ENDOWING THE MACHINE WITH **ACTIVE INFERENCE**:

A GENERIC FRAMEWORK

TO IMPLEMENT **ADAPTIVE BCI**

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Outline:

PART I:

Generic framework for adaptive BCI

PART II:

Active Inference

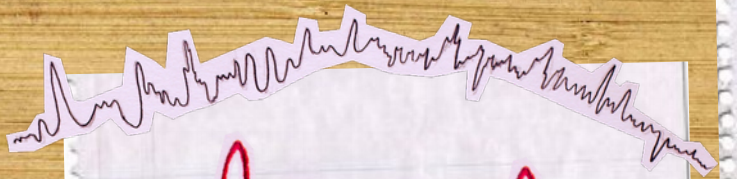
PART III:

Application to the P300-speller

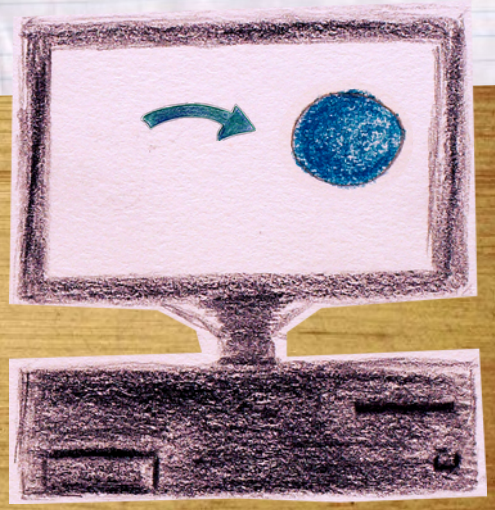
Human Brain-Computer Interface:

1. Measuring brain activity

2. Filtering, processing data



3. Translating data into commands



4. Providing feedback

- Human factors neglected

Modest performances

[Brain-computer interfaces for communication and control, J.R. Wolpaw, 2002]

Challenges/Motivation

Adaptive BCI methods:

Adjust to signal variabilities, and reduce them by influencing their causes;

Assist in learning, foster motivation, favor ergonomy, minimize fatigue….

Consider causes of signal variability

The equipment and experimental environment:

1. Equipment sensitivity or magnetic field present in the environment (Niedermeyer & da Silva, 2005, Maby 2016)

2. Quality of the instructions given to the user to follow through the task (Neuper 2005)

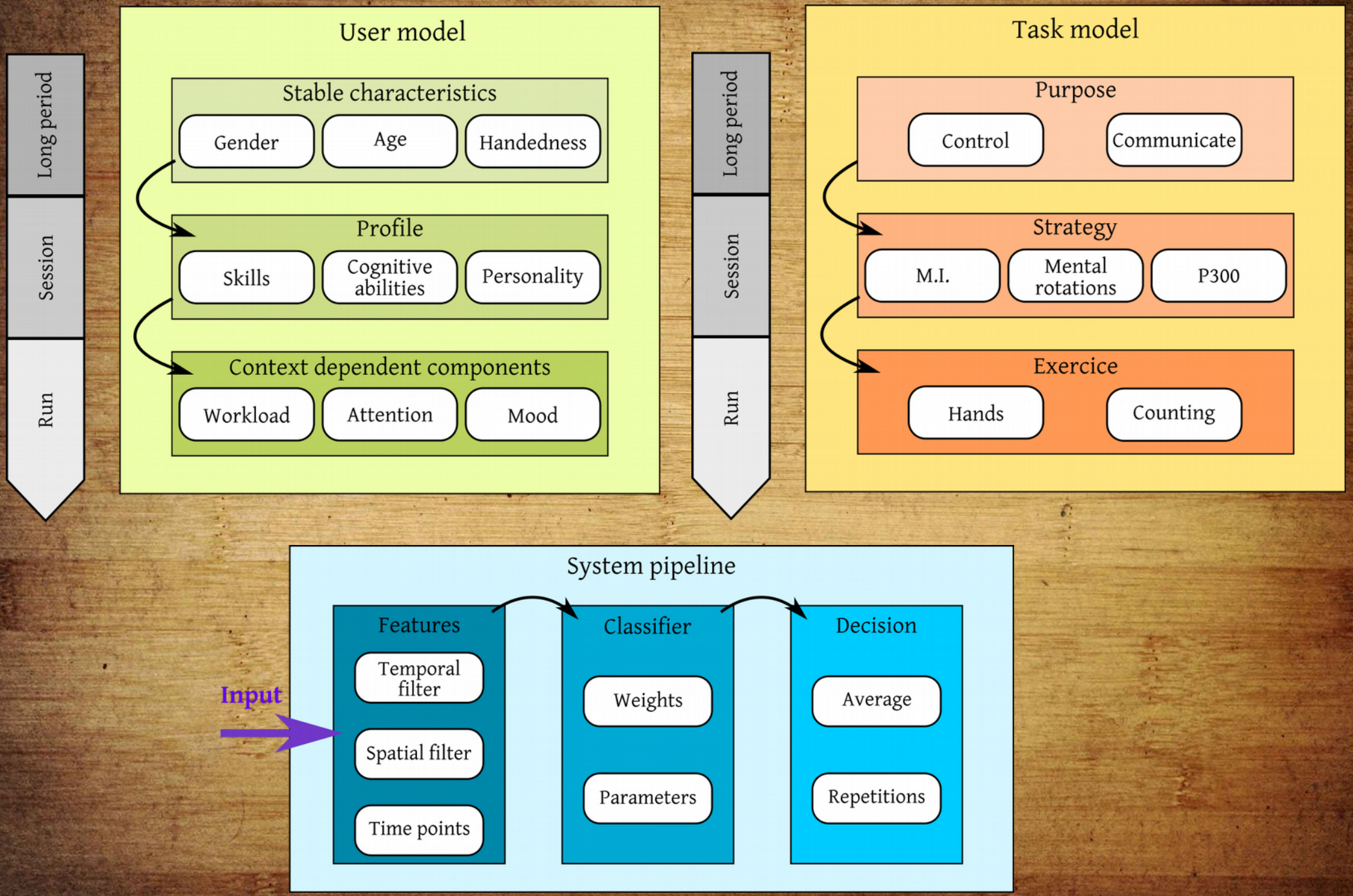
Short term user factors:

1. Attention, mood (Nijboer 2008, Jeunet 2016) muscle tension (Schumacher 2015)

2. User's mental command, e.g. for MI – kinesthetic or visual motor imagery (Neuper 2005)

Long term user factors:

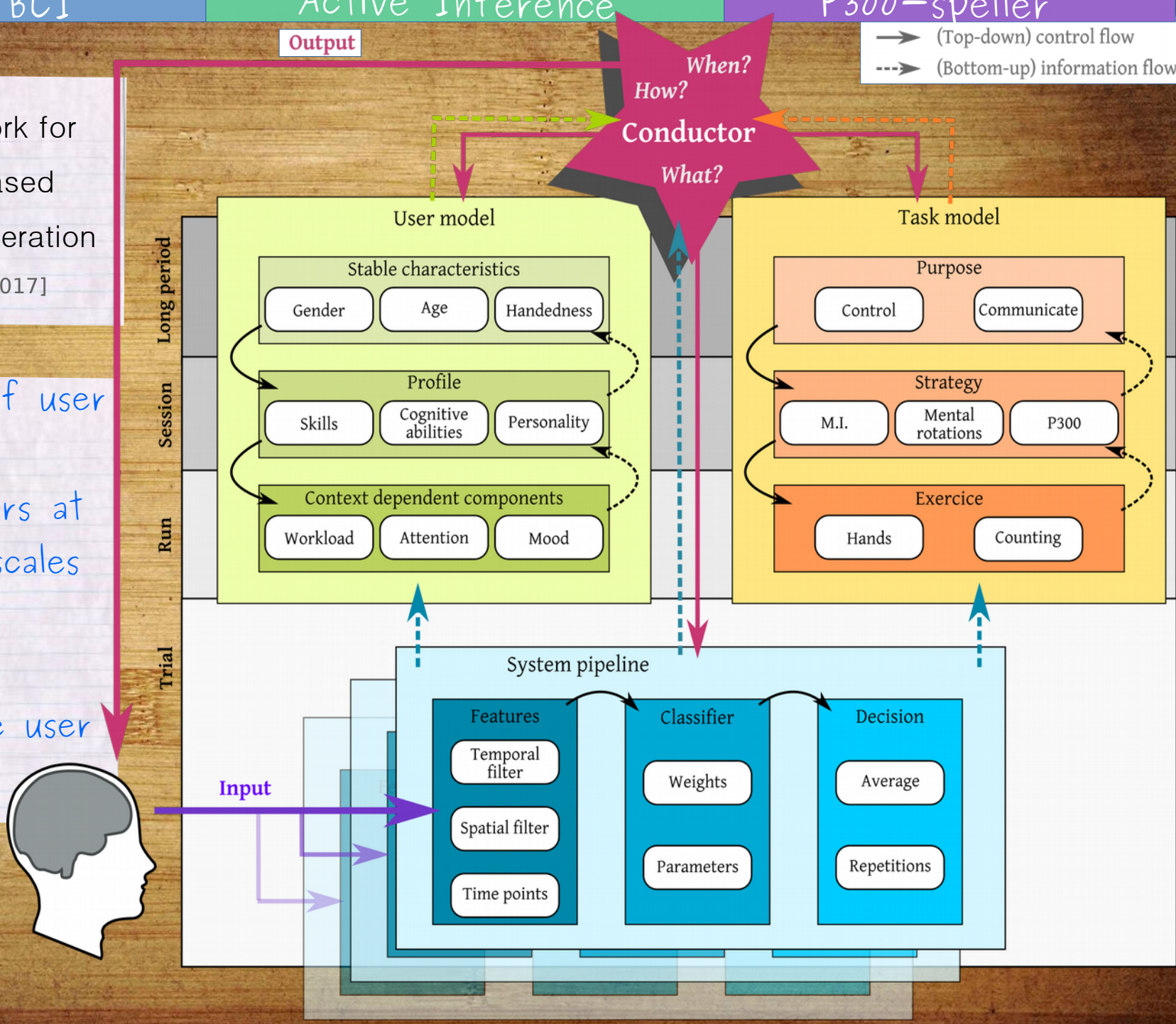
3. User's learning capacity depending on e.g. memory span, intrinsic motivation, imagination and skills (Jeunet 2016)


