

The neural basis of computer programming

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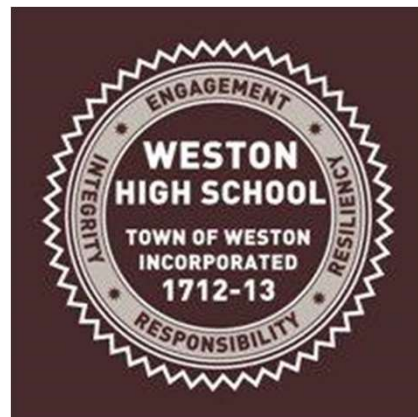
MIT

shash@mit.edu



Thanks, Weston High!

Thank you, Mrs Katie Tucker





Shash

- 3rd year Ph.D. student in CS at MIT
- Research interests in program analysis, machine learning, and neuroscience
- Check out datasciencekids.org



Dr. Una-May O'Reilly

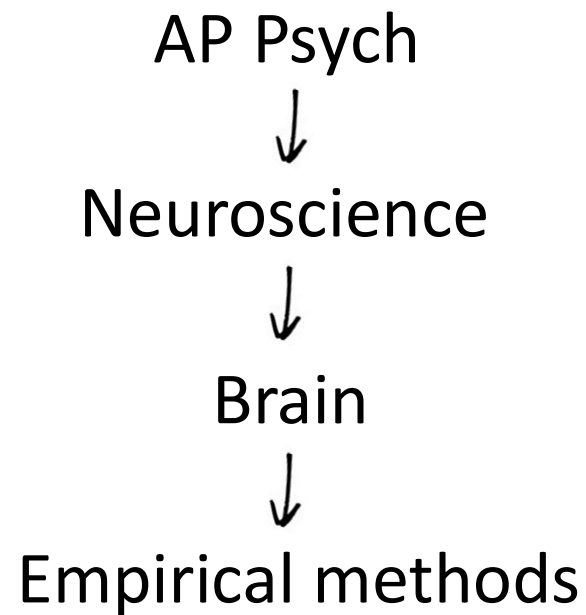
- Computer scientist at CSAIL, MIT
- Founded and directs *ALFA*, a research group working on problems at the intersection of scalable machine learning and cybersecurity.
- A parent of one of your peers!

Ask questions! Lots!

Make sure you call us out on jargon we use today



Big picture



We specifically analyze and reason about the *language regions* in the human brain

Today's talk

Tools to understand how our brains work

Our research shedding light on how we
comprehend computer programs

Questions, Discussion



Understanding the human brain

Understanding the functional organization of the brain has been a fundamental quest.

Lots of functions are handled by specialized regions. Modular. Tuned for specialization.

Many other functions seem to have no associated specialized regions



Understanding the human brain

Broad functions



Understanding the human brain

Broad functions

- Vision
- Audio
- Motor control and dexterity
- Emotions
- Language

Understanding the human brain

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Faces
Color
Places
Words/letters
Bodies
Motion
Shape

Understanding the human brain

Broad functions

- Vision
- Audio
 - Pitch
 - Music
 - Speech perception
- Motor control and dexterity
- Emotions
- Language

Understanding the human brain

Broad functions

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Grasping
Reaching

Understanding the human brain

Broad functions

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Other people's thoughts
Social perception

Understanding the human brain

Broad functions

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Very distinct language regions

Understanding the human brain

Broad functions

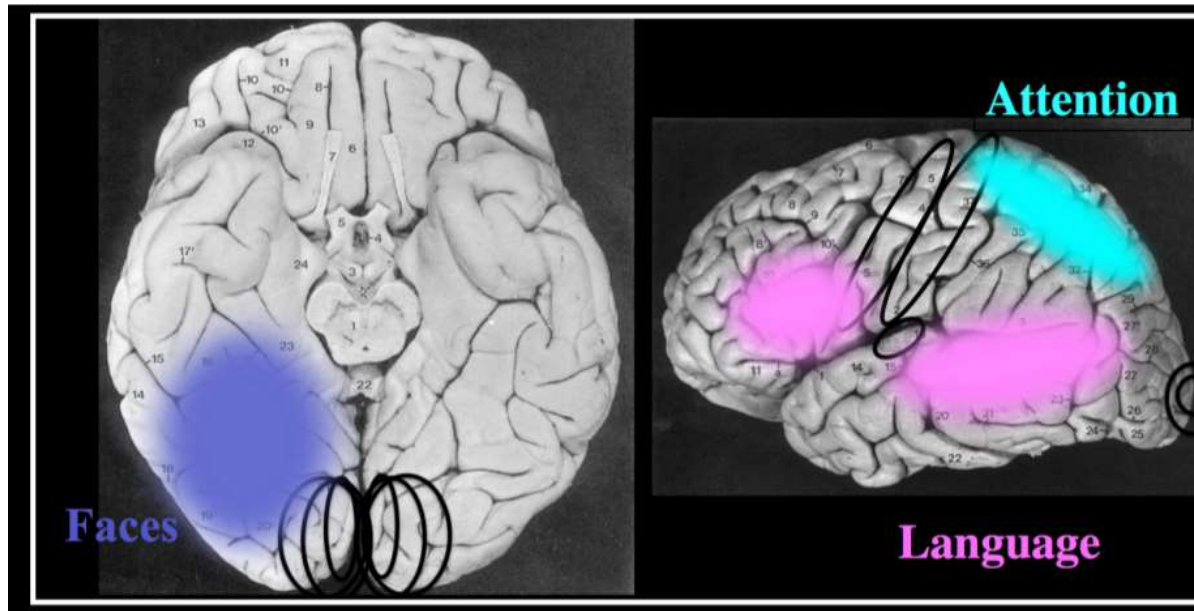
- Vision
- Audio
- Motor control and dexterity
- Emotions
- Language
- Multiple Demand system

Broadly *recruited* in math, logic, reasoning, learning like tasks



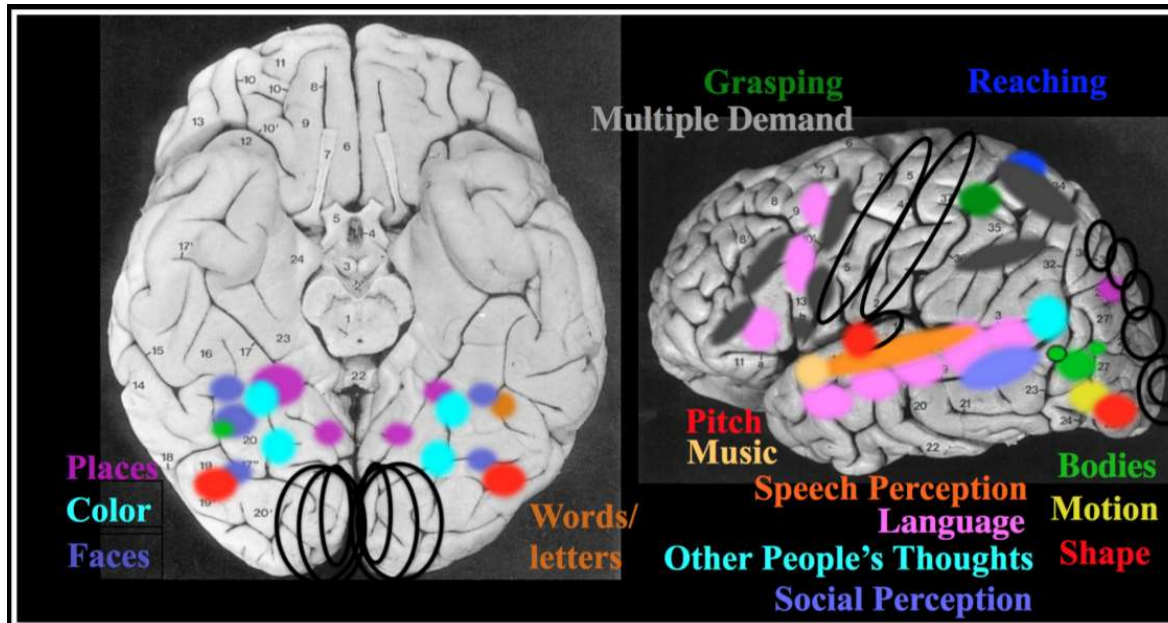
Understanding the human brain

Early 90s



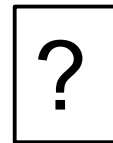
Understanding the human brain

Current understanding



Central question - How do we really determine how our brains are processing information we perceive?

