Language is distinct from thought in the human brain.

Art by Laura Bundesen
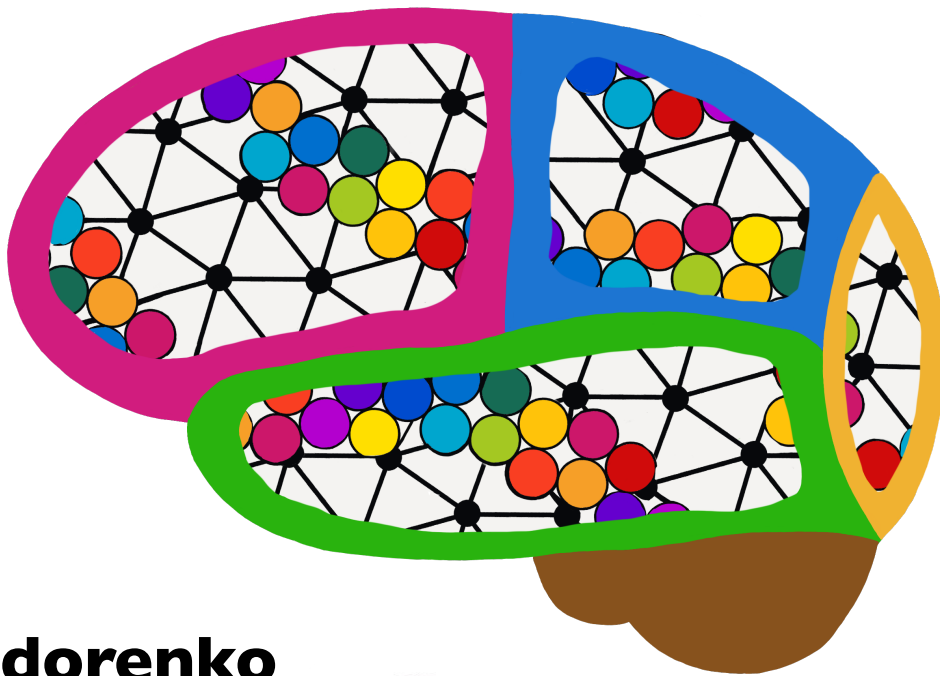
The Royal Society
Beyond the signals vs. symbols debate

London, UK

Ev Fedorenko
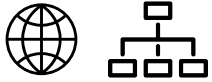October 28, 2024

Ev Lab

How to find us:
evlab.mit.edu
@ev_fedorenko
@evfedorenko.bsky.social

Concepts — the building blocks of thought

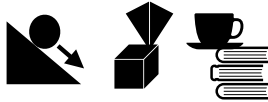**World knowledge + commonsense reasoning**

Spatial navigation

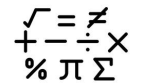**Numerical cognition**

Physical reasoning

Mathematical reasoning

Social reasoning / Theory of mind

Abstract problem solving

Music

Logic

Art

Executive functions

WHITE
BLACK

Intellectual / strategy games

Episodic memory and prospection

Building and programming machines

Planning + decision making

Scientific reasoning

Concepts — the building blocks of thought

World knowledge + commonsense reasoning

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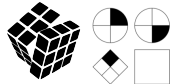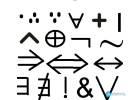
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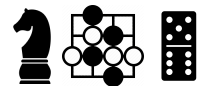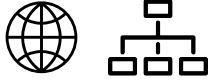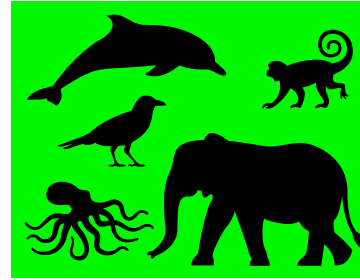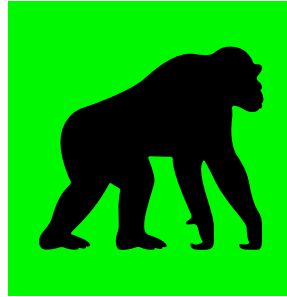
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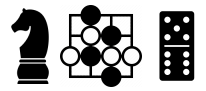**Social reasoning / Theory of mind**

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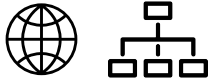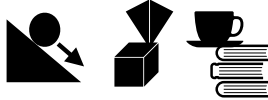Noam Chomsky

Concepts — the building blocks of thought

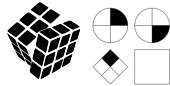World knowledge + commonsense reasoning

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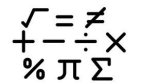Episodic memory and prospection

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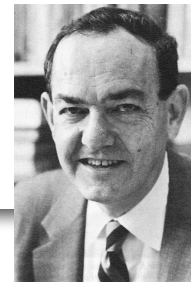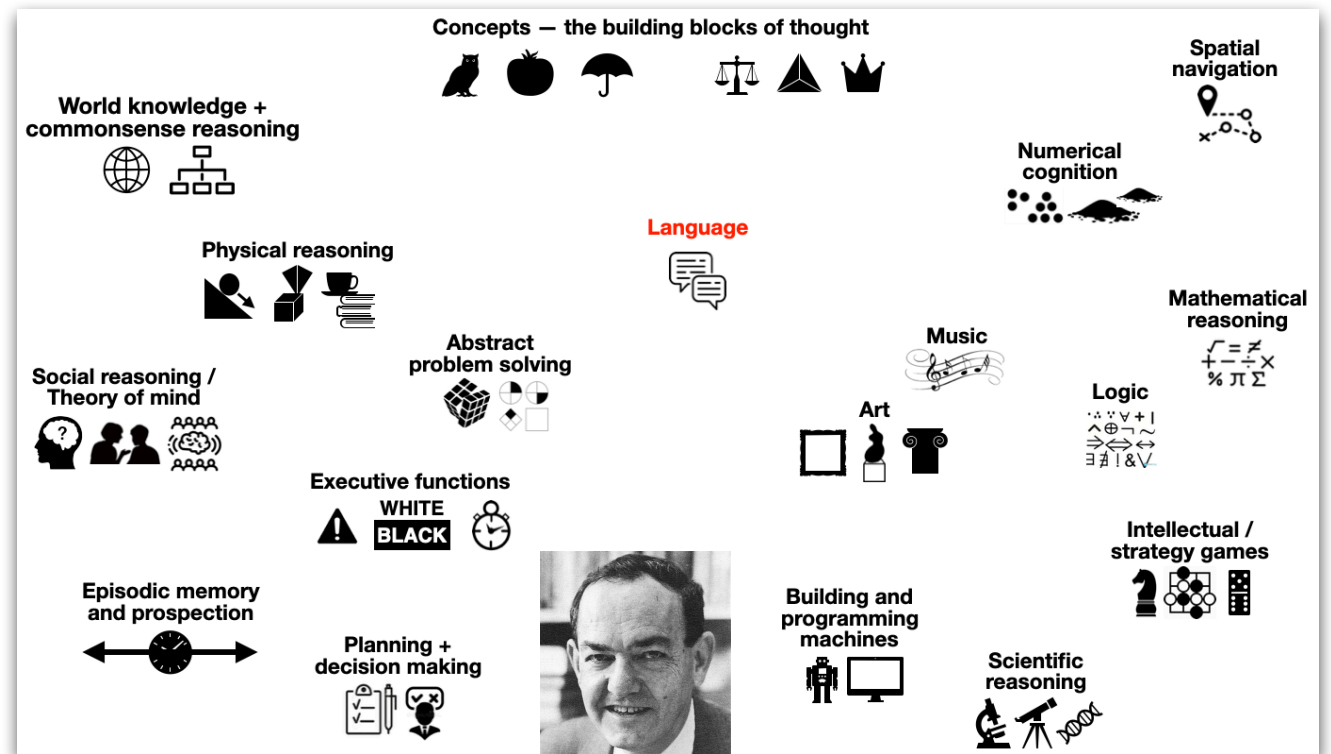
Herbert Simon