Long period
Session
Run
User model
Stable characteristics
Gender
Age
Handedness
Profile
Skills
Cognitive abilities
Personality
Context dependent components
Workload
Attention
Mood
Long period
Session
Run
Task model
Purpose
Control
Communicate
Strategy
M.I.
Mental rotations
P300
Exercice
Hands
Counting
System pipeline
Input
Features
Temporal filter
Spatial filter
Time points
Classifier
Weights
Parameters
Decision
Average
Repetitions

A generic framework for adaptive EEG-based BCI training and operation

[Mladenovic et al. 2017]

- Explicit model of user and task;
- Adaptation occurs at different time scales
- Address various criteria
- Learn about the user and act flexibly



What about a (generic) computational framework?

Active Inference

A computational neuroscience approach on how an adaptive system like the brain should implement perception, learning and action.

[Friston et al. 2017]

Importantly, such a system

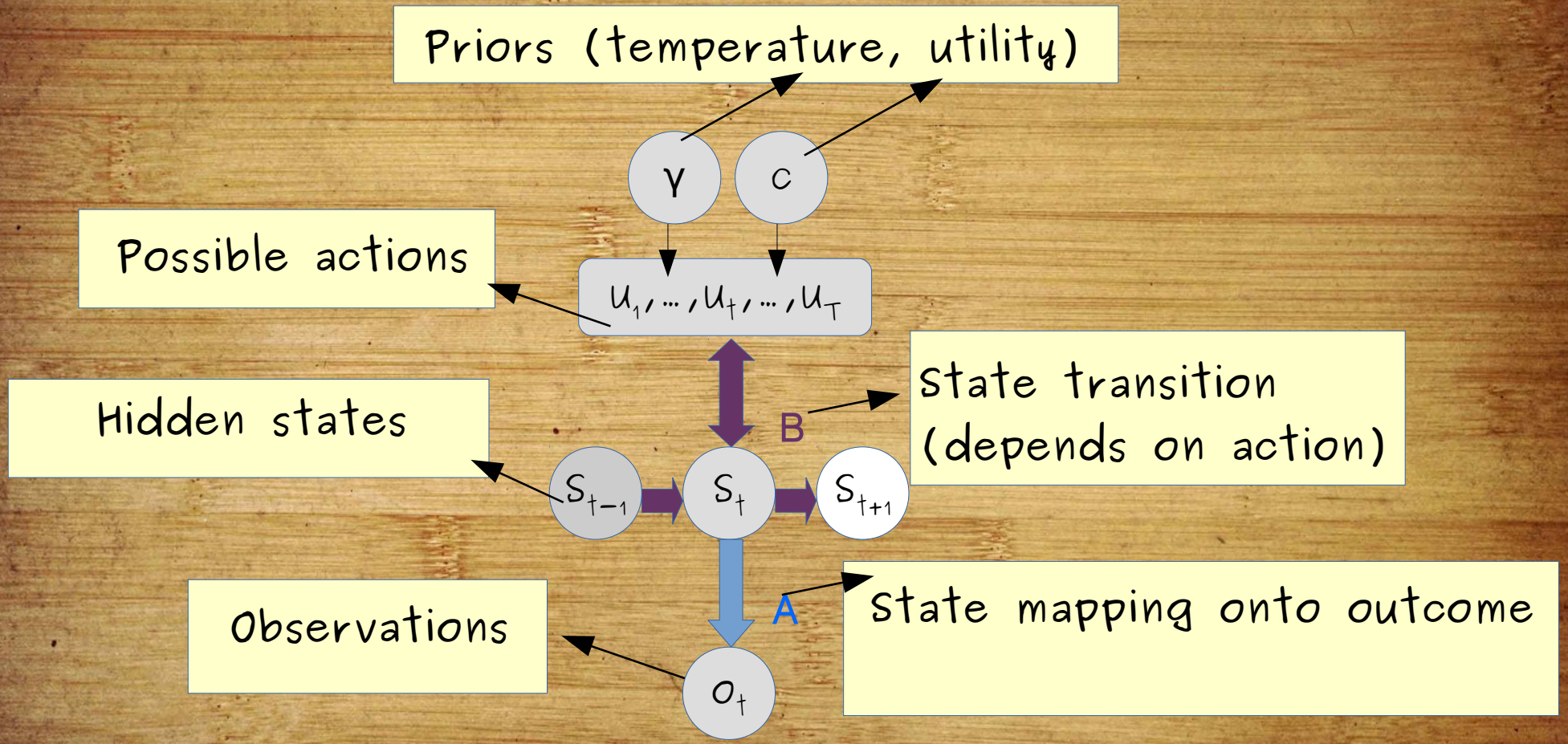
- Implements a model of its environment
- Optimizes its interactions through both making inference (about the environment) and acting (upon the environment)
- Inference and Action both rest on optimizing a single cost function called Free energy

[Friston 2010]

We propose to endow the BCI system with Active Inference in order to optimize cooperation with BCI user.

