THE FIRST INTERNATIONAL
WHOLE BRAIN ARCHITECTURE
WORKSHOP

Data for Brain Reference Architecture of TN24HippocampalFormation

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Outline

- Introduction
- SCID method
  - Region of interest
  - Brain Information flow
  - Hypothetical component diagram
  - Function realization graph
- Research based on the BRA data
- Conclusion

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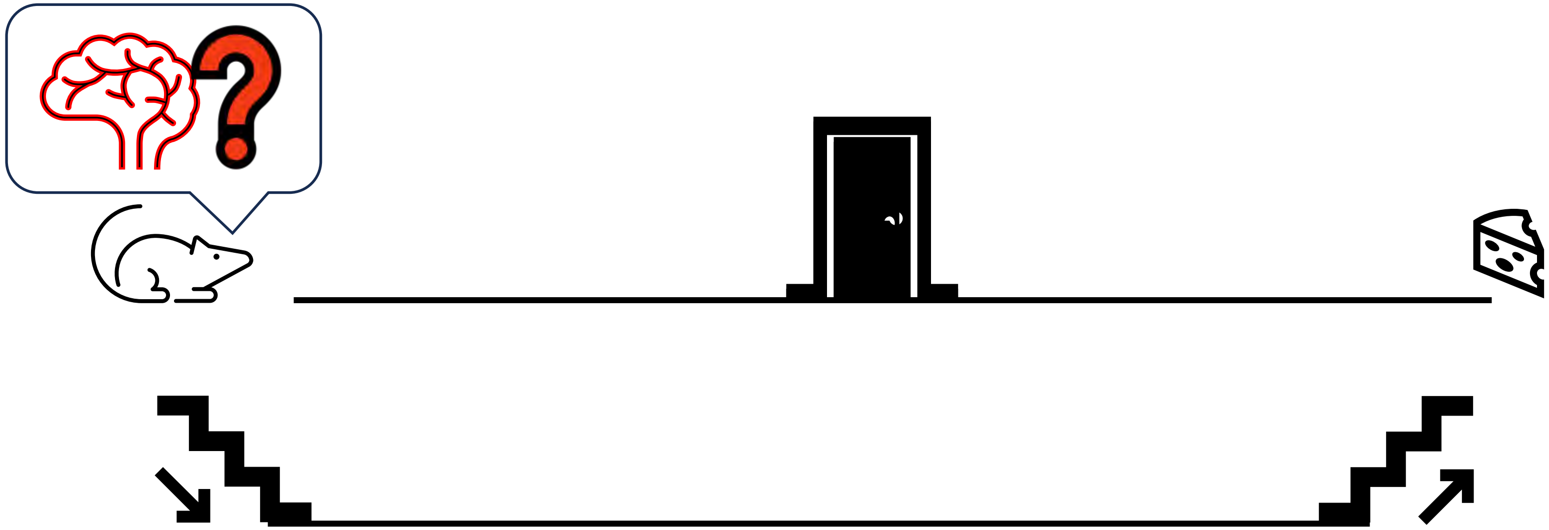
Introduction

For organisms, it is important to acquire internal representation that enable **flexible behavior** in complex and dynamic environments.



Research Question: What kind of internal representation should be acquired?

Approach: The **spatial cognition** computational model **inspired by brain**.

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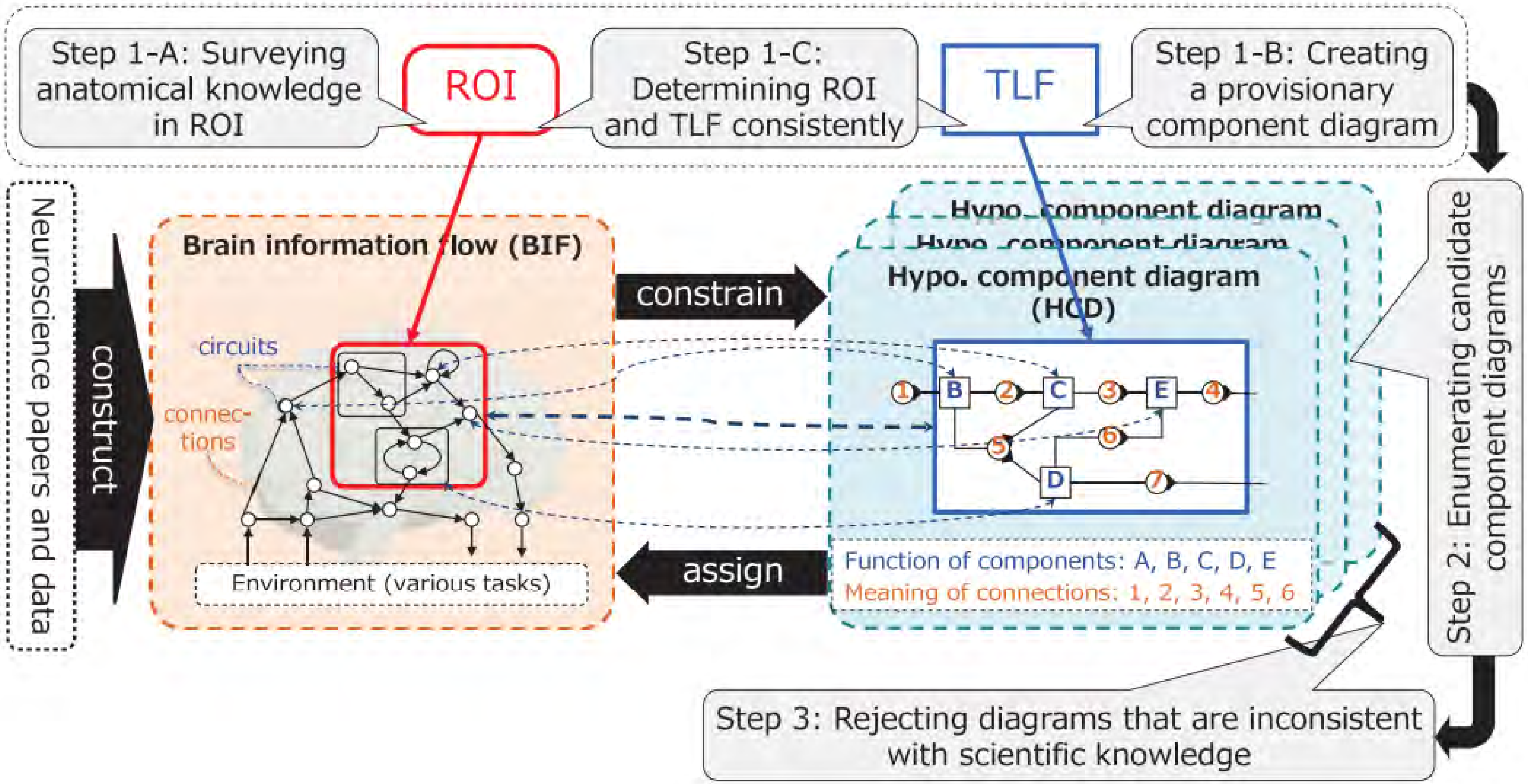
SCID method

