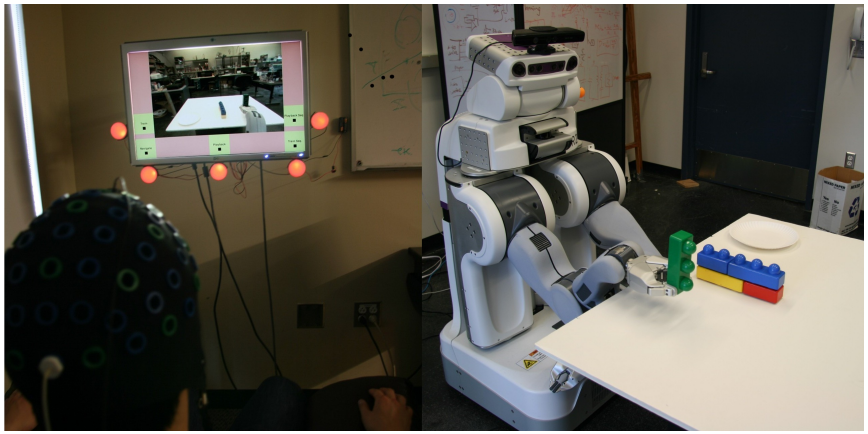
Interactive Hierarchical Brain-Computer Interfacing: Uncertainty-Based Interaction between Human and Robots



5th International BCI Conference 2011

Graz, Austria, September 22, 2011

Mike Chung,

Matt Bryan,

Willy Cheung,

Reinhold Scherer,

Rajesh P. N. Rao

Laboratory for Neural Systems
Computer Science & Engineering,
University of Washington,
Seattle, WA, USA

BCI-Lab
Institute for Knowledge Discovery
Graz University of Technology
Graz, Austria

Outline

- Hierarchical BCIs
- Uncertainty-based interactive hierarchical BCIs

Traditional BCIs for Robotic Control

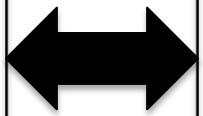
- Trade-off between cognitive load and scalability

High-level control paradigm: more robotic autonomy

low cognitive load

but

coarse-grained control



Low-level control paradigm: Finer-grained moment-by moment control

- **High-flexibility**

but

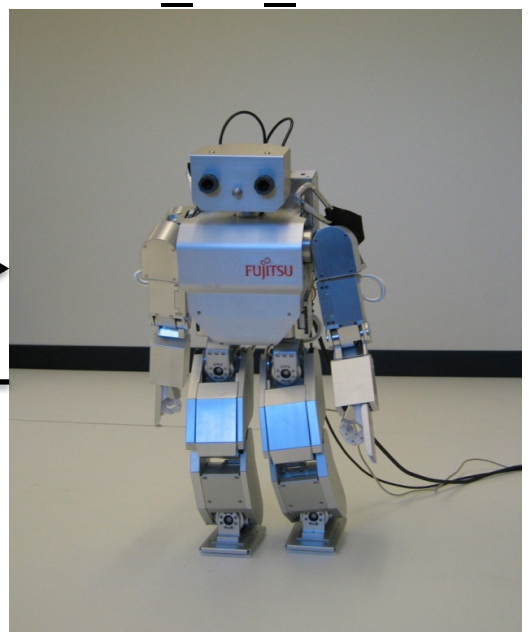
- **higher-cognitive load**

Hierarchical BCIs Phase I: Train

Available high-level control commands:
- GO_TO_KITCHEN

EEG command:
"Learn GO_TO_KITCHEN skill"

User intention:
"Go to kitchen"



User notices robot reached goal

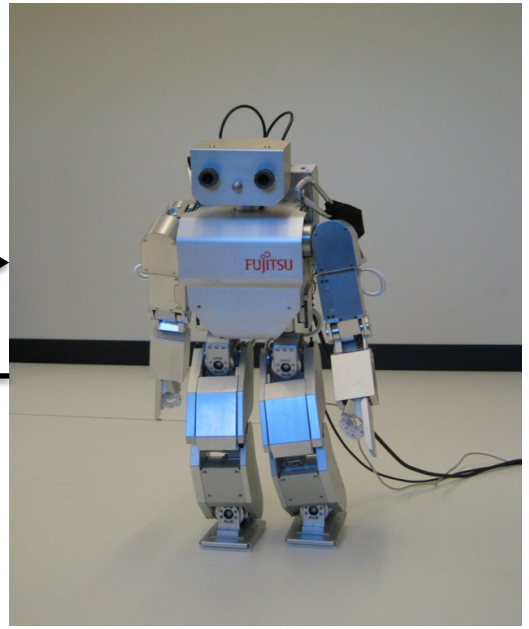
Robot "learns" a position-based navigation skill

