Introduction to Cognitive Science

Brief overview, syllabus

Vishnu Sreekumar

vishnu.sreekumar@iiit.ac.in

Outline

- Big questions in cognitive science
- What is cognitive science
- A brief history of cognitive science
- Course syllabus

Course Syllabus and Logistics

Random mini-quizzes

- Attendance is mandatory (will follow institute policy).
- Attention checks through mini-quizzes that will be conducted at a random point in class for extra credit of up to 5% (which can be the difference between an A and A-).

Chat GPT

- All term papers: mandatory section on the output of Chat GPT or equivalent. (~2500 words)
- Prompts + links to the output
- Your critique of the output and a comparison with what you yourself wrote.
- Next class: a demo of how exactly to do this.

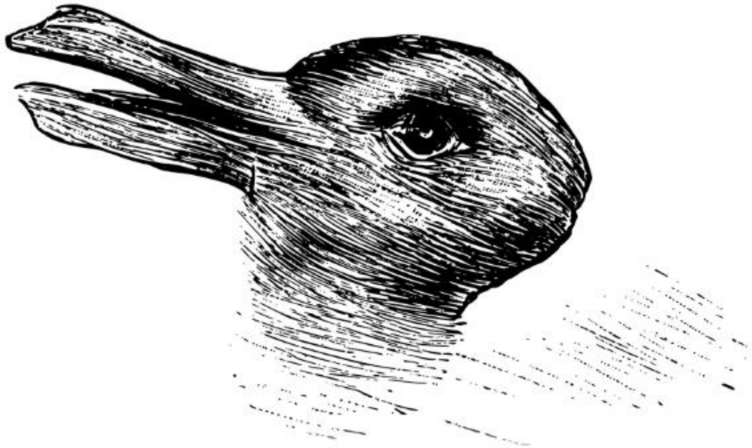
Optional

- Project and term paper based on your own project.
- Example from last year: Do LLMs have theory of mind? Giving LLMs false-belief tests.

Johannes Stoetter – fine art body painter

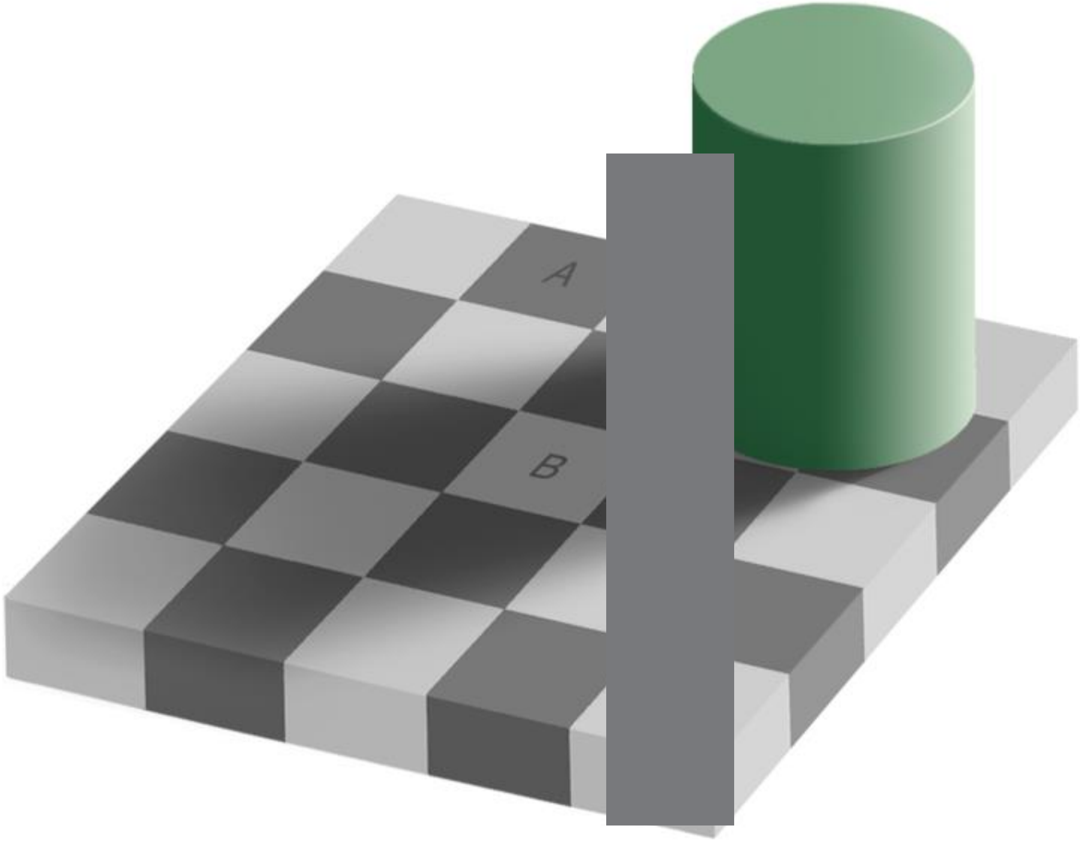
Everything is not as it seems

- *Top-down processing*
- Our experiences, memories, etc influence what we perceive
- Illustrated through many visual and auditory illusions



- Bistable perception?
- Helmholtz (1860s)

Color Constancy



Some big questions in cognitive science

- How are we able to rapidly process and interpret external information?
- How do all our sensations unify into a seamless unified experience of the world? – "The binding problem"
- How do we form and retrieve memories?
- How do we make decisions in a noisy uncertain world?

Cognitive Science: Interdisciplinary study of the mind with a focus on computation

As opposed to neuroscience which focuses on the neural apparatus that implements these computations

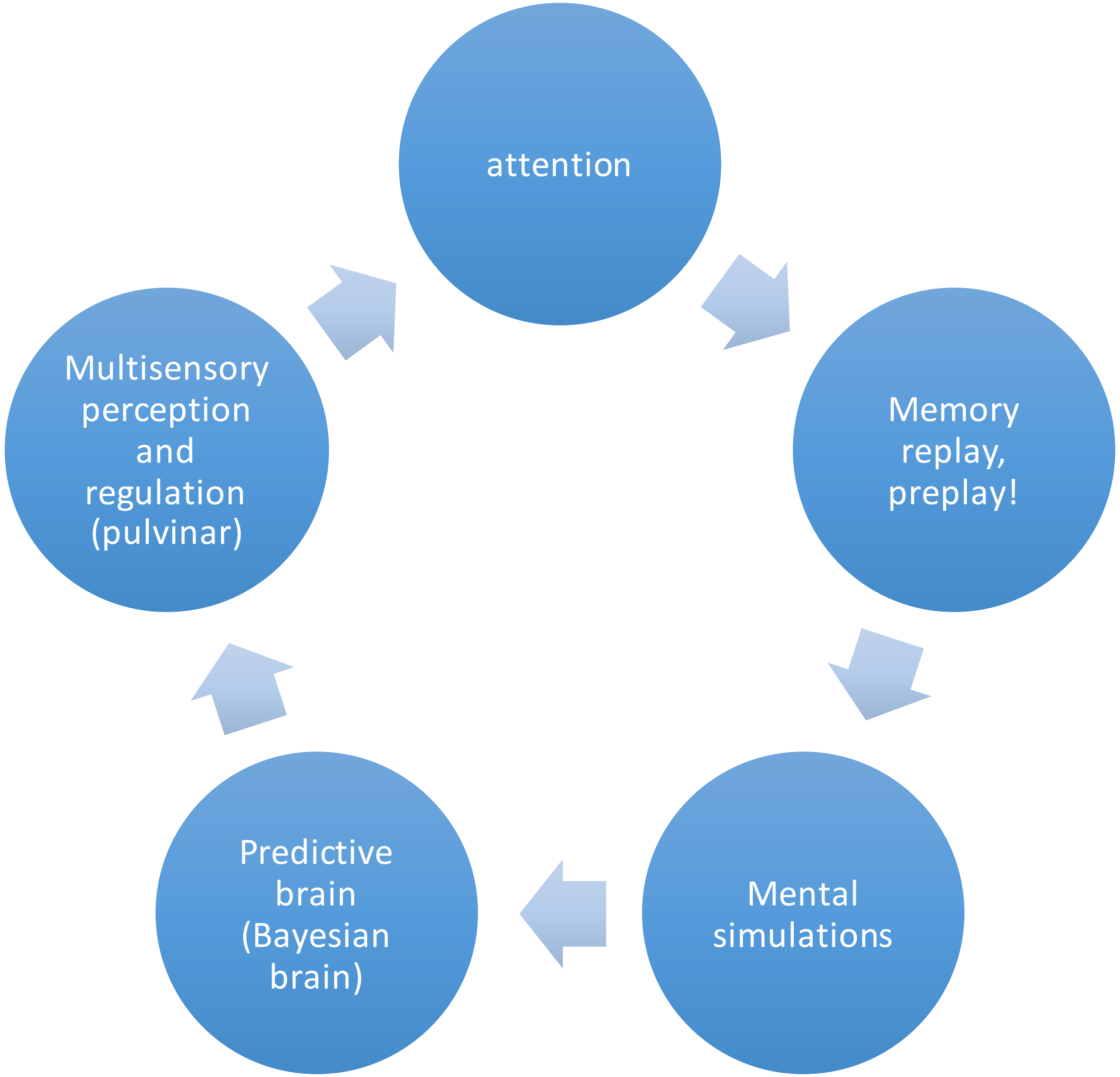
As opposed to psychology which focuses on the behavior, feelings, and thought processes of individuals and groups of people, and also addresses neuropsych issues, mood disorders, personality, social psych, etc

Despite the small differences in focus, there is significant overlap in topics and approaches amongst cognitive science, psychology, and neuroscience.

How are we able to rapidly process and interpret external information?

- Neurons: the brain's communicators.
- 100 billion neurons.
- Lined up side to side: Kashmir to Kanyakumari 4-5 times.
- Many neurons forge tens of thousands of connections with other neurons → a staggering 160 trillion connections in the brain!
- The world is complex, the brain even more so. A lot of pieces have to come together to explain how we are able to do this.

A lot of pieces have to come together to explain how we are able to rapidly process and interpret information!



The predictive brain

“The core task of all brains … is to regulate the organism’s internal milieu … by anticipating needs and preparing to satisfy them before they arise.”

