RITSUMEIKAN UNIVERSITY

Ritsumeikan Global Innovation Research Organization (R-GIRO)

Correspondence and Fusion of Artificial Intelligence and Brain Science

全脳確率的生成モデルWB-PGM

Tadahiro Taniguchi

1) Professor, College of Information Science & Engineering, Ritsumeikan University

2) Visiting General Chief Scientist, Technology Division, Panasonic

Invited talk at

第4回 WBAレクチャー「脳のコンポーネント図の作り方：プロセス間関係の整理と確率モデルによる記述」@Online, Zoom

11th December 2022

JST CREST

科研費 KAKENHI

Symbol Emergence

MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

経歴 Tadahiro Taniguchi (谷口忠大)

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- 2006: 京都大学大学院工学研究科精密工学専攻（機械系）
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- 2008: 立命館大学情報理工学部助教
- 2010: 立命館大学情報理工学部准教授
- 2015-2016 インペリアル・カレッジ・ロンドン 客員准教授
- **2016-: 一般社団法人ビブリオバトル協会代表理事**
- **2017-: 立命館大学情報理工学部教授**
- **2017-: パナソニック客員総括主幹技師 (クロスアポイントメント 20%)**
- **2022-: 立命館大学RARAフェロー**

横澤一彦、編「認知科学講座 4 心をとらえるフレームワークの展開」（東京大学出版会）2022/10/11 6章 記号創発ロボティクス(谷口忠大)