"nearly decomposable systems"

Today:

1 The human **language system**: Introduction and key properties

2 The relationship between **language and thought** in humans.
The **structure** of human thought.

3 The structure of cognition in humans: **Implications for AI.**

Today:

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The language system

Language > **Perceptually matched control**

Fedorenko et al. (2010, *J Neurophys*)

Sample individual language maps:
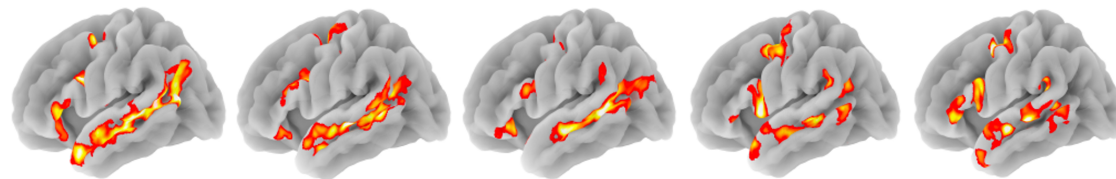
The language system

Activations are highly **stable** within individuals **over time**:

Sample participant 1

58 months   119 months

11/2007   09/2012   08/2022

Sample participant 2

8 months   36 months

08/2018   04/2019   04/2022
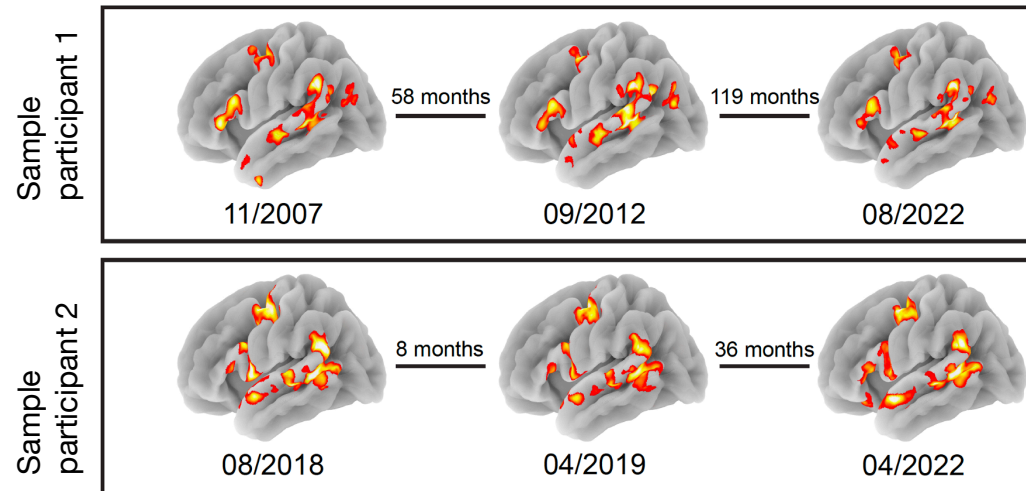
Mahowald & Fedorenko (2016, *NeuroImage*);
Lipkin et al. (2022, *Nat Sci Data*)

The language system

• robust response during
comprehension
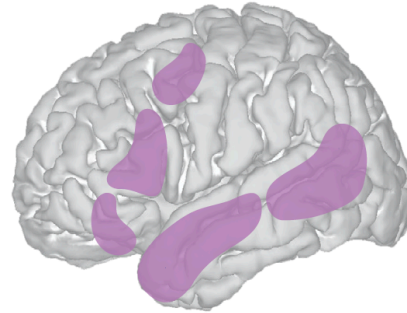
"encoder-decoder"

• robust response during
production

The language system

• robust response during **comprehension**

• robust response during **production**

"encoder-decoder"

The Classic Model

Broca's articulatory planning area
(planning oro-facial movements during speech production)

Sensorimotor cortex

Primary auditory cortex

Language network
(amodal language comprehension and production)

Broca's area
(language production)

Wernicke's area
(language comprehension)

Wernicke's speech perception area
(processing speech sounds during speech perception)

The language system

- robust response during **comprehension**

"encoder-decoder"

- robust response during **production**

- present and adult-like in topography in **children** (by 3-4y)

  Hiersche et al. (2023); Ozernov-Palchik, O'Brien et al. (2024); Olson et al. (in prep.)

