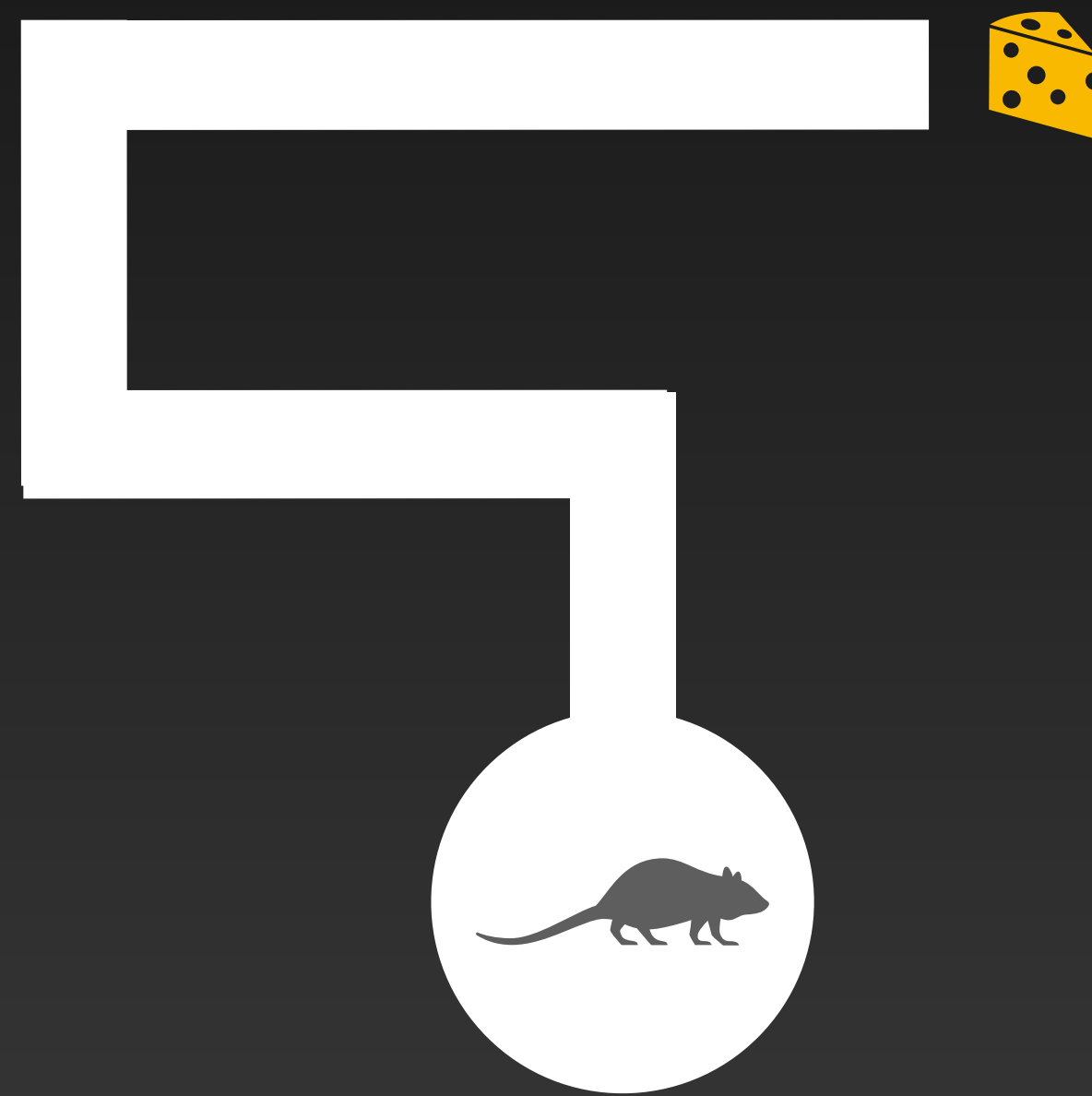# How to Build a Cognitive Map

James C. R. Whittington, David McCaffary, Jacob J. W. Bakermans and Timothy E. J. Behrens

