line segments all appear to changes size.
- The segments, in fact, stay the same length.

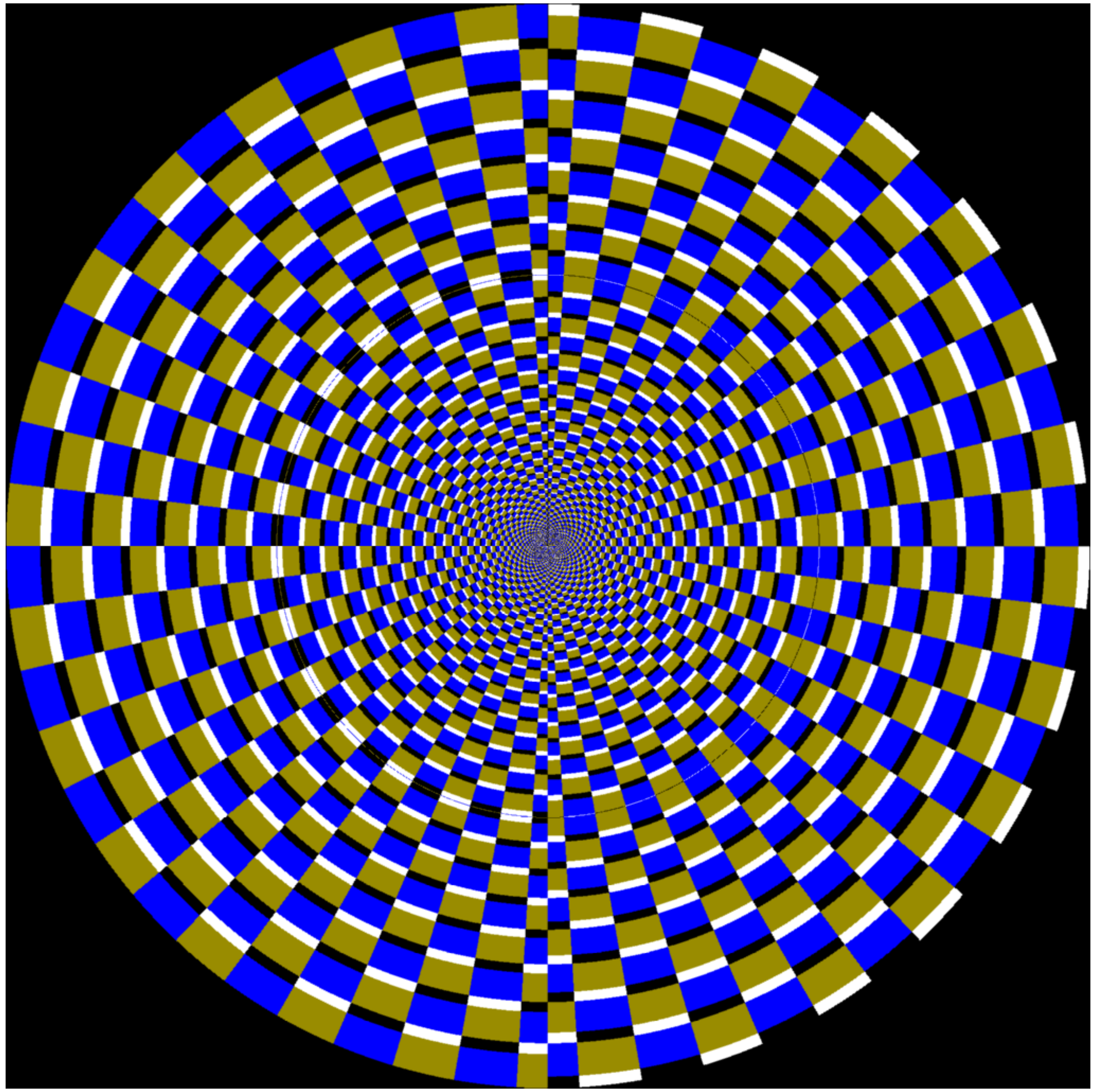


Is seeing really believing

Question: Do we perceive the world as it is?

Illusion: Peripheral Drift Illusion

- Static image.
- Perception of motion is in direction of dark-to-light contrast.



Source: Wikipedia

A matter of perspective

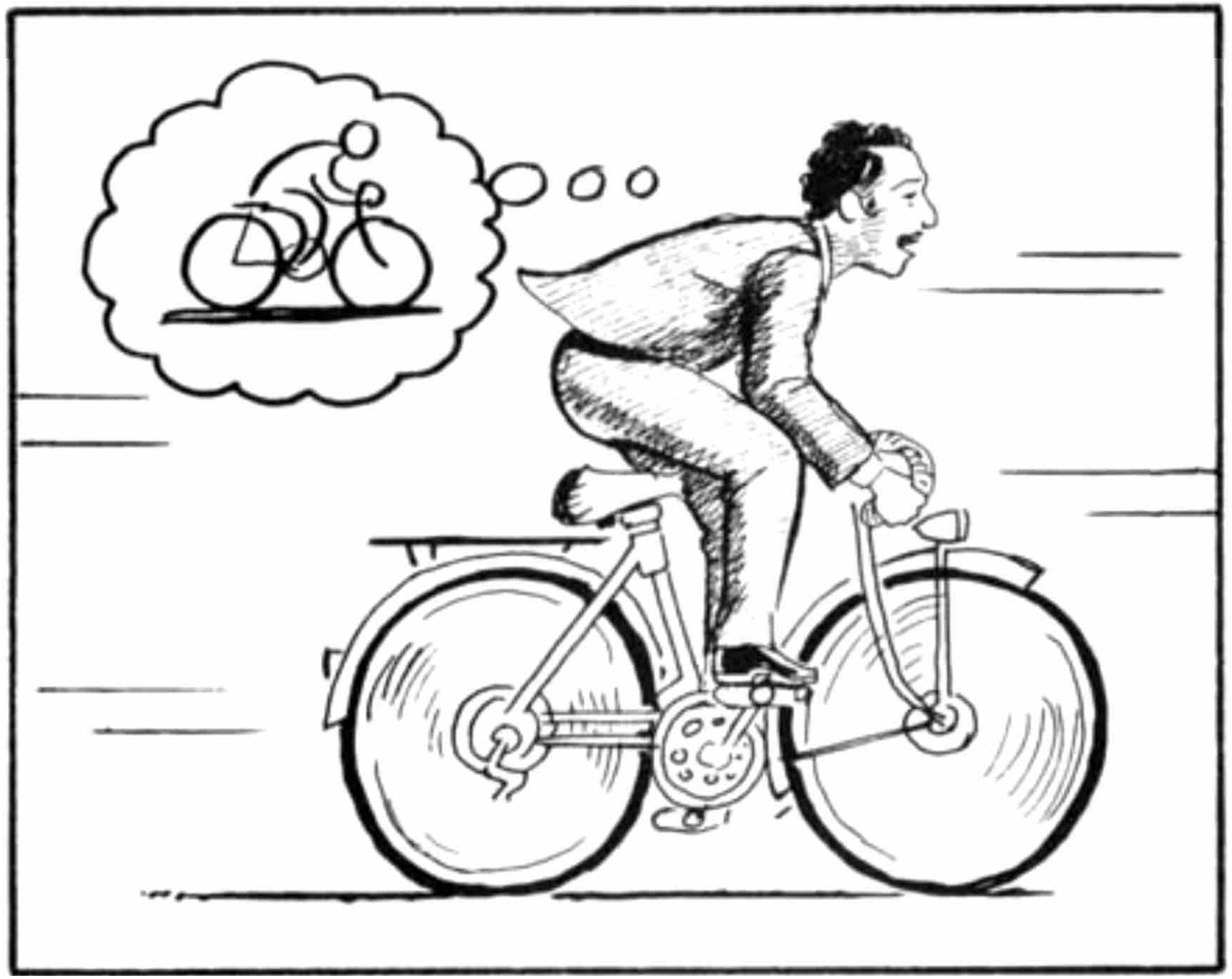
<u>Question</u>: Does the head follow you?