[Mattout 2012]

Active Inference – Generic Framework



Active Inference

Bayesian

HOW DO ADAPTIVE SYSTEMS (brains) ACT?

To minimize the surprise of the outcome:

Minimizing Kullback–Leibler divergence!

$$D_{\mathrm{KL}}(P\|Q) = \sum_i P(i)\,\log\frac{P(i)}{Q(i)}.$$

Resisting the natural tendency of disorder!
Minimizing relative entropy!

FREE ENERGY MINIMIZATION

To favor a certain outcome:

Encoded in the prior beliefs Or utility function!

[Friston et al. 2010]

Reminder of a P300-speller

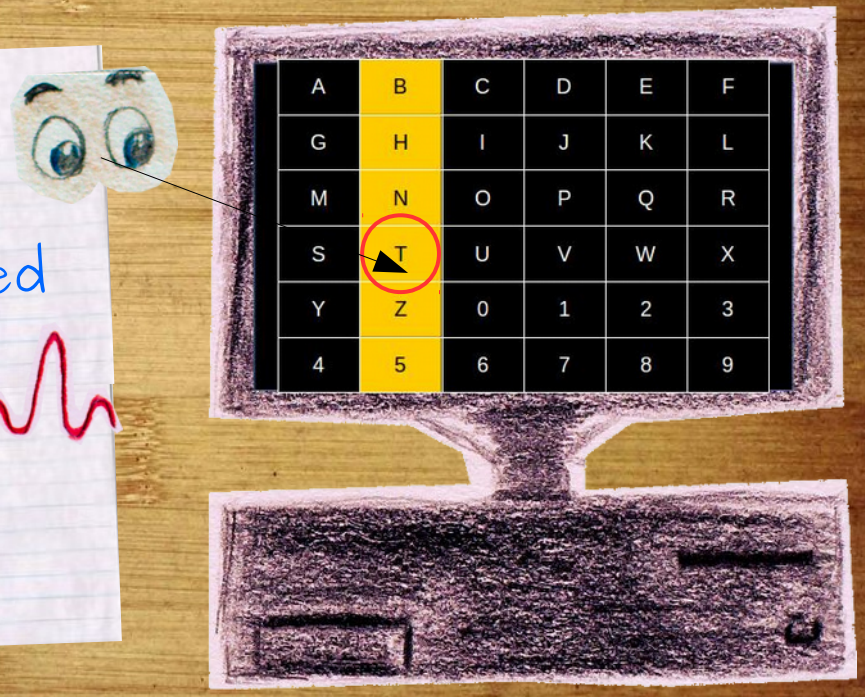
A communication device

Examples:

- Basic: row/column protocol, spell after n flashes
- optimal stopping, i.e. spell when enough evidence has been accumulated

Principle:

Items are flashed
ERP or P300
Visual oddball paradigm



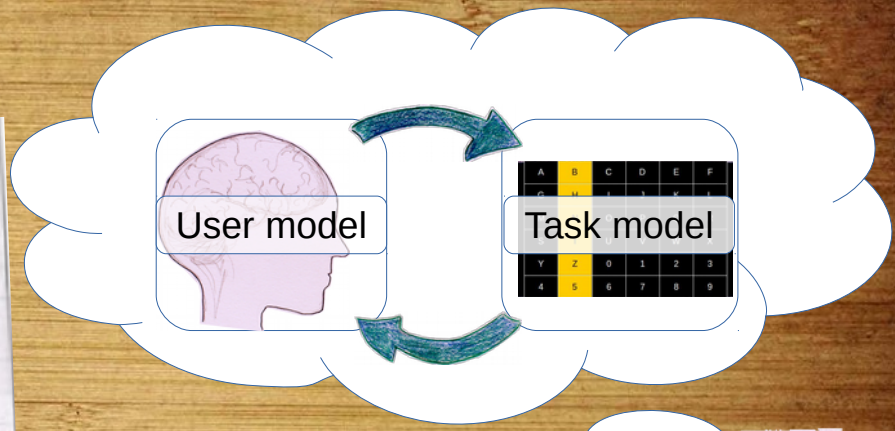
Applying Active Inference on a P300-speller