Presenter: Xuan Wen
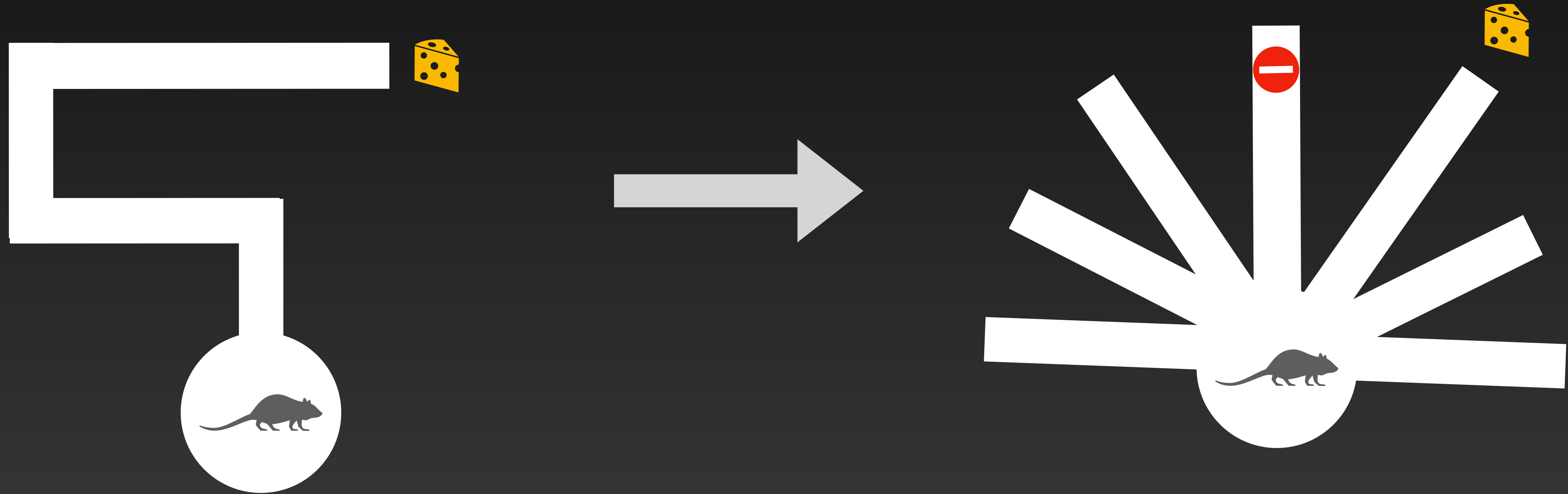Dec 7th, 2022

Classic Studies: Cognitive Mapping

- Edward C. Tolman, 1948

Straight -> Left -> Right -> Right

Classic Studies: Cognitive Mapping

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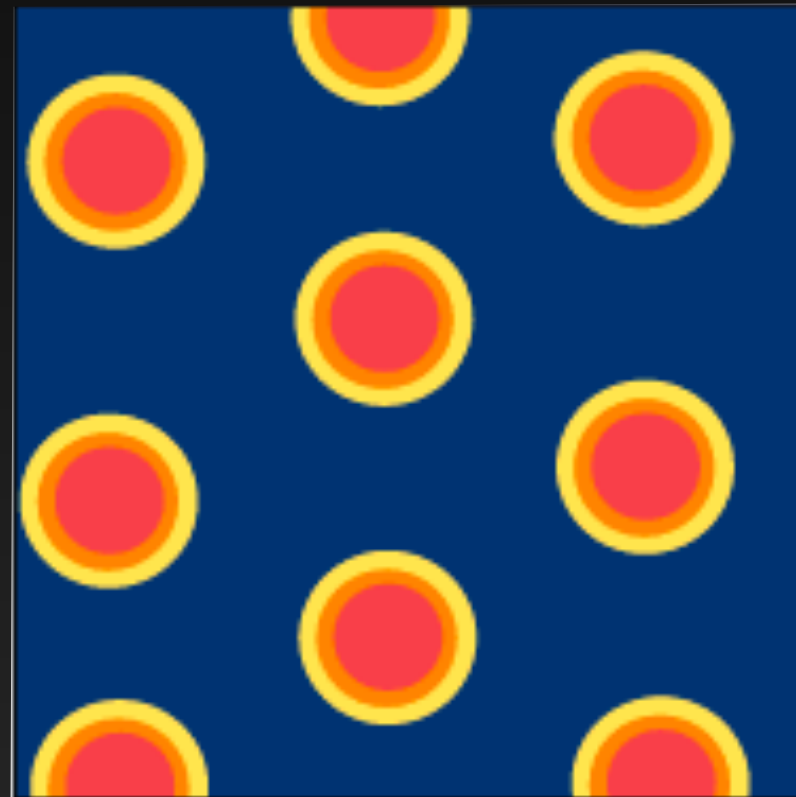
Functions of Cognitive Mapping

- Internal neural representations of spatial relationship that enable **flexible behavior**

  - Planning route

  - Finding shortcut

What brain areas support such function?

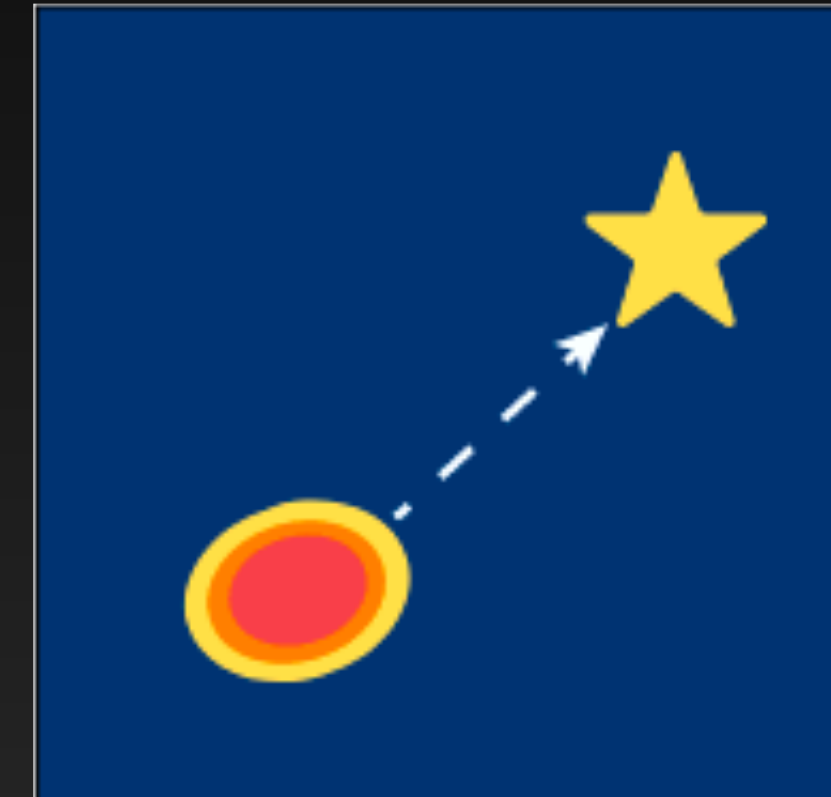# What brain areas support such function?


Place cell

Grid cell

Border cell

Object-vector cell

Functions of Cognitive Mapping

- Not restricted to spatial cognition

- Place cells firing to...

  - "Locations" in sound frequency

  - "Locations" in reward value

  - ...

Functions of Cognitive Mapping

- Not restricted to spatial cognition

- Grid cell firing pattern can be found in:

  - Stimuli with two abstract dimensions
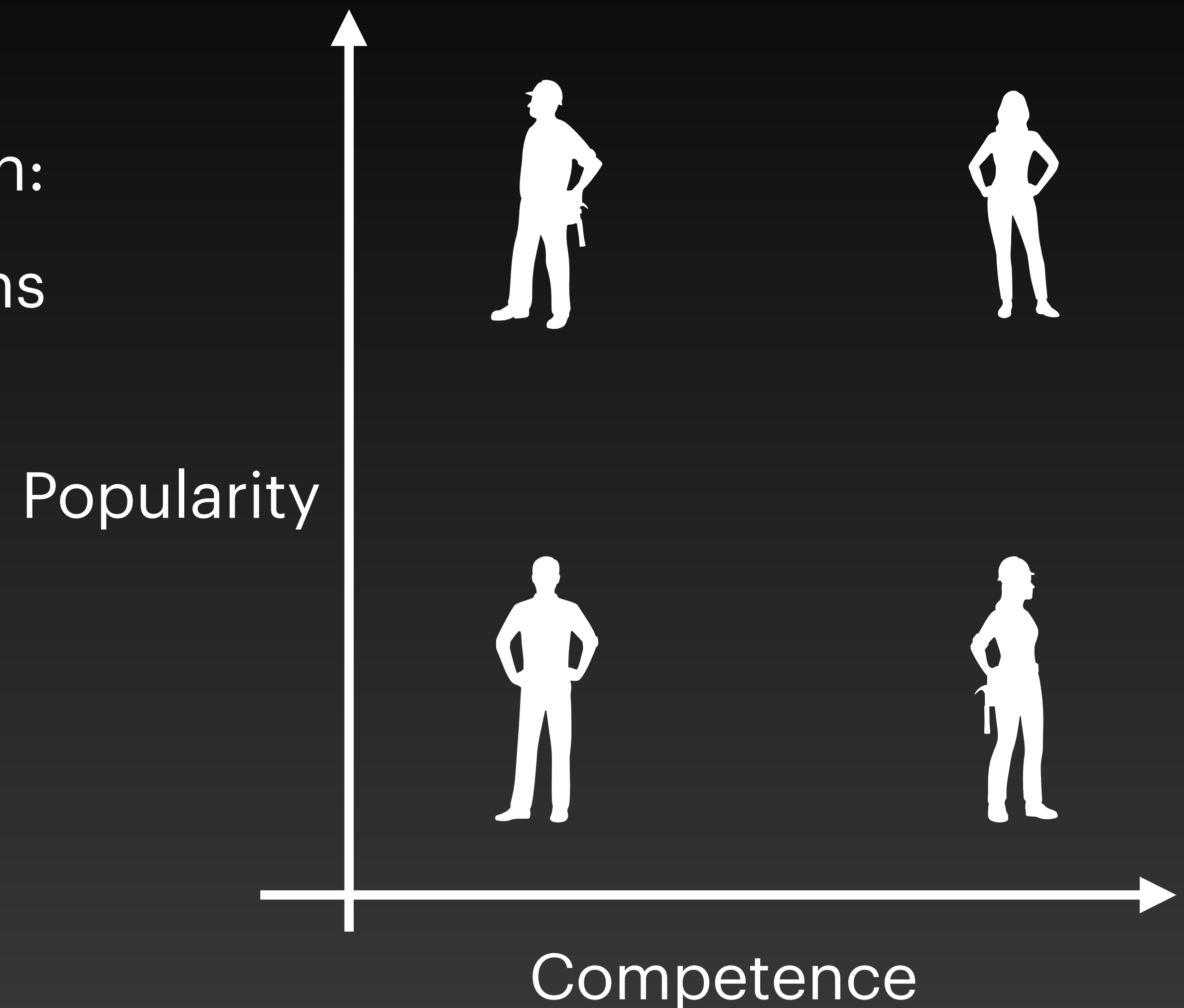
Leg
Length