-Sterling & Laughlin (2015), Principles of Neural Design (p. xvi)

Do these theories have any real-world value?

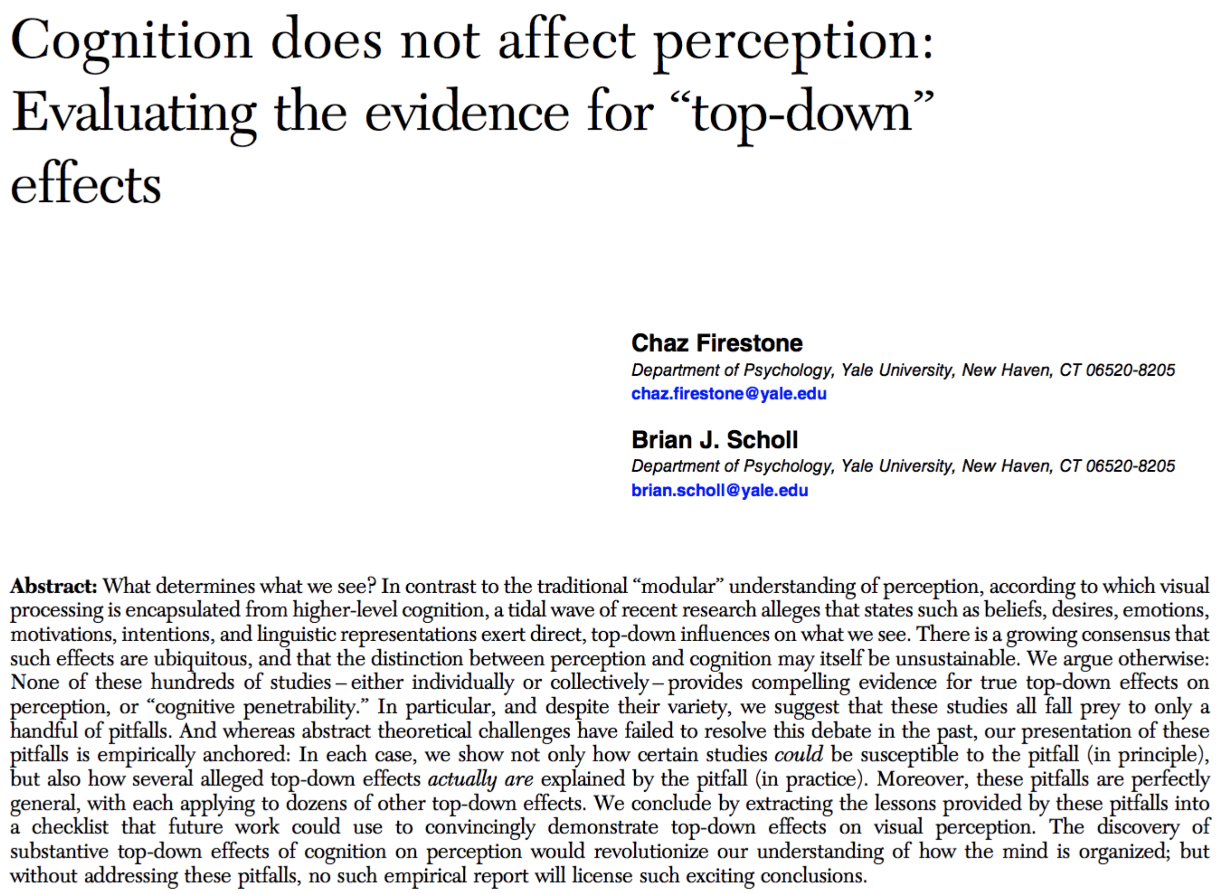
- Yes – both from a basic science perspective and in terms of application (e.g. treating mental/psychological disorders)

- https://youtu.be/c6OOtzbTXSU

Top-down effects?

- https://twitter.com/SteveStuWill/status/1553447928811110400

However,...


Cognition does not affect perception: Evaluating the evidence for "top-down" effects

Chaz Firestone
Department of Psychology, Yale University, New Haven, CT 06520-8205
chaz.firestone@yale.edu

Brian J. Scholl
Department of Psychology, Yale University, New Haven, CT 06520-8205
brian.scholl@yale.edu

Abstract: What determines what we see? In contrast to the traditional "modular" understanding of perception, according to which visual processing is encapsulated from higher-level cognition, a tidal wave of recent research alleges that states such as beliefs, desires, emotions, motivations, intentions, and linguistic representations exert direct, top-down influences on what we see. There is a growing consensus that such effects are ubiquitous, and that the distinction between perception and cognition may itself be unsustainable. We argue otherwise: None of these hundreds of studies – either individually or collectively – provides compelling evidence for true top-down effects on perception, or "cognitive penetrability." In particular, and despite their variety, we suggest that these studies all fall prey to only a handful of pitfalls. And whereas abstract theoretical challenges have failed to resolve this debate in the past, our presentation of these pitfalls is empirically anchored: In each case, we show not only how certain studies *could* be susceptible to the pitfall (in principle), but also how several alleged top-down effects *actually are* explained by the pitfall (in practice). Moreover, these pitfalls are perfectly general, with each applying to dozens of other top-down effects. We conclude by extracting the lessons provided by these pitfalls into a checklist that future work could use to convincingly demonstrate top-down effects on visual perception. The discovery of substantive top-down effects of cognition on perception would revolutionize our understanding of how the mind is organized; but without addressing these pitfalls, no such empirical report will license such exciting conclusions.

An Unsolved Problem in Perception

- Perception of an **apple** consists of many different components: size, shape, color, smell, weight, associations, etc., etc., etc.

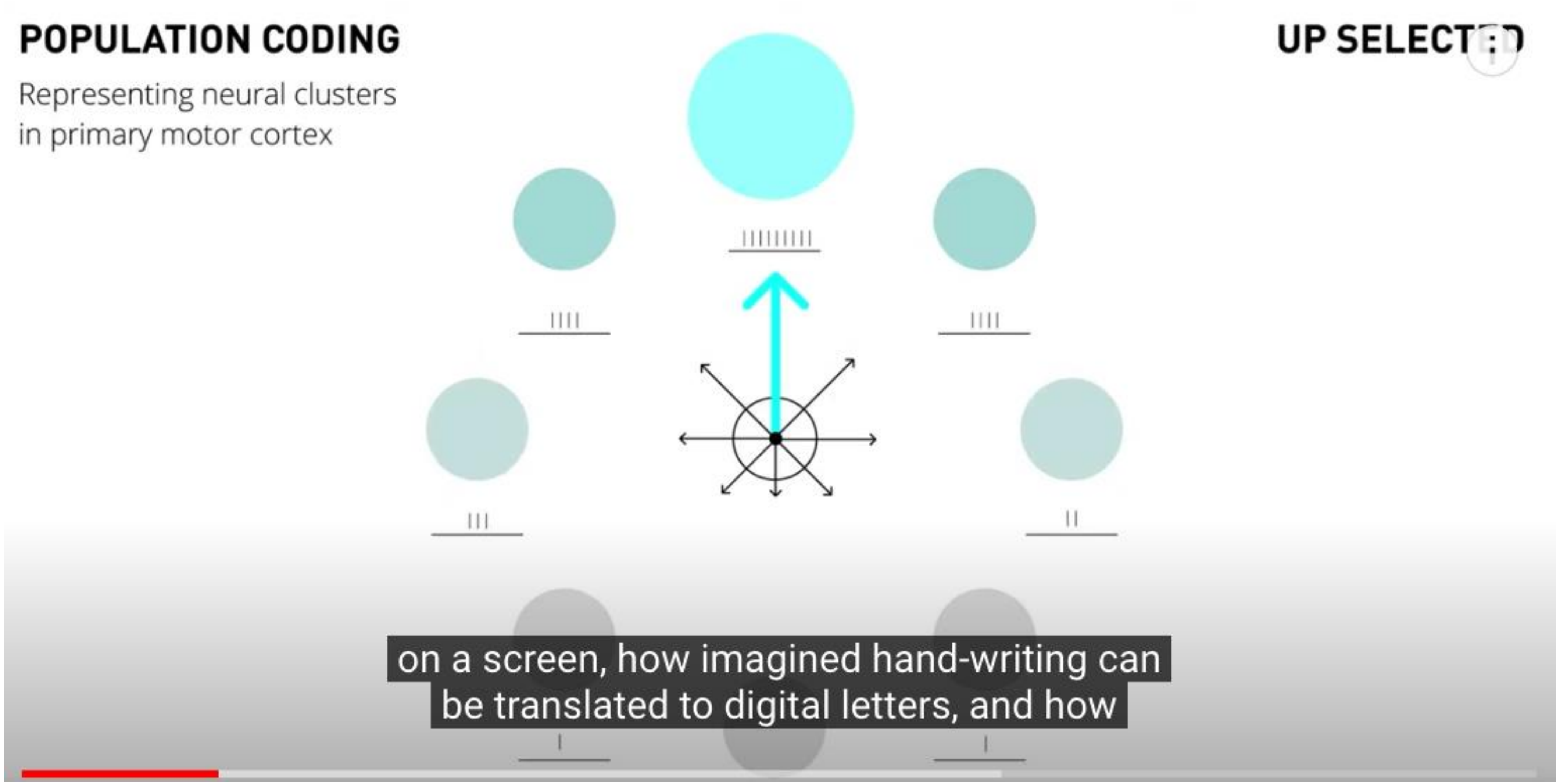
- How are these different components and senses **integrated** into a single perception?
  - This is called **the binding problem**

