An Adaptive Brain-Computer Interface for Humanoid Robot Control Matthew J. Bryan^{*}, Joshua Green^{*}, Mike Chung^{*}, Lillian Chang^{*,‡}, Reinhold Scherer[†], Prof. Joshua Smith^{*}, Prof. Rajesh P.N. Rao^{*}

1. The Problem

 Typical non-invasive BCI systems have very low-throughput

 Low-level moment-by-moment control tedious for users

•High-level commands easier to use, but coarse-grained control

2. Our Approach

•Use lower-level commands to teach the robot new higher-level commands

•Learn chains of high- and low-level commands to perform complex tasks

•Work since Humanoids shows we can apply this approach to systems that use arbitrarily complex and robust robotics algorithms (e.g. grasping routines)

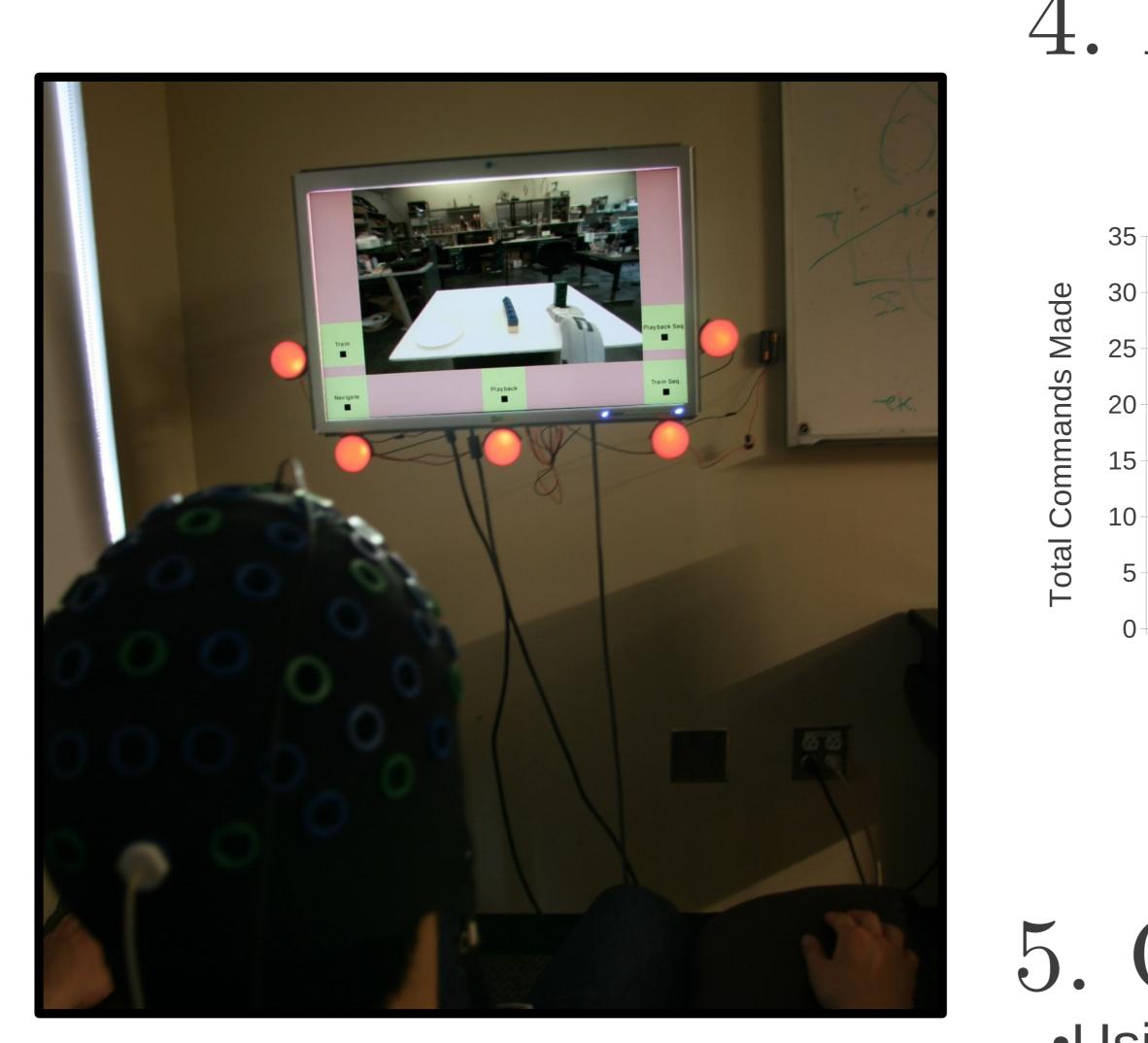
3. Example

•Use lower-level commands to learn how to maneuver the arm to the location of a bowl

