Non Invasive Brain-Robot interaction

Ricardo Chavarriaga, José del R. Millán

IDIAP Research Institute. Martigny, Switzerland

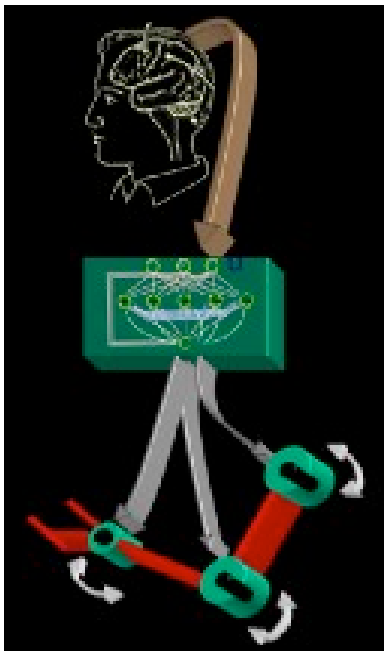
Ecole Polytechnique Fédérale de Lausanne, Switzerland

Ricardo.chavarriaga@idiap.ch

Brain-Machine Interface (BMI)

- Communication and control system that does not depend on the brain's normal output pathways of peripheral nerves and muscles

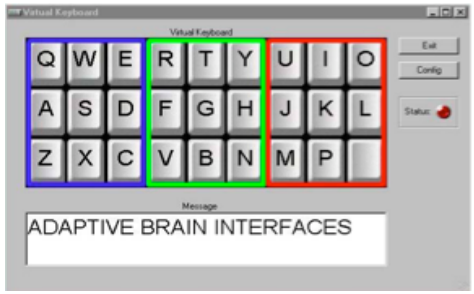
  Wolpaw et al.,2000



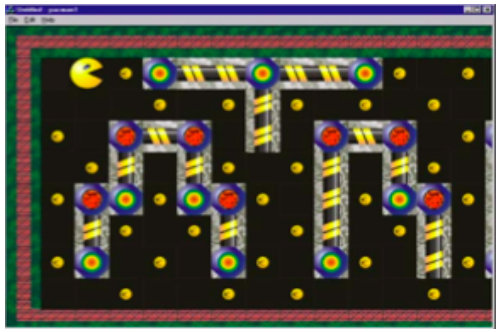
Outline

- Introduction
- Brain Actuated robots
  - Mobile robot
  - Wheelchair
- Cognitive related signals in BMI
- Conclusions

Brain-Machine Interface - What for?



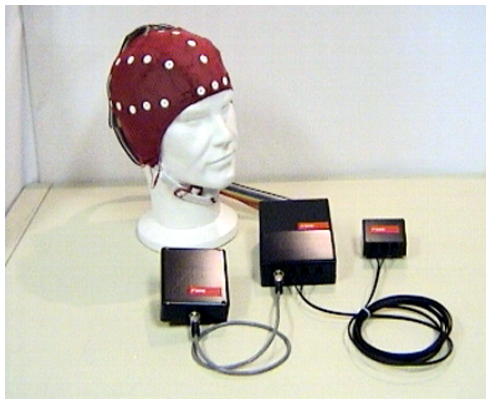
ABI project, 2000

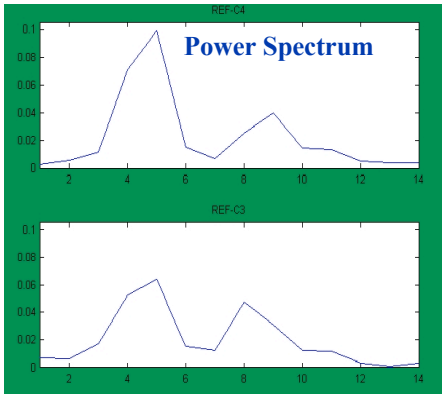


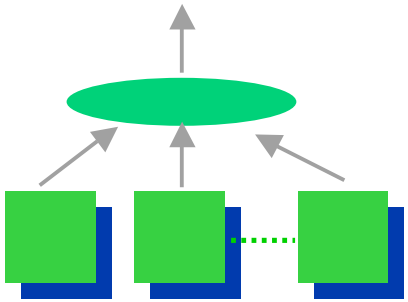
IST exhibition,2000

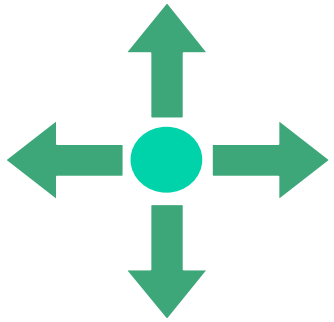
MAIA european project,2006

BMI Architecture



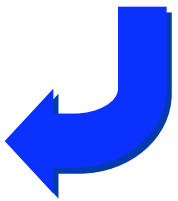






Acquisition System → **Feature Extraction** Digital Signal Processing → **Feature Classification** Statistical Classifier → **Action Generator**