How does our brain give rise to our mind?



- Motion
- Person
- R to L motion
- Mood
- Health

Central question - How do we really determine how our brains are processing information we perceive?

How does our brain give rise to our mind?

ENGLAND CAPTAIN David Beckham claims any different formation against Wales tomorrow will be down to Sven-Goran Eriksson - not player power - and called for "a little bit more respect" to be shown to the England manager. Eriksson has been experimenting with a 4-5-1 formation in training this week ahead of the World Cup qualifier in Cardiff, with Jermain Defoe set to lose out on a starting place even though Michael Owen is suspended.

There has been speculation that the reason for a planned tactical shift is down to the England players. But Beckham said: "It's important to find different formations because you come up against different teams, especially when you have players out or injured. You have to compensate for that, so if you have to play different roles you do what the manager says."

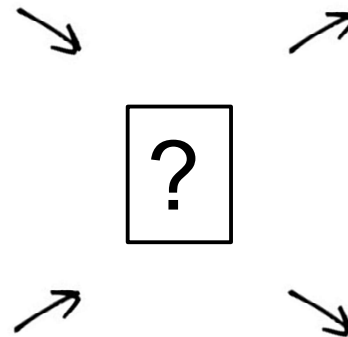
"This whole player power thing has come up this week but it's nothing to do with that," he continued. "It happens all the time - if the manager decides he wants a meeting with players to discuss different formations or ways of playing he calls a meeting. I think a little bit more respect has to be shown to the manager."

"He [Eriksson] picks the team and formations. He discusses things with players and players appreciate that - but the final decision is down to him and that's the way it's always been."



- Script
- Language
- Meaning
- Style
- Tone
- Font

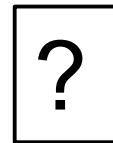
Let's work with vision. Face recognition in particular



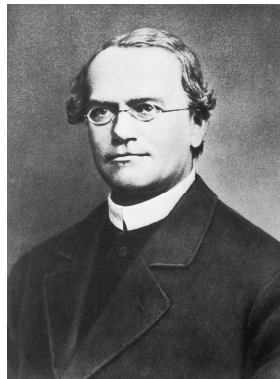
Let's work with vision. Face recognition in particular



Hedy Lamarr



Gregor Mendel



Let's work with vision. Face recognition in particular

How does this happen?

Where exactly in the brain does this happen?

Is it really specific to faces?

Is this an innate ability? Or does experience play a role?

Let's work with vision. Face recognition in particular

How does this happen?

Where exactly in the brain does this happen?

Is it really specific to faces?

Is this an innate ability? Or does experience play a role?

DEMO



A few famous faces will be shown for a short duration

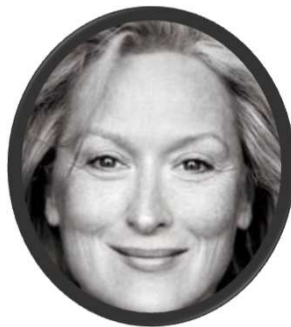
Note down how many you recognize

Don't shout out the names

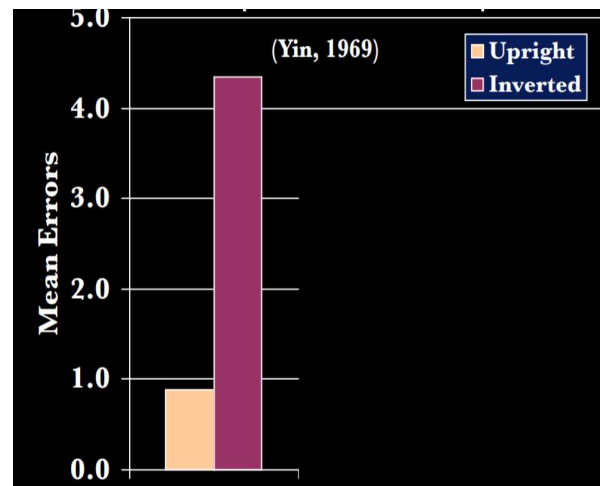








The unreasonable effectiveness of low tech



Yin, Robert K. "Looking at upside-down faces." *Journal of experimental psychology* 81.1 (1969): 141.

