Brain-Computer Interfaces for Interaction and Control

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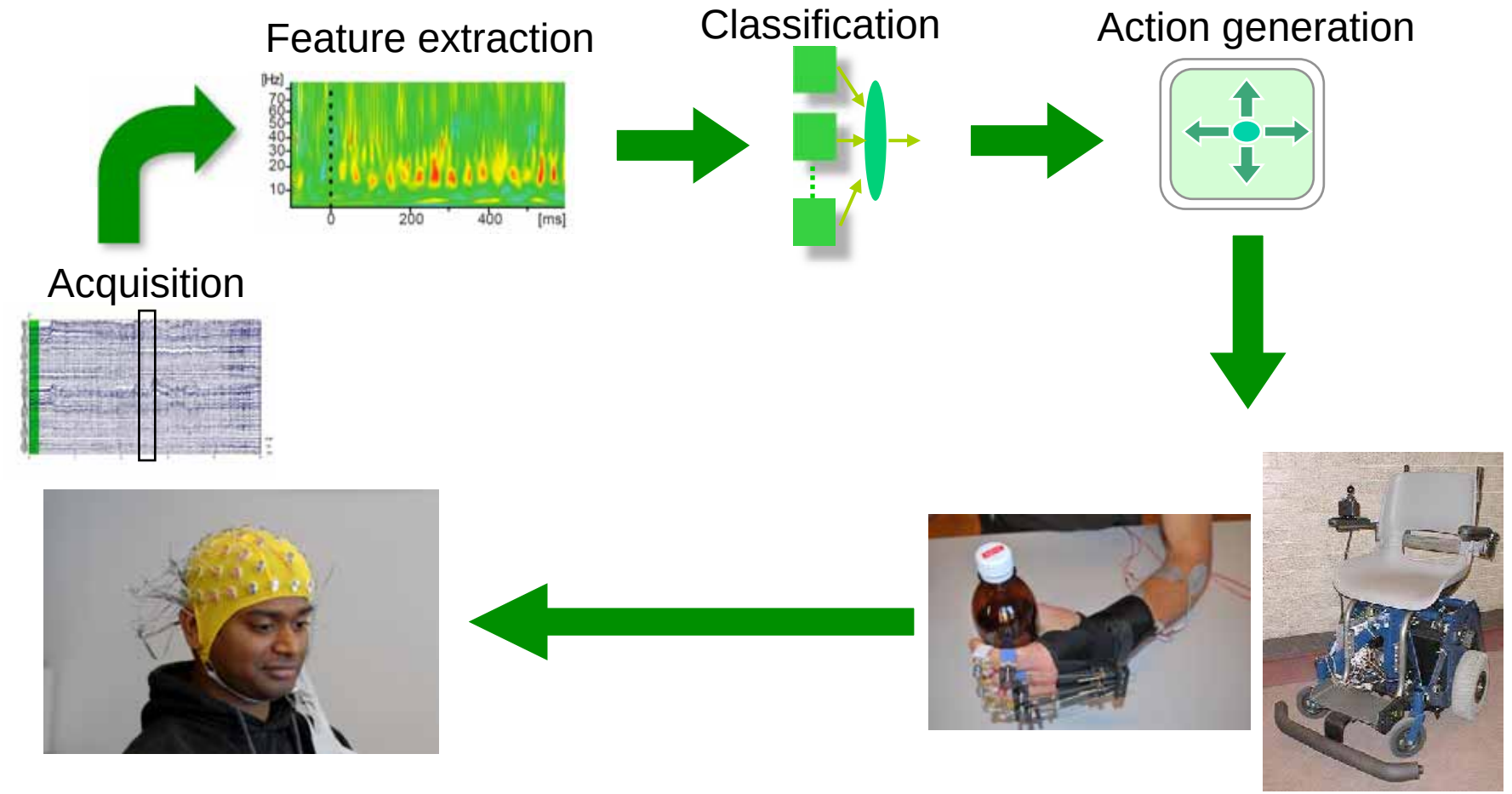
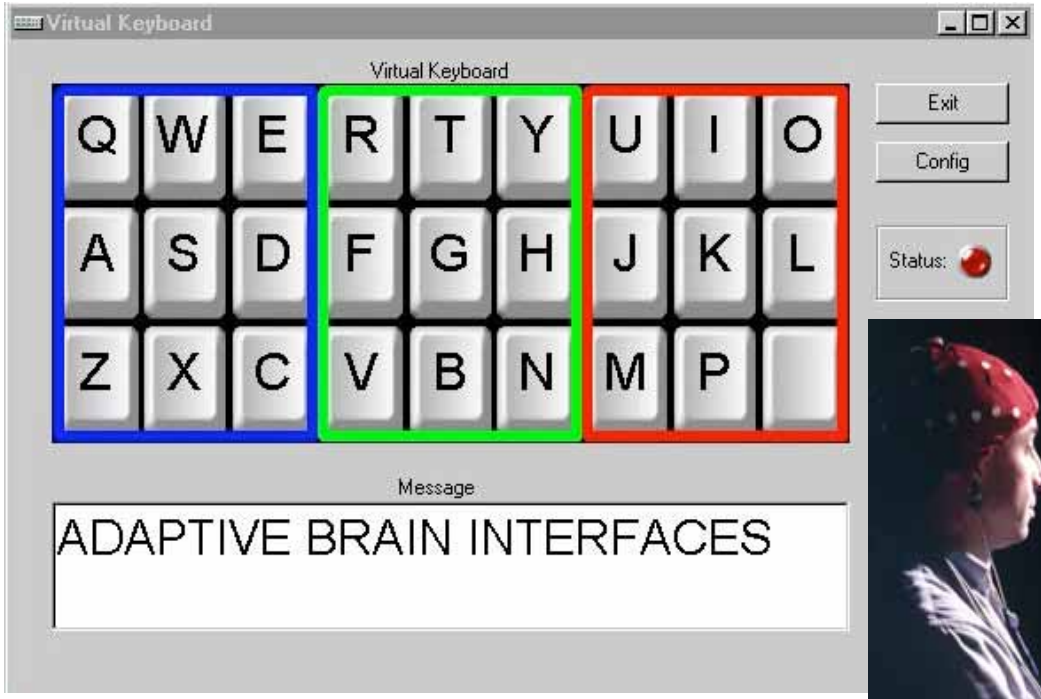
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

BCI Architecture



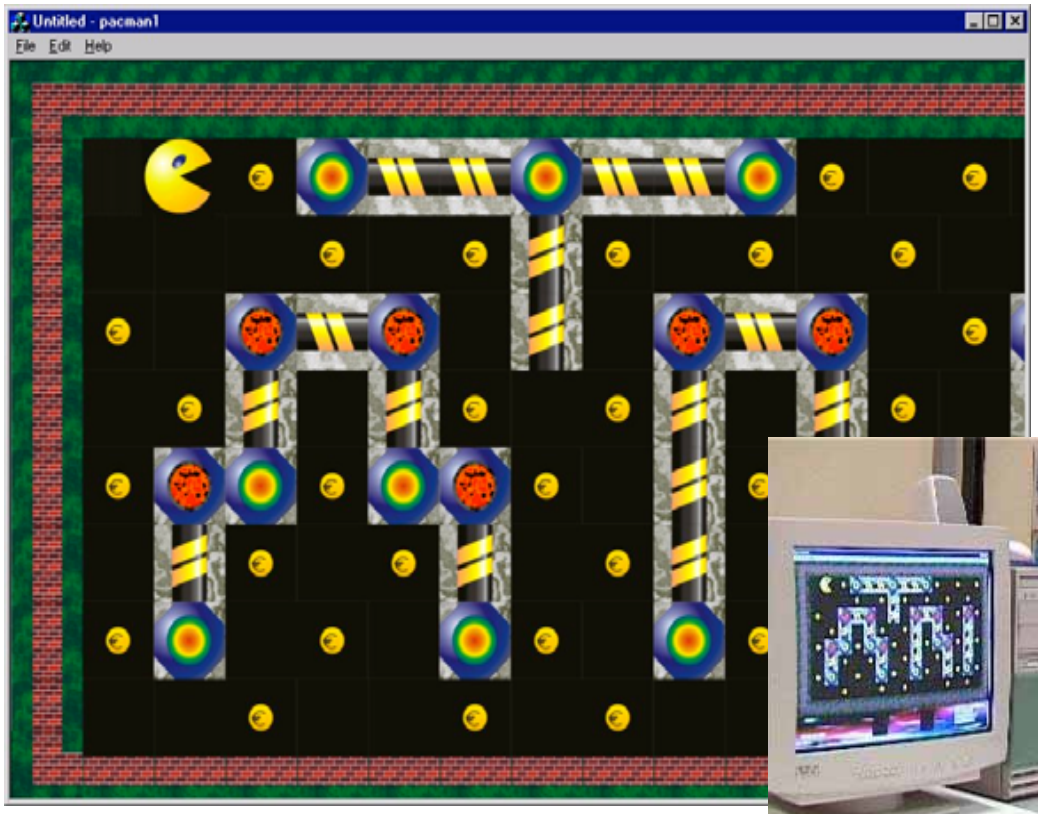
Brain-actuated Virtual Keyboard



ABI Project
1998-2001

- ***Asynchronous protocols***
- ***Machine learning approaches***

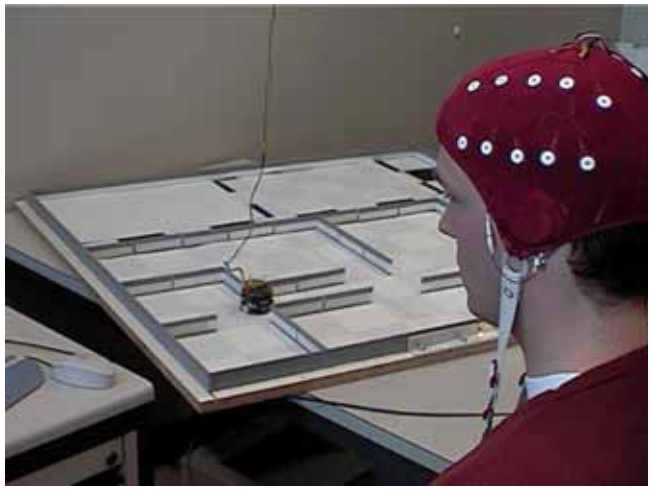
Brain-actuated Computer Game



ABI Project
1998-2001

- ***Asynchronous protocols***
- ***Machine learning approaches***

Brain-controlled Robots



➔ **big challenge, fast and timing decision-making is critical**

- ***1st demonstration of brain-controlled robots & wheelchairs***
- ***Novel principles to design intelligent neuroprosthetics***

Brain-controlled Robots

MAIA Project
2004-2007

- ***1st demonstration of brain-controlled robots & wheelchairs***
- ***Novel principles to design intelligent neuroprosthetics***

TOBI —
Tools for Brain-Computer Interaction

- TOBI will develop **practical** non-invasive BCI-based assistive technology endowed with **adaptive** capabilities that augment those other AT they are combined with: **hybrid architecture**