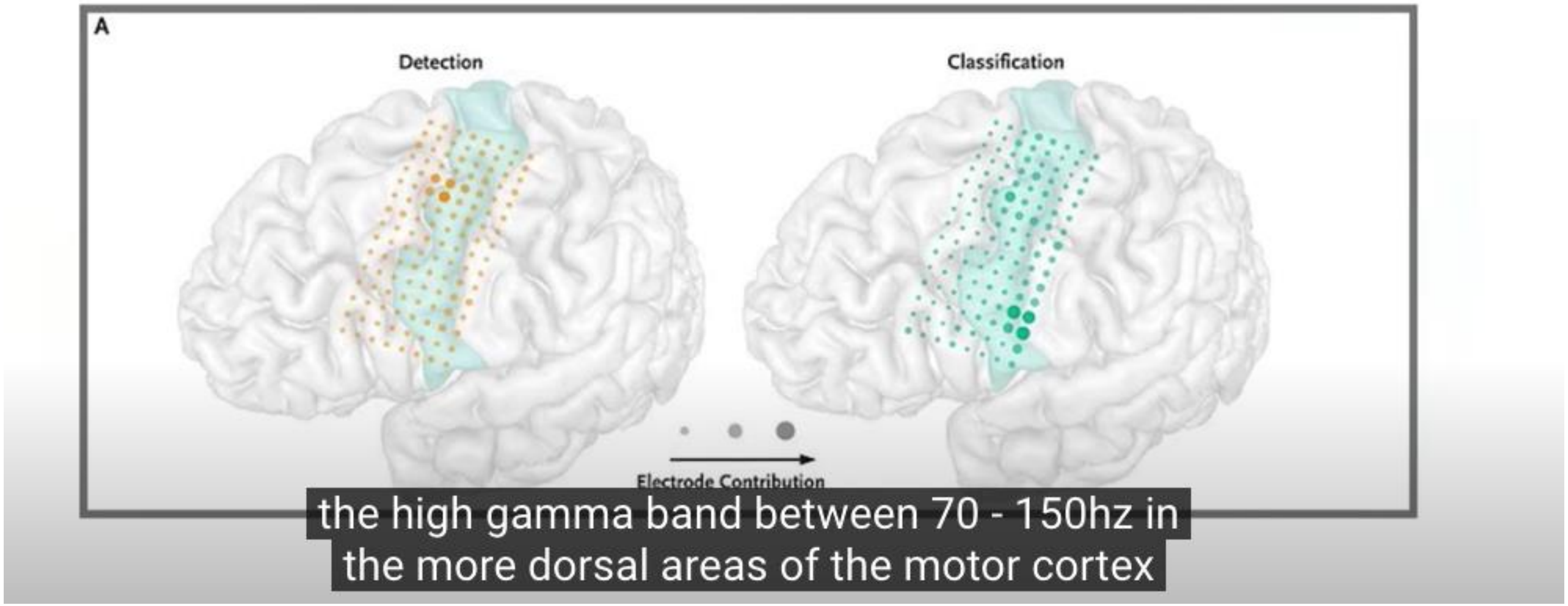
Other significant practical applications

- Brain-Computer Interfaces (BCIs)
- https://youtu.be/_GMcf1fXdW8 (a short 2 min video on the latest breakthrough in BCIs)
- https://youtu.be/CARRT4iUquM (a longer 7 min video with explanation)

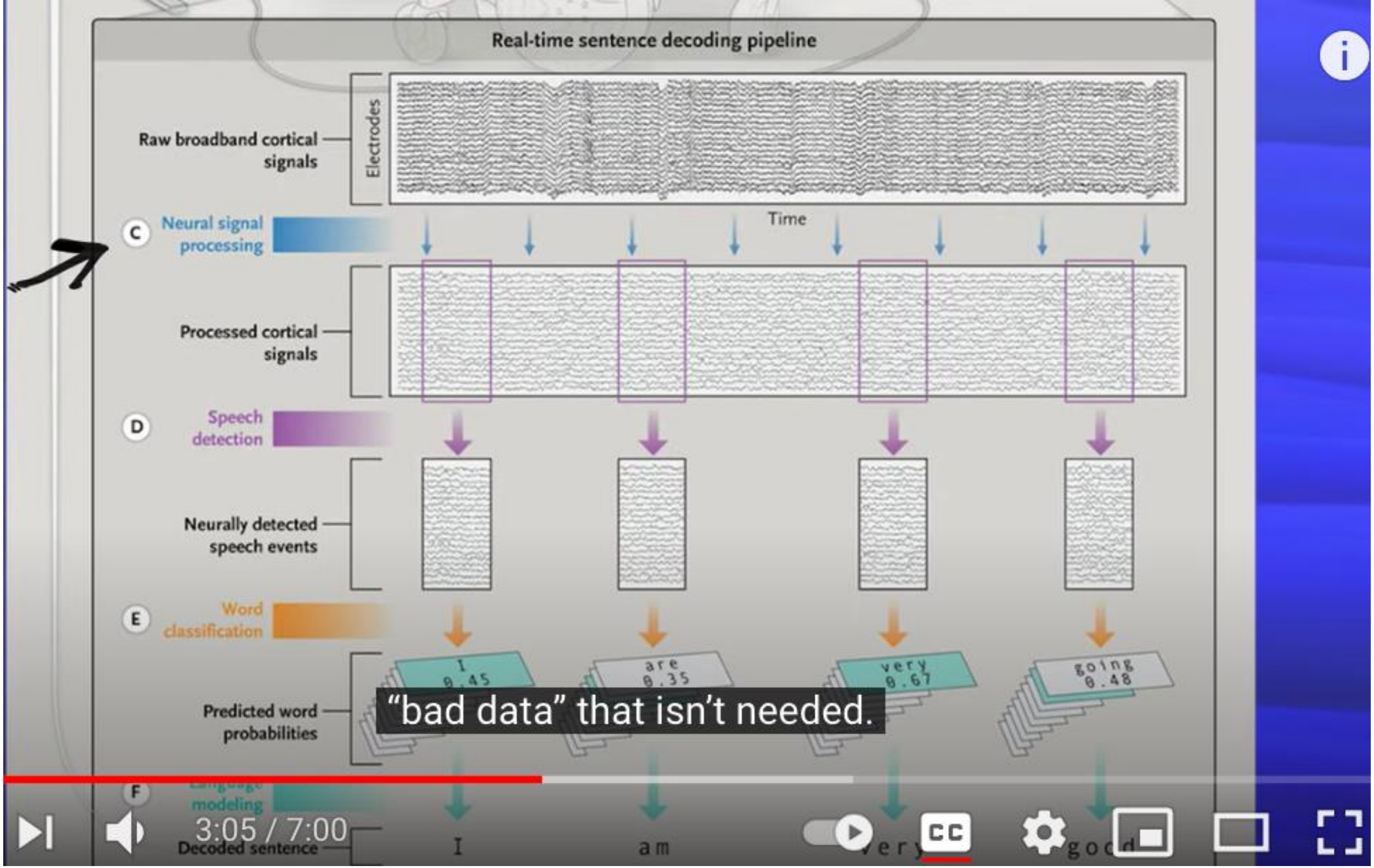
- How many different fields could you identify that contributed to this breakthrough?