Structure-constrained interface decomposition (SCID) method[1]:

This method enables the hypothetical construction of software architecture inspired by the brain, even though our neuroscience knowledge is still insufficient to elucidate the whole picture.

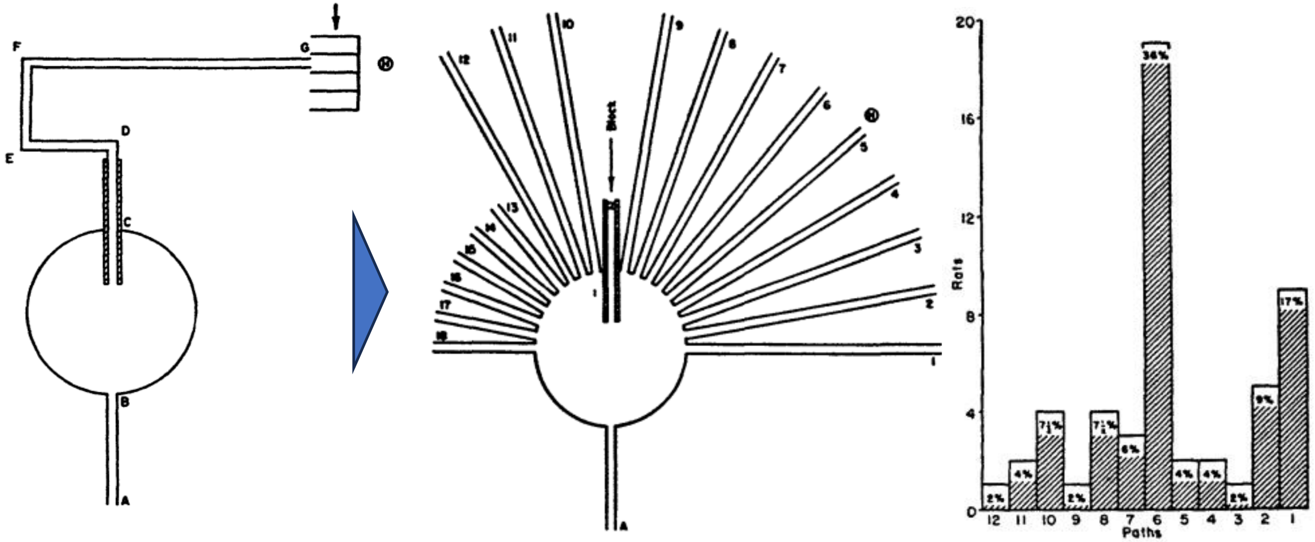


[1] Yamakawa, H. (2021). The whole brain architecture approach: Accelerating the development of artificial general intelligence by referring to the brain. Neural Networks, 144 , 478–495.

Region of interest(ROI)

Spatial cognition has been studied in the fields of cognitive science and neuroscience.

