Bringing the Human into the Loop

presented by

Barbara Weber

Software Engineers Missing

… the World is Looking for Software Engineers

Higher Quality and Productivity through Focus on People

- Numerous studies confirmed order-of-magnitude differences among software developers in terms of productivity
  (Curtis 1981, Mills 1983, DeMarco and Lister 1985, Curtis et al. 1986, Card 1987, Boehm and Papaccio 1988, Valett and McGarry 1989, Boehm et al 2000)

- Focus on people recognized as a a way to improve software quality and software developers’ productivity
  (Boehm & Papaccio, 1988)

Importance of Human Factors
Manifesto for Agile Software Development

We are uncovering better ways of developing software by doing it and helping others do it.

Through this work we have come to value:

Individuals and interactions over processes and tools
Working software over comprehensive documentation
Customer collaboration over contract negotiation
Responding to change over following a plan

That is, while there is value in the items on the right, we value the items on the left more.

(K. Beck et al. 2001)

Software Engineering Research Traditionally Focused on Technical Aspects

Only recently an increasing focus on human factors can be observed

Towards Individualized Software Engineering: Empirical Studies Should Collect Psychometrics

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Personality in Software Engineering

Computers in Human Behavior 46 (2015) 94–113

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

ELSEVIER

Forty years of research on personality in software engineering: A mapping study

Shirley Cruz [a], Fabio Q.B. da Silva [a,*], Luiz Fernando Capretz [b]

[a] Centre for Informatics, Federal University of Pernambuco, Av. Jornalista Anibal Fernandes, s/n - Cidade Universitária, Recife, PE 50.740-560, Brazil
[b] Department of Electrical & Computer Engineering, Western University, London, Ontario N6A5B9, Canada

CrossMark

covers 90 articles between 1970 and 2010
72% of studies published after 2002

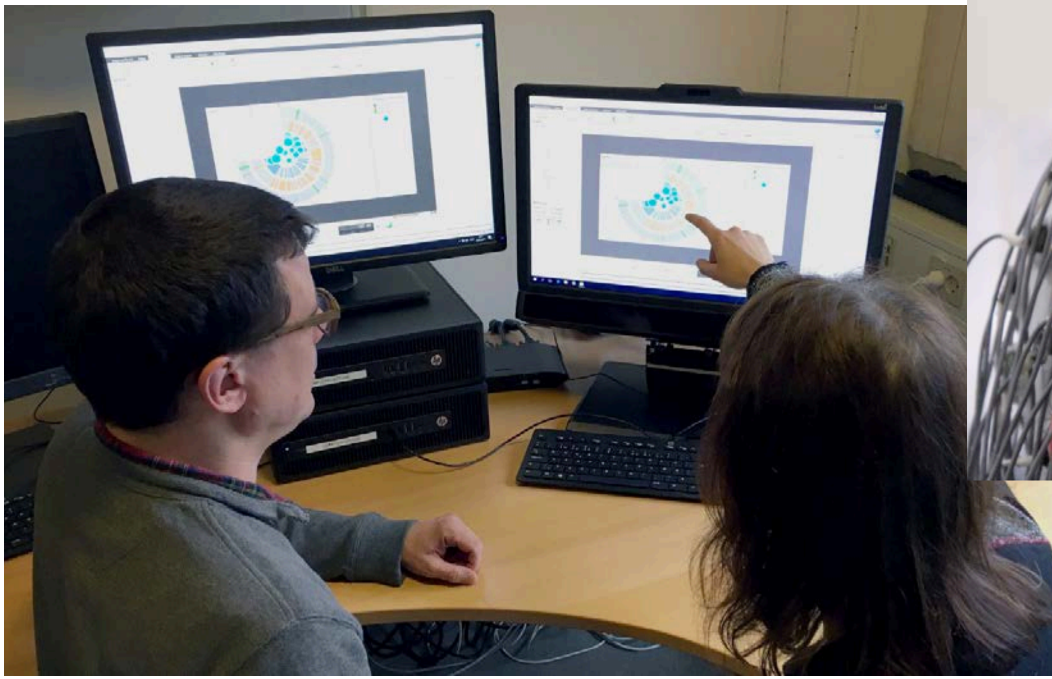
Happy Developers, Better Problem-Solver
Human Factors Matter

Happy software developers solve problems better: psychological measurements in empirical software engineering

(D. Graziotin, X. Wang, P. Abrahamsson 2014)

… so far, potential largely untapped

Substantial Potential of Neuroscience and Psychophysiological Methods and Tools



both from a design science/engineering perspective and from a theoretical perspective

Eye-tracking in Software Engineering

Contents lists available at ScienceDirect

Information and Software Technology

journal homepage: www.elsevier.com/locate/infsof

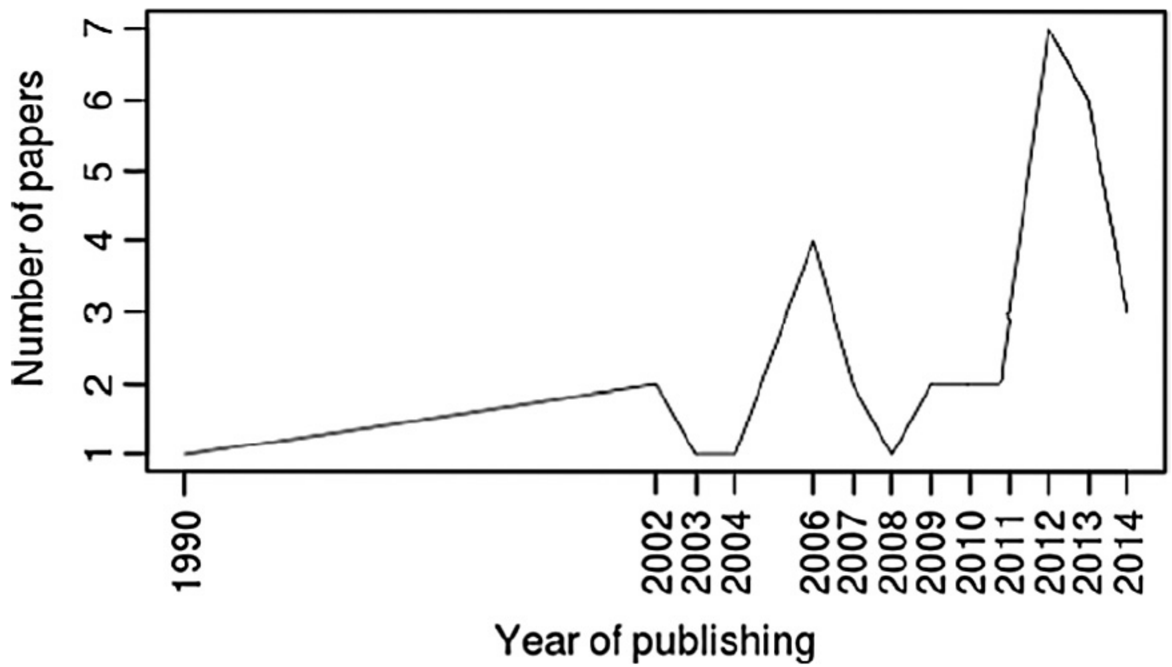
A systematic literature review on the usage of eye-tracking in software engineering

Zohreh Sharafi [1], Zéphyrin Soh *, Yann-Gaël Guéhéneuc *

Ptidej Team, Départment de Génie Informatique et Génie Logiciel, Polytechnique Montréal, Québec, Canada

covers 36 articles between 1990 and 2015

Eye-tracking in Software Engineering



covers 36 articles between 1990 and 2015
86,2% of studies published after 2006

The Role of the Brain in IS / SE Research

Design science
Methods and neuroscience literature

IT Artifact

(Riedl & Léger 2016)

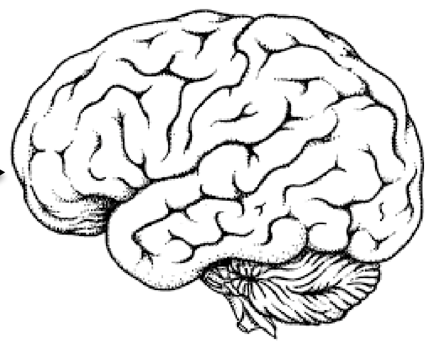
The Role of the Brain in IS / SE Research

Design science Methods and neuroscience literature

Neuroscience and Psychophysiological methods and tools

Brain activity as mediator

IT Artifact →



(Riedl & Léger 2016)

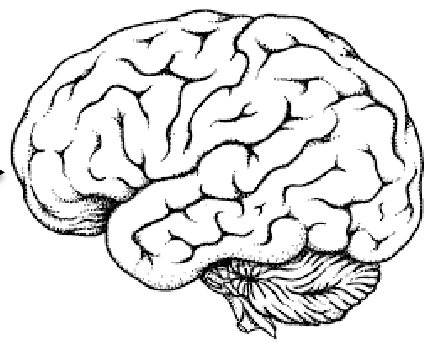
The Role of the Brain in IS / SE Research

Design science Methods and neuroscience literature

Neuroscience and Psychophysiological methods and tools

Self-reported questionnaires

Brain activity as mediator

IT Artifact →  → Antecendents of IT Behavior

- Feelings
- Beliefs
- Attitudes
- Behavioral Intentions

(Riedl & Léger 2016)

The Role of the Brain in IS / SE Research

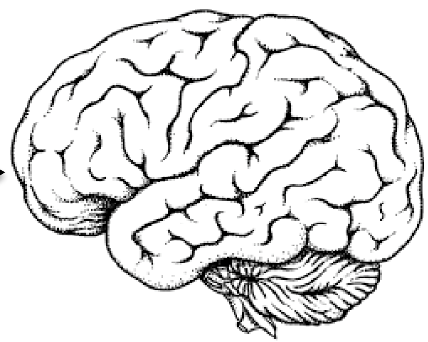
Design science Methods and neuroscience literature

Neuroscience and Psychophysiological methods and tools

Self-reported questionnaires

Computerized tools and observations

Brain activity as mediator

IT Artifact →  → Antecendents of IT Behavior → IT Behavior

Antecendents of IT Behavior:

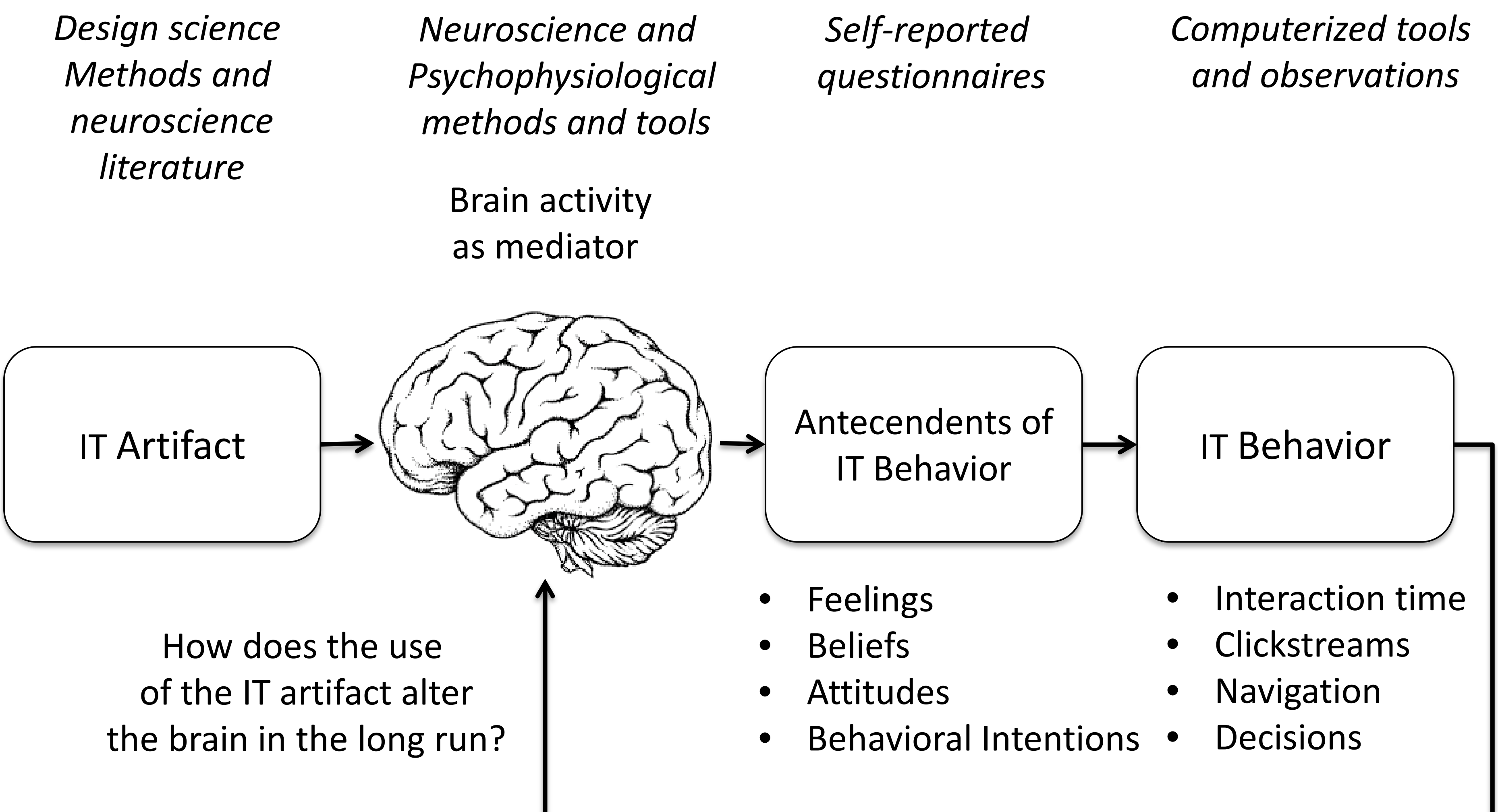
- Feelings
- Beliefs
- Attitudes
- Behavioral Intentions

