Data for Brain Reference Architecture of AF24Hippocampus-Amygdala

Integrating BRA for Spatial Cognition and Fear Conditioning

Akira Taniguchi[a*], Atsushi Fujii[a], Takeshi Nakashima[b], Tatsuya Miyamoto[c], Yoshimasa Tawatsuji[d,e], and Hiroshi Yamakawa[d,e]

[a] College of Information Science and Engineering, Ritsumeikan University, Osaka, Japan

[b] Graduate School of Information Science and Engineering, Ritsumeikan University, Osaka, Japan

[c] Waseda University, 3-4-1 Okubo, Shinjuku-ku 169-0072, Japan

[d] The Whole Brain Architecture Initiative, Tokyo, Japan

[e] School of Engineering, The University of Tokyo, Tokyo, Japan

[*]Corresponding author: Akira Taniguchi; a.taniguchi@em.ci.ritsumei.ac.jp

Abstract

The hippocampal formation plays a pivotal role in spatial cognition and episodic memory, while the amygdala is essential for adaptive fear conditioning. We have developed a brain reference architecture (BRA) data format by integrating "TM24Amygdala_ver4" (based on "YM24Amygdala") and "TN24HippocampalFormation" BRA data. This BRA data expands on previous BRA models by incorporating new brain information flow (BIF) that captures the connections between the hippocampus and amygdala. The constructed BIF provides a basis for defining higher-order functions related to spatial cognition and fear conditioning. These improvements deepen our understanding of the anatomical structure linking these regions and their interconnected functions. The BRA repository provides comprehensive access to these data, supporting further research into the functional and structural relationships between the hippocampal formation and the amygdala. This work not only advances our understanding of each region's individual role but also provides insights into how their interaction shapes complex cognitive and emotional processes.

Keywords: Amygdala; Brain Reference Architecture; Fear Conditioning; Hippocampal Formation; Spatial Cognition

Author roles:

Akira Taniguchi Writing-original draft, Conceptualization, Data curation, Investigation, Project administration, Funding acquisition

Atsushi Fujii Data curation, Investigation

Takeshi Nakashima Data curation, Investigation

Tatsuya Miyamoto Data curation, Investigation

Yoshimasa Tawatsuji Conceptualization, Data curation, Investigation, Project administration

Hiroshi Yamakawa Conceptualization, Data curation, Investigation, Project administration, Funding acquisition

1 Context

This data paper reports Brain Reference Architecture (BRA) data on spatial cognition in the hippocampal formation and fear conditioning in the amygdala. BRA data is usually limited to individual areas with specific functions, but to construct a whole BRA, it is important to construct BRA data for the connections between different areas. This is the first attempt to integrate BRA data.

Hippocampal formation In neuroscience and cognitive science, knowledge has accumulated on how hippocampal formation contributes to the spatial cognition of organisms. Tolman (1948) demonstrated that rats searching for food in an environment learn spatial representations that enable flexible behavior in response to

familiar path obstructions, rather than simple stimulus-response associations, and he termed this spatial representation a cognitive map. Later, various cells supporting the cognitive map, such as place and grid cells, were reported to exist in the hippocampal formation (O'Keefe & Nadel, 1979).

Taniguchi, Fukawa, and Yamakawa (2022) integrated neuroscientific knowledge of hippocampal formation (HF) with engineering knowledge from robotics, specifically simultaneous localization and mapping (SLAM), to propose a probabilistic generative model for navigation in uncertain environments. The hippocampal formation-inspired probabilistic generative model (HF-PGM) is designed to closely match the anatomical structure and functions of the hippocampal formation.

Amygdala The amygdala is a critical brain region involved in the processing of emotions, particularly fear (Maren, 2001). Fear conditioning is when an innocuous conditioned stimulus is paired with a noxious unconditioned stimulus, leading to a fear response to the previously innocuous conditioned stimulus. This process is modulated by the hippocampal CA1 region, which processes contextual information—such as environmental cues, temporal context, and physiological state—to ensure that fear responses are appropriate to the specific context.