僕とアリスの夏物語 人工知能の,その先へ (岩波科学ライブラリ) **2022/1/15**

「心を知るための人工知能」（共立出版）2020

「賀茂川コミュニケーション塾」（世界思想社）2019

「記号創発ロボティクス」（講談社メチエ）2014

「コミュニケーションするロボットは創れるか」（NTT出版）2010

WBAレクチャー **協力**

研究拠点Ⅲ：生産年齢人口減の克服

記号創発システム科学創成：

実世界人工知能と次世代共生社会の学術融合研究拠点

Symbol Emergence

PL: 谷口忠大（情報理工学部）

GL: 李周浩（情理）
TL: 島田伸敬（情理）

グループ2 空間知能 ロボティクス

記号創発システム科学

GL: 安田裕子（心理）
TL: サトウタツヤ（心理）

グループ4 共生環境デザイン

実世界人工知能
Real-world AI

次世代共生社会
Symbiotic Society

グループ3 音響心理技術

グループ1
記号創発・人工知能

PL(GL): 谷口忠大（情理）
TL: 萩原良信（情理）

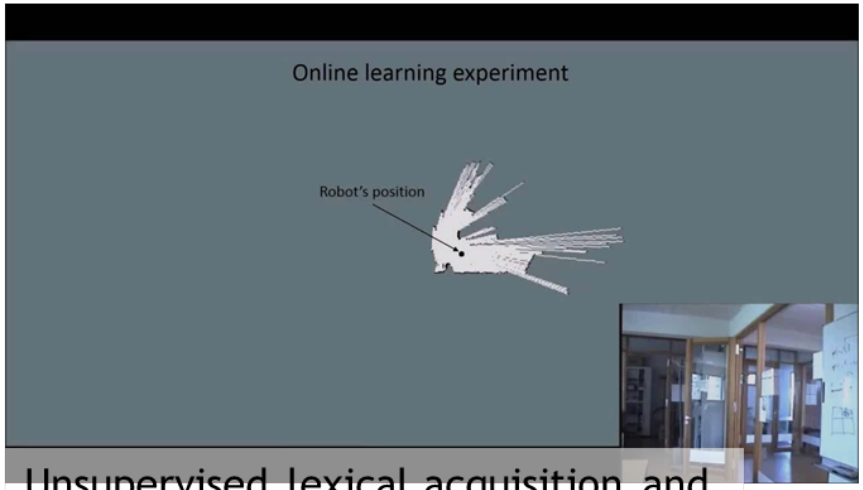
グループ5 ﾏﾙﾁﾓｰﾀﾞﾙ言語教育

GL: 西浦敬信（情理）
TL: 添田喜治（産総研）

GL: 山中司（生命）※
TL: 井上明人（映像）
※英語教育

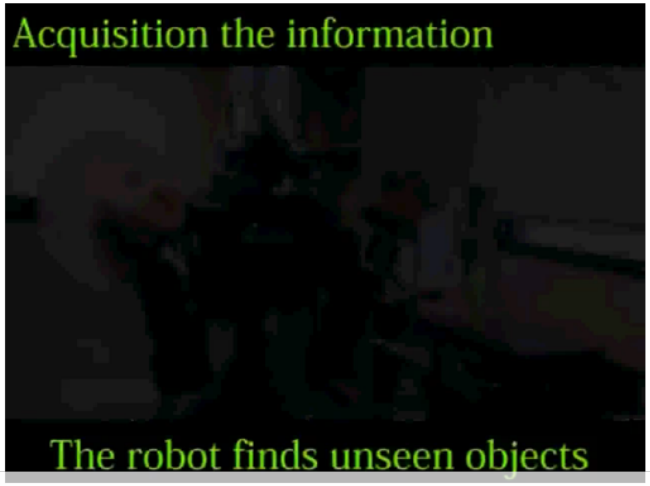
Symbol emergence in robotics

using probabilistic generative models

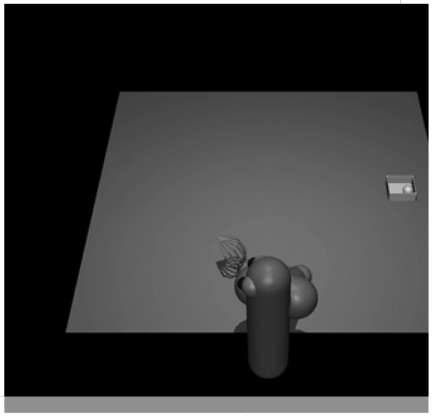


Unsupervised lexical acquisition and spatial concept formation

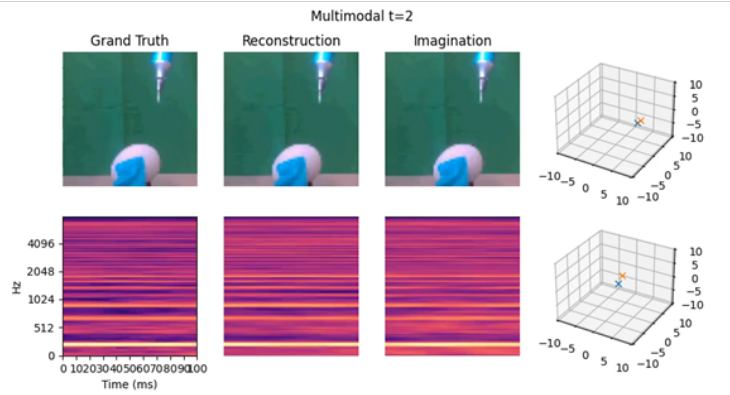
Application to service robotics



Multimodal object categorization



Integration of imitation and reinforcement learning



Multimodal World modeling for manipulation

Neural Networks 150 (2022) 293–312

Contents lists available at ScienceDirect

Neural Networks

journal homepage: www.elsevier.com/locate/neunet

2021 Special Issue on AI and Brain Science: AI-powered Brain Science

A whole brain probabilistic generative model: Toward realizing cognitive architectures for developmental robots

Tadahiro Taniguchi [a,*], Hiroshi Yamakawa [b,g,h], Takayuki Nagai [c], Kenji Doya [d], Masamichi Sakagami [e], Masahiro Suzuki [b], Tomoaki Nakamura [f], Akira Taniguchi [a]

[a] Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Japan
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ARTICLE INFO

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Keywords:
Cognitive architecture
Probabilistic generative model
Brain-inspired artificial intelligence
Artificial general intelligence
Developmental robotics

ABSTRACT

Building a human-like integrative artificial c
(AGI), is the holy grail of the artificial intel
that enables an artificial system to achieve cognitive development will be an excellent reference for
brain and cognitive science. This paper des
by integrating elemental cognitive modules
approach is based on two ideas: (1) brain-
human-level intelligence, and (2) a probabili
to develop a cognitive system for developme
ment framework is called a whole brain PG
cognitive architectures in that it can learn
information.

Taniguchi, Tadahiro, et al. "A whole brain probabilistic generative model: Toward realizing cognitive architectures for developmental robots." *Neural Networks* 150 (2022): 293-312.

新学術領域「人工知能と脳科学の対照と融合」(2016-2021)
領域代表・銅谷賢治

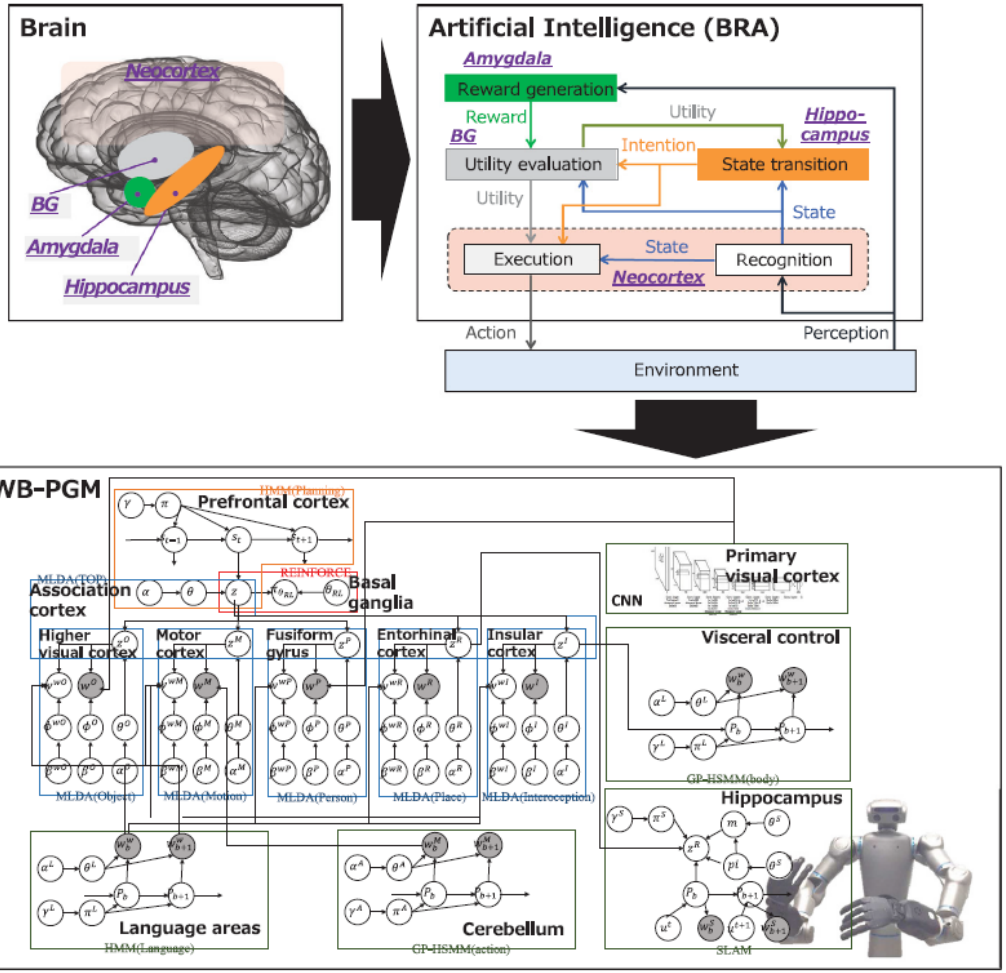
視覚や聴覚といった個別のモダリティ
その神経系による処理にとどまらず，
脳の構造に学び，**マルチモーダル**かつ**全脳**的な**認知アーキテクチャ**を構成する方法論に関する議論へと発展.