Hierarchical BCIs Phase II: Test

Available commands:
"GO_TO_KITCHEN"

User intention:
"Go to kitchen"

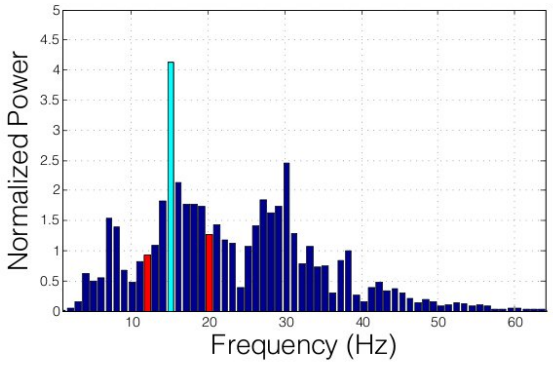
EEG command:
"GO_TO_KITCHEN"

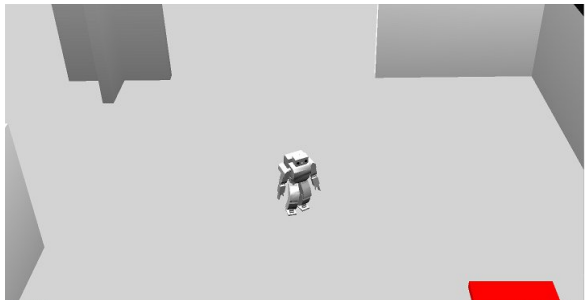


Robot goes to kitchen

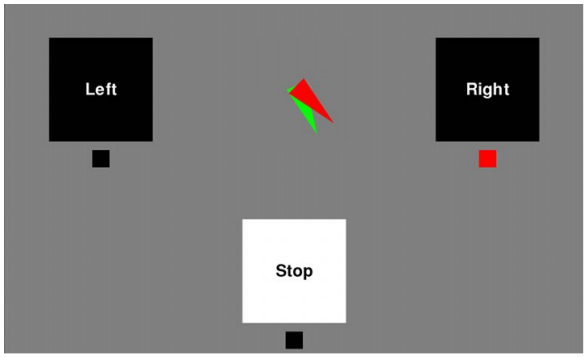
System Components

SSVEP-based BCI





Robot Application



Hierarchical Adaptive Menu