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- similar **across languages** across and within speakers

Malik-Moraleda, Ayyash et al. (2022); Malk-Moraleda, Jouravlev et al. (2024)

Arabic   Korean
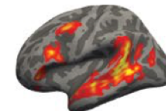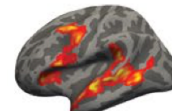
Czech   Gujarati

The language system

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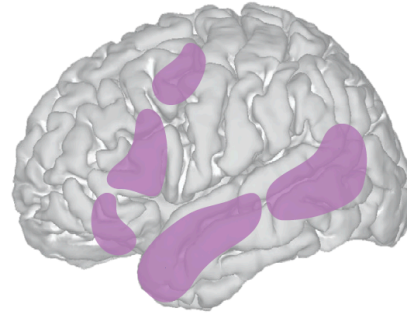
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Saima Malik-Moraleda

L2 (Japanese) · L2 (German) · L2 Mandarin · L1 (English)

L3 (French) · L3 (Spanish) · L4 (German) · L2 (Klingon)

The language system

- robust response during **comprehension**

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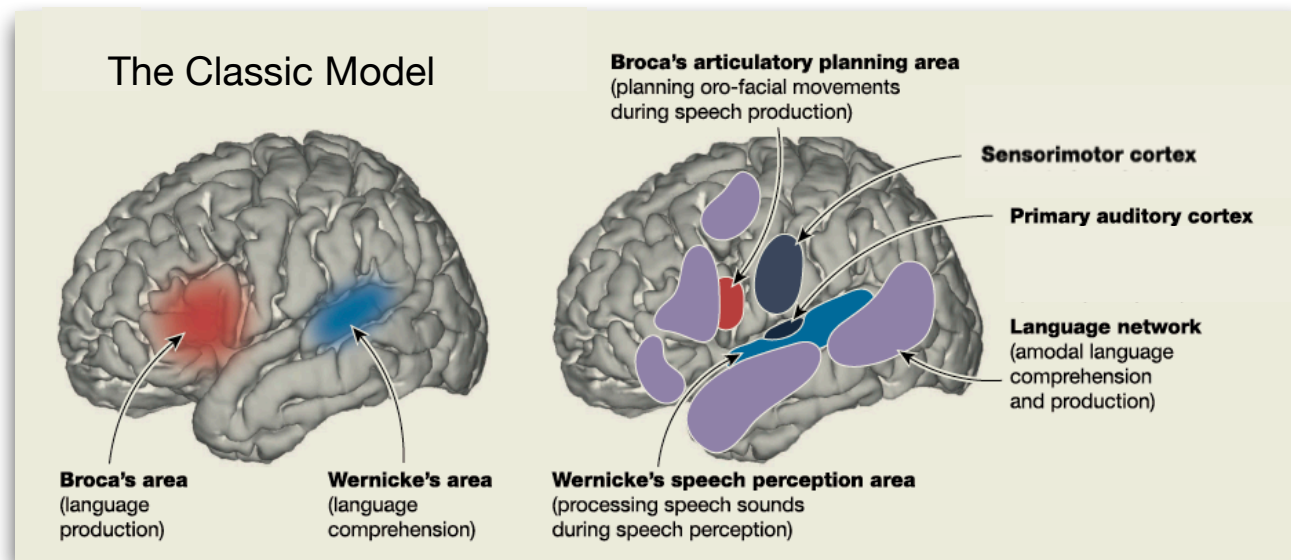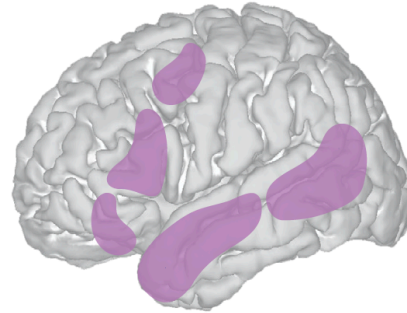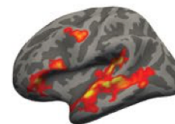- present and adult-like in topography in **children** (by 3-4y)

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- **causally** important for language function

a large body of work on aphasia

The language system

- robust response during **comprehension**

"encoder-decoder"

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To learn more:
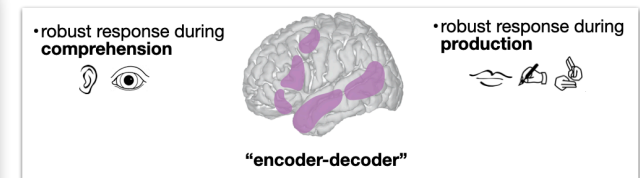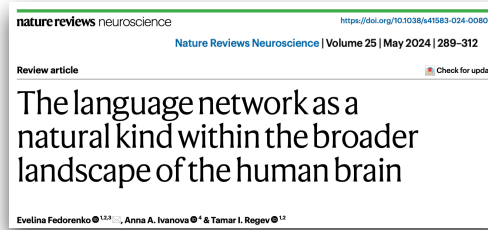
The language network as a natural kind within the broader landscape of the human brain

Evelina Fedorenko [1,2,3] ✉, Anna A. Ivanova [4] & Tamar I. Regev [1,2]

Today:

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- robust response during **comprehension**
- robust response during **production**

"encoder-decoder"

2 The relationship between **language and thought** in humans.

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"The systems of thought … use <u>linguistic expressions</u> for reasoning, interpretation, organizing action, and other mental acts."

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Noam Chomsky

How do we test this hypothesis?

Is the language system engaged when we think?

Response in the language areas

2+17=

? ? ?
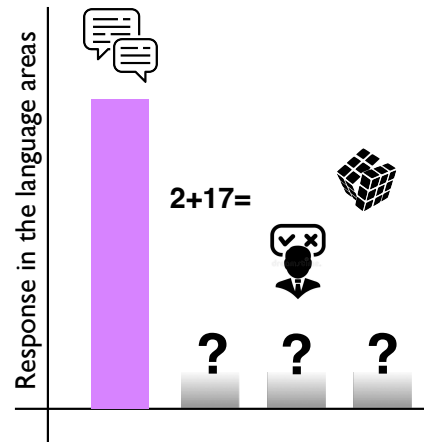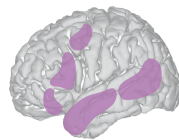
Language vs. thought (and other non-linguistic functions)

Language areas are highly **selective** relative to diverse **non-linguistic inputs and tasks**.

34 experiments, 79 conditions;
780 participants across 1,051 scanning sessions

% BOLD signal change

1 2 3

Language:
1 - Auditory sentence comprehension (listening)
2 - Visual sentence comprehension (reading)
3 - Spoken sentence production (speaking)

Speech perception
(syllables+nonwords)

Speech perception
(Foreign lang)

Letter perception
(Consonant strings+nonwords)

Articulation

Music perception

**Numerical
cognition**

**Executive
functions**

Fedorenko et al. (2011 PNAS);
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Pritchett et al. (2018 J Neurophys);
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Benn, Ivanova et al. (2023 Cer Cort);
Chen et al. (2023 Cer Cort), inter alia

Object semantics

Scene semantics

Event semantics

Face perception

Hand+body perception

Gesture perception

Action perception

Social event
perception

Theory
of mind

Language vs. thought (and other non-linguistic functions)

Language areas **show little/no response** when we engage in diverse thought-related activities.