IT Behavior:

- Interaction time
- Clickstreams
- Navigation
- Decisions

(Riedl & Léger 2016)

The Role of the Brain in IS / SE Research



(Riedl & Léger 2016)

Potential from a Theoretical Perspective

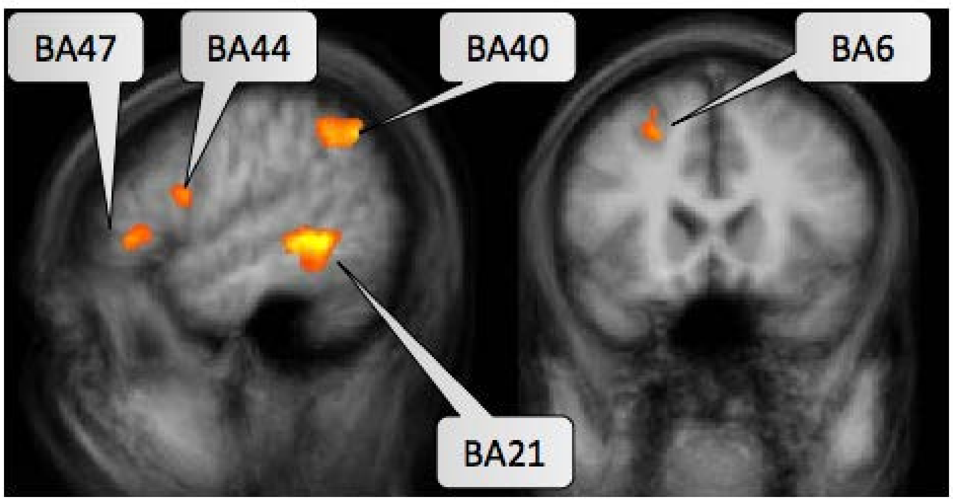
- Brain activity as a mediator between IT artifact and IT behavior
- Advanced theoretical understanding of mechanism underlying the influence of the IT artifact on IT behavior
- Measurement of constructs that cannot be reliably measured through self-reports
- Biological states and processes as better predictors for behaviorally relevant outcome variables than self-reported ones
- Long-term effect of IT artifact on brain

(Riedl & Léger 2016)

Brain Activation During Source Code Reading

Understanding Understanding Source Code with Functional Magnetic Resonance Imaging

Janet Siegmund[π,*], Christian Kästner[ω], Sven Apel[π], Chris Parnin[β], Anja Bethmann[θ], Thomas Leich[δ], Gunter Saake[σ], and André Brechmann[θ]
[π]University of Passau, Germany [ω]Carnegie Mellon University, USA
[β]Georgia Institute of Technology, USA [θ]Leibniz Inst. for Neurobiology Magdeburg, Germany
[δ]Metop Research Institute, Magdeburg, Germany [σ]University of Magdeburg, Germany



Brain Activation Patterns during Source Code Reading

- Working Memory and Divided Attention
- Language Processing

Brain Activation During Source Code Reading

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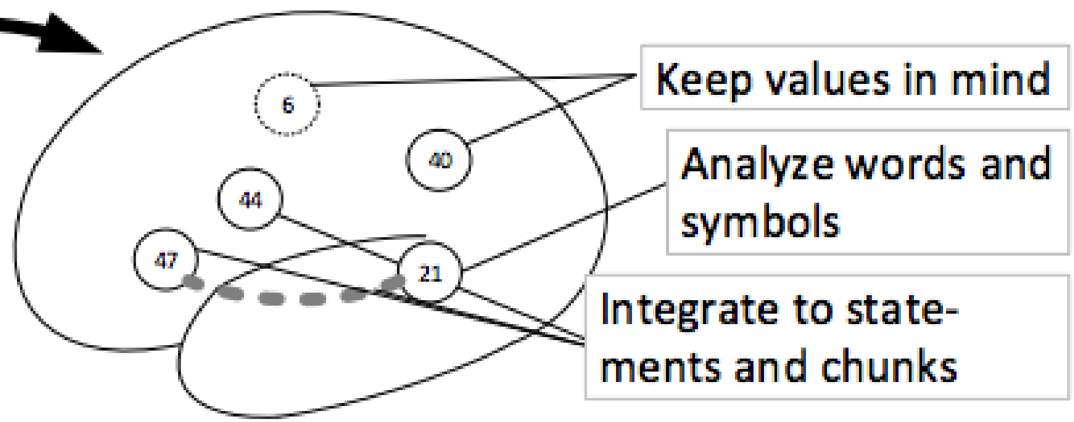
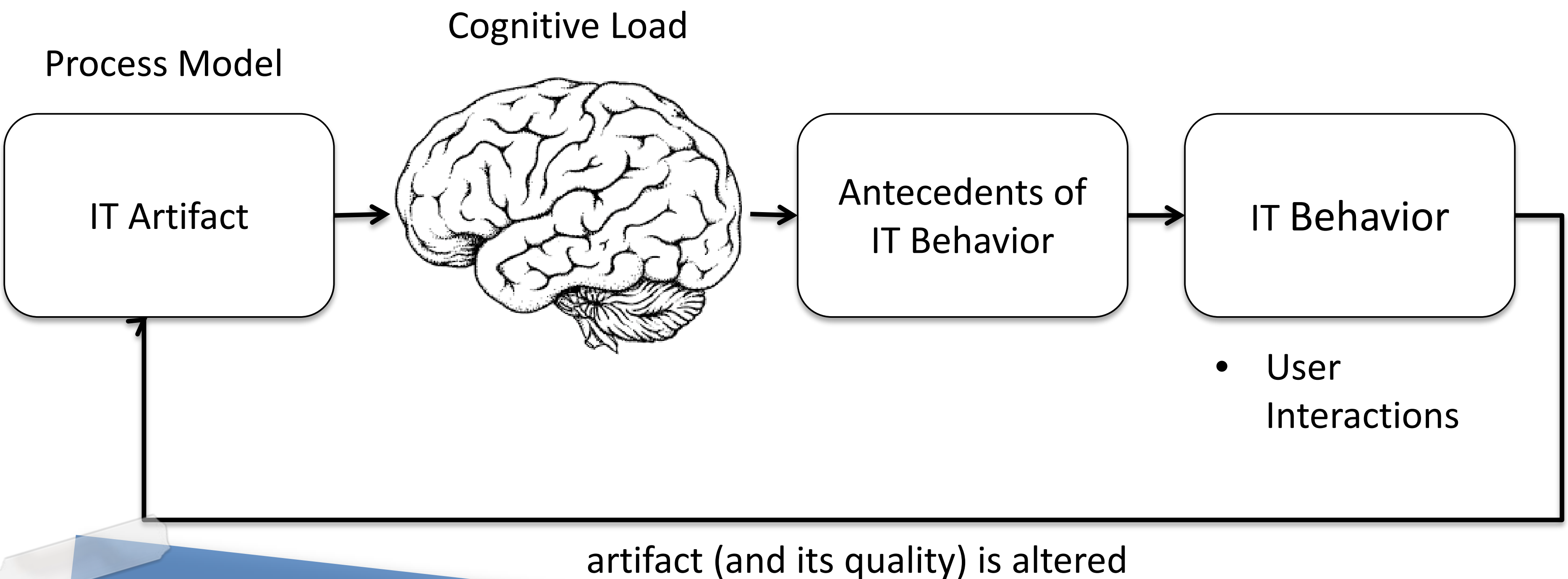
[δ]Metop Research Institute, Magdeburg, Germany [σ]University of Magdeburg, Germany

```
public static void main(String[] args) {
  String word = "Hello";
  String result = new String();
  for (int j = word.length() - 1;
         j >= 0; j--)
    result = result + word.charAt(j);
  System.out.println(result);
}
```



Model for Bottom-Up Program Comprehension

Cognitive Load
During Process Model Creation

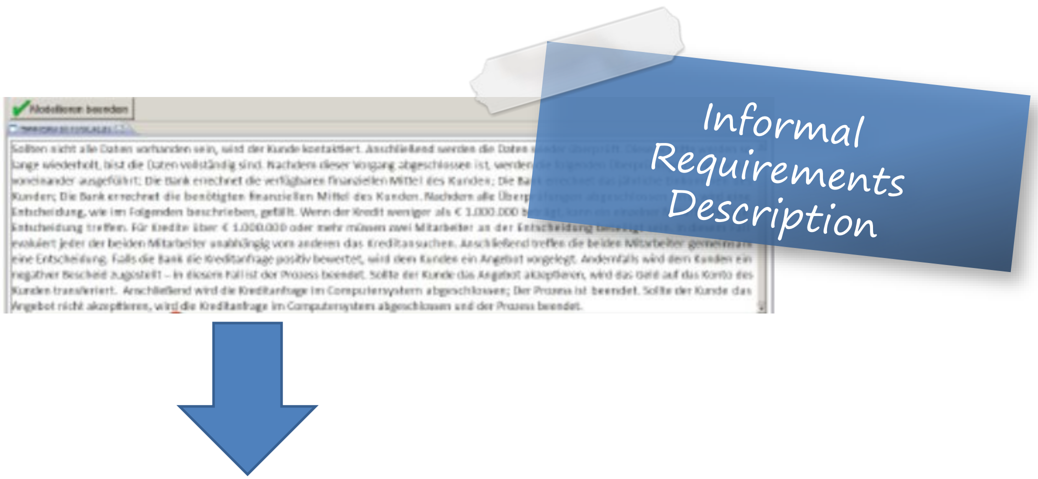


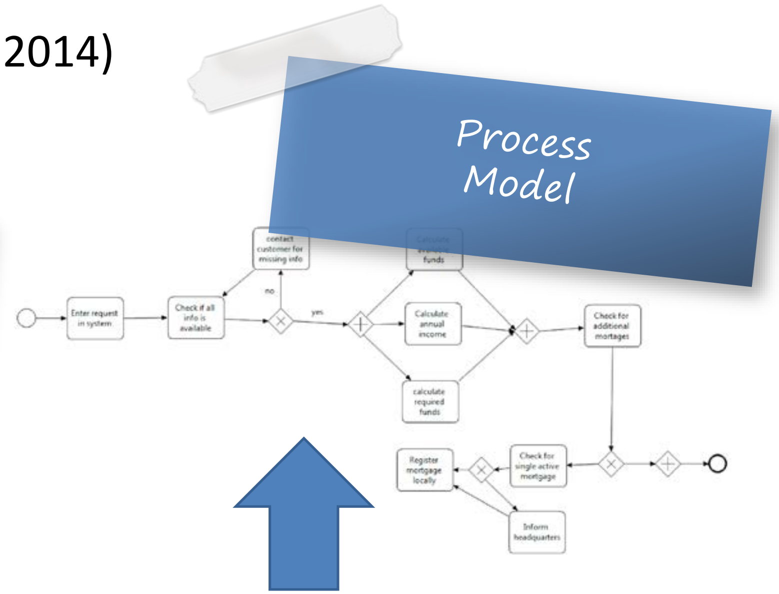
What are the mechanisms underlying the influence cognitive load on the quality of the IT artifact?

