Tracking User Behaviours: Laboratory-Based and In-The-Wild User Studies

Gianluca Demartini and Shazia Sadiq
University of Queensland, Australia
g.demartini@uq.edu.au
gianlucademartini.net
@eglu81

Slides available at http://gianlucademartini.net/userbehaviours/

Research Interests

- **Entity-centric Information Access** (2005-now)
  - Structured/Unstruct data (SIGIR 12), TRank (ISWC 13, WSemJ 16)
  - NER in Scientific Docs (WWW 14), Prepositions (CIKM 14)
  - IR Evaluation (IRJ 2015, ECIR 16 Best Paper Award, CIKM 17, SIGIR 18)
- **Human-in-the-loop Information Systems** (2012-now)
  - ZenCrowd (WWW 12, VLDBJ), CrowdQ (CIDR 13), Remove noise (WWW 19)
  - Huml systems overview (COMNET 15, FnT 17)
- **Better Crowdsourcing Platforms** (2013-now)
  - Platform Dynamics (WWW 15), Wikidata (CSCWJ 18)
  - Pick-a-Crowd (WWW 13), Scheduling Tasks (WWW 16)
  - Agreement (ICTIR 17, HCOMP 17), Pricing Tasks (HCOMP 14)
- **Human Factors in Crowdsourcing** (2015-now)
  - Malicious Workers (CHI 15), Attack Schemes (HCOMP 18 Best Paper Award)
  - Modus Operandi (UBICOMP 17), Gender Bias (SIGIR 18)
  - Time (HCOMP 16), Complexity (HCOMP 16), Abandonment (WSDM 19)

Thanks to:

European Commission

Australian Government
Australian Research Council

EPSRC
Engineering and Physical Sciences Research Council

Outline

- Introduction: Motivation and Examples
  - User Behaviours (Why and How)
- Part I - Tracking In-Browser Behavioural Features (40min)
  - Data to be collected
  - Example research using behavioural logs
  - Datasets and tools
- Part II - Running In-Lab User Behaviour Studies (40min)
  - User Engagement Scale
  - Neuro-physiological measurements
  - Example research using Eye-tracking
  - Cognitive Load
- Conclusions
  - Combined use of both

Before we start …

- Have you done any studies with human participants?
  - If yes, what method did you use?

- Have you used neuro-physiological measurement (devices) in your research?
  - If yes, which device/method did you use

Introduction:
Motivation and Examples

The Need for User Studies

- The Information Systems we build are “used”

- In the field of database and data analytics research we tend to focus on effectiveness, efficiency, scalability, optimization, etc.
  - Which is great for the user!

- More broadly, users interact with systems through Data Visualizations, Dashboards, Search engine result pages, Uis
- Users have increased expectations on system interaction which are offered by competing systems

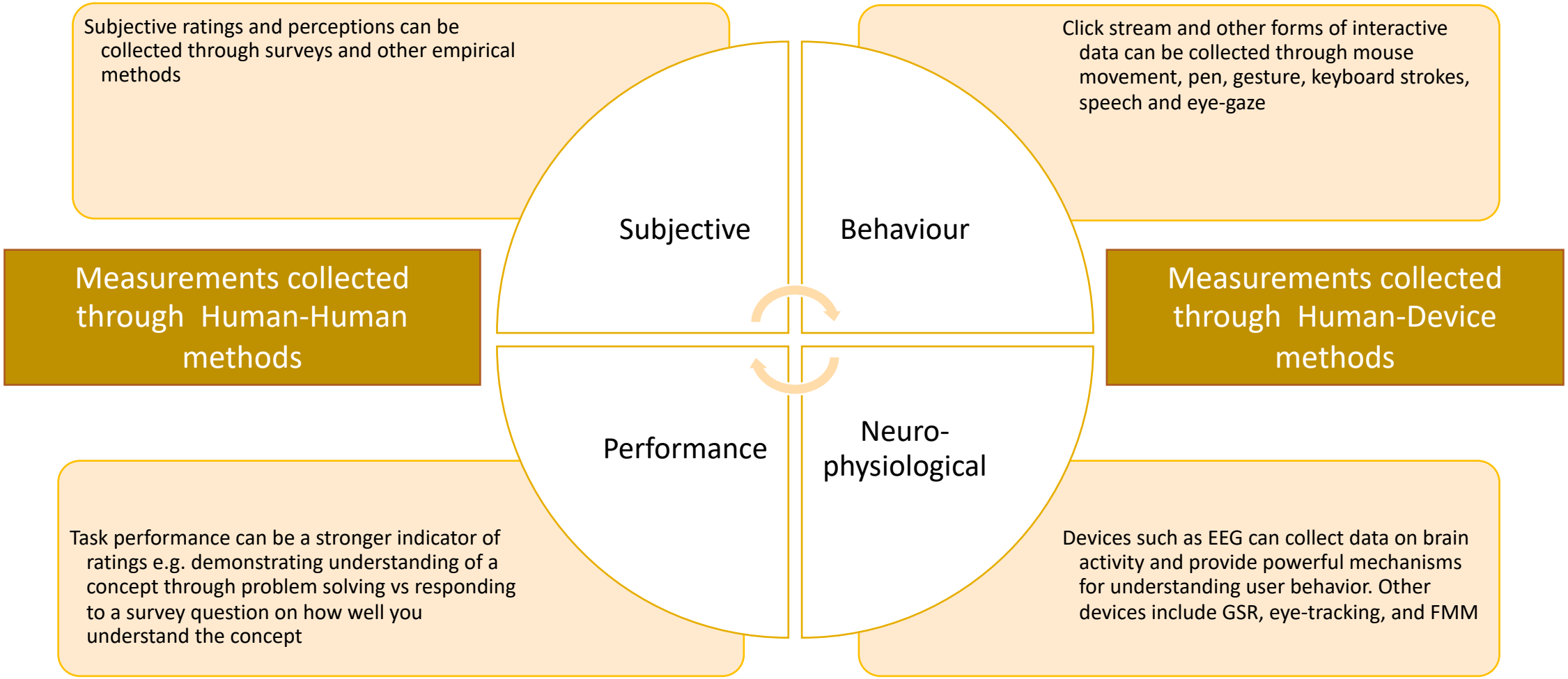
Understanding User Behaviors

- Done by a data collection and analysis effort

- Large-scale
  - In-the-wild (on the web), log-based, quantitative, interaction analysis, implicit user feedback, data-driven observations

- Small-scale
  - In-lab, detailed, qualitative, interviews, explicit user feedback, manual observations

User Behavior Tracking – A Multi-Modal Perspective

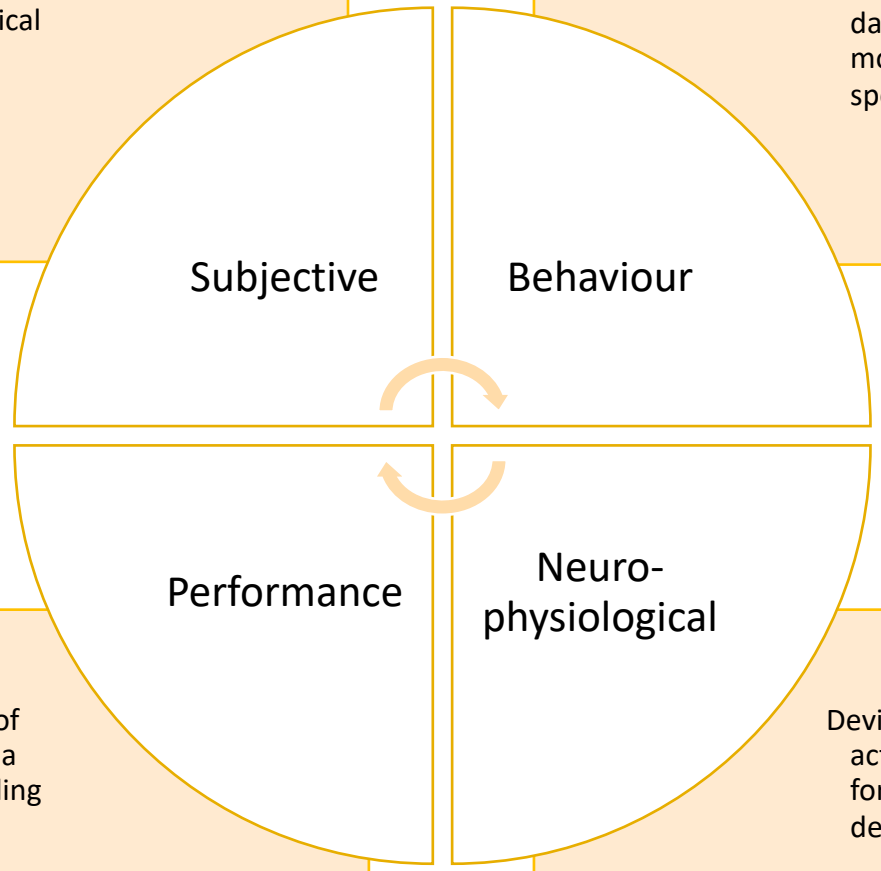


User Behavior Tracking – A Multi-Modal Perspective

PART 1

Subjective ratings and perceptions can be collected through surveys and other empirical methods

Click stream and other forms of interactive data can be collected through mouse movement, pen, gesture, keyboard strokes, speech and eye-gaze



PART 2

Task performance can be a stronger indicator of ratings e.g. demonstrating understanding of a concept through problem solving vs responding to a survey question on how well you understand the concept

Devices such as EEG can collect data on brain activity and provide powerful mechanisms for understanding user behavior. Other devices include GSR, eye-tracking, and FMM

User / System Interaction

- A Classic Human-Computer Interaction topic
  - Survey, Interviews, human observation
- More recently considered as data-driven questions
  - Loggers, sensors, specialized hardware
- Best study designs combine both sources of data and use a mix of qualitative and quantitative research methodologies

Elements of a user-centred system evaluation

- System(s) to be analysed and compared
  - Comparing systems or variants of a system (A/B testing, within-subject, between-subject)
- Users to be involved
  - Sampling strategy (representative of a population, convenience sampling. bias on the observations?)
- Experimental setting
  - Tasks, system datasets, UI
- Data to be collected
  - Different collection methods
- Analyses to be performed
  - Statistical validity

Elements of a user-centred system evaluation

- System(s) to be analysed and compared
  - Comparing systems or variants of a system (A/B testing, within-subject, between-subject)
- Users to be involved
  - Sampling strategy (representative of a population, convenience sampling. bias on the observations?)
- Experimental setting
  - Tasks, system datasets, UI
- **Data to be collected**
  - Different collection methods
- Analyses to be performed
  - Statistical validity

Structure of this Tutorial

- Part I - Tracking In-Browser Behavioural Features (40min)
  - Data to be collected
  - Example research using behavioural logs
  - Datasets and tools
- Part II - Running In-Lab User Behaviour Studies (40min)
  - User Engagement Scale
  - Neuro-physiological measurements
  - Example research using Eye-tracking
  - Cognitive Load

Part I - Tracking In-Browser Behavioural Features (40min)

Behavioral logs - Why

- Web-based studies allow to scale-up the data collection effort
- Involve many users, have a diverse subject population