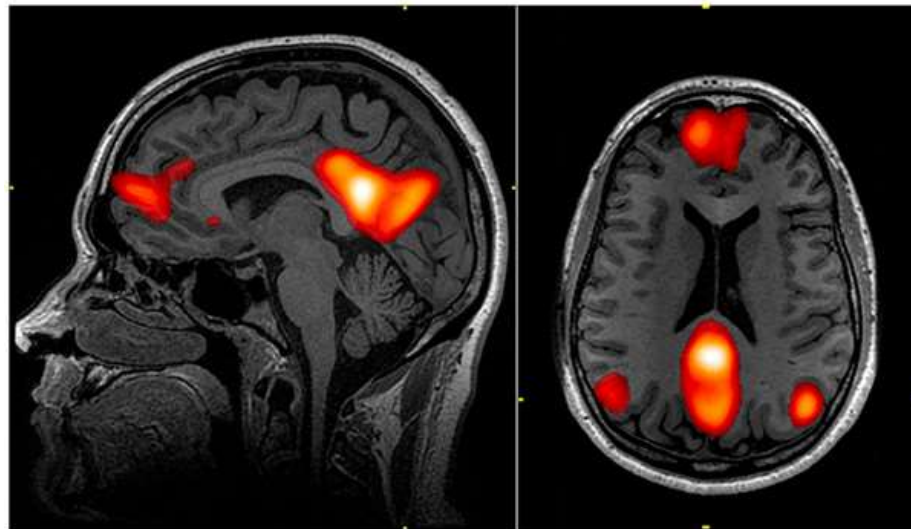
Digging deeper - fMRI

State of the art to investigate which areas of the brain involved in an action

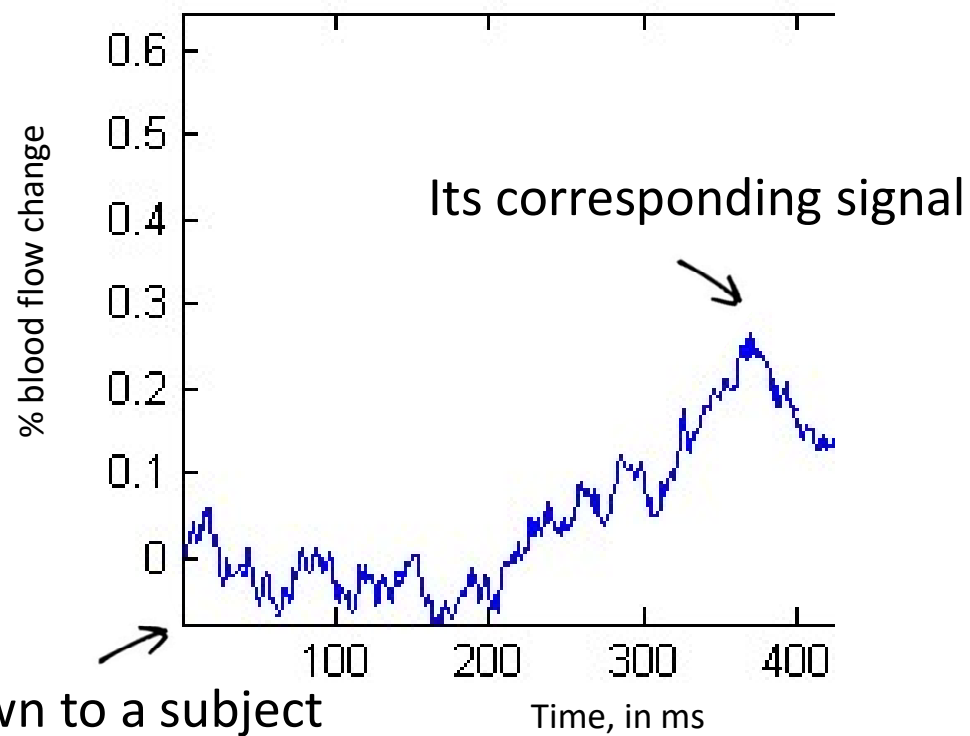


Digging deeper - fMRI

Measures blood flow changes in a region of interest (ROI)



Digging deeper - fMRI



Digging deeper - fMRI

Lots of pros and cons.

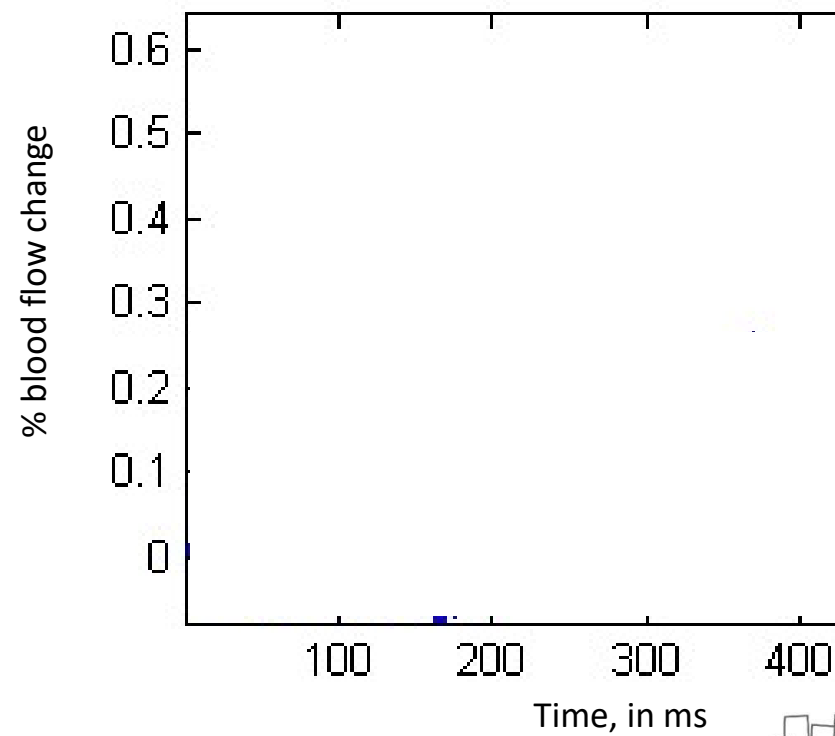
Major pro – Non-invasive; Time resolution

Major con – Time resolution; Spatial resolution

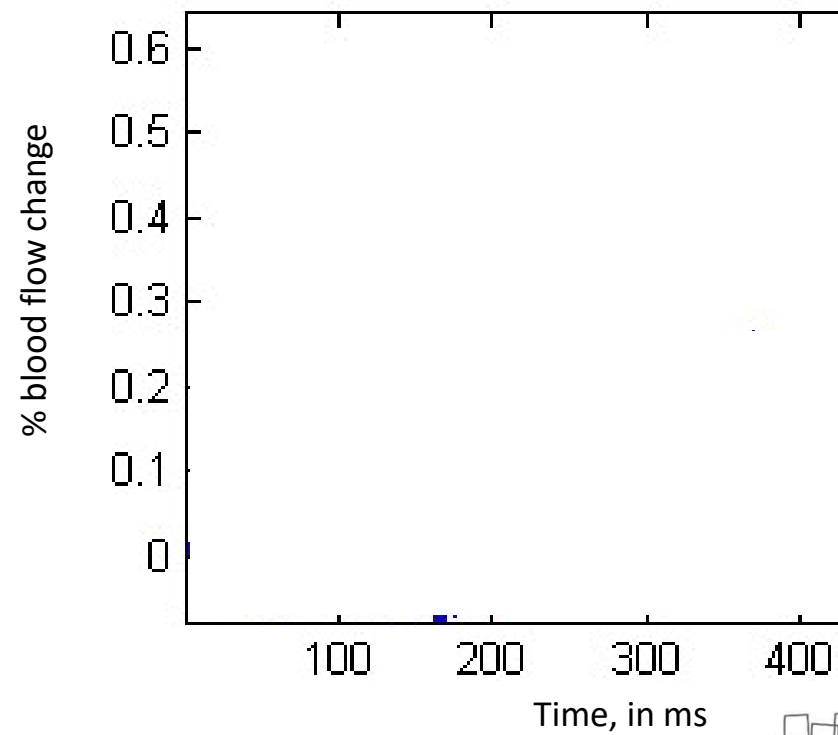
Absolute measurements meaningless. Comparative analysis.



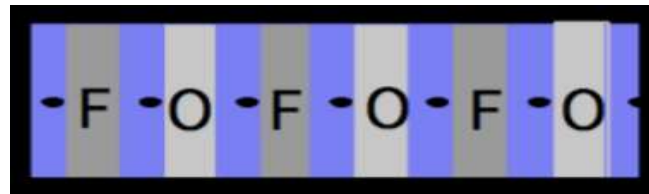
Designing fMRI experiments for face recognition



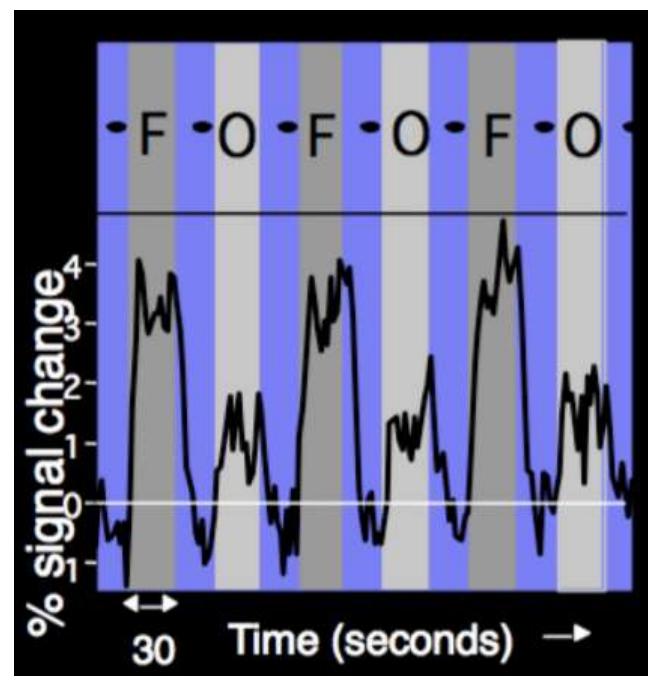
Designing fMRI experiments for face recognition