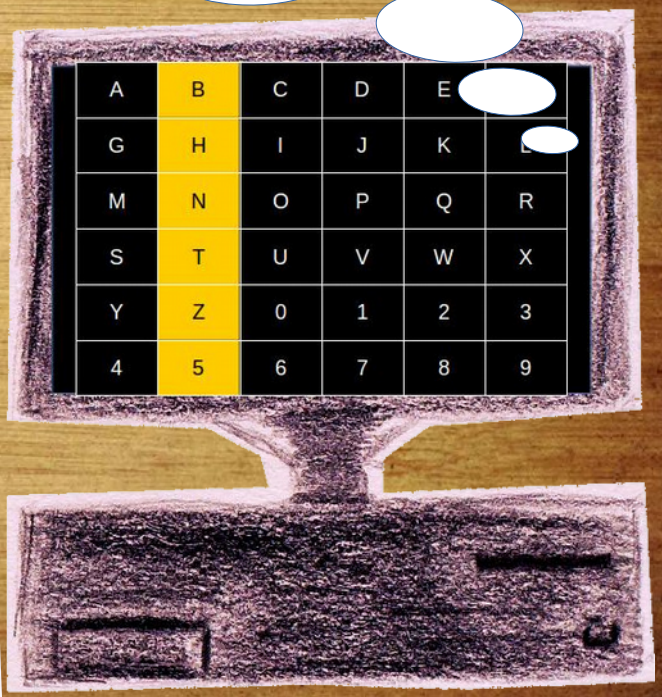
ACTION/PERCEPTION

P300 OR
ERROR POTENTIALS

PERCEPTION/ACTION

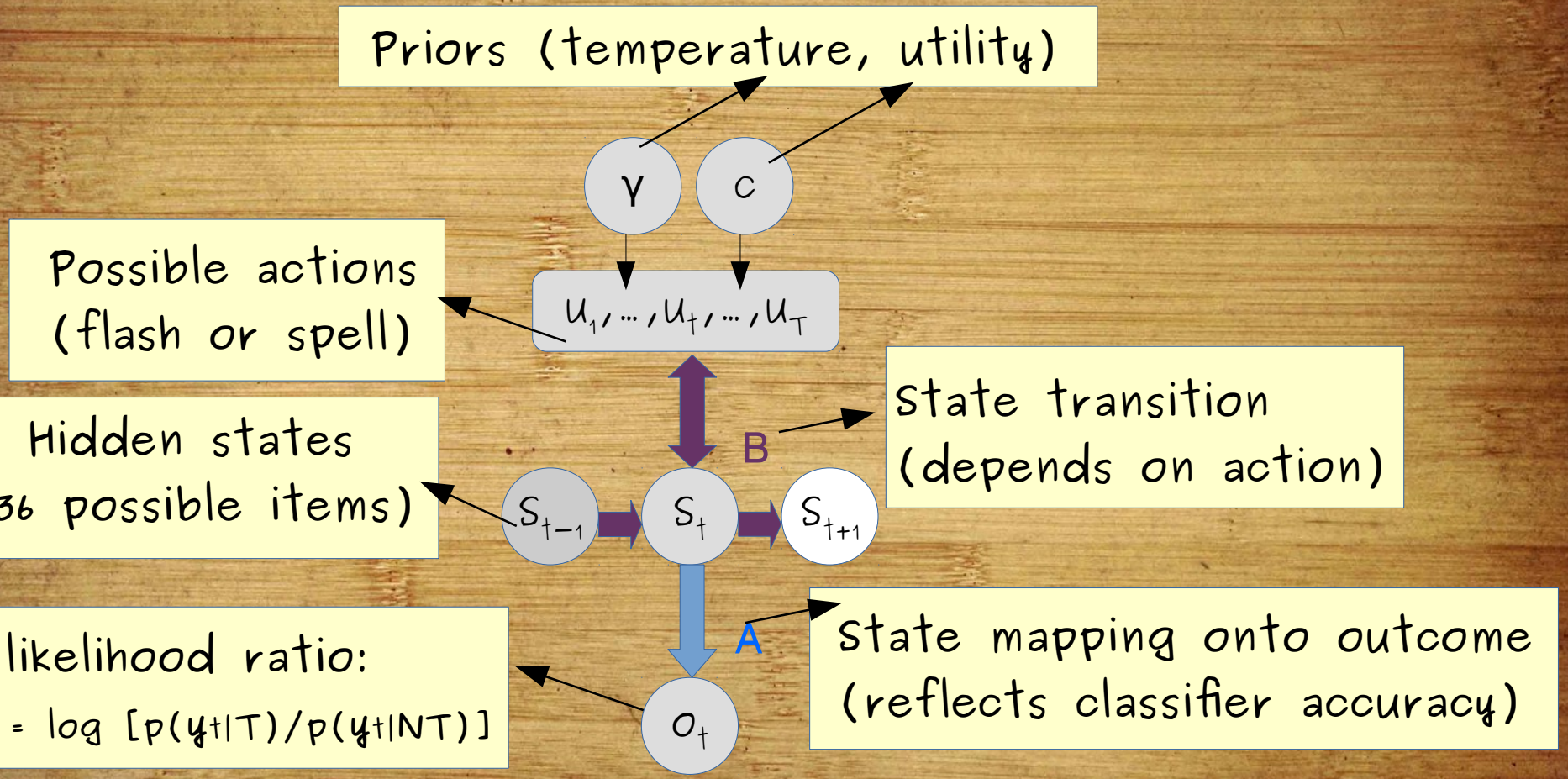
FLASHING OR SPELLING





What can be the choice of rows/columns to flash to reveal the target?