<u>Illusion</u>: Framing

- We assume consistent geometric relations of objects based on relative orientation.
- Invariance leads to <u>*assumptions*</u> of 3d shape.

https://imgur.com/INY1RBd

World models



“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.” - Forrester, 1971

(Ha & Schmidhuber, 2018)

Why have world models?

Pros:

- Fast information processing.
- Reduces computational burden of processing sensory information.
- Overcomes sensory lags.
- Builds predictions that increase speed (and hopefully accuracy) of responses.

Cons:

- Abstraction = ↓accuracy
- Actions based on faulty models will be faulty.
- Can't act on information not incorporated in the model.

The utility of dreaming

What if we give an AI a world model?

At each time step, our agent receives an **observation** from the environment.

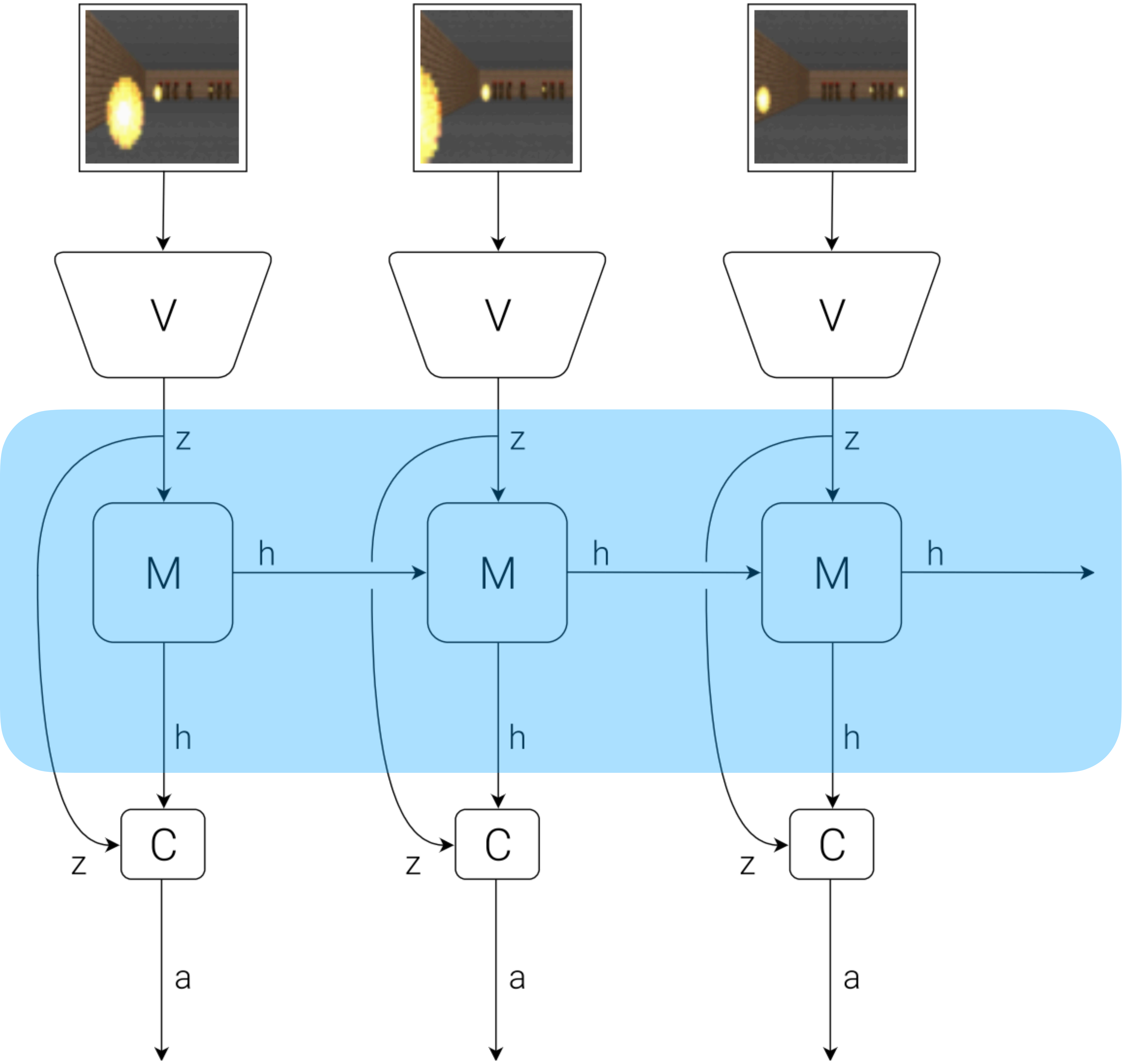
World Model

The **Vision Model (V)** encodes the high-dimensional observation into a low-dimensional latent vector.

The **Memory RNN (M)** integrates the historical codes to create a representation that can predict future states.

A small **Controller (C)** uses the representations from both **V** and **M** to select good actions.