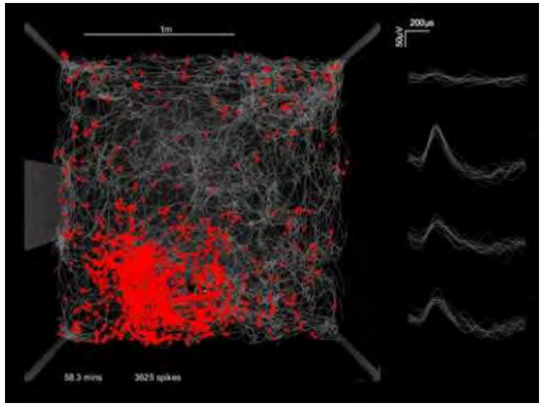
- **Cognitive map**[2]



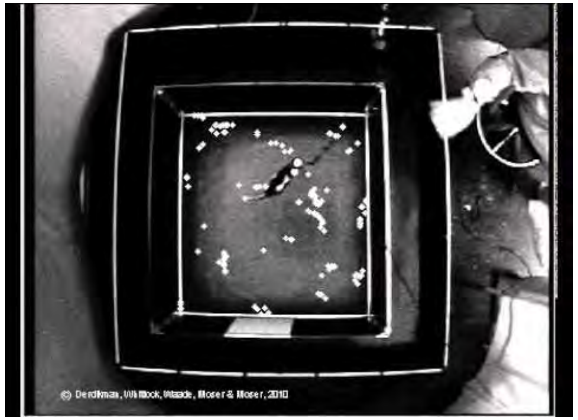
Rats do not learn a simple stimulus-response mapping, but spatial representation that enable flexible behavior.

- Place cell[3] / Grid cell[4]

Place cell



Grid cell



Place cell in the **hippocampus** and grid cell in the medial **entorhinal cortex**(MEC) as cognitive map.

The hippocampal formation is a crucial part of spatial cognition.

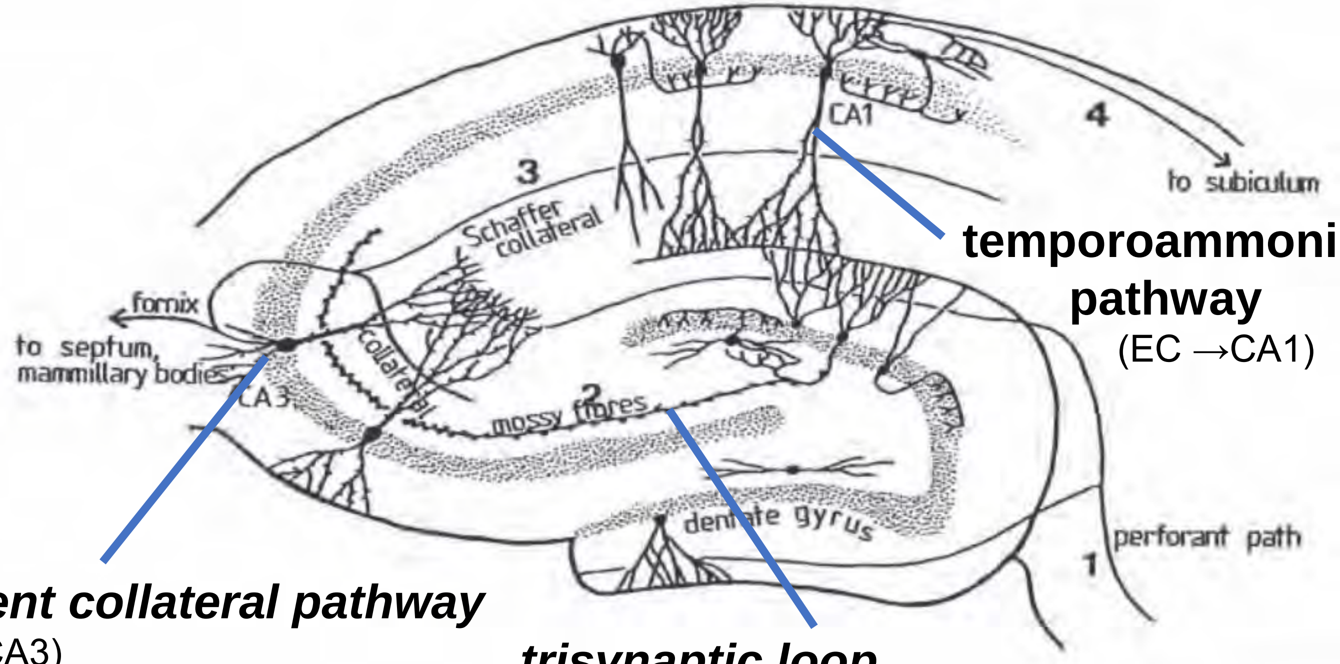
[2]Edward C Tolman. Cognitive maps in rats and men. Psychological review, Vol. 55, No. 4, p. 189, 1948.
[3]O'Keefe J. Place units in the hippocampus of the freely moving rat. Exp. Neurol. 51:78–109,1976
[4]Moser, E. I.. "Microstructure of a spatial map in the entorhinal cortex". Nature. 436 (7052): 801–806.2005

Region of interest(ROI)

ROI of this study is hippocampal formation including :

- dentate gyrus (DG)
- cornu ammonis-1 and - 3 (CA1, CA3)
- lateral entorhinal cortex (LEC)
- medial entorhinal cortex (MEC)
- subiculum (Sb)
- parasubiculum (ParaSb)
- perirhinal cortex (PER)
- postrhinal cortex (POR)
- retrosplenial cortex (RSC)

} **hippocampus** (DG, CA1, CA3)