Neck Length
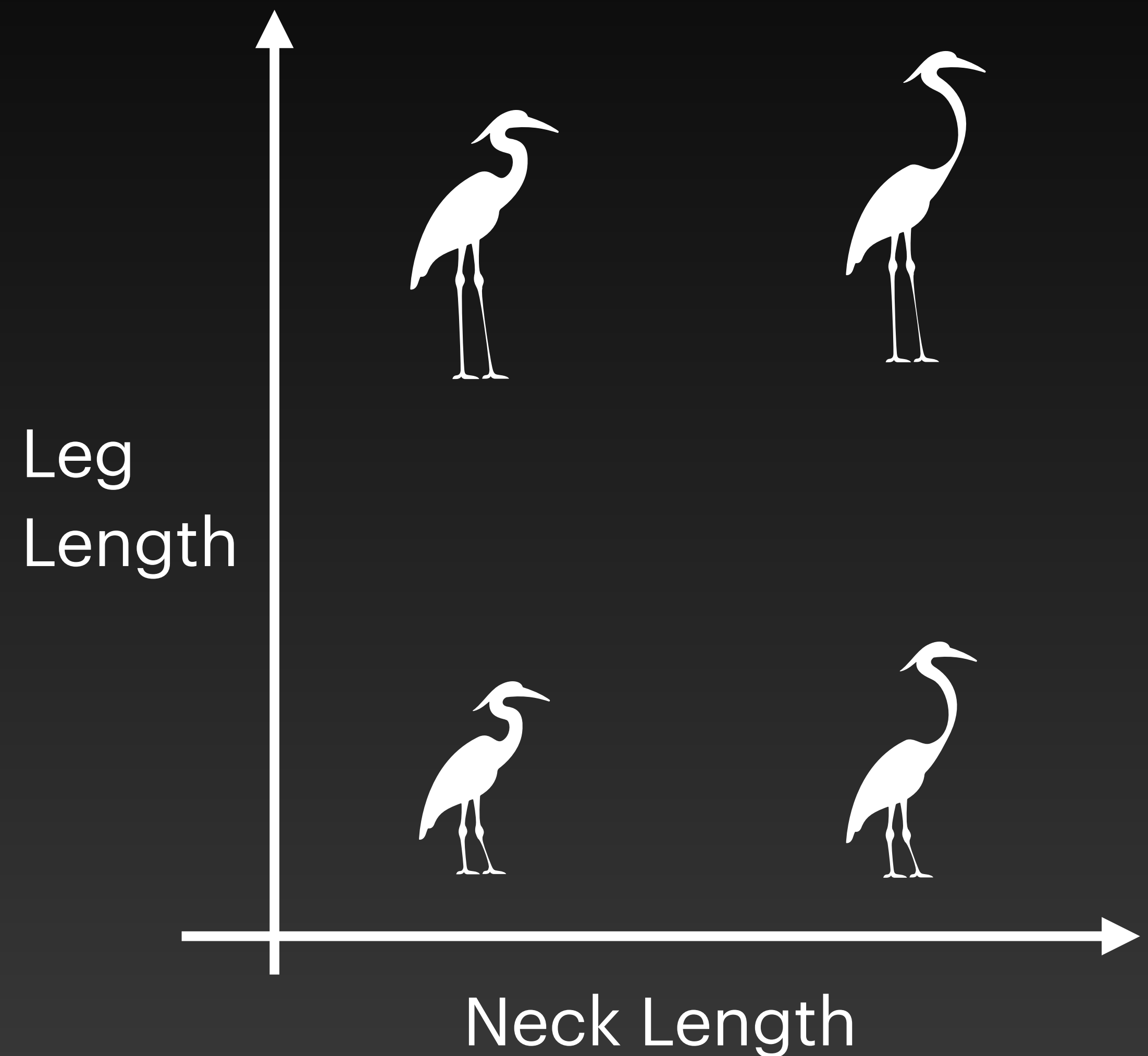
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Functions of Cognitive Mapping

- Internal neural representations of spacial relationship that enable **flexible behavior**

  - Planning route

  - Finding shortcut

- Spacial Cognitive Map is just an instance of a broader coding mechanism

  - Organizing knowledge for **generalization**

  - Enable the rapid inference from sparse observations

How the brain represents these different domains of cognition in the same way?

Cognitive Mapping Problem

- We need a model to connect physical & abstract domains.