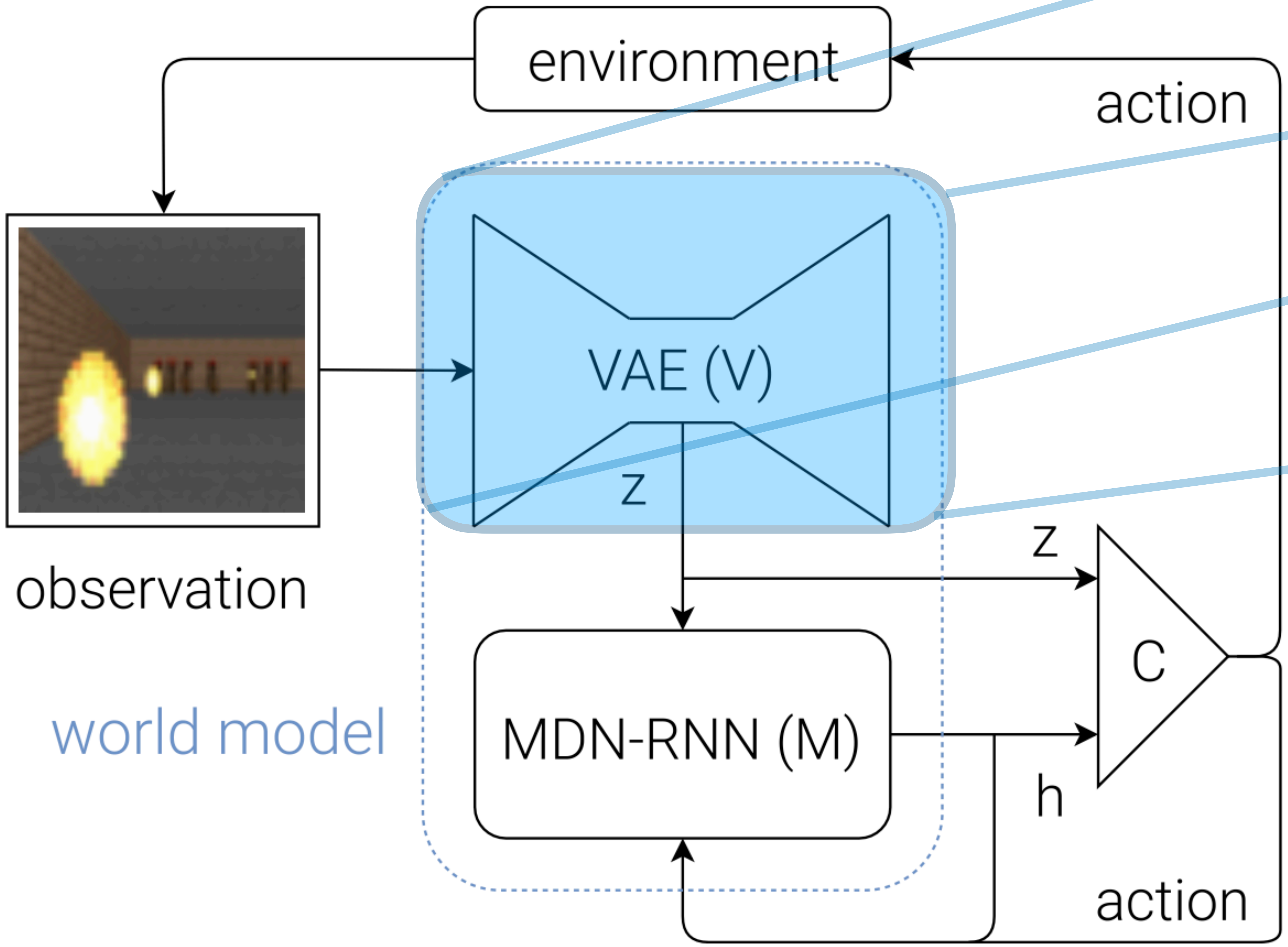
The agent performs **actions** that go back and affect the environment.

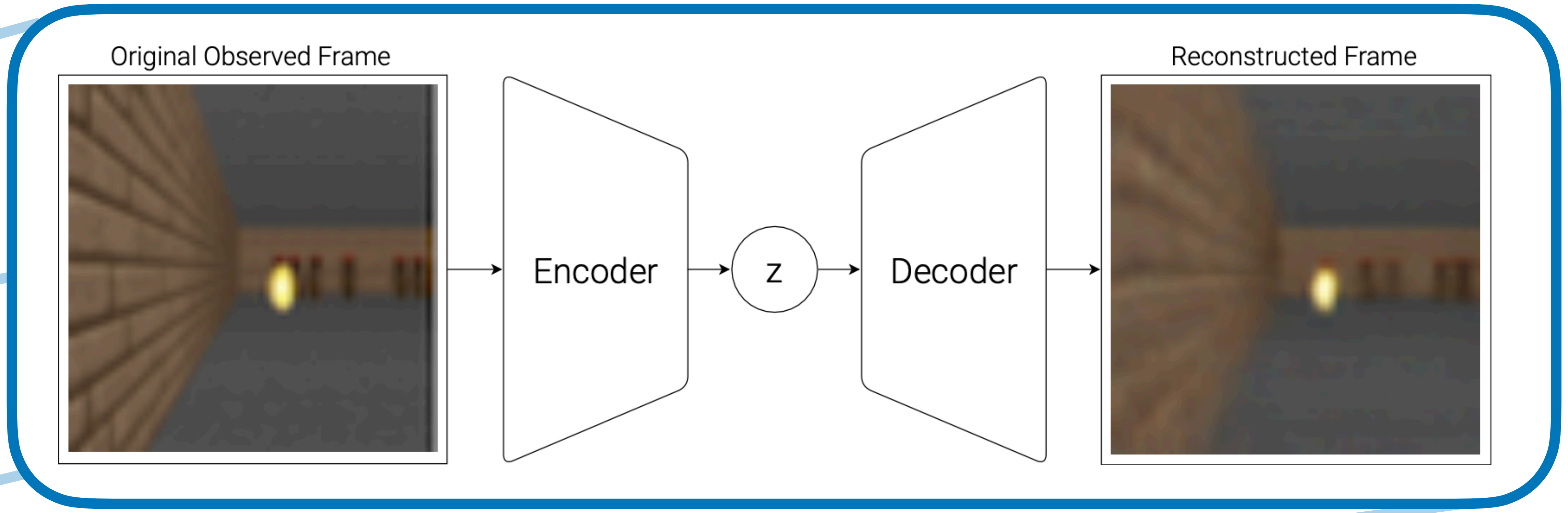


The world model

(Ha & Schmidhuber, 2018)