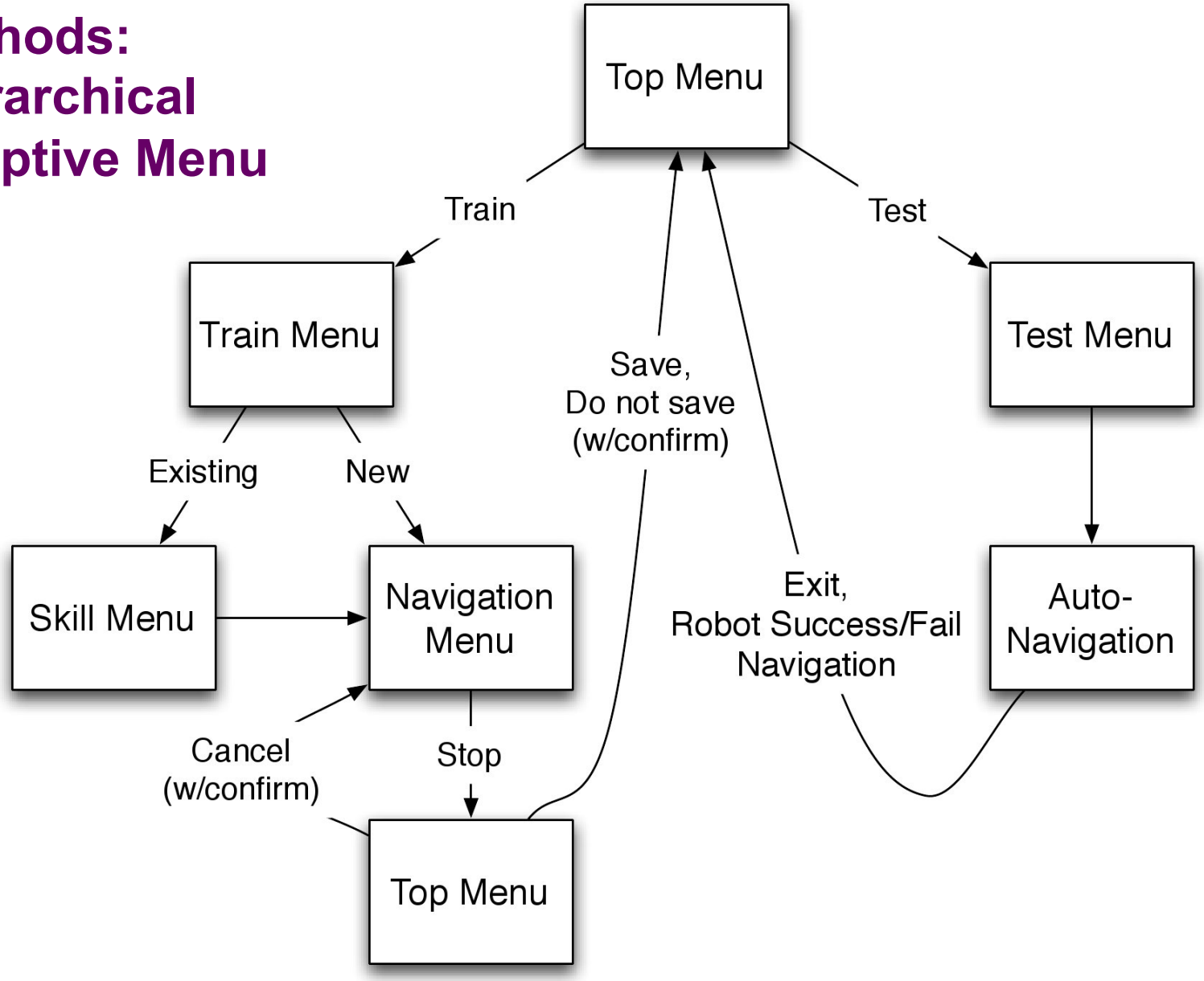
Methods: BCI

- Current system uses SSVEP (but not limited to)
  - TFT monitor with refresh rate of 60Hz.
  - Three options: 12 Hz, 15 Hz, and 20 Hz
  - Asynchronous BCI paradigm (e.g., motor imagery) could be a more natural interface
- Classification
  - data collection (4s), refractory periods (2s)
  - classification using frequency domain features