Computational neuroscience

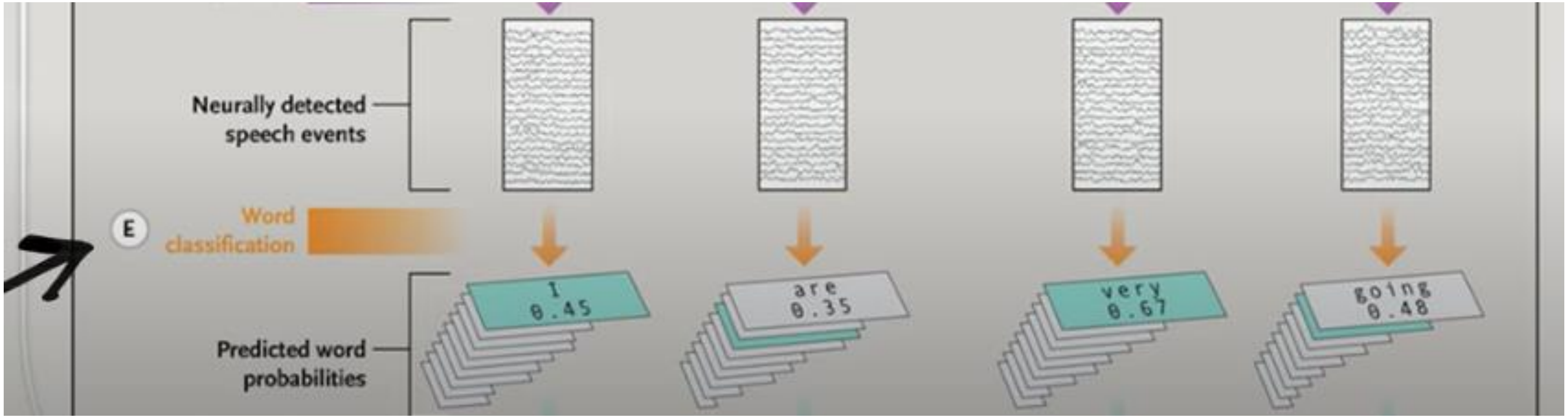




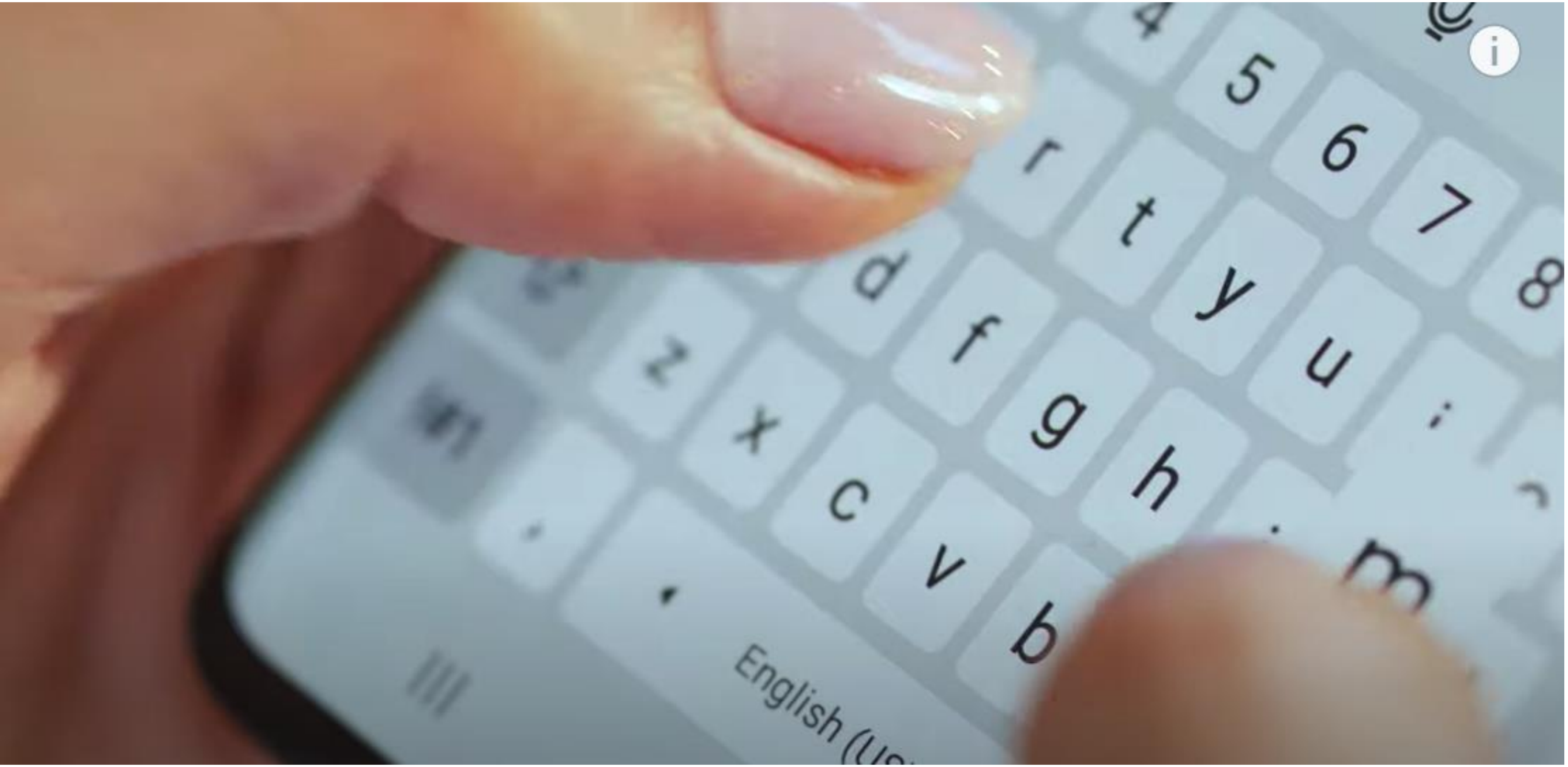
Signal Processing (ECE)!


Real-time sentence decoding pipeline
Electrodes
Raw broadband cortical signals
Time
C
Neural signal processing
Processed cortical signals
D
Speech detection
Neurally detected speech events
E
Word classification
I
0.45
are
0.35
very
0.67
going
0.48
Predicted word probabilities
"bad data" that isn't needed.
F
modeling
Decoded sentence
I
am
3:05 / 7:00
CC

Machine learning



Natural language processing models for predictive text
Computational linguistics



Curiosity-driven research

- Public speaking. Do pauses, uhms and ahs have any effect on how people remember information?

> J Exp Psychol Learn Mem Cogn. 2022 Jul 21. doi: 10.1037/xlm0001156. Online ahead of print.

The effect of disfluency on memory for what was said

Evgeniia Diachek [1], Sarah Brown-Schmidt [1]

Affiliations + expand

PMID: 35862078 DOI: 10.1037/xlm0001156

Abstract

Disfluencies such as pauses, "um"s, and "uh"s are common interruptions in the speech stream. Previous work probing memory for disfluent speech shows memory benefits for disfluent compared to fluent materials. Complementary evidence from studies of language production and comprehension have been argued to show that different disfluency types appear in distinct contexts and, as a result, serve as a meaningful cue. If the disfluency-memory boost is a result of sensitivity to these form-meaning mappings, forms of disfluency that cue new upcoming information (fillers and pauses) may produce a stronger memory boost compared to forms that reflect speaker difficulty (repetitions). If the disfluency-memory boost is simply due to the attentional-orienting properties of a disruption to fluent speech, different disfluency forms may produce similar memory benefit. Experiments 1 and 2 compared the relative mnemonic benefit of three types of disfluent interruptions. Experiments 3 and 4 examined the scope of the disfluency-memory boost to probe its cognitive underpinnings. Across the four experiments, we observed a disfluency-memory boost for three types of disfluency that were tested. This boost was local and position dependent, only manifesting when the disfluency immediately preceded a critical memory probe word at the end of the sentence. Our findings reveal a short-lived disfluency-memory boost that manifests at the end of the sentence but is evoked by multiple types of disfluent forms, consistent with the idea that disfluencies bring attentional focus to immediately upcoming material. The downstream consequence of this localized memory benefit is better understanding and encoding of the speaker's message. (PsycInfo Database Record (c) 2022 APA, all rights reserved).

INTERDISCIPLINARY approach

- Division of labour
  - Psychology – cognitive psychology, developmental psychology ...
  - Linguistics – syntax, semantics, phonology ...
  - Neuroscience – brain structures, localization ...
  - Computer science – AI, computer models ...
  - Philosophy – theoretical foundations ...

Why study cognitive science?

- Understand the diverse approaches to understanding how the human mind works
- Appreciate that different fields (AI, Philosophy, Neuroscience, Psychology, Physics, etc) that contribute to this endeavor
- Understand the potential applications of cognitive science in society
- It’s fun to think about thinking! → cognitive science

A brief history of cognitive science

- The roots date back far in history but the real genesis of the interdisciplinary cog sci field lies in the 1950s (Bechtel, Abrahamsen, Graham, 2001: reading uploaded on Moodle)
- Symposium of information theory (MIT) – Sept 11, 1956
- Alan Newell, Herbert Simon (computer scientists), Noam Chomsky (linguist), and George Miller (psychologist) presented work that each took a cognitive turn
- Miller (1979) wrote about how he left the symposium with a conviction about how experimental psychology, linguistics, and the computer simulation of cognitive processes were all part of a larger whole.

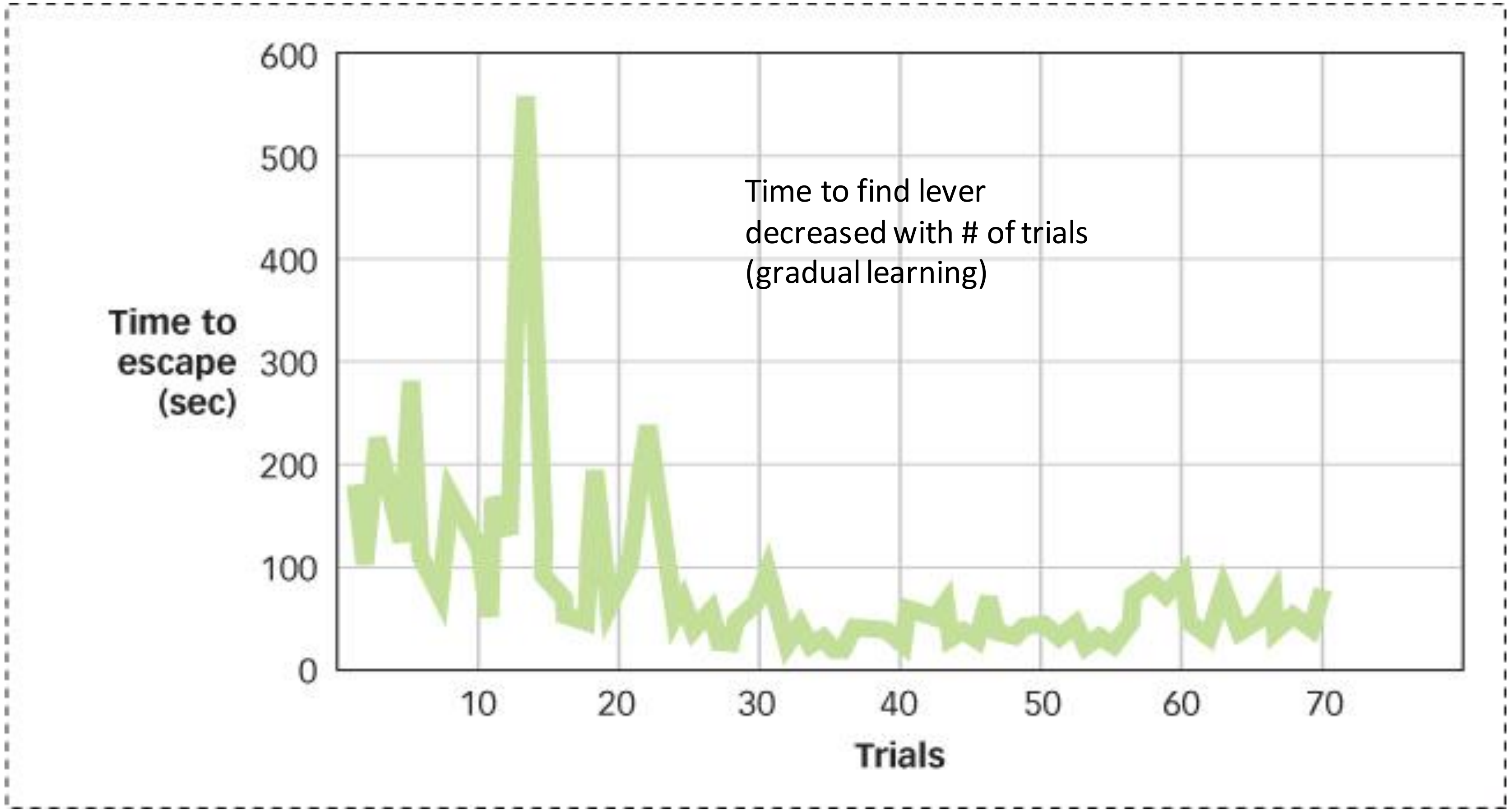
Developments in Psychology

- A huge influence of *behaviorism* early on in psychology: B.F. Skinner even opposed positing internal processes and focused on only what was observable: behavior changes with stimulus (and reinforcement/reward structure) changes.
- However, some people thought differently. Tolman for example even posited that rats navigate environments by forming cognitive maps.
- Behaviorism and S-R models → Cognitivism and S-O-R models → computational view of the mind → connectionism → dynamical systems approaches.
- Combined with advances in brain recording techniques (more in lecture #4)