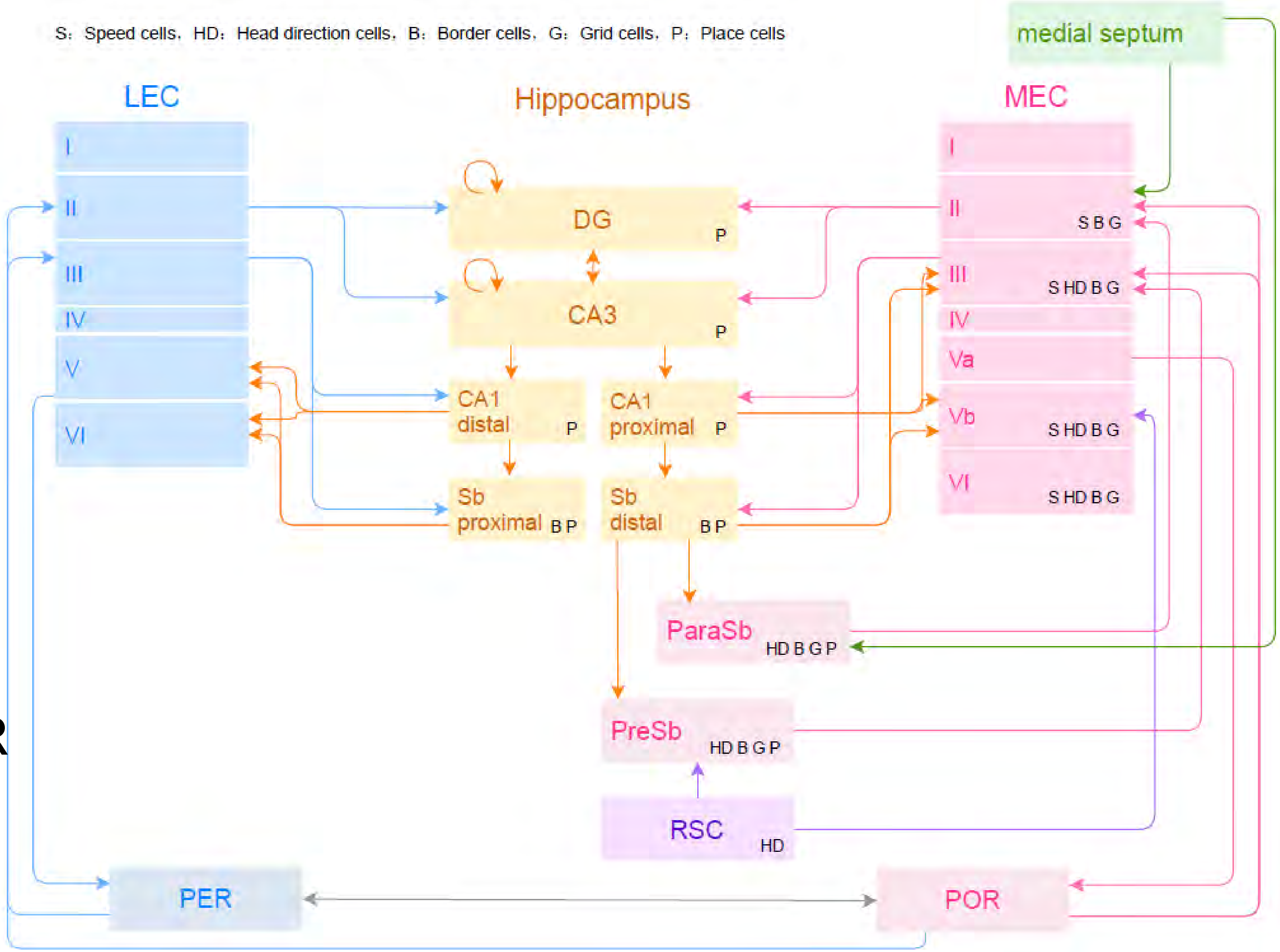
Connections within the hippocampus [5]

[5]E. T. Rolls, Brain computations and connectivity. Oxford University Press, 2023.

Brain Information Flow (BIF)[6]

- Rectangles represent brain regions and Arrows represent projections.

- Input/Output
  <u>Input:</u>
  POR, PER, and RSC
  <u>Output:</u>
  the predicted values of POR and PER at the next time step



[6] Taniguchi, A., Fukawa, A., & Yamakawa, H. (2022). Hippocampal formation-inspired probabilistic generative model. Neural Networks, 151 , 317-335.

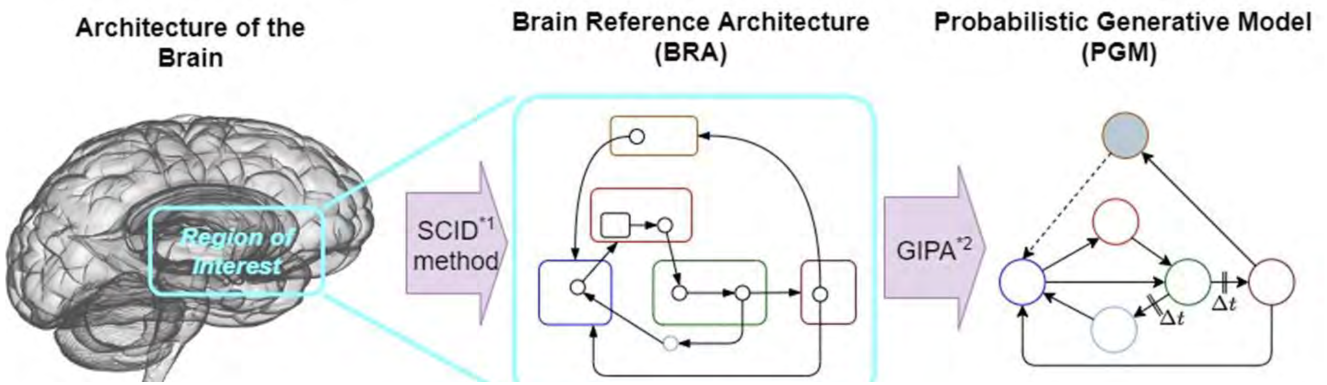
Hypothetical component diagram (HCD)