The ghost in the machine



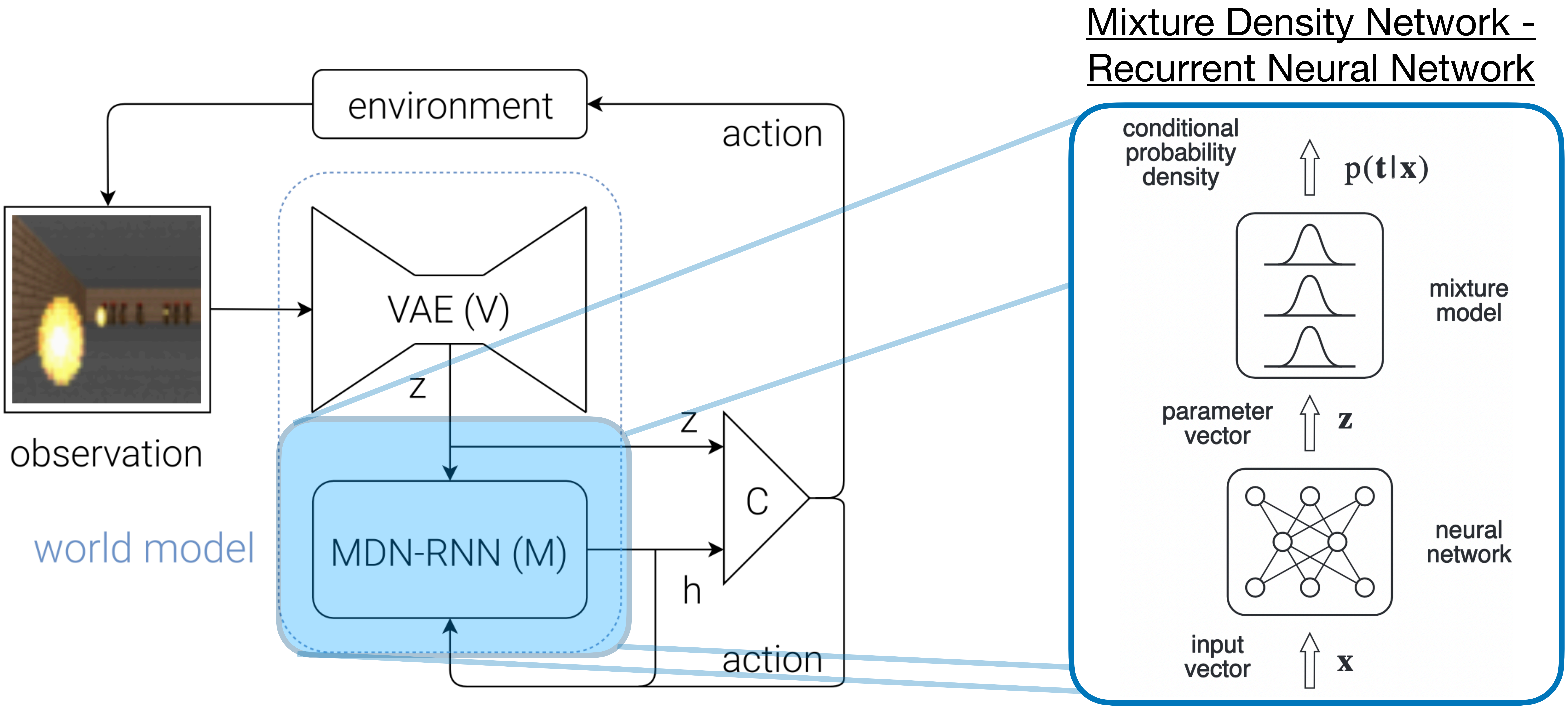


<u>Variational Autoencoder (VAE)</u>:

Find the low dimensional structure (z) of an input.

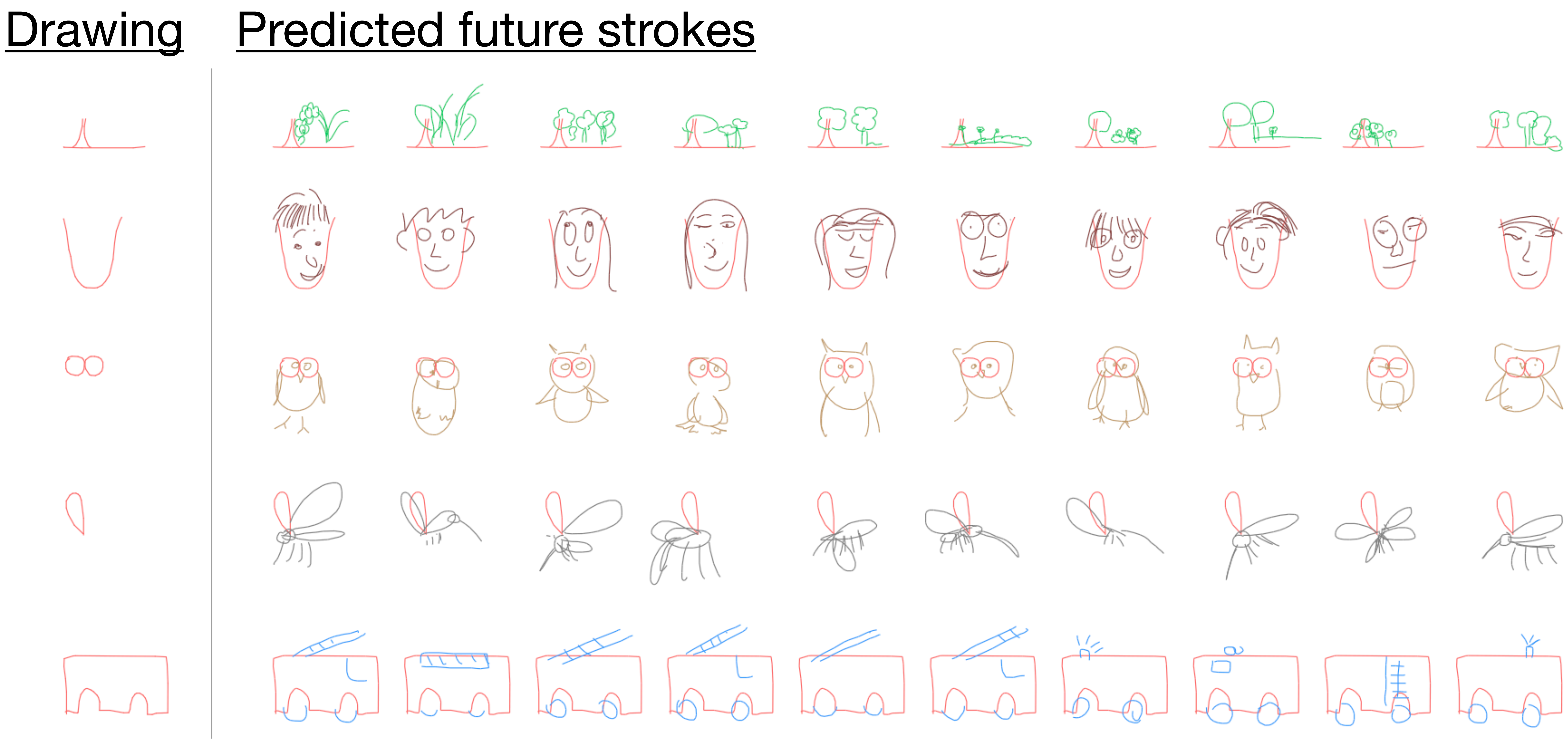
(Ha & Schmidhuber, 2018)