  - Contain information relevant to behavioral tasks

  - Enable new behaviors in the face of new challenges

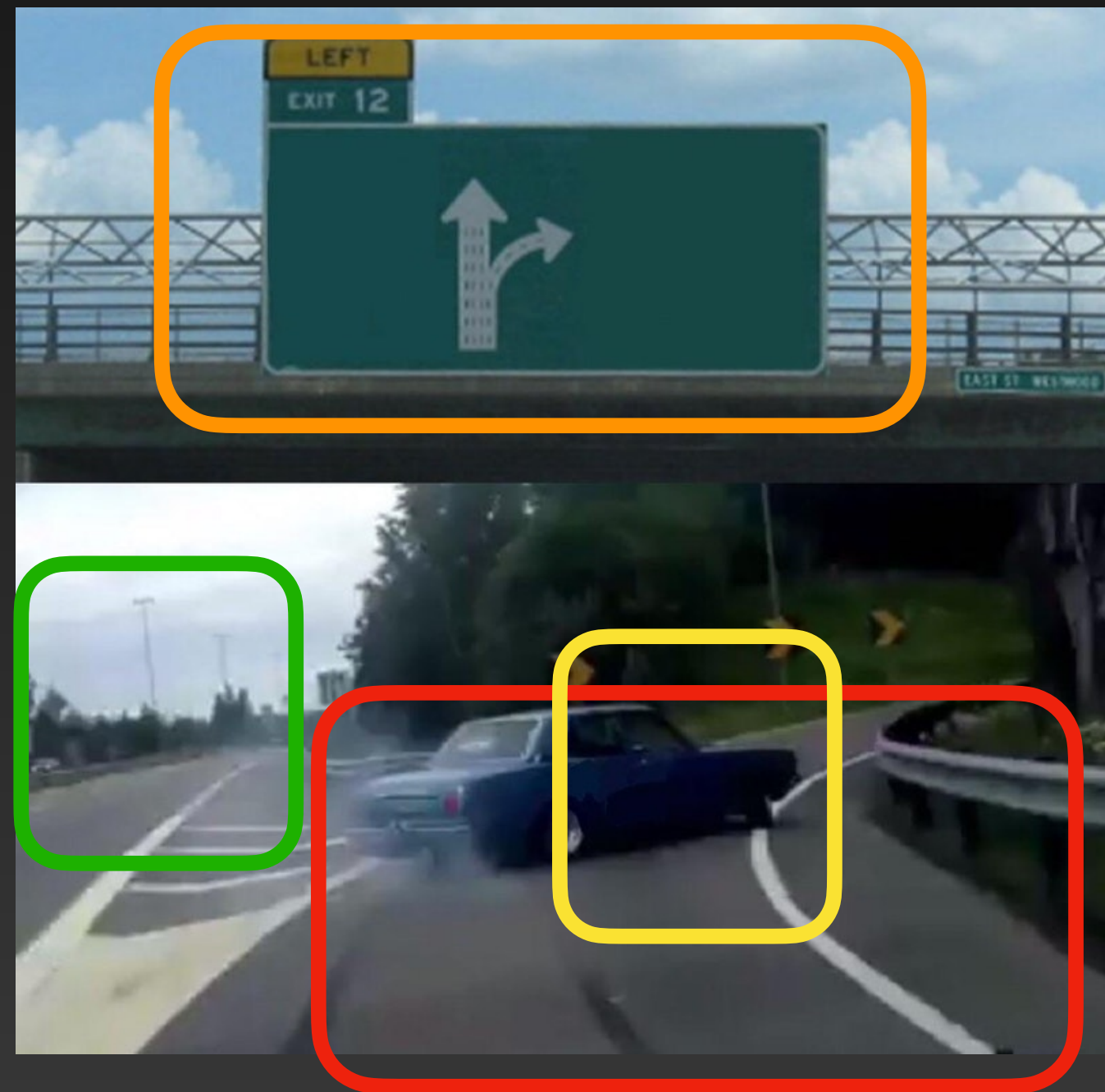 - Minimize time & resources for computation

Reinforcement learning and planning

- Classic Model-free Reinforcement Learning
  - Make decision based on the value of "states"

Reinforcement learning and planning

- Classic Model-free Reinforcement Learning

    - Make decision based on the value of "states"

Reinforcement learning and planning

- Classic Model-free Reinforcement Learning
  - Make decision based on the value of "states"
  - **It's impossible to representing ALL states**

# *Reinforcement learning and planning*

- Classic Model-free Reinforcement Learning

  - Make decision based on the value of "states"

  - **It's impossible to representing ALL states**

- Need appropriate abstraction

- Need to know the relationship between states (state-space structure)