Integrationg BRA We have developed a BRA data format by integrating "TM24Amygdala_ver4" and "TN24HippocampalFormation" BRA data. Nakashima, Taniguchi, Fukawa, and Yamakawa (2024) have constructed "TN24HippocampalFormation" BRA data. Tatsuya Miyamoto constructed "TM24Amygdala_ver4" based on "YM24Amygdala" BRA data, which Maruyama, Miyamoto, Tawatsuji, and Yamakawa (2024) have been constructed. This BRA data expands on previous BRA models by incorporating new brain information flow (BIF) that captures the connections between the hippocampus and amygdala.

2 Method

BRA-driven development/SCID method BRA-driven development is a methodology for building software based on brain architecture (Yamakawa, 2021). It acknowledges that neuroscience knowledge is still insufficient to elucidate the whole picture and constructs a hypothetical software architecture using anatomical structures as constraints. The structure-constrained interface decomposition (SCID) method was used to design software that was consistent with the brain's structure and function, as obtained through neuroscience. The software consisted of the following three steps:

Step 1. Brain Information Flow (BIF) construction.

Step 2. Consistent determination of the region of interest (ROI) and top-level function (TLF).

Step 3. HCD creation.

Step 3-1. Enumerating candidate component diagram.

Step 3-2. Rejecting diagrams that are inconsistent with scientific knowledge.

You can see more details about these steps in (Yamakawa, 2021). As the computational model verification of HF-PGM is not within the scope of the BRA data paper, a detailed explanation is provided in the paper (Nakashima, Otake, et al., 2024; Taniguchi et al., 2022).

Brain information flow (BIF) In this data, the BIF is constructed using the SCID method. Figure 1 shows the ROI and BIF of this study. Table 1 shows the abbreviation list of BRA data.

Here, we will describe the circuits added to the BRA data. First, CA1-Context in TM24Amygdala was changed to CA1_ventral. Then, S_ventral was added. CA1_distal and CA1_proximal in TN24HippocampalFormation were defined as sub-regions of CA1_dorsal (Masurkar, 2018; Paw-Min-Thein-Oo, Sakimoto, Kida, & Mitsushima, 2020). In addition, S_distal and S_proximal inTN24HippocampalFormation were defined as sub-regions of S_dorsal (Park et al., 2024).

Here, we will describe the connections added to the BRA data. CA1_ventral was known to project to BA_Fear and BA_Ext (Pitkänen, Jolkkonen, & Kemppainen, 2000). Additionally, there is a projection from BA to CA1_ventral (Yang & Wang, 2017). In particular, Yang and Wang (2017) states that "Work in rodents has shown that negative and positive emotion neurons are spatially segregated into the BLa and BLp (Kim, Pignatelli, Xu, Itohara, & Tonegawa, 2016)." Here, BLAa is the anterior part of the basolateral amygdala, and BLAp is the posterior part of the basolateral amygdala. Similarly, S_ventral has bidirectional projection to BA (Fanselow & Dong, 2010). CA1_ventral has projections from CA3 and LEC_III (Lines, Nation, & Fellous, 2014). MEC_III has projections to CA1_ventral and S_ventral (Lines et al., 2014; Ohara et al., 2023). From CA1_ventral, there are projections to La_Fear (Lee et al., 2024), S_ventral (Fanselow & Dong, 2010), S_dorsal (Park et al., 2024), and MEC_V (Ohara et al., 2023). There is also a projection from S_ventral to MEC_V (Ohara et al., 2023). La_Fear and BA in the amygdala and LEC_II, III have bidirectional projections (Wang, Tambini, & Lapate, 2022). BA has a projection to CA3 ventral (Wang et al., 2022), but in this BRA data, it is assumed to be CA3.

It has been suggested that IL and PL within the PFC and BM within the amygdala nucleus are important for fear conditioning and elimination (Asede, Doddapaneni, & Bolton, 2022). Therefore, we added projection with the PFC as an updated version of the BIF in the amygdala.