実世界で作動し**発達し続ける**真のAGIに向けて

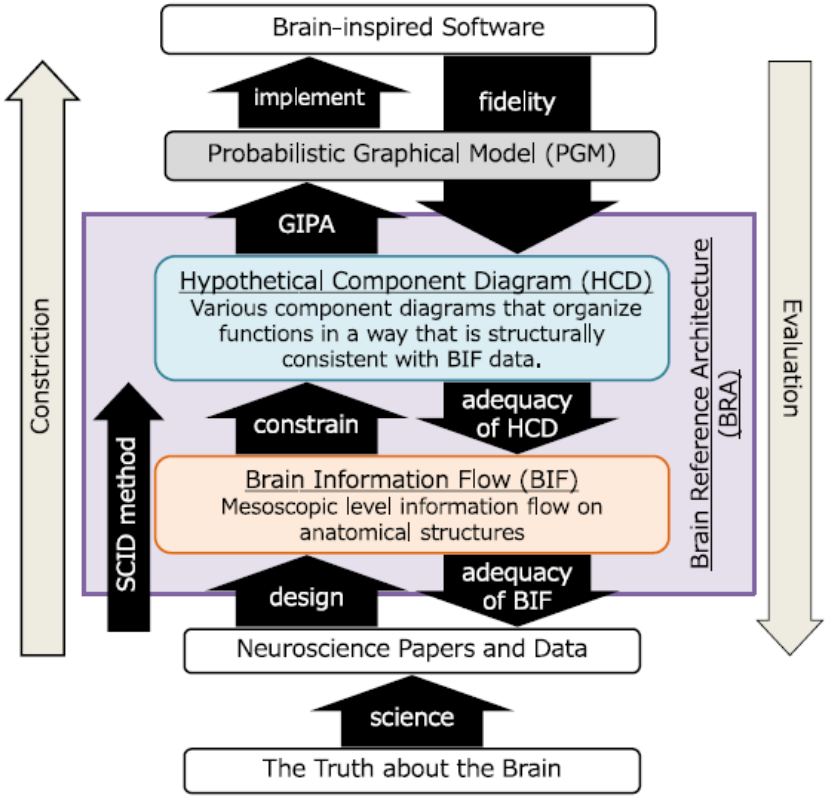
WB-PGMの２つのポイント

① Brain-inspired AI

② PGM-based cognitive architecture



Extension of BRA-driven development [Yamakawa+ 2021]



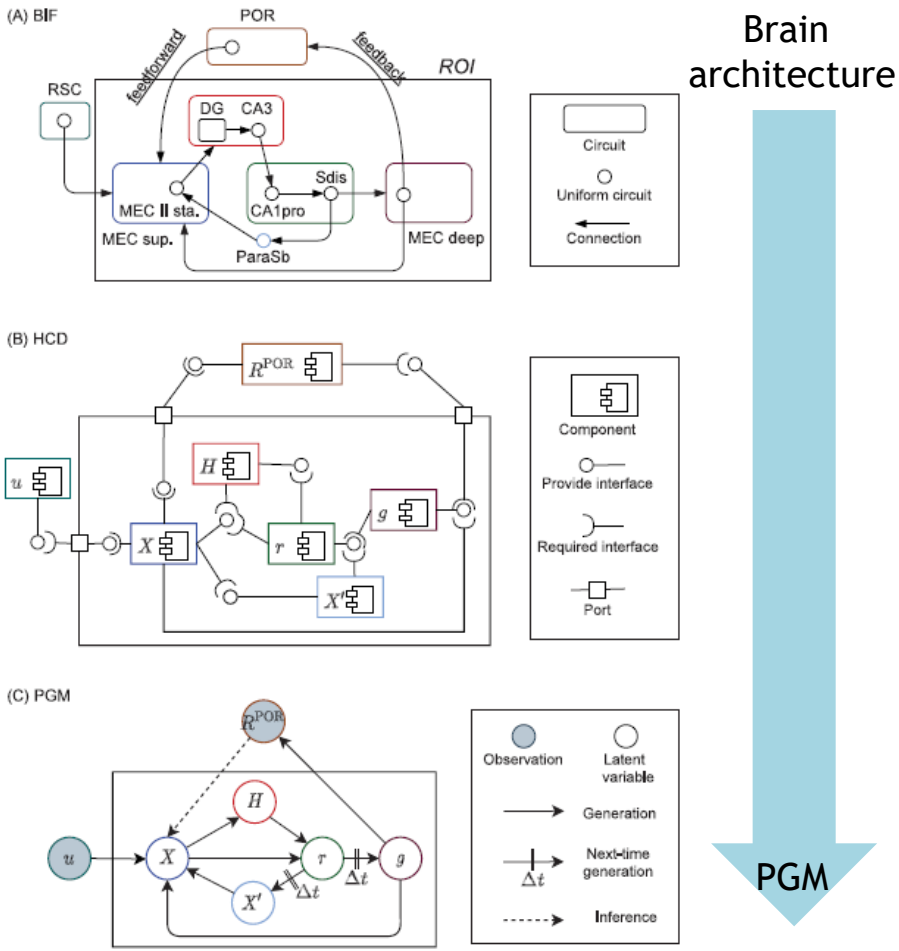
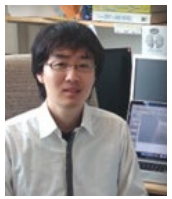


Fig. 2. WB-PGM development as extended BRA-driven development. A development method that extends BRA-driven development, which utilizes BRA data such as BIF and HCD, by adding GIPA, thus creating PGMs. The construction process is shown in the upward direction, while the downward direction shows the evaluation process.



- Yamakawa, Hiroshi. "The whole brain architecture approach: Accelerating the development of artificial general intelligence by referring to the brain." *Neural Networks* 144 (2021): 478-495.
- Taniguchi, Akira, Ayako Fukawa, and Hiroshi Yamakawa. "Hippocampal formation-inspired probabilistic generative model." *Neural Networks* 151 (2022): 317-335.