The ghost in the machine



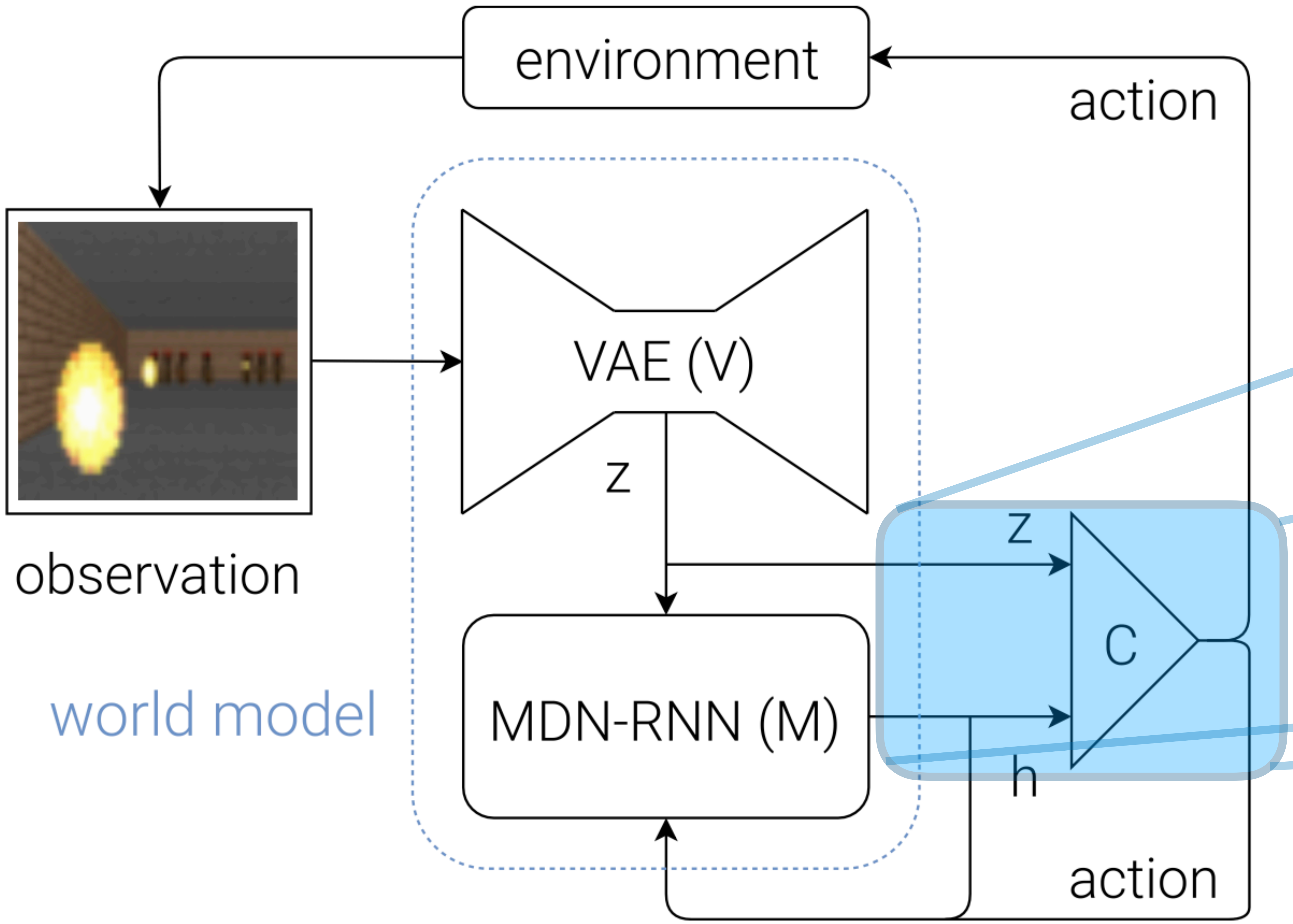
(Ha & Schmidhuber, 2018, Bishop, 1994)