- 4 application areas where TOBI technology can have a real, measurable impact in terms of pre-clinical validation, for people with motor disabilities

tobi
tools for brain-computer interaction

http://www.tobi-project.org/

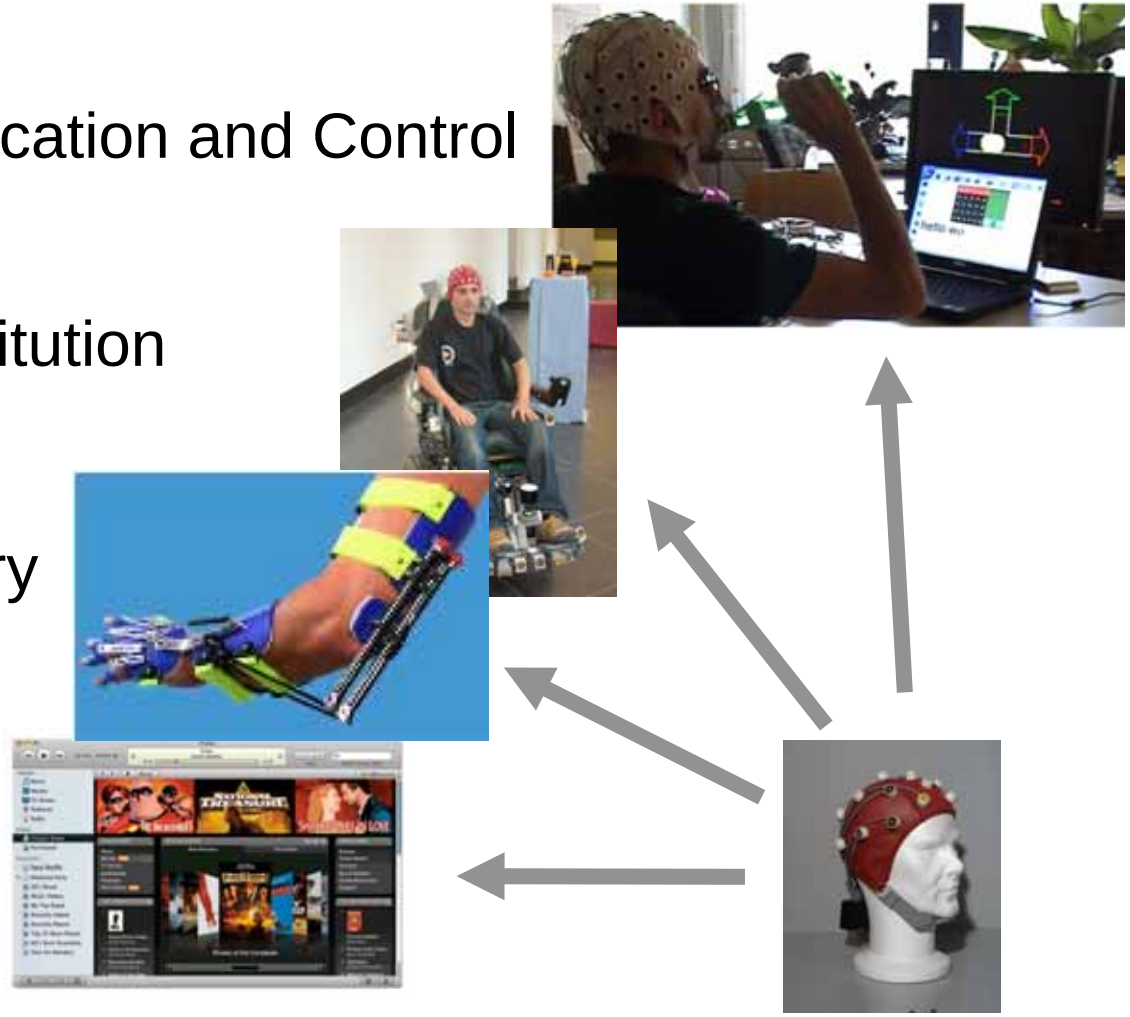
TOBI — Partners

- Ecole Polytechnique Fédérale de Lausanne, CH (coordinator); **BCI, NeuroProsthetics**
- Technical University Berlin, DE; **BCI**
- Technische Universitaet Graz, AT; **BCI**
- Fondazione Santa Lucia, IT; **BCI, clinics**
- Eberhard-Karls Universitaet Tübingen, DE; **BCI, ethics**
- University Glasgow, UK; **HCI**
- QualiLife, CH; **Applied AT, industry**
- Stiftung orthopaedische Universitaetsklinik Heidelberg, DE; **NeuroProsthetics, clinics**
- Schweizerische Unfallversicherungsanstalt; CRR-Suvacare, CH; **clinics**
- Kreuznacher Diakonie; Beratungsstelle für Unterstützte Kommunikation, DE; **Applied AT, user groups**
- Associazione Italiana per l'assistenza agli spastici provincia di Bologna, IT; **Applied AT, user groups**
- Julius-Maximilian Universitaet Würzburg, DE; **BCI**

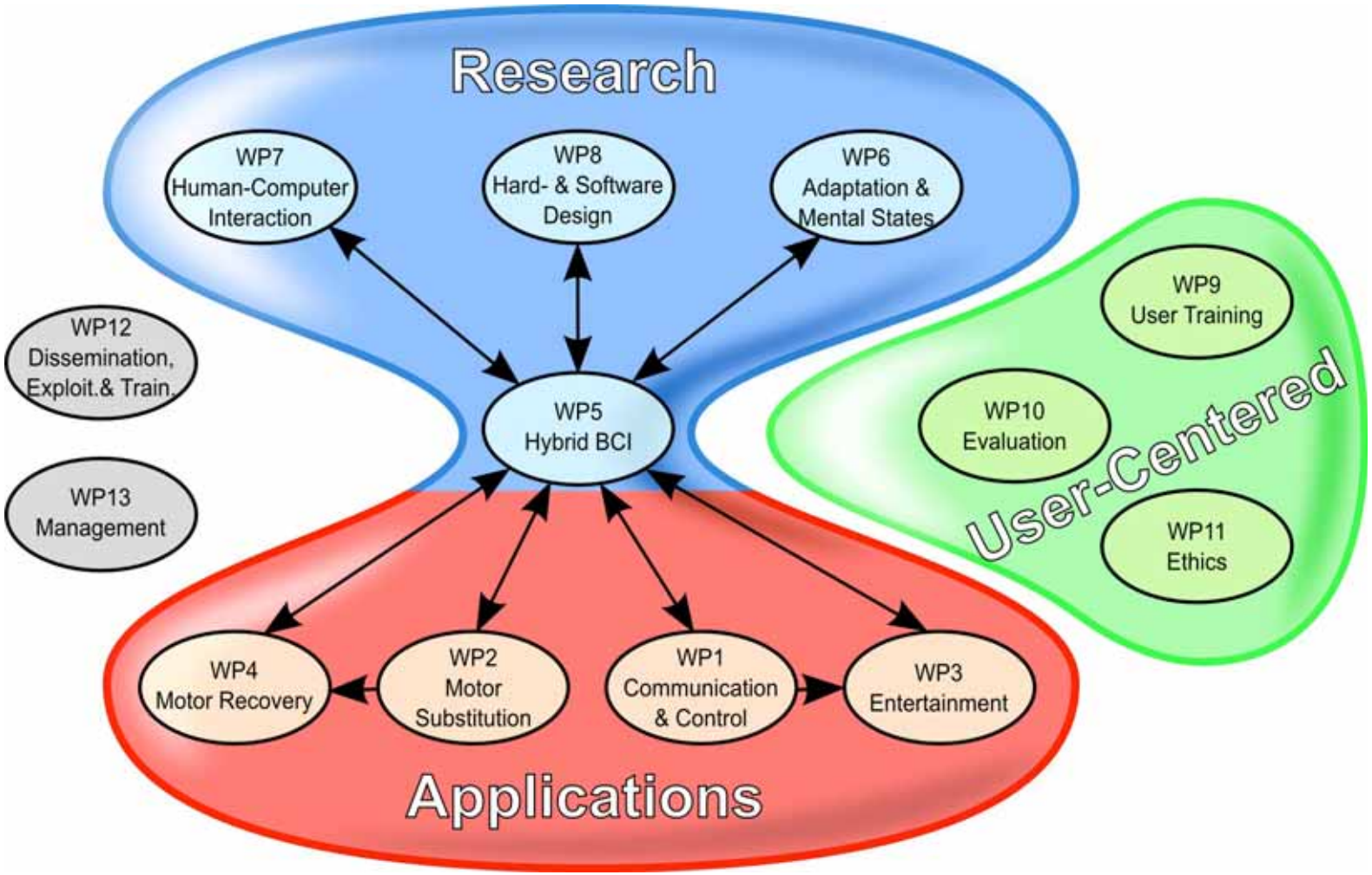
tobi
tools for brain-computer interaction

TOBI Applications

- Communication and Control
- Motor Substitution
- Motor Recovery
- Entertainment



TOBI Workpackages



User-Centered Approach — Helping Market Pick-up

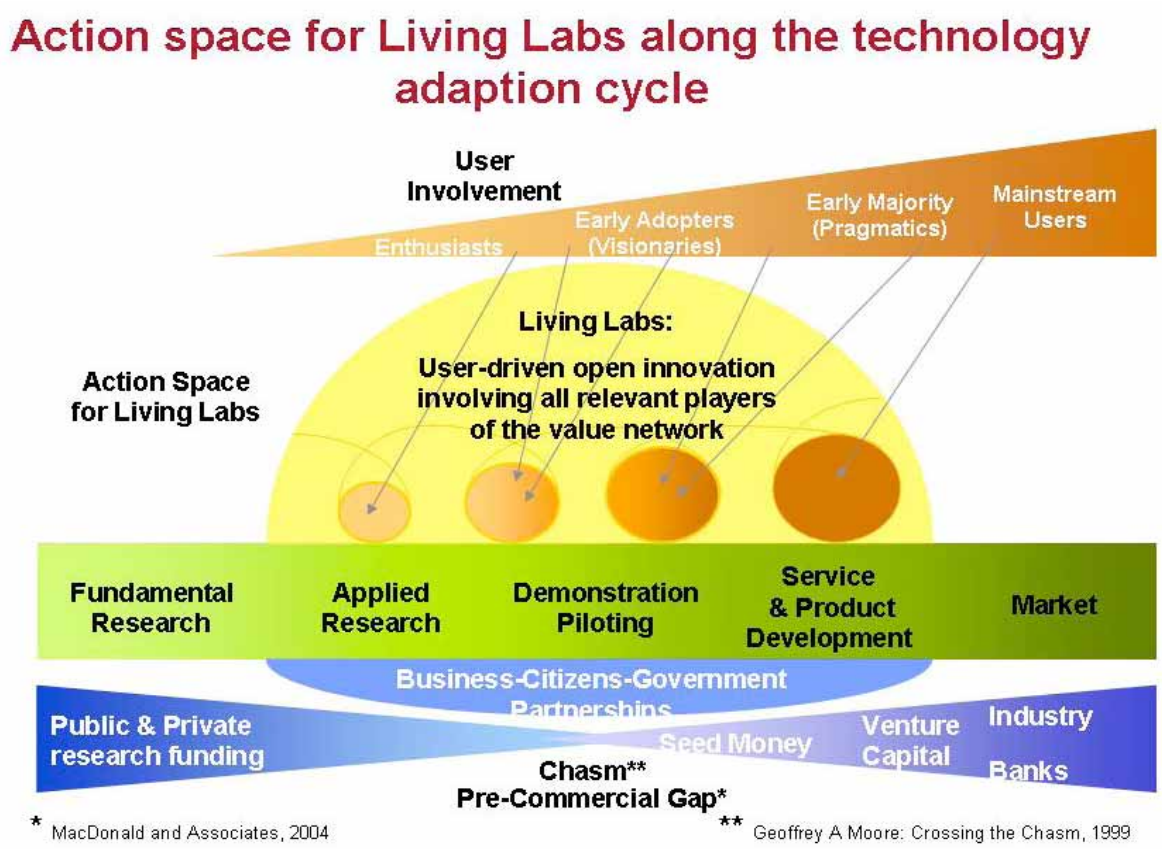
User forums of end users and independent AT experts (professional users).	***Testing in clinics and AT Centres starting from first prototype.***	***Increasing number of end users involved.***

