A Hierarchical Architecture for Adaptive Brain-Computer Interfacing

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Motivation:

- Non-invasive BCIs, such as electroencephalographic (EEG) signals, **suffer from low-signal-to-noise ratio** which limits the bandwidth of control.
- Traditional BCIs for robotic control have a **trade-off between cognitive load and scalability**. More robotic autonomy [1] implies coarse-grained control and less flexibility, while fine-grained control [2] provides greater flexibility but higher cognitive load.
- **Hierarchical architecture for brain computer interfacing** allows a user to teach the BCI new skills on-the-fly; these learned skills are later invoked directly as high-level commands, relieving the user of tedious low-level control.

Methods:

- **Three main components** in hierarchical BCI

1. EEG-based BCI, e.g. steady state visual evoked potential (SSVEP).
2. Hierarchical menu and learning system that allows the user to teach the BCI new skills.
3. The application, e.g. a simulation of a humanoid robot, wheeled robot, or real PR2 semi-humanoid robot.

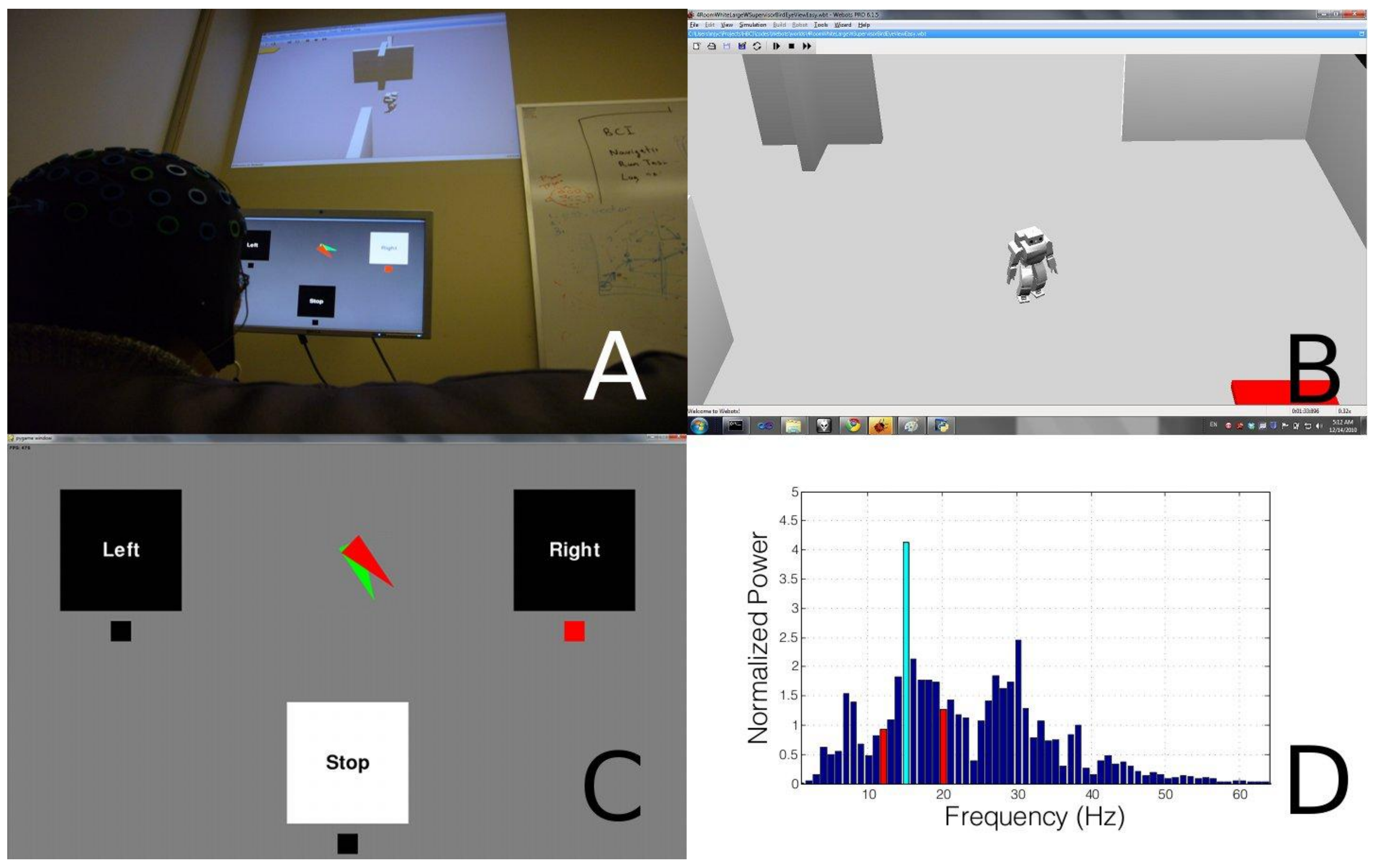

Figure 1. **A Hierarchical BCI System.** A. Experimental setup, B. Application, C. Menu and SSVEP stimulation, D. Frequency domain of a subject's EEG signal