Behaviorism

- Thorndike and the law of effect
- https://www.youtube.com/watch?v=fanm--WyQJo&ab_channel=GeertStienissen
- No “Aha” moment. Trial and error learning.
- Behavior changes because of its consequences – “The law of effect”

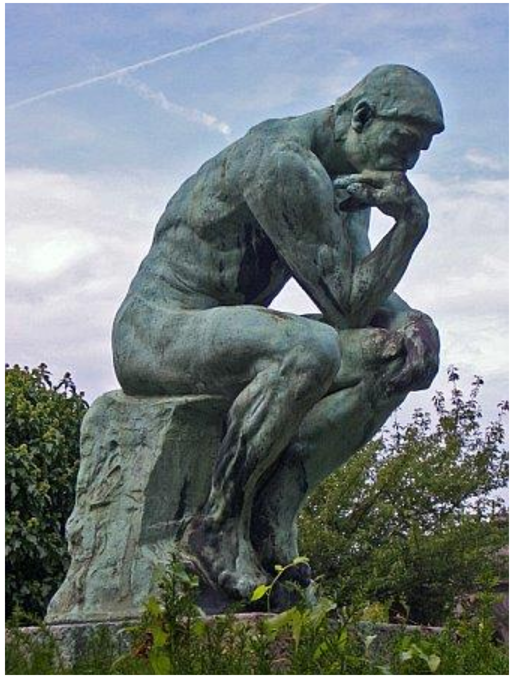
The Law of Effect



Time to find lever
decreased with # of trials
(gradual learning)

Cognitive Models of Learning

- Behaviorism: S-R models (Stimulus-Response)
- Skinner rejected cognitive models because thoughts are unobservable (*radical behaviorism*)
- Where does thinking come into play?



The Thinker *(French: Le Penseur) is a bronze* ***sculpture*** *by Auguste Rodin, usually placed on a stone pedestal. The work shows a nude male figure sitting on a rock with his chin resting on one hand as though deep in thought, and is often used as an image to represent philosophy.*

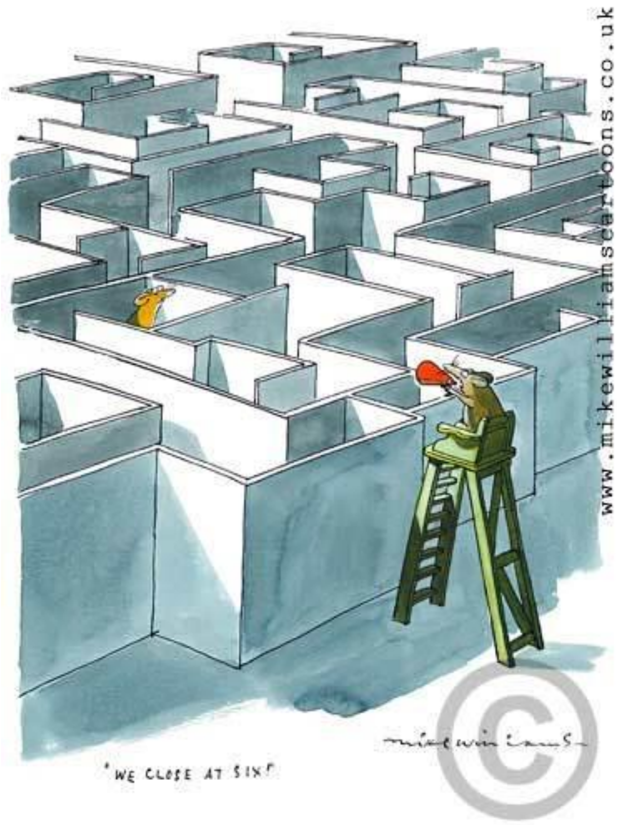
S-O-R Models

- S-O-R Models: Stimulus-**Organism**-Response

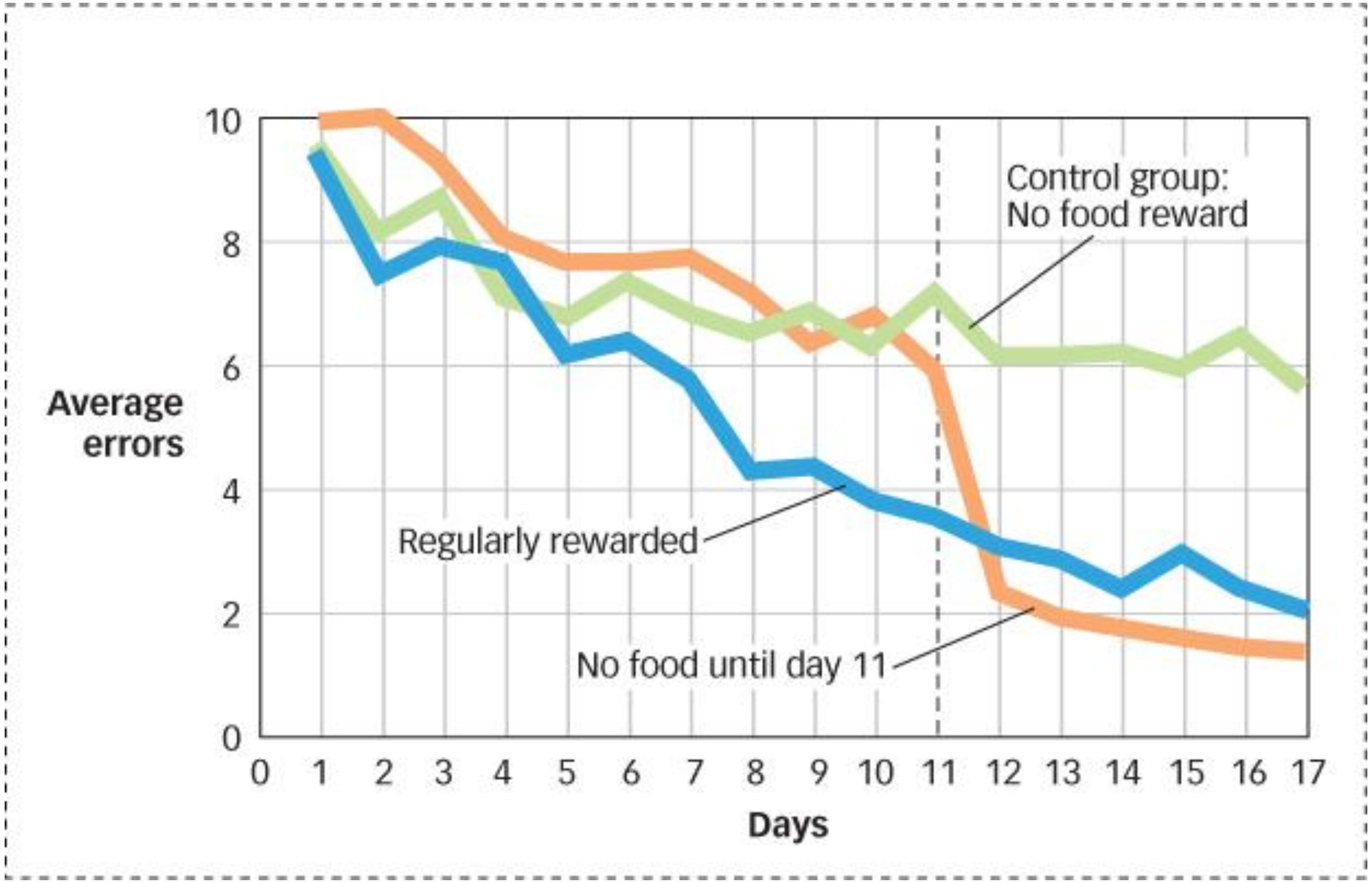
- The organism's interpretation is just as important as the stimulus in determining behavior

Latent Learning

- Rats that weren't reinforced developed spatial representations of the maze anyway
- **Cognitive maps** are a challenge to radical behaviorism



Latent Learning in a Maze



Cognitivism →The computer model of the mind

- The mind is like a computer.
- Information Processing View of the mind
- A distinctive feature of cognitive science.

Slide from Prof Bapi Raju

What is the computer model?

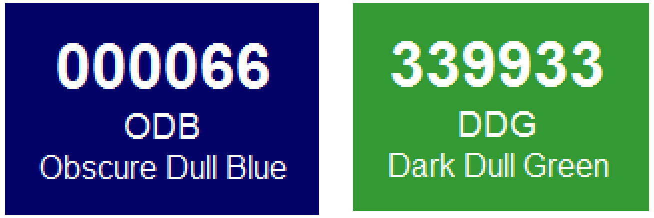
- The mind is an information processing system.
- Information processing is best explained by computations and symbols.
  - Information processing in the computer = **programs** operating on **symbols**.
  - Information processing in the brain = **neural computations** involving **mental representations**.

Slide from Prof Bapi Raju

A typical computer

- Inside a computer, we have :
  - **Symbols**

    e.g. HTML color codes



    symbols are objects to which meaning can be assigned.

  - **Programs**

    e.g. Str_replace(“I have a cat” , “c” , “h”)

    programs are procedures for manipulating symbols.

Slide from Prof Bapi Raju

Mental representations

- Mental representations are symbols in the brain that have meaning or encode information.
- Thinking P ~ Activating a mental representation that means P.

Slide from Prof Bapi Raju

Information processing in the mind

- Perception
  - acquiring real-time information about the surrounding environment.
- Language use
  - making use of information about syntax, semantics and phonology.
- Reasoning
  - combining different sources of information, deriving new information, testing consistency of information, etc.
- Action
  - making use of information in action planning and guidance.
- Memory
  - storing and retrieving information

Slide from Prof Bapi Raju

Marr’s Three Levels of Analysis

How would you even study this complex system?

Marr (1982)

"Trying to understand perception by studying only neurons is like trying to understand bird flight by studying only feathers; it just cannot be done. To understand bird flight, you need to understand aerodynamics, only then can one make sense of the structure of feathers and the shape of wings. Similarly, you can't reach an understanding of why neurons in the visual system behave the way they do, just by studying their anatomy and physiology."

"The nature of the computations that underlie perception depends more upon the computational problems that have to be solved than upon the particular hardware in which their solutions are implemented"

What the heck does this mean?

PLEASE READ Marr (1982) – uploaded on Moodle!