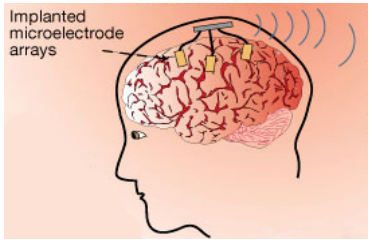
Feedback

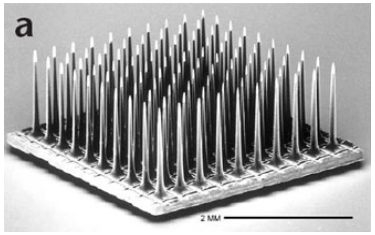


Signal Acquisition

- Implanted electrodes

  Activity is directly measured by microelectrodes

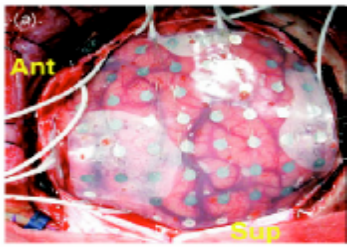


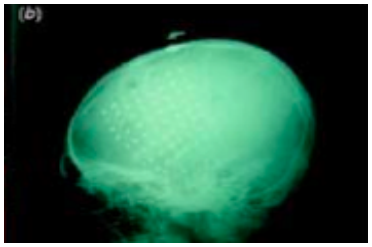


(Nicolelis, 2001) (Donoghue, 2002)

- Electrocorticogram (ECoG)

  Recordings on the cortical surface of the brain

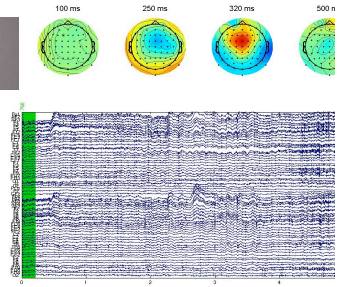




(Leuthardt et al., 2004)

- Electroencephalography (EEG)

  Activity measured on the scalp



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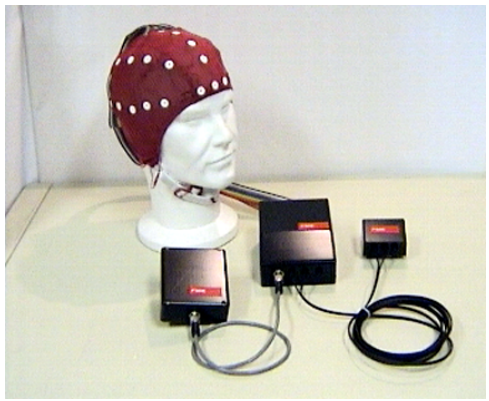

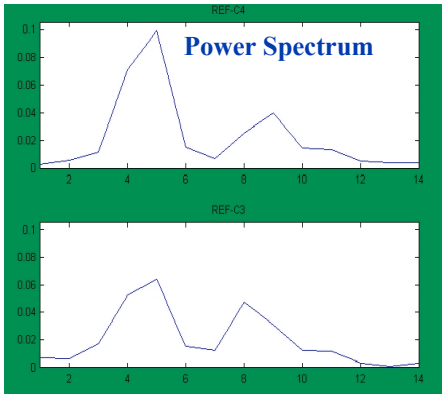

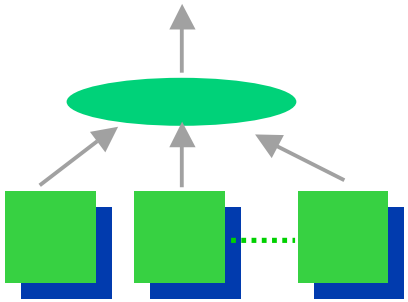

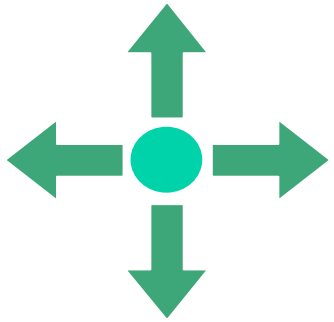

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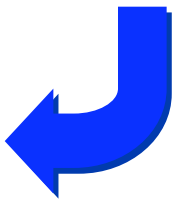

Adaptive BMI: Basic Principles

- *Asynchronous* operation
  - spontaneous and self-paced decisions, no external cues
  - fast response, 0.5 second
- *Mutual* learning process
  - statistical classifier
  - increase likelihood of success and enable rapid mastering
- *Blending* of intelligences
  - user's mental capabilities + intelligent device

Blending of Intelligences

- *Challenge:* Design sound principles of *adaptive* shared control
  - user's mental capabilities + smart device
  - facilitate interaction and reduce cognitive workload

- *Intelligent brain-actuated device*
  - recognizes, and anticipates, user's mental intent
  - executes it automatically, relieving user from detailed low-level control
  - device's intelligence complements user's mental capabilities, never takes over