Survey into user needs

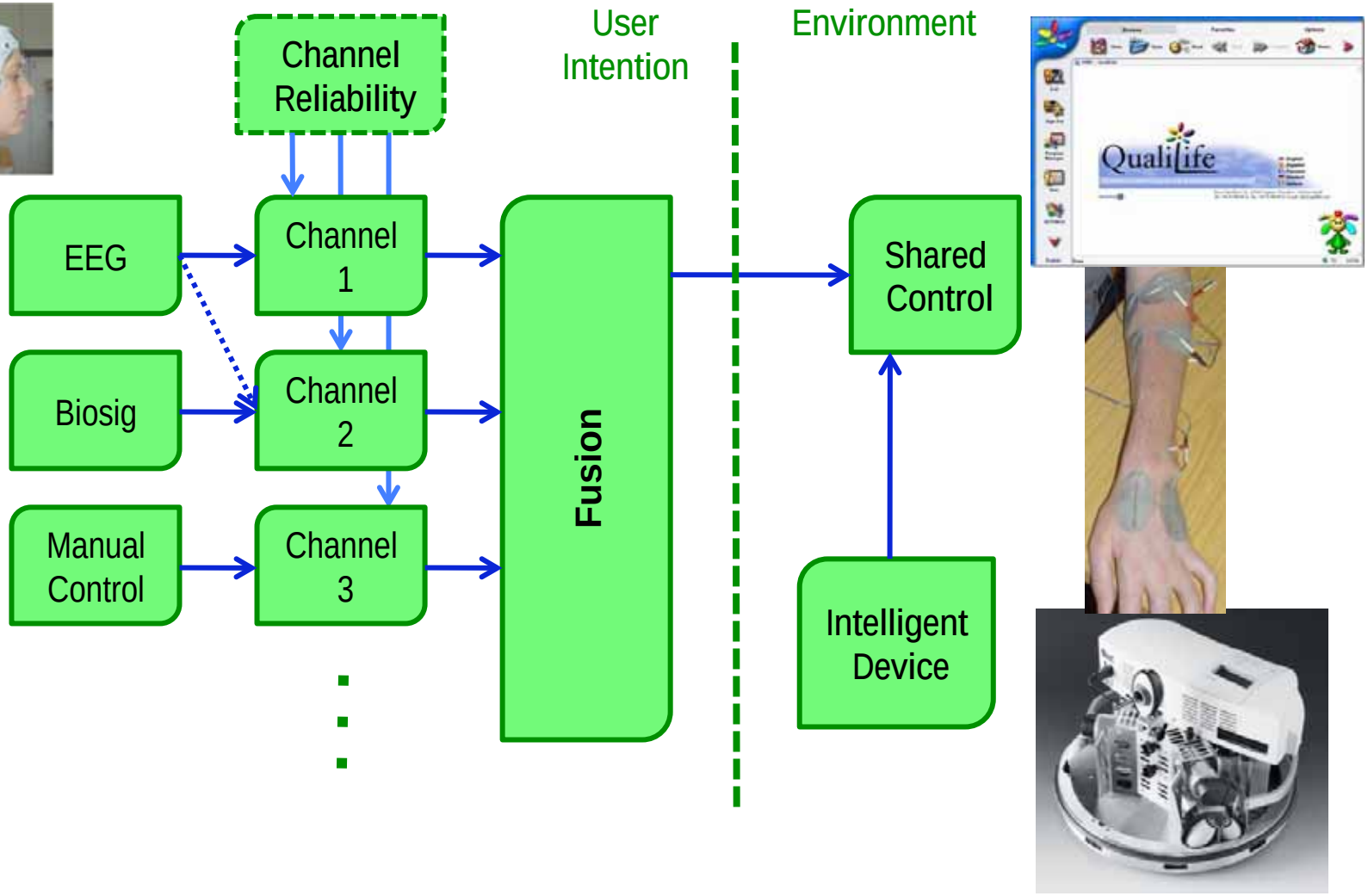
User-centered evaluation criteria and scales

Assessment expected impact on quality of life

Testing in real life situation



Hybrid BCI Architecture (hBCI)



BCI at Work — A Glimpse

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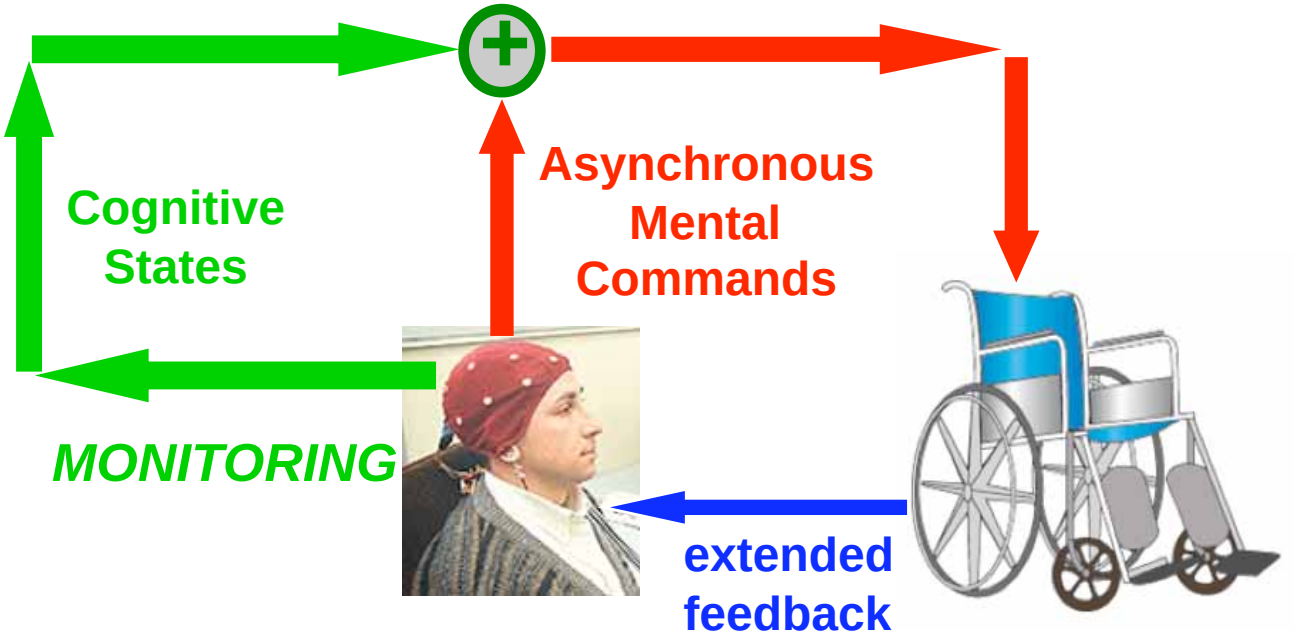
BCI at Work — A Glimpse

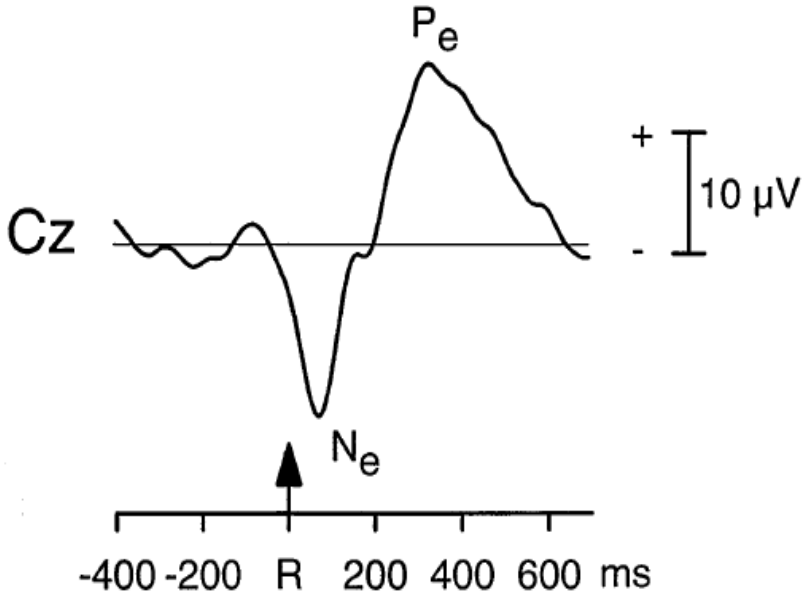
Interaction Principles

- Asynchronous approach
  - User can send commands anytime
  - Spontaneous activity, no external cues
- Machine Learning Way to BCI
  - Mutual learning process
  - Feature extraction & classification
- Blending of Intelligences
  - User's mental capabilities + intelligent device
  - Shared Control
- Cognitive Interfaces
  - Recognition of human mental states (e.g., error awareness, anticipation, fatigue)