(Neurauter et al.: Does Creating Process Models Induce Cognitive Overload? Exploring Interactions (in perparation))

Process Model Creation

- Process model creation can be characterized as an interactive design activity (Recker et al. 2012, Figl et al. 2014)





Process Model Creation as Interactive Design Activity

Process Model Creation

An Example of an Interactive Design Activity

- Process model creation can be characterized as an interactive design activity (Recker et al. 2012, Figl et al. 2014)

1 Mental model

Internal representation

(Soffer, Kaner, and Wand 2011)

Process Model Creation

An Example of an Interactive Design Activity

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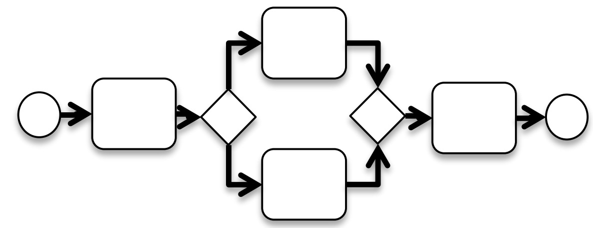
2

Physical model

External representation



1 **Mental model**

Internal representation

(Soffer, Kaner, and Wand 2011)

Process Model Creation

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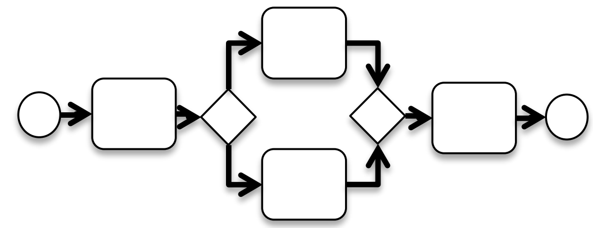
2

Physical model

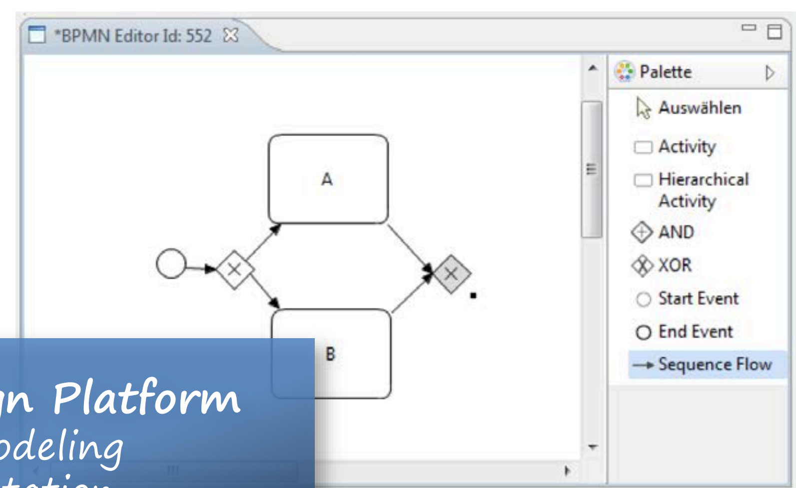
External representation



1 **Mental model**

Internal representation

constrained by



Design Platform
- *Modeling notation*
- *Tool support*

(Soffer, Kaner, and Wand 2011)

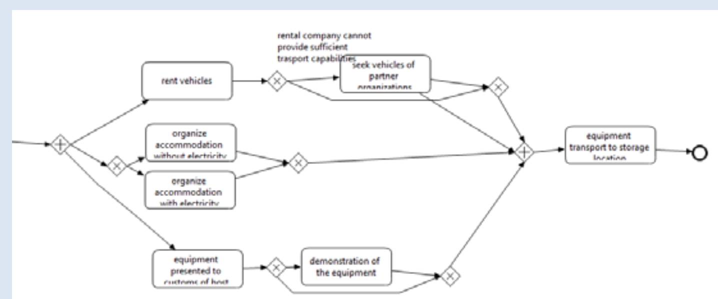
The Design Platform: Cheetah

Conducting modeling sessions with Cheetah Experimental Platform (CEP)

Log of Model Interactions

13	08:43:27	Horizontal Scroll
14	08:43:27	Horizontal Scroll
15	08:44:02	Create Activity 'transport to disaster area'
16	08:44:04	Move Activity 'transport to disaster area'
17	08:44:13	Rename Activity 'transport to disaster area' to 'transpo...
18	08:44:38	Create Activity 'present equipment'
19	08:44:43	Create Sequence Flow from Start Event to Activity 'tra...
20	08:44:47	Create Sequence Flow from Activity 'transport equip...
21	08:45:03	Create XOR
22	08:45:03	Vertical Scroll
23	08:45:16	Create Activity 'demonstrate equipment'
24	08:45:16	Vertical Scroll
25	08:45:16	Horizontal Scroll
26	08:45:18	Move Activity 'demonstrate equipment'
27	08:45:19	Horizontal Scroll

Final Process Model



J. Pinggera, S. Zugal and B. Weber: Investigating the Process of Process Modeling with Cheetah Experimental Platform. In: Proc. ER-POIS ’10, pp. 13–18, 2010.

The Design Platform: Cheetah

Logged model interactions

Type of Modeler Interaction	Description
CREATE NODE	Create activity or gateway
CREATE EDGE	Create an edge connecting two nodes
CREATE CONDITION	Create an edge condition
RECONNECT EDGE	Reconnect an edge fron one node to another
DELETE NODE	Delete activity or gateway
DELETE EDGE	Delete an edge conneting two nodes
DELETE CONDITION	Delete an edge condition
RENAME	Rename an activity
MOVE NODE	Move a node
MOVE EDGE LABEL	Move the label of an edge
CREATE/DELETE/MOVE EDGE BENDPOINT	Update the routing of an edge
UPDATE CONDITION	Update an edge’s condition
VSCROLL	Scroll vertically
HSCROLL	Scroll horizontally

Cognitive Load During Design Activities

Cognitive Load characterizes the demands tasks imposed on the limited information processing capacity of the brain.

Modeler-specific factors

- Process Modeling Expertise
- Domain Knowledge
- Cognitive Abilities

Task-specific factors

- Inherent complexity of task
- Task representation
- Design platform including
  - Modeling notation
  - Tool support

Design Artifact

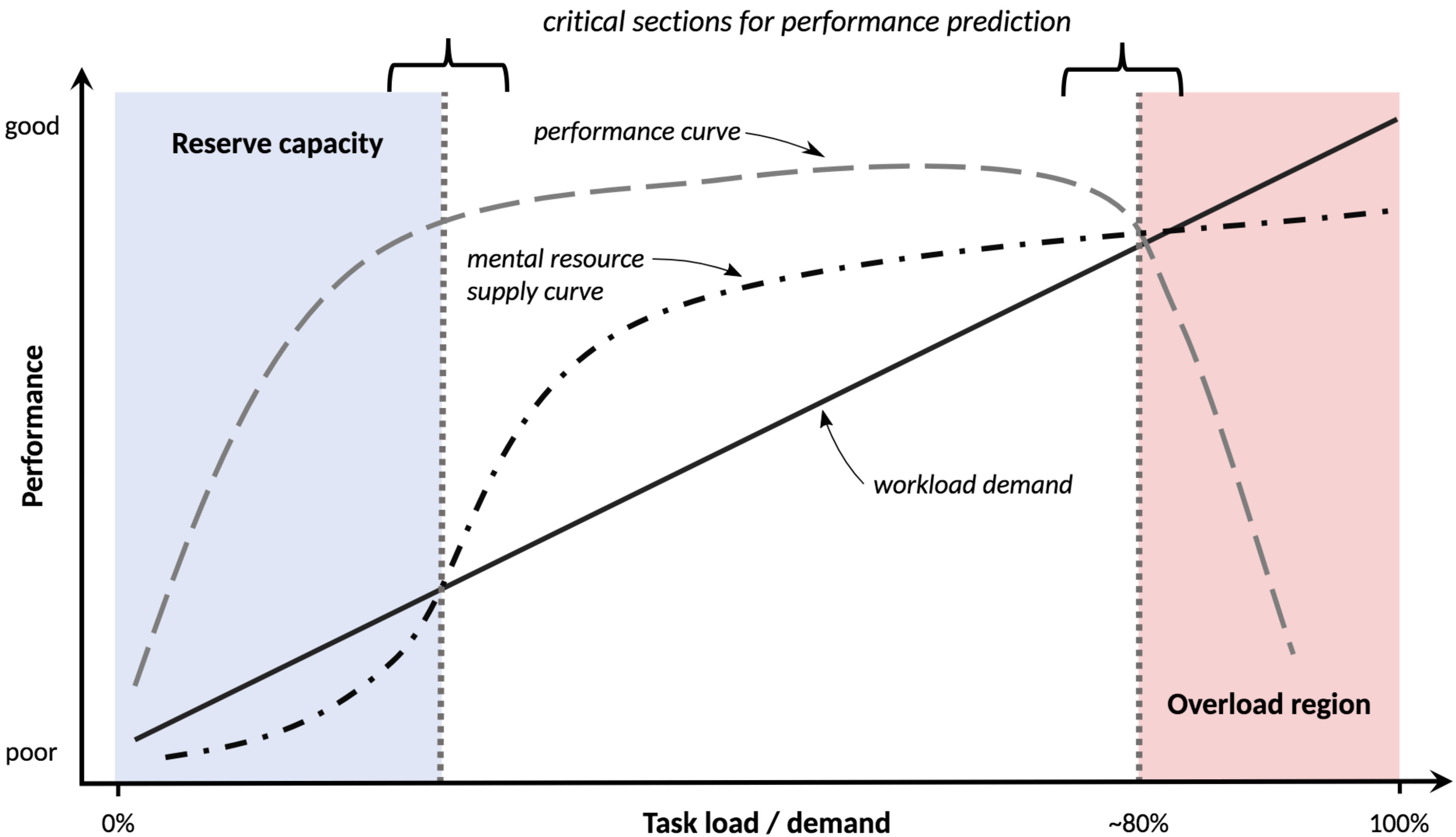
(Wickens and Hollands 1988, Figl 2017)

Assessment of Cognitive Load

- Subjective Ratings
  – SWAT, NASA-TLX
- Performance measures
  – Dual-task setting
- **Behavioral and physiological measures**
  – Heart rate variability
  – Eye tracking, i.e., **pupillary responses**, eye blink rate
  – EEG
  – Galvanic Skin Response

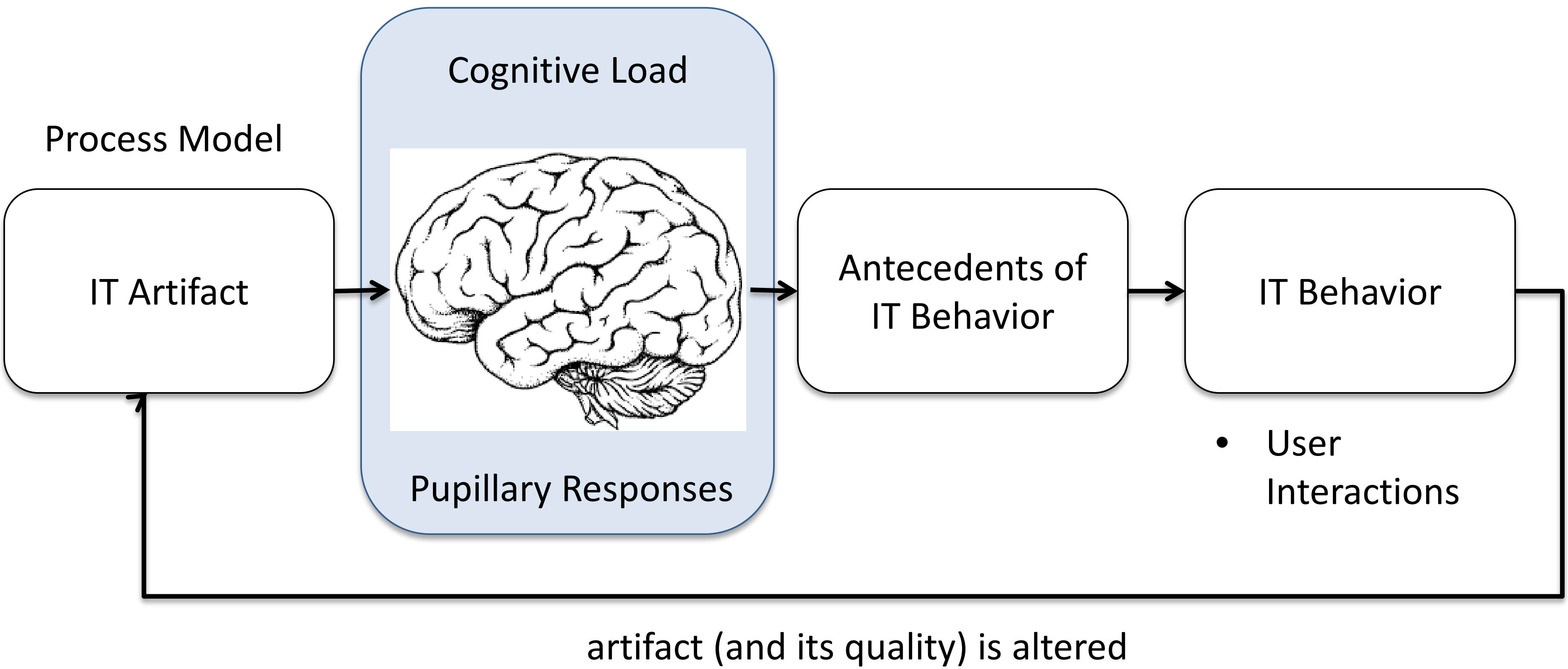
(Schmeck et al. 2015)

Cognitive Load: A Predictor for Task Performance



(Chen et al. 2016)

What is the Relationship of CL and the Quality of the IT Artifact?