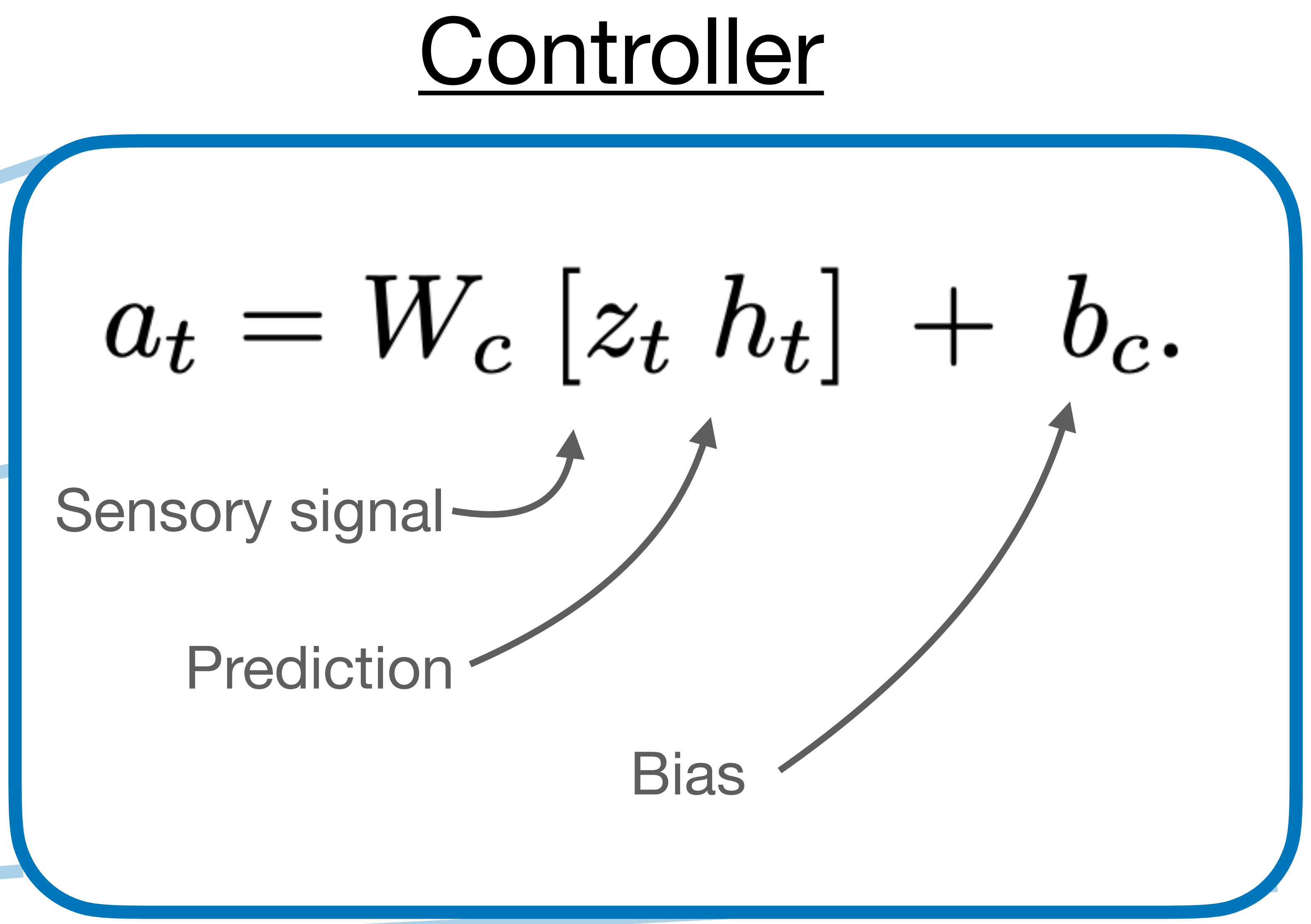
MDN-RNN: predicting the future



(Ha & Eck, 2017)

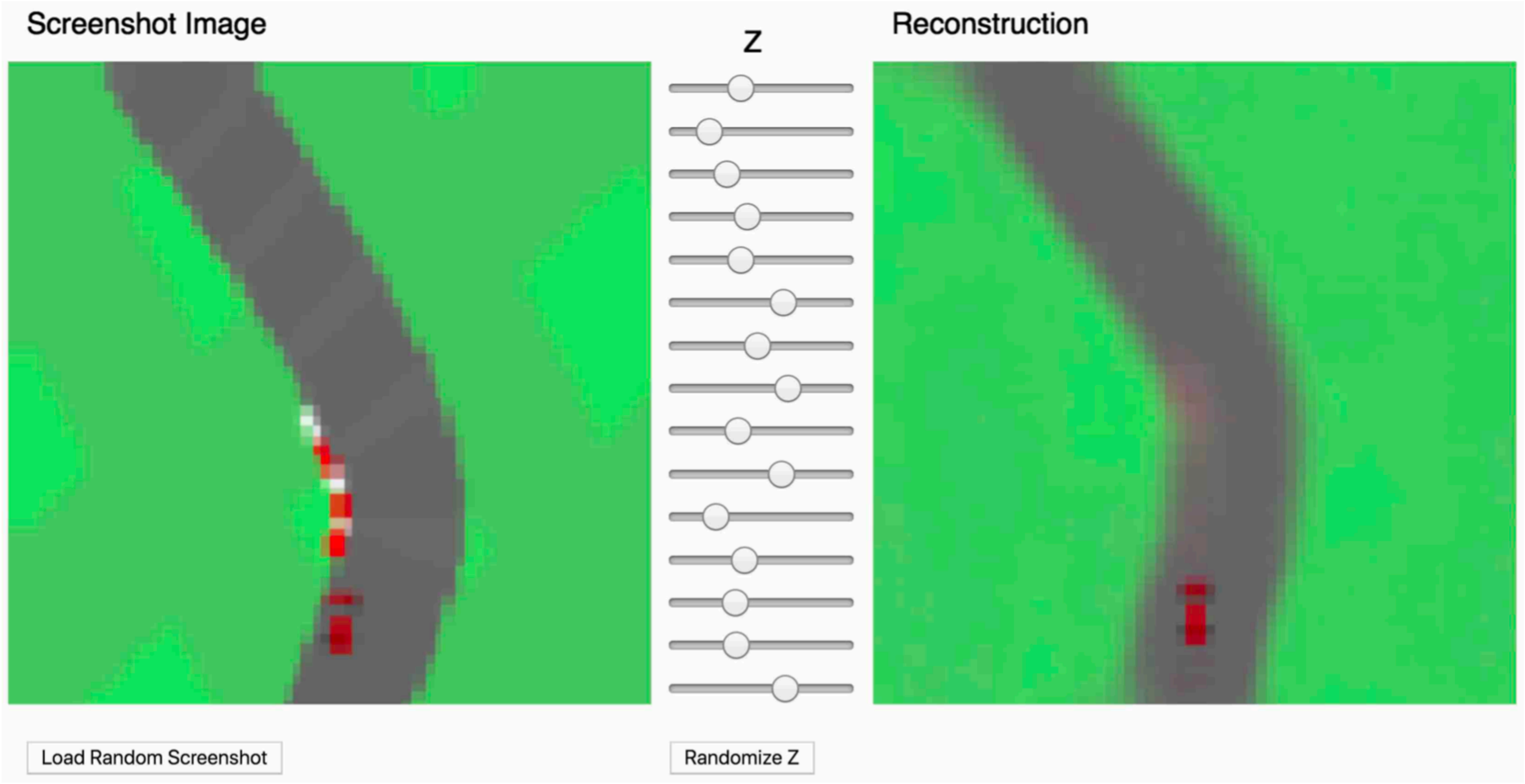
The ghost in the machine





(Ha & Schmidhuber, 2018)