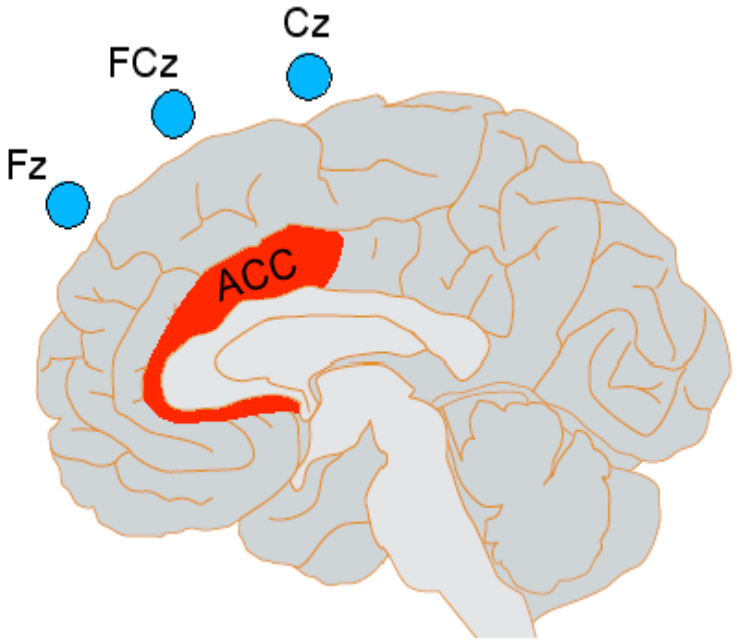
Cognitive States: Human in the Loop



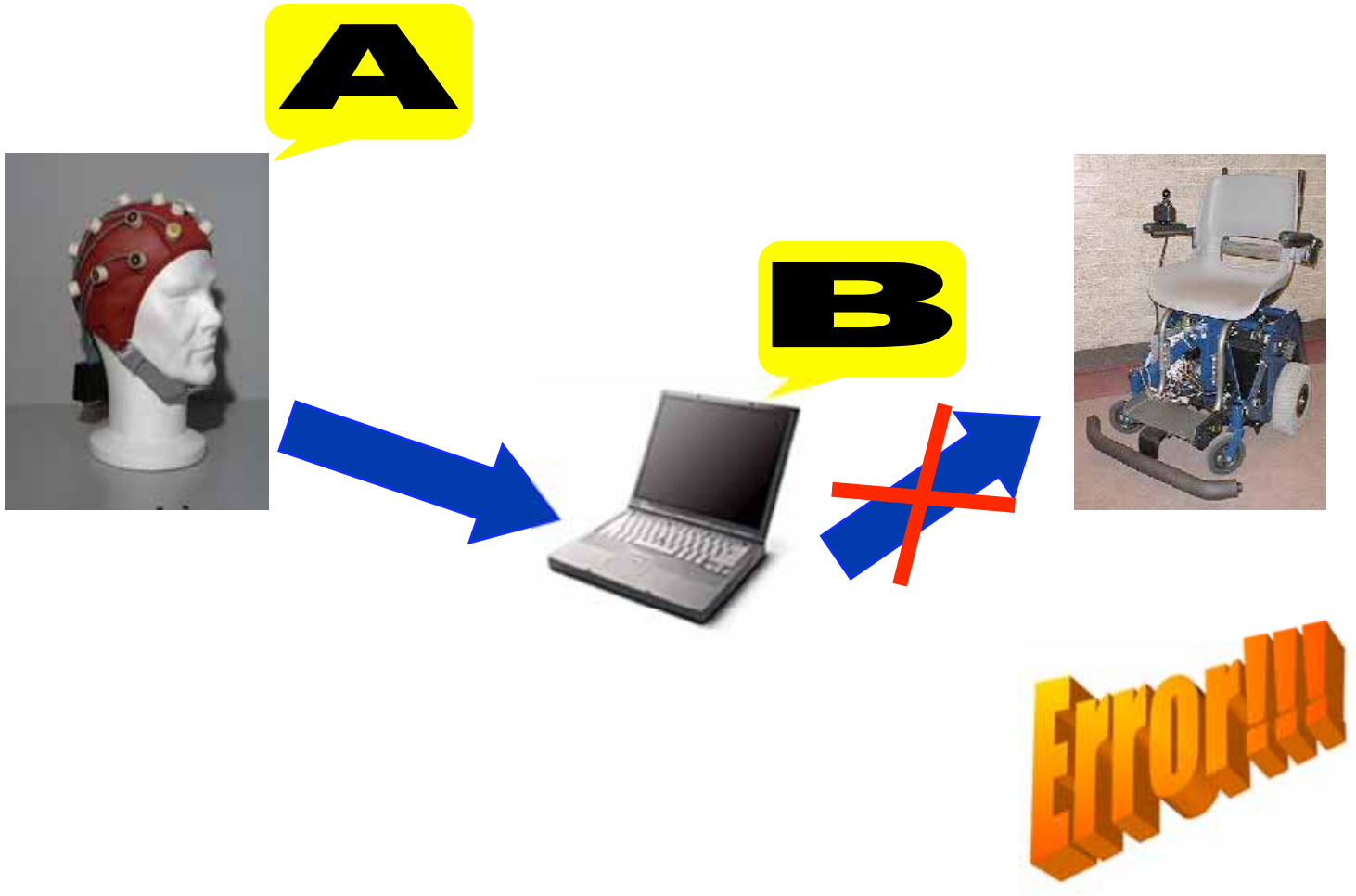
You Got Me Wrong! — Recognition of Cognitive States



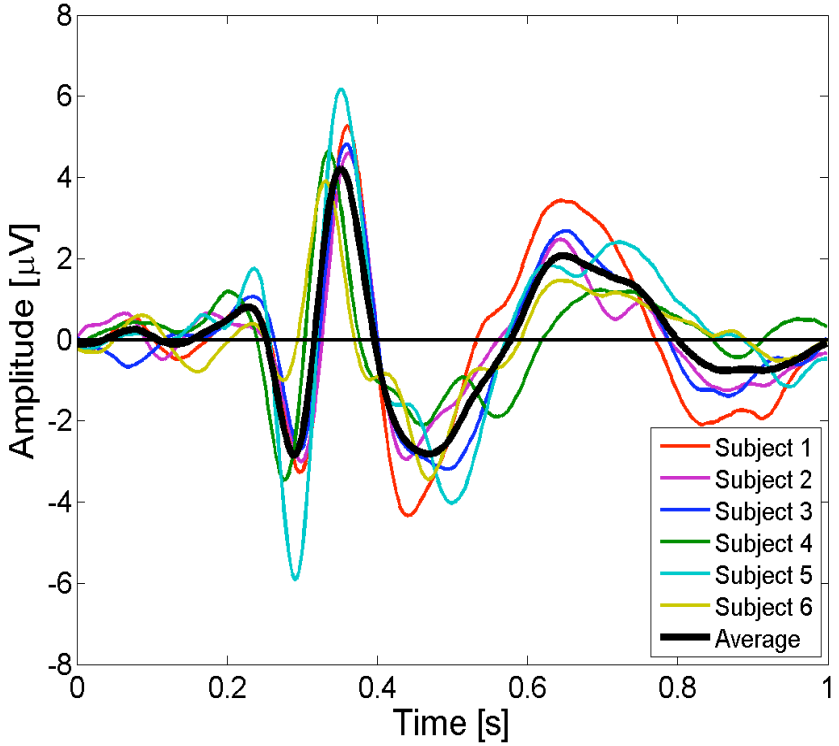
(Falkenstein et al., 2000)

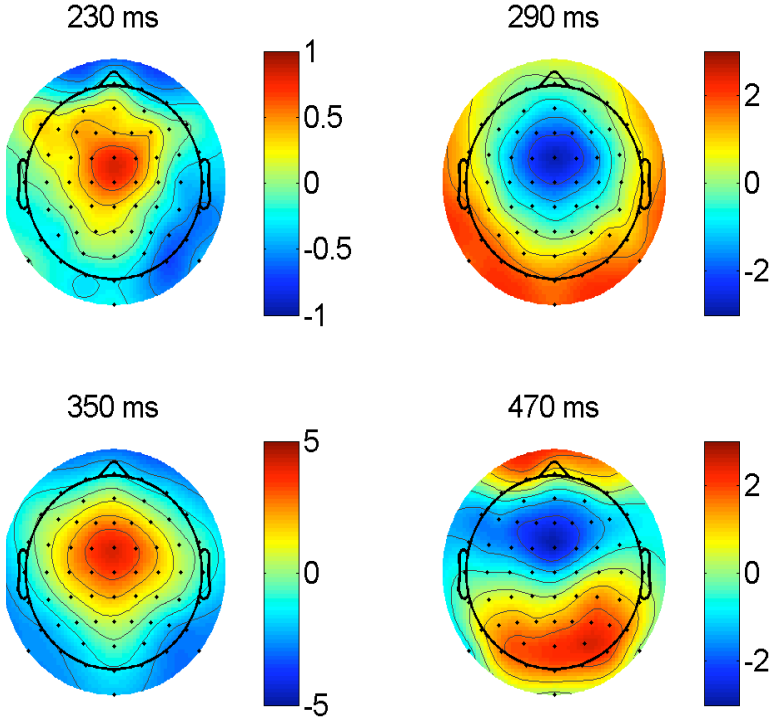


Cognitive States: Error Recognition

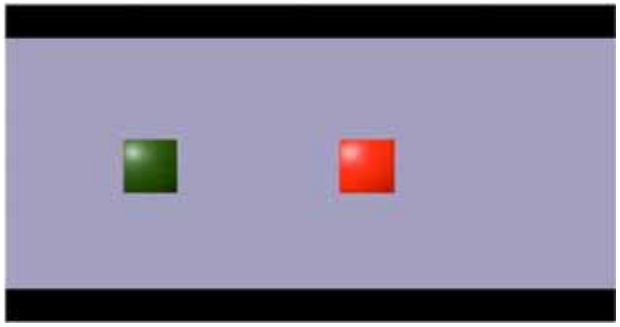


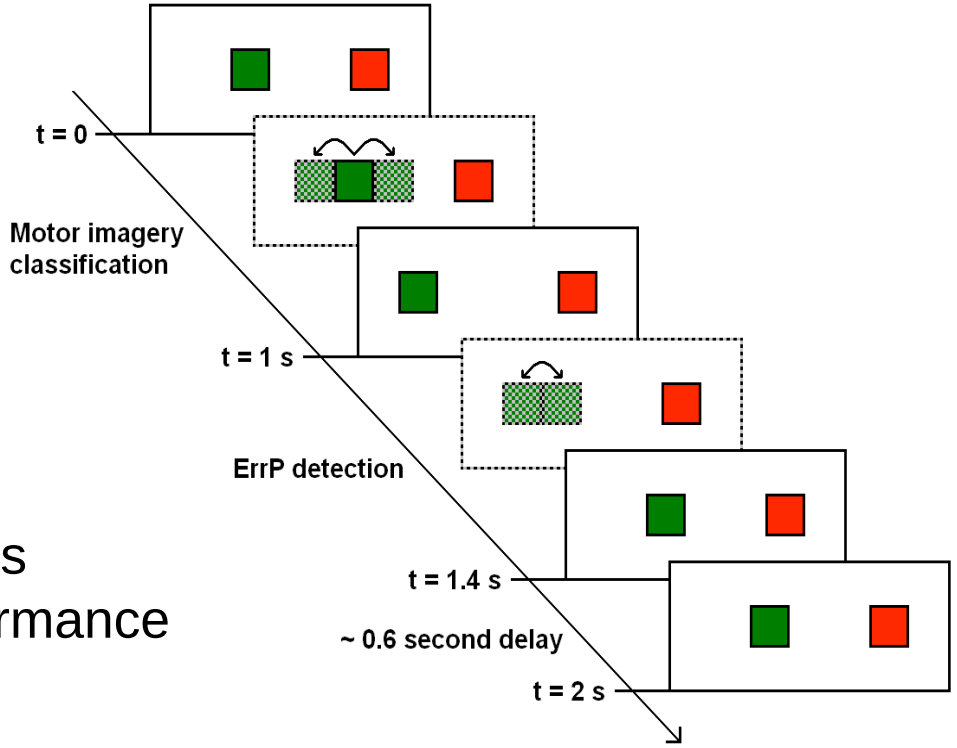
Interaction Error-related Potentials





ErrP: Online Implementation



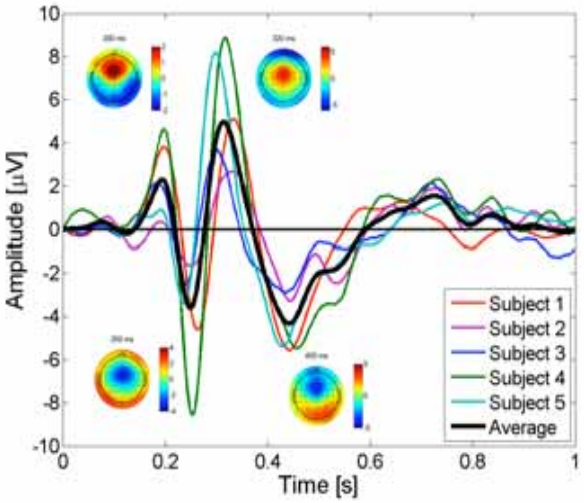


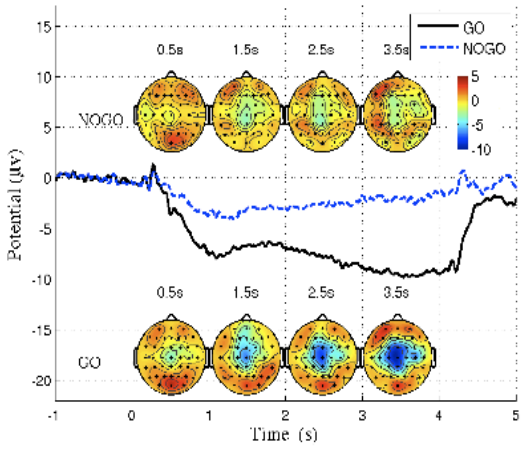
- Two naïve subjects
- Two different days
- 150 ms window: 250 → 400 ms
- Above 200% increase in performance (Bits per Trial)