Designing fMRI experiments for face recognition



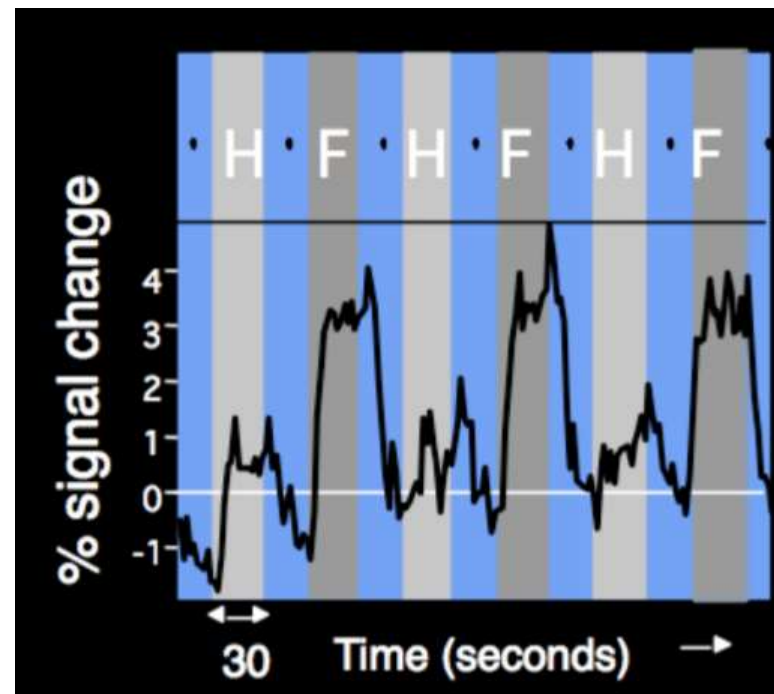
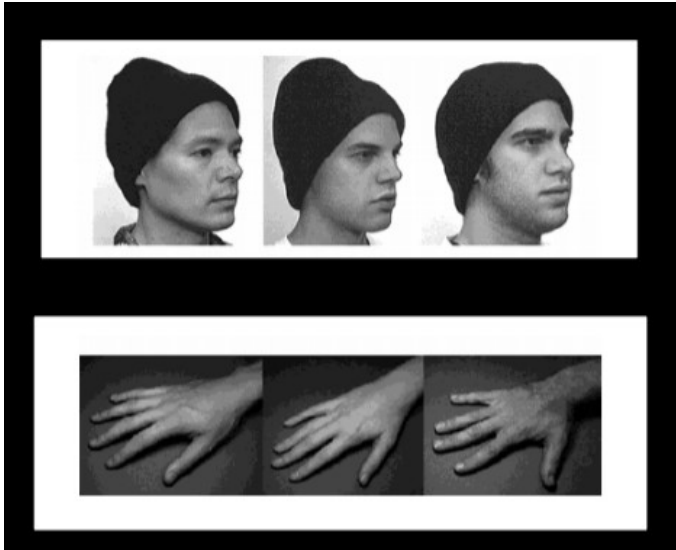
Designing fMRI experiments for face recognition



Designing fMRI experiments for face recognition

Any other sharper design? To test our hypothesis











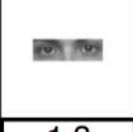








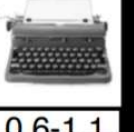
Designing fMRI experiments for face recognition



Designing fMRI experiments for face recognition

Any other sharper design? To test our hypothesis

Designing fMRI experiments for face recognition

Front-View  1.9-2.3	Profile-View  1.8	"Mooney"  2.0	Cat Face  1.6	Cartoon  1.7
Inv. Grey  1.6	No Eyes  1.7	Human Head  1.7	Animal Head  1.3	Inv. Cartoon  1.4
Eyes Only  1.3	Inv. Mooney  1.3	Whole Animal  0.9	Human Body  1.0	External Ftrs  1.1
Hand  0.7	Buildings  0.6	Back of Head  1.0	Animal Body  0.8	Object  0.6-1.1

A quick note on asking the right questions

Science is all about framing the right questions.

I made it seem obvious just now that face recog is possibly different from general object detection.

Neuroscience works closely with the medical sciences. Need to be aware of strange symptoms that occur in the area.

fMRI is not the end-game though

Activity in the region \Rightarrow Specialization

fMRI is not the end-game though

Activity in the region \Rightarrow Specialization

Activity in the region $\stackrel{?}{\leftarrow}$ Specialization

A quick recap

- Ask the right questions. Important.
- Simple, low tech behavioral experiments can reveal startling things about our brains. Good starting point.
- fMRI – a popular method to understand functional organization. Does not show causality.
- Need to be careful in designing experiments for fMRI based studies. Many things can go wrong.

Alright, let us switch gears



Programming

- Are there guidelines to designing a PL which maximizes information exchange?
- How do you de-emphasize the machine aspect and increase human aspect?
- How do you teach programming effectively?
- How do we keep track of concepts arising in a program? And how do we reason through it?
- Do our brains work like the tools developed for machines (compilers, intermediate datastructures) to understand programs?

Programming

What's so special about it?



Programming

What's so special about it?