Math
2+17=
56x3=

Executive
functions

World
knowledge

Social perc. +
reasoning

% BOLD signal change

1 2 3

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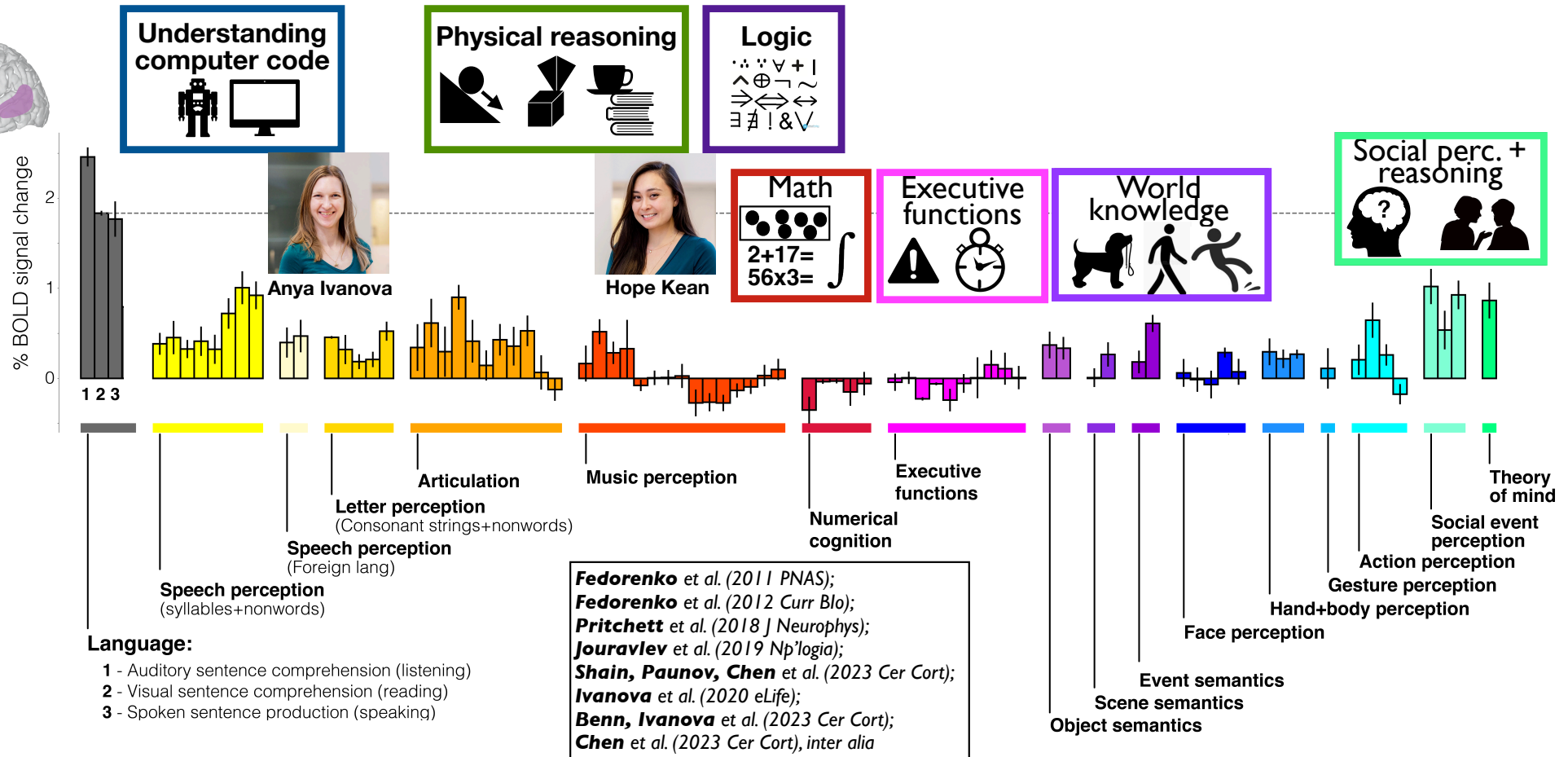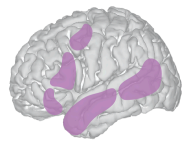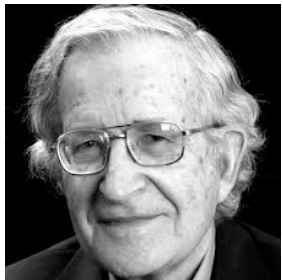
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Understanding computer code

Physical reasoning

Logic

Math
2+17=
56x3=

Executive functions

World knowledge

Social perc. + reasoning

Anya Ivanova

Hope Kean

% BOLD signal change

1 2 3

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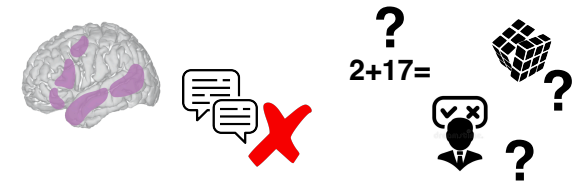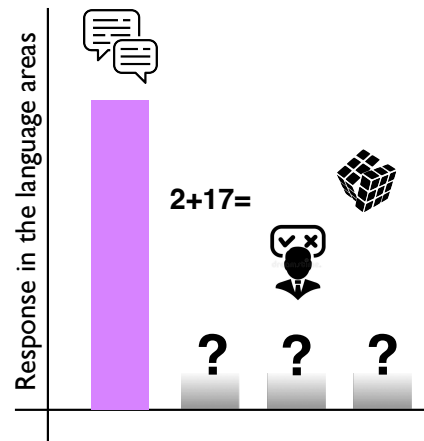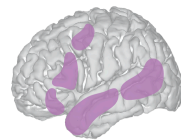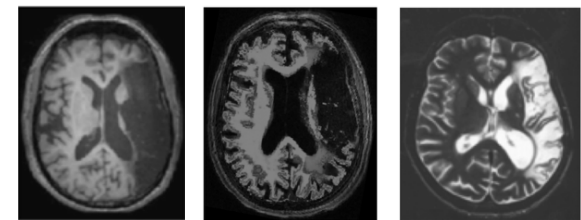
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Can we think without language?