- **Hierarchical Menu**

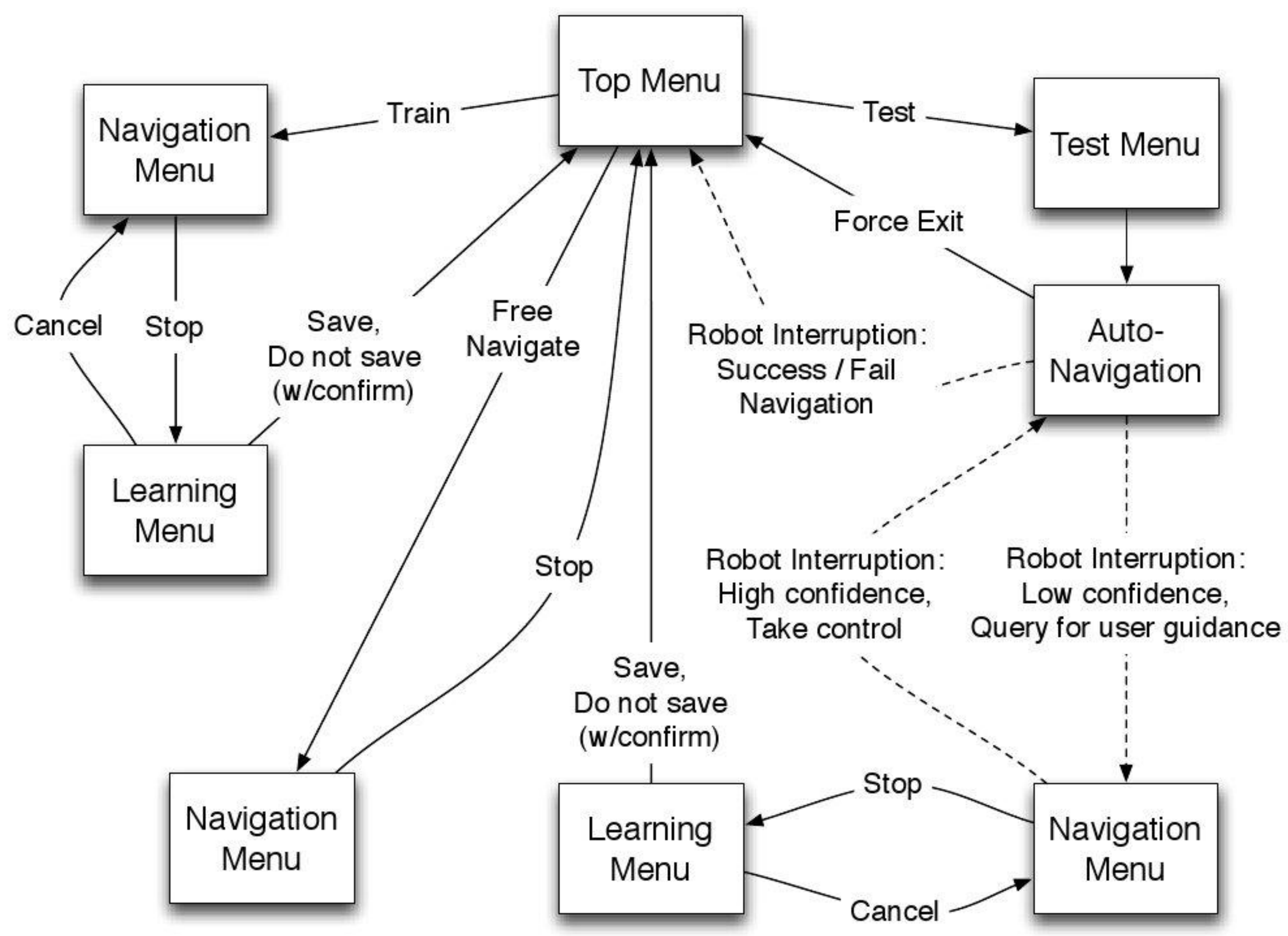

Figure 2: **Overview of control flow in the hierarchical menu system.**

References:

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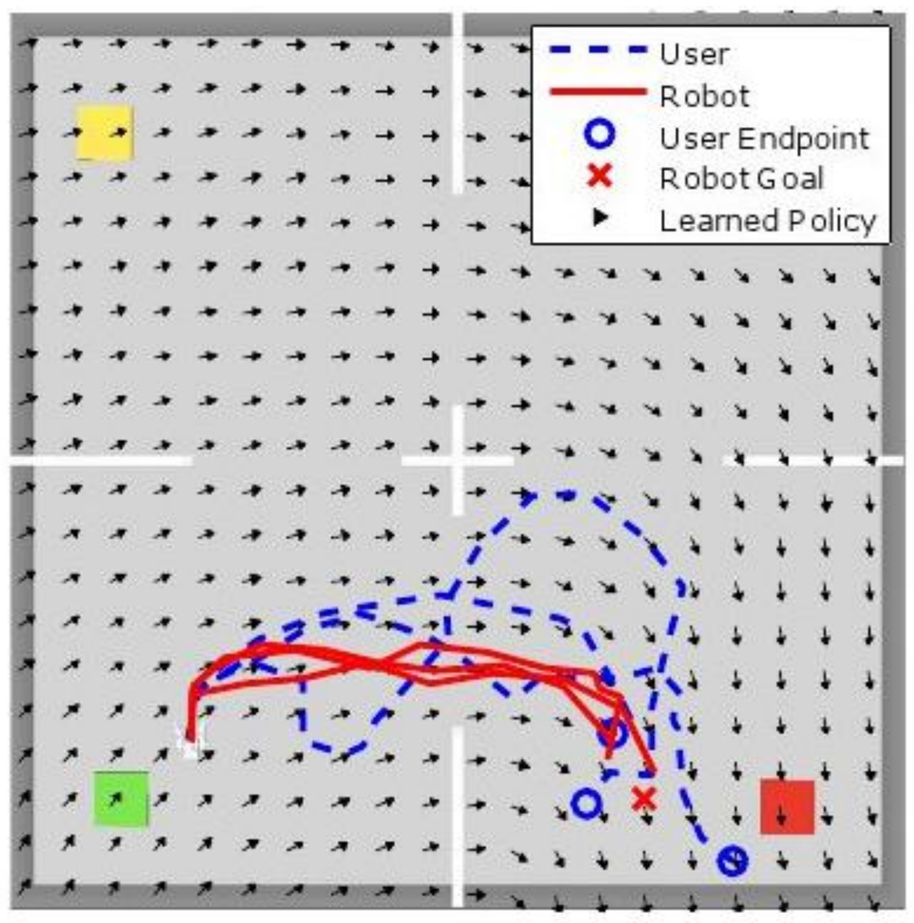
[4] M. Chung, M. Bryan, W. Cheung, R. Scherer and R. Rao, 2011, "Interactive Hierarchical Brain-Computer Interfacing: Uncertainty-Based Interaction between Humans and Robots," *5th International Brain-Computer Interface Conference 2011 (BCI2011)*, Graz, Austria, September 2011 (accepted)

[5] M. Bryan, J. Green, M. Chung, L. Chang, R. Scherer, J. Smith and R. Rao, 2011, "An Adaptive Brain-Computer Interface for Humanoid Robot Control," *IEEE-RAS/RSJ International Conference on Humanoid Robots (Humanoids11)*, Bled, Slovenia, October 2011 (submitted).

Results:

- Study1: Testing the Hierarchical Architecture.



Mean among four subjects (std)		
	Low-level BCI	Hierarchical BCI
Num Selections	20 (7)	5 (2)
Task Time	220 (67)	112 (25)
Nav Time	124 (37)	73 (19)
Mean of three trials from best subject (std)		
Num Selections	Low-level BCI	Hierarchical BCI
Task Time	15 (5)	4 (1)
Nav Time	141 (42)	86 (4)
Minimum		
	Low-level BCI	Hierarchical BCI
Num Selections	8	4
Task Time	91	75
Nav Time	59	59

Figure 3 & Table 1.. **Example Robot Trajectories from User-Demonstrated Low-Level Control and Hierarchical Control** and **Performance Comparison**

- Study2: Uncertainty-Guided Interaction [4].