Generic Framework for P300-speller

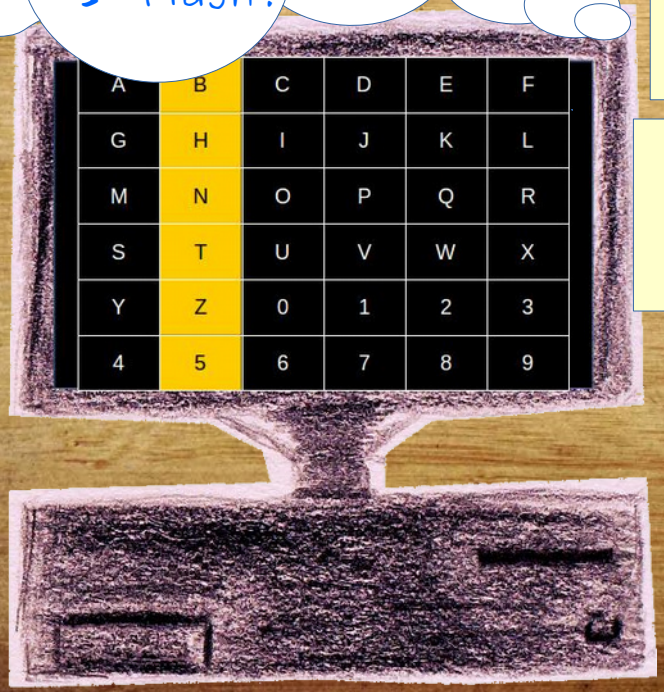


[Mladenovic et al. 2017]

P300-speller
optimal stopping + flashing

optimal stopping
– Should I go on flashing or spell?

optimal flashing
– Which items should I flash?



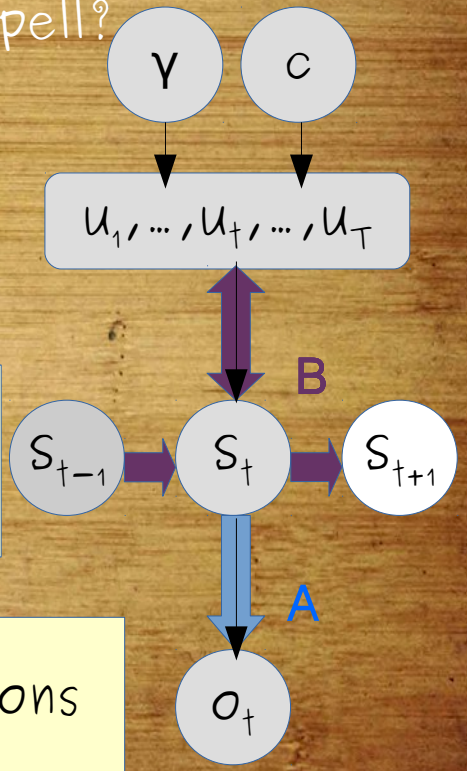
Possible actions (flash or spell)

Hidden states (36 possible items)

Observations

How confident I want to be before I spell?

Which outcome do I favor?



Which action minimizes Free Energy?

[Mattout et al. 2015]

[Mladenovic et al. 2017]

RESULTS:

Comparing Simulations between Active Inference with and without Optimal Flashing

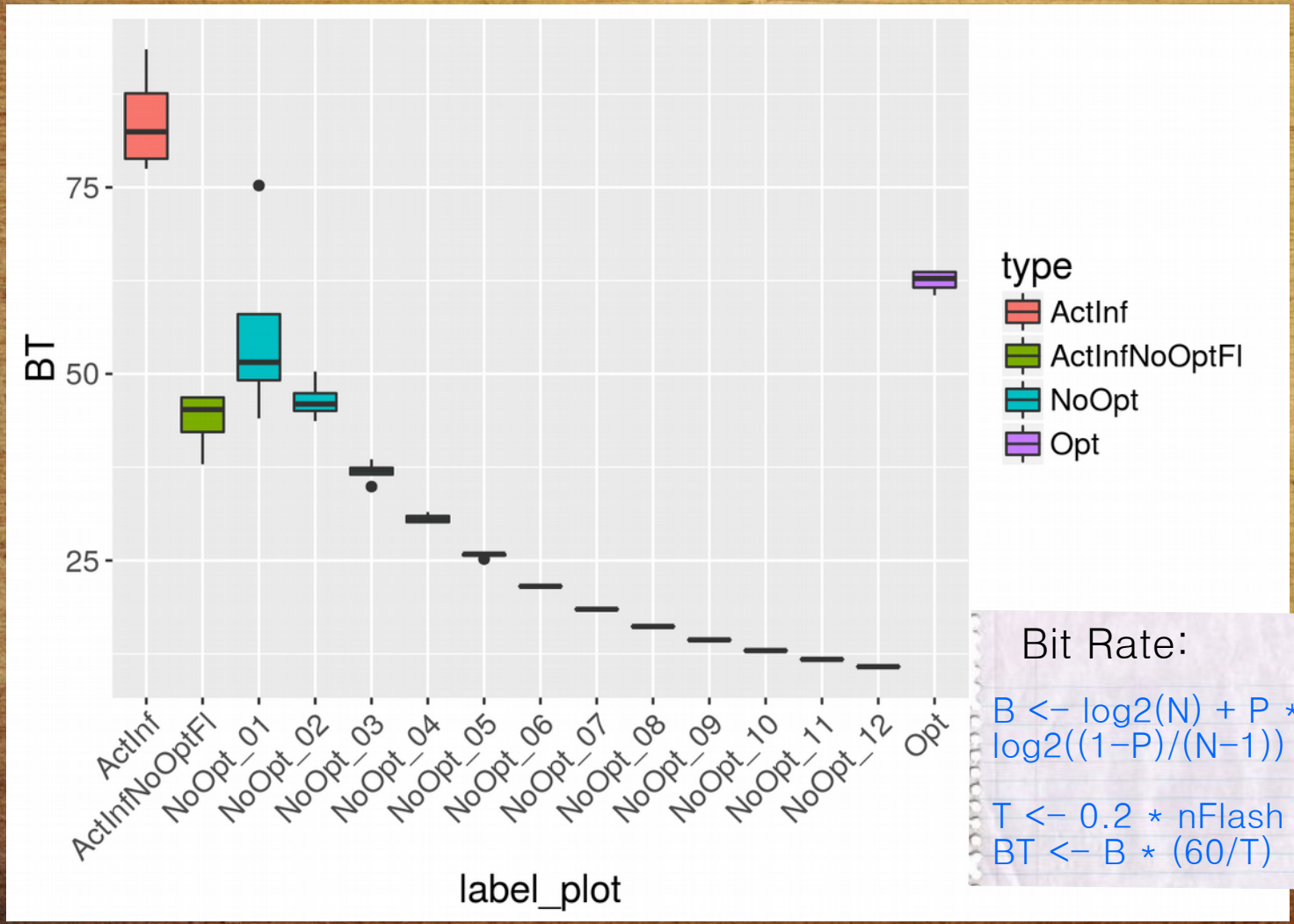
Optimal stopping & flashing showed increased accuracy in reduced time