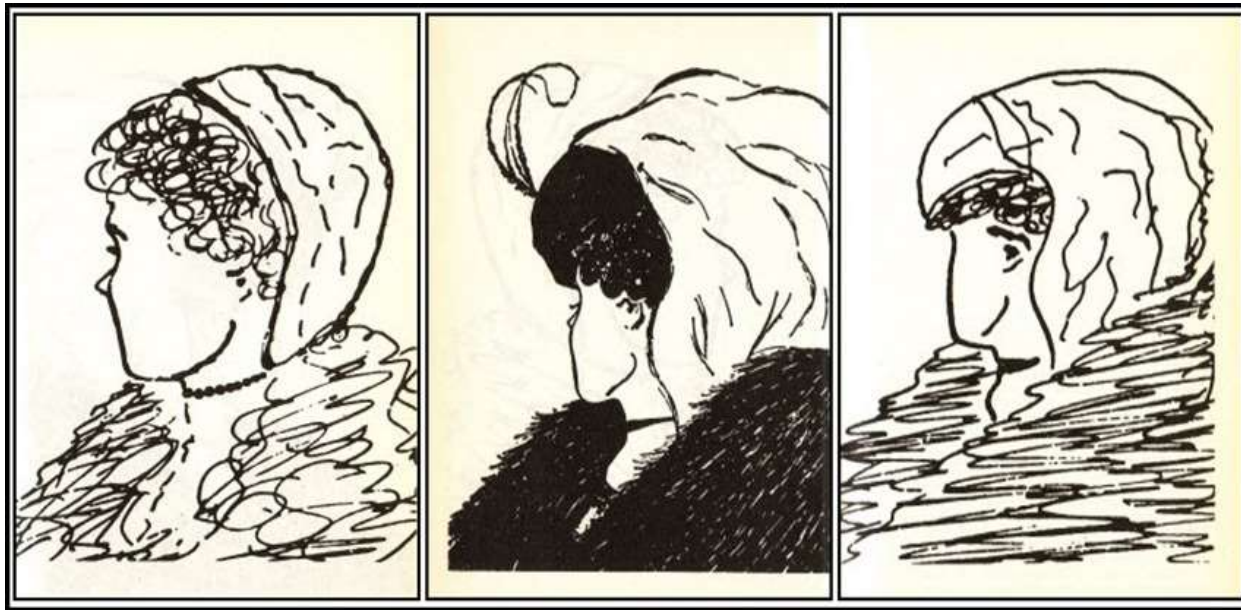


Programming



Programming

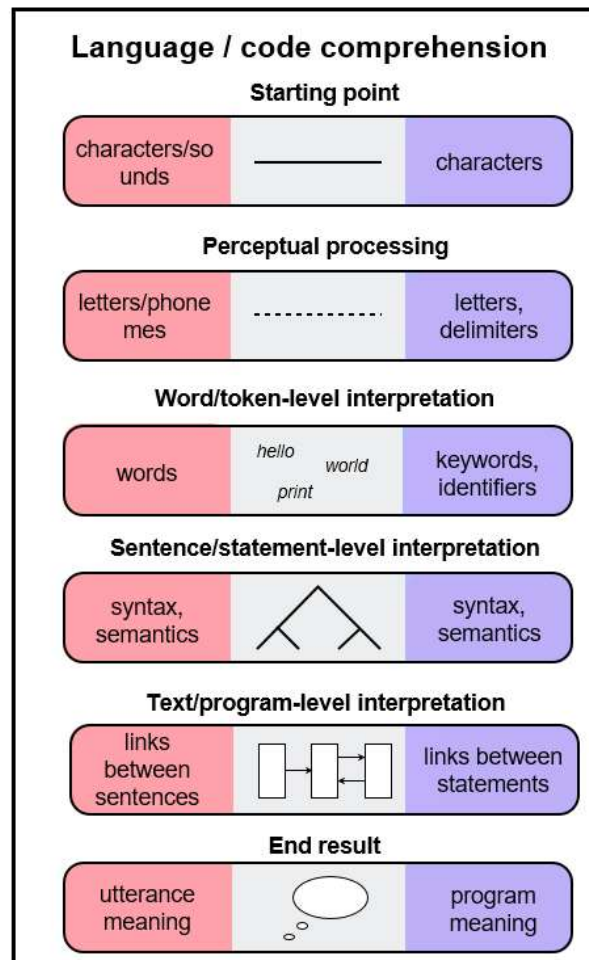
CS
folks



Neuro
folks

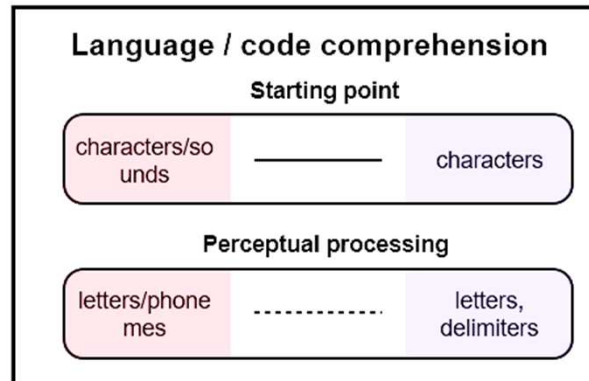


Programming



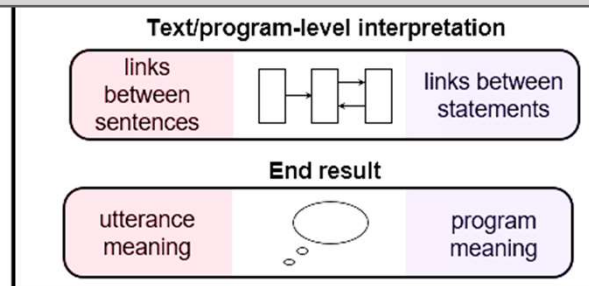
Fedorenko, Ivanova et al, 2019

Programming



The parallel didn't show up for music or math.

(Fedorenko et al, 2011, 2012)



Fedorenko, Ivanova et al, 2019

Understanding the human brain

Broad functions

- Vision
- Audio
- Motor control and dexterity
- Emotions
- Language
- Multiple Demand system



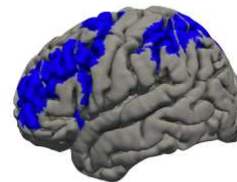
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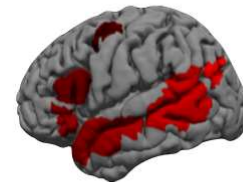
- Language
- Multiple Demand system

Multiple demand
(MD)