<u>Probabilistic Generative Model</u> in brain-inspired computational model enable :

- easy integration of PGM modules [7].
- creation of models incorporating the Bayesian brain hypothesis[8], the free energy principle[9], and the predictive coding hypothesis.

Constructing the HDC requires performing **<u>Generation-inference process allocation (GIPA)</u>**[10] which involves :

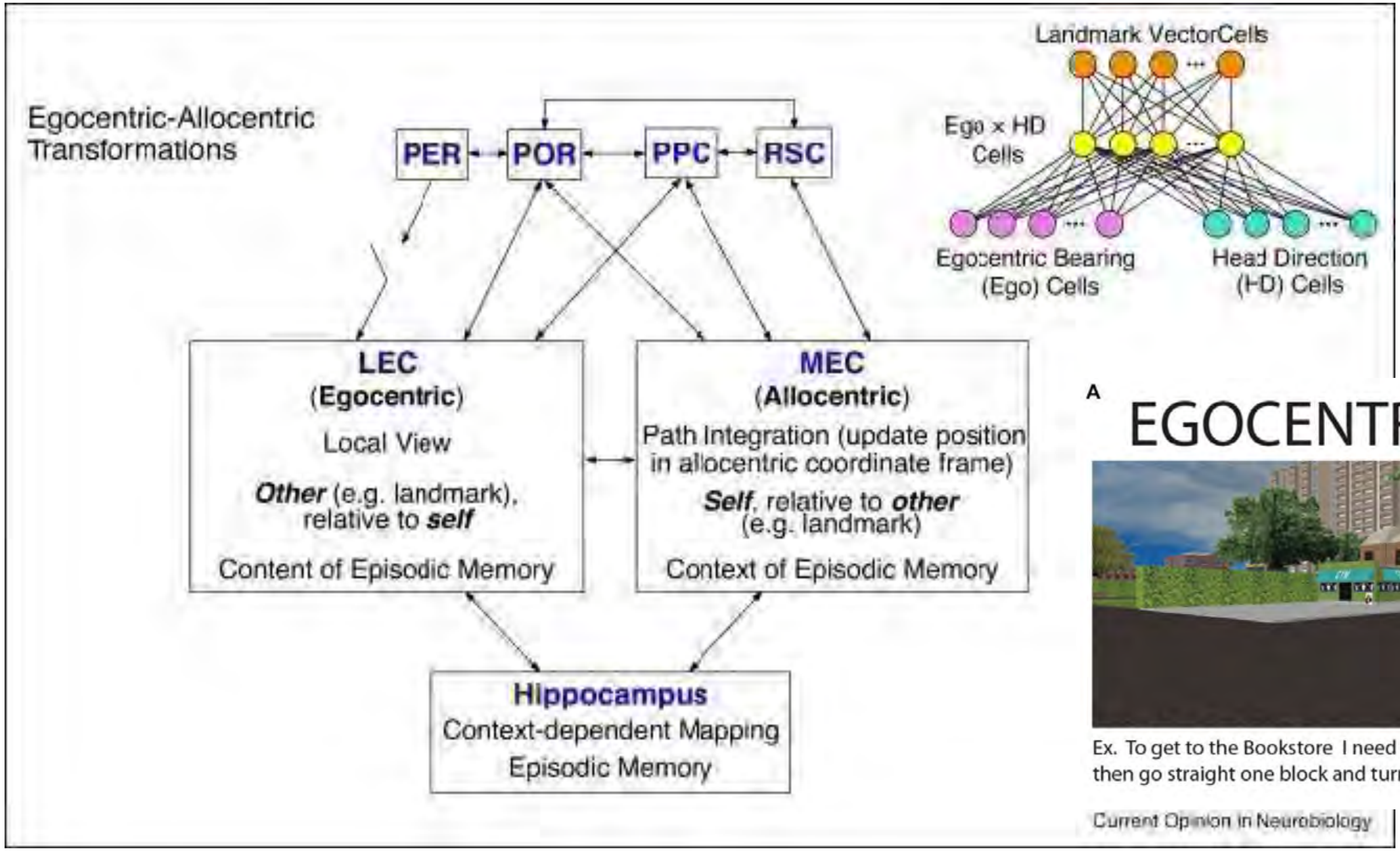
- assigning the generative or inference models to projections.
- introduction time delay in the brain's loop circuits to ensure PGMs are directed acyclic graphs.