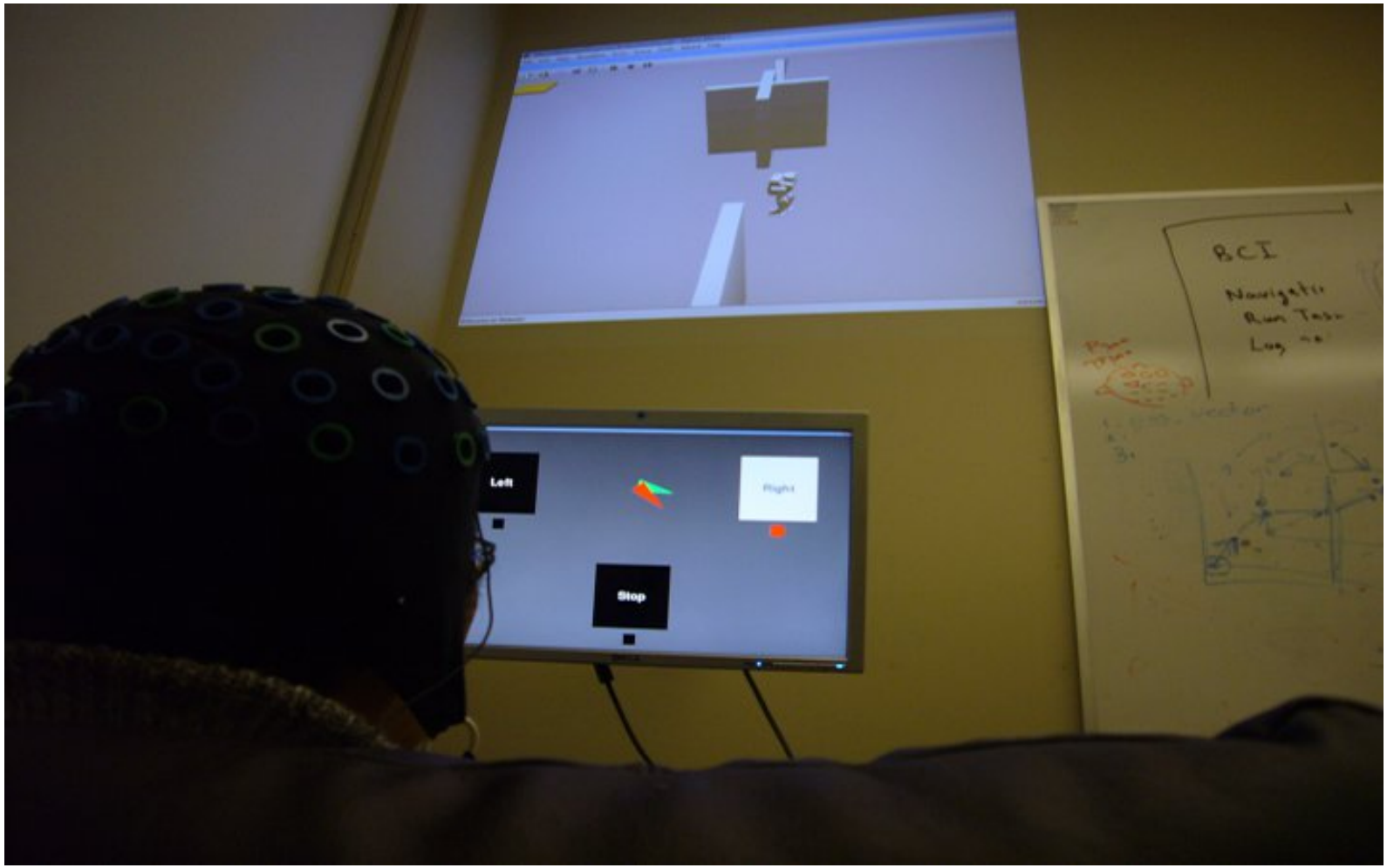
Methods: Robot Learning

- Learning “high-level” control commands on-the-fly from “low-level” control demonstration traces.
  - function approximator, e.g., RBF Neural Network, or Gaussian Process Regression
  - training data: position based traces from “low-level” control demonstrations
  - output of function approximator produces sequence of control commands until goal-state is reached
  - one function approximator for each high-level control command