Achievements of WB-PGM-based approach

Neural Networks 151 (2022) 317–335

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journal homepage: www.elsevier.com/locate/neunet

2021 Special Issue on AI and Brain Science: Brain-inspired AI

Hippocampal formation-inspired probabilistic generative model

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Hippocampal formation
Simultaneous localization and mapping
Probabilistic generative model
Phase precession queue assumption

ABSTRACT

In building artificial intelligence (AI) agents, referring to how brains function in real environments can accelerate development by reducing the design space. In this study, we propose a probabilistic generative model (PGM) for navigation in uncertain environments by integrating the neuroscientific knowledge of hippocampal formation (HF) and the engineering knowledge in robotics and AI, namely, simultaneous localization and mapping (SLAM). We follow the approach of brain reference architecture (BRA) (Yamakawa, 2021) to compose the PGM and outline how to verify the model. To this end, we survey and discuss the relationship between the HF findings and SLAM models. The proposed *hippocampal formation-inspired probabilistic generative model* (HF-PGM) is designed to be highly consistent with the anatomical structure and functions of the HF. By referencing the brain, we elaborate on the importance of integration of egocentric/allocentric information from the entorhinal cortex to the hippocampus and the use of discrete-event queues.

1. Introduction

In building artificial intelligence (AI) agents, referring to how brains function in real environments can accelerate development by reducing the design space. Hippocampal formation (HF) supports crucial neural capabilities, such as spatial cognition, self-localization for navigation, mapping, and episodic memory. In neuroscience, HF and its functions have attracted increasing attention in recent years. The hippocampus has long been considered the brain region responsible for configuring the cognitive map (O'keefe & Nadel, 1978; Tolman, 1948). To this end, designated neurons, such as place cells in the hippocampus (O'keefe & Nadel, 1978) and grid cells in the medial entorhinal cortex (MEC), exist to execute these functions (Fyhn et al., 2004; Hafting et al., 2005). From the perspective of computational neuroscience, numerous computational model-based studies have focused on functions involving the hippocampus (Banino et al., 2018; Kowadlo et al., 2019; Madl et al., 2015; Milford et al., 2004; Schapiro et al., 2017; Scleidorovich et al., 2020). Alongside these computational studies, the use of brain-inspired AI and intelligent robotics is crucial to the implementation of these spatial functions. From an engineering perspective, simultaneous localization and mapping (SLAM) (Thrun et al., 2005) represents a typical approach in computational geometry and robotics. Spatial cognition and place understanding are important challenges that must be overcome to facilitate the advance of robotics (Taniguchi et al., 2019). However, despite the abundancy of neuroscience knowledge related to HF and the progress in AI technology, combining knowledge from both fields and applying it to robotics remains a major challenge.

Purposes: This study aims to bridge the gap between neuroanatomical/biological findings of the HF and engineering technologies of probabilistic generative models (PGMs), particularly in AI and robotics. This paper is a feasibility study on the methodology proposed by Yamakawa (2021). We establish a correspondence between the function/structure of the HF in neuroscience and spatial cognitive methods in robotics. The main objectives of this study are as follows.

- To provide suggestions for the construction of a computational model with functions of HF by surveying the association between SLAM in robotics and HF in neuroscience.
- To construct a *brain reference architecture* (BRA) that operates with biologically valid and consistent functions, as a specification for implementing a brain-inspired model.

Type of paper: This report is a hypothesis-suggestion paper that presents a novel argument, interpretation, or model intended to introduce a hypothesis/theory, based on a literature review, and provides the direction for its verification. We

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Brain-inspired Probabilistic Generative Model for Double Articulation Analysis of Spoken Language

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***Abstract*—In human spoken language, words are connected to form a sentence, and words are composed of phonemes or syllables. This hierarchy structure is a double articulation structure. Here, the function of analyzing the double articulation structure is called double articulation analysis. The human brain has a function to analyze the double articulation structure. However, existing methods of spoken language acquisition using a double articulation analyzer are not designed with reference to brain circuitry. This study proposed a probabilistic graphical model as a double articulation analysis hypothesis that can be realized in the brain based on many neuroscience surveys. We performed the following procedure: (i) investigated and organized**

guage, it is important to promote correspondence and fusion with each other. It is assumed that some regions in the brain are responsible for the function in order for the double articulation structure to be processed. However, it is still unsolved (although partial knowledge has been gathered) where and how the DAA is actually performed in the human brain [2]. In contrast, there are computational models that allow for DAA [3]–[5]. Nonparametric Bayesian double articulation analyzer (NPB-DAA) [3] is an unsupervised learning method based on Bayesian inference in the probabilistic generative