- Optimal stopping: 20.1±9 flashes / 80.6% accuracy
- Optimal stop & flashing: 15.8±6 flashes / 85.2% accuracy

[Mladenovic et al. 2017]

RESULTS 2:

Compared real data between ActInf (OptFlash and NoOptFlash) basic, and optimal stopping P300-speller (good, bad subject)



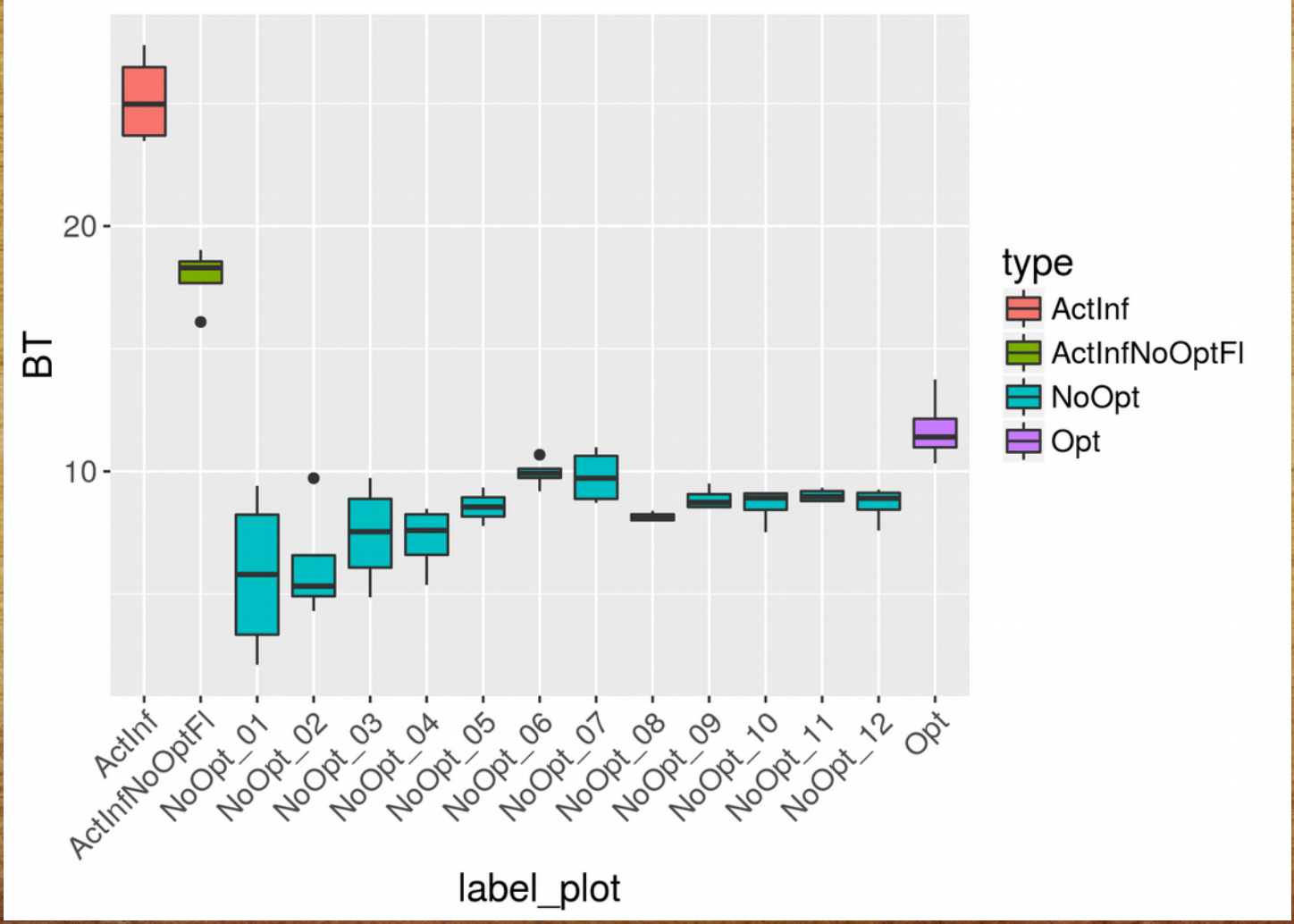
Bit Rate:

```
B <- log2(N) + P * log2(P) - (1-P) * log2((1-P)/(N-1))

T <- 0.2 * nFlash
BT <- B * (60/T)
```