Predicting future sensory signals

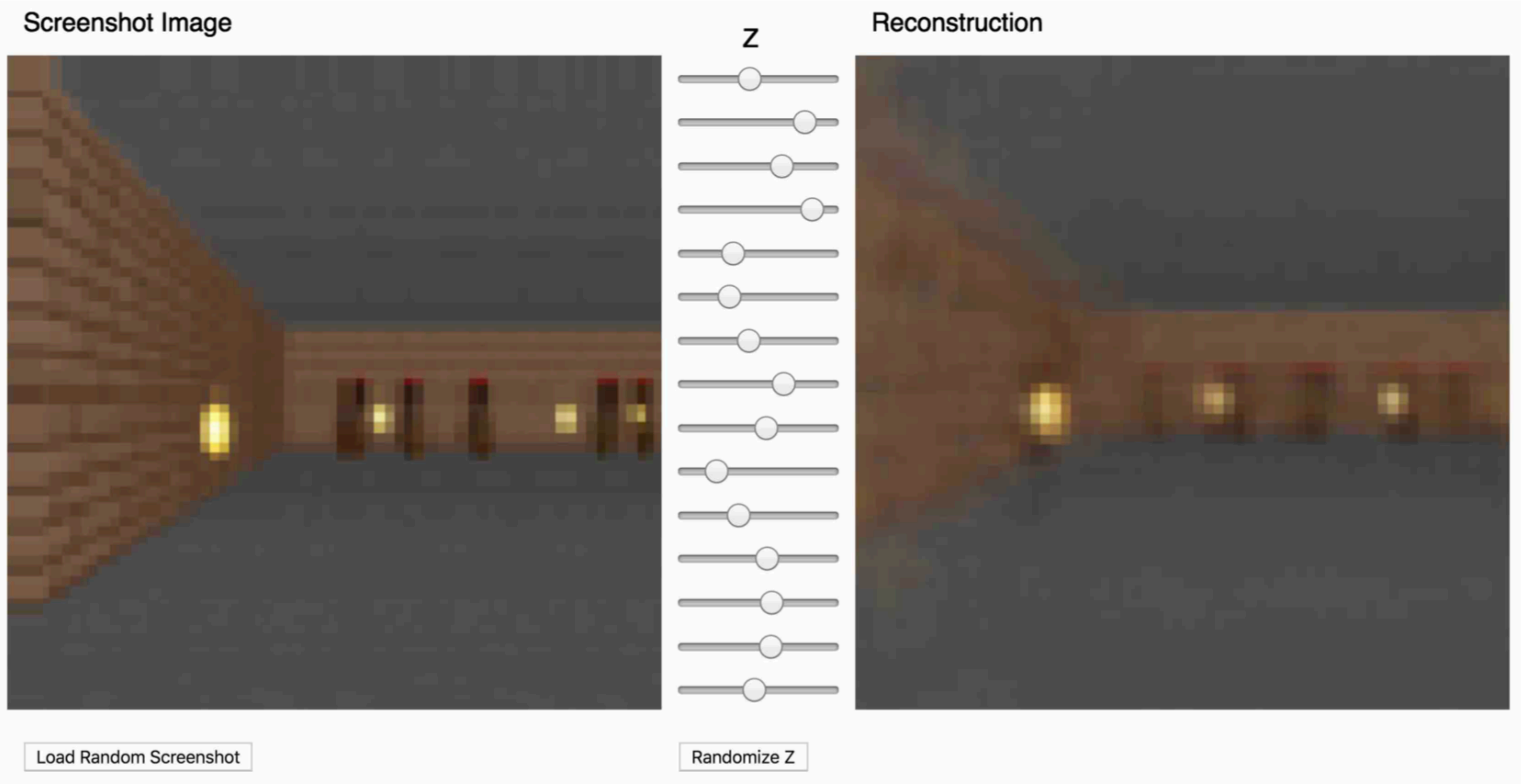


Model	Parameter Count
VAE	4,348,547
MDN-RNN	422,368
Controller	867

Method	Avg. Score
DQN (Prieur, 2017)	343 ± 18
A3C (continuous) (Jang et al., 2017)	591 ± 45
A3C (discrete) (Khan & Elibol, 2016)	652 ± 10
ceobillionaire (Gym Leaderboard)	838 ± 11
V model	632 ± 251
V model with hidden layer	788 ± 141
Full World Model	$\mathbf{906 \pm 21}$

(Ha & Schmidhuber, 2018)

Learning only from your dreams



MODEL	PARAMETER COUNT
VAE	4,446,915
MDN-RNN	1,678,785
CONTROLLER	1,088

Goal: • Avoid the fireballs.

Training:

1. Collect 10,000 rollouts from a random policy.
2. Train VAE (V) to encode each frame into a latent vector $z \in \mathcal{R}^{64}$, and use V to convert the images collected from (1) into the latent space representation.
3. Train MDN-RNN (M) to model $P(z_{t+1}, d_{t+1} \mid a_t, z_t, h_t)$.
4. Define Controller (C) as $a_t = W_c \, [z_t \; h_t]$.
5. Use CMA-ES to solve for a W_c that maximizes the expected survival time inside the virtual environment.
6. Use learned policy from (5) on actual environment.

(Ha & Schmidhuber, 2018)

In your dreams!

τ: Randomness of internal simulations ("dreams")

Temperature τ	Virtual Score	Actual Score
0.10	2086 ± 140	193 ± 58
0.50	2060 ± 277	196 ± 50
1.00	1145 ± 690	868 ± 511
1.15	918 ± 546	1092 ± 556
1.30	732 ± 269	753 ± 139
Random Policy	N/A	210 ± 108
Gym Leader	N/A	820 ± 58

Virtual Score:

Performance of agent in the internal simulations

Actual Score:

Performance of agent when playing the actual game

Increasing randomness of the dreams impaired performance in the dream, but improved performance in the external world.

(Ha & Schmidhuber, 2018)

Take home message

- Our perception of the world is mostly driven by internal models.
- These internal world models help for robust and effective learning in complex environments.