Spatial & Non-spatial states

- How to formalize the representation of states?
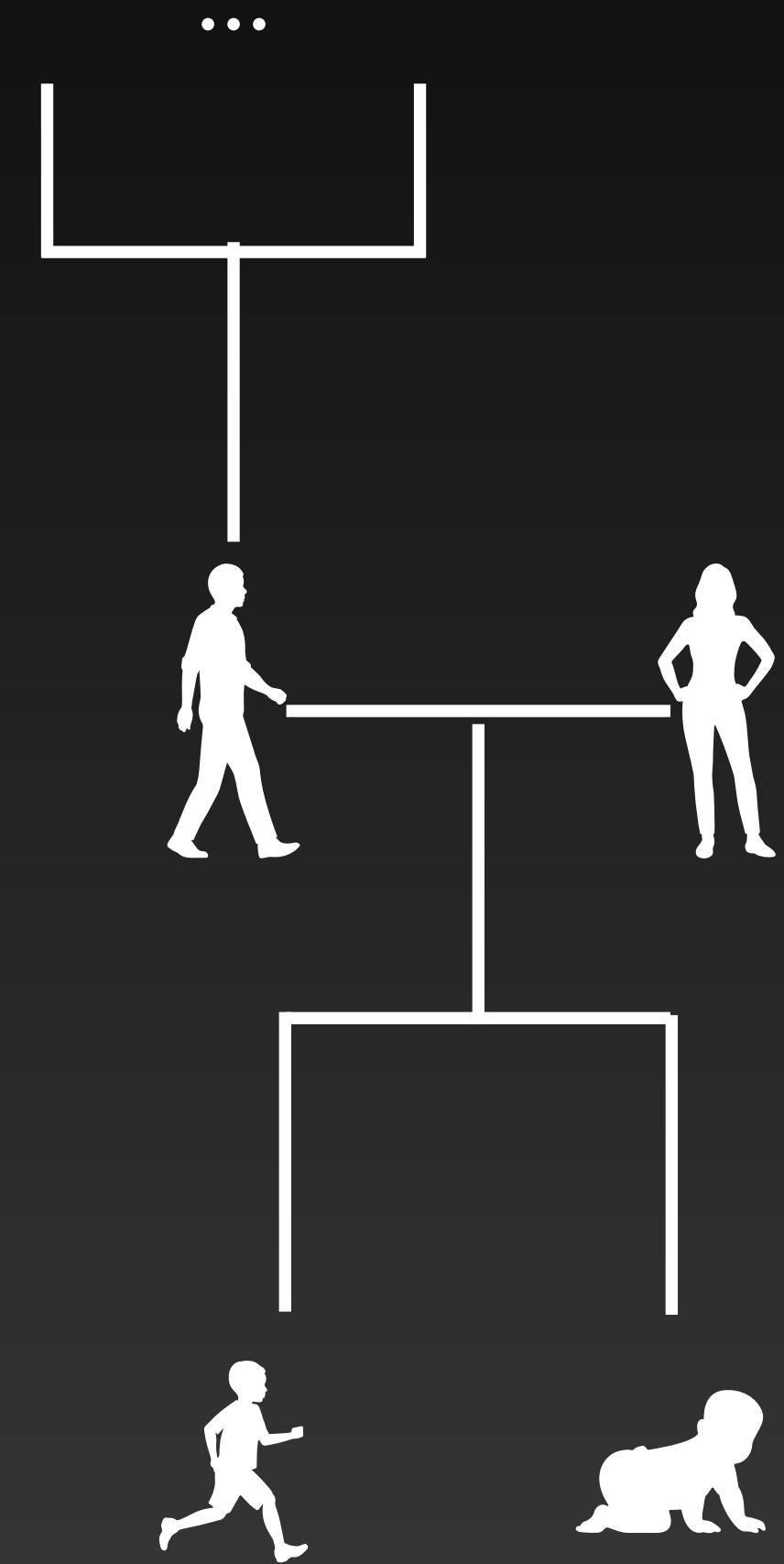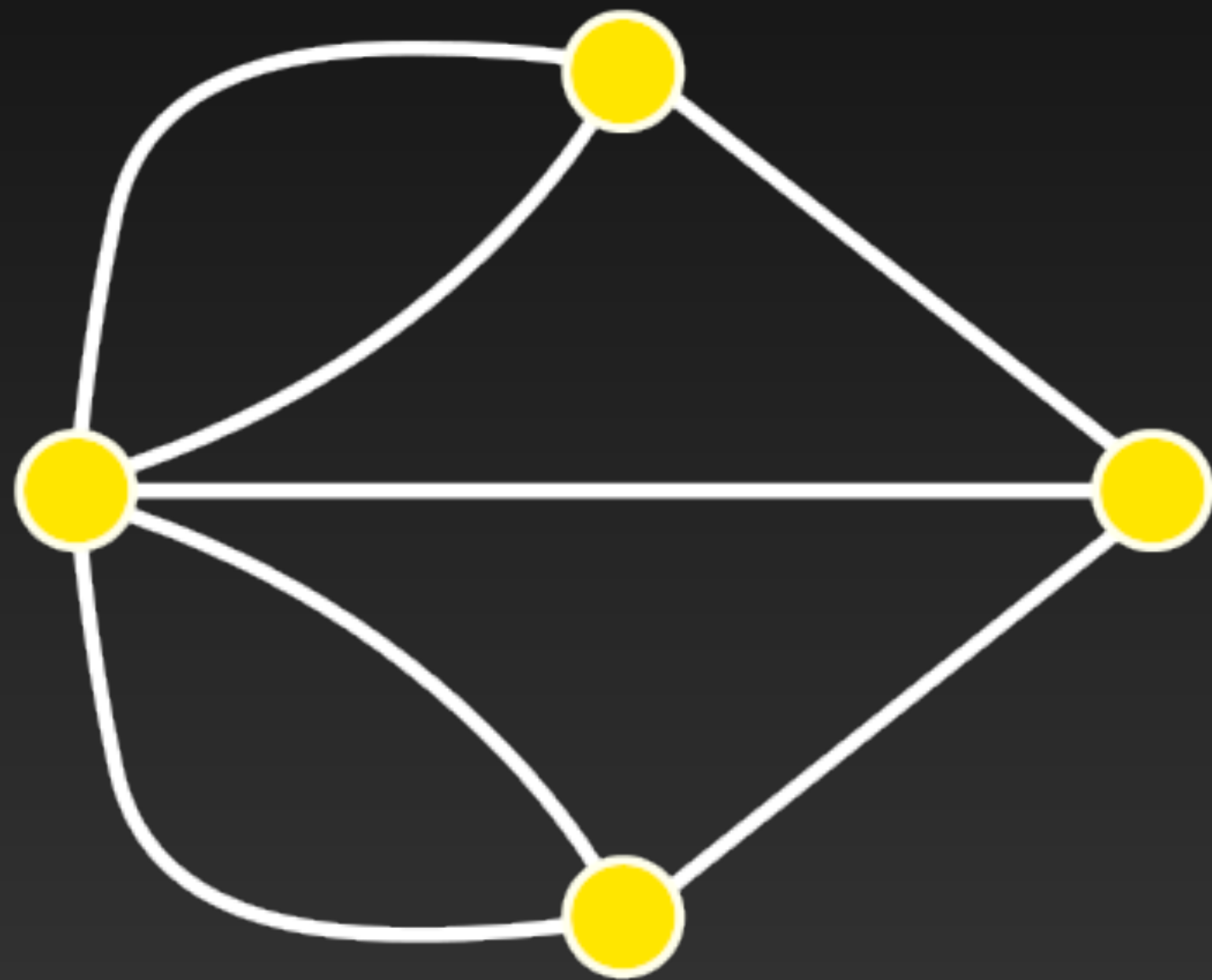
Spatial & Non-spatial states

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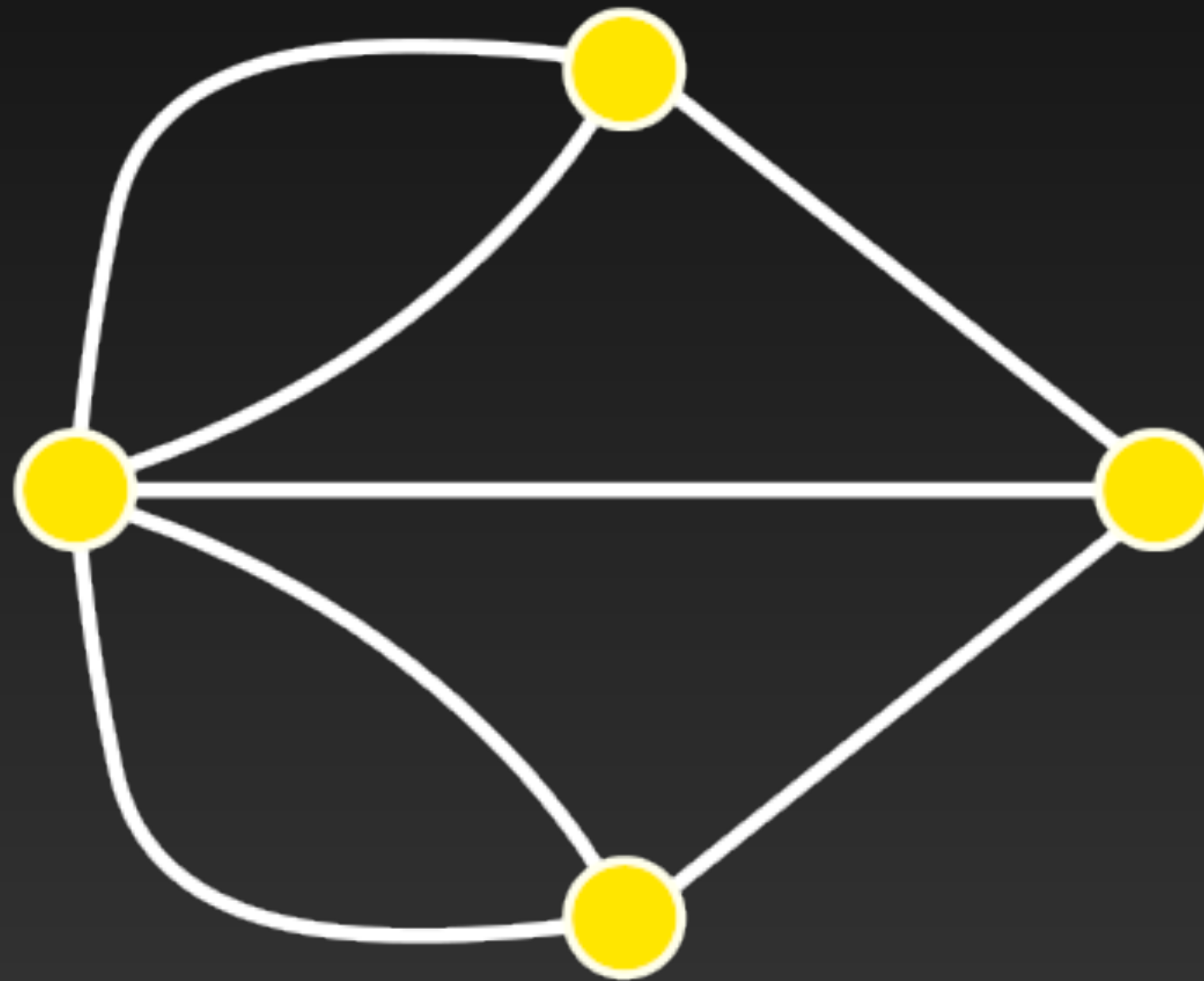
- Graph theory!