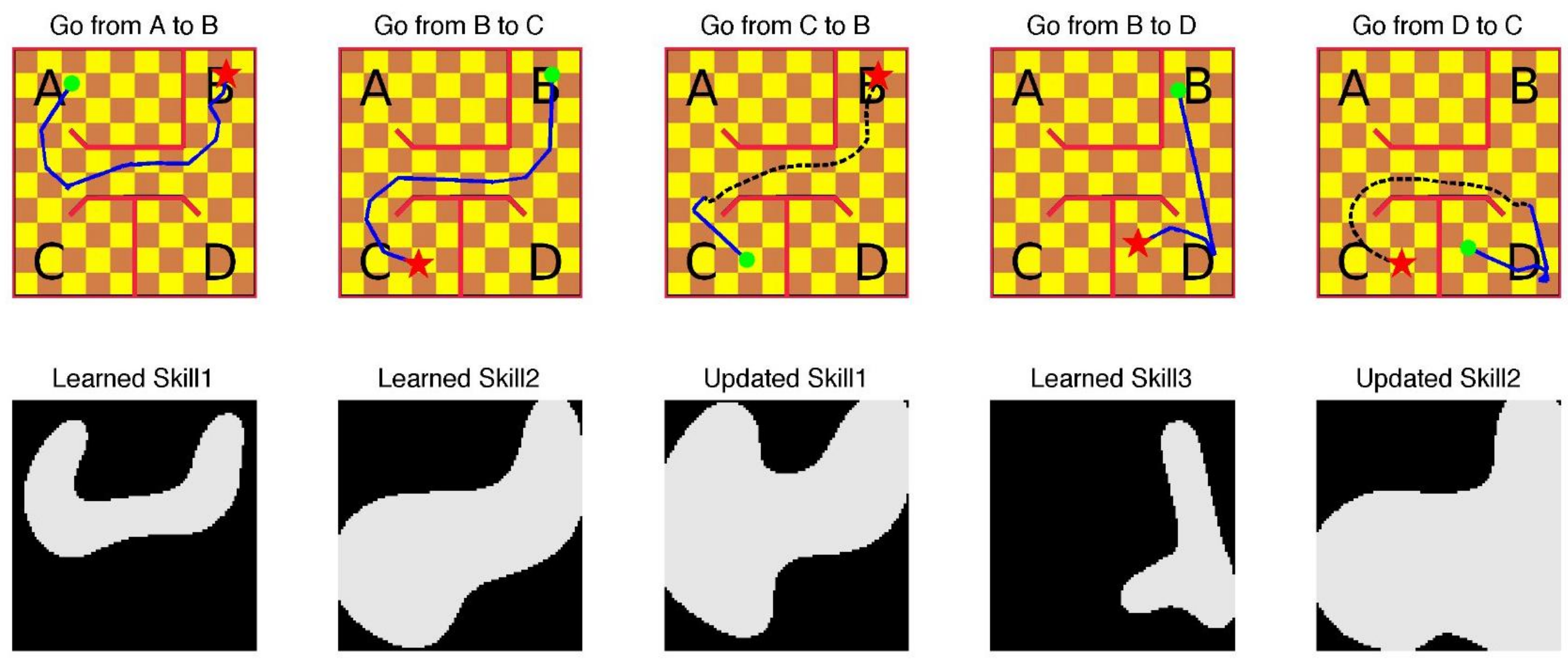
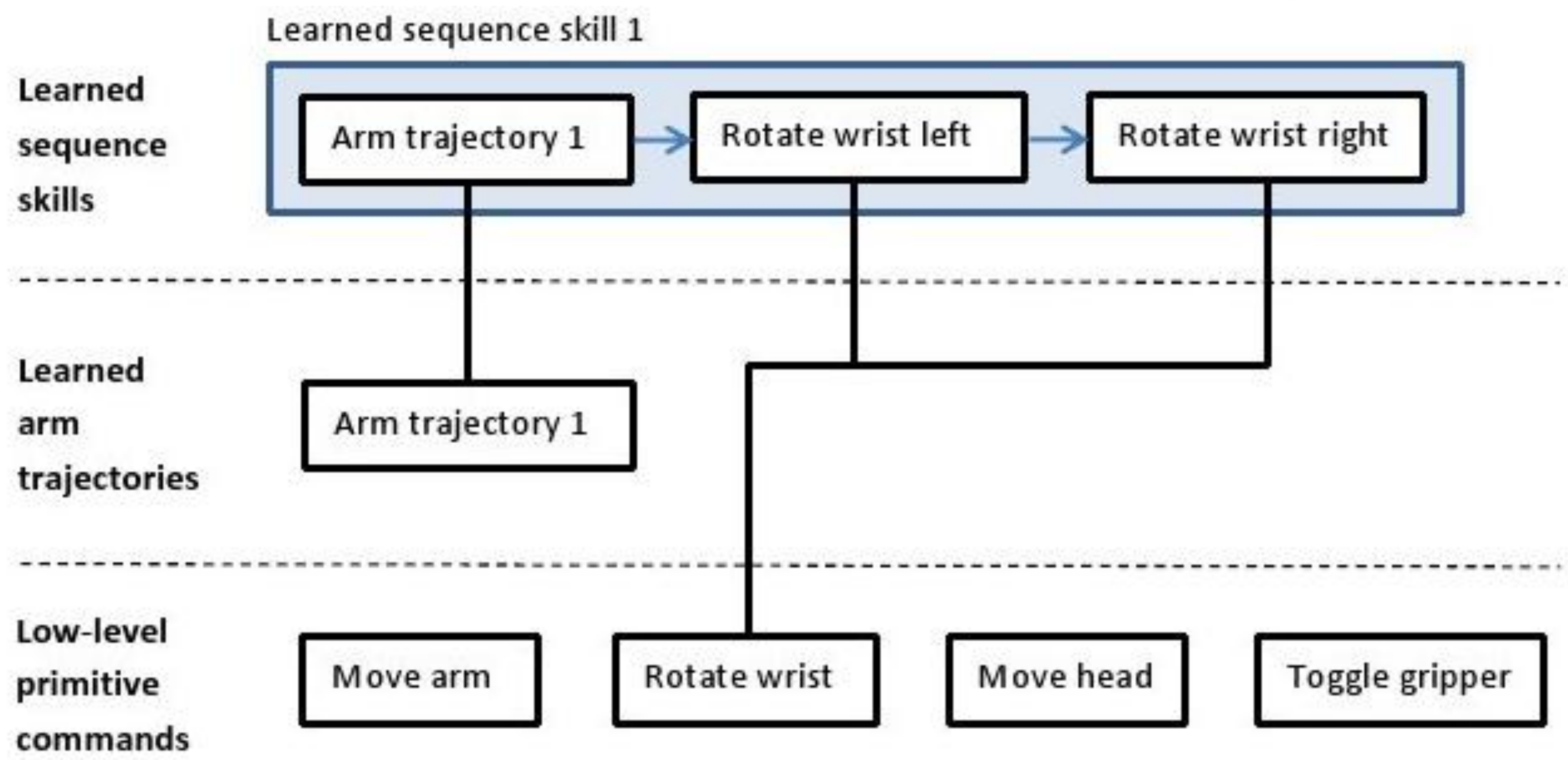
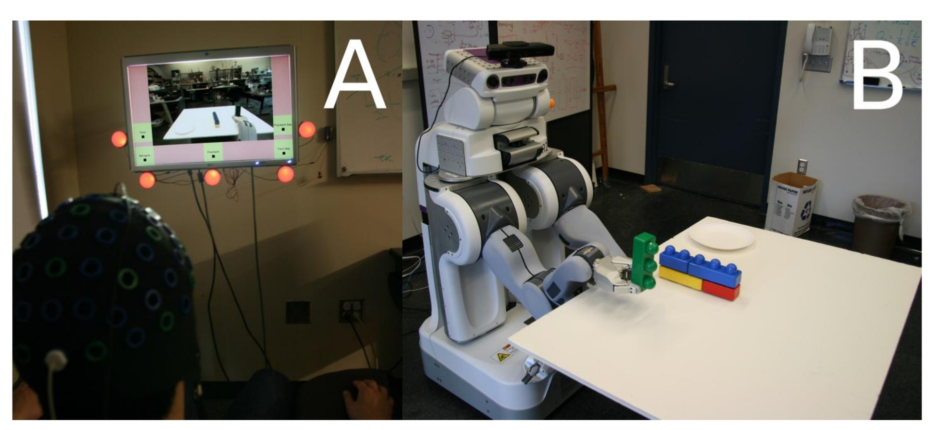


Figure 4: **Navigational traces and learning in the hierarchical BCI.**

- Study3: Scaling up to Real Robot and Complex Task Learning [5].



Conclusion:



- Combining Scalability and Efficiency
- Interaction Based on Probabilistic Model
- Hierarchical Architecture, Learning with both low and high level skills
- Multi-tasking for Increasing Bandwidth
- Long-term usability

Acknowledgements:

This research was supported by the National Science Foundation (0622252, 0642848 & 0130705), the Microsoft External Research program, and the Packard Foundation.