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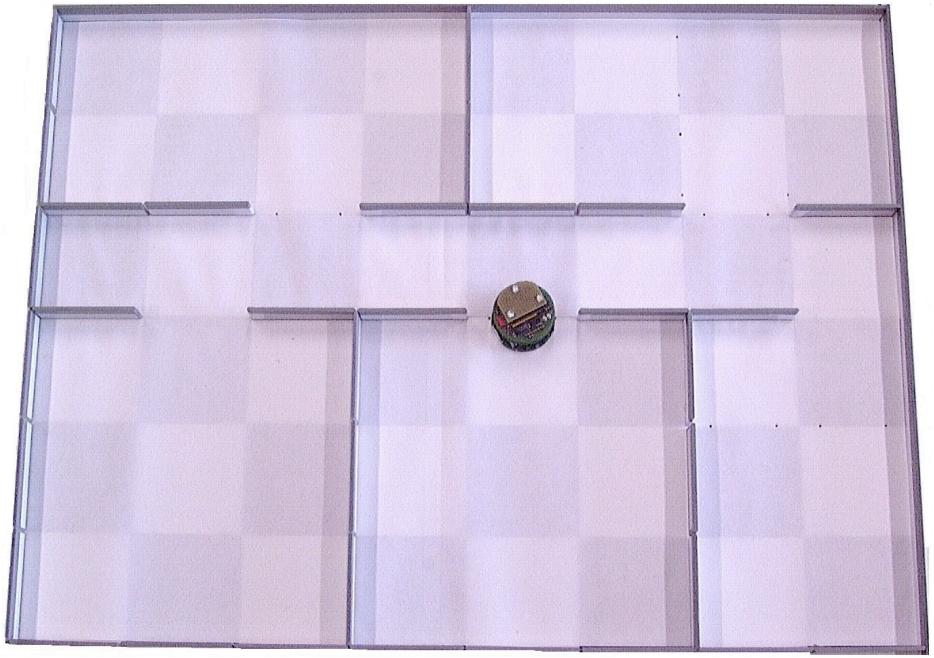
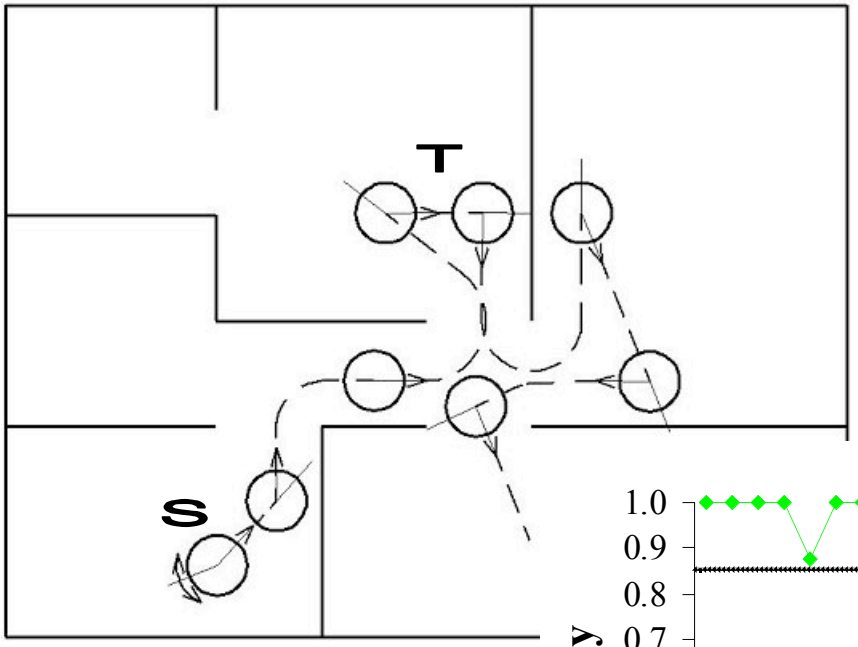
Brain-Actuated Control of a Mobile Robot

Users address the task at high level and all the low level details are handled automatically:

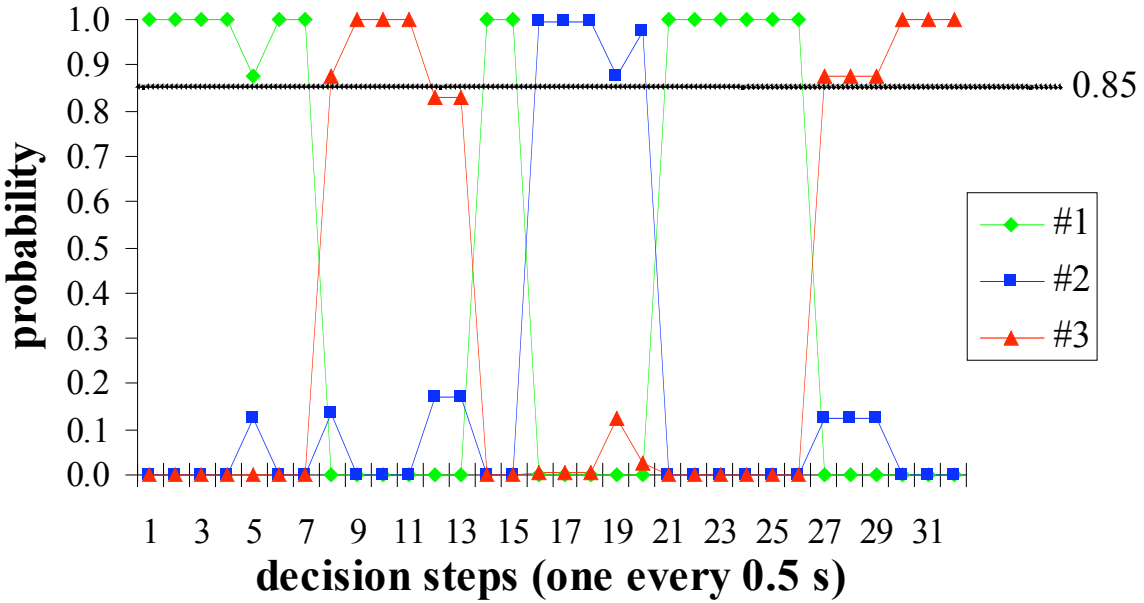
behavior-based architecture



Experimental Results: Fast Decisions



Qualitatively
good trajectories



Experimental Results: Execution Time (sec)

Subject 1

Relax, Left, Cube

Trial	Mental	Manual	Ratio
1	149	124	0.83
2	183	135	0.74
3	191	129	0.68
Average	***174***	***129***	***0.75***

Subject 2

Relax, Left, Right

Trial	Mental	Manual	Ratio
1	219	156	0.71
2	189	155	0.82
3	175	117	0.67
Average	***194***	***143***	***0.73***

Conclusions … and Challenges

- Non-invasive BMI, combination of:
  - Asynchronous protocol for EEG analysis,
  - Machine learning techniques,
  - AI robotics.