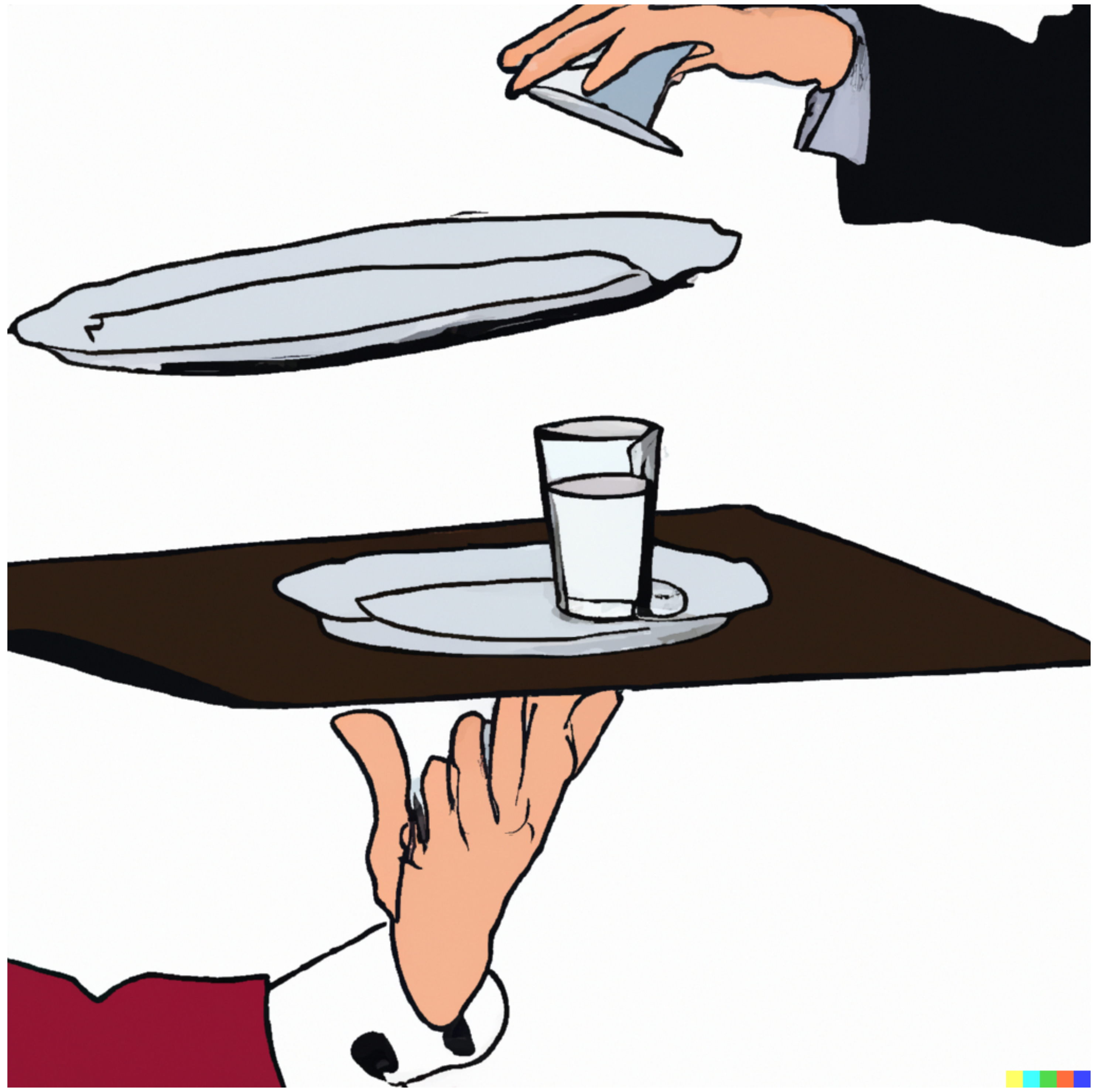
Beyond the senses

Setup:
- Teams of 3.
- Grab one of the books.
- Determine roles:

  Person A: Holds the book in one hand.

  Person B: Designated lifter.

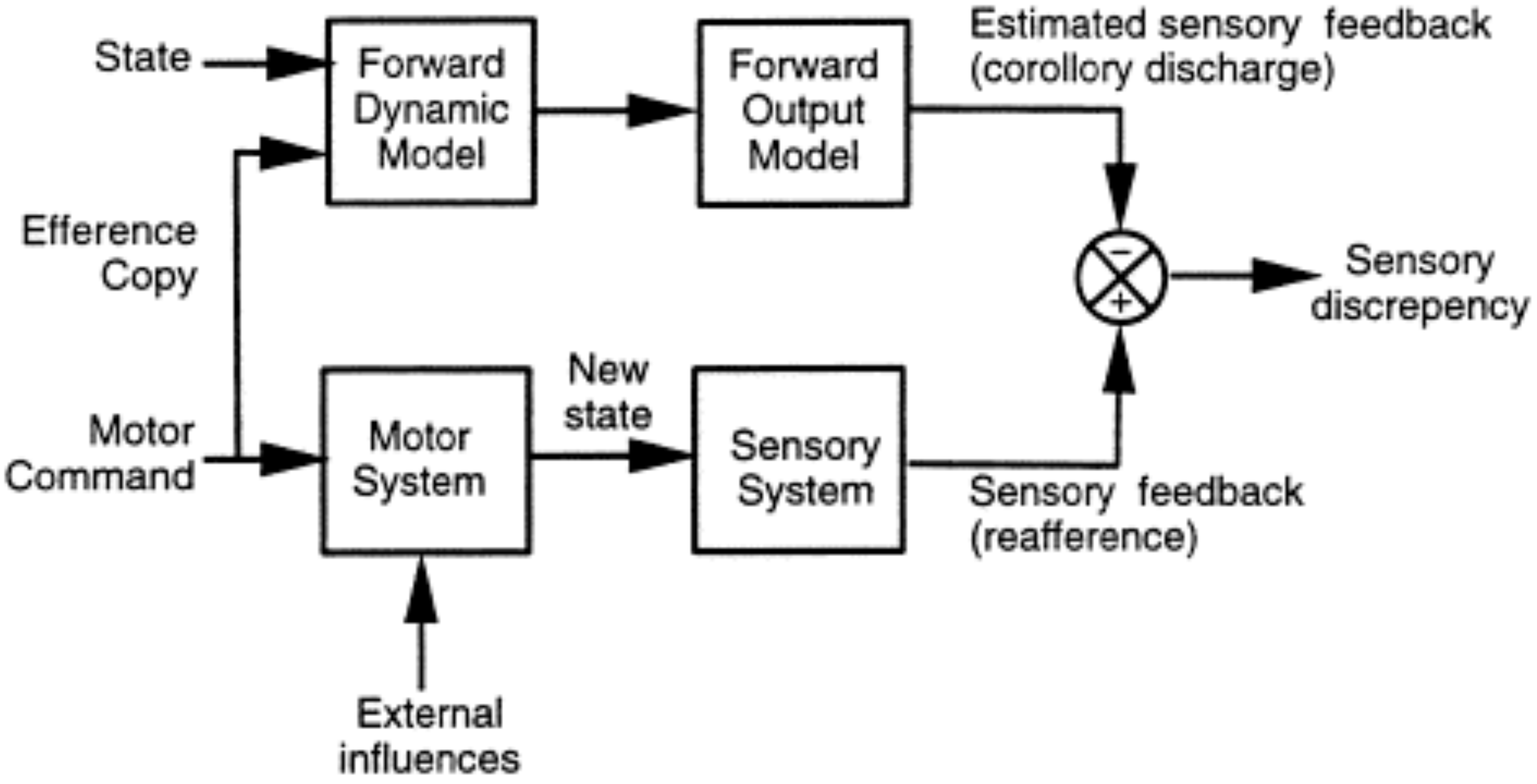
  Person C: Data recorder.



Exp.:
- **A** holds book with one hand.
- **Self trials (5)**: **A** quickly lifts off the book with their other hand.
- **External trials (5)**: **B** quickly lifts off the book.
- **C** records results of **A**'s supporting hand: no rise, some rise, a lot of rise.

Task:
- Is there a difference in **A**'s support hand between Self & External Lifting?
- Sketch out a model for how this effect happens.

Forward & inverse models



(Miall & Wolpert, 1996)