Spatial & Non-spatial states

- How to formalize the representation of states?
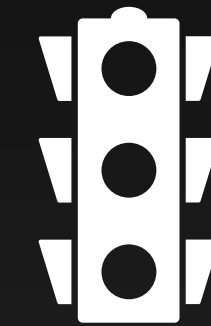
- Graph theory!

Latent States

- How can we define which graph to build?
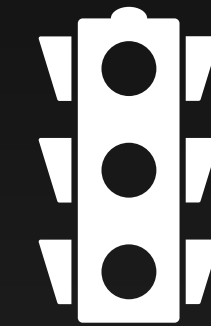
- One sensory input, multiple possibilities.

Latent States

- How can we define which graph to build?

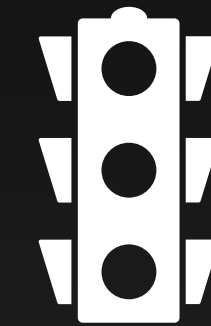- One sensory input, multiple possibilities.

Latent States

- How can we define which graph to build?

- One sensory input, multiple possibilities.

The United State

Latent States

- How can we define which graph to build?
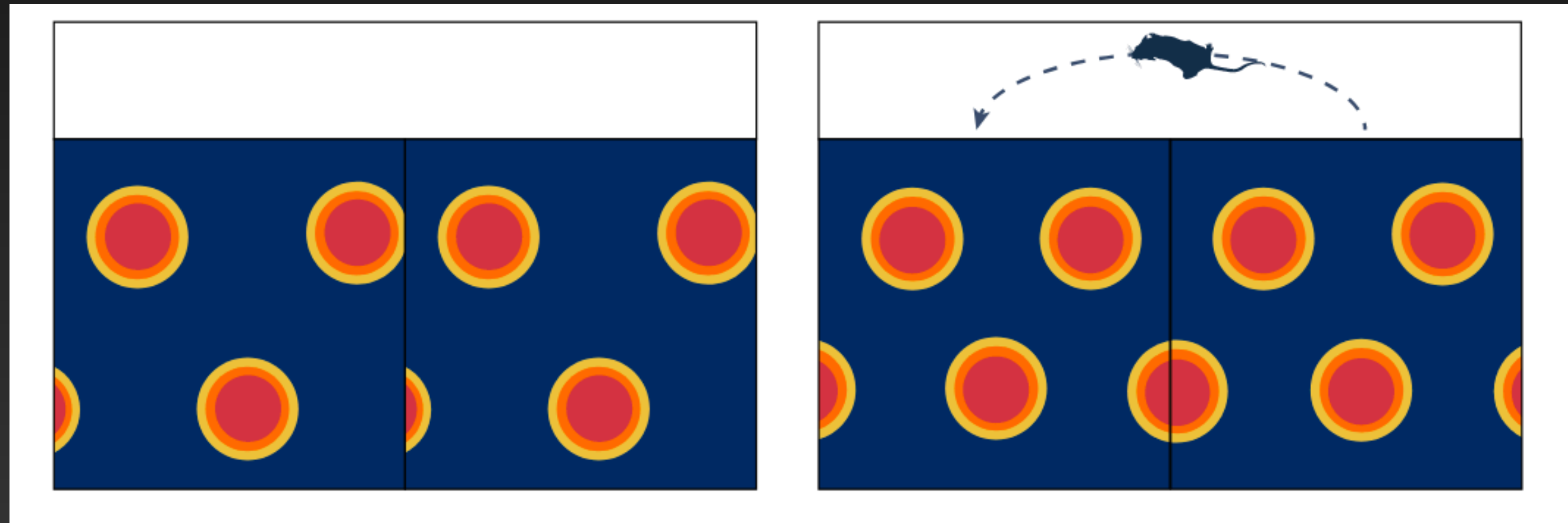
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The United Kingdom

Latent States

- How can we define which graph to build?