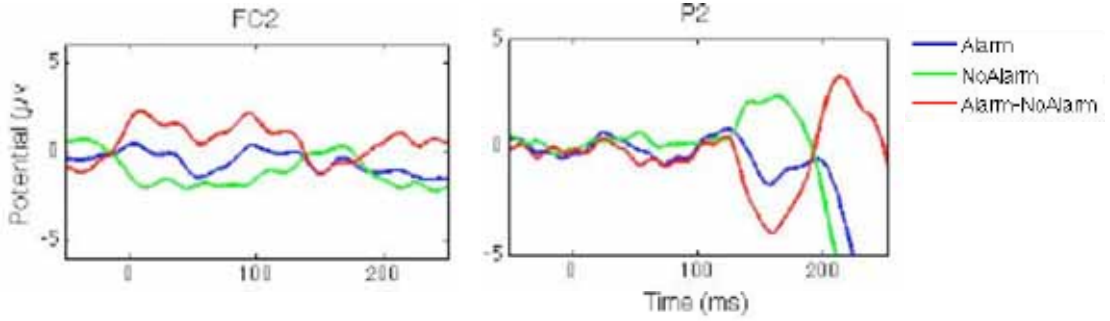
ErrP: Real-World Application

Look behind the Scene — Other Cognitive States

- error, anticipation, alarm
  - ↳ trigger automatic behaviors



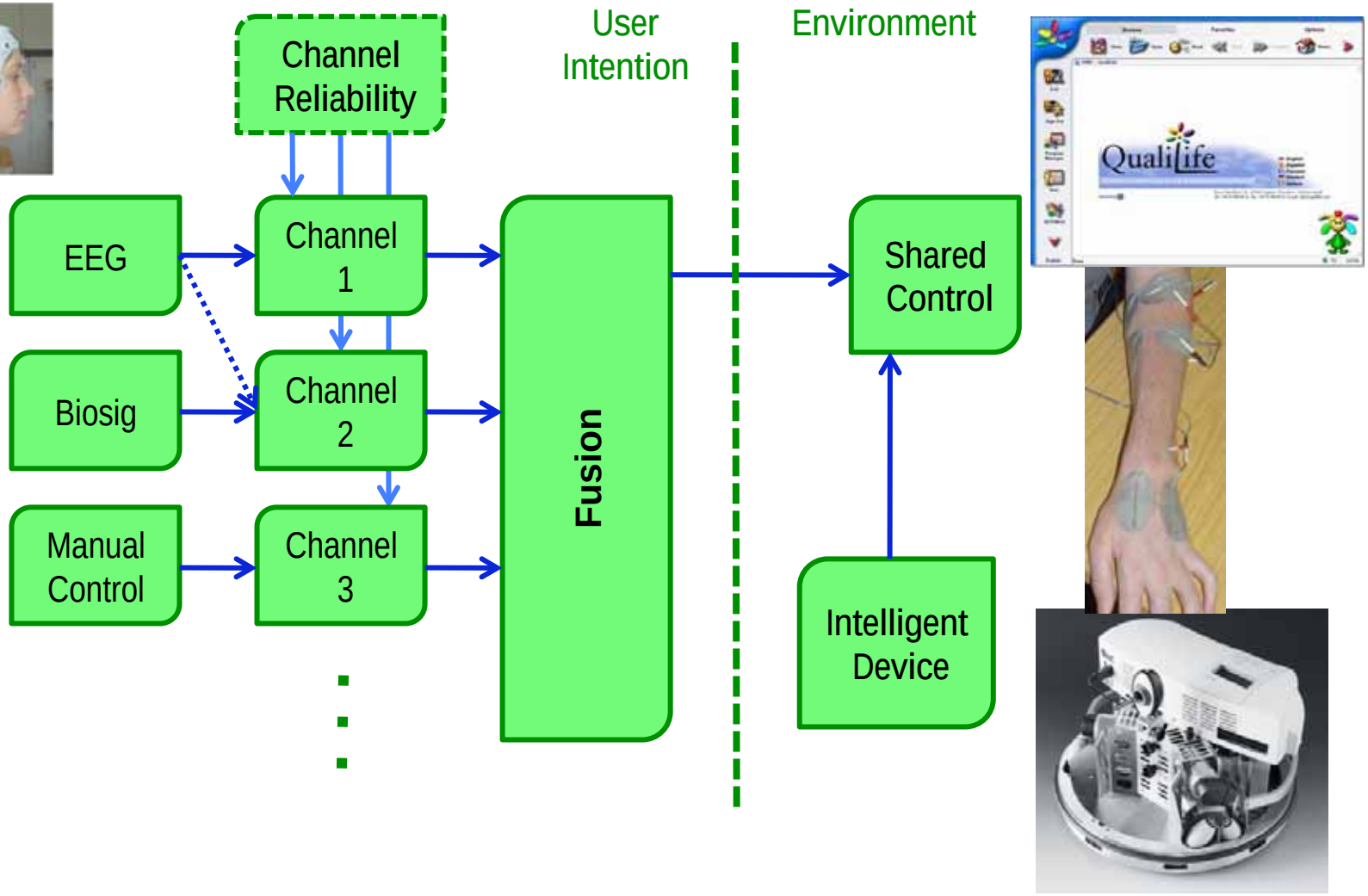




Look behind the Scene — Other Cognitive States

- error, anticipation, alarm
  - ↳ trigger automatic behaviors
- attention level, fatigue, mental workload
  - ↳ customize interaction

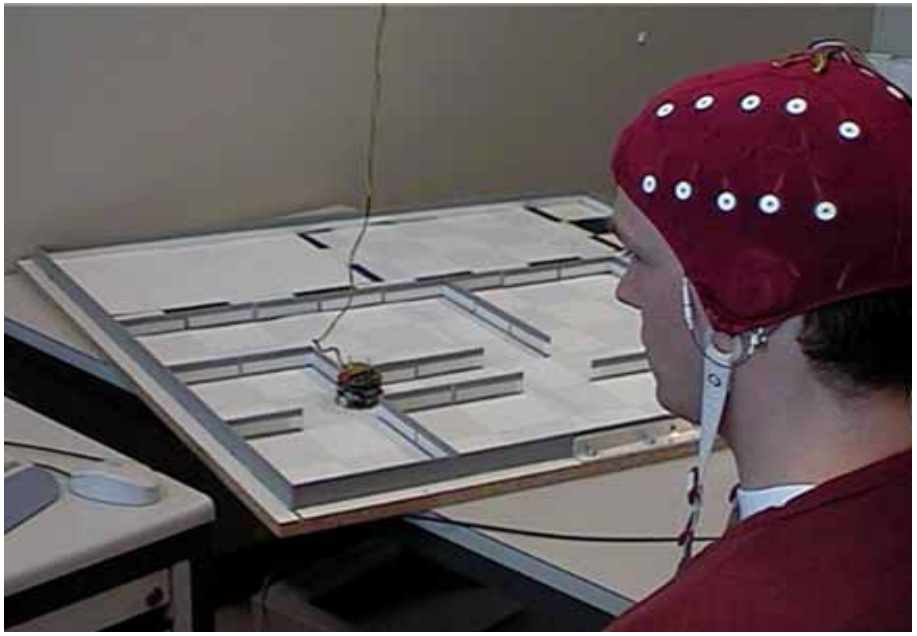
Hybrid BCI Architecture (hBCI)

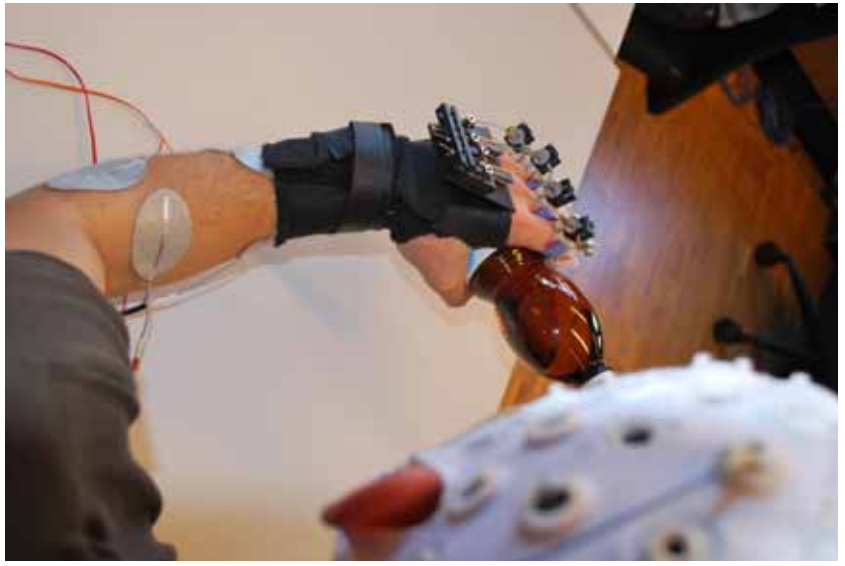


Brain-Controlled Robots

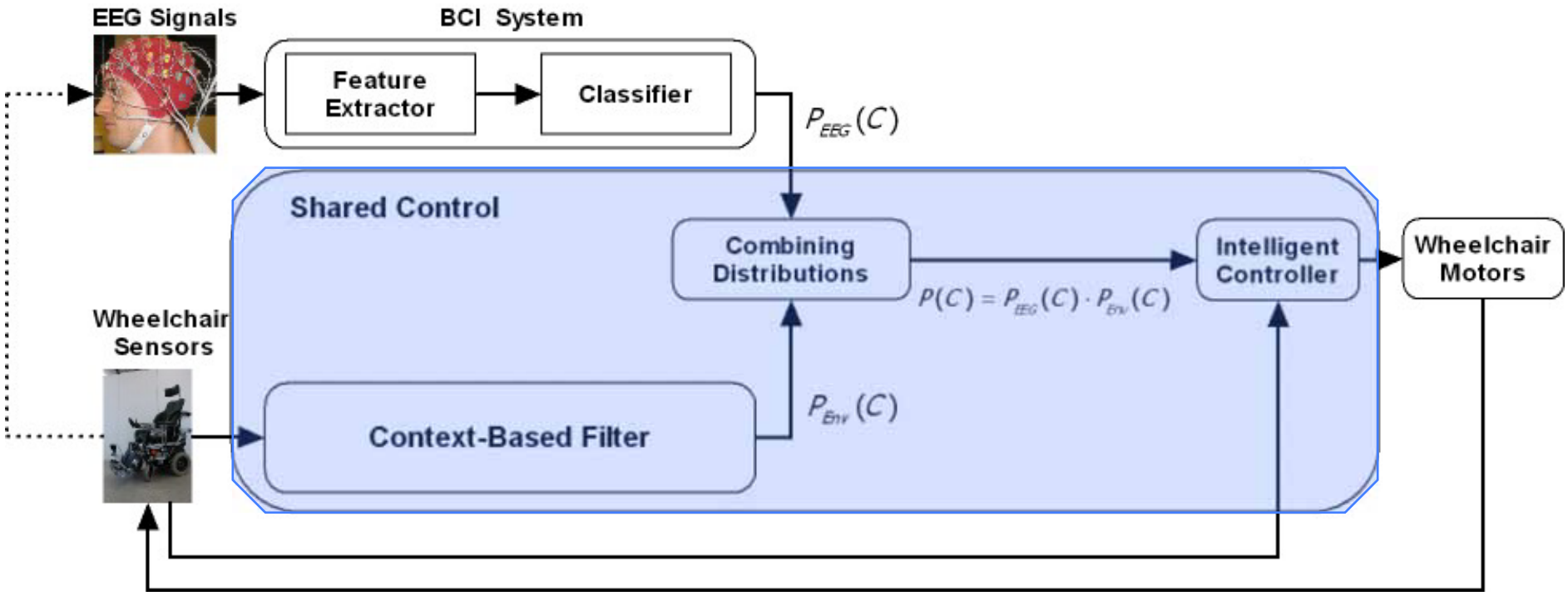
Users address the task at high level and all the low level details are handled automatically:

Intelligent Robotics



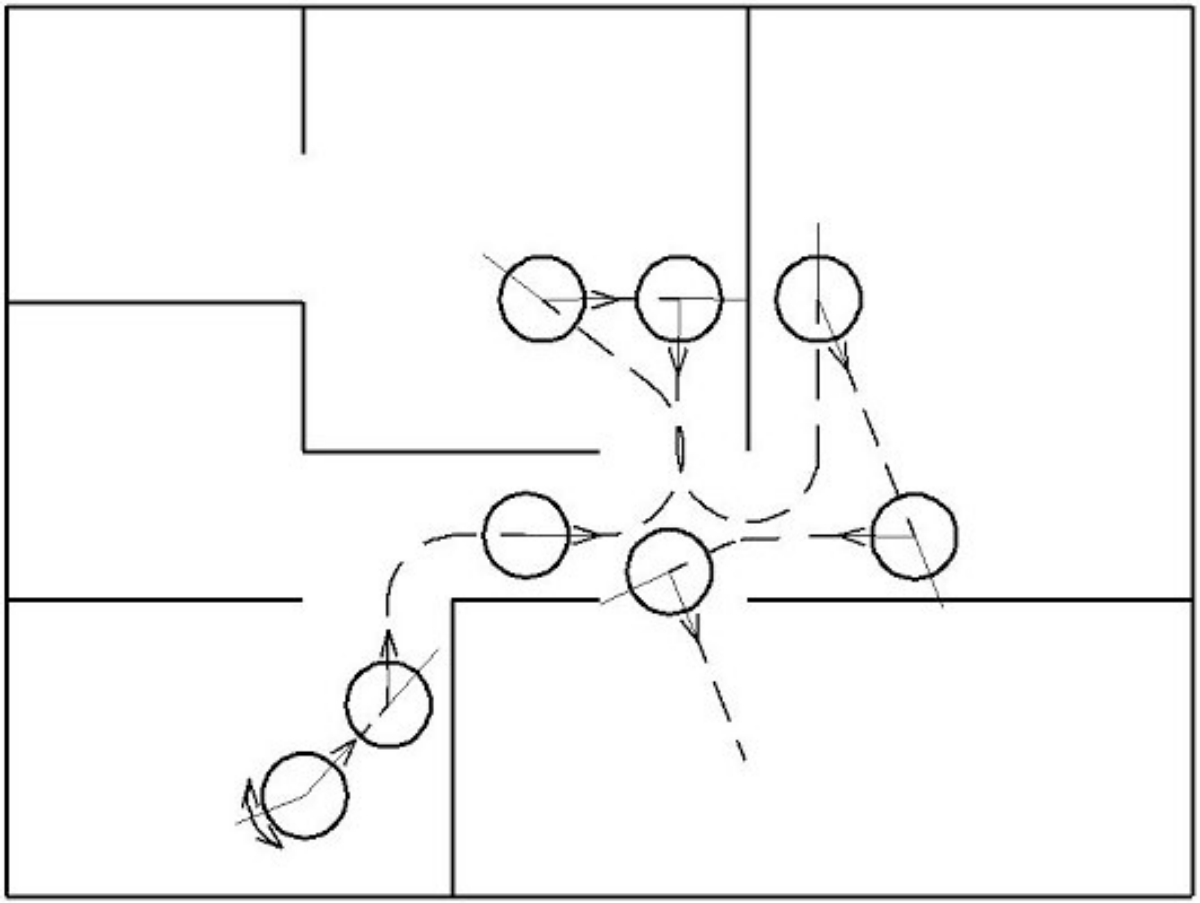


Adaptive Shared Control



Experiment I: Robot Navigation

Qualitatively
good trajectories



Experiment I: Execution Time (sec)

Subject 1

Relax, Left, Cube

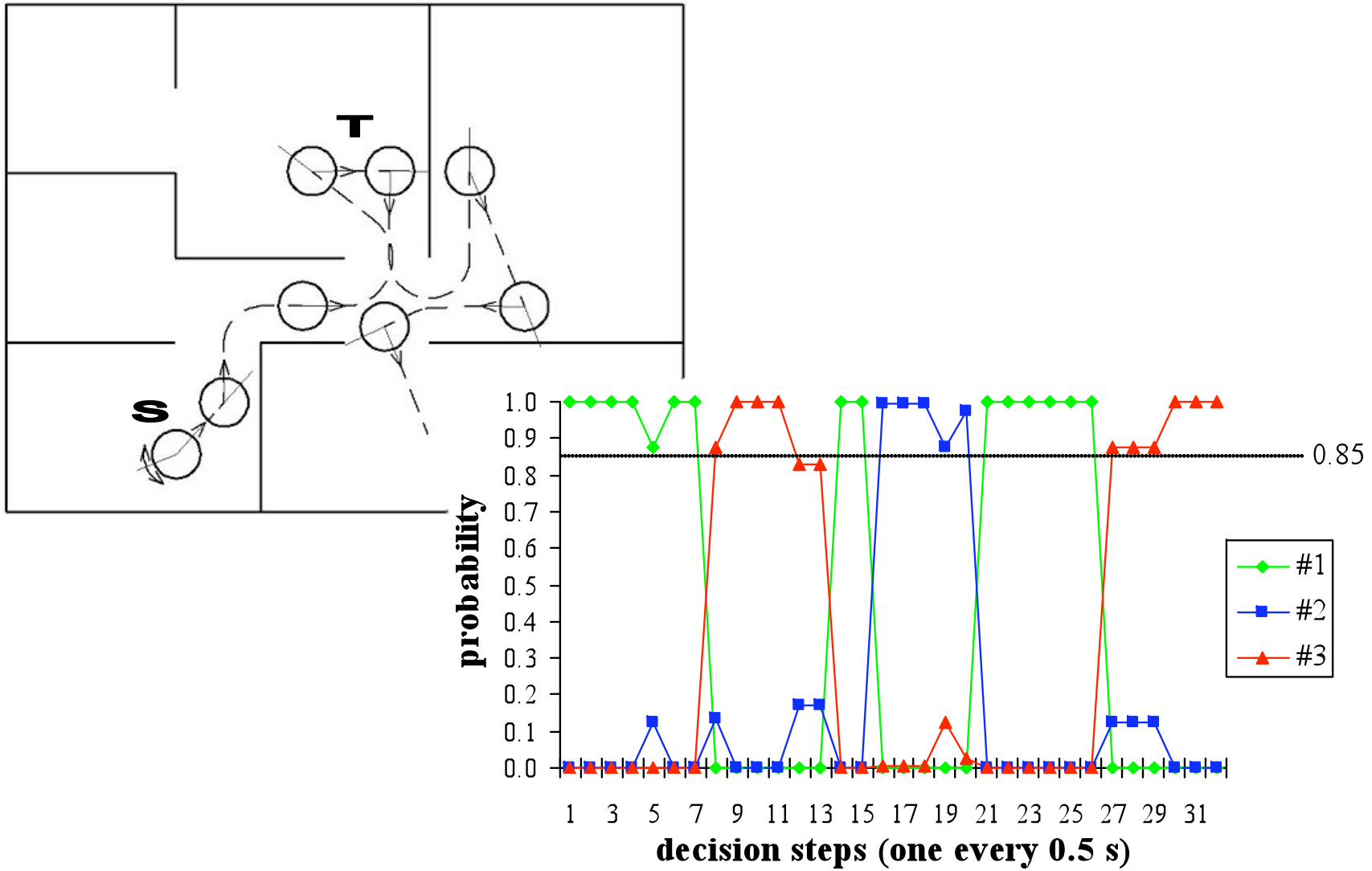
Trial	Mental	Manual	Ratio
1	149	124	0.83
2	183	135	0.74
3	191	129	0.68
Average	***174***	***129***	***0.75***

Subject 2

Relax, Left, Right

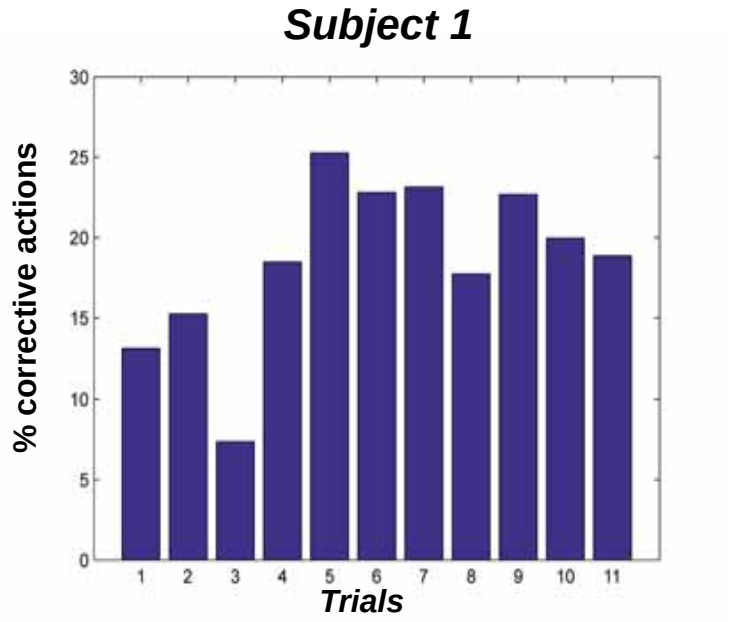
Trial	Mental	Manual	Ratio
1	219	156	0.71
2	189	155	0.82
3	175	117	0.67
Average	***194***	***143***	***0.73***

