Informatics 1 Cognitive Science

Lecture 2: Introduction to Cognitive Science

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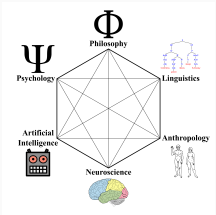
Overview

Cognitive Modelling

Cognitive Technology

Is Language a Cognitive Technology?

Recap



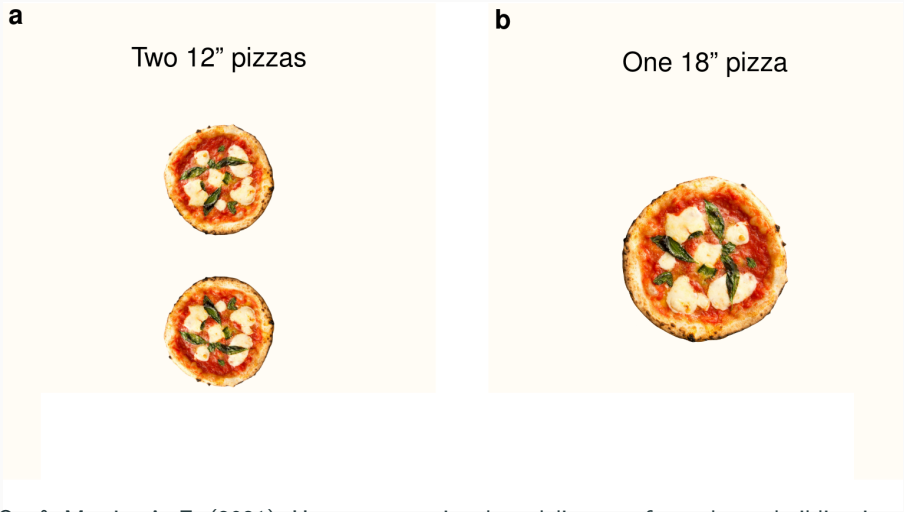
Central to cognitive science are **mental representations and processes:**

- A mental representation is a description of information in the mind.
- A mental process is a procedure for translating:
  - sensory information into representations;
  - representations into other representations; and
  - representations into actions/behavior.

Computational modeling can be used to **evaluate theories, generate new hypotheses, guide the collection of new data.**

Cognitive Modelling

The Pizza Problem



Guest, O., & Martin, A. E. (2021). How computational modeling can force theory building in psychological science. Perspectives in Psychological Science 16(4), 789–802. Listen to the talk here.

The Pizza Problem

a

Two 12” pizzas

$$\text{Area} = 2 \times \pi 6^2 = 226\,\text{in}^2$$

b

One 18” pizza

$$\text{Area} = \pi 9^2 = 254\,\text{in}^2$$

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A Model of Pizza Selection

The amount of food in a order of N_i pizzas with a radius of R_i is:

$$\Phi_i = N_i \pi R_i^2$$

The function to decide between two orders is:

$$\omega(\Phi_i, \Phi_j) = \begin{cases} i, & \text{if } \Phi_i > \Phi_j \\ j, & \text{otherwise} \end{cases}$$

```
import numpy as np
def food(ds):
  return (np.pi * (ds/2)**2).sum()
# Order option a, two 12'' pizzas:
two_pizzas = np.array([12, 12])
# Option b, one 18'' pizza:
one_pizza = np.array([18])
# Decision rule (eq. 2):
print(food(two_pizzas) >
food(one_pizza))
```

Why Cognitive Modelling?

According to Guest and Martin, computational modeling:

- takes a verbal description and formalises it to make it implementable
- forces us to make a theory explicit and to specify its scope, its assumptions and its computational repercussions
- improves theories by uncovering aspects that are not well specified or ambiguous
- stops us from atheoretically testing hypotheses
- allows us to systematically compare theories and generate new hypotheses

Cognitive modeling is **a multi-step process**.

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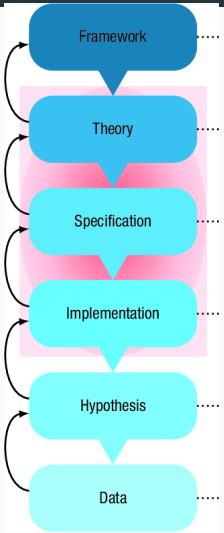
What is Cognitive Modelling?

Guest and Martin analyze this process as:



What is Cognitive Modelling?

Framework: A conceptual system of building blocks for creating simulations of complex psychological systems. Described in natural language or diagrams. (concepts of pizza, food, an order)

Theory: A scientific proposition—described by natural language, mathematics, logic, diagrams—that introduces causal relations with the aim of describing, explaining, or predicting a set of phenomena. (number of pizzas=food / or post-hoc area of pizza=food)

Specification: A formal description of a system to be implemented based on a theory. It provides a means of discriminating between theory-relevant claims and theory-irrelevant auxiliary assumptions. It constraints the space of possible computational models. (equations for area and decision rule)

What is Cognitive Modelling?