- Data to be collected:
- User clicks, page views, mouse over, and keyboard actions

Behavioral Logging Architecture

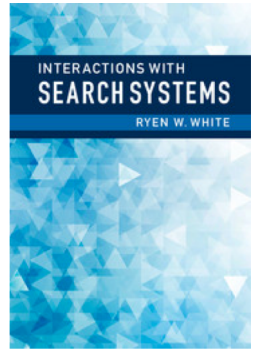
- Server: receiving and storing log messages from clients
- Clients: JavaScript code running in the users' browser while visiting your website

- Need JS to be enabled
- Also use cookies for intra-session logs

User interaction in web search

- Example Research:
  - Estimating the distribution of the length of time that a user will spend on a web ad considering post-click engagement to select ads to show [1]
  - Understand what makes user more engaged with an online portal (e.g., e-commerce) [2]

- White, R.W.: Interactions with search systems.
  - Ch 2, Collecting and Representing Search Interaction



[1] Barbieri et al, Improving Post-Click User Engagement on Native Ads via Survival Analysis, WWW2016
[2] Zhuang et al, Understanding Engagement through Search Behaviour, CIKM 2017

User engagement in web search

- Go beyond a single session / query / website visit
- Track user behaviors over recurring visits and observe trends and changes

- **User Engagement Scale** (O'Brien & Toms)
  - Focused attention
  - Positive Affect
  - Aesthetics
  - Endurability
  - Novelty
  - Richness
  - Trust
  - Motivation
- Typically measured in-lab, but recent research shows correlations with behavioral data

Measuring Engagement

- Self-reported (subjective)
  - Questionnaires
- Cognitive (objective, easy to scale)
  - Time spent, activity on task and post-task
  - Physiological measures (mouse tracking, which correlated with sight)
- Interaction (objective, easy to scale)
  - Metrics, paths (Markov chains)

See also User Engagement tutorial at WWW2013
and book “Measuring User Engagement” by Lalmas et al.

Intra-session measures

- Dwell time / session duration
- Play time (video)
- Click through rate (CTR) (e.g., on ads, recommendations)
- Mouse movement
- Number of pages viewed (click depth)
- Conversion rate (mostly for e-commerce)

Inter-session measures

- Fraction of return visits (How many users return for another visit?)
- Time between visits (inter-session time, absence time)
- Number of views (video)
- Total view time per month (video)
- Lifetime values
- Number of sessions per unit of time
- Total usage time per unit of time
- Number of friends on site (Social networks)

Clickthrough rate (CTR)

- Number of clicks / number of impressions

- Few issues:
  - Ranking bias
    - Various way to deal with it such as “interleaving”
  - Presentation bias
    - Perceived relevance from reading the snippet

Joachims. Optimizing Search Engines using Clickthrough Data, KDD 2002

Artwork Personalization at Netflix

Image A

Image B

Figure 3: Example of contextual image selection based on the type of profile. Comedy refers to a profile that mostly watches comedy titles. Similarly, Romance watches mostly romantic titles. The contextual bandit selects the image of Robin Williams, a famous comedian, for comedy-inclined profiles while selecting an image of a kissing couple for profiles more inclined towards romance.

https://medium.com/netflix-techblog/artwork-personalization-c589f074ad76

Collecting data by means of Crowdsourcing

- For academic researchers (who do not run a multi-billion user web platform), crowdsourcing platforms can be used to recruit users/subjects
- Amazon MTurk, Figure Eight
- Can recruit several hundreds subjects within hours

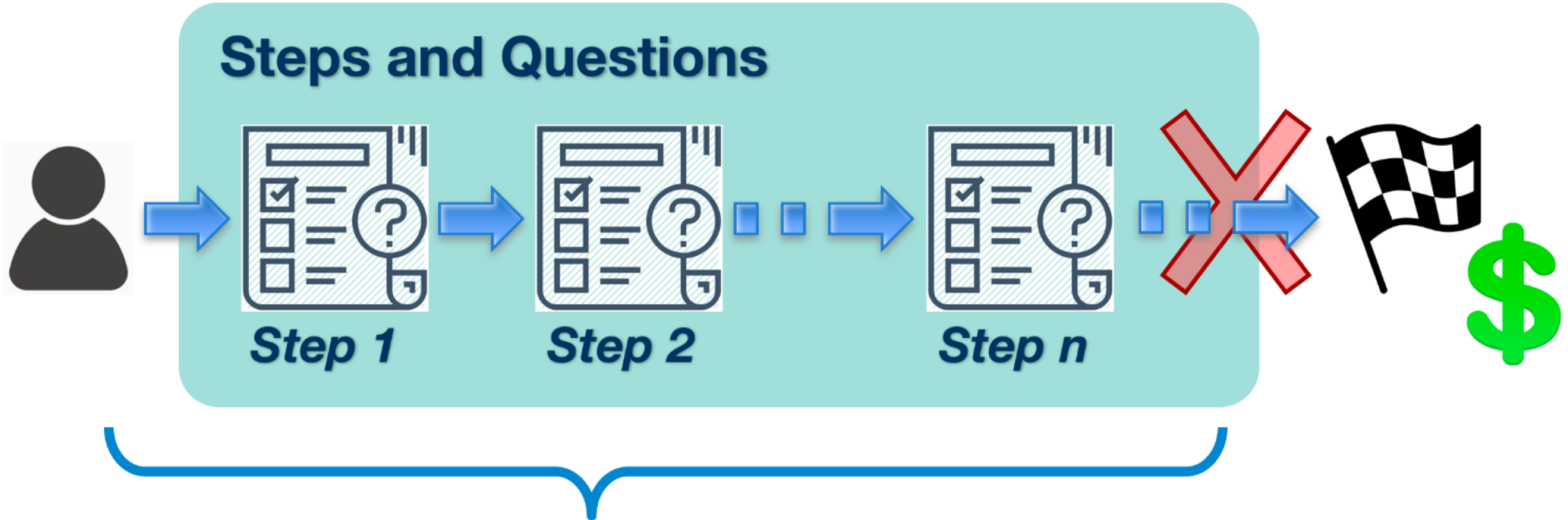
- Need to control for quality/spam
- Difficult to follow-up after the task/experiment

Collecting data by means of Crowdsourcing

- Crowdsourcing as a convenient way to attract human subject to your study
  - Can customize population (e.g., US only)
  - Not representative
  - Reward the driving factor for participation
  - Generally not malicious, but need to do prep work to get quality data
- Task Design (e.g., ”use our search engine to find information about..”)
- Reward (and use of bonus)
- Ethics / Informed consent

Example of Crowd Behavior Research

- Han et al. All Those Wasted Hours: On Task Abandonment in Crowdsourcing, WSDM 2019
- Quantify the task abandonment phenomenon (i.e., workers who start but do not finish a task



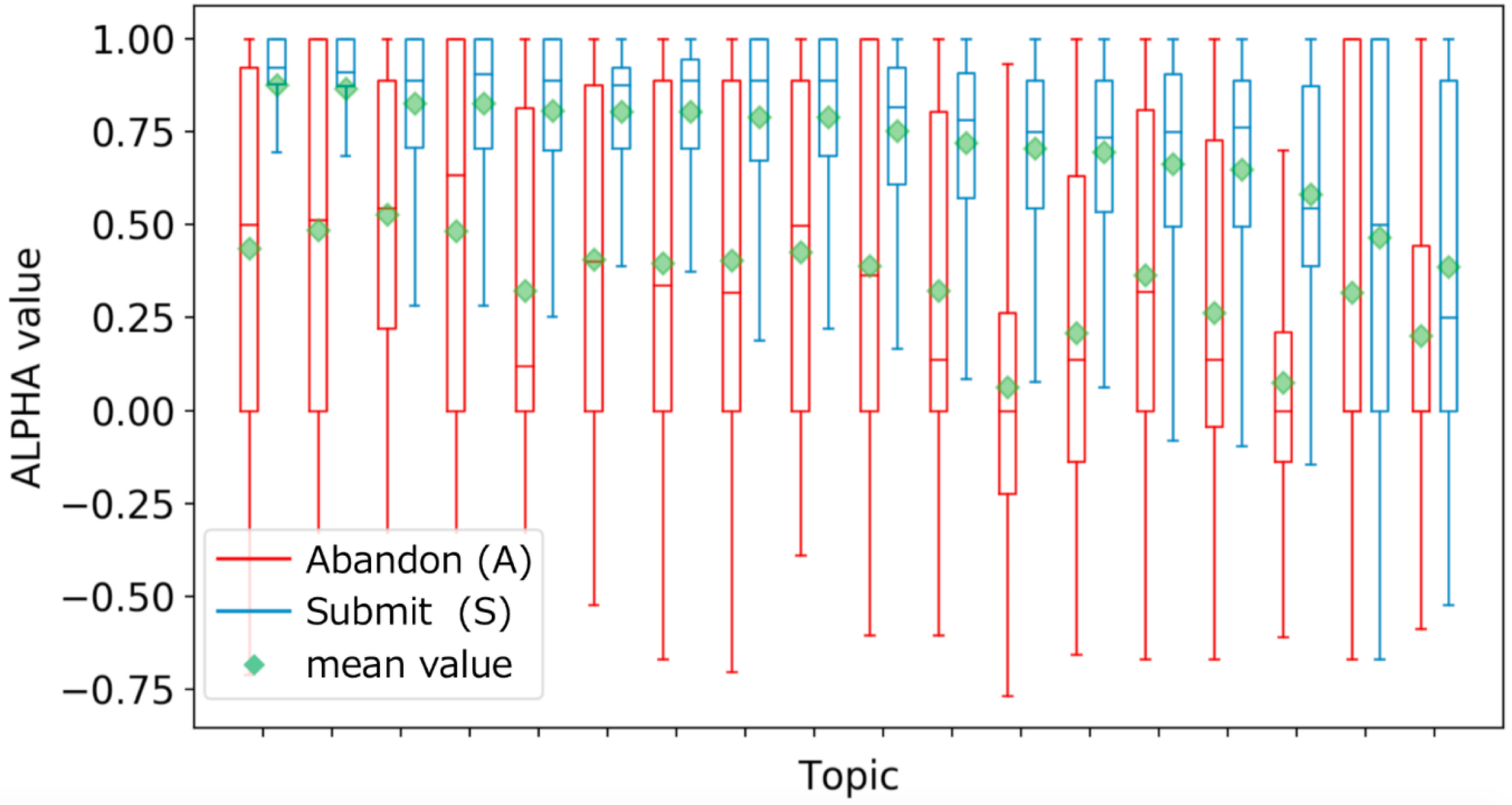
Logged behaviors

- Logged each click and keystroke and sent to our external server
- This data would usually be **invisible** to crowd requesters as they only see ”submitted” tasks, not started ones.

- 5265 workers, 280K log entries over 4K documents
- Total time not rewarded due to abandonment: 616 hours

Data-driven observations

- Group comparison: how do abandoning worker perform in terms of quality?