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Sample lesions of patients with global aphasia:

Language vs. thought

World knowledge + commonsense reasoning ✓

Physical reasoning ✓

Social reasoning / Theory of mind ✓
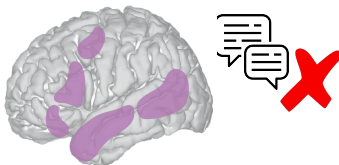
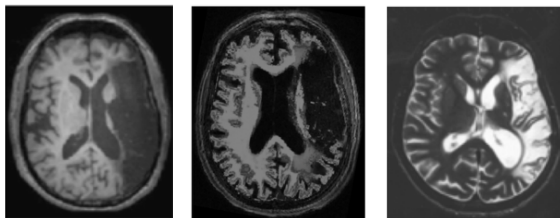**Abstract problem solving** ✓

Executive functions ✓

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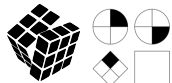
Episodic memory and prospection ✓

Planning + decision making ✓

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Spatial navigation ✓

Numerical cognition ✓

Music ✓

Mathematical reasoning ✓

Art ✓

Logic ✓

Scientific reasoning ✓

Intellectual / strategy games ✓

Rosemary Varley (UCL)

Anya Ivanova (Georgia Tech)

Hope Kean (MIT)
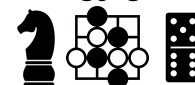
Fedorenko & Varley (2016 ANYAS);
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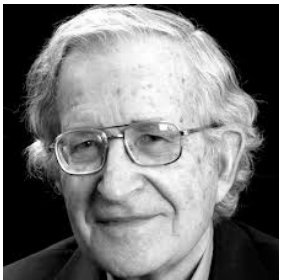
Noam Chomsky

Is the language system engaged when we think?

No

Can we think without language?

Yes

Language is a defining characteristic of our species, but the function, or functions, that it serves has been debated for centuries. Here we bring recent evidence from neuroscience and allied disciplines to argue that in modern humans, language is a tool for communication, contrary to a prominent view that we use language for thinking. We begin by introducing the brain network that supports linguistic ability in humans. We then review evidence for a double dissociation between language and thought, and discuss several properties of language that suggest that it is optimized for communication. We conclude that although the emergence of language has unquestionably transformed human culture, language does not appear to be a prerequisite for complex thought, including symbolic thought. Instead, language is a powerful tool for the transmission of cultural knowledge; it plausibly co-evolved with our thinking and reasoning capacities, and only reflects, rather than gives rise to, the signature sophistication of human cognition.

The structure of thought

World knowledge + commonsense reasoning
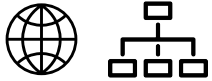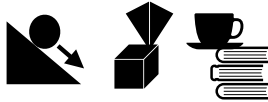
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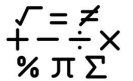
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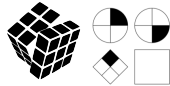
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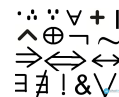
Intellectual / strategy games
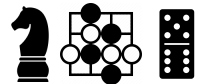
Episodic memory and prospection

Building and programming machines

Planning + decision making

Scientific reasoning

The structure of thought

Multiple demand network
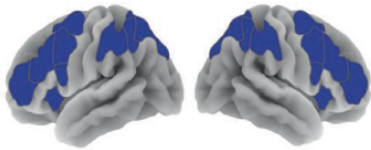
e.g., Duncan (2010); Assem et al. (2020)

Numerical cognition

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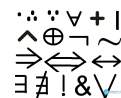
Building and programming machines

The structure of thought

Theory of mind network

e.g., Saxe & Kanwisher (2003)

Social reasoning / Theory of mind

Abstract problem solving

Executive functions

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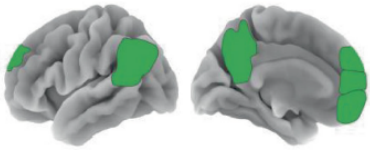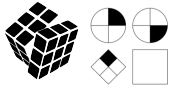**Numerical cognition**

Mathematical reasoning
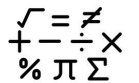
Logic

Building and programming machines

The structure of thought

Default network

Broadly similar areas as the Theory of Mind network, but robustly dissociable within individuals.

Braga & Buckner (2017)

Default

Theory of Mind

Numerical cognition

Mathematical reasoning

Logic

Social reasoning / Theory of mind

Abstract problem solving

Executive functions

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Episodic memory and prospection

Spatial navigation

Building and programming machines
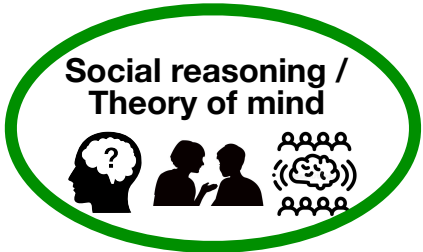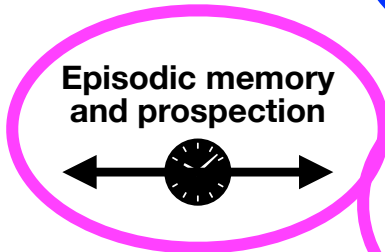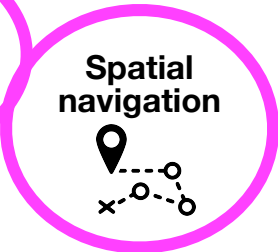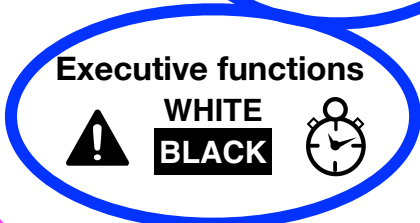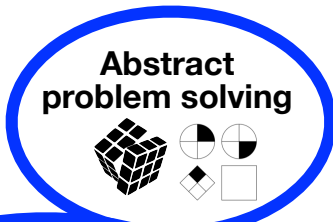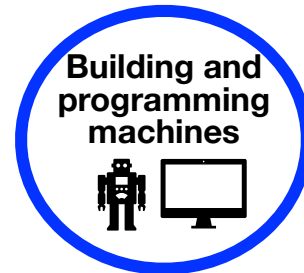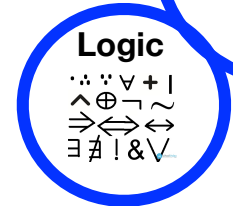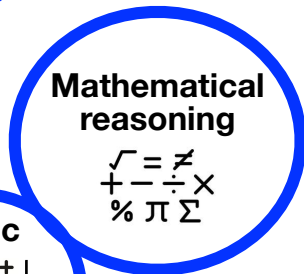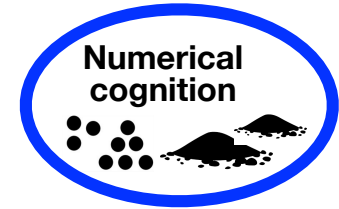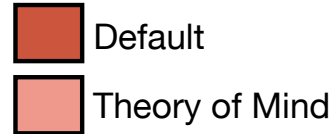
The structure of thought