RESULTS 2:

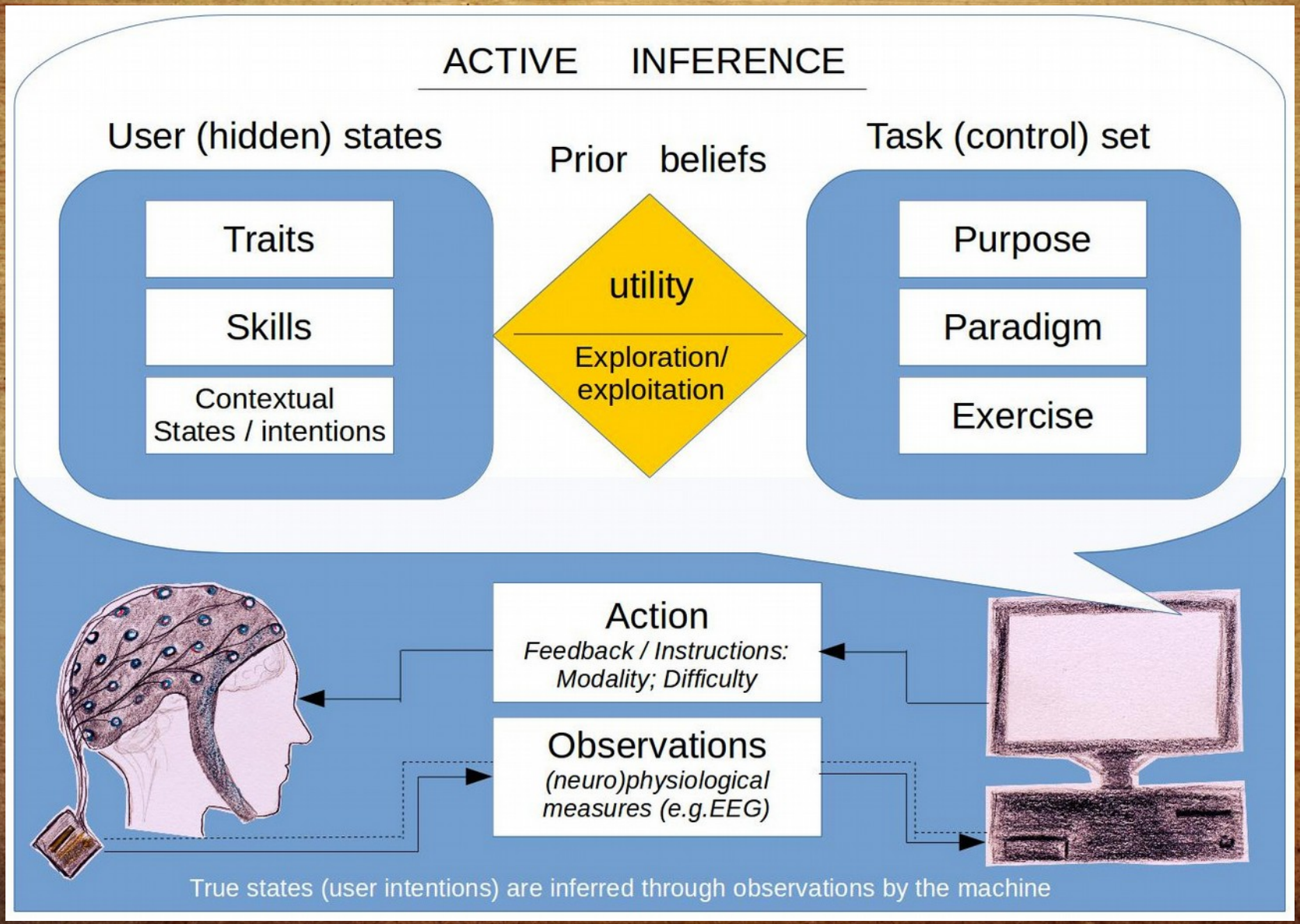
Compared real data between ActInf (optFlash and NoOptFlash) basic, and optimal stopping P300-speller (good, bad subject)



A few Perspectives:

- Optimize parameters between and within subjects
- Extend the model to incorporate new observations:
  e.g. Error Related Potentials
- Extend the model to incorporate new actions:
  e.g. switching off
- Extend the framework to other BCIs:
  e.g. Motor Imagery

Active Inference for adaptive BCI



Thank You!

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Questions?