Crowd behavior dataset

- WebCrowd25K Dataset
  - Behavioural signals from crowd workers judging the relevance of search results
  - http://ir.ischool.utexas.edu/webcrowd25k/
- 25,099 information retrieval relevance judgments
  - 50 topics x 100 documents x 5 workers
- Behavioural Data
  - using MmmTurkey (https://github.com/CuriousG102/turkey)

Example research

- Goyal et al. Your Behavior Signals Your Reliability: Modeling Crowd Behavioral Traces to Ensure Quality Relevance Annotations, HCOMP 2018
- Behavioural data can be effectively used to predict work quality
  - Good for *cold start (*i.e., new, previously unseen, workers)
  - Can be used for label aggregation
  - Reduce cost

Some tools you can use to log behavioral data

- MmmTurkey https://github.com/CuriousG102/turkey
  - Customized for Amazon MTurk
- Bigbro https://github.com/hscells/bigbro
  - General web page interaction logging
- UQCrowd logger https://github.com/d-lab/uqcrowd-log
  - Recent, developed by us, focus on scalability and analytics (use ElasticSearch)

Outline

- Introduction: Motivation and Examples
  - User Behaviours (Why and How)
- Part I - Tracking In-Browser Behavioural Features
  - Data to be collected
  - Example research using behavioural logs
  - Datasets and tools
- **Part II - Running In-Lab User Behaviour Studies**
  - User Engagement Scale
  - Neuro-physiological measurements
  - Example research using Eye-tracking
  - Cognitive Load
- Conclusions
  - Combined use of both

Part II - Running In-Lab User Behaviour Studies (40min)

Lab-based user studies

- Small-scale (10-50 subjects)
- Detailed observations by the experimenter who is looking at the subject while completing a task (can observe thinking, pauses, doubts, difficulties)
- Qualitative
- Interviews and think-aloud
  - Explicit user feedback on the system

Designing the user study

1. Informed consent
2. Instructions, task description, tutorial
3. Pre-task questionnaire / interview

4. User interacts with the system (completes a task)
    1. Data logging
    2. Human observations

5. Post-task questionnaire / interview

Using questionnaire to measure the user experience

- Pre/Post-task questionnaires
  - Demographics
  - Experience with the system
  - Background and expertise

- User Engagement Scale
  - Post-task
  - Measure how the user felt while using the system
  - Self-reported

7-Item Focused Attention Subscale

- 5-point scale (Strongly disagree to Strongly agree)

1. I lost myself in this news tasks experience
2. I was so involved in my news tasks that I lost track of time
3. I blocked things out around me when I was completing the news tasks
4. When I was performing these news tasks, I lost track of the world around me
5. The time I spent performing these news tasks just slipped away
6. I was absorbed in my news tasks
7. During the news tasks experience I let myself go

Why should we care about neuro-physiological measurement?

The Role of the Brain in IS Research

Design science Methods and neuroscience literature

IT Artifact

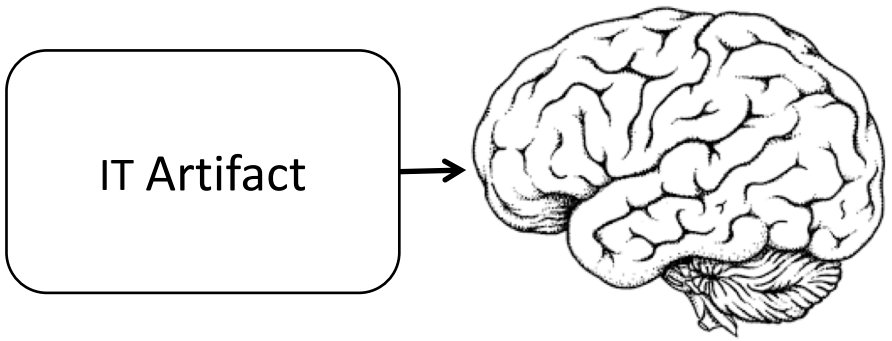
(Riedl & Léger 2016)

The Role of the Brain in IS Research

Design science Methods and neuroscience literature

Neuroscience and Psychophysiological methods and tools

Brain activity as mediator



(Riedl & Léger 2016)

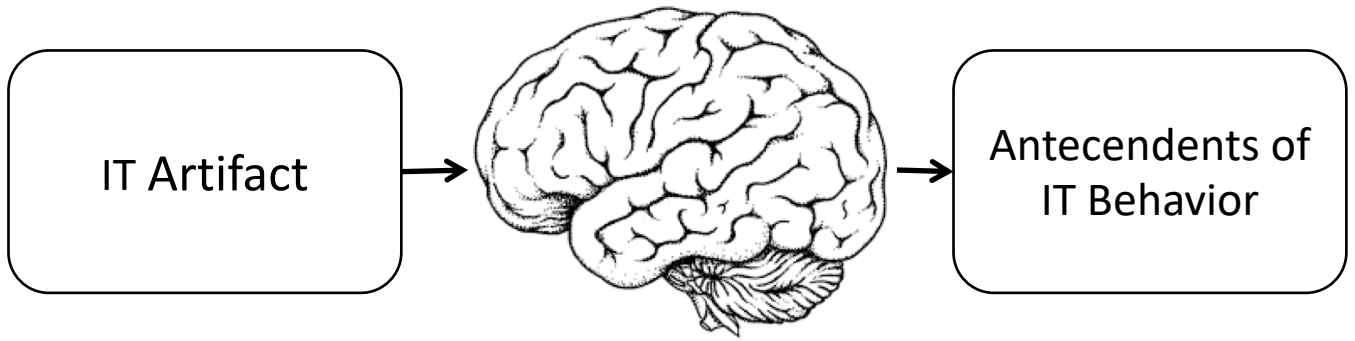
The Role of the Brain in IS Research

Design science Methods and neuroscience literature

Neuroscience and Psychophysiological methods and tools

Self-reported questionnaires

Brain activity as mediator



- Feelings
- Beliefs
- Attitudes
- Behavioral Intentions

(Riedl & Léger 2016)

The Role of the Brain in IS Research

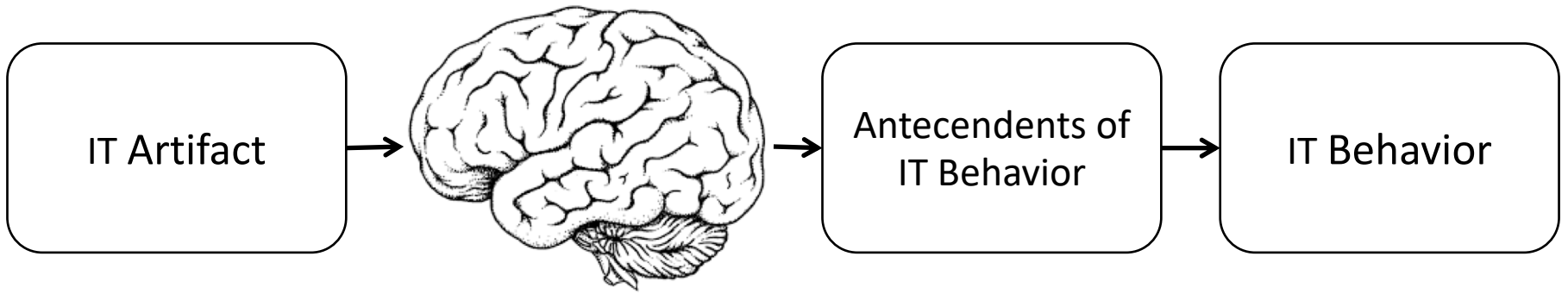
Design science Methods and neuroscience literature

Neuroscience and Psychophysiological methods and tools

Self-reported questionnaires

Computerized tools and observations

Brain activity as mediator



- Feelings
- Beliefs
- Attitudes
- Behavioral Intentions

- Interaction time
- Clickstreams
- Navigation
- Decisions

(Riedl & Léger 2016)

The Role of the Brain in IS Research

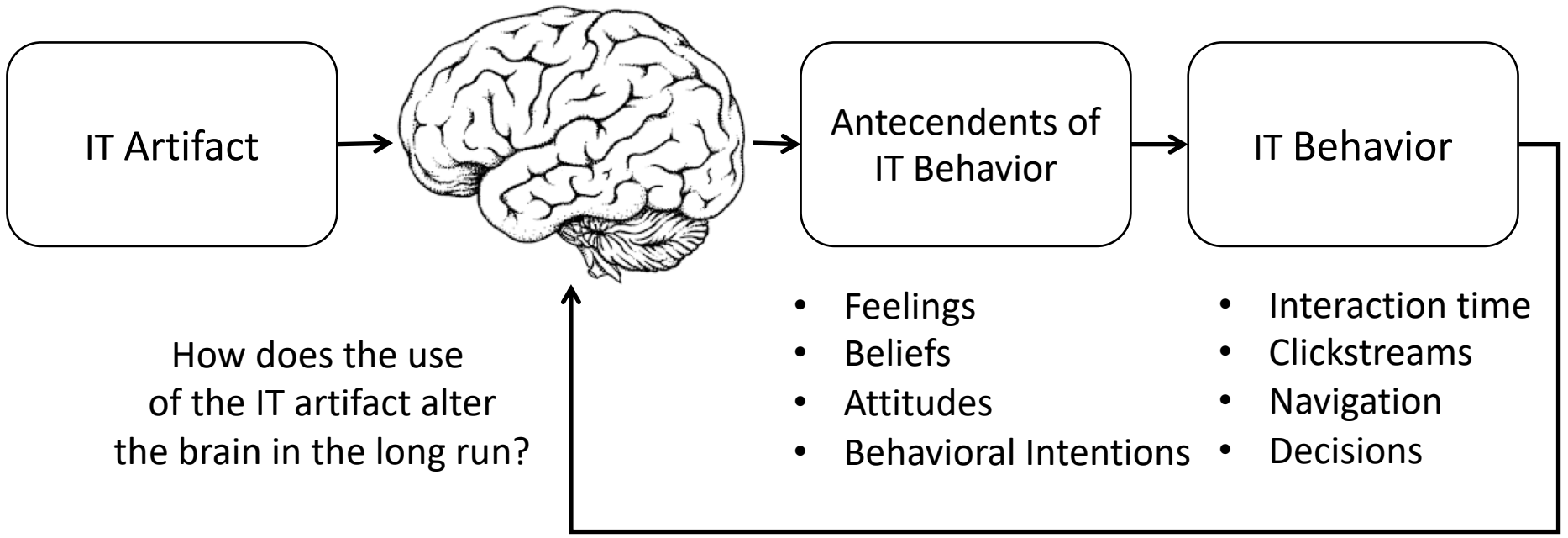
Design science Methods and neuroscience literature

Neuroscience and Psychophysiological methods and tools

Self-reported questionnaires

Computerized tools and observations

Brain activity as mediator



(Riedl & Léger 2016)

Potential from a User Behavior Tracking 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)

What is neuro-physiological measurement?