Implementation: An instantiation of a model created using anything from physical materials, e.g., a scale model or software. (Python code for pizza decision)

Hypothesis: A narrow testable statement. Hypotheses in psychology focus on properties of the world that can be measured and evaluated by collecting data and running inferential statistics. Any sentence that is directly testable by statistical means can be a hypothesis. (e.g., "two 12" pizzas is more food").

Data: Observations collected from the "real world" or from a computational model. (e.g. weight of order)

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Let's look at an example for language acquisition.

What is Cognitive Modelling?

Data
"I eated the cheerios."

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Theory
Words and Rules

Framework
Sympol Manipulation vs. Neural Networks

What is Cognitive Modelling?

Framework
Productivity & Reuse vs Connectionism

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Implementation
`def past_tense(verb): return verb + 'ed'`

Hypothesis
The child will say "seeed" more than "saw."

The child will say "helped" more than "helpen."

Cognitive Technology

Innate Instincts vs Cognitive Gadgets

Cecilia Heyes' (2019) theory of "cognitive gadgets":

- Psychologists have previously posited a set of **innate cognitive instincts:** imitation, mind reading, language, etc.
- however, the evidence for the innateness of these cognitive abilities is disputed;
- we can instead assume that they are the result of **general learning mechanisms**;
- what is learned are **culturally transmitted** capabilities: cognitive technologies or cognitive gadgets, examples: navigation, food chains, kinship systems;
- cultural transition happens through interaction and communication.
- Research should focus on learning mechanisms and developmental environments, not on search for innate modules.
- Is language itself a cognitive technology?

What is a Cognitive Technology?

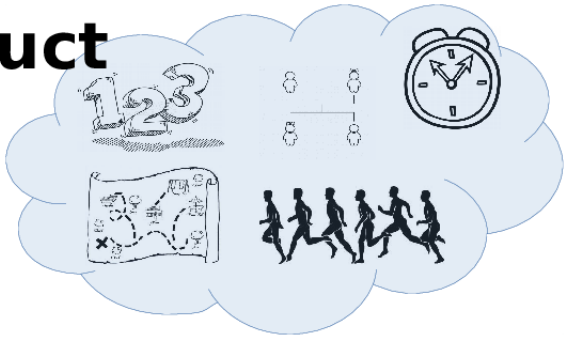
We humans have **created** not just physical machines . . . but also mental machines; mechanisms of thought, embodied in our nervous systems, that enable our minds to go further, faster, and in different directions than the minds of any other animals . . . They are "gadgets," rather than "instincts" because, like many physical devices, they are products of **cultural rather than genetic evolution**. New cognitive mechanisms—different ways of thinking—have emerged, not by genetic mutation, but by innovations in **cognitive development**. (Heyes, 2019, p. 1)

What is a Cognitive Technology?

What is a Cognitive Technology?

“Three koalas”

Construct



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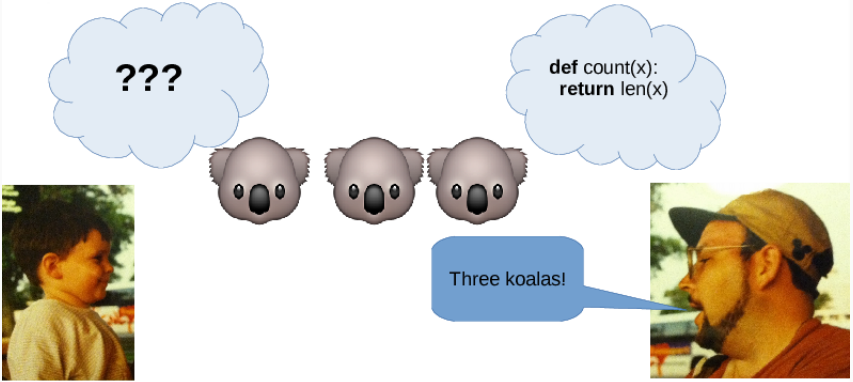

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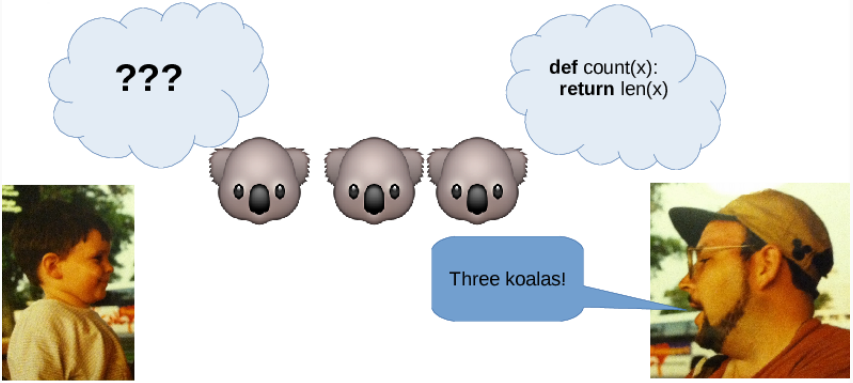

- Cognitive technology: the representations and processes
- Cognitive artifact: the linguistic signal
- Environment: the koalas and the teacher

What is a Cognitive Technology?