Methods: Hierarchical Adaptive Menu

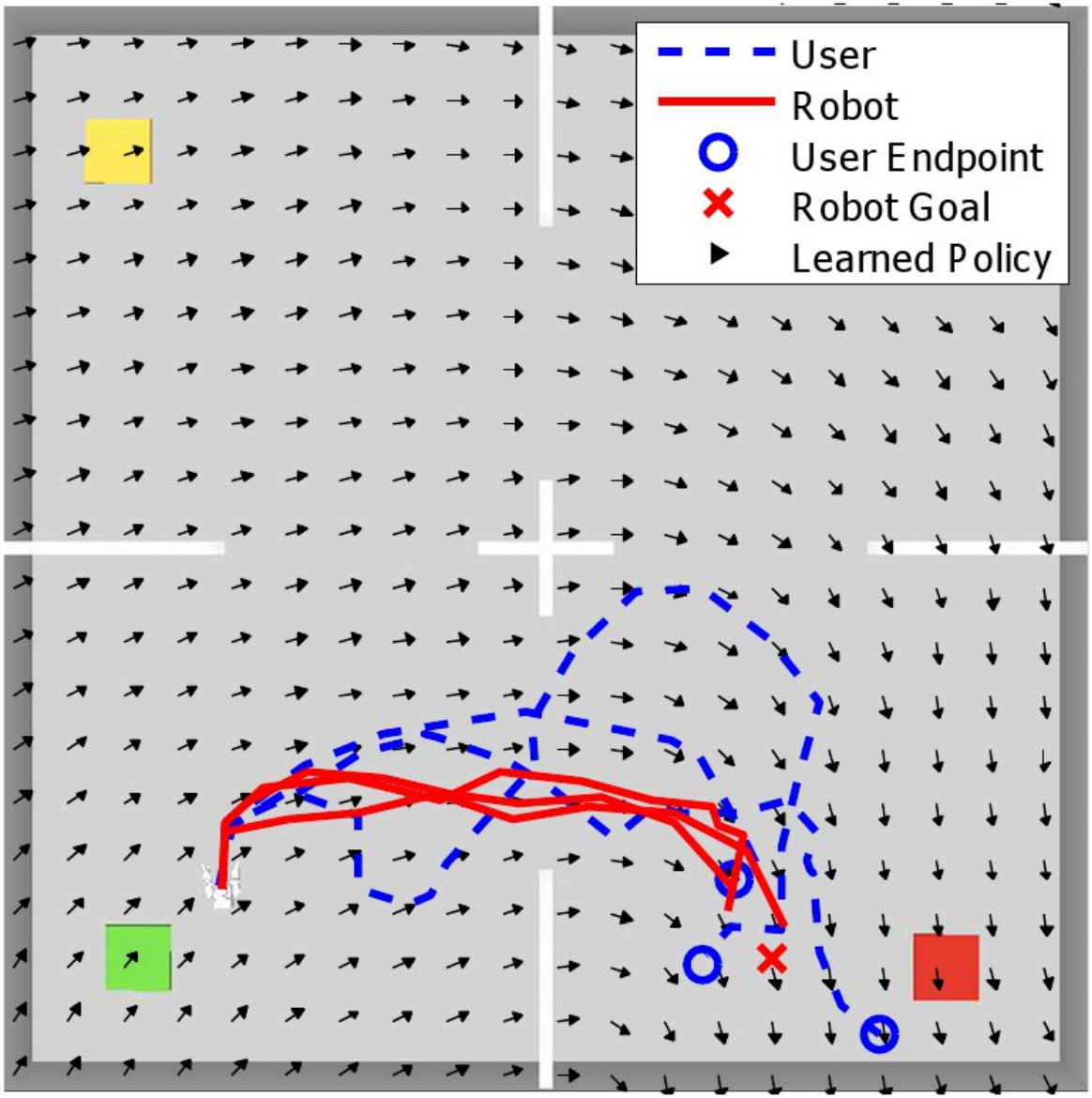


Experimental Setup



Results

Navigation traces and policy



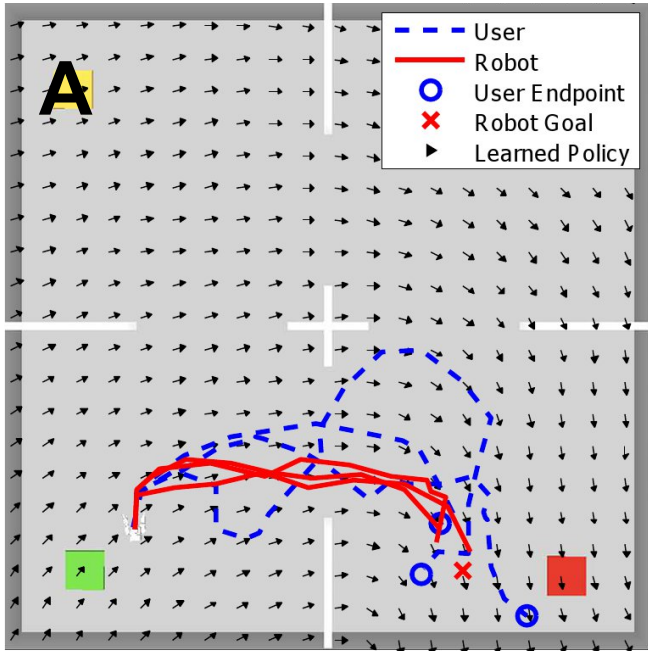
Results

	Low-level BCI	**Hierarchical BCI**
Mean among four subjects (std)		
Number of selections made	20 (7)	**5 (2)**
Task completion time (s)	220 (67)	**112 (25)**
Navigation only time (s)	124 (37)	**73 (19)**
Mean of three trials from best subject (std)		
Number of selections made	15 (5)	**4 (1)**
Task completion time (s)	141 (42)	**85 (4)**
Navigation only time (s)	99 (30)	**74 (9)**
Minimum (std)		
Number of selections made	8	**4**
Task completion time (s)	91	**75**
Navigation only time (s)	59	**58**

Interactive Hierarchical BCIs

- Unreliable “high-level” skills due to incomplete, or insufficient training data
- Example:

Q: What happens if the robot starts from location “A”?