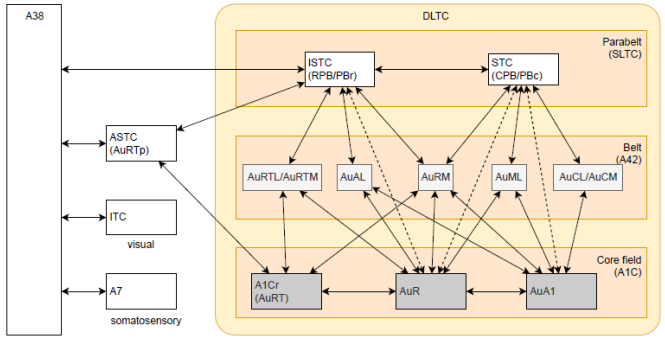
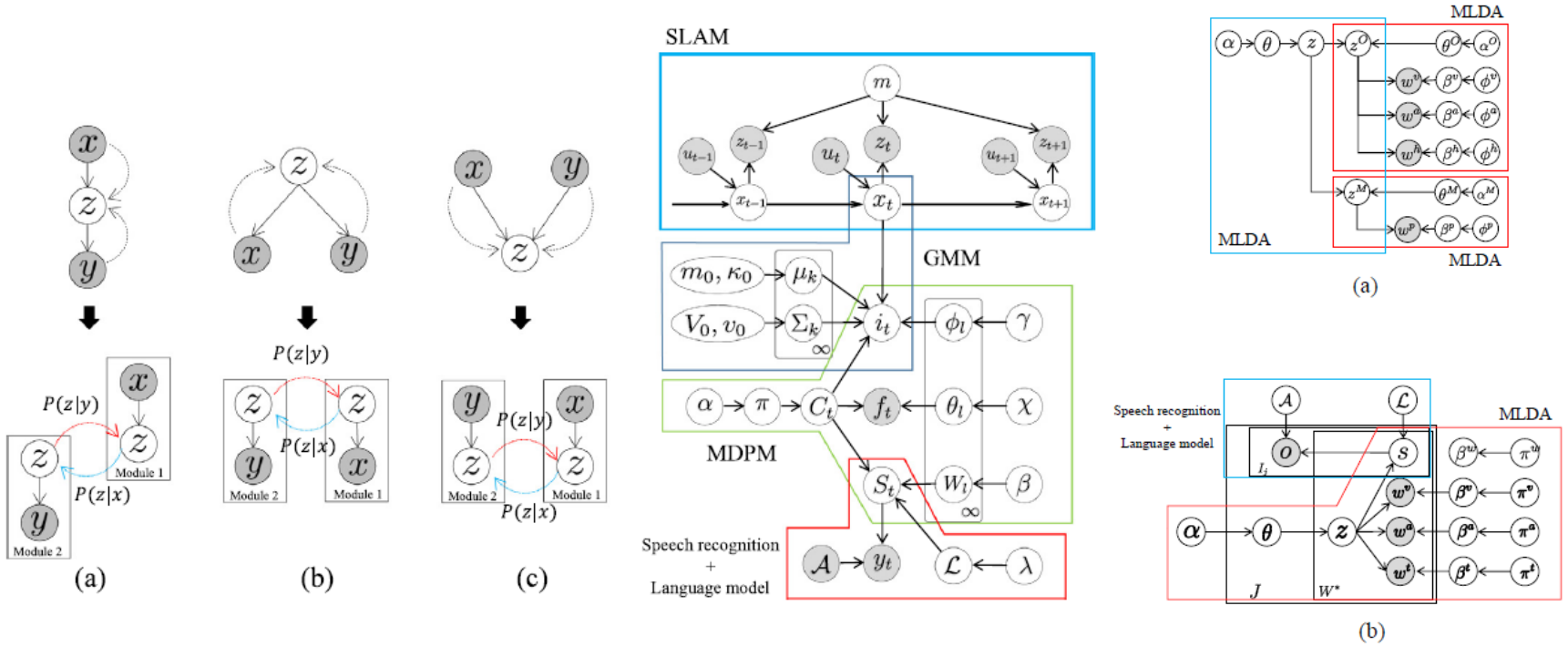


Fig. 3. Brain information flow (BIF) related to double articulation analysis (DAA). The bi-directional arrows indicate the connections between regions in the cortex.

Taniguchi, Akira, Ayako Fukawa, and Hiroshi Yamakawa. "Hippocampal formation-inspired probabilistic generative model." *Neural Networks* (2022).

A. Taniguchi, M. Muro, H. Yamakawa, T. Taniguchi, Brain-inspired Probabilistic Generative Model for Double Articulation Analysis of Spoken Language, ICDL 2022

SERKET: An Architecture for Connecting Stochastic Models to Realize a Large-Scale Cognitive Model [Nakamura+ 18]



- Connecting cognitive modules developed as probabilistic generative models and letting them work together as a single unsupervised learning system.
- Having inter-module communication of probabilistic information and guaranteeing theoretical consistency to some extent.
- Neuro-SERKET supports deep generative models, i.e., VAE, as well.

Nakamura T, Nagai T and **Taniguchi T,** SERKET: An Architecture for Connecting Stochastic Models to Realize a Large-Scale Cognitive Model. Front. Neurorobot. 12:25. (2018) doi: 10.3389/fnbot.2018.00025

Taniguchi, T., Nakamura, T., Suzuki, M. et al. Neuro-SERKET: Development of Integrative Cognitive System Through the Composition of Deep Probabilistic Generative Models. New Gener. Comput. 38, 23–48 (2020). https://doi.org/10.1007/s00354-019-00084-w

Example: unsupervised categorization of image and speech [Taniguchi+ 2020]

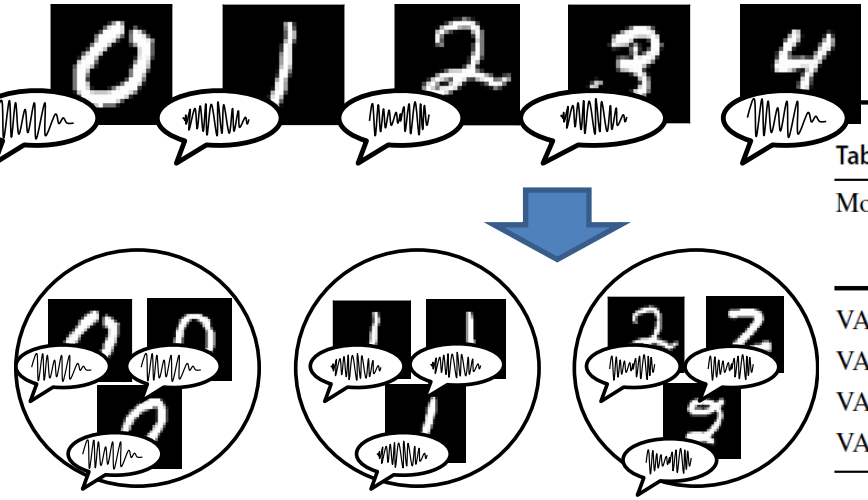


Table 4 Classification accuracy in the GMM and LDA modules

Model	Accuracy (%)		Features introduced in Neuro-SERKET		
	GMM	LDA	Head-to-head	Tail-to-tail	Neura
VAE GMM LDA ASR	62.0	27.4			
VAE GMM LDA + ASR	62.0	91.8	✓		
VAE + GMM LDA + ASR	63.7	91.8	✓		✓
VAE + GMM + LDA + ASR	**91.0**	**93.7**	✓	✓	✓