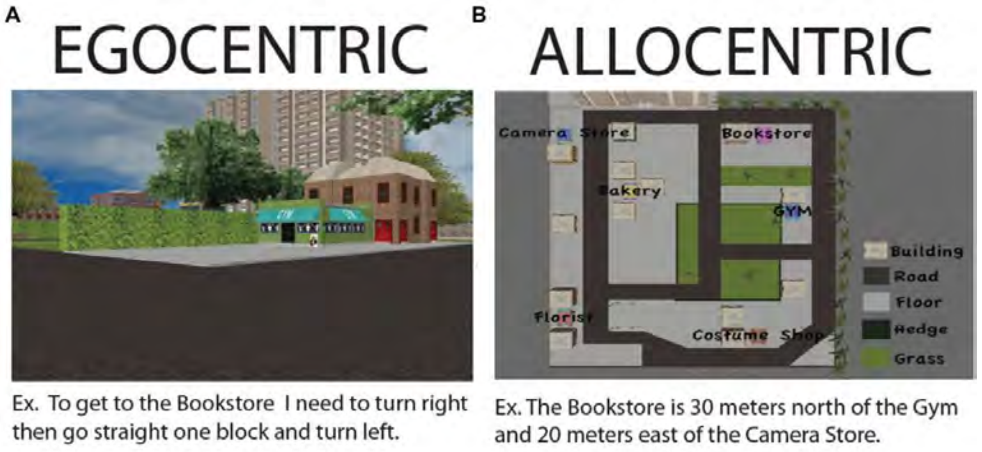
[7] Taniguchi, Tadahiro, et al. "Neuro-serket: development of integrative cognitive system through the composition of deep probabilistic generative models." New Generation Computing 38 (2020): 23-48.
[8] Doya, Kenji, ed. Bayesian brain: Probabilistic approaches to neural coding. MIT press, 2007.
[9] Karl Friston, et al. "Free energy, value, and attractors." Computational and mathematical methods in medicine 2012.
[10] Taniguchi, Tadahiro, et al. "A whole brain probabilistic generative model: Toward realizing cognitive architectures for developmental robots." *Neural Networks* 150 (2022): 293-312.

Hypothetical component diagram (HCD)

Egocentric and allocentric representations of space are handled by the LEC and MEC, respectively[11].



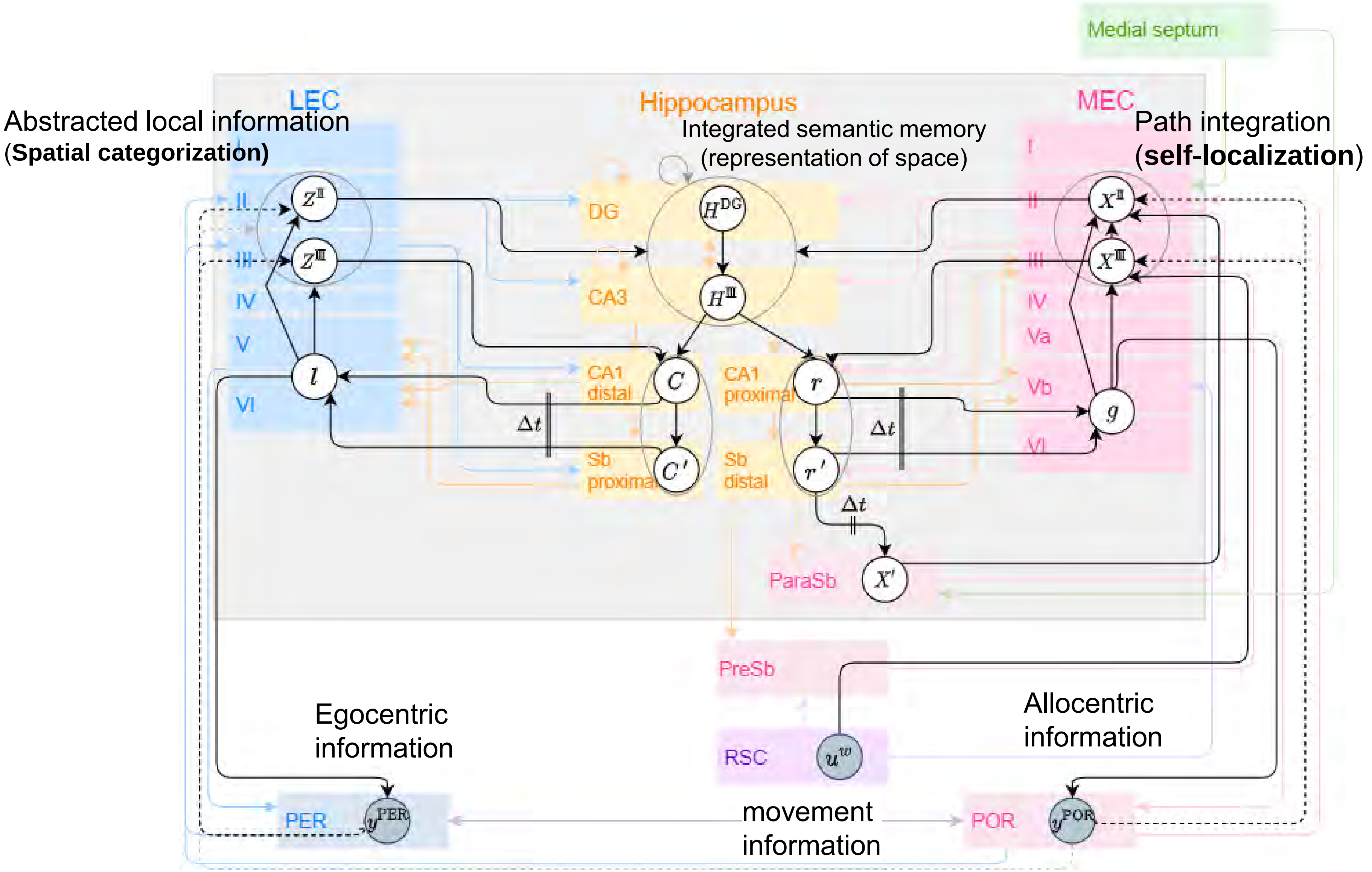
[12]