 Combine learned trajectory with lower-level commands for rotating the wrist

•Remember this sequence as an even higher-level skill representing pouring milk on cereal

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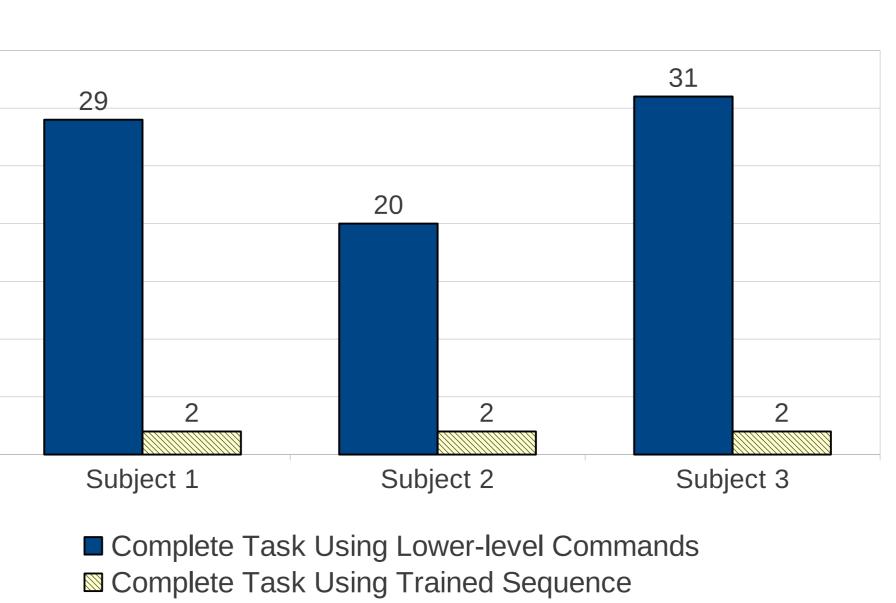
User controlling a Willow Garage PR2 Robot

earned sequence skills	Learned sequence skill 1 Arm trajectory 1 Rotate wrist left Rotate wrist right			
earned arm trajectories	Arm trajectory	1		
.ow-level orimitive commands	Move arm	Rotate wrist	Move head	Toggle grippe

Red indicates training path; blue indicates examples of the We build command hierarchies in order to create command abstraction on the fly. This results in an increase in effective robot's autonomous navigation given the learned policy; throughput of the BCI system by allowing the user to do more the black circle is the target area. with fewer commands.

4. Results and Conclusions

Command Count to Complete Milk Pouring Task

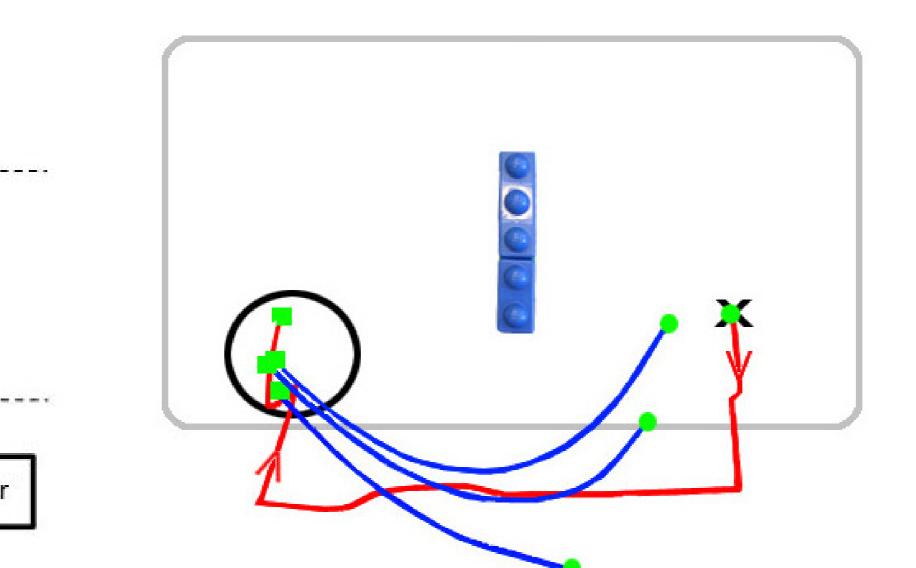


•Building command abstractions on the fly results in an **increased effective** throughput of the BCI •Combines scalability with efficiency

•Learning over command sequences allows the system to perform more **complex tasks** since it avoids dimensionality problems associated with learning over high-dimensional state spaces

5. Ongoing Work

•Using sequence-learning algorithms to automatically extract patterns from user's command history (ICRA submission) •More advanced user studies of hierarchical command learning for BCI



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