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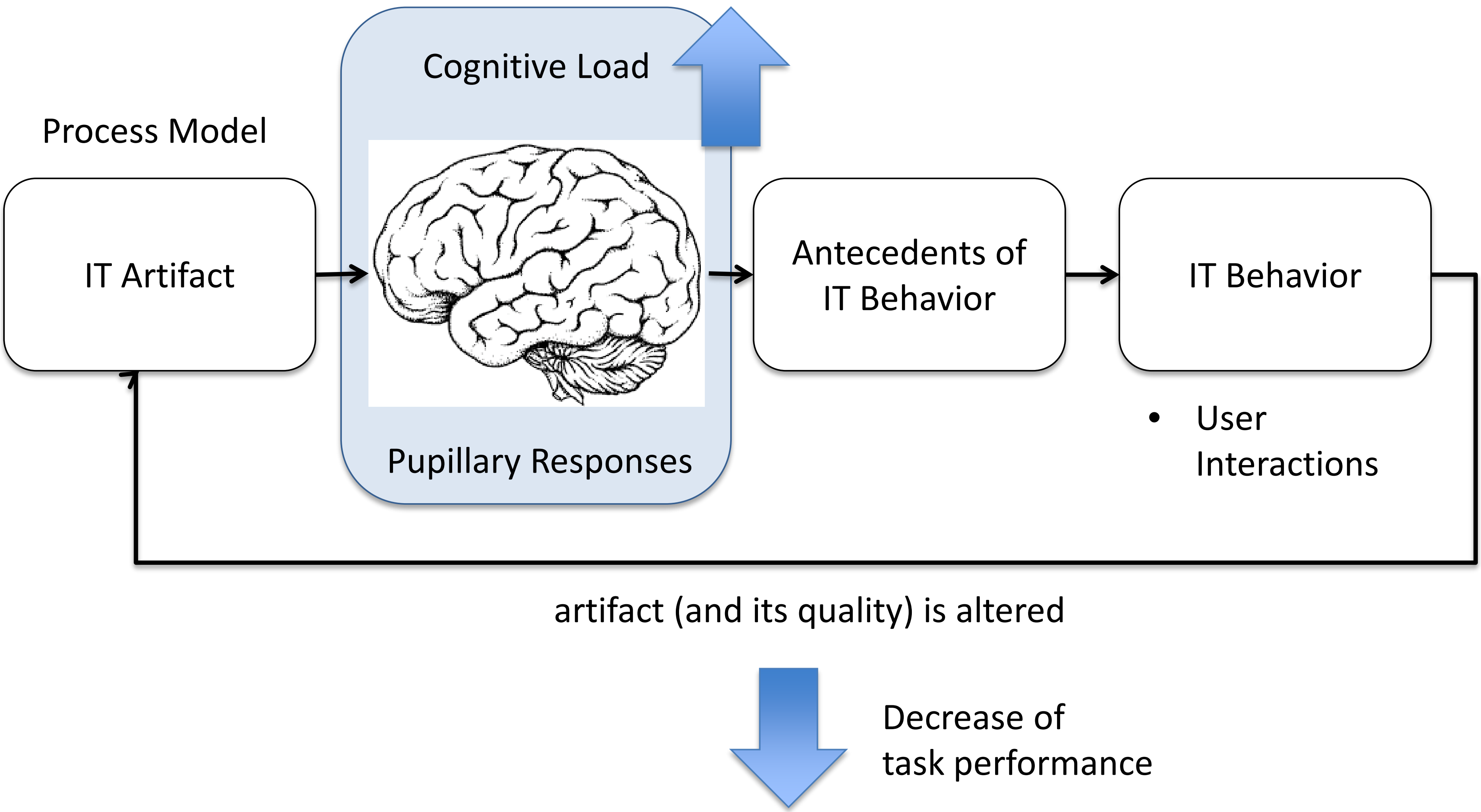

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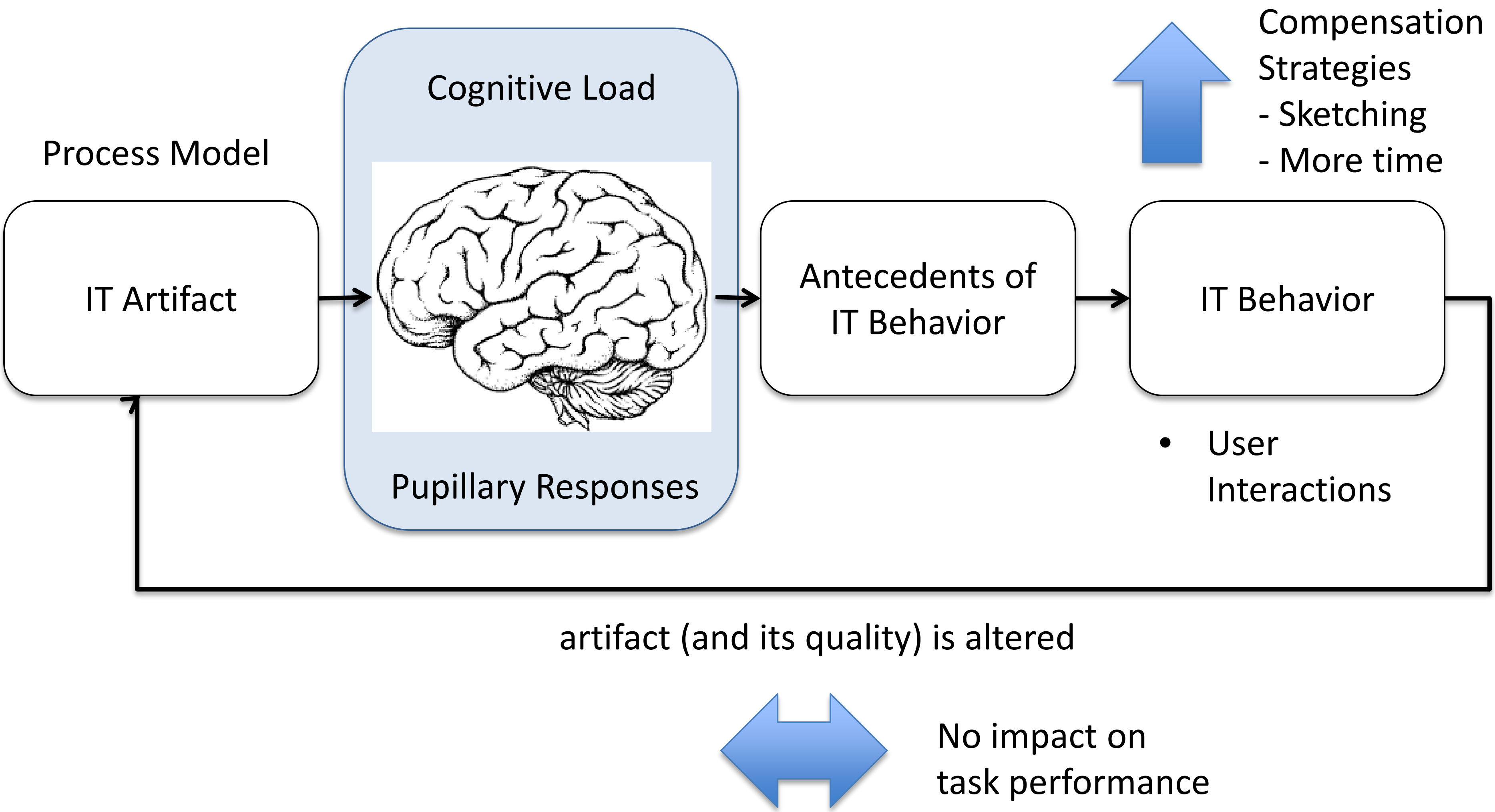
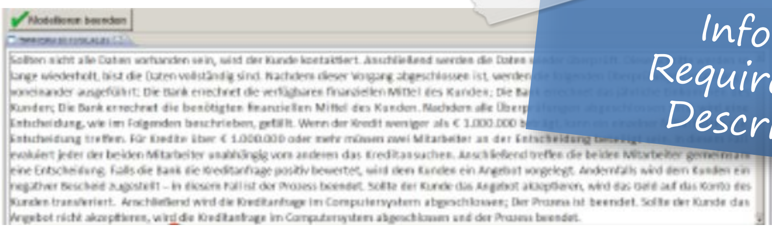


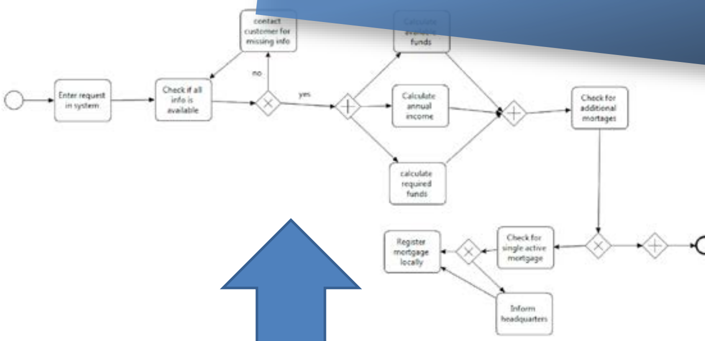
Process Model Creation

An Interactive Design Activity



Informal Requirements Description

Process Model



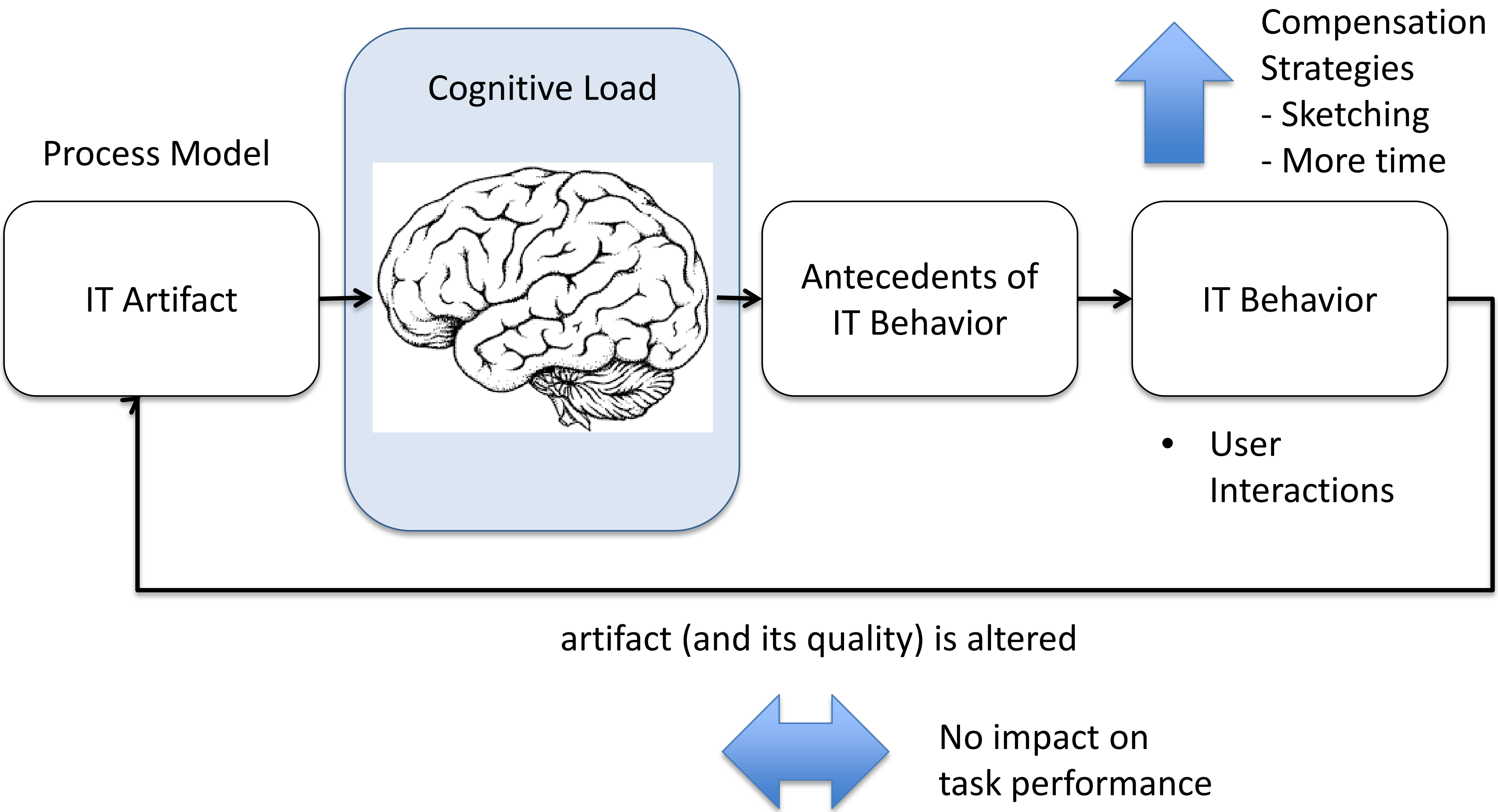
Process Modeling as Cognitive Design Activity