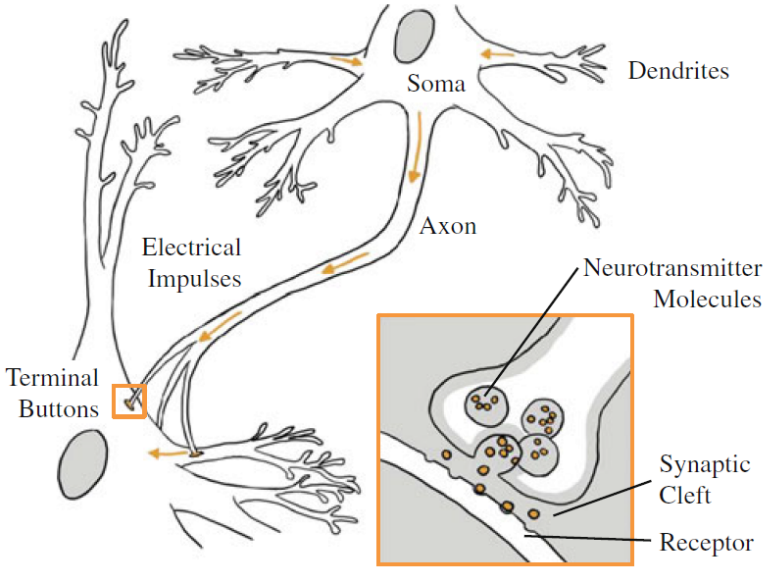
Physiological Measures

- Eye tracking
- Mouse movement
- Face expression
- Psychophysiological measures
  - Respiration, Pulse rate Temperature, Brain wave, Skin conductance

Neurophysiology

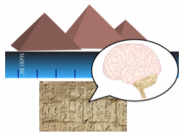
Neurophysiology (a sub-branch of neuroscience) is the *study of nervous system function* …

How the generation and propagation of electrical impuls processes driving human thought and emotion?



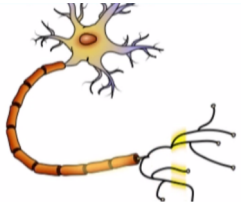
(Riedl & Léger 2016)

A long history



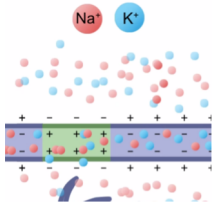
Earliest mention

1600 BC



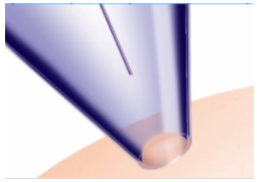
nerve impulse

1840



charged particles in axon

1939



patch-clamp

1976

1771

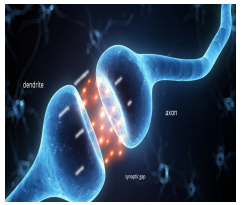
"animal electricity"

1924

EEG

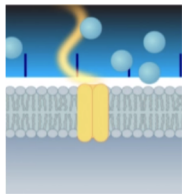
1951

Inter-neuron information transmition

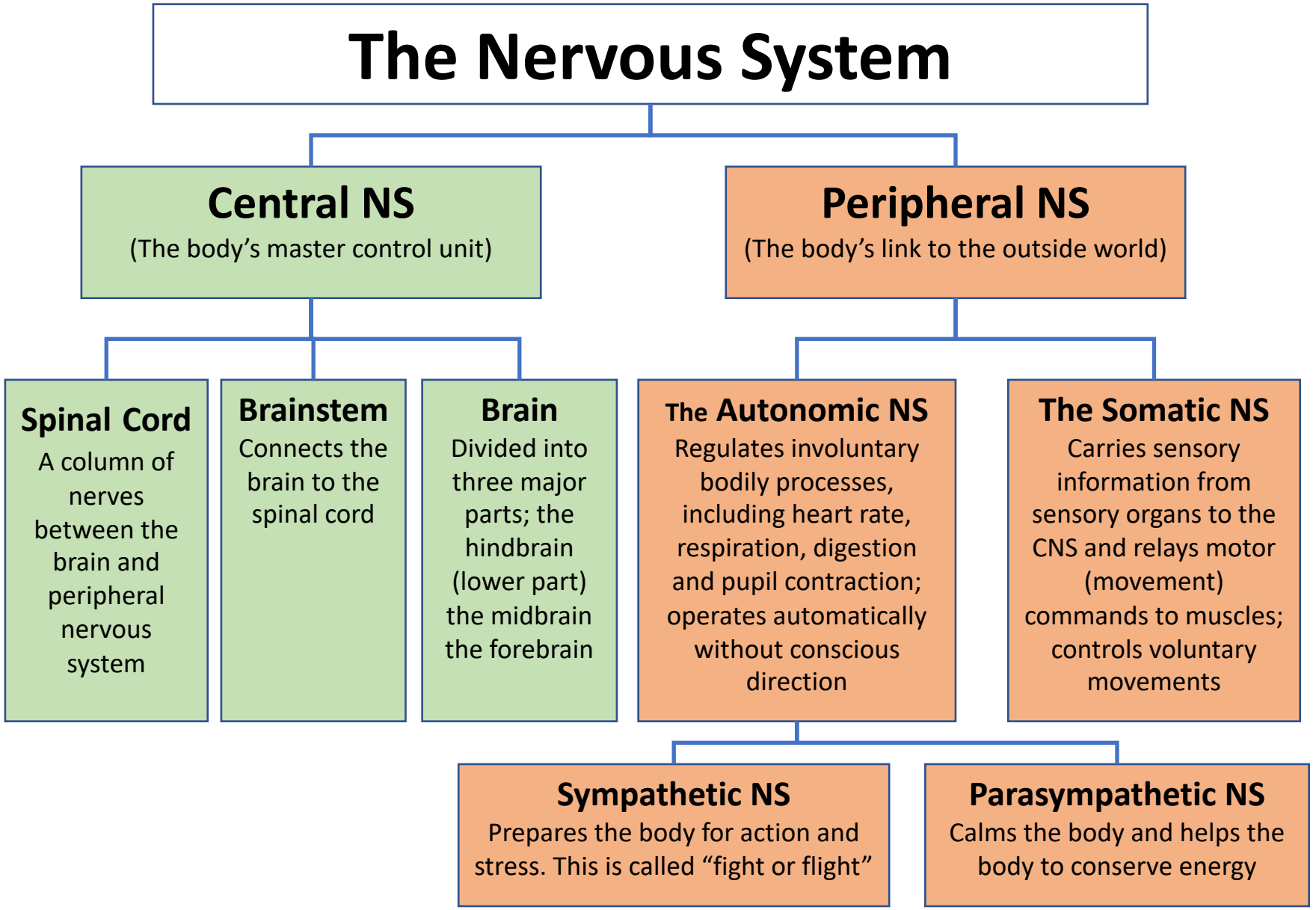


2005

optogenetics

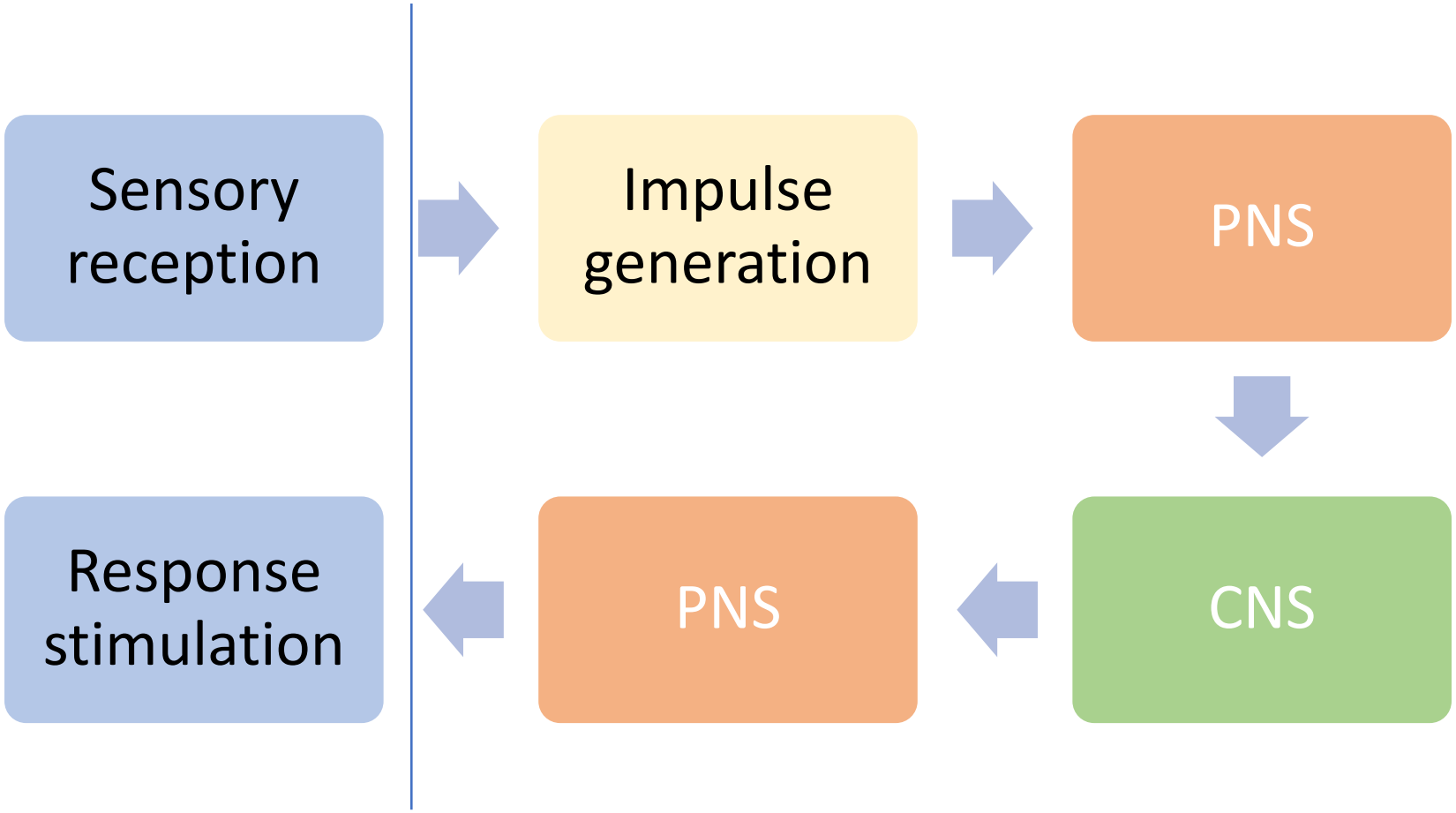


(jove-science)



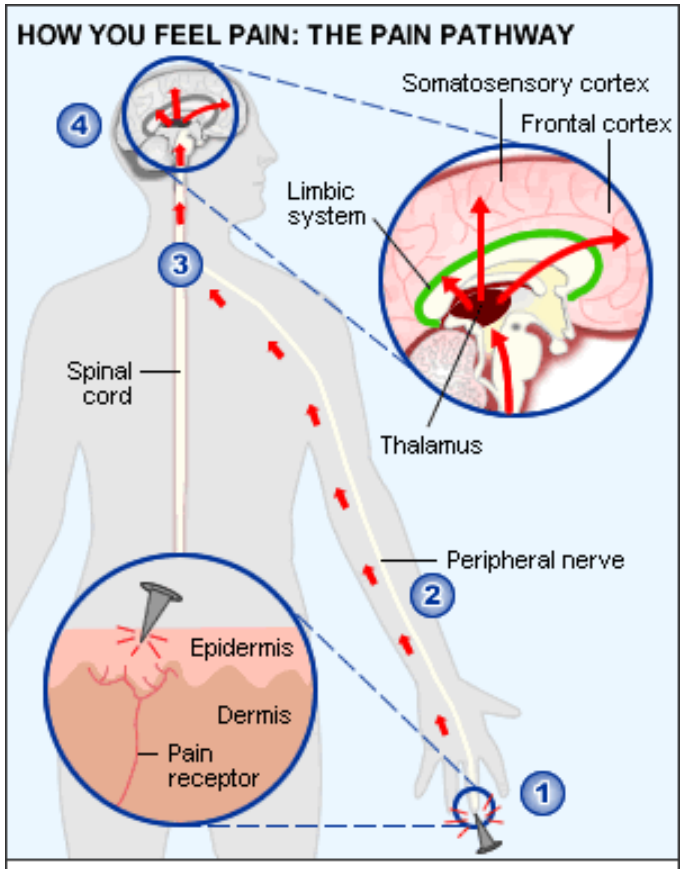
(sciencejl.blogspot.com)

Signals in the Nervous System*



*Over simplified!!

