Towards the Emergence of Procedural Memories from Lifelong Multi-Modal Streaming Memories for Cognitive Robots

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Motivations & Objectives

- Robots can benefit from **taking their procedural and episodic memories into consideration** when choosing appropriate actions according to previous experiences [1].
- We present a reasoning algorithm that **generalises the robots' understanding of actions** by finding the point of commonalities with the former ones.
- This represents a first step towards the **emergence of a procedural memory** within a long-term autobiographical memory framework for robots.

Introduction

- We present steps towards the emergence of a procedural memory **by clustering annotated self-actions**. Our method
  1. learns templates of actions,
  2. acquires labels in a human-robot interaction, and
  3. stores the labelled actions in the long-term memory.
- We follow the paradigm of lifelong machine learning proposed by Silver *et al.* [2], which states that the **consolidation of memories from specific episodes to abstract knowledge** results in concepts that can be used as prior knowledge when learning new tasks.

New Contributions

Based on our **autobiographical multi-modal memory framework for cognitive robots** [3] to store, augment, and recall streaming episodes, with two key differences:

- Data was **recorded without any specific intention**, and thus was lacking annotation by the human.
- Rather than augmenting a single, specific episode, the proposed framework finds **patterns in groups of related episodes**. As an example, we use iCub's pointing actions executed with the left hand.

Architecture and Overview

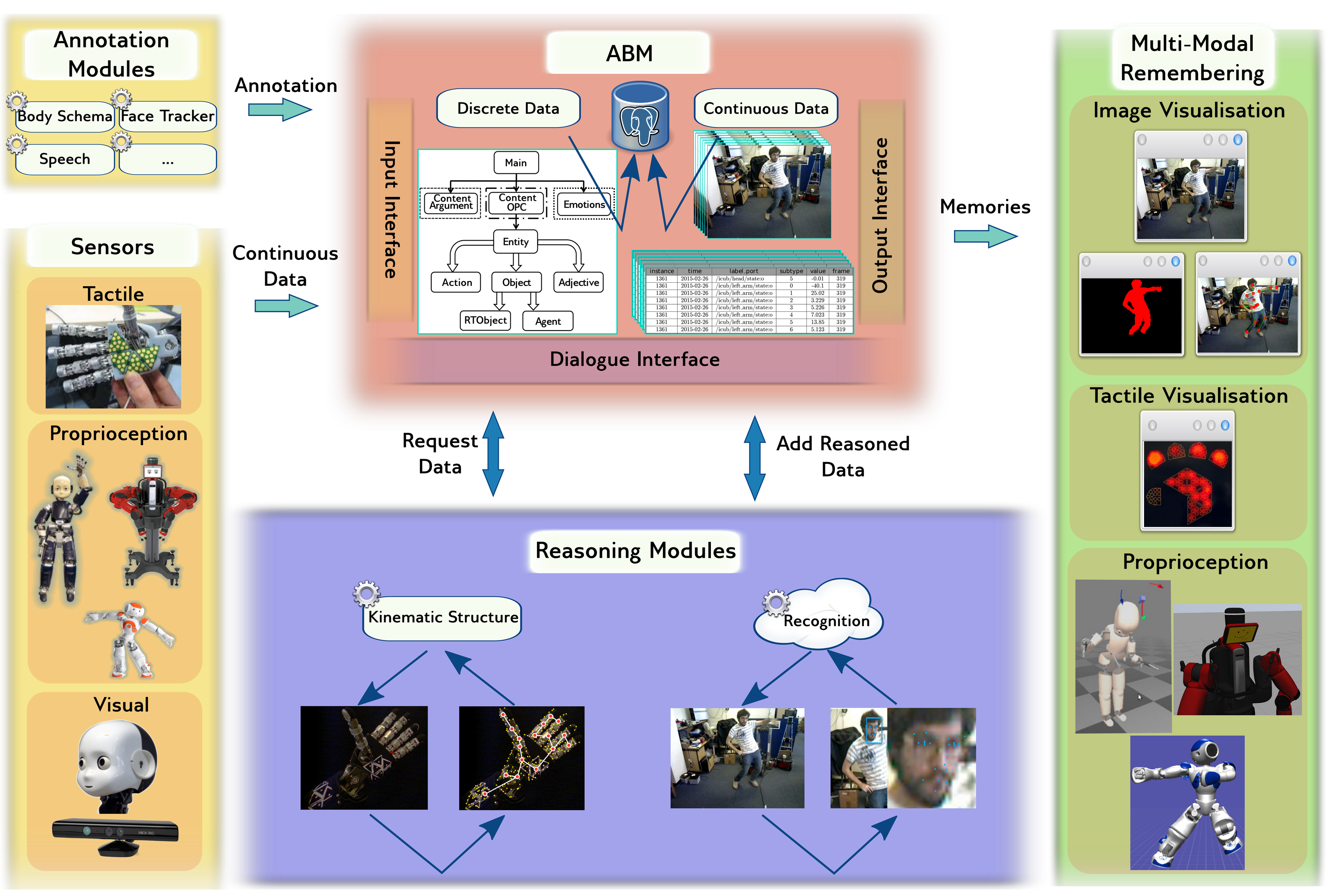

Figure 1: Overview of the autobiographical memory framework. The data can cover multiple modalities, as well as multiple levels of abstraction. Several interfaces are in place to store, augment and recall the memories.