Three Levels of Description (David Marr: 1945-1980)

- A complete understanding of a computational system has to involve three levels:

I. **Computation**: What is the input? What is the output? What is the information that needs to be extracted and in order to solve what problem? Is the output readily inferred or extracted from the input? (usually no) – what additional assumptions must one make to make the problem tractable?

II. **Algorithm/representation** (software): which computational procedures are used

III. **Implementation** (hardware): how the computations are implemented

Inspired by Nancy Kanwisher’s lecture on Marr’s levels of analysis

Example (applied to social behavior): Waiting in line for office hours

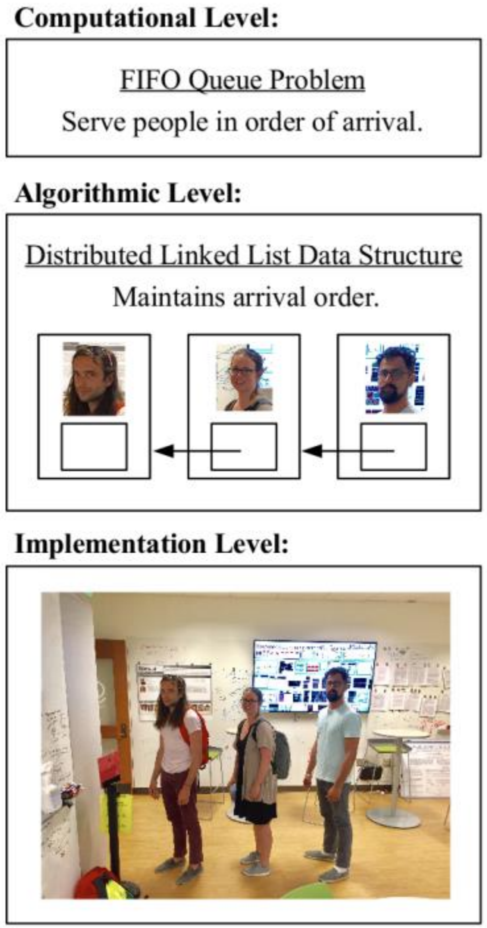
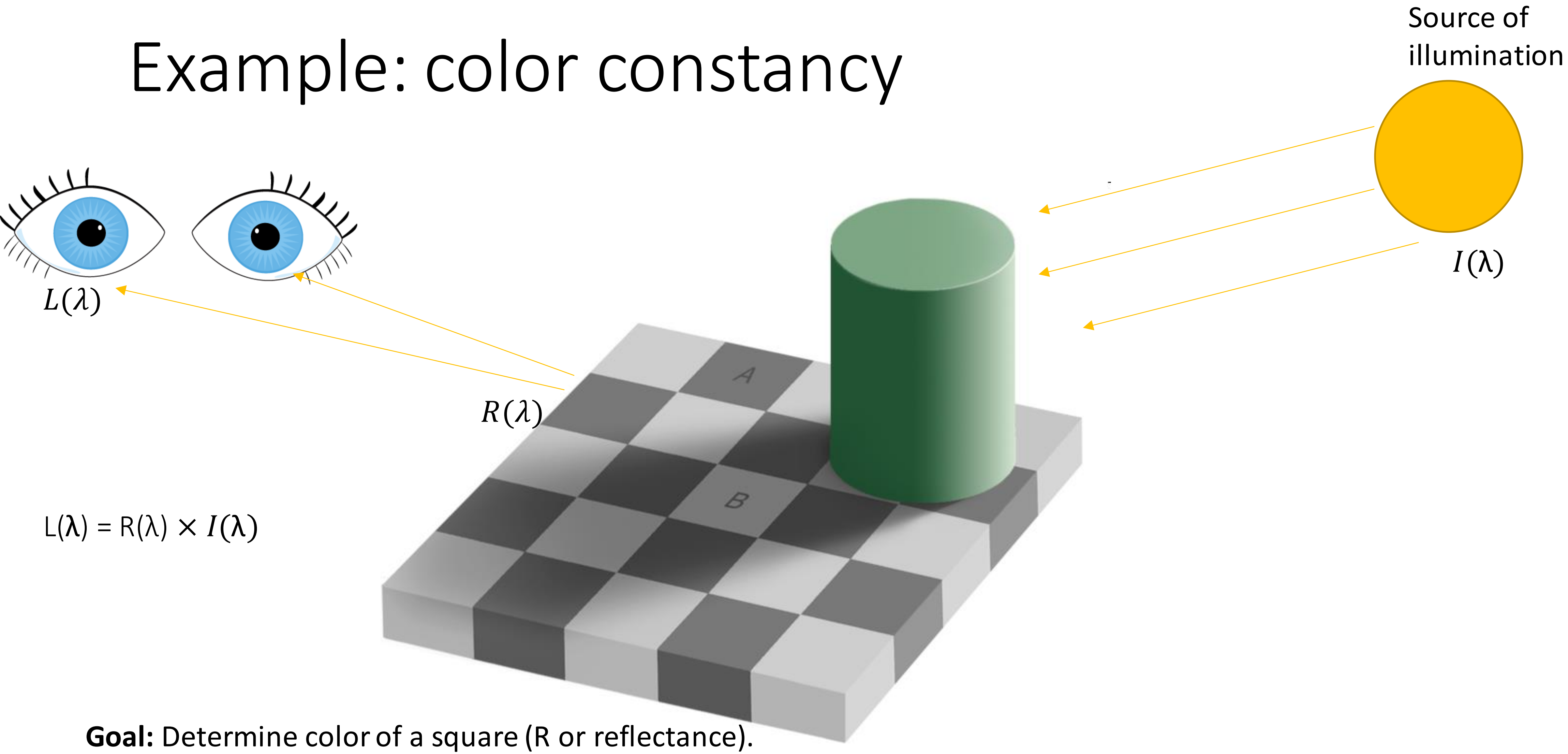


Figure 1: Marr's levels of analysis for waiting in line.

https://cocosci.princeton.edu/papers/krafftCogsci.pdf

Example: color constancy



$L(\lambda) = R(\lambda) \times I(\lambda)$

Goal: Determine color of a square (R or reflectance).
Information we have: The light coming to our eye from the object (L)
However, L also depends on the illuminant I! Usually we don't have direct access to I. So this is an ill-posed or underdetermined problem: Determine R given L. Like asking let XY = 54, determine X.

- Many problems in cognitive science are similarly ill-posed.
- We have to bring in additional assumptions to make these problems tractable.
- E.g. to solve the color constancy problem (i.e., how the brain achieves it), we must first analyze what sorts of constraints we must impose on spectral reflectances and illuminants. This is how theory is developed in cognitive science.
- Such an analysis of the problem to be solved, the information we have, the additional information we must assume to make a solution possible, etc constitute the computational level of Marr’s 3 levels of analysis.

Another illustration from color vision

- Watch from 16:19: https://nancysbraintalks.mit.edu/video/12-how-can-we-study-human-mind-and-brain-marr%E2%80%99s-level%E2%80%99s-analysis

Example: word learning

Gavagai!

Philosopher Quine:

- Ears?
- Fur?
- Eyes?
- Rabbit?
- Detached rabbit parts?

The problem of “reference”
Another ill-posed problem
Additional assumptions: where people look, social cognition, etc

II. Algorithm/representation

- How does the system do what it does?
  - Can we write the "code" to do this task?
  - What assumptions, computations, and representations?
  - How would we find out?

  - In color vision, how we would find out is via psychophysics!

Inspired by Nancy Kanwisher's lecture on Marr's levels of analysis
Watch here: https://youtu.be/Di_3pGAveGs

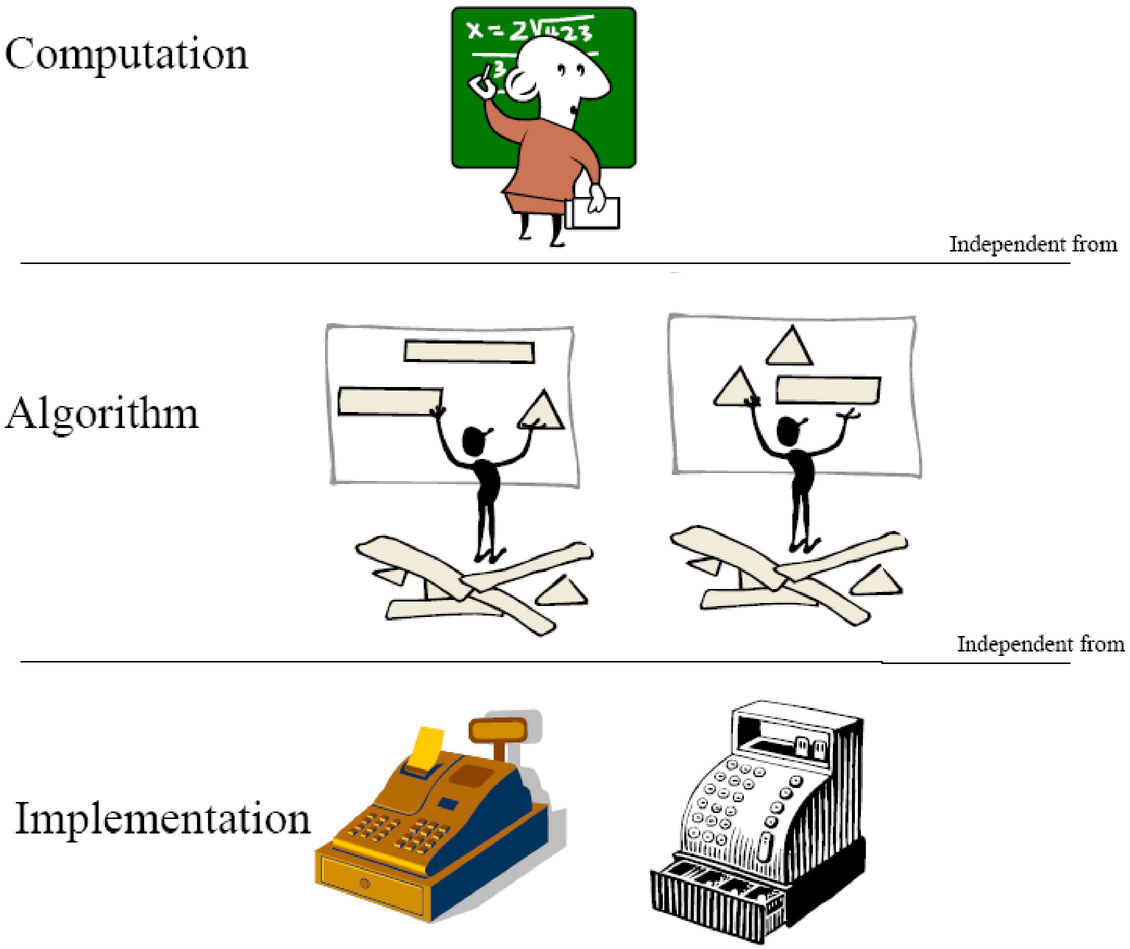
III. Hardware

- How is the computation physically realized in neurons and brains and even computer models?
  - How would we find out?
  - via brain recordings (EEG, iEEG, single unit, fMRI, MEG, etc), computer simulations, etc.