Example: Pain Signals

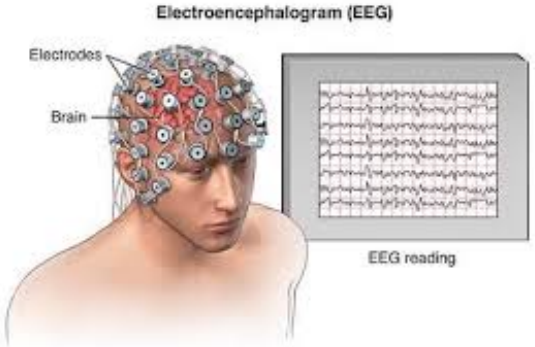


1. You prick your finger on something sharp.
2. The tissue damage triggers the microscopic *pain receptors*
3. The pain receptor sends an electrical signal up the *peripheral nerve*
4. The electrical signal reaches the spinal cord and then transmitted from one *neurone* to another across junctions (*synapses*) by means of chemical messengers (*neurotransmitters*) to the brain
5. In the brain, the signals pass to the *thalamus*, onto the *somatosensory cortex* (responsible for physical sensation), the *frontal cortex* (in charge of thinking), and the limbic system (linked to emotions).
6. You feel a sensation of pain in your finger, and think 'Ouch!

(www.mydr.com.au/pain/pain-and-how-you-sense-it)

Tools for Measuring CNS Signals

fMRI (Functional Magnetic Resonance Imaging)



EEG (Electroencephalography)

fNIRS (Functional Near-Infrared Spectroscopy)

and … PET, TMS, TDCS

(kingnail.info, healyourselfeveryday.com, theperfectinvestor.com)

Tools for Measuring PNS Signals

- Electrocardiogram (Heart)
- Galvanometer (Skin)
- Oculometry (Eye)
- Electromyography (Face)

Electrocardiogram (Heart Rate)

(Riedl & Léger 2016)

Galvanometer (Skin Response)

(Riedl & Léger 2016)

Electromyography (Facial Muscular Movement)

(Riedl & Léger 2016)

Oculometry (Eye Tracking)

(prattsi.org)

Eye-tracking data

- Raw data in the form of x,y coordinates at a timestamp (usually every 50ms)
- Processed into:
  - Time to First Fixation
  - Fixations Before
  - First Fixation Duration
  - Fixation Duration
  - Total Fixation Duration
  - Fixation Count
  - Visit Duration
  - Visit Count

Eye tracking – pro and con

- Fine-grained data/resolution
- Direct measure of user attention

- Not scalable
- Slow and expensive
- Not natural

- In some cases mouse movement can act as a (weak) proxy of gaze [1]
  - Javascript

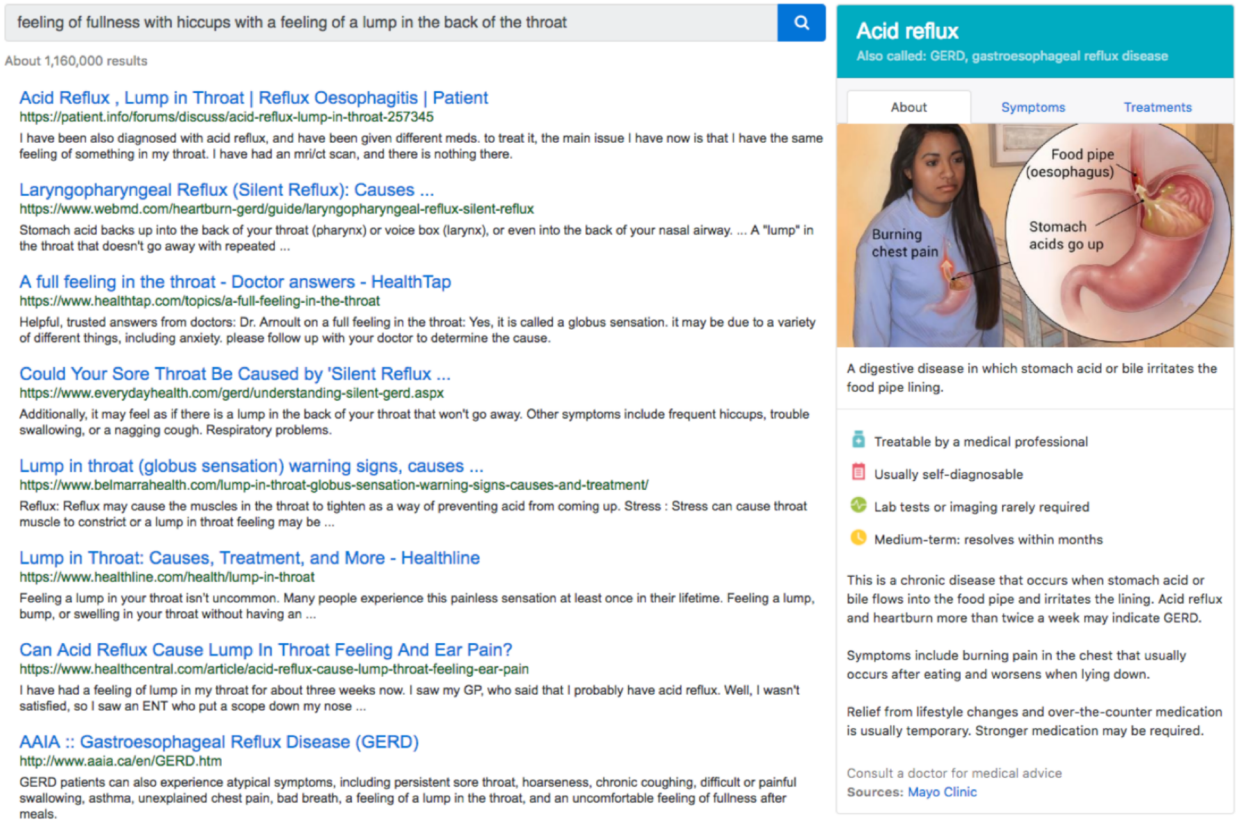
[1] Guo and Agichtein. Towards Predicting Web Searcher Gaze Position from Mouse Movements. CHI 2010

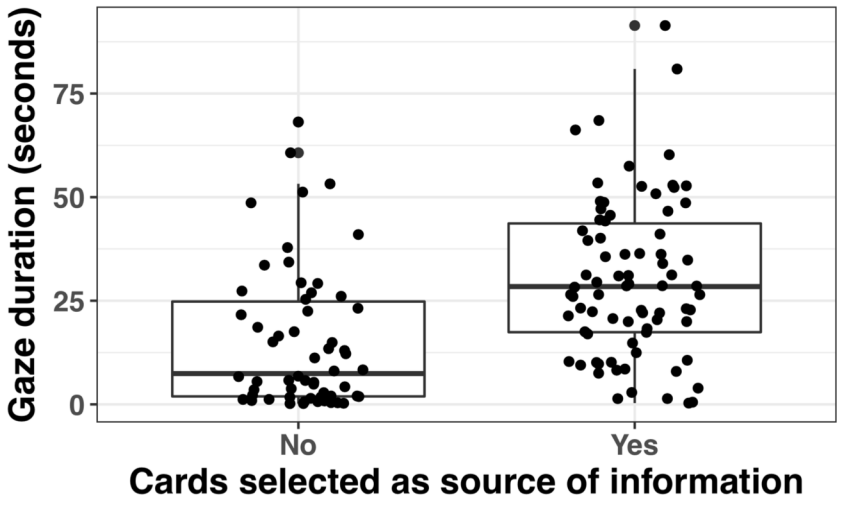
Eye-tracking example research

- Jimmy et al. Health Cards for Consumer Health Search, SIGIR 2019
- Tobii Pro Spectrum
  - Frequency of 300Hz
  - Monitor resolution of 1920 x 1080
  - Calibrated for each participant
  - Velocity-threshold identification algorithm for fixation points
  - Fixation duration threshold to 100 ms
  - Mapped the fixation points to three Area-of-Interests (AOI)
- Used to measure how much time they spend looking at an Heath card on a SERP
- Combined with questionnaire and Click and query logs

Eye-tracking example research

- Users who find the card information relevant spend more time looking at it





Advantages of neuro-physiological measurement

- More objective data (not dependent on language, memory)
- Can be performed continuously during message/task processing
- Can provide information on emotional and attentional responses often not available to conscious awareness

Word of caution

Providing evidence of causalities, or even an association, between

signals (e.g. pupillary dilation) and

phenomena of study (e.g. mental task)

is confounded by a large number of *factors* (e.g. light) and

further complicated by variability in *experiment* settings,

thus making studies involving these measurements very challenging!

Expensive equipment, does not scale

Summary

- Brain research including neuroscience (anatomy + physiology) is an enduring area of study

- Computer science and database researchers interested in studies that involve measurement of human processes, must learn and/or rely on reference disciplines, including

Biology, Medicine, Signal Processing, Psychology, Cognitive Science, Neuroergonomics, Computer Science, Affective Computing, Human Factors, Brain Computer Interaction, …

Cognitive Load as an exemplar measurement

What do you see?

One stimulus

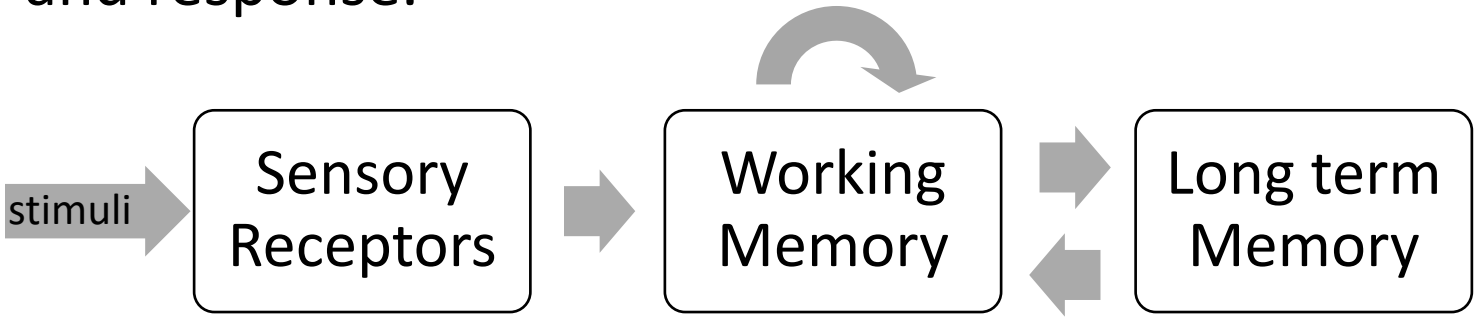
→

Multiple perspectives!