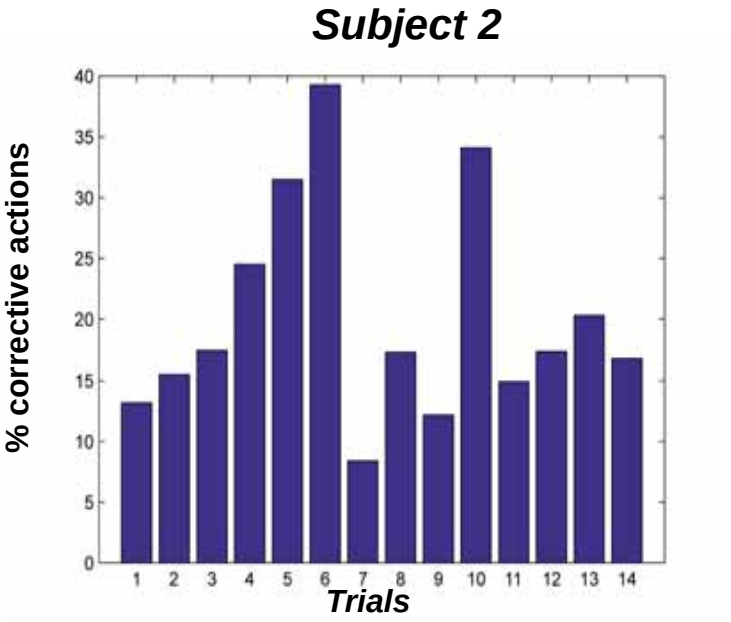
Experiment I: Fast Decisions



Experiment II: Wheelchair in Corridor

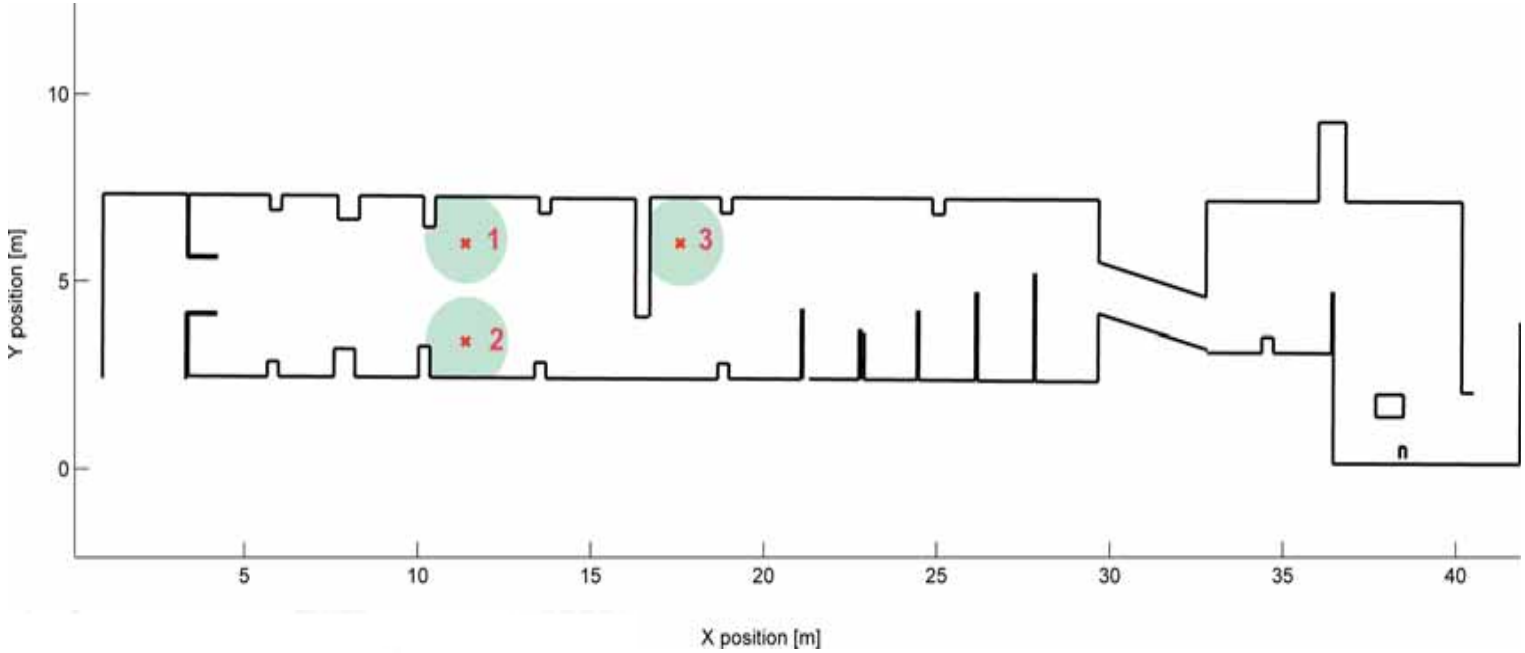
Percentage of corrective actions by Obstacle Avoidance behaviour (trial: ~250 - 350 seconds)

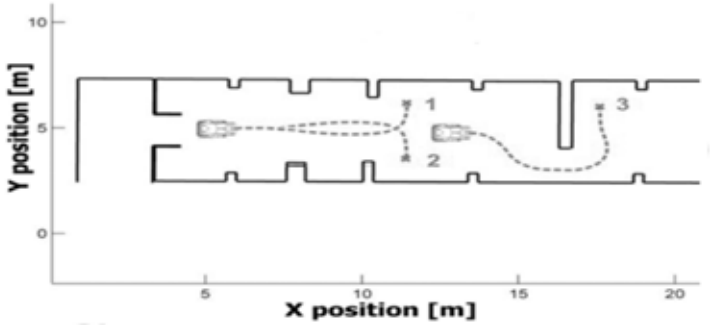




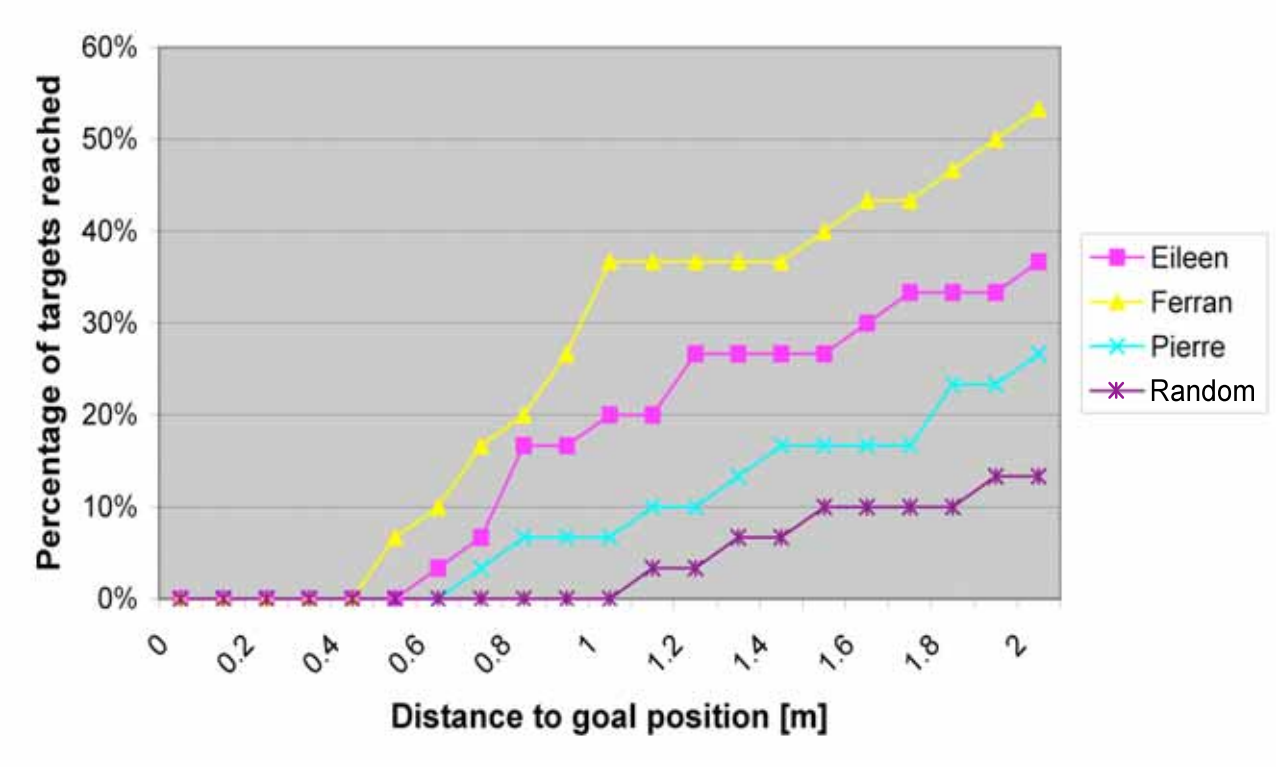
Variable level of assistance: it depends on context, fatigue, concentration, “exploiting” the assistance, …

Experiment III:
Wheelchair Docking





Experiment III: Wheelchair Docking



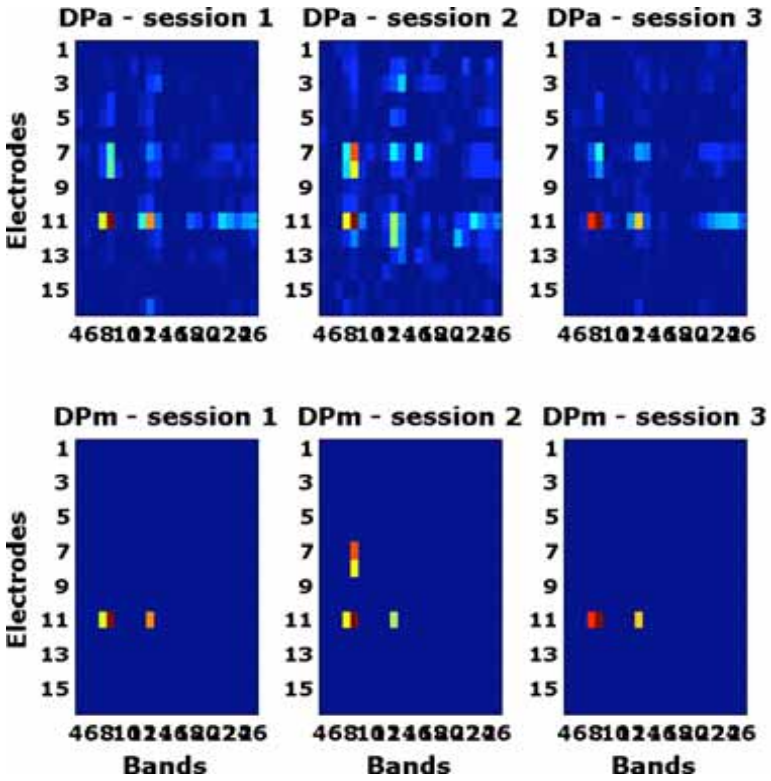
The Machine Learning Way: Invariances

- Selection of stable discriminant features based on canonical variates analysis (CVA):
  - The subject selects 2 (3) motor imagery tasks she/he feels comfortable with
  - 4 sessions, fake feedback, ~20 minutes overall training time

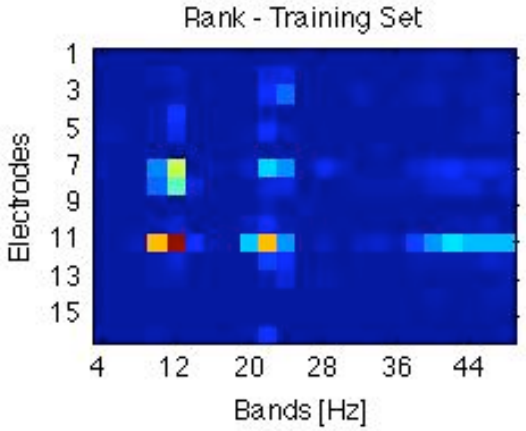
Feedback Visualization

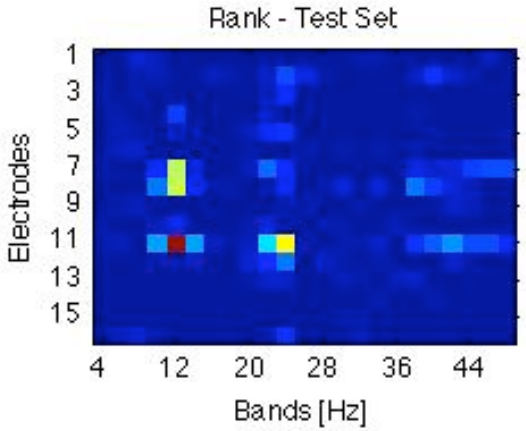
Stable, Discriminant Features

- Features ranked according to discriminant power
- Selected Features: high DP across sessions