math
logic
spatial reasoning

Language

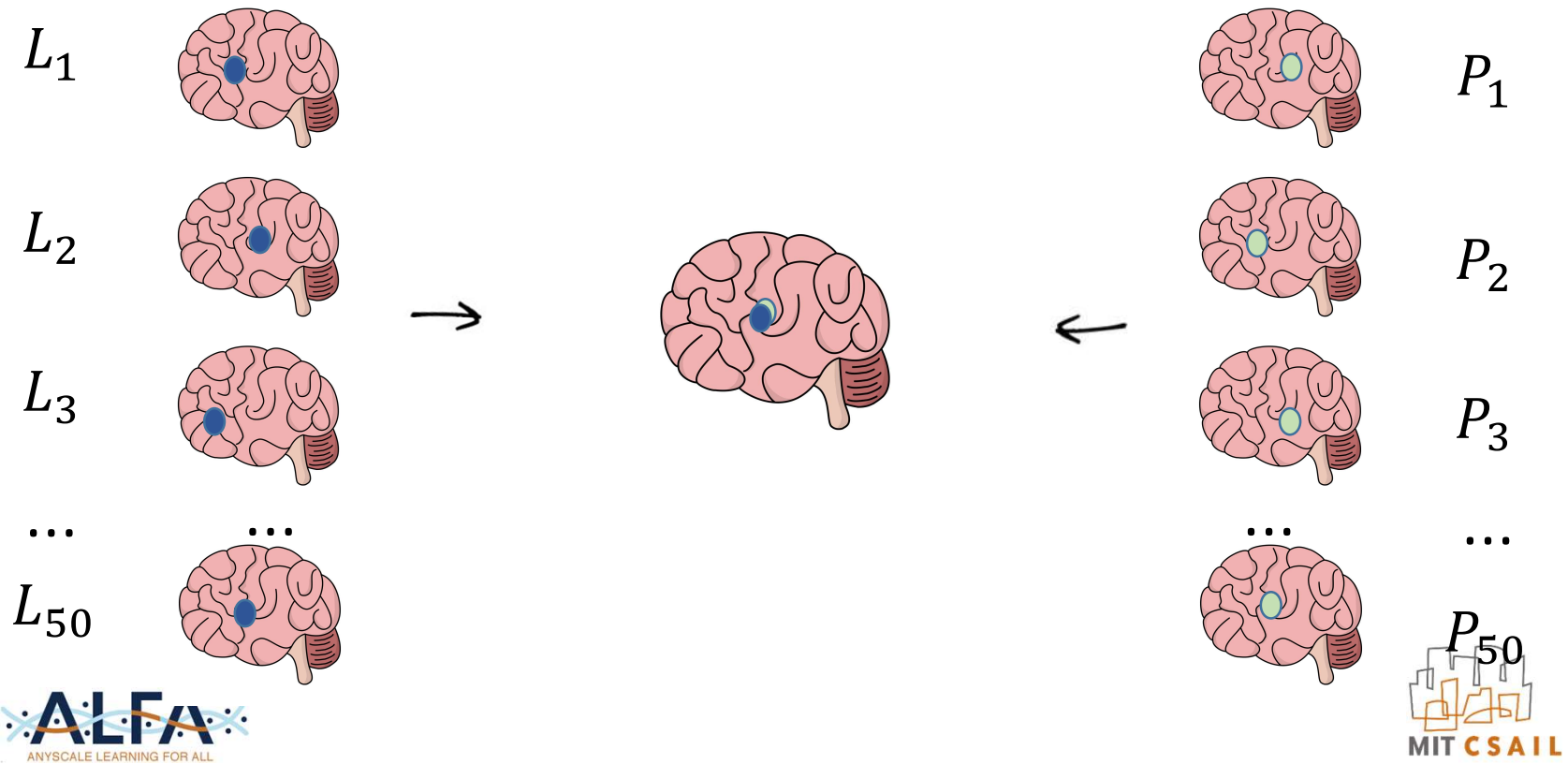


words
sentences

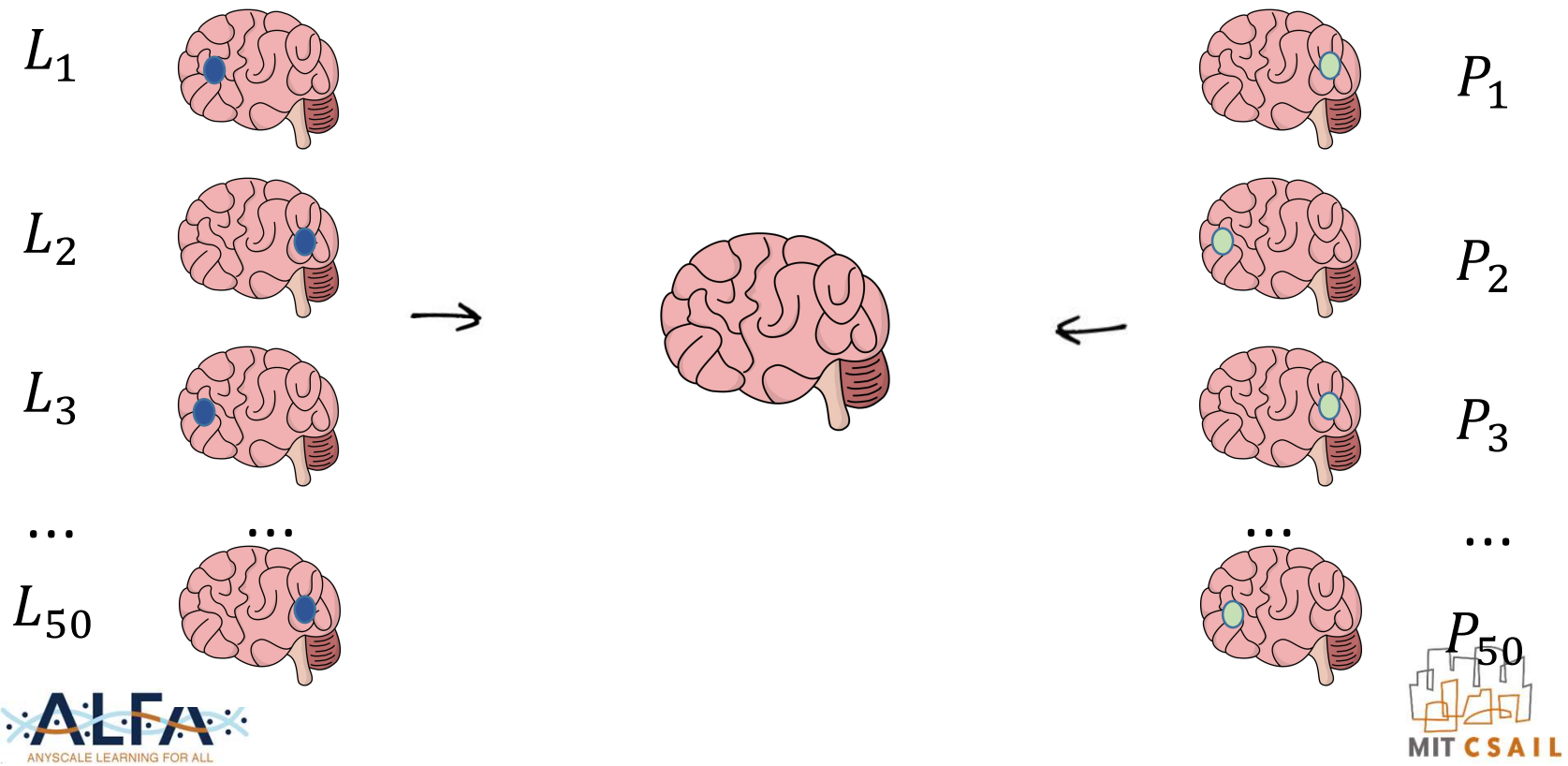
Experiment setup 1

- Get 50 of you enrolled in our experiments
- Give each of you a language test in an fMRI – Region L_i
- Give each of you a programming test in an fMRI – Region P_i
- Find the mean region of R1
- Find the mean region of R2
- If R1 and R2 coincide, you conclude that programming and languages are processed in the same region

Experiment setup 1

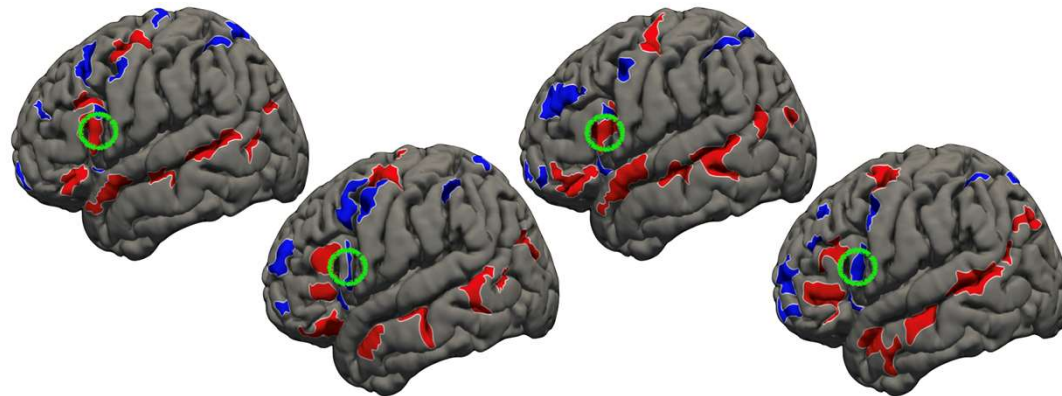


Experiment setup 1



Experiment setup 1

Set up a *functional localizer*



Experiment setup 1



Experiment setup 2

```
filename = "alphabet.java"  
modified = filename.split(".")  
  
print(modified[-1])
```

Carol's sweater is red. You and Alex need to be quiet. I'll split this pie into two.

Experiment setup 2

- Word-like variable names can be lighting up the language region
- Similar lengths of characters being processed
- String constants in the programs causing activation?
- Both stimuli coincidentally made you think of the same concept?

What's a tighter design choice?

```
filename = "alphabet.java"  
modified = filename.split(".")  
  
print(modified[-1])
```

A file is named "alphabet.java". You split the name at the dot character. What is the last part of resultant split?

What's a tighter design choice?