- Encouraging … but not yet a realistic application

Brain-actuated Wheelchair

Brain-Actuated wheelchair

Asynchronous approach.

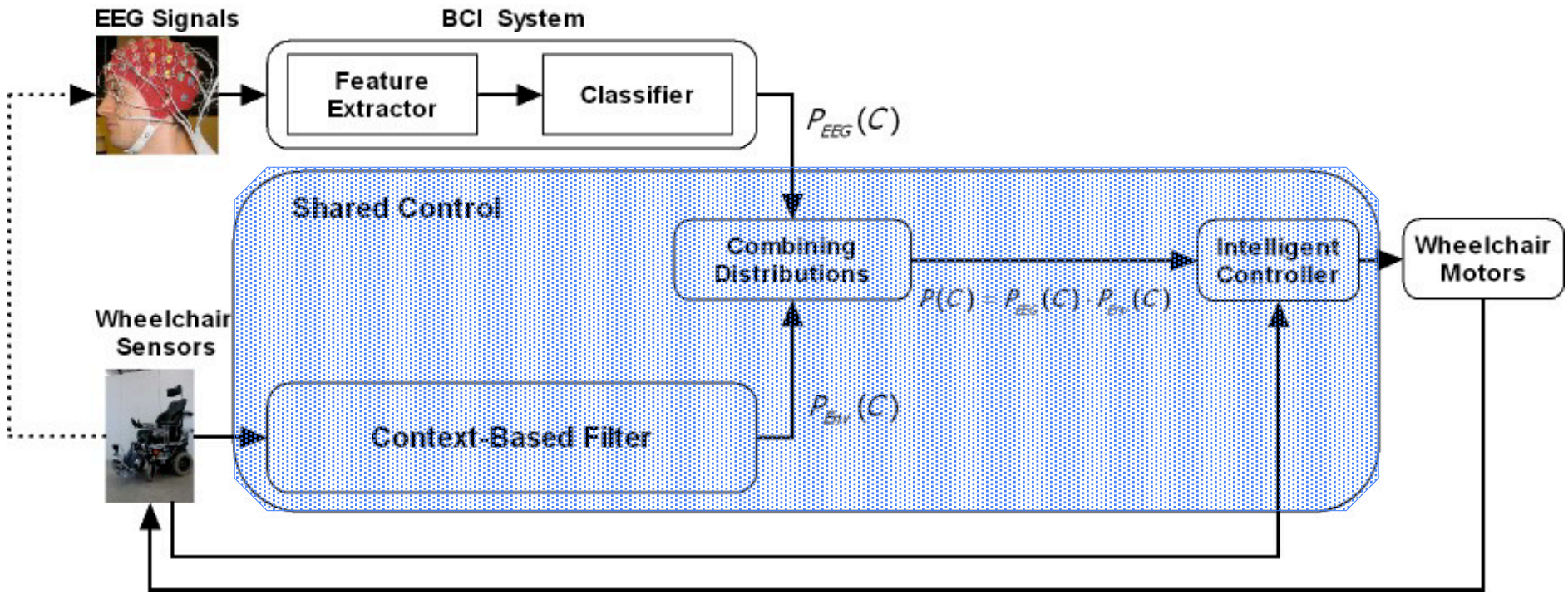
3 mental tasks (forward, turn left, turn right).

- *adaptive shared control*
- *cognitive signals: error potentials*

- online adaptation
- multimodal feedback

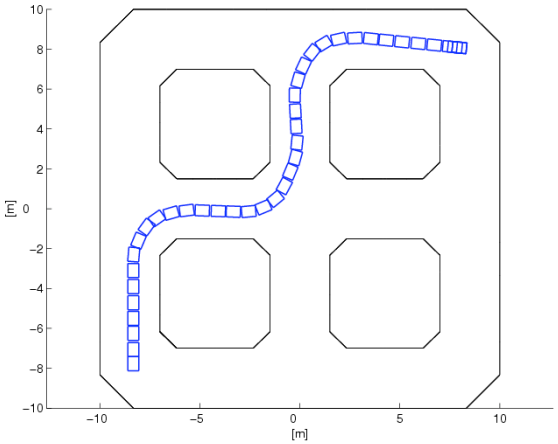
Adaptive Shared Control

- Estimation of the user's intent from the combination of BCI outputs and robot's sensory readings