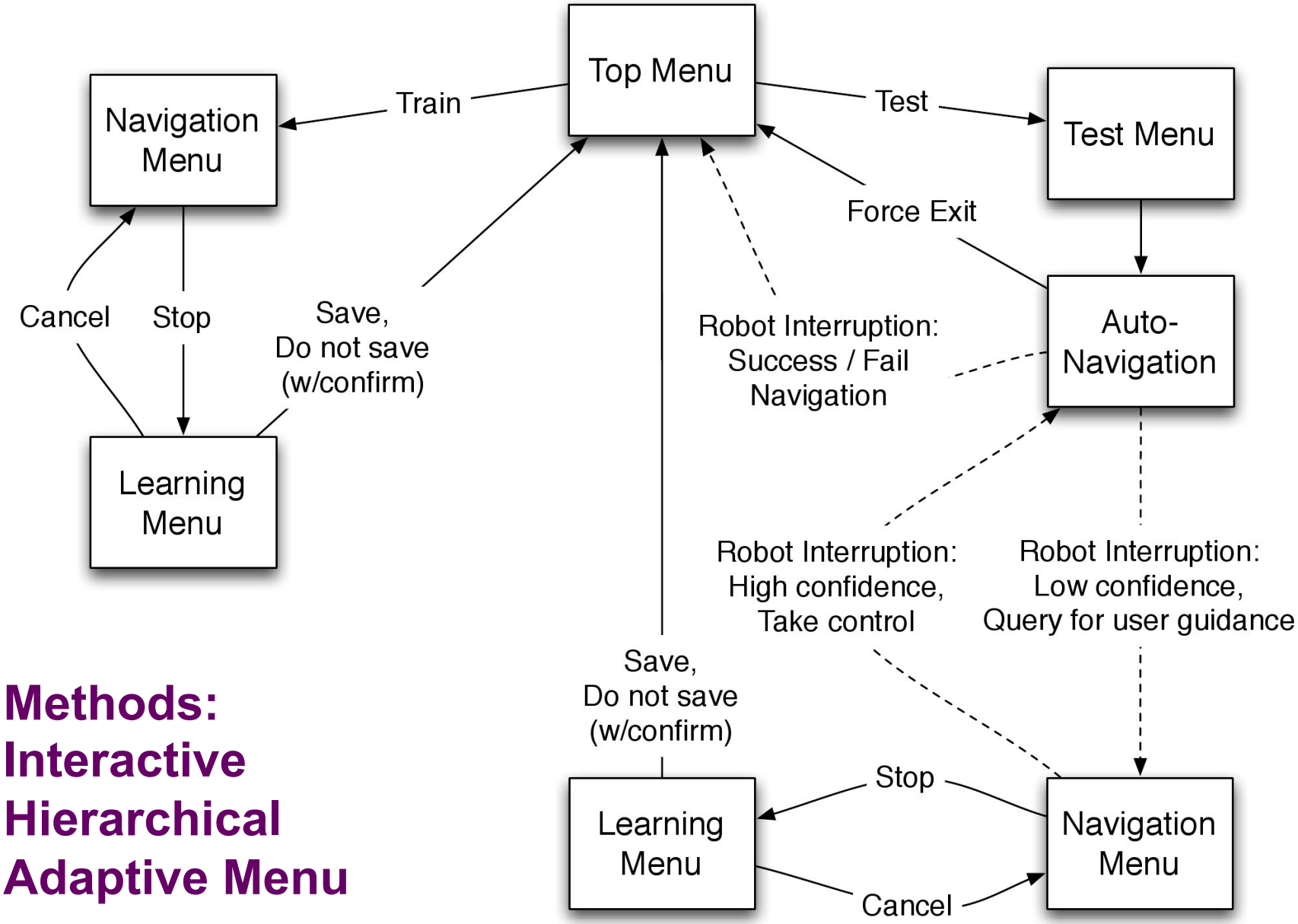


Uncertainty-based Interaction

- High-uncertainty region: Ask for user guidance
  - User gives additional “low-level” control commands to help robot finish the high-level command.
- Low-uncertainty region: Take control from user, autonomously finish an issued high-level command.
  - Relieves the user from engaging in low-level control.