Time for a short quiz!

Is Language a Cognitive Technology?

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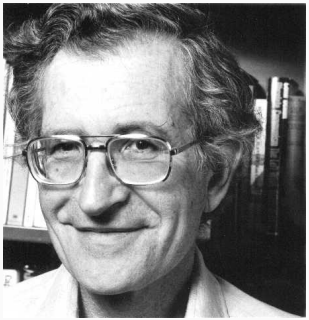


A human language is a system of **remarkable complexity.** To come to know a human language would be an extraordinary intellectual achievement for a creature not **specifically designed** to accomplish this task. A normal child acquires this knowledge on relatively slight exposure and without specific training. He can then quite effortlessly make use of an **intricate structure of specific rules** and guiding principles to convey his thoughts and feelings to others, arousing in them novel ideas and subtle perceptions and judgments. (Chomsky, 1975, p. 4)

Is Language a Cognitive Technology?

A few potential sources of evidence to consider:

- Genetic and neuroscientific evidence
- Animal communication
- Linguistic universals and diversity
- Acquisition: critical periods

Is Language a Cognitive Technology?

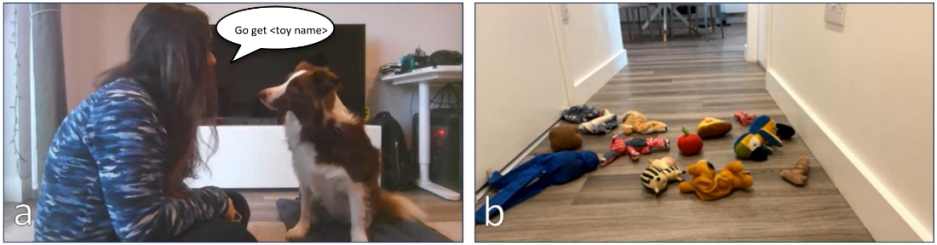


Figure 2: the setup during the test. a - the owner is sitting with the dog in one room. b - the toys are placed in a different room, out of the owner's view.

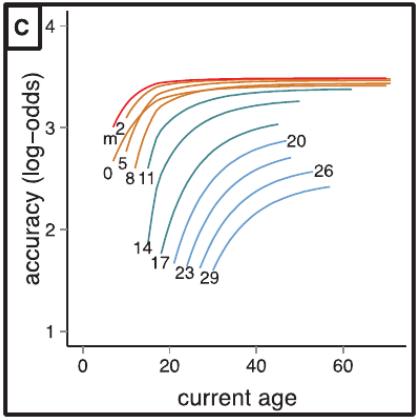
Shany Dror et al., Dogs with a large vocabulary of object labels learn new labels by overhearing like 1.5-year-old infants. Science 391,160-163 (2026).
https://www.science.org/doi/10.1126/science.adq5474

Is Language a Cognitive Technology?

There is a **critical period** in development during which a language can be acquired like a native speaker.

- child vs. adult language learning
- native vs. non-native speakers
- age of immigration and language ability
- arrive before age 6 $\rightarrow$ generally pass as native speakers
- arrive after puberty $\rightarrow$ generally do not pass as native speakers
- Evidence: "feral children", "wolf children", "attic children" growing up with minimal human contact - late first exposure to language and deprivation can lead to lasting language difficulties.

Is Language a Cognitive Technology?



Red: monolinguals; orange: age of exposure: 0–9 years old;

green: AoE 10–19; blue: AoE 20–30.

A critical period for second language acquisition: Evidence from 2/3 million English speakers, J.K. Hartshorne, J.B. Tenenbaum, S. Pinker. Cognition 177 (2018), 263–277.

Summary

- **Why cognitive modelling? (Guest & Martin)**
  - Formalises verbal theories so they are **implementable**.
  - Forces explicit assumptions, scope, and computational consequences.
  - Reveals ambiguity/underspecification; improves theory quality.
- **Heyes: instincts vs cognitive gadgets (cognitive technology)**
  - Many proposed "innate instincts" (imitation, mindreading, language) are disputed.
  - Alternatives: **generalised learning** + **cultural transmission** build cognitive capacities.
- **Is language a cognitive technology?**
  - **Chomsky:** specialised design, but this is debated
  - **Critical/sensitive period:** earlier exposure predicts more native-like outcomes