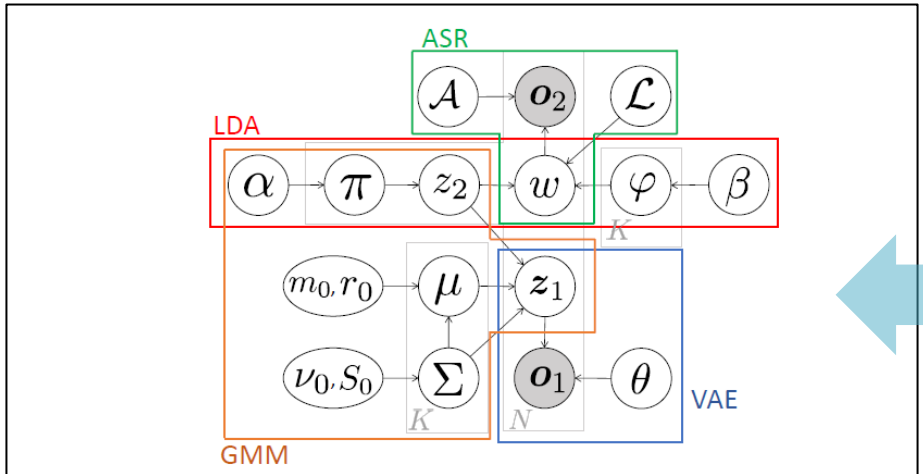


Fig. 5 The original graphical model of the integrative PGM (VAE+GMM+LDA+ASR). Each block shows each module.

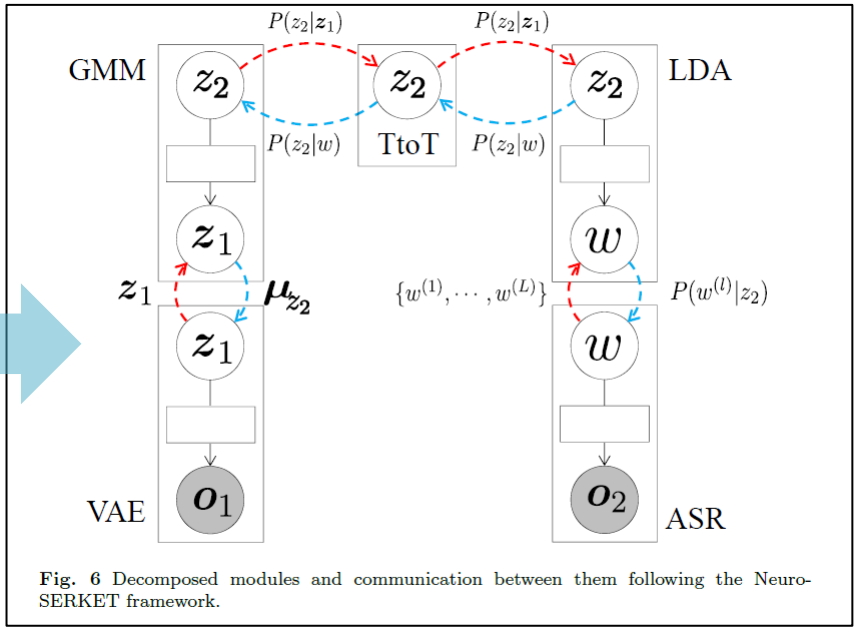
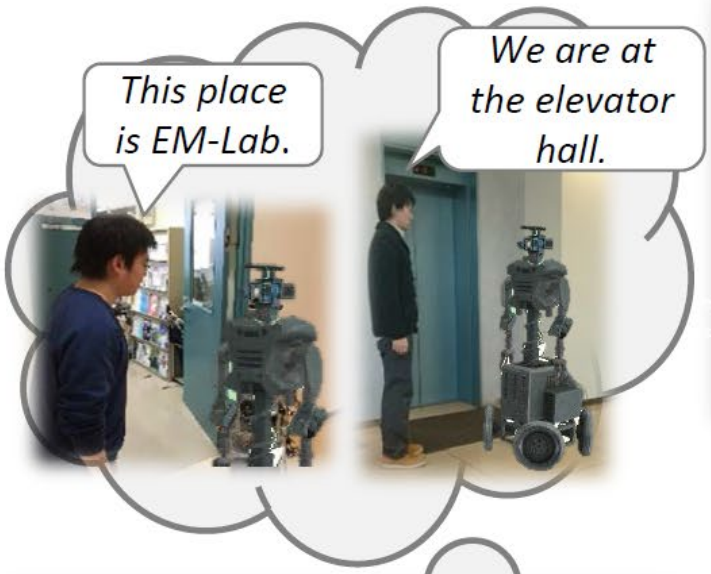
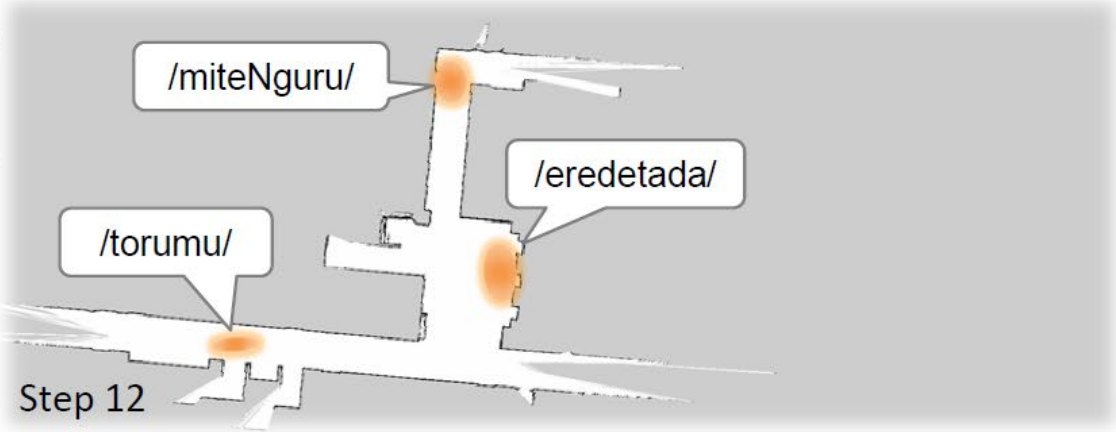


Fig. 6 Decomposed modules and communication between them following the Neuro-SERKET framework.