Methods: Robot Learning

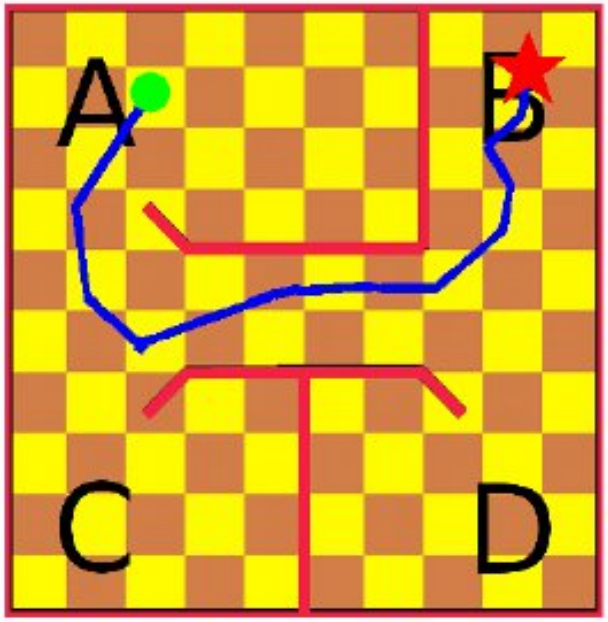
- Gaussian Process (GP) function approximator
  - Output of GP: <mean, variance>
  - Variance used as “uncertainty-metric”



Methods: Interactive Hierarchical Adaptive Menu

Result

Train Mode: Go to location B



RedStar: Goal position
GreenDot: Start position
BlueLine: User demonstration trace

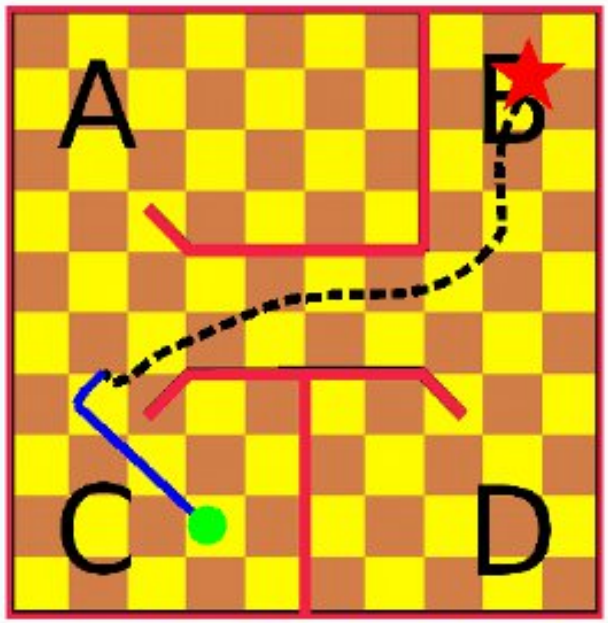
Learned confidence map

BlackArea: High-uncertainty region
WhiteArea: Low-uncertainty region

Result

Test: High-level command
"Go to location B"

Immediately switches to user demonstration mode due to high-uncertainty!
*(**blue line trace**)*



Once the user drives the robot to low-uncertainty region, BCI takes control from user.
*(**black dotted line**)*

Red Star: Goal position
Green Dot: Start position
Blue Line: User demonstration trace
Black DottedLine: Autonomous robot navigation trace

Result

Updated confidence map after incorporating more data

Black Area: Highly uncertain region
White Area: Less uncertain region

Comparison

Learned confidence map before update

Updated confidence map after incorporating more data

Conclusion

- Hierarchical BCI
  - Combines advantages of fine-grained and high-level autonomous control paradigms.
  - Learns high-level commands on-the-fly from user demonstrations with “low-level” control.
- Uncertainty-based interactive hierarchical BCIs
  - Interaction based on “uncertainty-metric” makes BCI more reliable and robust while remaining adaptive to user’s needs
  - Ability to handle uncertainty opens the door to practical real-world BCIs

Towards Practical Hierarchical BCIs

Acknowledgments

Funding: National Science Foundation (0622252 & 0930908), the Office of Naval Research (ONR), and the ICT Collaborative Project BrainAble (247447).

Other: Rawichote Chalodhorn for helping with the HOAP- 2 robot and Webots , Josef Faller for helping with the implementation of the SSVEP stimuli.