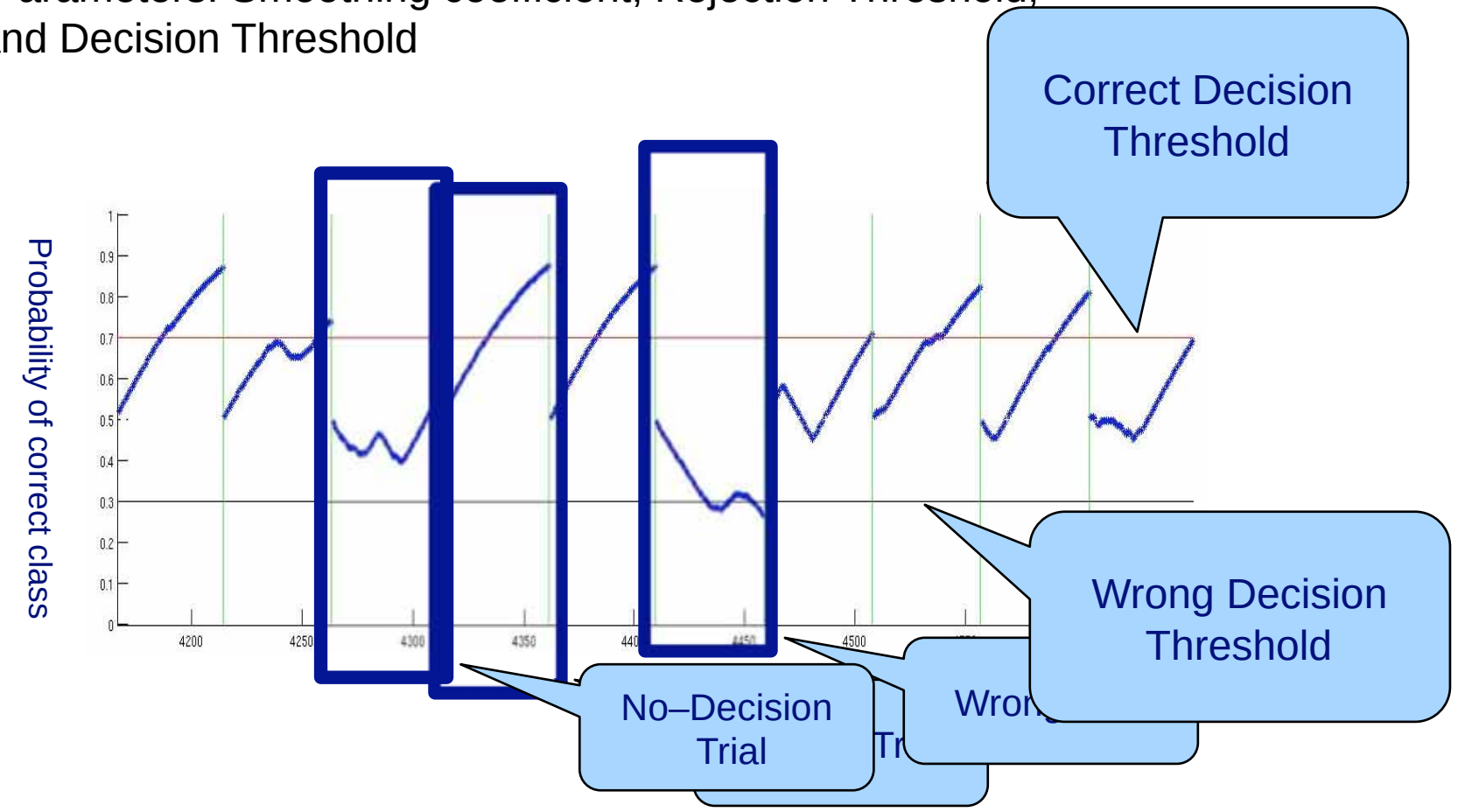
Across session stability





Evidence Accumulation for Probabilistic Decision Making

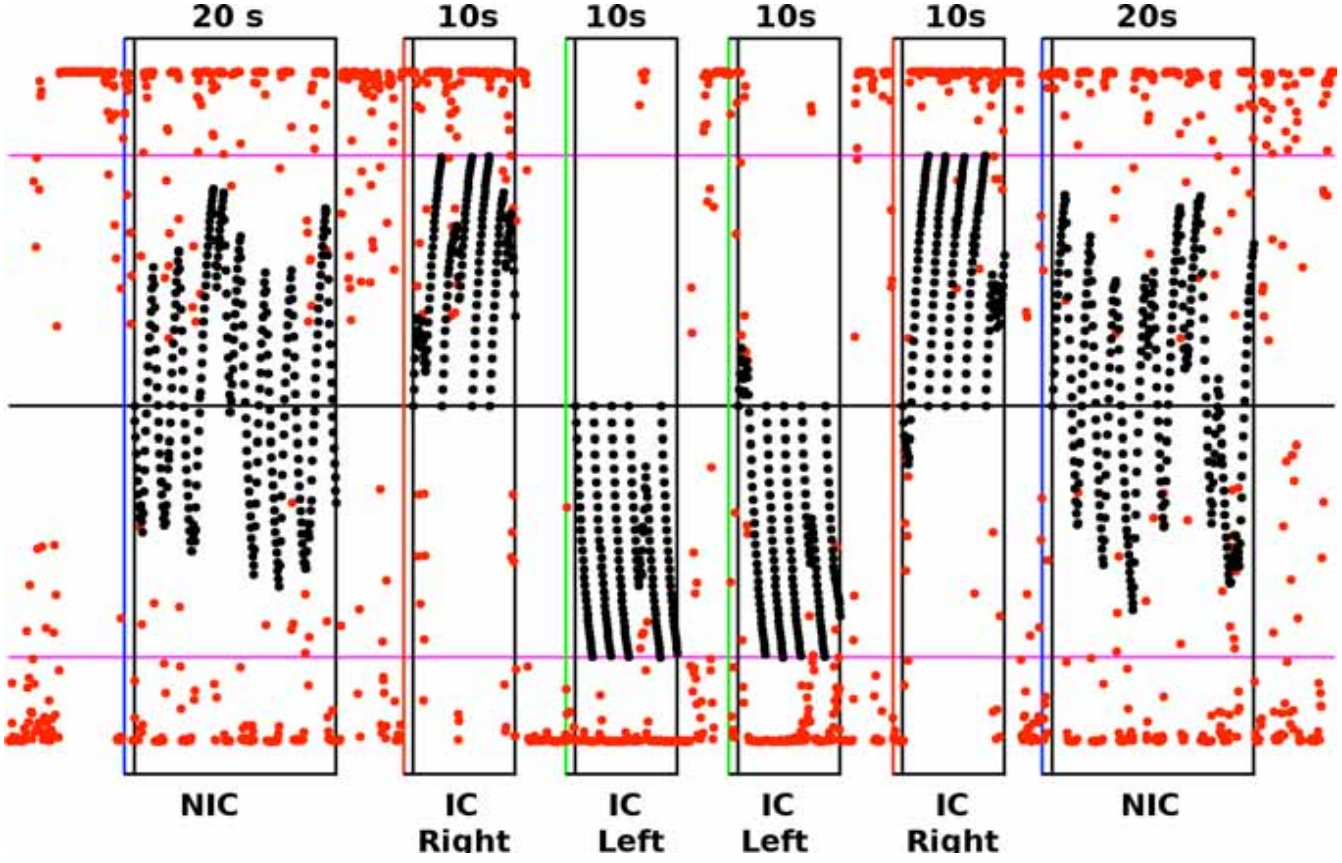
- Exponential Smoothing Integration:
  - Parameters: Smoothing coefficient, Rejection Threshold, and Decision Threshold



Multitasking & Intentional Non-Control

Michele Tavella. *EPFL*

- Preliminary results suggest our probabilistic approach allow subjects to perform ***multitasking*** and even achieve ***intentional non-control***

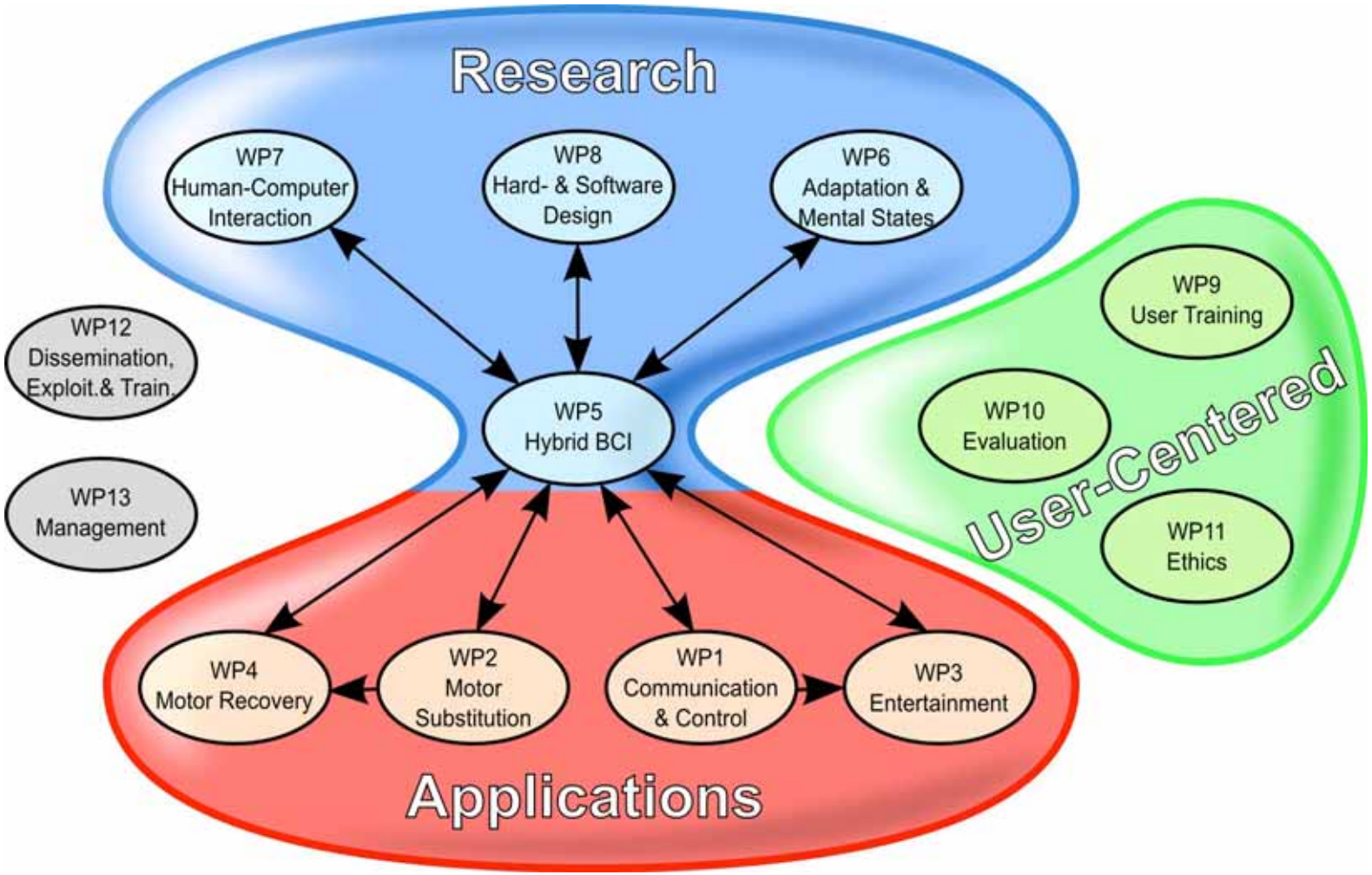


Multitasking & Intentional Non-Control

Conclusions

- ***Non-invasive neuroprosthetics*** — radical departure from current assumptions
  - ➢ Adaptive Shared Control, Machine Learning Way, Asynchronous Protocols, Cognitive Signals, Tactile Feedback
- ***EEG carries cognitive information*** — unique feature of the “brain channel”
  - ➢ It conveys information about intents (mental commands) **AND** cognitive states (errors, alarms, attention, fatigue, etc.) that are crucial for a purposeful interaction

TOBI Workpackages



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