- The central component of the employed framework [3] is a SQL database, which was designed to **store data originating from various sources** in a general manner (see Fig. 1).
- Annotations can be used by reasoning modules (*e.g.* clustering algorithms) **to retrieve related episodes**, and **add augmented data** to these original memories.

Understanding of Actions

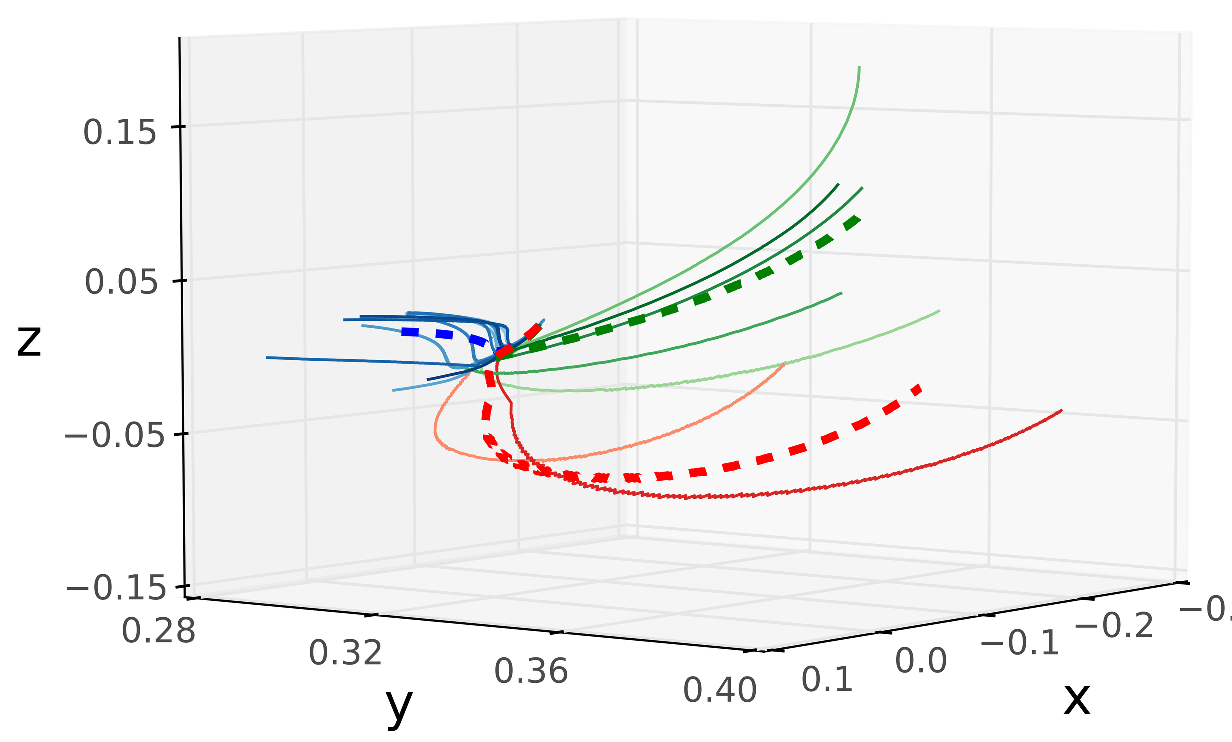

Figure 2: Trajectories of 19 distinct pointing actions of the iCub's left hand end-effector retrieved from the autobiographical memory. The computed mean trajectories are plotted dashed and bold.

- **Mean Shift algorithm** [4] is used to find clusters in the data, allowing to detect three clusters among the 19 pointing gestures of the iCub with the left hand (see Fig. 2).
- Emerging types of pointing actions are: **pointing to the left and right** (blue and red trajectories respectively), and **pointing right+upwards** (green). However, the autobiographical memory does not yet contain this semantic information.
- Thus, we extend the human-robot interaction abilities of [3] such that the iCub is able to **ask a human to provide labels of the newly found clusters**.
- iCub has then discovered commonalities within these pointing actions, which can be seen as **higher-level primitives**. Now, it can *"point upwards with your left hand"*, *"point to the right with your left hand"*, and *"point to the left with your left hand"*.

Conclusion

- Using clustering algorithms allows **gaining further insights to already annotated actions**.
- A long term autobiographical memory with *a-posteriori* reasoning is used to **learn new action concepts without conducting specific experiments**. This can be seen as the first step towards the emergence of a procedural memory.
- For our future works, we aim to use the action clusters found on the iCub, and **transfer this knowledge to other robots**.

References

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[4] D. Comaniciu and P. Meer, "Mean Shift: A Robust Approach Toward Feature Space Analysis," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 24, no. 5, pp. 603–619, 2002.