Image credit: sharenator.com/Optical_illusions

How do humans (brain) respond to, and learn from external stimuli remains an open question inspite of significant advancements in neuroscience, psychology, learning theories and biomedicine.

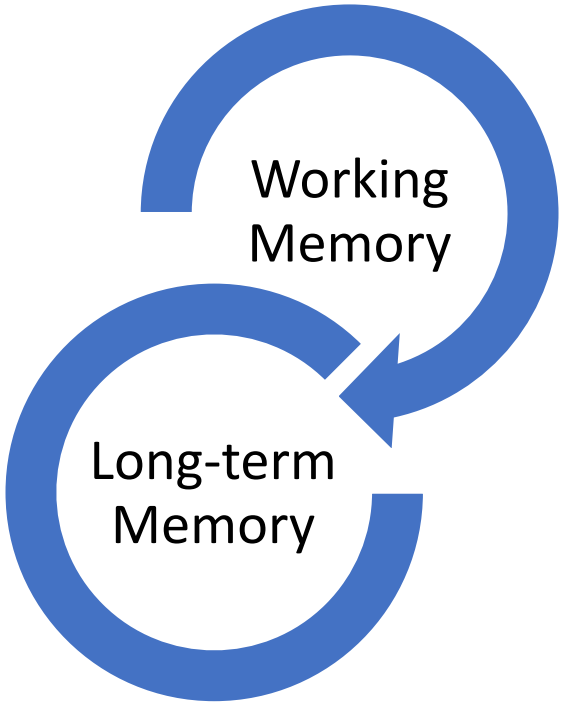
Cognitive load is one construct that has provided some explanation of the transmissions between stimuli, brain and response.



Other relevant constructs include: Emotion, Trust, Stress, Fear, Frustration, ….
(see studies in www.neurois.org/publications)

Cognitive Load

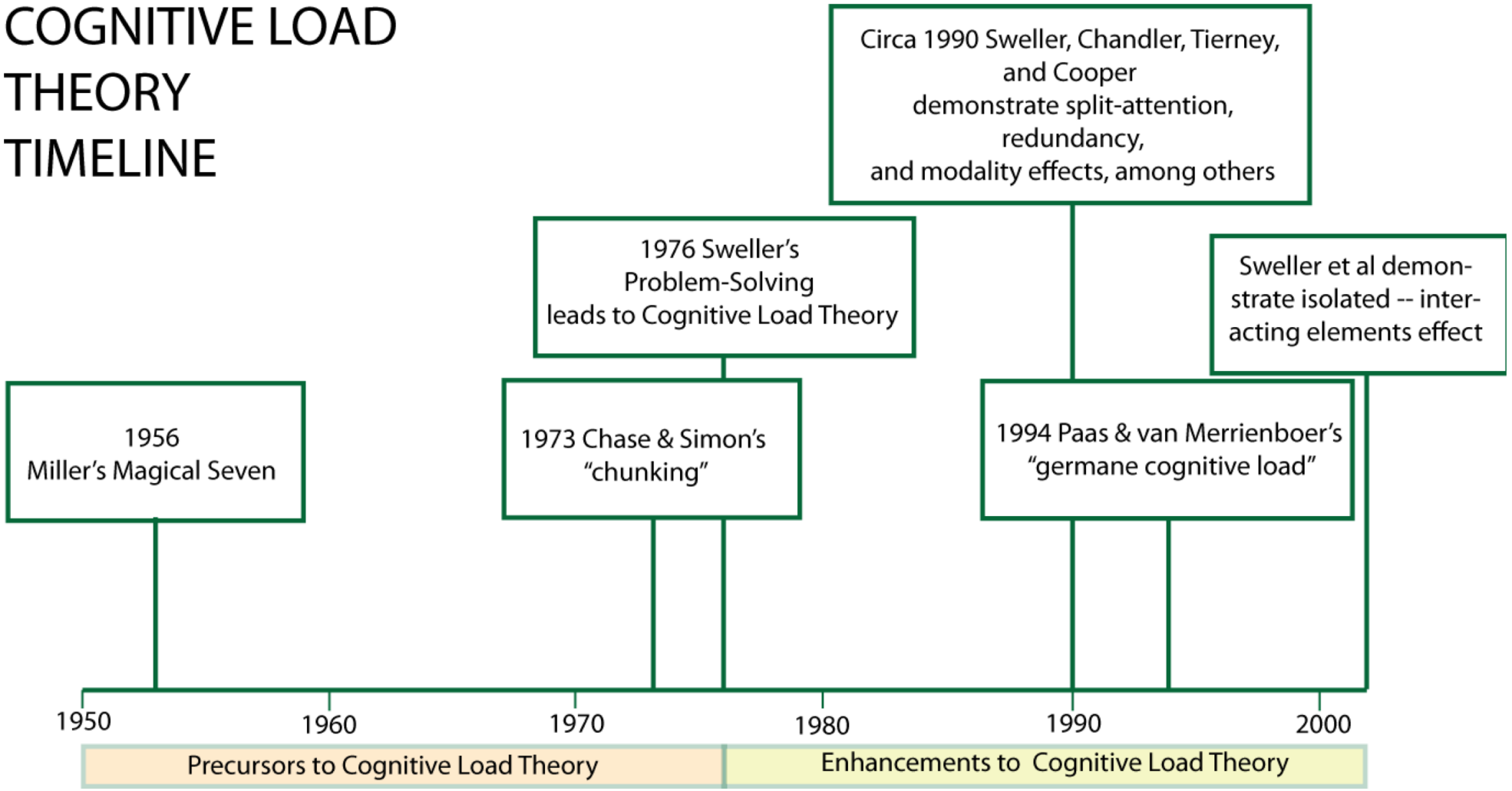
Effort of Working Memory



Cognitive load helps to understand and inform instruction(al design) on how to efficiently and effectively move knowledge* from working memory to long-term memory

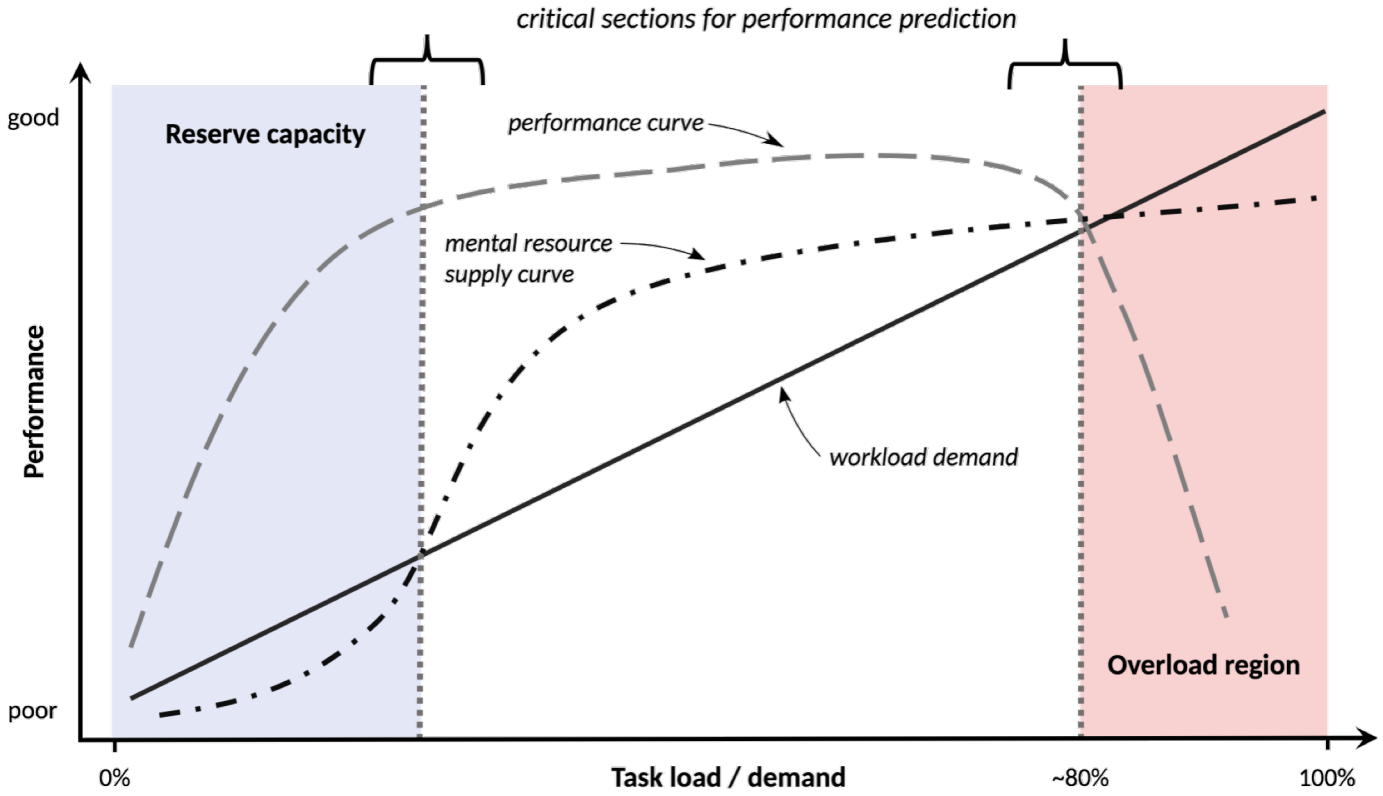
* Primary concerned with *Secondary* Knowledge as opposed to *Primary* Knowledge

Cognitive Load Theory



(kathyillian.com)

*“ a […] construct that represents the load imposed on working memory during performance of a cognitive task”**



(Chen et al. 2016)

(Sweller, Van Merrienboer, & Paas, 1998)

- Cognitive load is one of the constructs in empirical research involving human participants that helps to explain *why* one design is better than another
- Due to its strong link to task performance (and related comprehension and learning measures), Cognitive Load is widely used in IS/BPM studies

- Cognitive load is highly dynamic (even within a task), and hence subjective ratings of task difficulty or mental effort post-task completion are not always an accurate measure
- Operationalizing and measuring Cognitive Load requires multi-disciplinary knowledge and consequently is highly challenging!

Unpacking Cognitive Load

- Underlying Principles
- Types of Cognitive Load
- Measures of Cognitive Load
- Effects of Cognitive Load
- Factors affecting Cognitive Load

→ How to Measure Cognitive Load …

Based on (Sweller, Kalyuga and Ayres, 2011)

Principles of Acquiring Information

What (forms of Instruction Design) provides efficient and effective procedures for acquiring information that gets stored in *long-term* memory?