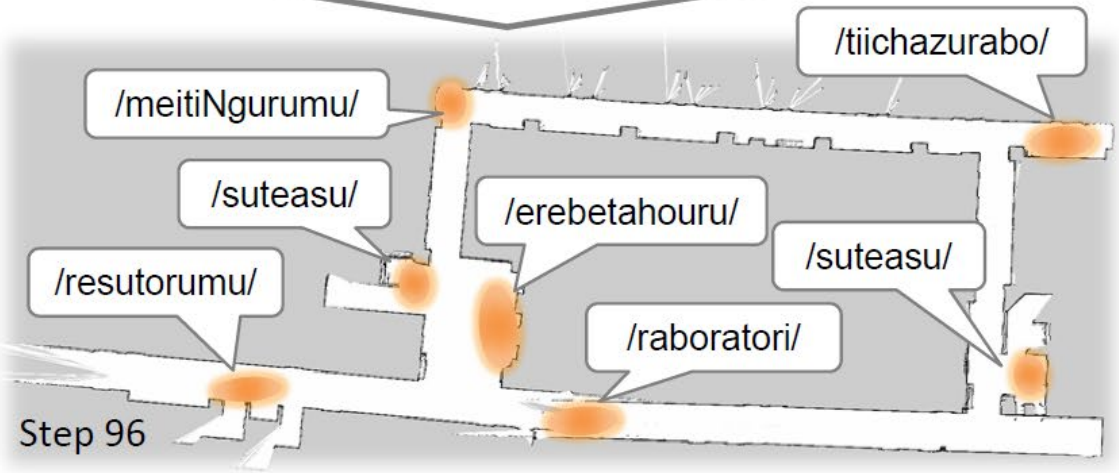
Taniguchi, T., Nakamura, T., Suzuki, M. et al. Neuro-SERKET: Development of Integrative Cognitive System Through the Composition of Deep Probabilistic Generative Models. New Gener. Comput. 38, 23–48 (2020). https://doi.org/10.1007/s00354-019-00084-w

Online spatial concept formation and lexical acquisition: **SpCoSLAM** [Taniguchi+ 2017]