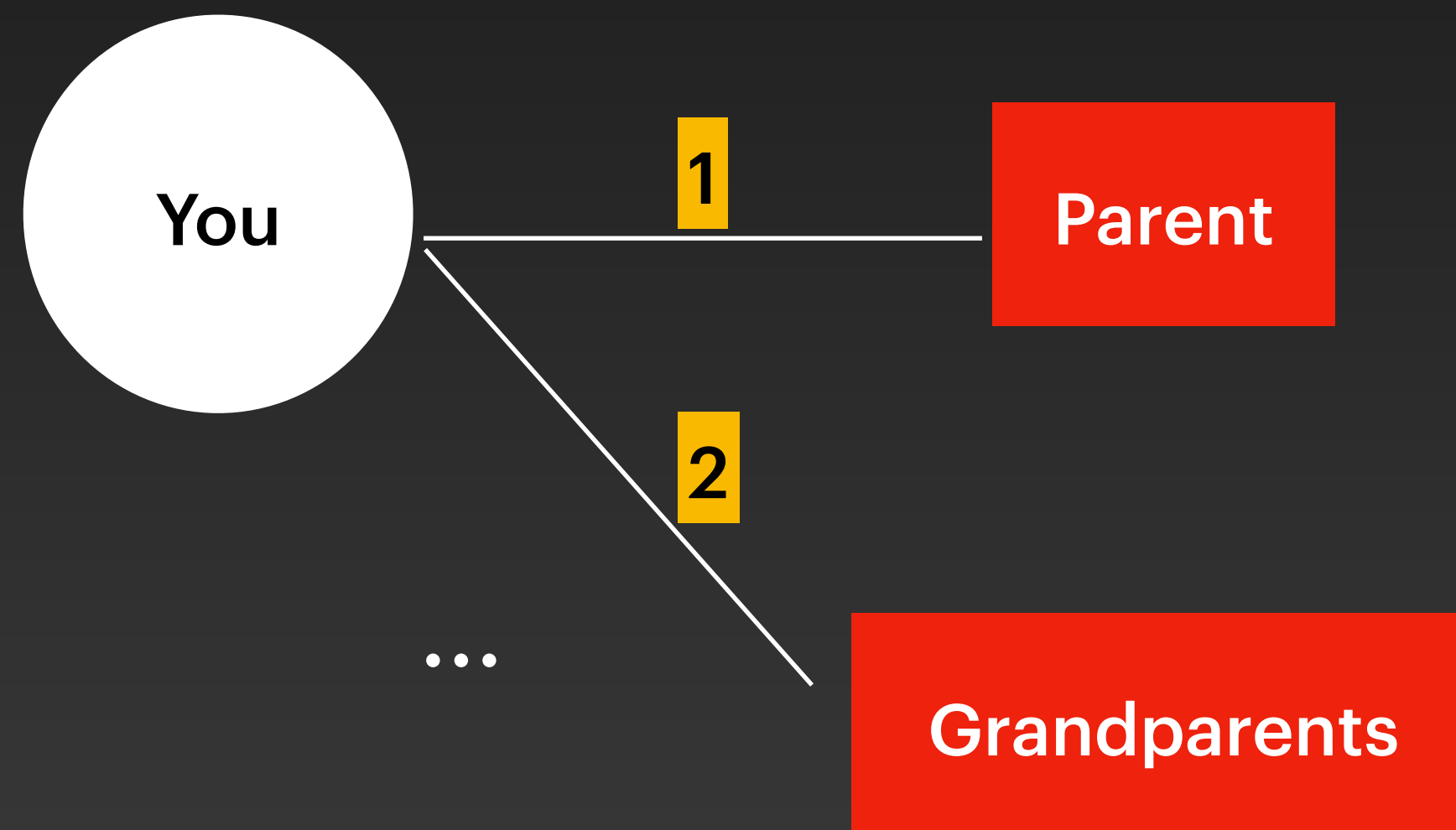- One sensory input, multiple possibilities.

Path Integration

- Accumulate self movement in space

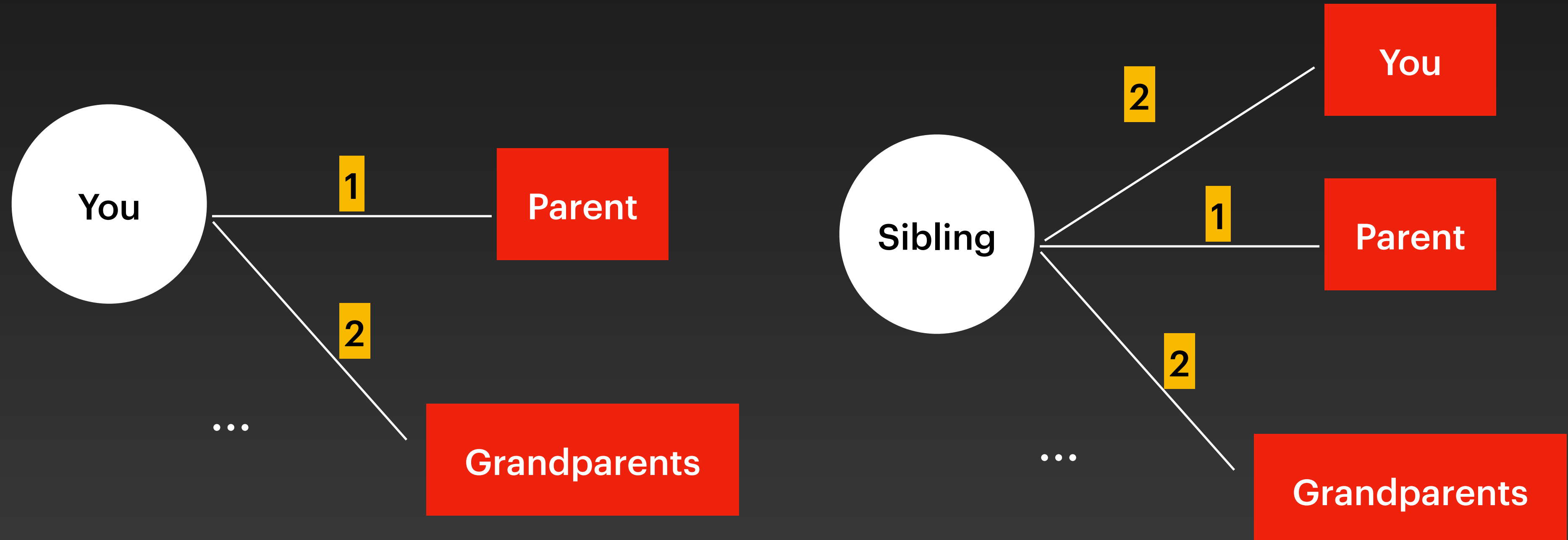- Accumulate relations in non-spatial concepts