Fischer et al. (2016)

Physical reasoning

Social reasoning / Theory of mind

Abstract problem solving

Executive functions
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Episodic memory and prospection

Spatial navigation
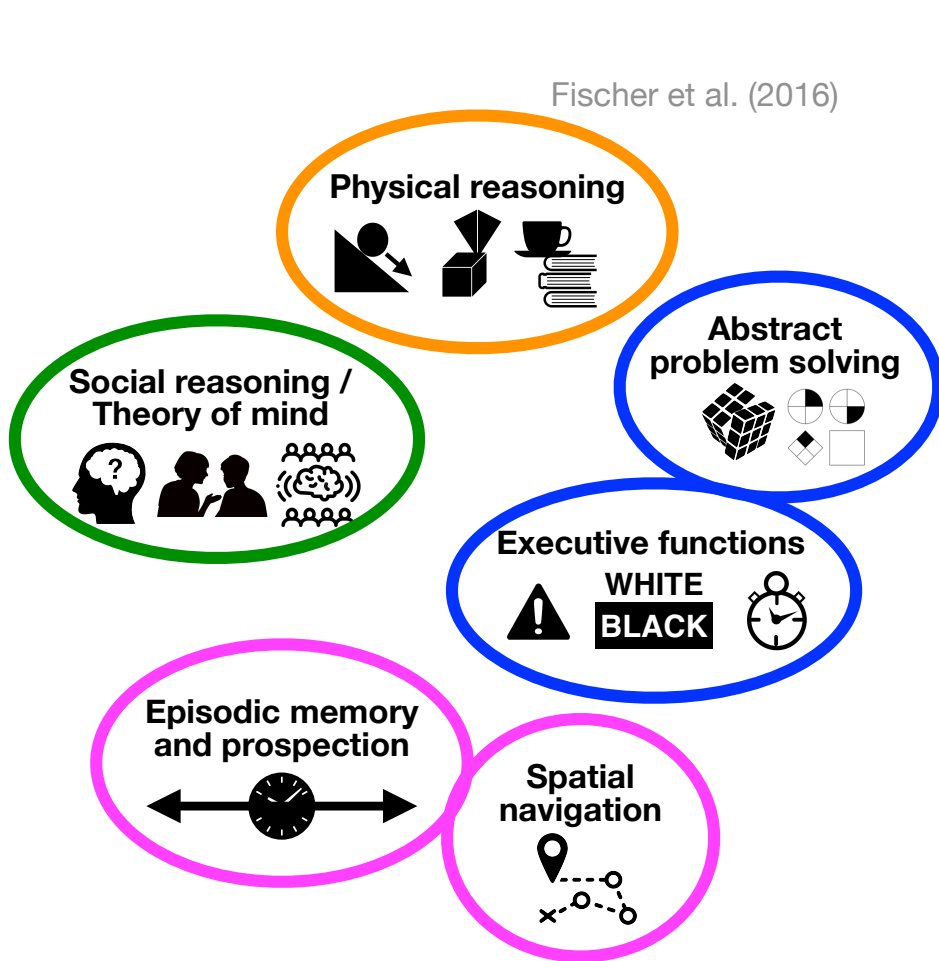
Pramod et al. (in prep.)

Numerical cognition

Causal reasoning

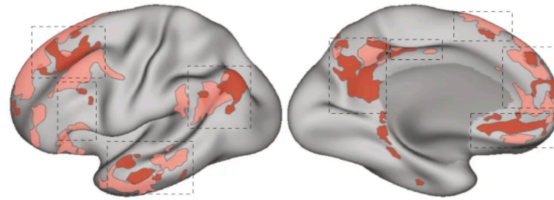**Mathematical reasoning**

Logic

Kean et al. (in prep.)

Deductive reasoning

Building and programming machines
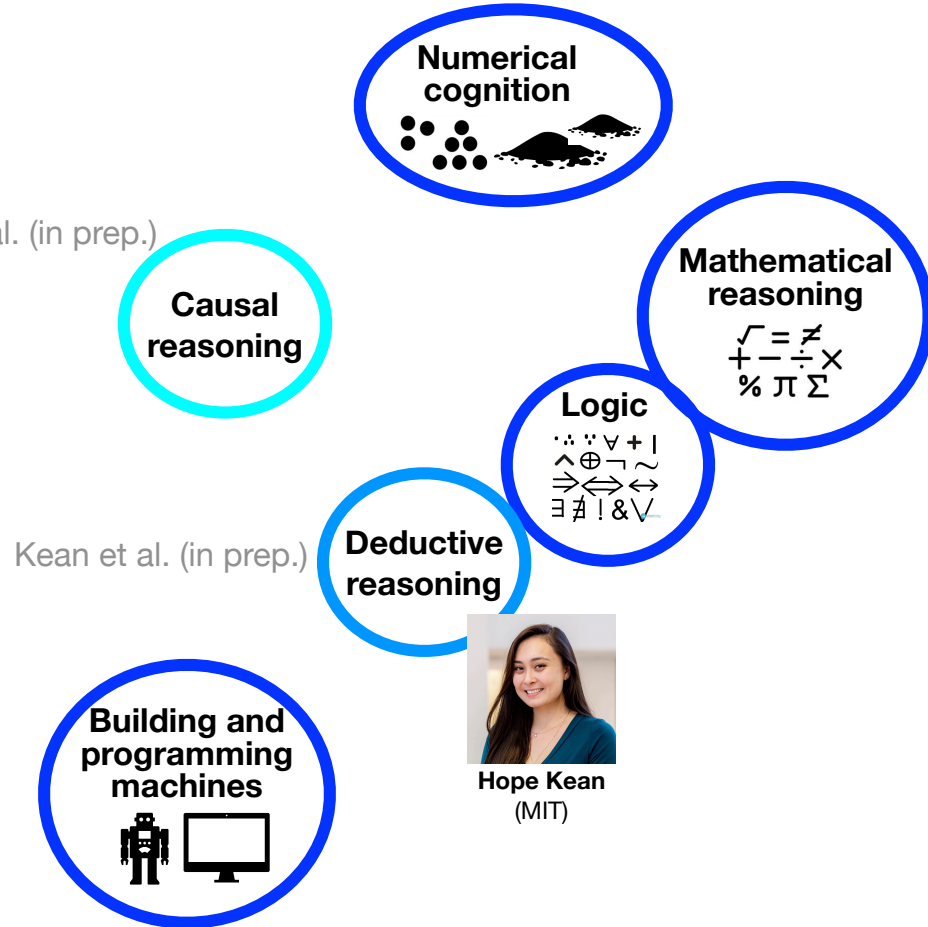
Hope Kean
(MIT)