Experiment with 117 novice modelers creating a process model in BPMN

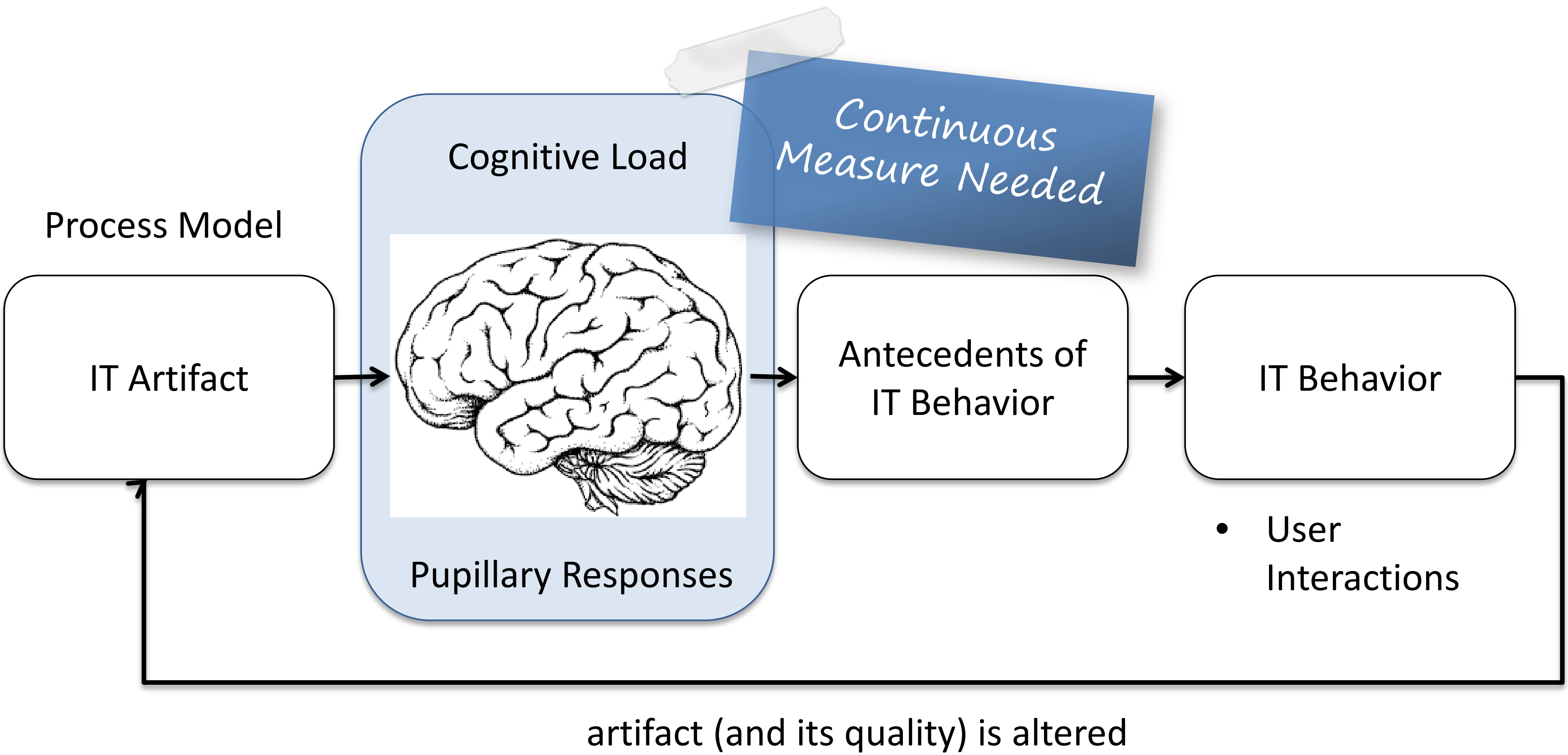
Continuous measure of cognitive load for entire design activity

- Pupillary responses

What is the Relationship of CL and the Quality of the IT Artifact?



Enable Measurements that are not Possible with Self-Reports



Continuous Assessment of Cognitive Load

- Subjective Ratings
  - SWAT, NASA-TLX
- Performance measures
  - Dual-task setting
- Behavioral and physiological measures
  - Heart rate variability
  - Eye tracking, i.e., pupillary responses, eye blink rate
  - EEG
  - Galvanic Skin Response

No continuous measures

Interrupt the main task

(Schmeck et al. 2015)

Measuring Emotions

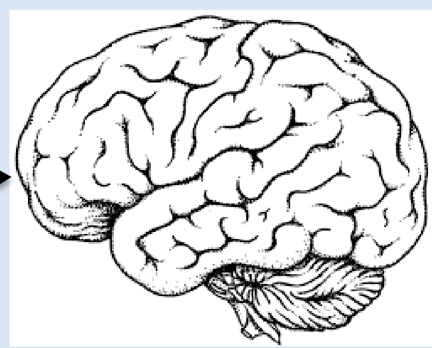
Multi-modal data collection using
brain related measures (EEG)
eye related measures (Eye Tracking), and
heart and skin related measures (Empatica E3 Wristband)

Change Tasks

Valence
Arousal

Perceived
Progress

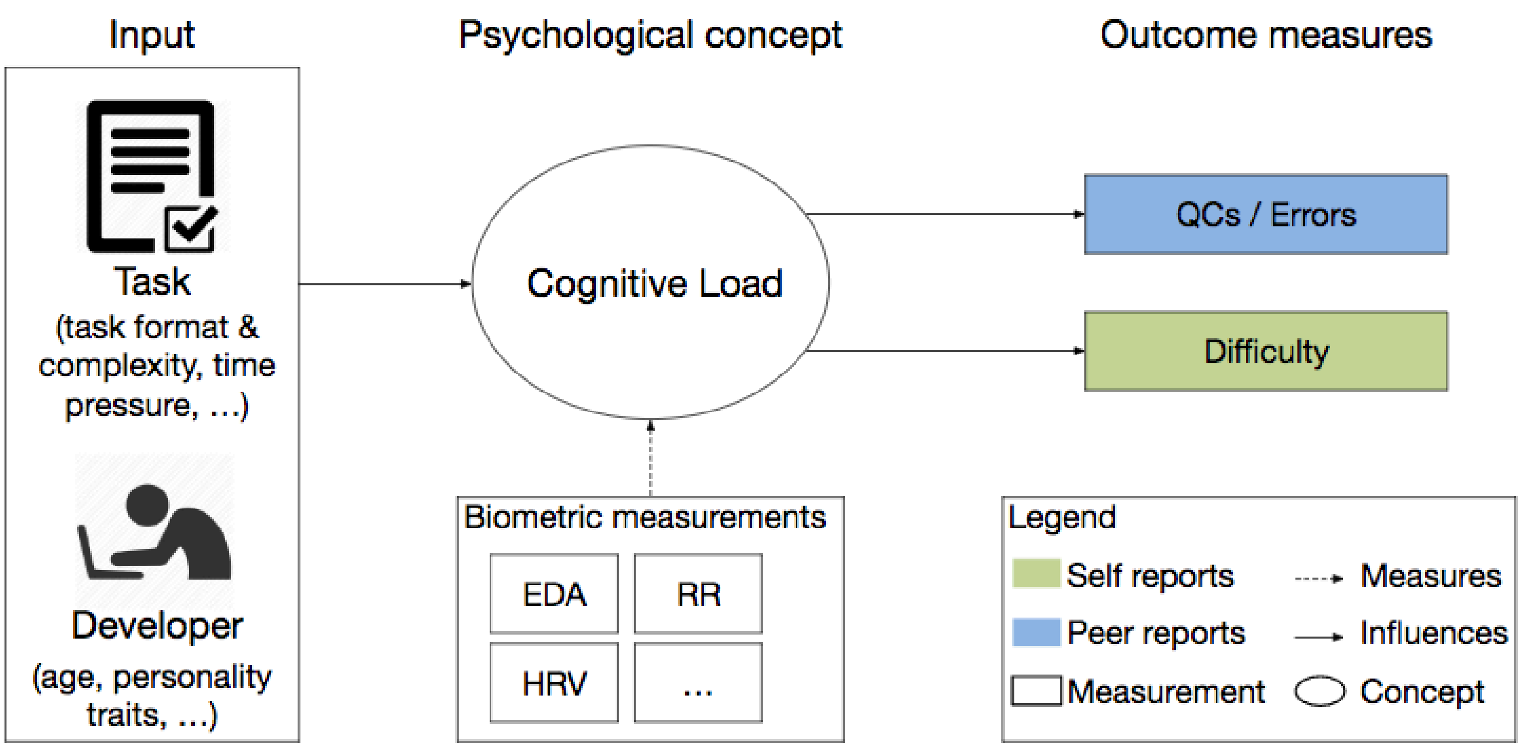
IT Artifact →



→ Antecendents of IT Behavior → IT Behavior

Sebastian C. Müller, Thomas Fritz: Stuck and Frustrated or in Flow and Happy: Sensing Developers' Emotions and Progress. ICSE (1) 2015: 688-699

Biological States and Processes as Better Predictors



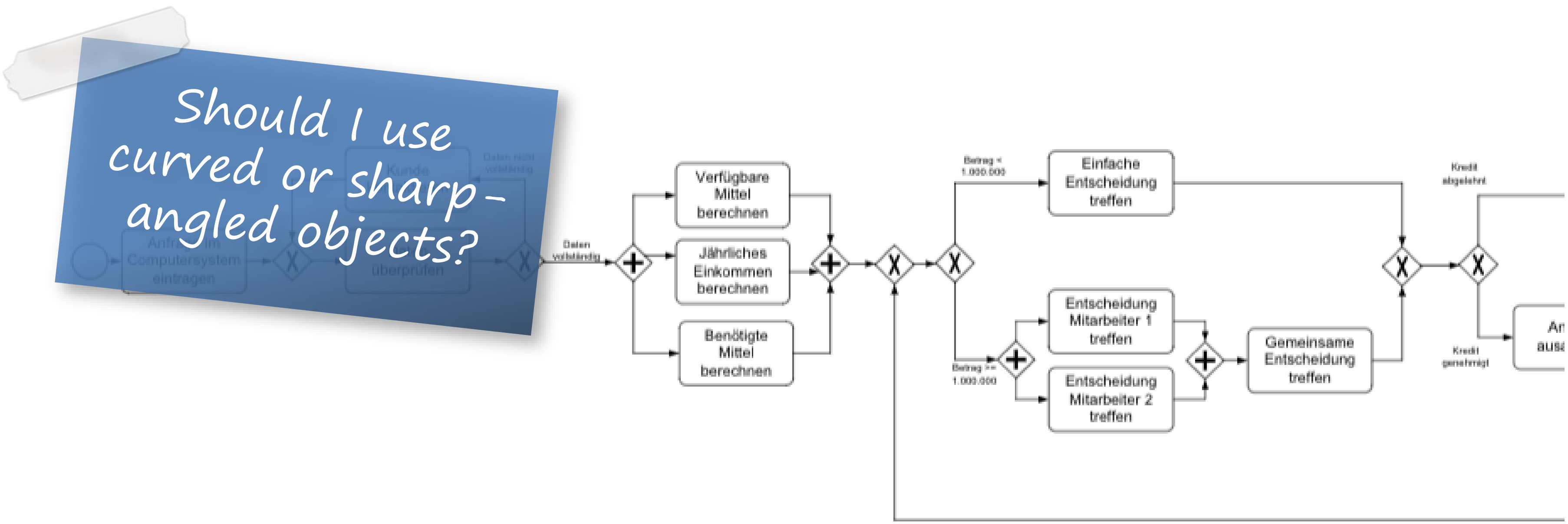
Sebastian C. Müller, Thomas Fritz:
Using (bio)metrics to predict code quality online. ICSE 2016: 452-463

Potential from a Design Science Perspective

- Design of IT artifacts
- Brain-based IT artifact evaluation
- Design of neuro-adaptive systems
- Development of biofeedback systems
- Development of brain computer interfaces

(Riedl & Léger 2016)

Neuroscience can Inform the Design of IT Artifacts

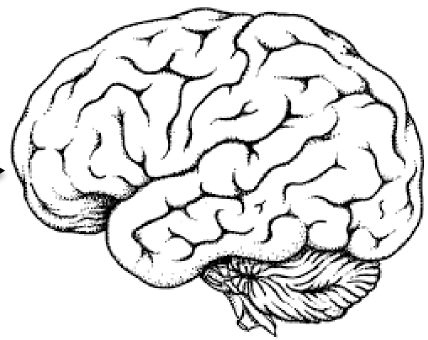


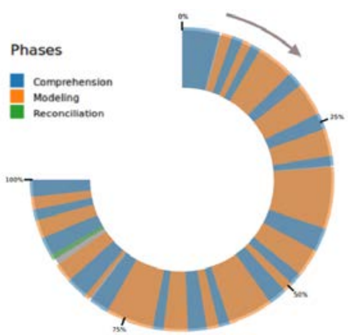
Humans prefer curved objects (rather than sharp-angled ones) (Bar and Neta 2007)

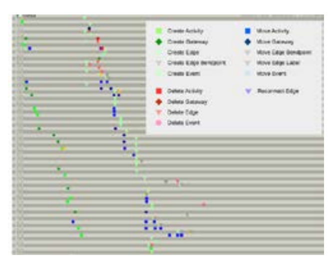
Brain-based IT Artifact Evaluation

Which design alternative is better?