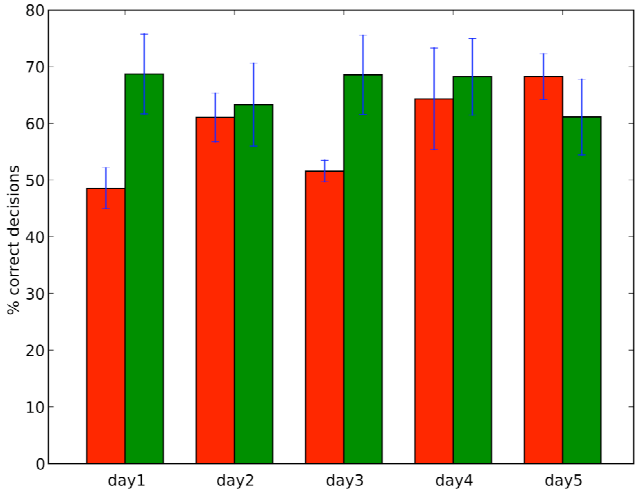


Vanacker et al., 2007; Galán et al., 2008

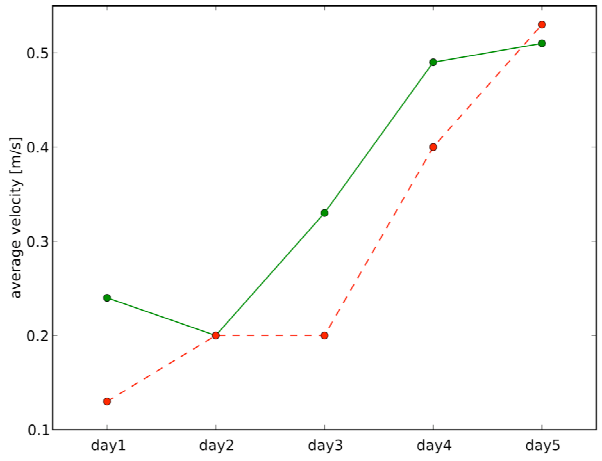
Adaptive Shared Autonomy



% Correct decisions



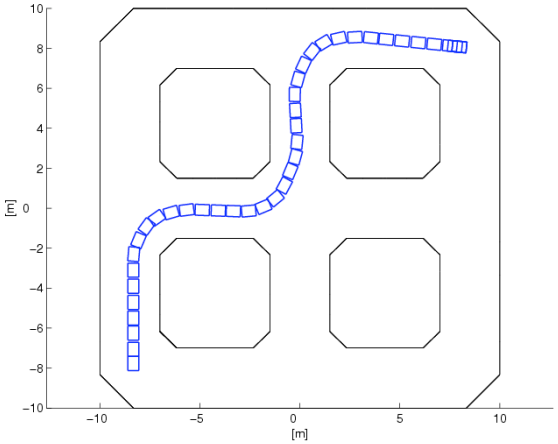
Avg Velocity

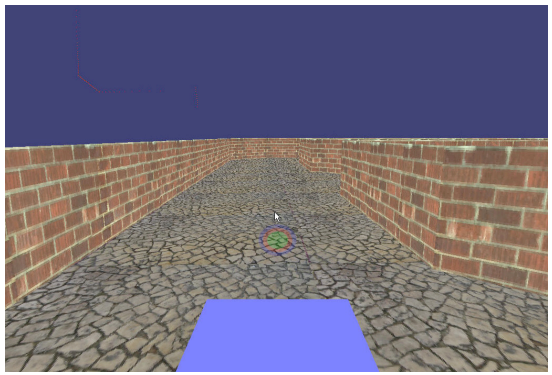


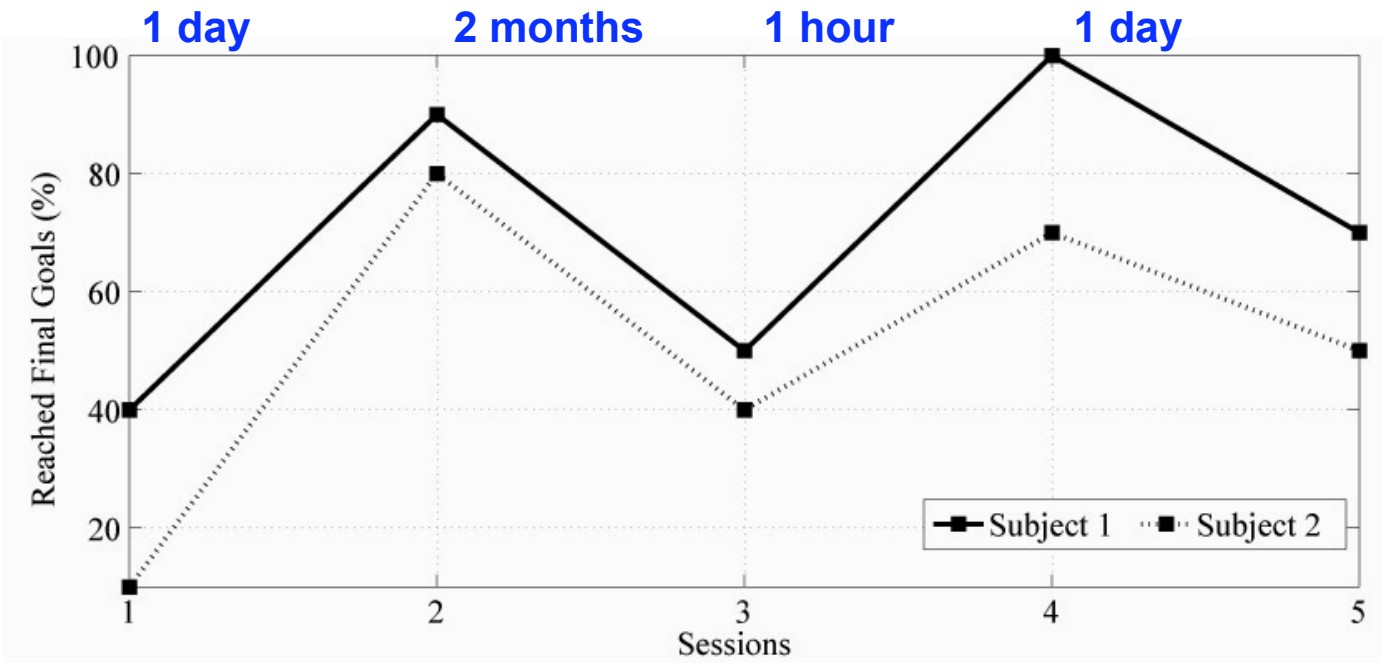
Percentage of trials in which the goal was reached

day	overall (all sessions)	sessions without filtering	sessions with filtering
day 2	60.00%	40.00%	80.00 %
day 3	80.00%	66.67%	85.71%
day 4	70.00%	60.00%	80.00%
day 5	80.00%	100.00%	60.00%