Formal vs. functional linguistic competence

Feature Review

Dissociating language and thought in large language models

Kyle Mahowald[1,5,*], Anna A. Ivanova[2,5,*], Idan A. Blank[3,*], Nancy Kanwisher[4,*], Joshua B. Tenenbaum[4,*], and Evelina Fedorenko[4,*]

Kyle Mahowald
(UT Austin)

Anya Ivanova
(Georgia Tech)

Formal vs. functional linguistic competence

Formal linguistic competence:

- knowledge of **sounds**

- knowledge of **words**

- knowledge of **rules**

- knowledge of **non-rule-like regularities (constructions)**

Language network:
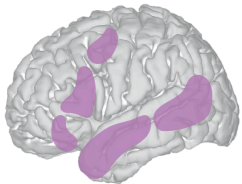
Functional linguistic competence:

- **using** language in the **world**

Language network working with other, non-language-specific cognitive networks

Theory of Mind network

Default Network

Multiple Demand network
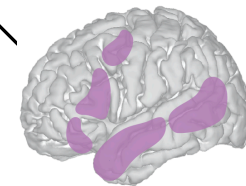
??Network

??Network

Formal vs. functional linguistic competence

Theory of Mind network

- recruited during some aspects of **non-literal** language comprehension
- supports the processing of **conversation**
- processes particular **content** (e.g., related to mental states)
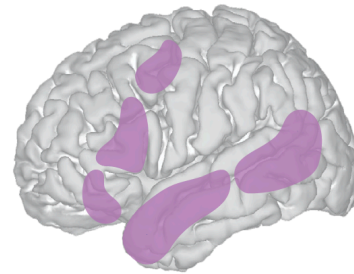
Default Network

- supports the processing of **discourse-level** structure
- may process particular **content** (spatial information)

Multiple Demand network

- recruited in the presence of **task demands**
- processes particular **content** (e.g., mathematical statements)
- supports some cases of **effortful** language comprehension

Today:

1 The human **language system**: Introduction and key properties

nature reviews neuroscience — https://doi.org/10.1038/s41583-024-00802-4
Nature Reviews Neuroscience | Volume 25 | May 2024 | 289–312
Review article

The language network as a natural kind within the broader landscape of the human brain

Evelina Fedorenko, Anna A. Ivanova & Tamar I. Regev

- robust response during **comprehension**
- robust response during **production**

"encoder-decoder"

2 The relationship between **language and thought** in humans.
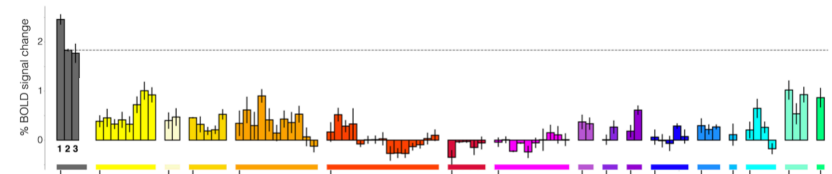
3 The structure of cognition in humans: **Implications for AI.**

Implications for how we think about and build AI

Formal linguistic competence:

- knowledge of **sounds**
- knowledge of **words**
- knowledge of **rules**
- knowledge of **non-rule-like regularities (constructions)**

???

Language models

Functional linguistic competence:

- **using** language in the **world**

Implications for how we think about and build AI

Formal linguistic competence:

✅

- knowledge of **sounds**
- knowledge of **words**
- knowledge of **rules**
- knowledge of **non-rule-like regularities (constructions)**

No longer ~~WHY~~ ONLY US

LANGUAGE AND EVOLUTION

Robert C. Berwick · Noam Chomsky

???

Language models

Output Probabilities

Softmax

Linear

Add & Norm

Feed Forward

Add & Norm

Feed Forward

Add & Norm

Multi-Head Attention

Add & Norm

Multi-Head Attention

Nx

Add & Norm

Masked Multi-Head Attention

Nx

Positional Encoding

Positional Encoding

Input Embedding

Output Embedding

Inputs

Outputs (shifted right)

Functional linguistic competence:

- **using** language in the **world**

Implications for how we think about and build AI

Formal linguistic competence:

- knowledge of **sounds**
- knowledge of **words**
- knowledge of **rules**
- knowledge of **non-rule-like regularities (constructions)**

???

Language models

Functional linguistic competence:

- **using** language in the **world**

Annual Review of Neuroscience

ANNUAL REVIEWS

Language in Brains, Minds, and Machines

Greta Tuckute, Nancy Kanwisher, and Evelina Fedorenko

Department of Brain and Cognitive Sciences and McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA; email: evelina9@mit.edu

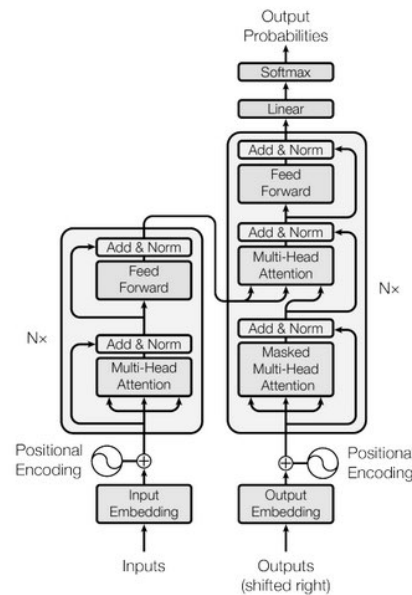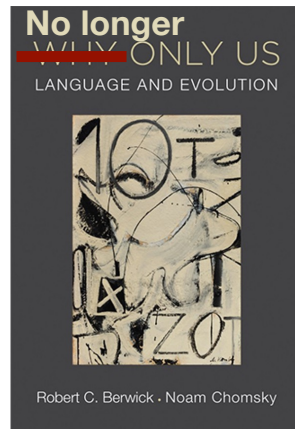# Implications for how we think about and build AI