Design Alternatives

IT Artifact →  → Antecendents of IT Behavior → IT Behavior





J. Gulden et al: From Analytical Purposes to Data Visualizations: A Decision Process Guided by a Conceptual Framework and Eye Tracking (submitted)

Brain-based IT Artifact Evaluation

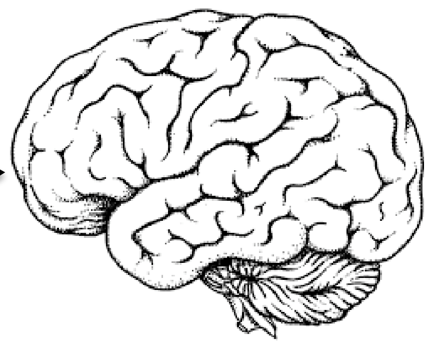
Which design alternative is better?

Design Alternatives

Perceived Mental Effort

Answering Time Accuracy

IT Artifact →



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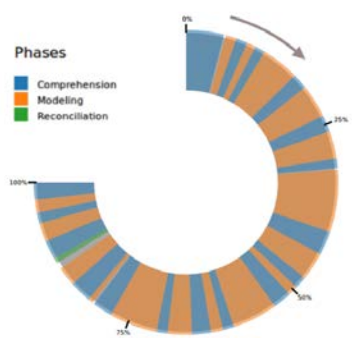

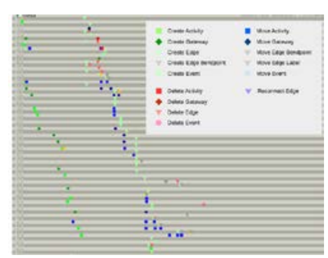

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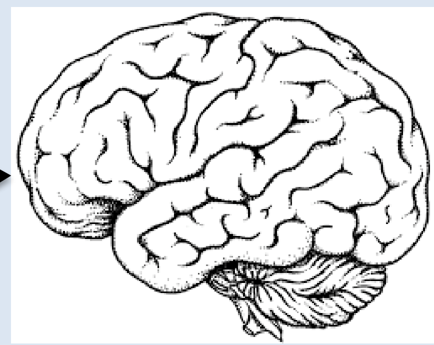
Brain-based IT Artifact Evaluation

Which design alternative is better?

Design Alternatives

IT Artifact →

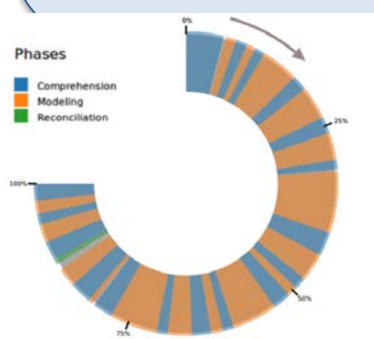
Cognitive Load
Visual Effort

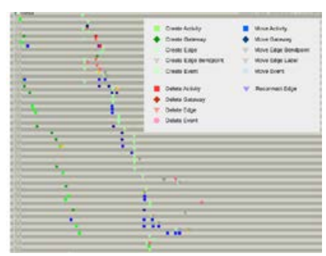


→ Antecendents of IT Behavior → IT Behavior

Perceived Mental Effort

Answering Time
Accuracy





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Brain-based IT Artifact Evaluation

Which design alternative is better?

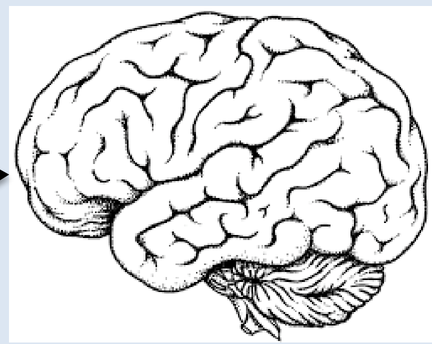
Cognitive Load
Visual Effort

Design
Alternatives

Perceived
Mental Effort

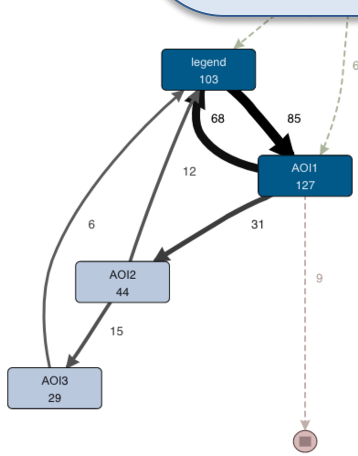
Answering Time
Accuracy

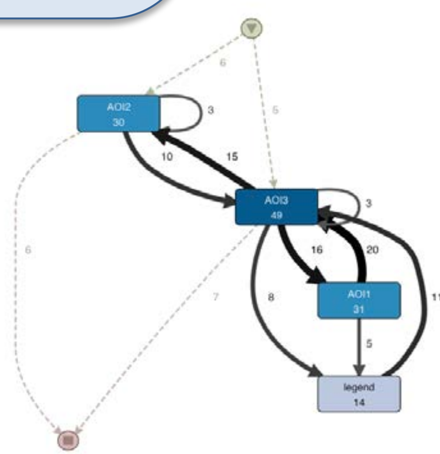
IT Artifact



Antecendents of
IT Behavior

IT Behavior



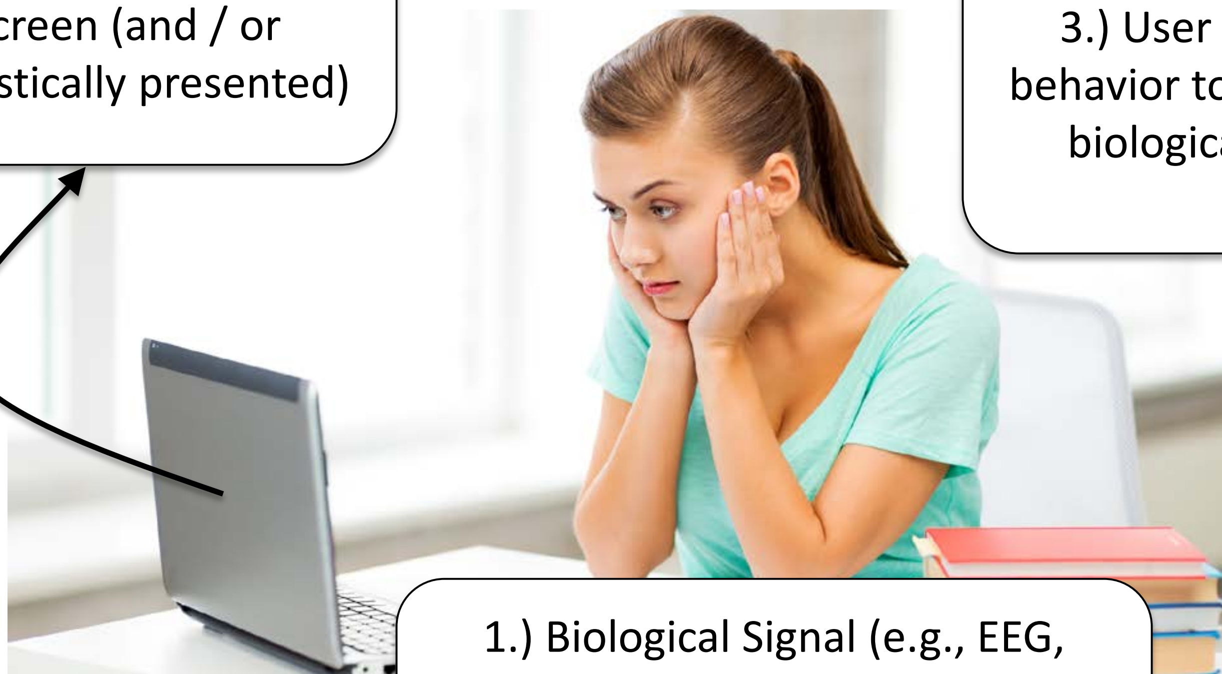


Mining of
Reading Patterns

Biofeedback System

2.) Biological signal is illustrated on the screen (and / or acoustically presented)

3.) User alters the behavior to control the biological system



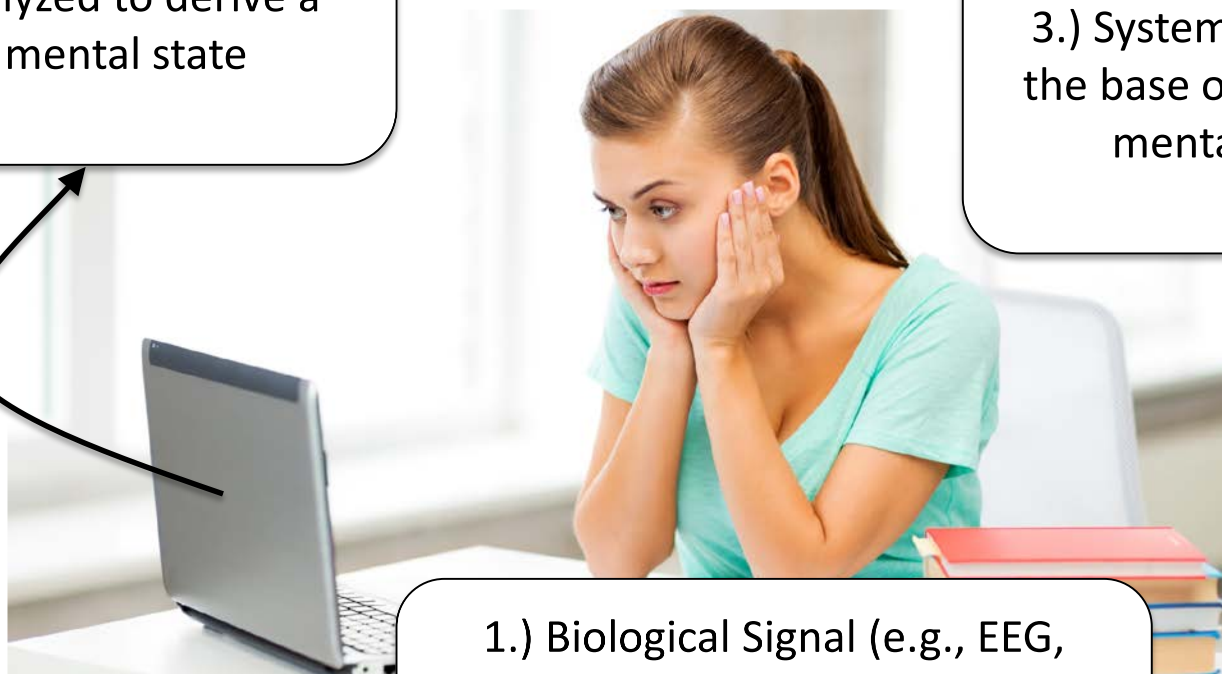
1.) Biological Signal (e.g., EEG, pupil dilation, HRV, skin conductance) is recorded from the user

(Riedl & Léger 2016)