Toward the Construction of a Functional Hypothesis In CA1 and subiculum, spatial information is related to the proximal area, and non-spatial information is related to the distal area. In addition, functional differences exist between the dorsal and ventral areas in CA1 and the subiculum (Masurkar, 2018). The ventral area is mainly connected to the amygdala and is responsible for processing related to anxiety, goal-directedness, fear, and sociality. The dorsal area is responsible for spatial processing, compared to the ventral area.

Wang et al. (2022) suggests two functionally different pathways between the BA and the hippocampus: direct and indirect pathways. The indirect pathway, which passes through the LEC, will likely carry integrated, semantically rich emotional information that includes recent experiences and environmental elements. In direct projection, it plays a role in mediating fear conditioning learning (Fanselow & Dong, 2010).

Although this is outside of the ROI with this BRA, there is also a pathway between the hippocampus and the amygdala that goes via the ventral medial prefrontal cortex (vmPFC) (Sierra-Mercado, Padilla-Coreano, & Quirk, 2010) However, Park et al. (2024) reported that cognitive control in an active place avoidance task is not dependent on mPFC damage.

Summary This study revealed that multiple pathways connect the amygdala and hippocampus. The BIFs of the hippocampal formation and amygdala were integrated by connections between the ventral and dorsal hippocampus and an indirect pathway through connections between the amygdala and the LEC, mainly.