- Borrowing and Reorganizing Principle
- Randomness as Genesis Principle

Types of Cognitive Load

- Extraneous Load
- Intrinsic Load
- Germane Load

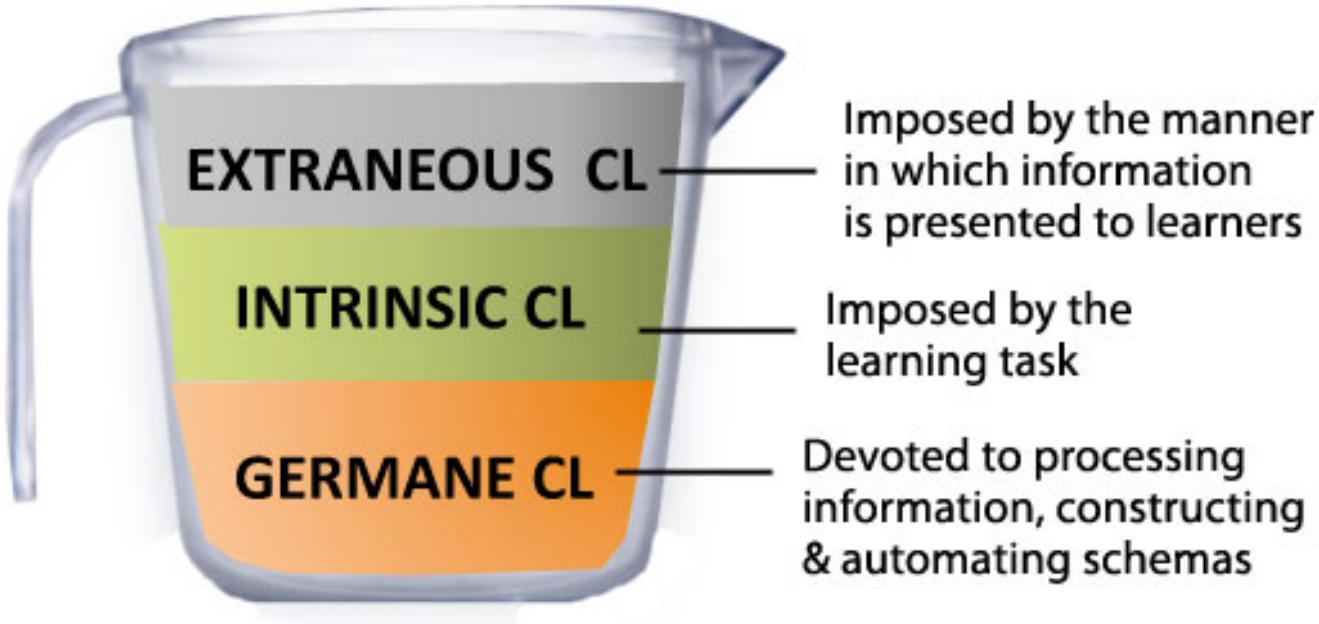
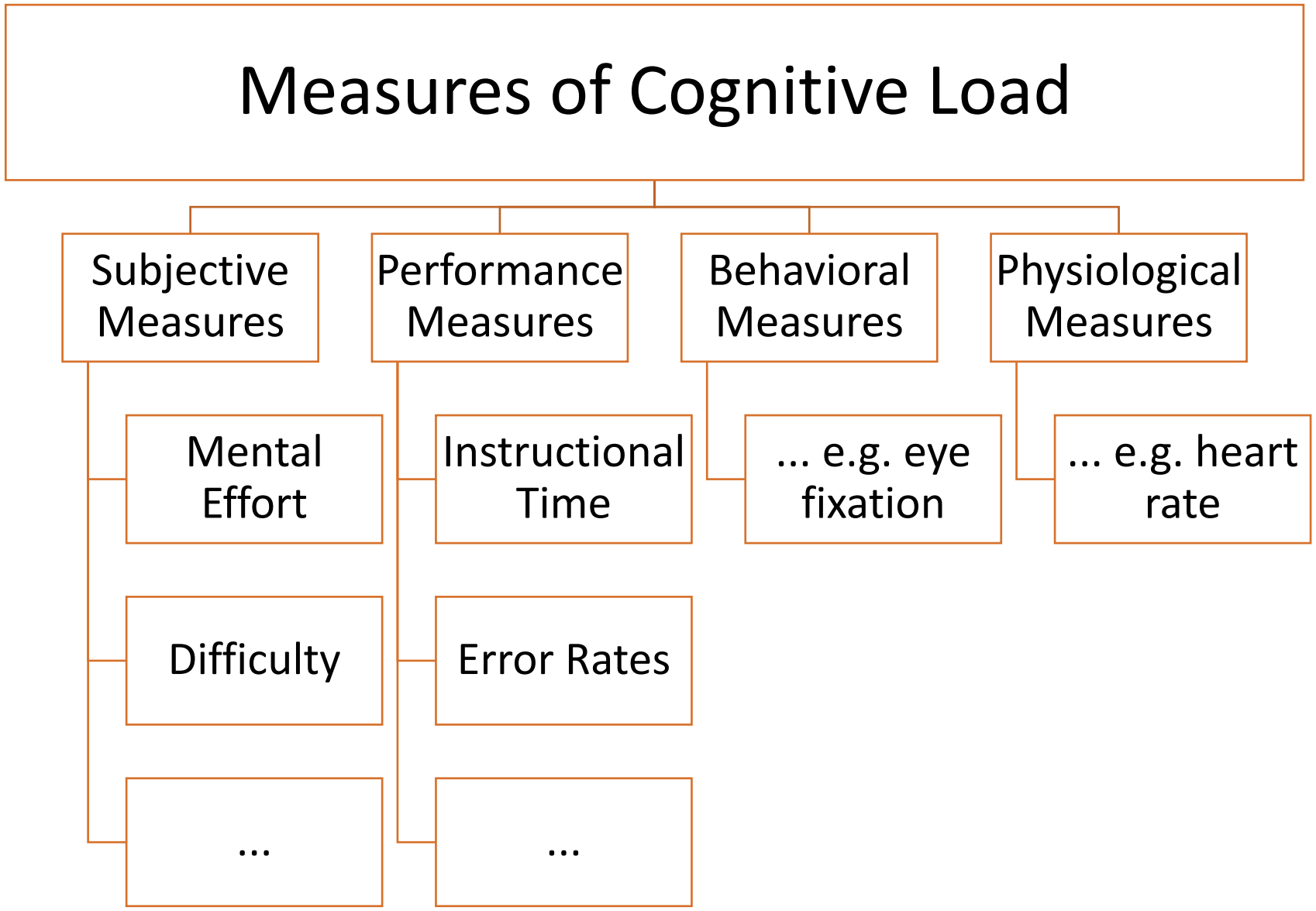


Image credit: neilatkin.com

Measures of Cognitive Load



Effects of Cognitive Load

- Goal-Free Effect
- **Worked Example** and Problem Completion Effect
- **Split-Attention Effect**
- Modality Effect
- Redundancy Effect
- Expertise Reversal Effect
- Guidance Fading Effect
- Imagination and Self-explanation Effect
- Element Interactivity Effect

Worked Example Effect

Providing a step-by-step solution to the problem reduces (extraneous) cognitive load; provide problem-solving schemas that can be stored in long term memory, and then retrieved for solving related problems

Example

Make a the subject of the equation $(a + b) /c = d$.

Solution

$(a + b)/c = d$

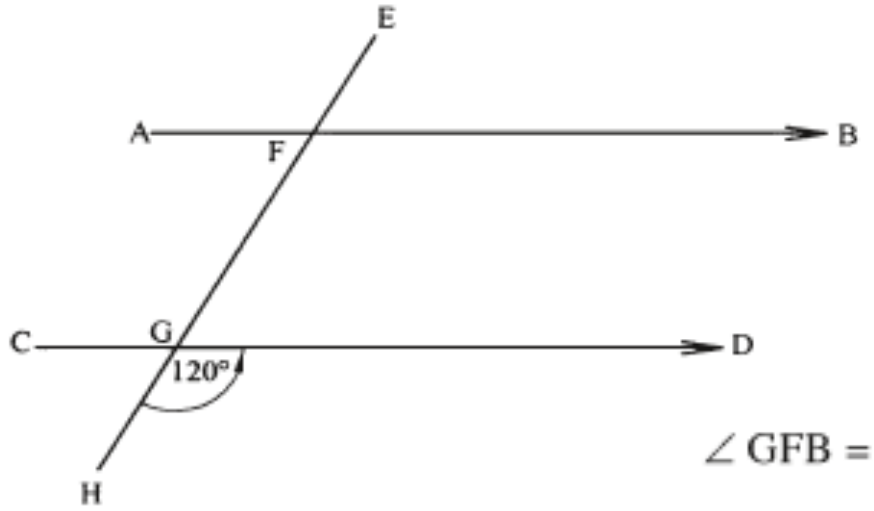
$a + b = dc$

$a = dc - b$

Split-Attention Effect

Not all worked examples (WE) are equally effective, that is the structure of a problem may diffuse the benefit of WE. Split attention occurs when learner attentions is split spatially or temporally, and working memory resources are diverted away from schema formation while dealing with extraneous load resulting from multiple interacting elements

Find ∠ EFB



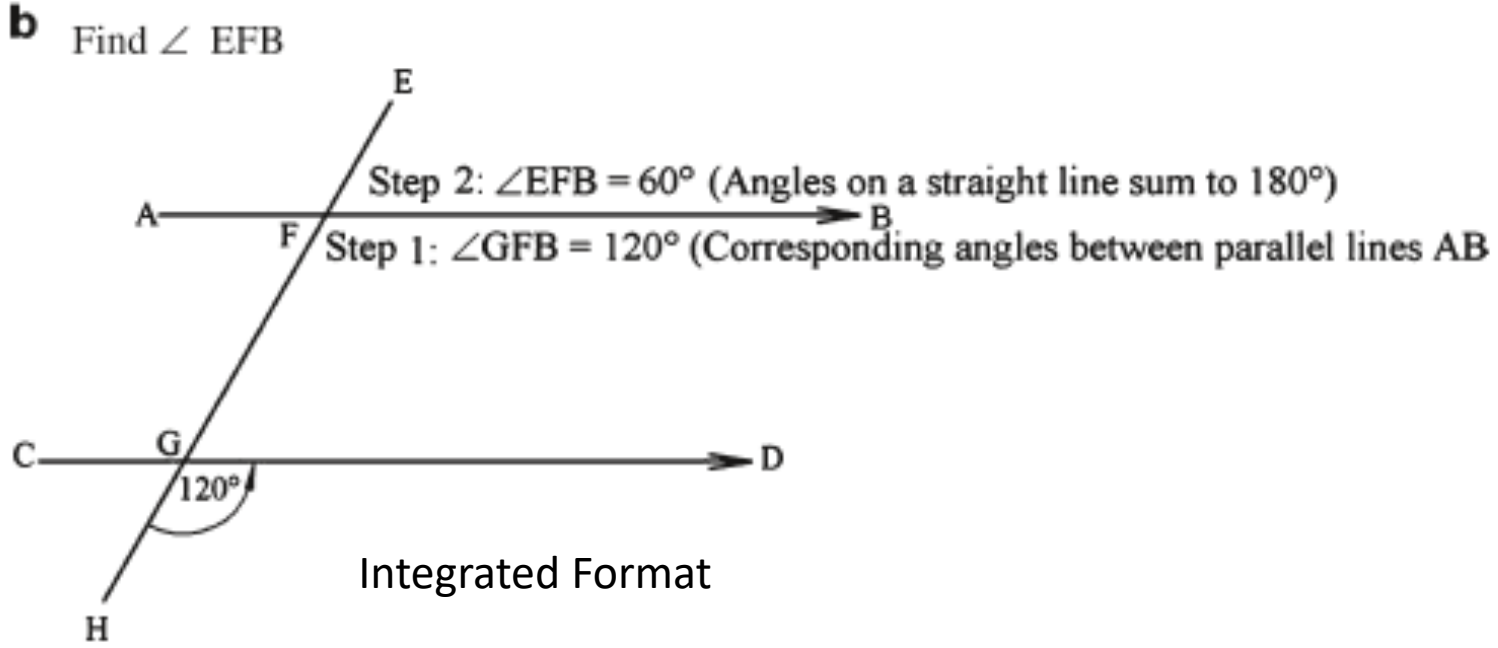
∠ GFB = 120° (corresponding angles between parallel lines AB & CD)