[11] Wang, C., Chen, X., and Knierim, J. J. (2020). Egocentric and allocentric representations of space in the rodent brain. Current Opinion in Neurobiology 60, 12–20

[12] Ekstrom, A. D., Arnold, A. E. G. F., and Iaria, G. (2014). A critical review of the allocentric spatial representation and its neural underpinnings: toward a network-based perspective. Frontiers in Human Neuroscience 8

Hypothetical component diagram (HCD)

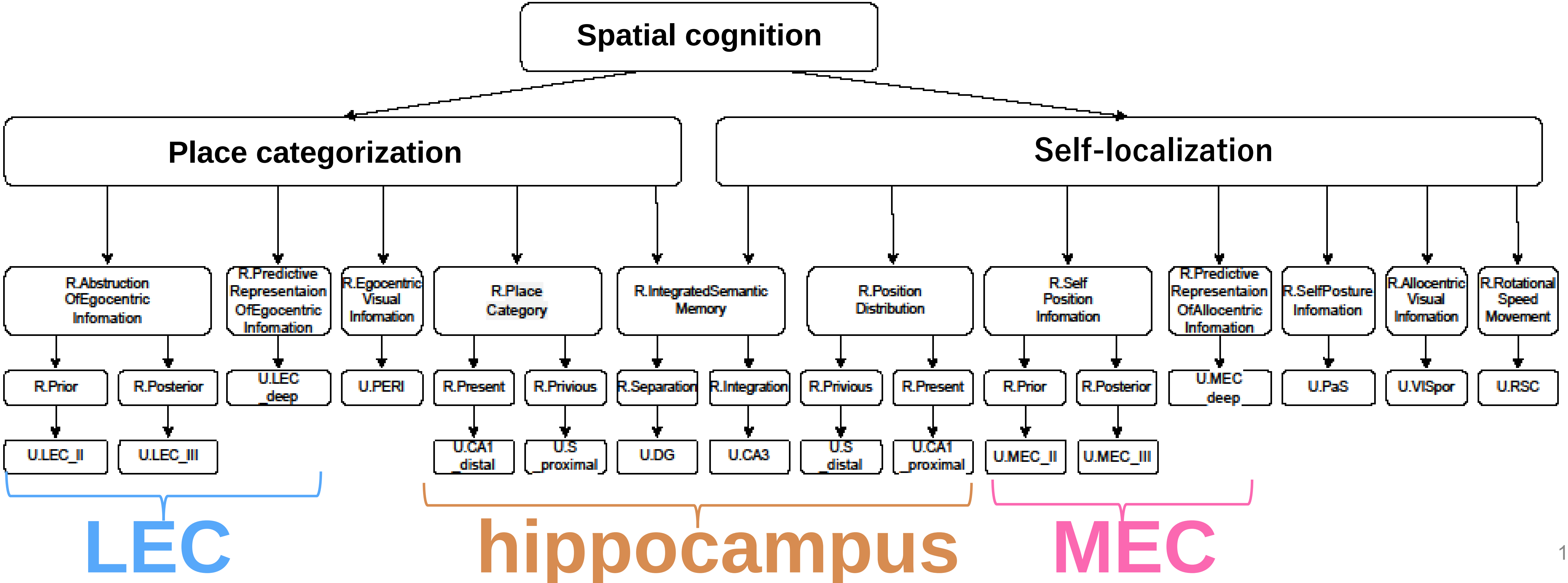


Symbol	Function of components on HCD
C	Place category (internal representation of visual spatial information)
r	Position distribution (cluster information regarding positions)
C'	Place category at the previous time
r'	Position distribution at the previous time
H^{III}	Integrated semantic memory and episodic memory of information from X and Z
H^{DG}	Integrated semantic memory
X^{II} ($\{x_t\}$)	Self-position information, predictive distribution
X^{III} ($\{x_t\}$)	Self-posture information (position and orientation), observation likelihood
g	Predictive representation of X (Prediction at future time regarding movement/speed amount or posture)
Z^{II}	Abstraction of information from y^{PER} (transmission of prediction, generation of prediction signal)
Z^{III}	Abstraction of information from y^{PER} (Observation transmission)
l	Predictive representation of Z (Prediction at future time from the difference between C' and C)
X' ($\{x_{t-1}\}$)	Self-posture information
y^{POR} ($\{y_t\}$)	Allocentric visual information (distal distance/landmarks, absolute object positions)
y^{PER}	Egocentric visual information (proximal distance/landmarks, relative object positions, object category, landscape information)
u^w ($\{u_t\}$)	Rotational speed movement

[6] Taniguchi, A., Fukawa, A., & Yamakawa, H. (2022). Hippocampal formation-inspired probabilistic generative model. Neural Networks, 151 , 317-335.