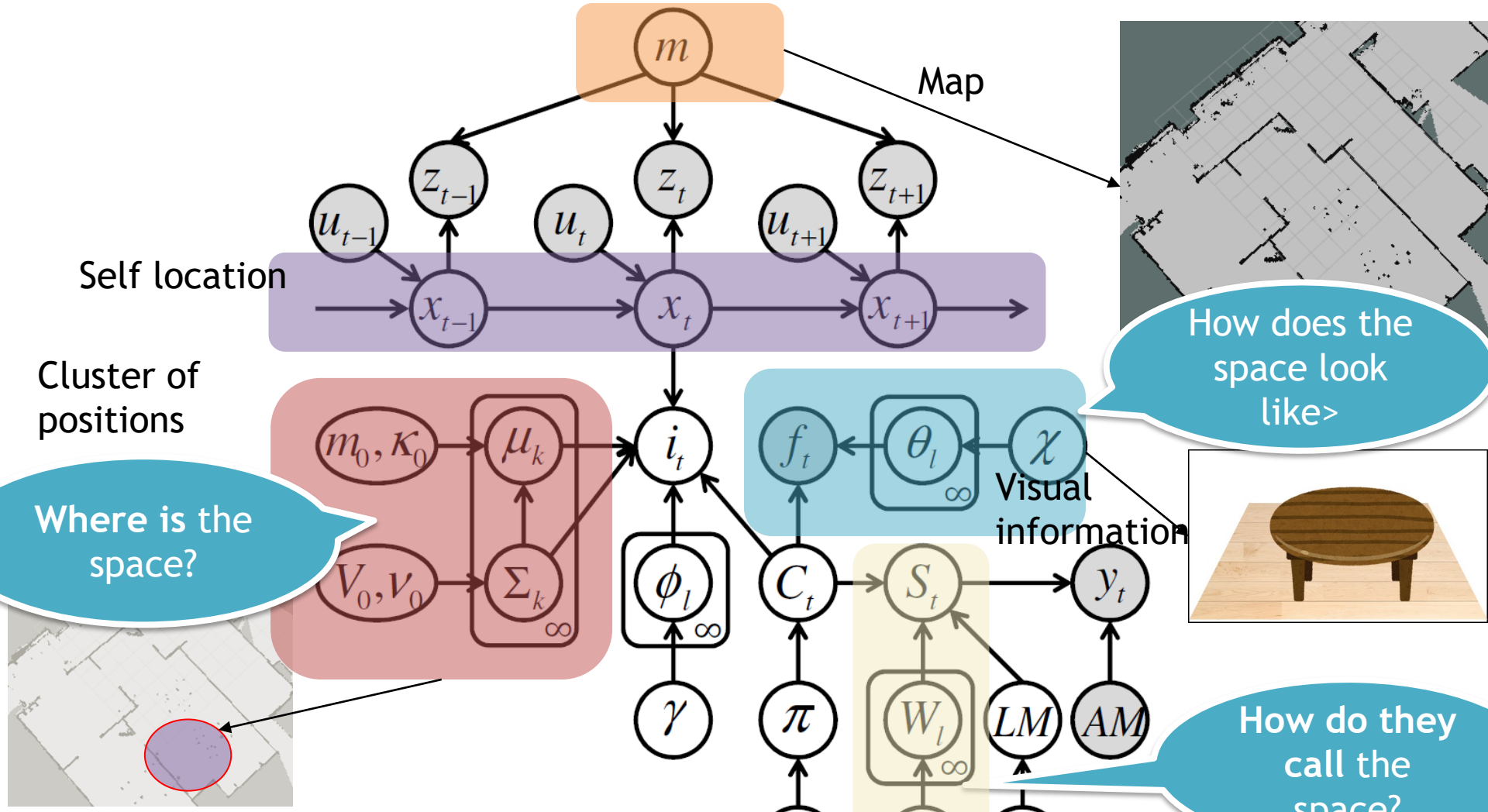


Online learning



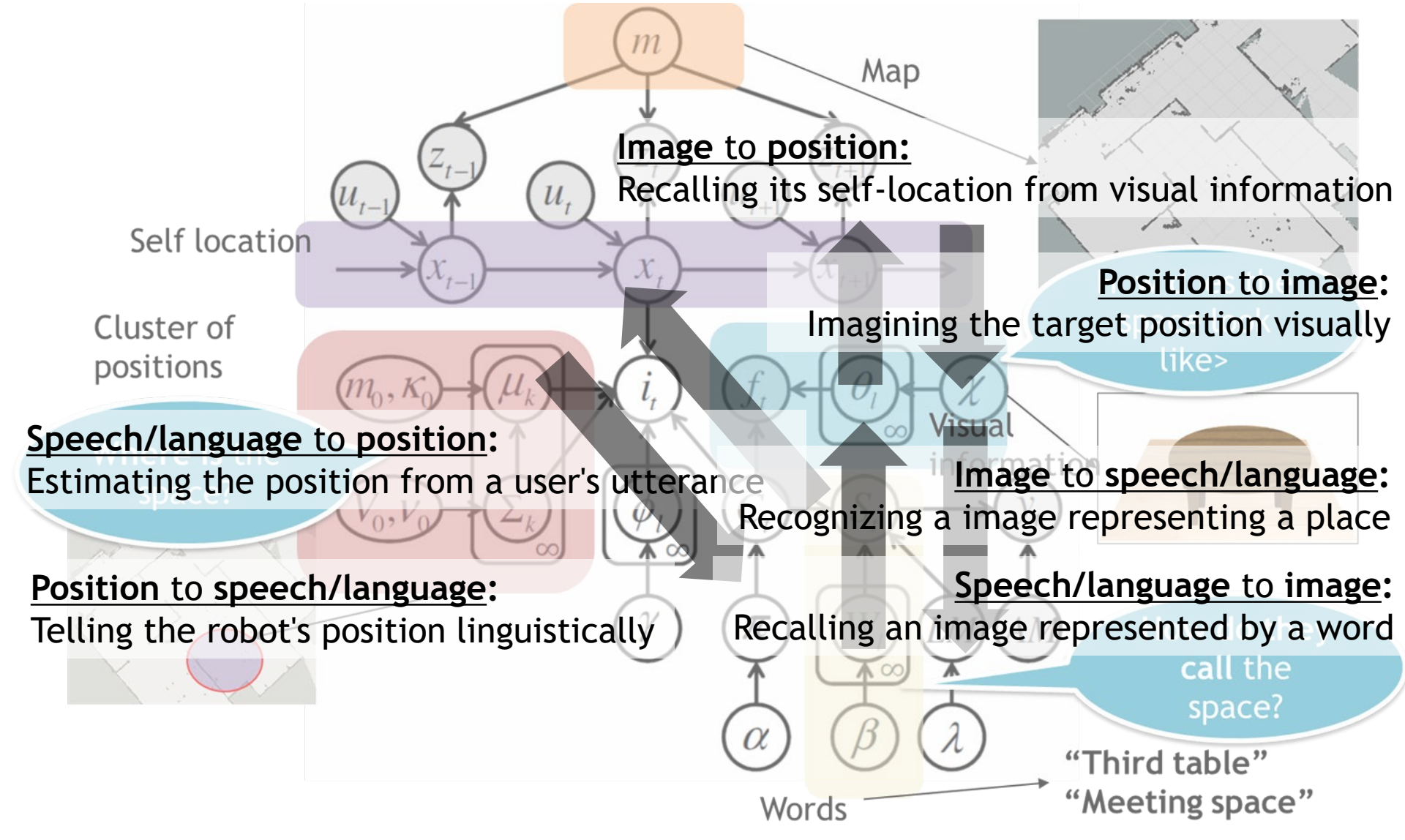
Akira Taniguchi, Yoshinobu Hagiwara, **Tadahiro Taniguchi** and Tetsunari Inamura, Online Spatial Concept and Lexical Acquisition with Simultaneous Localization and Mapping, IEEE IROS 2017
Akira Taniguchi, Yoshinobu Hagiwara, **Tadahiro Taniguchi**, Tetsunari Inamura, Improved and scalable online learning of spatial concepts and language models with mapping, Autonomous Robots, 2020. DOI: 10.1007/s10514-020-09905-0

SpCoSLAM



Online learning of Multimodal spatial concept

Notably, **Cross-modal inference** provides "**functions**" to a cognitive system



まとめと展望

まとめ

- ✓ 脳に学び確率的生成モデルに基づき全脳の認知アーキテクチャの構成を目指すWB-PGMのアプローチについて紹介した.
- ✓ いくつかのWB-PGMのアプローチに基づく仮説生成とモデル構築の事例について紹介した.

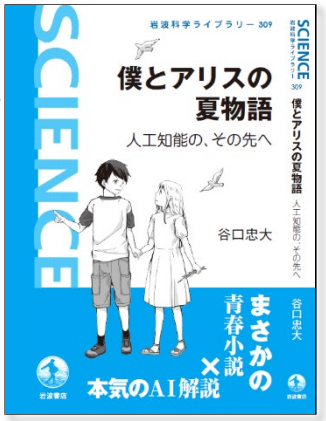
展望

- ✓ WB-PGMのアプローチはフレームワークとして明らかになったが，その開発自体は今後の課題である．多くの研究者や開発者と協調しての研究開発推進が期待される.

- ◘ 神経科学知見からBrain Information Flow(BIF)を構築する。
- ◘ BIFから仮説的コンポーネント図(HCD)やPGMを設計する。
- ◘ HCDやPGMに基づいて実装と計算機実験を行う

そのための**WBAレクチャー**！！

Information



NEW

僕とアリスの夏物語 人工知能の,その先へ
岩波書店, **2022年1月**

http://ai.tanichu.com
公式サイト
【無料】講義資料・講義動画配信中

記号創発ロボティクス
講談社, 2014

イラストで学ぶロボット工学
講談社, 2017

NEW

横澤一彦・編「認知科学講座４
心をとらえるフレームワークの展開」
（東京大学出版会）**2022年10月**
6章　記号創発ロボティクス(谷口忠大)

イラストで学ぶ人工知能概論
改訂第2版, 講談社, 2020

心を知るための人工知能
共立出版, 2020

賀茂川コミュニケーション塾
世界思想社, 2019

Amazon 著者ページ https://amzn.to/3bkPW3i

Funding

科研費 KAKENHI
RITSUMEIKAN GLOBAL INNOVATION RESEARCH ORGANIZATION R-GIRO
JST CREST
MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

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