Path Integration

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Path Integration

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Path Integration

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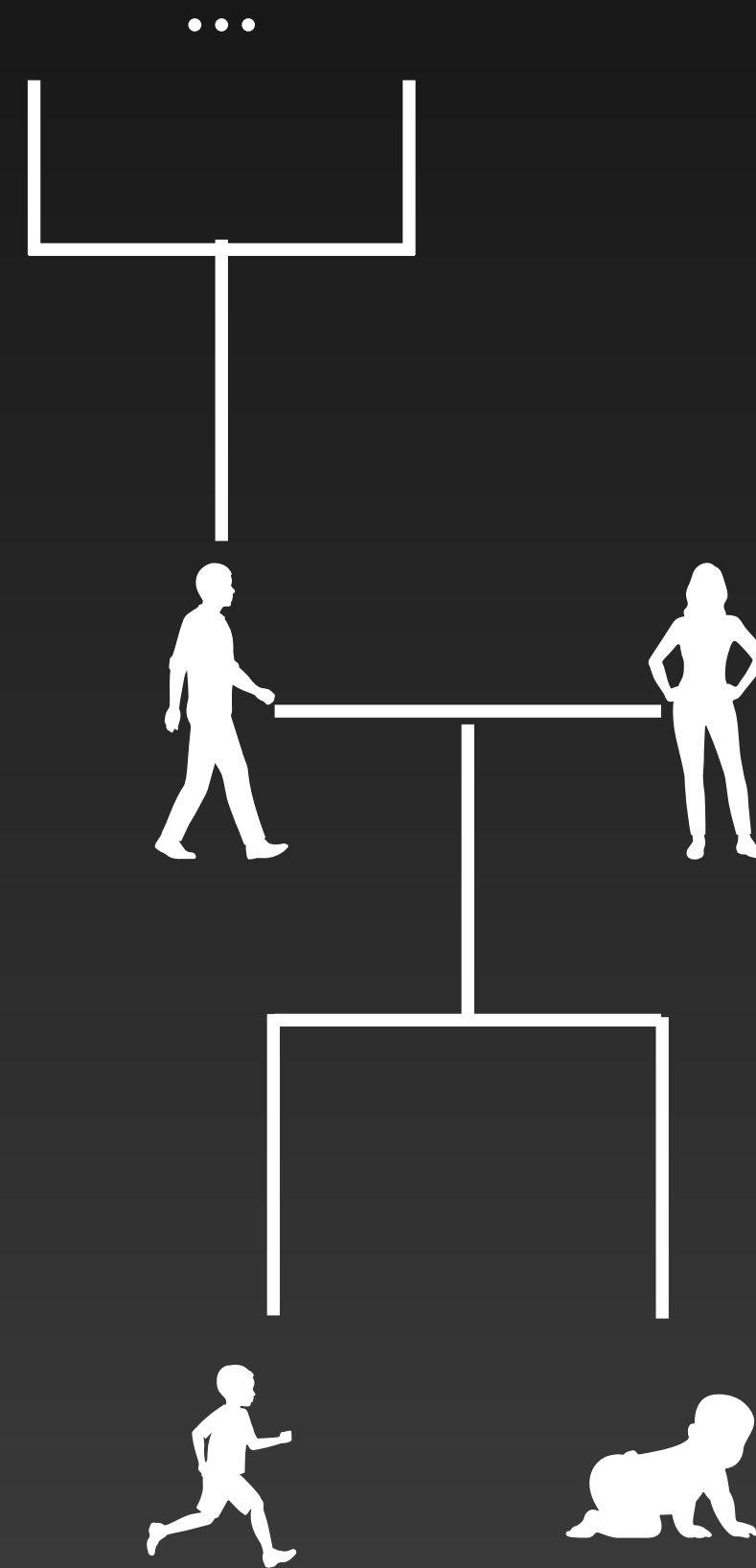
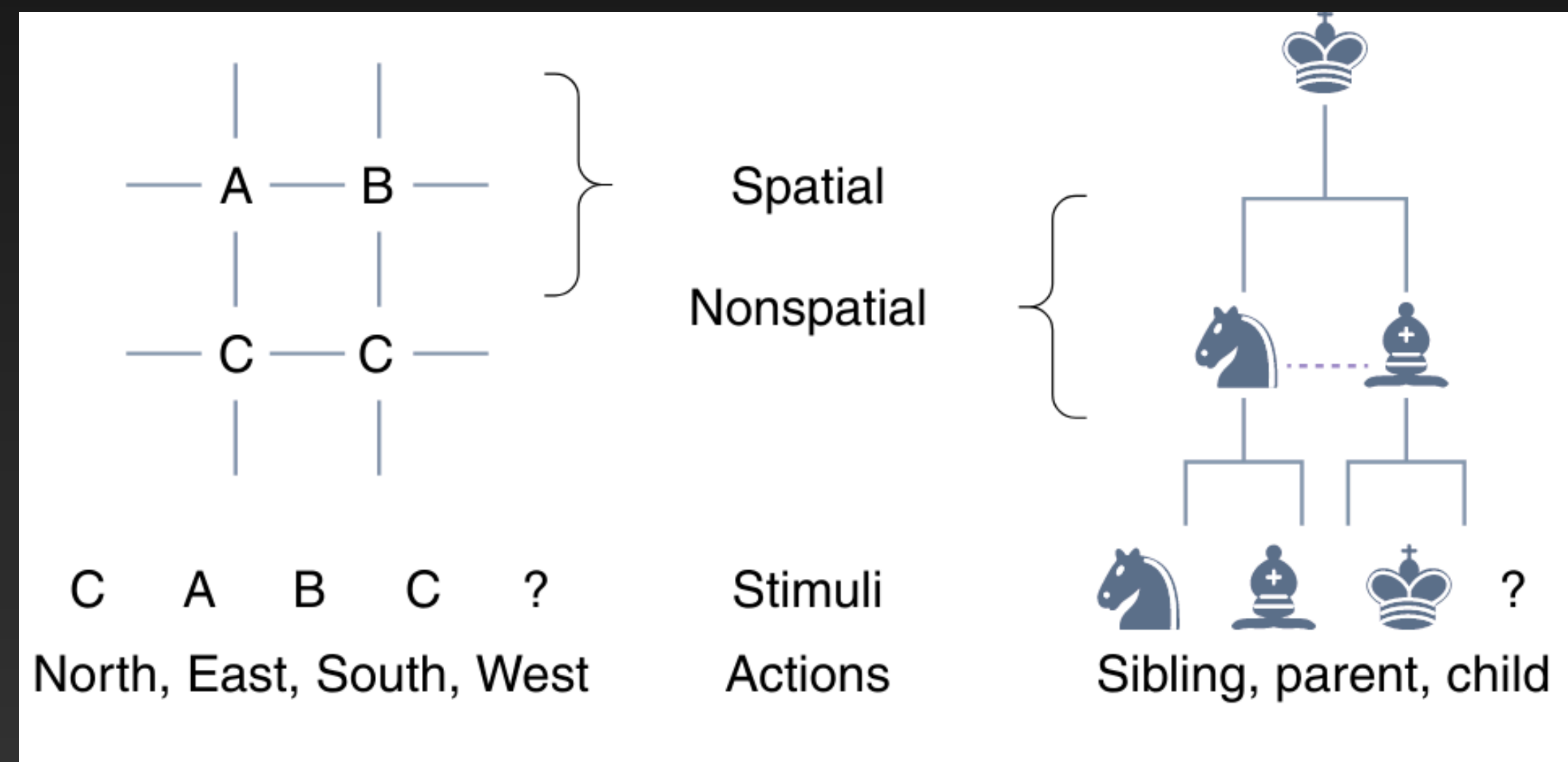- Accumulate relations in non-spatial concepts

Generalization

- Same rule should be able to generalize to other environment

- "Sequence Learning Problem"

Summary

- Cognitive map is a coding mechanism, encoding spatial & non-spatial relationships.

  - Enable flexible behavior

  - Fast learning on new environment

  - Minimize computational resources

- To construct models that describe cognitive mapping, we need to satisfy several requirements observed in empirical experiments.

Thank You!