Adaptive Shared Control: Simulation







1% reached final goals with random BCI sequences of commands

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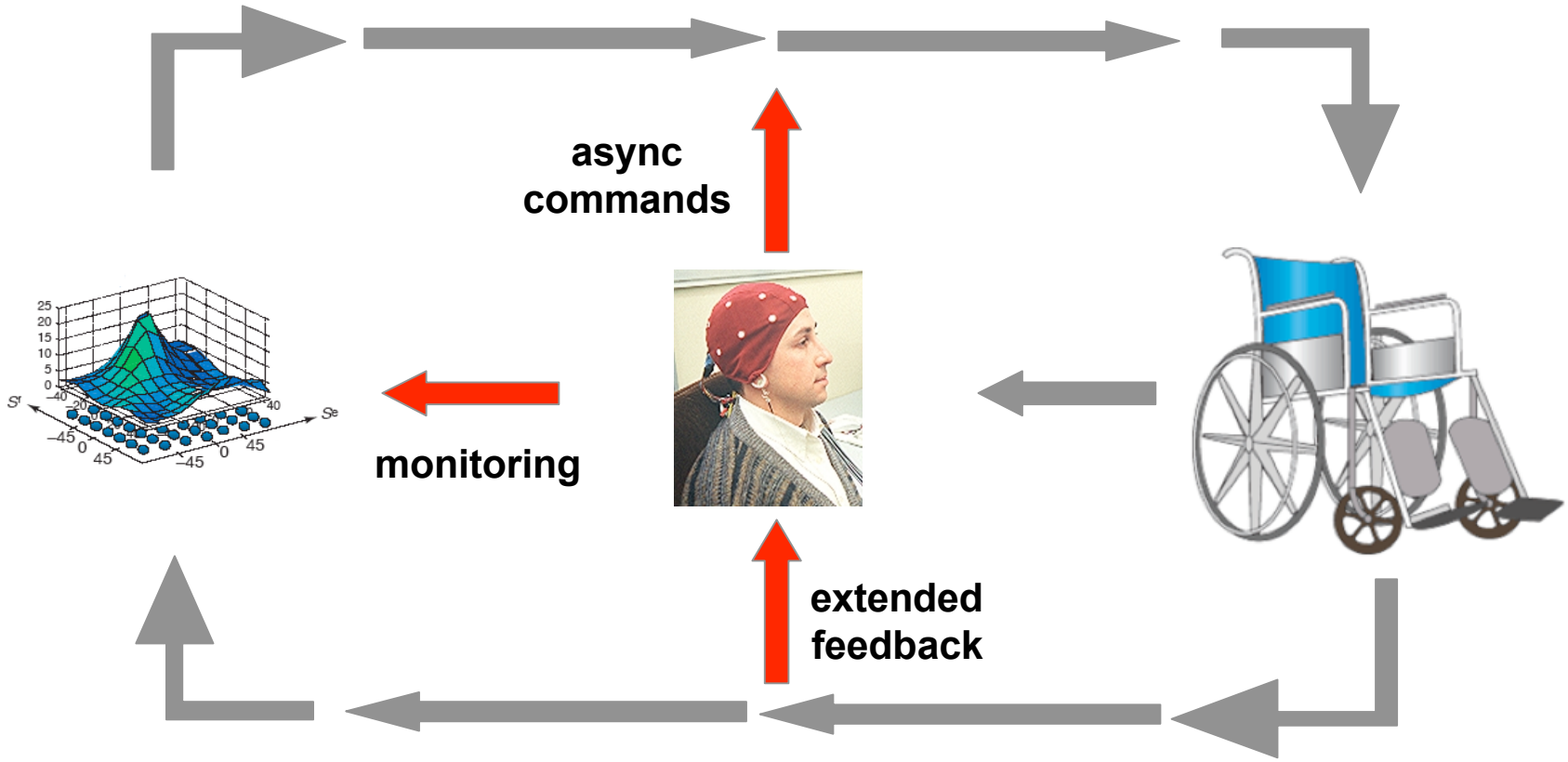
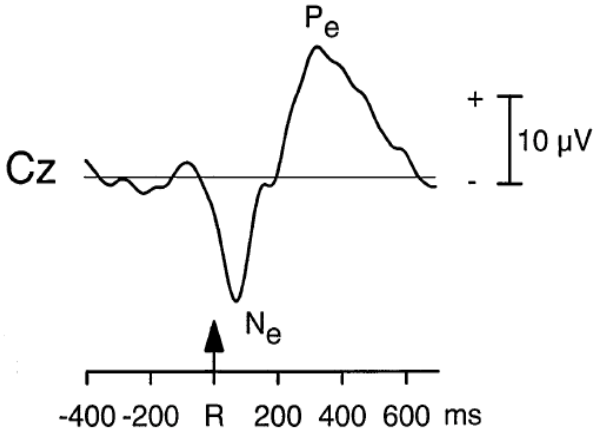
Human in the loop