Function realization graph (FRG)

The top-level function is **spatial cognition**, supported by **spatial categorization** and **self-localization**. Spatial categorization **(Egocentric)** is primarily supported by the LEC, while self-localization **(Allocentric)** is mainly supported by the MEC. These functions are integrated by the hippocampus.



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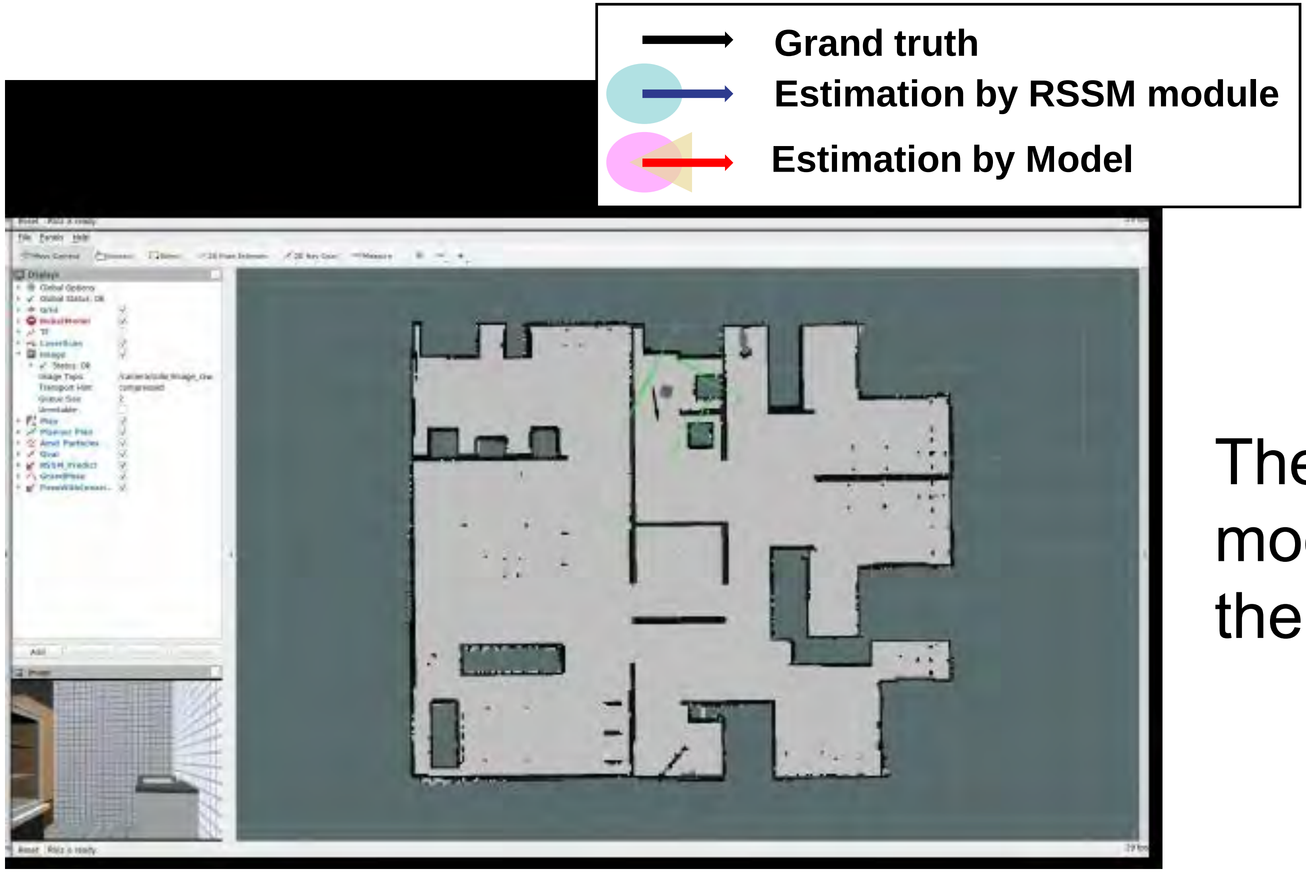
Research based on the BRA data

We constructed and evaluated a spatial cognition model based on this **Data for Brain Reference Architecture**, and it was accepted for the journal Frontiers in Computational Neuroscience last month[13].



The Hippocampal formation-inspired model showed **adaptability** even in the **sudden change** of teleportation.

[13] Nakashima, Takeshi, et al. "Hippocampal formation-inspired global self-localization: quick recovery from the kidnapped robot problem from an egocentric perspective." *Frontiers in Computational Neuroscience* 18: 1398851.

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Conclusion

- The BIF and HDC of hippocampal formation inspired spatial cognition model is constructed using the **SCID method**.
  In this process, the **GIPA** is used to create the HDC from the BIF for building the spatial cognition model with a **probabilistic generative model**.

- The spatial cognition model is being created based on the BRA data and shows higher **adaptability** in the **sudden change** situation.