Formal linguistic competence: ✅

- knowledge of **sounds**
- knowledge of **words**
- knowledge of **rules**
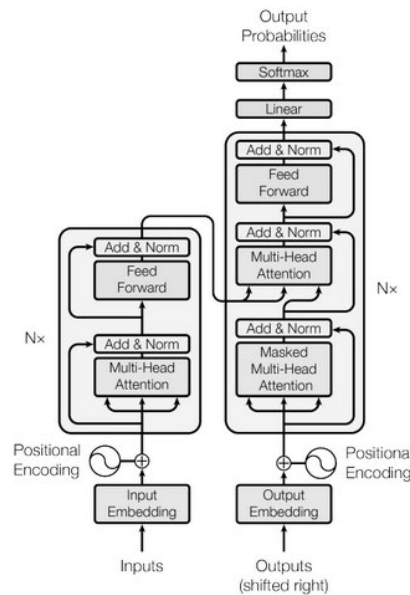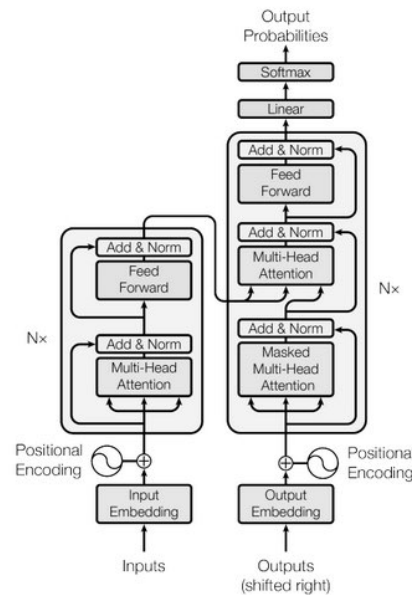- knowledge of **non-rule-like regularities (constructions)**
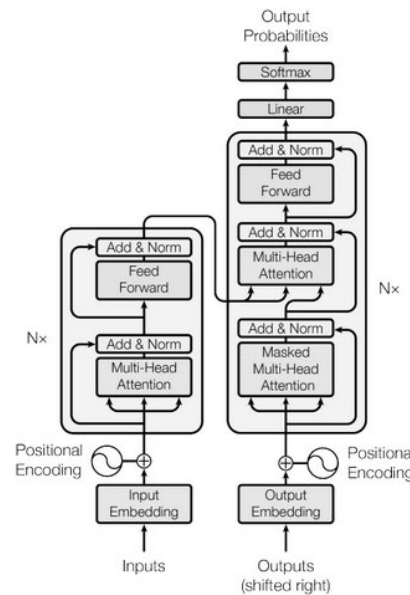
???

Language models

? **Functional** linguistic competence:

- **using** language in the **world**

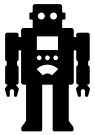**Many demonstrations of world/domain knowledge and reasoning,**

but these abilities lack robustness and generalizability.

Implications for how we think about and build AI

Why do we want to get to human-level AI?

To build smarter machines:

- better, more rigorous **evaluations** (control conditions!)
- understand not just whether a model can do x, but **why** it succeeds or fails (*circuit analysis tools*)

- **approaches to making models better:**
  - scaling
  - taking inspiration from the human brain (e.g., **neurosymbolic** approaches, building in **modularity**, or testing for **emergent modularity** in the end-to-end systems)

  Are there multiple ways to build intelligence?

To understand how the brain works:

- build more **biologically** and **cognitively plausible** models of language and cognition
  - **biological** plausibility: modularity, recurrence, more complex neurons, wiring length costs
  - **cognitive** plausibility: memory constraints, learning from less data (i.e., developmental plausibility)

Cool new opportunites:
- distill the necessary and sufficient features for an LM to align with human behavior / neural data
- test how far language statistics can take you
- evaluate inter-system interaction (questions for which no great tools exist in neuroscience)

Take-aways:

Language and thought are robustly **distinct** in the human brain.

Language is supported by a **specialized** brain network.
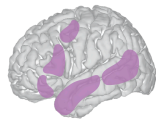
Different aspects of **thought** rely on several distinct networks, but the ontology of thought requires more work.

The language system and the systems of thought have to **work together** to enable real-life language use.
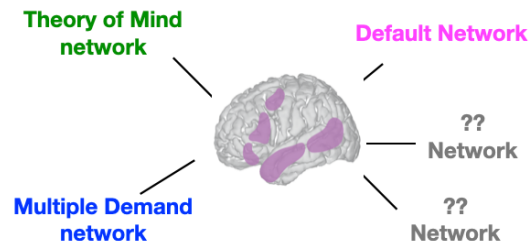
LLMs have masted **formal** linguistic competence

but struggle with **functional** linguistic competence.

nature reviews psychology · https://doi.org/10.1038/s44159-024-00283-3

Perspective · Check for updates

Uniquely human intelligence arose from expanded information capacity

Jessica F. Cantlon [1,2] & Steven T. Piantadosi [3,4]

Theory of Mind network · Default Network · Multiple Demand network · ?? Network · ?? Network

Thank you!

My amazing labbies!

Not pictured current/incoming members:
Halie Olson, Sara Swords, Alex Fung, Selena She,
Agata Wolna, Chiebuka Ohams, Anvitha Kachinthaya,
Aaron Wright, Kumar Duraivel

Former labbies:

- Idan Blank
- Alex Paunov
- Zuzanna Balewski
- Olessia Jouravlev
- Terri Scott
- Zach Mineroff
- Bri Pritchett
- Caitlyn Hoeflin
- Melissa Kline
- Nafisa Syed
- Moataz Assem
- Jeanne Gallée
- Dima Ayyash
- Yev Diachek
- Matt Siegelman
- Yotaro Sueoka
- Jessica Chen
- Alvincé Pongos
- Miriam Hauptman
- Rachel Ryskin
- Josef Affourtit
- Hannah Small
- Maya Taliaferro
- Sammy Floyd
- Anna Ivanova
- Aalok Sathe
- Hee So Kim
- Niharika Jhingan
- Carina Kauf
- Chengxu Zhuang
- Cory Shain

Select collaborators:

- **Nancy Kanwisher**
- **Ted Gibson**
- **Steve Piantadosi**
- **Kyle Mahowald**

- Jacob Andreas
- Anne Billot
- Peter Brunner
- Anila D'Mello
- Simon Fisher
- John Gabrieli
- Swathi Kiran
- Roger Levy
- Frank Mollica
- Alfonso Nieto-Castañón
- Sam Norman-Haignere
- Amanda O'Brien
- Ola Ozernov-Palchik
- Mark Richardson
- Rebecca Saxe
- Zeynep Saygin
- Martin Schrimpf
- Josh Tenenbaum
- Rosemary Varley
- Maria Varkanitsa
- Noga Zaslavsky

Funding support:

NIH NIDCD · NIH NICHD · NIH NINDS

MCGOVERN INSTITUTE

SCSB Simons Center for the Social Brain

K. Lisa Yang ICoN Center

brain+cognitive sciences

MIT Quest for Intelligence

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