Inspired by Nancy Kanwisher's lecture on Marr's levels of analysis
Watch here: https://youtu.be/Di_3pGAveGs

Marr’s Three-Level Approach

- Computation
  - Specifies the problem
- Algorithm
  - Specifies the way the problem is solved
- Implementation
  - Specifies the medium or physical substrate in which the problem-solving procedure is executed



Slide from Prof Bapi Raju

Summary of Marr’s levels of analysis

We need many levels of analysis to understand what minds do and what they are made up of!

Methods in Cognitive Science

- Thinking/theorizing
- Writing code
- Analyzing natural stimuli
- Physics, ecology
- Psychophysics (RT, accuracy, etc)
- Individual differences
- Neuropsych patients
- fMRI, ECoG, EEG, MEG, single units, etc
- And many more…
- Not always a one to one relationship with Marr’s levels of analysis, but they are very useful as a guide when analyzing a given problem in cognitive science.

Summary

- Cognitive science as an inter-disciplinary science of mind and intelligence.
- The computational approach : using computations and representations to explain mental processes.

Slide from Prof Bapi Raju

Beyond mental representations

- **Embodied cognition** (sometimes a radical version of it: Anthony Chemero) – you are not just your brain, pay attention to the body and the environment (as opposed to Descartes' Dualism: *the mind was physically separate from the body*).
  - Lakoff and Nunez: The mind arises from the nature of our brains, bodies, and bodily experiences…
  - Has only really been studied empirically in the last few decades
- **Dynamical Systems** (e.g. dynamical field theory explanations for A not B tasks) – rejects the information processing view of the mind, eschews the need for mental representations, seeks to understand cognitive systems as dynamical systems that change over time using nonlinear dynamical systems theory.
- Will be covered in a later lecture

Work at CogSci Lab

Cognitive Science Research Focus

- Faculty: Bapi Raju, Priyanka Srivastava, Kavita Vemuri, Vinoo Alluri, Vishnu Sreekumar, Bhaktee Dongaonkar

- Understanding Cognition
  - Spatial Cognition (Navigational abilities of visually impaired vs. sighted people, 360 degree vision)
  - Sensory Systems (Visual and Auditory)
  - Functional and Structural Analysis of the brain networks involved in functions such as Language, Memory, Emotion, Empathy, etc.
  - Neurodynamics of memory and learning
  - Stress and memory

Cognitive Science Research Focus

- Simulation Systems
  - Large-scale models of the brain
  - Connectomics: Resting state network analysis using fMRI, MEG, EEG
  - Intelligent data analysis methods using Structural and Functional Neuroimaging data
  - Structure-Function relationship in health and disease using Computational Modeling

Cognitive Science Research Focus

- Assistive Systems
  - For Dyslexia and Dementia
  - Human-Machine Interface (Gesture Recognizers, Game Interfaces, Vehicle Control Systems, Virtual Reality, etc.)
  - Neuro-Rehabilitation

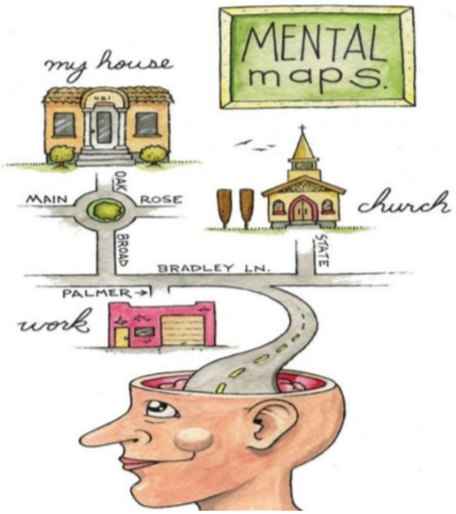
- Time Perception
  - Behavioral, EEG, Patient Studies, Computational Models
- Sense of Number
  - Behavioral, Computational modeling
- Motor Sequence Learning
  - Hand-motor / Oculomotor using Behavioral, fMRI, Computational modeling on Normal, Hearing-handicapped, etc.
- Action Representation and Learning
- Large Scale Models of Brain

Dr Bapi Raju

Sight Without Light **Enhancing Vision**

Dr Priyanka Srivastava

Creative Thinking



Research Focus

Spatial Cognition

- How do we perceive, represent and act in the spatial-world around us.
- What determines our spatial ability, specifically navigational ability?
- Research shows that we differ in our spatial abilities. What causes these differences?
- What is the role of vision in making sense of space or spatial representation? How compensatory channels, specifically auditory cues, enable them to perform navigation and way-finding activities?
- How do visual limitations, such as field of view, affects spatial awareness?

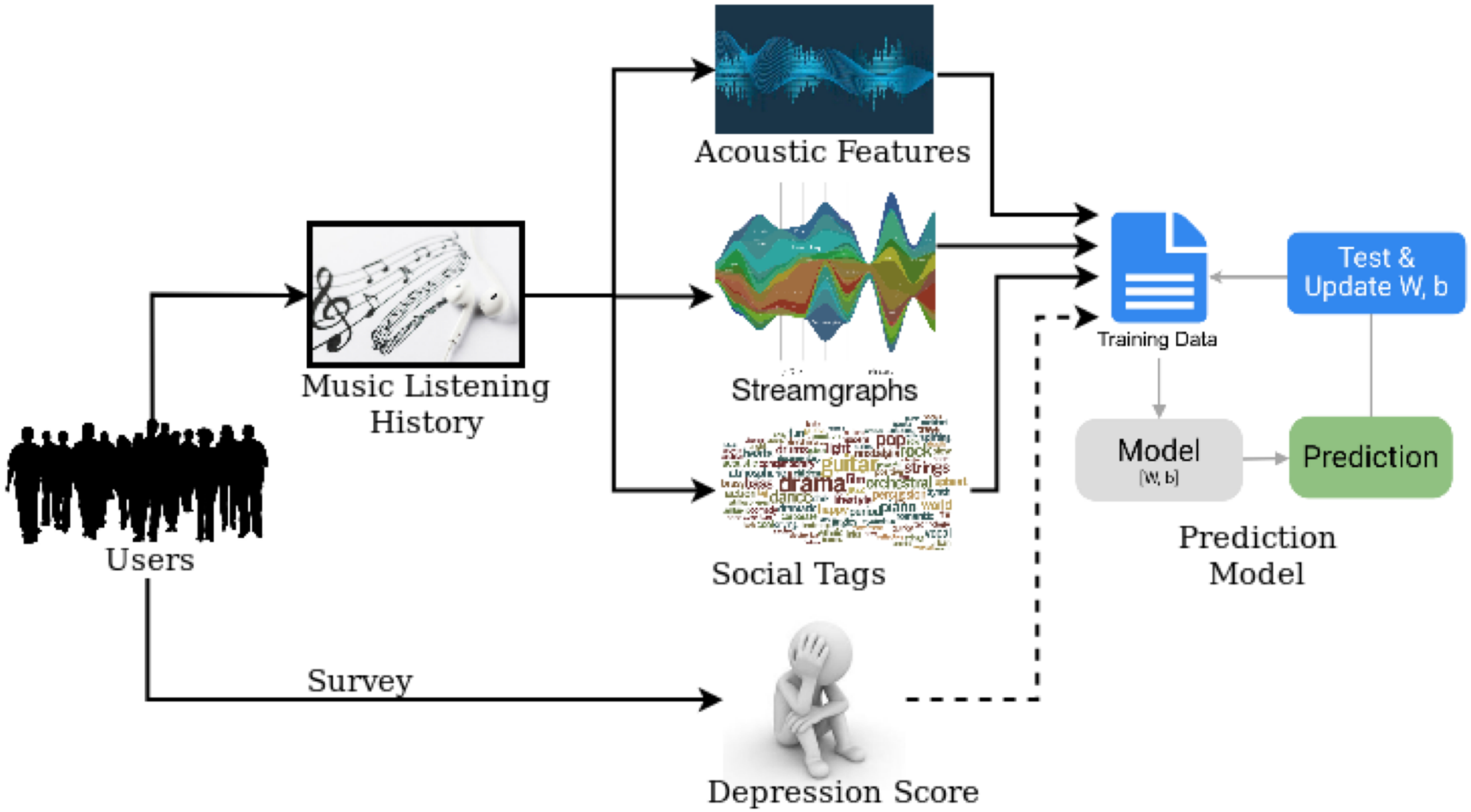
Can technology be an aid to reduce the sensory limitations and enhance the spatial cognitive ability? Current technological aid for visually impaired, such as auditory-based navigation system, as well as sighted people such as Night Vision Devices and 360-degree vision, are changing the face of sensory limitations and further the cognitive abilities. We are interested in realizing the strength and limitations of the course of such interactions.