Split Attention Format

∠ EFB = 60° (angles on a straight line sum to 180°)

Split-Attention Effect

Not all worked examples (WE) are equally effective, that is the structure of a problem may diffuse the benefit of WE. Split attention occurs when learner attentions is split spatially or temporally, and working memory resources are diverted away from schema formation while dealing with extraneous load resulting from multiple interacting elements



Integrated Format

Summary

- Cognitive Load is a fundamental construct that has been widely studied and acknowledged for its importance in the study of human learning behavior

- Measurement of CL is challenging due to ..
  - Different types of CL (Intrinsic, Extraneous, Germane)
  - Variety of measures (subjective, performance, …)
  - Many effects on CL (worked example, split attention,…)
  - Factors that in turn effect CL (Emotion, Stress, Trust)

Outline

- Introduction: Motivation and Examples
  - User Behaviours (Why and How)
- Part I - Tracking In-Browser Behavioural Features (40min)
  - Data to be collected
  - Example research using behavioural logs
  - Datasets and tools
- Part II - Running In-Lab User Behaviour Studies (40min)
  - User Engagement Scale
  - Neuro-physiological measurements
  - Example research using Eye-tracking
  - Cognitive Load
- **Conclusions**
  - Combined use of both

Setting up for success

- Equipment → Costly, Room settings, Logistics
- Data → Non-trivial pre-processing effort
- Measures → Connect with theory
- Team → Developers, Cross-disciplinary, Statistics
- Experiment design → Watch out for confounding factors
- Participants → Commitment, Incentives, Exclusions

Putting it all together

- Combine lab-based studies with web-based data collection

- First run a controlled small-scale lab study to observe common behaviors and motivations
- Then run a large-scale behavior data collection effort to confirm hypotheses

- First collect behavioral and analyze data to form hypotheses
- Then run focused small-scale lab studies to validate and **understand** the reasons

Q&A

Thanks and Feedback

References

- 1.Andaloussi, A.A., Slaats, T., Burattin, A., Weber, B.: Evaluating The Understandability of Hybrid Process Model Representations Using Eye Tracking: First Insights. 6 (2018).
- 2.Andaloussi, A.A., Slaats, T., Burattin, A., Hildebrandt, T.T., Weber, B.: Understandability of Hybrid Process Models Using DCR Graphs. In: 30th International Conference on Advanced Information Systems Engineering (2018).
- 3.Brocke, J.V., Riedl, R., Léger, P.-M.: Application strategies for neuroscience in information systems design science research. Journal of Computer Information Systems. 53, 1–13 (2013).
- 4.Burattin, A., Kaiser, M., Neurauter, M., Weber, B.: Eye tracking meets the process of process modeling: a visual analytic approach. In: International Conference on Business Process Management. pp. 461–473. Springer (2016).
- 5.Chen, F., Ruiz, N., Choi, E., Epps, J., Khawaja, M.A., Taib, R., Yin, B., Wang, Y.: Multimodal Behavior and Interaction As Indicators of Cognitive Load. ACM Trans. Interact. Intell. Syst. 2, 22:1–22:36 (2013).
- 6.Chen, F., Zhou, J., Wang, Y., Yu, K., Arshad, S.Z., Khawaji, A., Conway, D.: Robust Multimodal Cognitive Load Measurement. Springer International Publishing (2016).
- 7.Chen, T., Wang, W., Indulska, M., Sadiq, S.: Business Process and Rule Integration Approaches - An Empirical Analysis. In: Weske, M., Montali, M., Weber, I., and vom Brocke, J. (eds.) Business Process Management Forum. pp. 37–52. Springer International Publishing (2018).
- 8.Claes, J., Vanderfeesten, I., Gailly, F., Grefen, P., Poels, G.: The Structured Process Modeling Method (SPMM) What is the best way for me to construct a process model? Decision Support Systems. 100, 57–76 (2017).
- 9.Gruhn, V., Laue, R.: Reducing the cognitive complexity of business process models. In: Cognitive Informatics, 2009. ICCI'09. 8th IEEE International Conference on. pp. 339–345. IEEE (2009).
- 10.Hart, S.G., Staveland, L.E.: Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In: Hancock, P.A. and Meshkati, N. (eds.) Advances in Psychology. pp. 139–183. North-Holland (1988).

References

- 11.Kalyuga, S., Chandler, P., Sweller, J.: Managing split-attention and redundancy in multimedia instruction. Applied cognitive psychology. 13, 351–371 (1999).
- 12.Kurzhals, K., Fisher, B., Burch, M., Weiskopf, D.: Evaluating visual analytics with eye tracking. Presented at the November 10 (2014).
- 13.Leppink, J., Paas, F., Van der Vleuten, C.P.M., Van Gog, T., Van Merriënboer, J.J.G.: Development of an instrument for measuring different types of cognitive load. Behav Res. 45, 1058–1072 (2013).
- 14.Maier, A.M., Baltsen, N., Christoffersen, H., Störrle, H.: Towards diagram understanding: A pilot study measuring cognitive workload through eye-tracking. In: Proc. Intl. Conf. Human Behavior in Design (2014).
- 15.Neurauter, M., Pinggera, J., Martini, M., Burattin, A., Furtner, M., Sachse, P., Weber, B.: The Influence of Cognitive Abilities and Cognitive Load on Business Process Models and Their Creation. In: Information Systems and Neuroscience. pp. 107–115. Springer, Cham (2015).
- 16.Paas, F., Tuovinen, J.E., Tabbers, H., Gerven, P.W.M.V.: Cognitive Load Measurement as a Means to Advance Cognitive Load Theory. Educational Psychologist. 38, 63–71 (2003).
- 17.Petrusel, R., Mendling, J.: Eye-Tracking the Factors of Process Model Comprehension Tasks. In: Advanced Information Systems Engineering. pp. 224–239. Springer, Berlin, Heidelberg (2013).
- 18.Petrusel, R., Mendling, J., Reijers, H.A.: Task-specific visual cues for improving process model understanding. Information and Software Technology. 79, 63–78 (2016).
- 19.Petrusel, R., Mendling, J., Reijers, H.A.: How visual cognition influences process model comprehension. Decision Support Systems. 96, 1–16 (2017).
- 20.Pinggera, J., Furtner, M., Martini, M., Sachse, P., Reiter, K., Zugal, S., Weber, B.: Investigating the Process of Process Modeling with Eye Movement Analysis. In: Business Process Management Workshops. pp. 438–450. Springer, Berlin, Heidelberg (2012).

References

- 21.Recker, J., Reijers, H.A., van de Wouw, S.G.: Process model comprehension: the effects of cognitive abilities, learning style, and strategy. Communications of the association for information systems. 34, 199–222 (2014).
- 22.Riedl, R., Léger, P.-M.: Fundamentals of NeuroIS. Springer Berlin Heidelberg, Berlin, Heidelberg (2016).
- 23.ruth-clark, frank-nguyen: Efficiency in e-Learning: Proven Instructional Methods for Faster, Better, Online Learning, https://www.learningsolutionsmag.com/articles/245/efficiency-in-e-learning-proven-instructional-methods-for-faster-better-online-learning.
- 24.Sharafi, Z., Soh, Z., Guéhéneuc, Y.-G.: A systematic literature review on the usage of eye-tracking in software engineering. Information and Software Technology. 67, 79–107 (2015).
- 25.Sweller, J., Van Merrienboer, J.J., Paas, F.G.: Cognitive architecture and instructional design. Educational psychology review. 10, 251–296 (1998).
- 26.Wang, W., Indulska, M., Sadiq, S., Weber, B.: Effect of Linked Rules on Business Process Model Understanding. In: Business Process Management. pp. 200–215. Springer, Cham (2017).
- 27.Weber, B., Pinggera, J., Neurauter, M., Zugal, S., Martini, M., Furtner, M., Sachse, P., Schnitzer, D.: Fixation Patterns During Process Model Creation: Initial Steps Toward Neuro-Adaptive Process Modeling Environments. In: 2016 49th Hawaii International Conference on System Sciences (HICSS). pp. 600–609 (2016).
- 28.Weber, B., Gulden, J., Burattin, A.: Designing Visual Decision Making Support with the Help of Eye-tracking. Proceedings of the Radar tracks at the 18th International Working Conference on Business Process Modeling, Development and Support (BPMDS). (2017).
- 29.Weber, B., Neurauter, M., Burattin, A., Pinggera, J., Davis, C.: Measuring and Explaining Cognitive Load During Design Activities: A Fine-Grained Approach. In: Information Systems and Neuroscience. pp. 47–53. Springer, Cham (2018).
- 30.Weber, B., Neurauter, M., Pinggera, J., Zugal, S., Furtner, M., Martini, M., Sachse, P.: Measuring cognitive load during process model creation. In: Information Systems and Neuroscience. pp. 129–136. Springer (2015).
- 31.Zheng, R.Z.: Cognitive Load Measurement and Application: A Theoretical Framework for Meaningful Research and Practice. Routledge (2017).
- 32.Zimoch, M., Mohring, T., Pryss, R., Probst, T., Schlee, W., Reichert, M.: Using Insights from Cognitive Neuroscience to Investigate the Effects of Event-Driven Process Chains on Process Model Comprehension. In: Business Process Management Workshops. pp. 446–459. Springer, Cham (2017).
- 33.Zimoch, M., Pryss, R., Layher, G., Neumann, H., Probst, T., Schlee, W., Reichert, M.: Utilizing the Capabilities Offered by Eye-Tracking to Foster Novices' Comprehension of Business Process Models. In: Cognitive Computing – ICCC 2018. pp. 155–163. Springer, Cham (2018).
- 34.Cognitive Load – What it means in your classroom- Part 2, https://www.neilatkin.com/2018/01/18/cognitive-load-what-it-means-in-your-classroom-part-2/, (2018).