Neuro-adaptive System

2.) Biological signal is analyzed to derive a mental state

3.) System adapts on the base of the user‘s mental state



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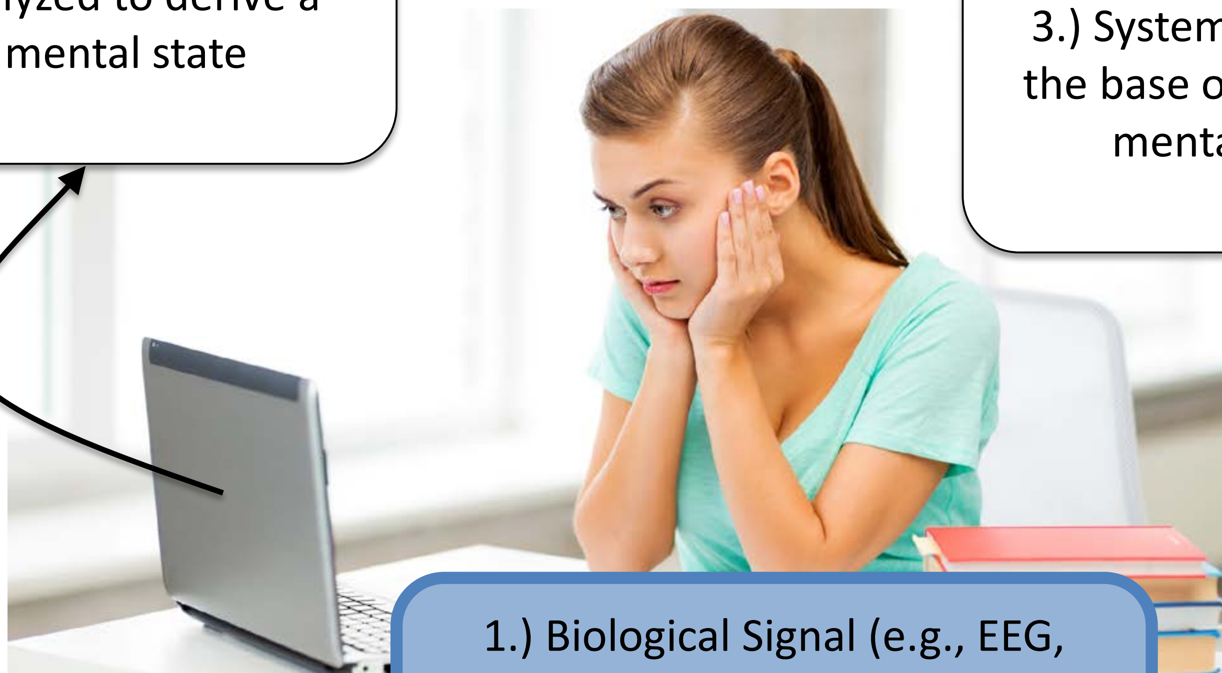
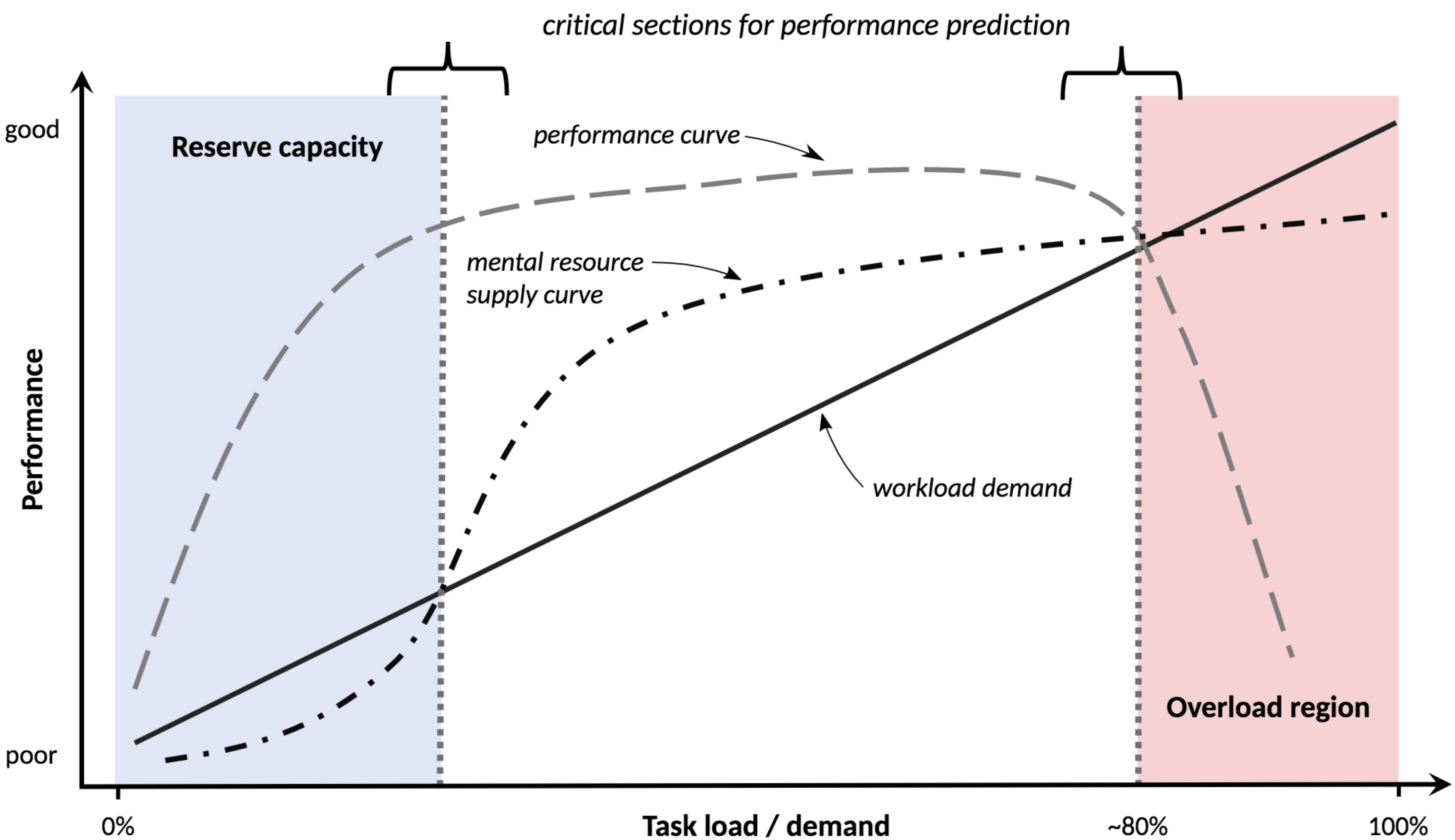


1.) Biological Signal (e.g., EEG, pupil dilation, HRV, skin conductance) is recorded from the user