Error related potentials - background

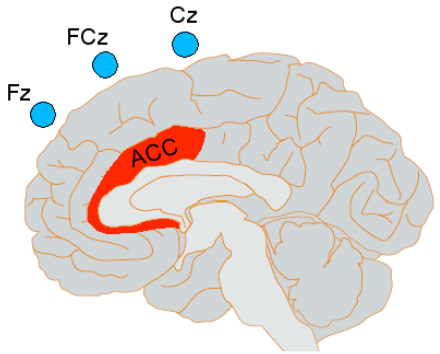
- Evoked potentials in speed response tasks. Errors are committed by the subject

Falkenstein et al., 2000



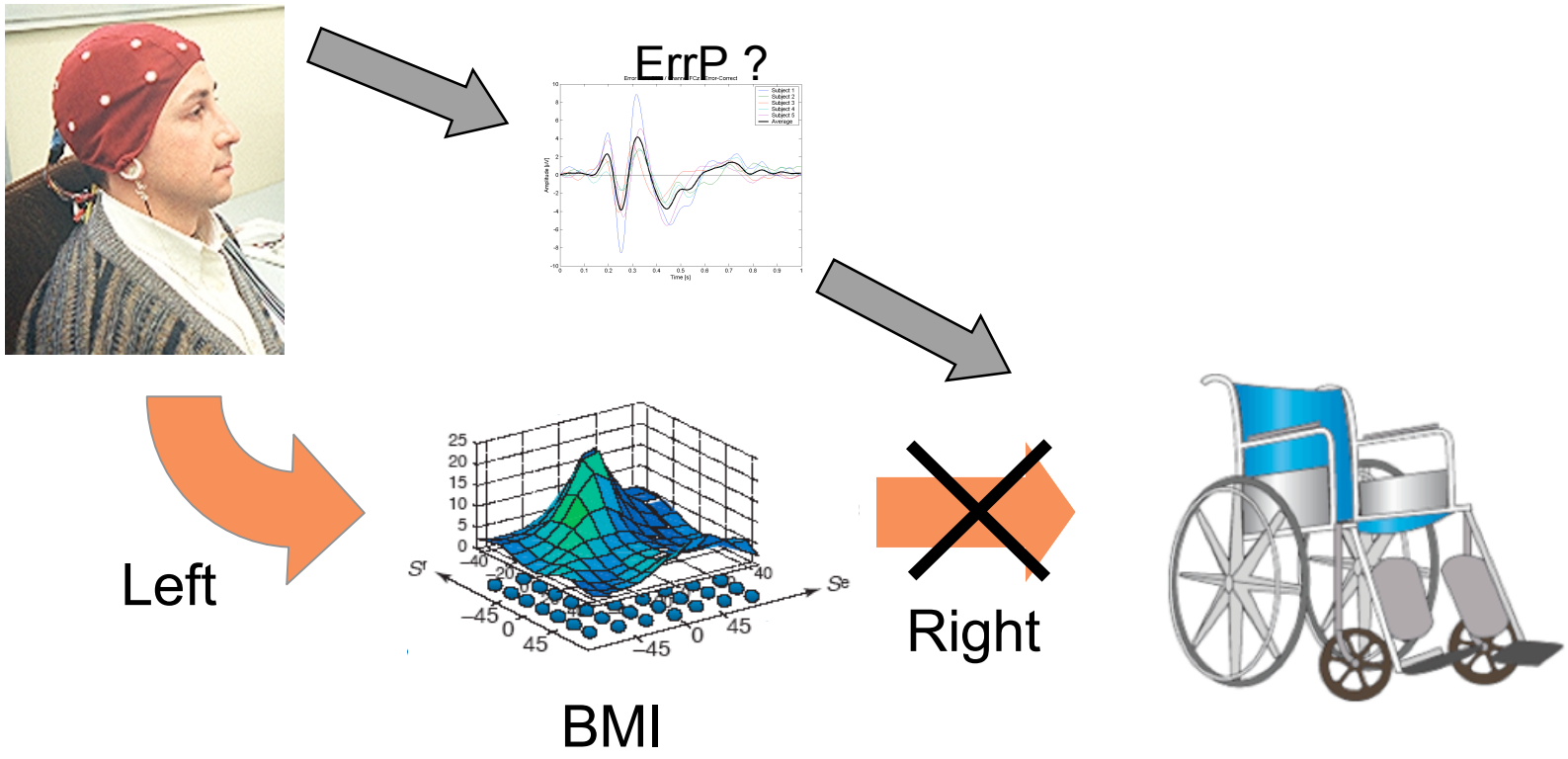
- Generated in Anterior Cingulate Cortex (ACC)

- linked to RL theories of learning. Dopaminergic activity related to reward prediction errors