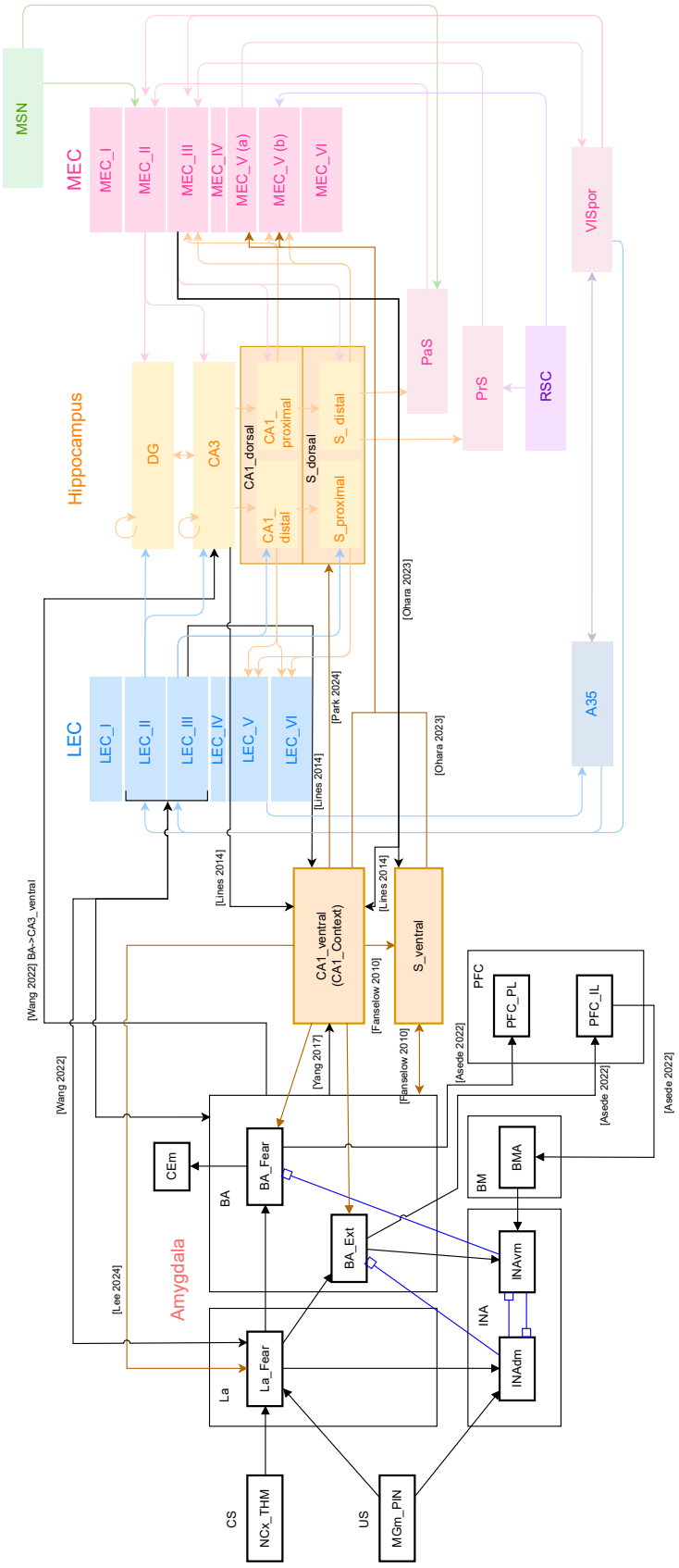

Figure 1: The brain information flow (BIF) of the BRA data

Table 1: List of hippocampal and amygdalar field units with updated definitions

Abbreviation	**Region Name**
LEC_I, II, III, IV, V, VI	Lateral Entorhinal Cortex Layer I, II, III, IV, V, VI
MEC_I, II, III, IV, V(a), V(b), VI	Medial Entorhinal Cortex Layer I, II, III, IV, V(a), V(b), VI
DG	Dentate Gyrus
CA3	Cornu Ammonis-3
CA1_dorsal	Dorsal Cornu Ammonis-1 Region (Spatial Information)
CA1_proximal	Proximal Cornu Ammonis-1 Region
CA1_distal	Distal Cornu Ammonis-1 Region
CA1_ventral	Ventral Cornu Ammonis-1 Region (Context information)
S_dorsal	Dorsal Subiculum
S_proximal	Proximal Subiculum
S_distal	Distal Subiculum
S_ventral	Ventral Subiculum
BA	Basal Nucleus of the Amygdala
↪ BA_Fear	Fear Cell of the BA
↪ BA_Ext	Extinction Cell of the BA
La	Lateral Nucleus of the Amygdala
↪ La_Fear	Fear Part of the La
CEm	Medial Central Amygdala
INA	Intercalated Cells of the Amygdala
↪ INAvm	Ventromedial INA
↪ INAdm	Dorsomedial INA
BM	Basomedial nucleus (accessory basal nucleus)
↪ BMA	Basomedial amygdala
PFC	Prefrontal Cortex
↪ PFC_PL	Prelimbic mPFC
↪ PFC_IL	Infralimbic mPFC
A35	Perirhinal Cortex
VISpor	Postrhinal Cortex
RSC	Retrosplenial Cortex
PaS	Parasubiculum
PrS	Presubiculum
MSN	Medial septum
NCx_THM	Conditioned Stimulus of Fear Conditioning (Sensory information about the external world; neutral stimuli, preconditioned stimuli)
MGm_PIN	Unconditioned Stimulus of Fear Conditioning (Aversive Stimuli)

3 Dataset Description

Repository location BRA Editorial System (BRAES) https://sites.google.com/wba-initiative.org/braes/data

Object name and versions Please refer to the "Project" sheet in the BRA data for the more detail of data summary.

Creation dates The start and end dates of when the data was created (2024-09-16 to 2025-01-24).

Language English.

License The open license under which the data has been deposited (CC-BY 4.0).

Publication date 2025-01-24.

Table 2: BRA DATA SUMMARY

BRA Data			
Object Name	Template	Including Content(s)	
		BIF	HCD/FRG
AF24Hippocampus-Amygdala.bra	*version 2-1-1*	√	-

Table 3: BRA IMAGE SUMMARY

Graphic Files: BIF Image	
File Type	Object Name
BIF Image	AF24Hippocampus-AmygdalaBIF.xml

4 Caveats for Data Usage

It should be noted that the current BRA data focuses on spatial cognition functions and proposes hypothetical FRG and HCD. The hippocampus is also considered to play an important role in higher cognitive functions such as episodic memory.

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Competing interests

Yoshimasa Tawatsuji and Hiroshi Yamakawa are managers of BRAES but did not take part in the editorial process or decisions pertaining to this manuscript. The other author(s) has/have no competing interests to declare.

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