Cognitive Load: A Predictor for Task Performance



Continuous Measurement of Cognitive Load

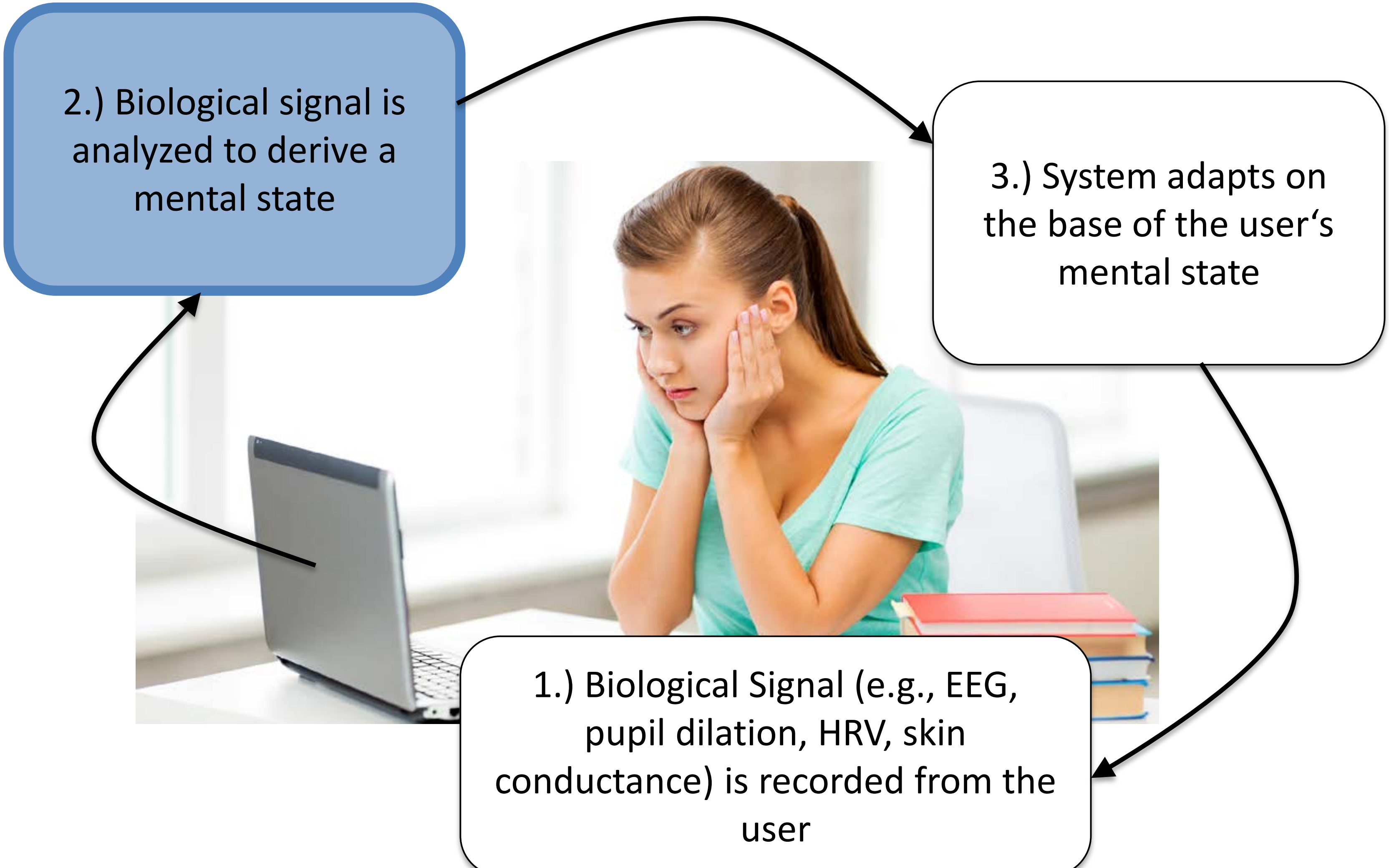
potentially using different modalities

Pupillary responses

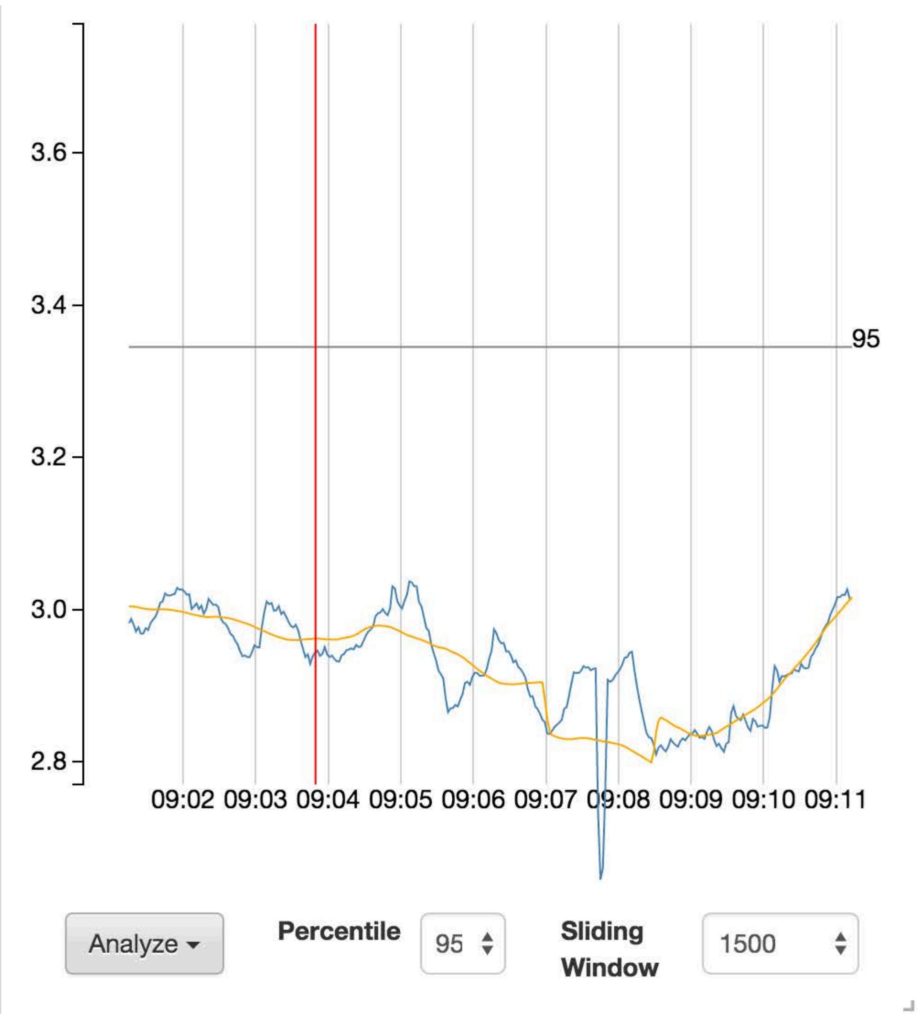
Blink rate

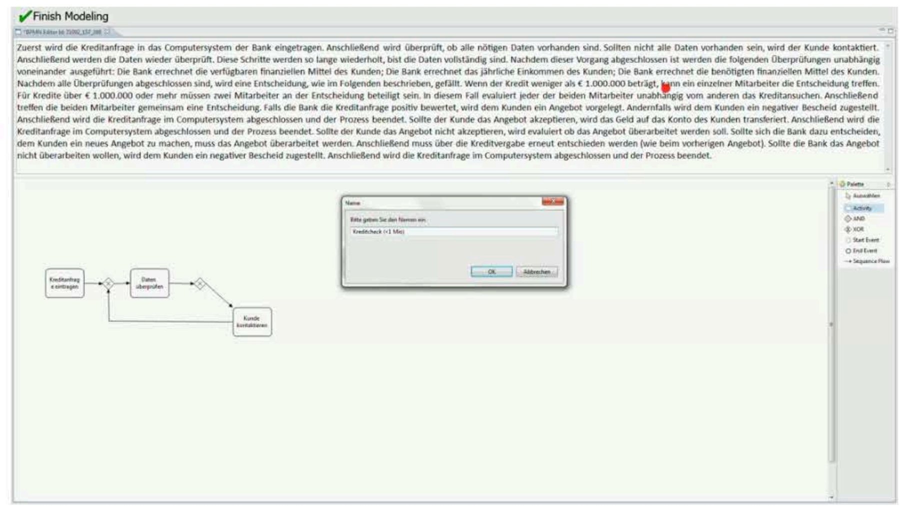
Heart rate variability

Neuro-adaptive System



Cleaning Pupillary Data with Cheetah Web 1.0

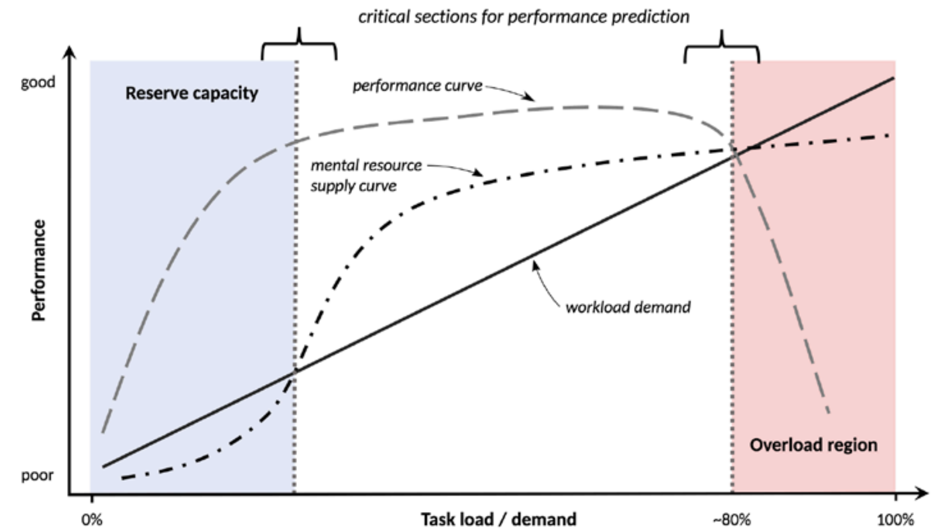


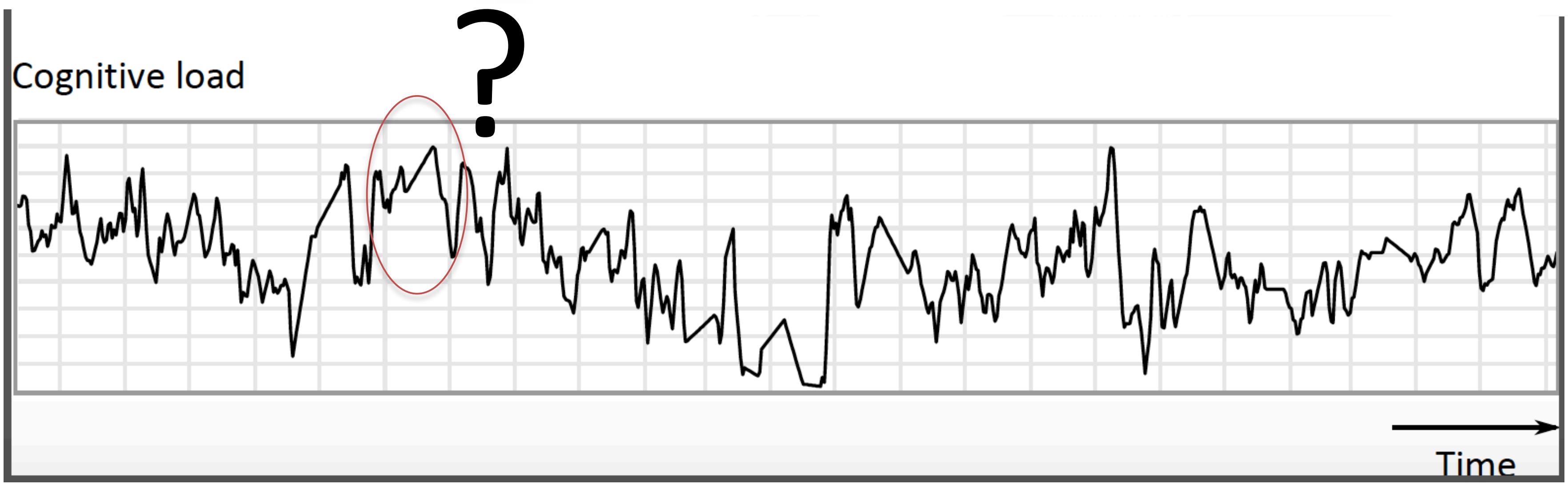


S. Zugal, J. Pinggera, M. Neurauter, T. Maran and B. Weber: Cheetah Experimental Platform Web 1.0: Cleaning Pupillary Data. Technical Report arXiv:1703.09468. arXiv, 2017.

Cognitive Overload Detection

Is the user in the overload region where performance decreases can be expected?





Neuro-adaptive System

1.) Biological Signal (e.g., EEG, pupil dilation, HRV, skin conductance) is recorded from the user

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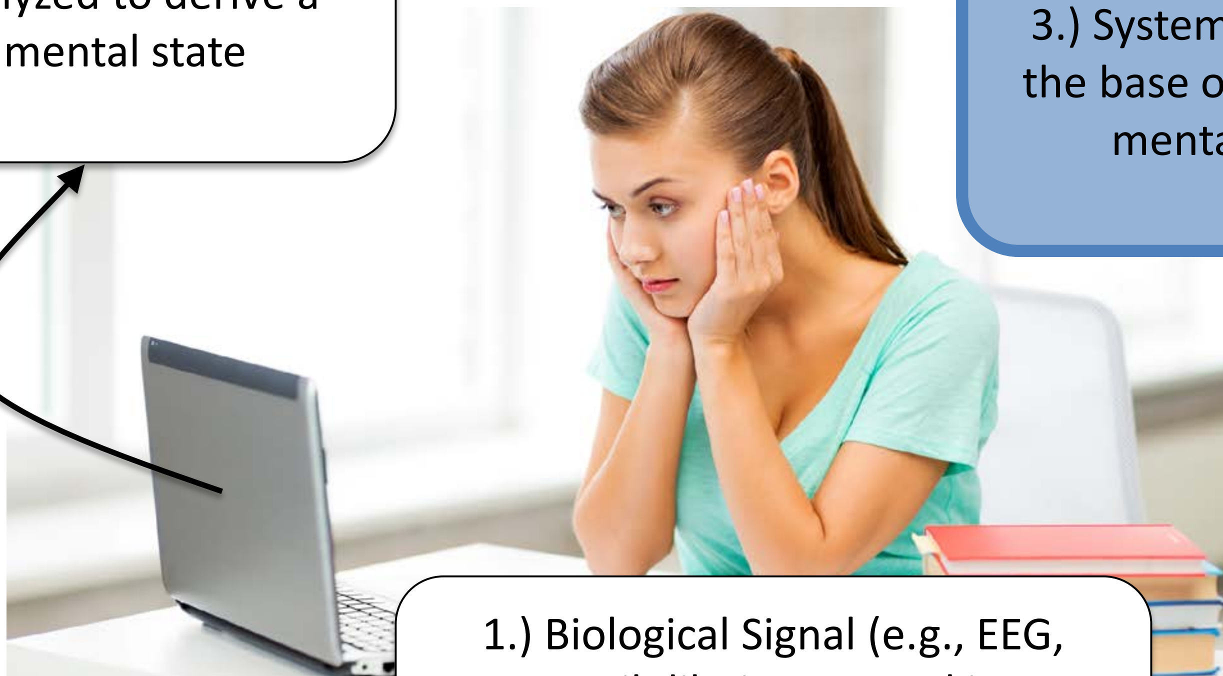

How to Adapt?

- What is the context in which a particular mental state was observed?
- Challenge: Establishing the link between the IT artifact and the sensor data, for example:
  - between elements in the source code eye fixations
  - between sub-tasks and cognitive load or eye fixations
  - between the state of the IT artifact (e.g., its quality) and cognitive load

Brain-computer Interfaces

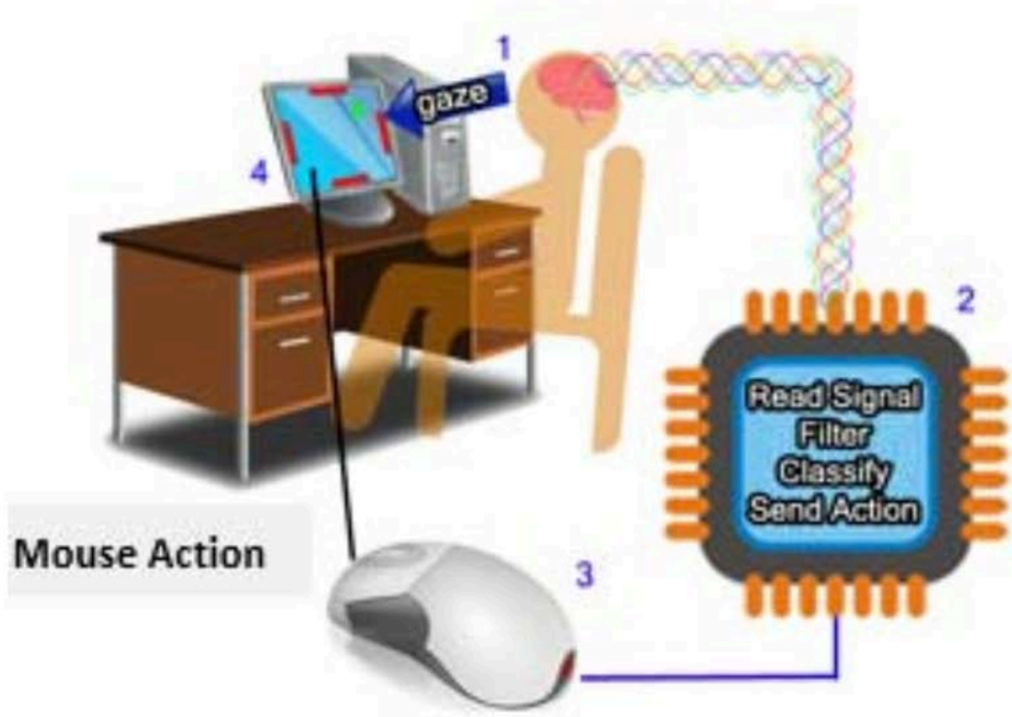

Fig. 2: Adaptive System Circuit. Part 1: User gazes at a specific stimulus on the computer screen. Part 2: DSP processes the EEG signals to identify an event in the user's brain. Part 3: DSP translates the EEG event into a mouse event. Part 4: Computer performs the mouse event.

Shihong Huang, Pedro Miranda:
Incorporating Human Intention into Self-Adaptive Systems. ICSE (2) 2015: 571-574

Summary

- Human factors in software engineering require increased attention
- Potential of neuroscience and psychophysiological methods and tools both from a theoretical perspective and a design science perspective
- Many interesting challenges that require highly interdisciplinary research efforts

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