English identifiers

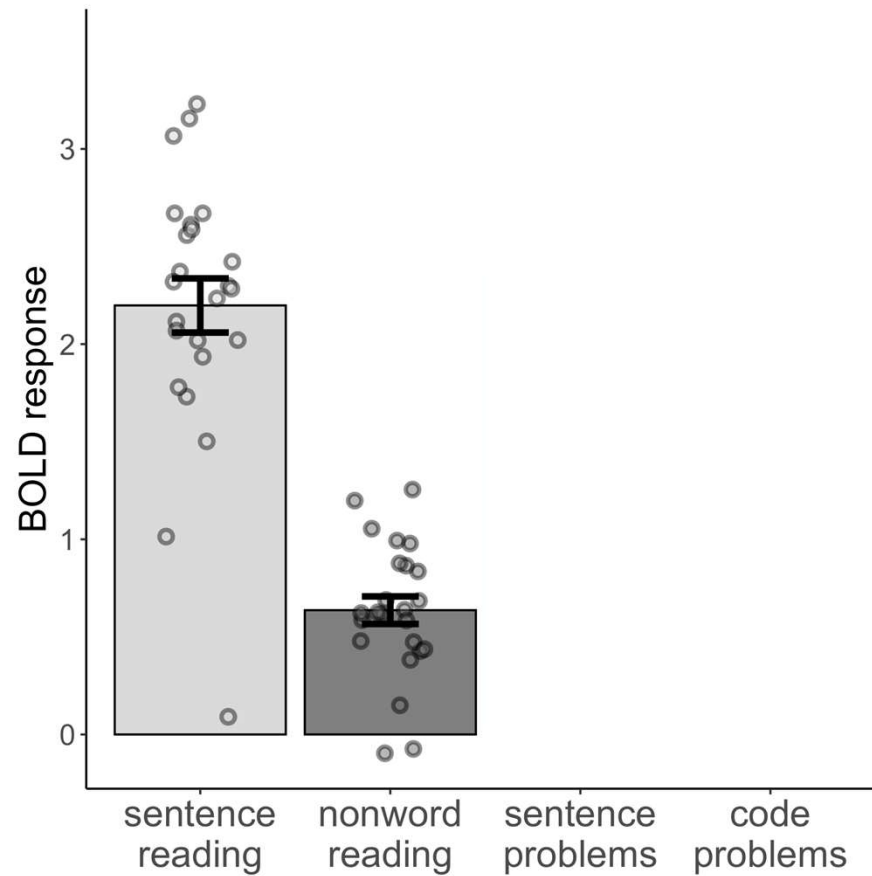
```
height = 5  
weight = 100  
bmi = weight / (height*height)  
print(bmi)
```

Japanese identifiers

```
sincho = 5  
taiju = 100  
keisu = taiju / (sincho*sincho)  
print(keisu)
```

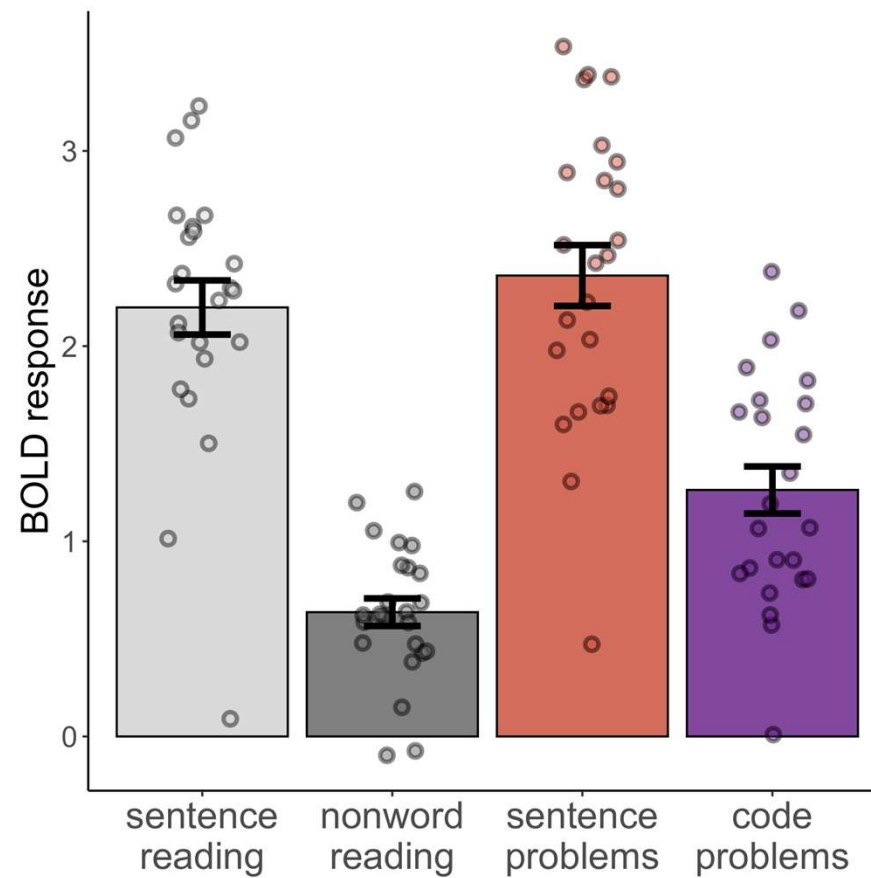
What do we see?

language system



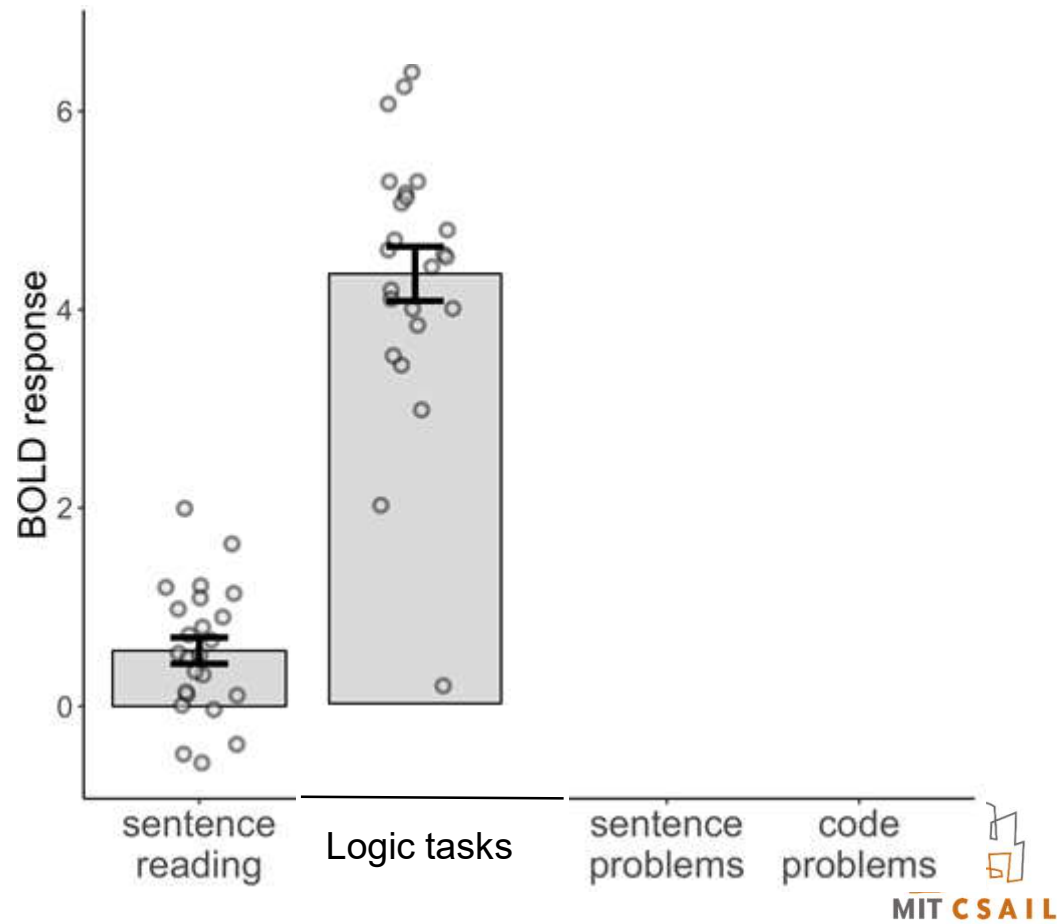
What do we see?