Neurorehabilitation through games

Dr Kavita Vemuri

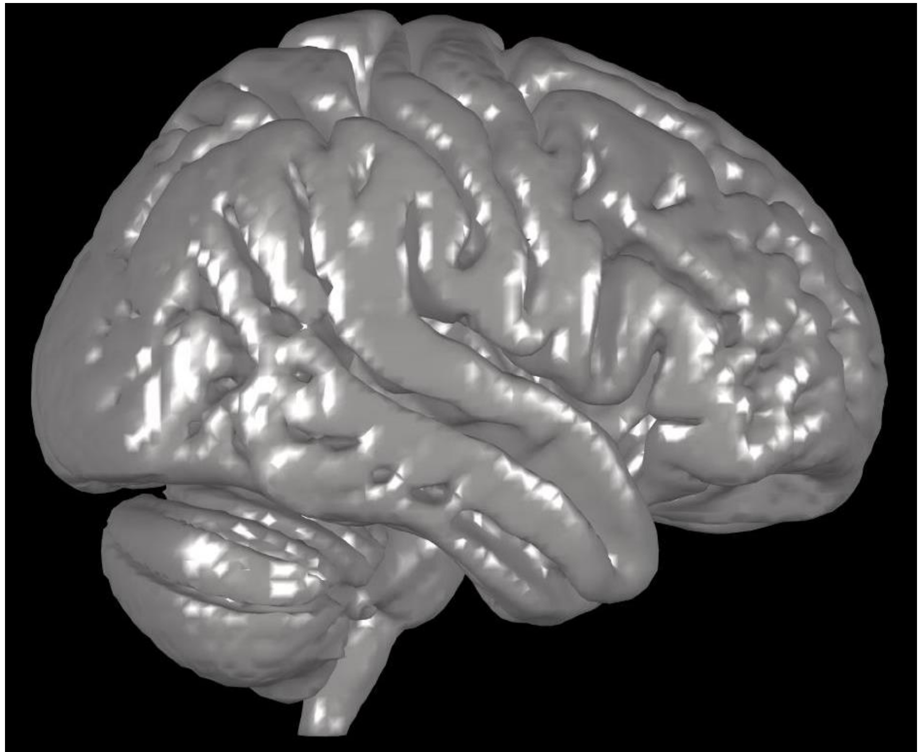
Predicting Depression from Music Listening Habits

Dr Vinoo Alluri



Individual traits modulate brain connectivity

Dr Vinoo Alluri



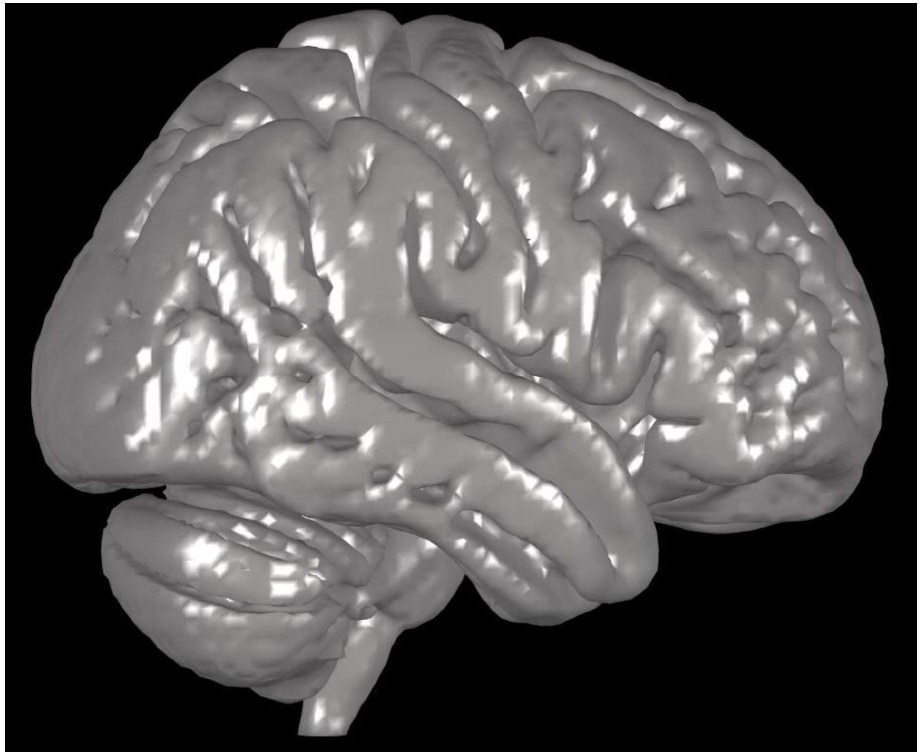
Empathy

MUSICAL TRAINING

Familiarity

Decoding brain states at rest in Cocaine users

Dr Vinoo Alluri



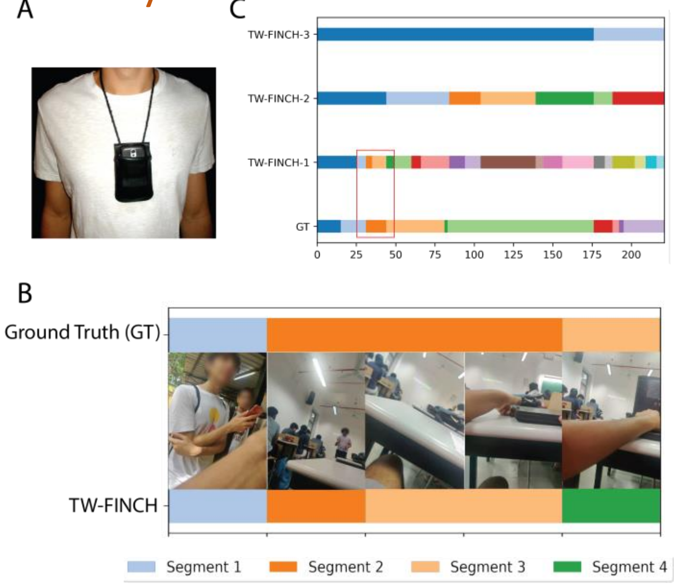
www.mandalab.org

MANDA MEMORY AND NEURODYNAMICS LAB

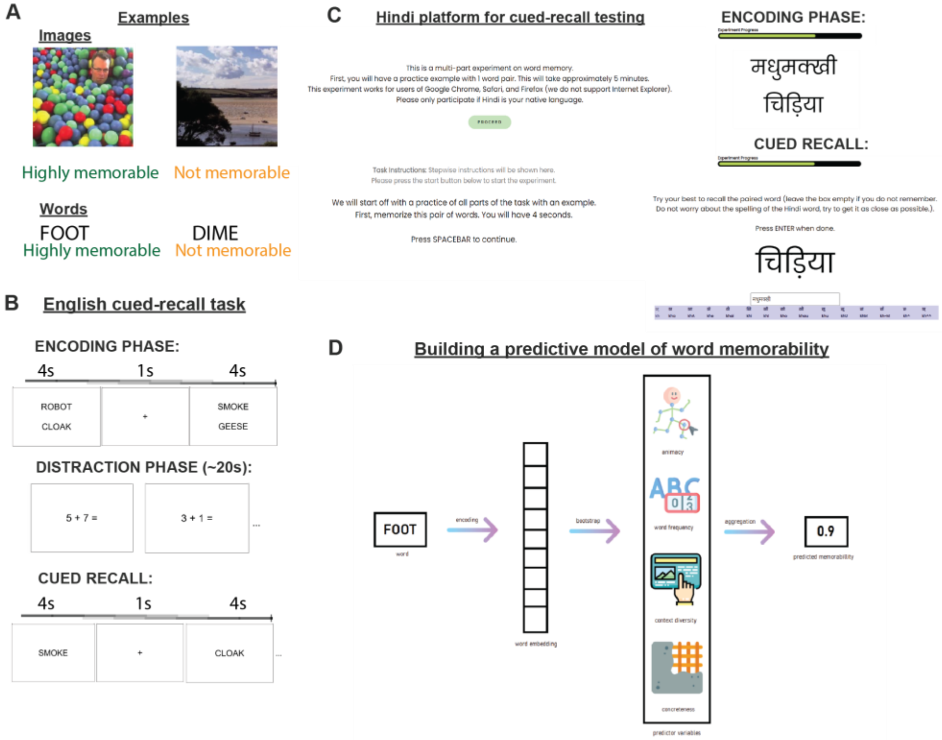
Dr Vishnu Sreekumar

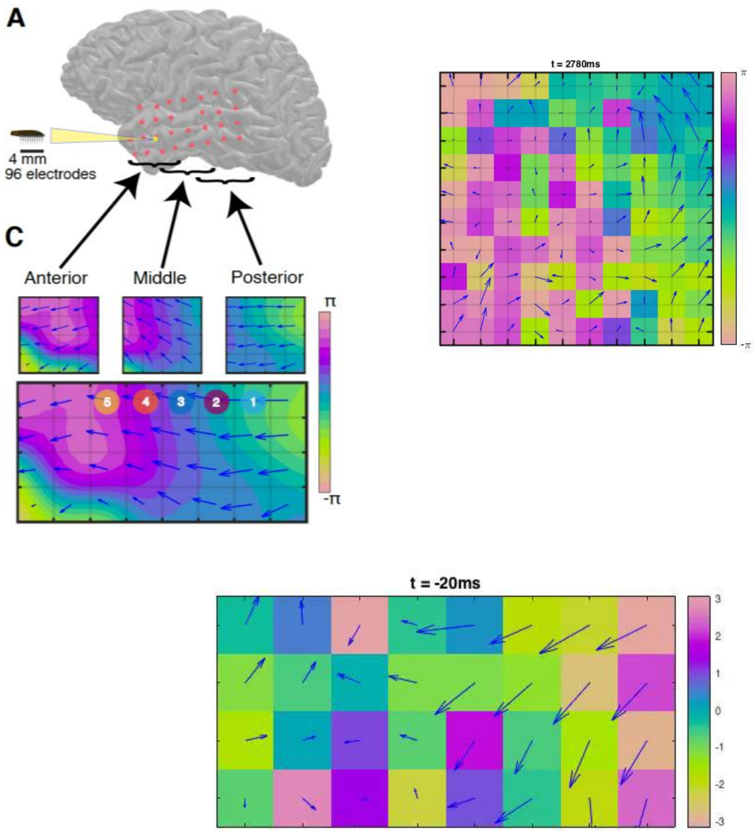
3. Neural dynamics (iEEG/EEG/fMRI)

1. Extended reality studies of human memory



2. Language and Memory





How does stress & depression affect memory processes?

How do long term memories influence decision-making & creativity?

Do rich experiences help to override effects of stress?

Looking for students who can -

1. Design ingenious behavioural paradigms that can answer the above questions

2. Are committed to learning and completing projects.

Bhaktee Dongaonkar
(stress and cognition)