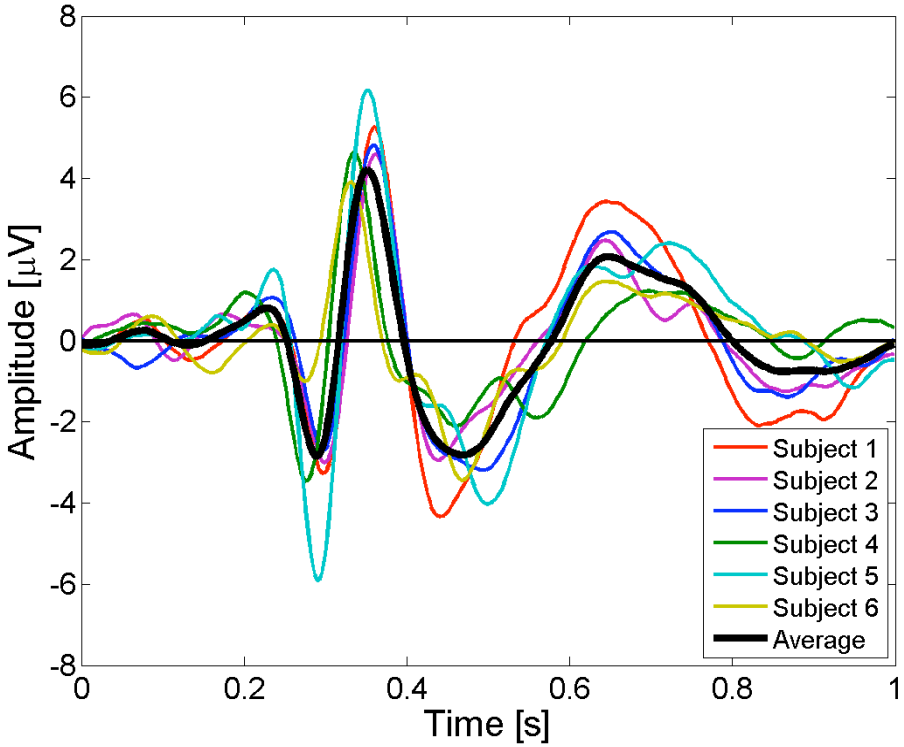


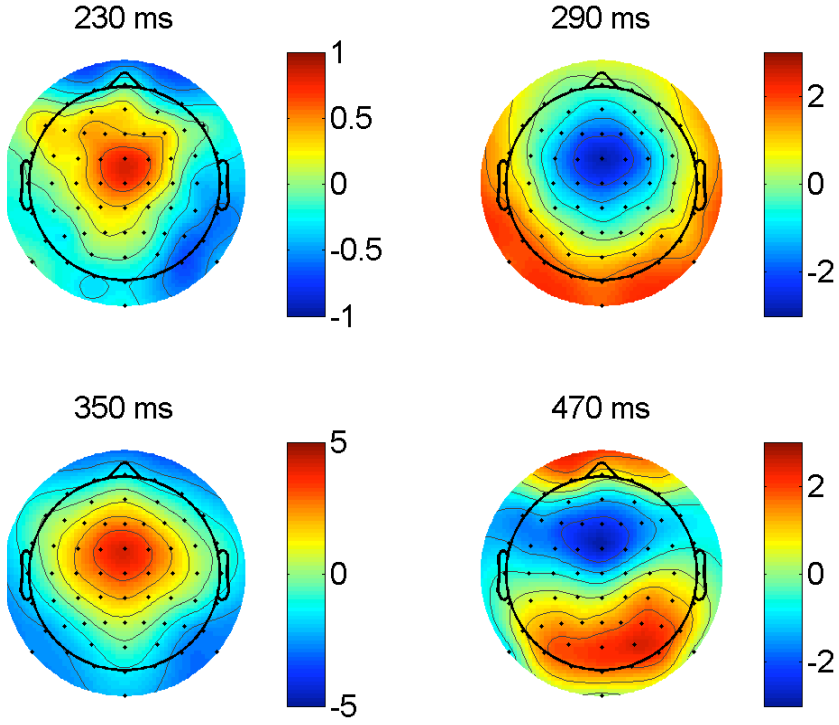
Are error potentials evoked during Brain-robot interaction ?

Error signals during human-robot interaction



“Interaction” Error-related Potentials





Ferrez and Millán, 2005, 2007
Chavarriaga et al., 2007

Error-related potentials: On-Line detection

- 2 naive subjects
- BCI and ErrP classification accuracy
- Performance with and without ErrP integration

		I	II	III	IV	Average	SD
ErrP detection	**Error [%]**	94.8	76.6	76.5	80.2	**82.0**	**8.7**
	Correct[%]	68.0	88.5	86.1	91.4	**83.5**	**10.6**
BCI without ErrP	**Error rate [%]**	31.3	30.2	31.1	29.2	**30.5**	**1.0**
	Rejection rate [%]	0.0	0.0	0.0	0.0	**0.0**	**0.0**
BCI with ErrP	**Error rate [%]**	1.6	7.6	7.6	5.8	**5.7**	**2.8**
	Rejection rate [%]	51.6	32.5	33.1	29.5	**36.7**	**10.1**
Performance	**BpT initial**	0.10	0.12	0.11	0.13	**0.12**	**0.01**
	BpT final	0.38	0.36	0.33	0.42	**0.37**	**0.04**
	Increase [%]	280	200	200	223	**226**	**38**

Look behind the scenes: Other cognitive states

- error, anticipation (Gangadhar et al., 2008, In Press), *alarm*
  - ↳ trigger automatic behaviors
- decision making (Bourdaud et al., 2008)
- attention level, fatigue
- mental workload
- prediction of performance accuracy and speed
  - ↳ customize interaction
- *Challenge:* reliable recognition of such states in real time

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Conclusions: Towards Brain Technology

- ***MAIA*** project — radical departure from current assumptions to develop non-invasive neuroprostheses:

  adaptive shared control, error-related potentials

- ***BACS*** project — Development of Human-in-the-loop approach. Further use of cognitive related signals in human-robot interaction:

  Error and anticipation related potentials, multimodal feedback

- ***EEG carries cognitive information*** — unique feature of the "brain channel":

  it conveys information about intents (mental commands) **AND** cognitive states (errors, alarms, attention, frustration, confusion, etc.) that are crucial for a purposeful interaction

Acknowledgments

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- Gangadhar Garipelli
- Nicolas Bourdaud

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BACS http://www.bacs.ethz.ch

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