language system



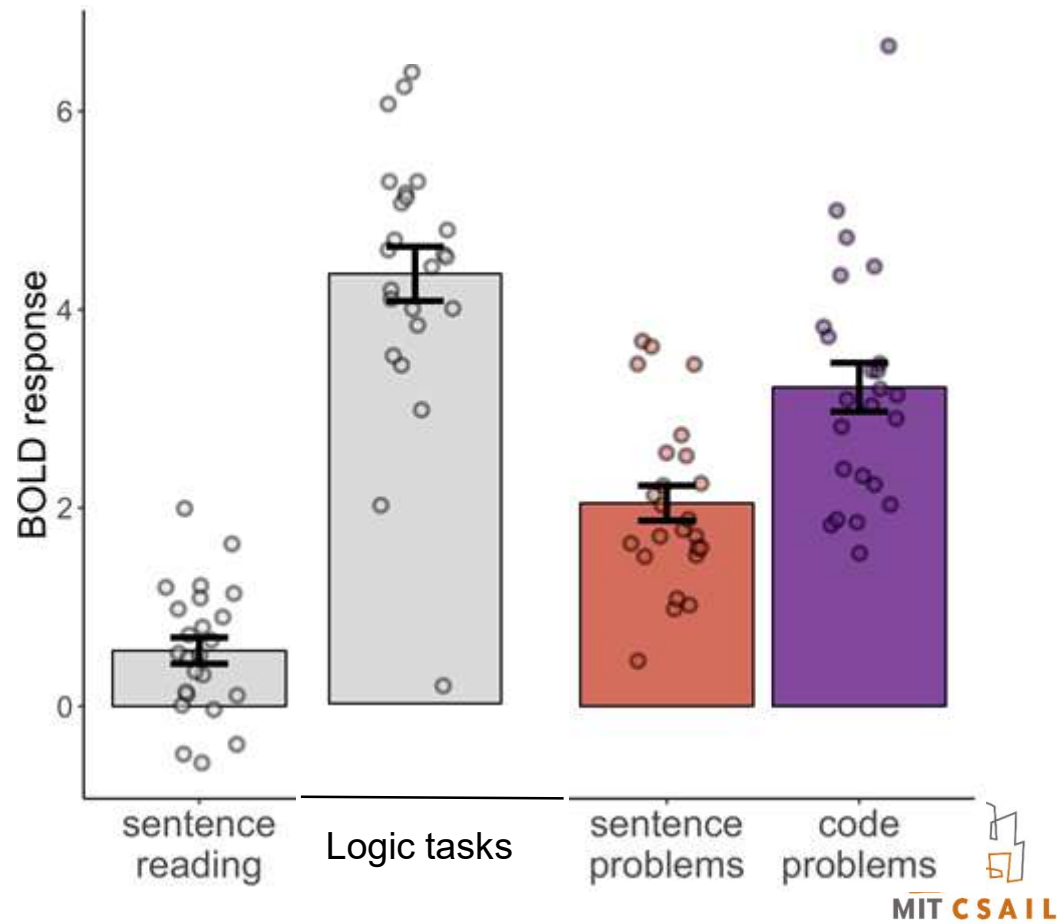
What do we see?

MD system

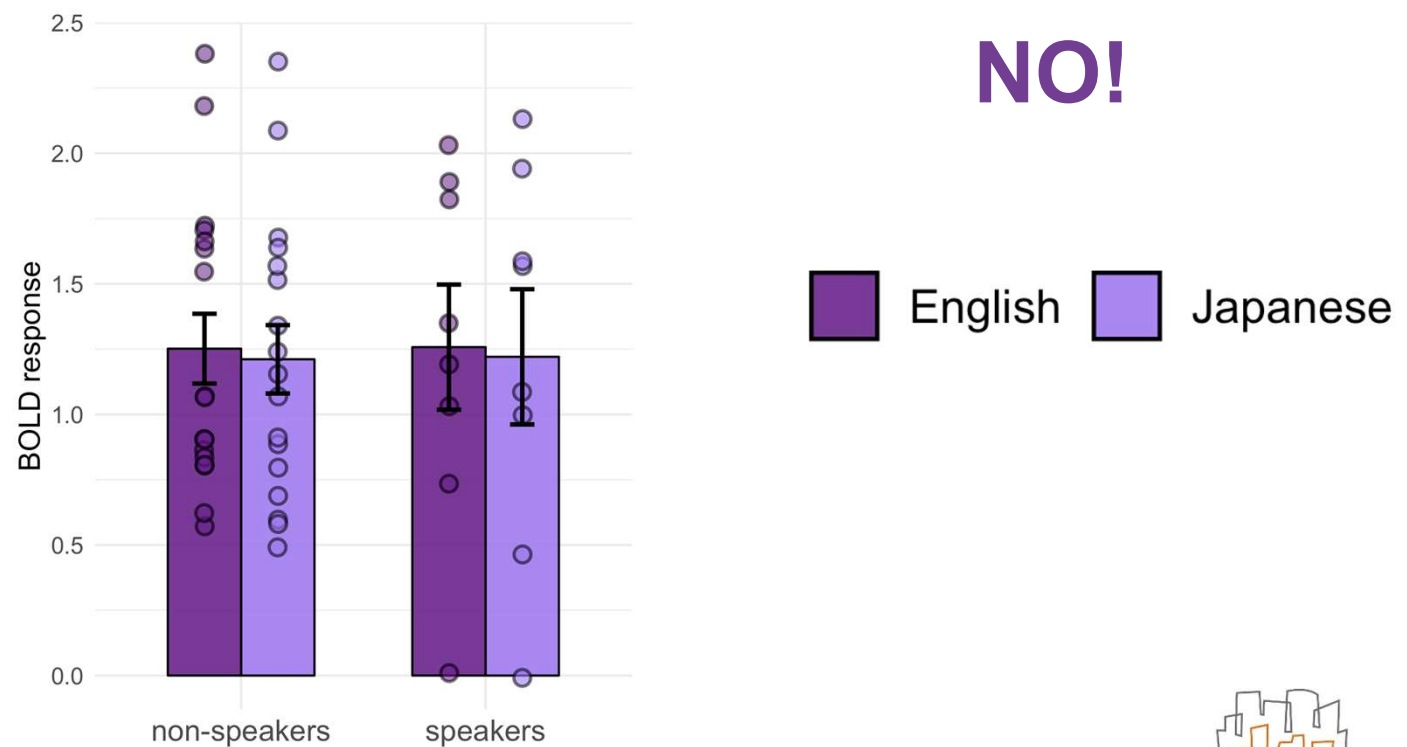


What do we see?

MD system



Do variable names contribute to the activity we see?



To conclude

- Fascinating area of research
- Lot many more questions to ask and answer
- We hope you are as intrigued by it as we are, and make a career finding answers to such questions!

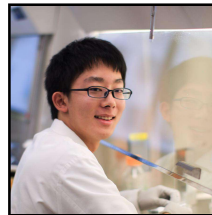
MIT

Tufts

Thanks!



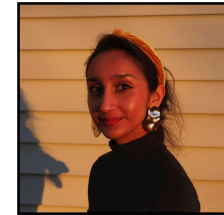
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Riva Dhamala

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Ev Fedorenko



Una-May O'Reilly



Marina Bers

Some slides adapted from Nancy Kanwisher's course on The Human Brain (9.17, 2019)



7 Nov 2019

