

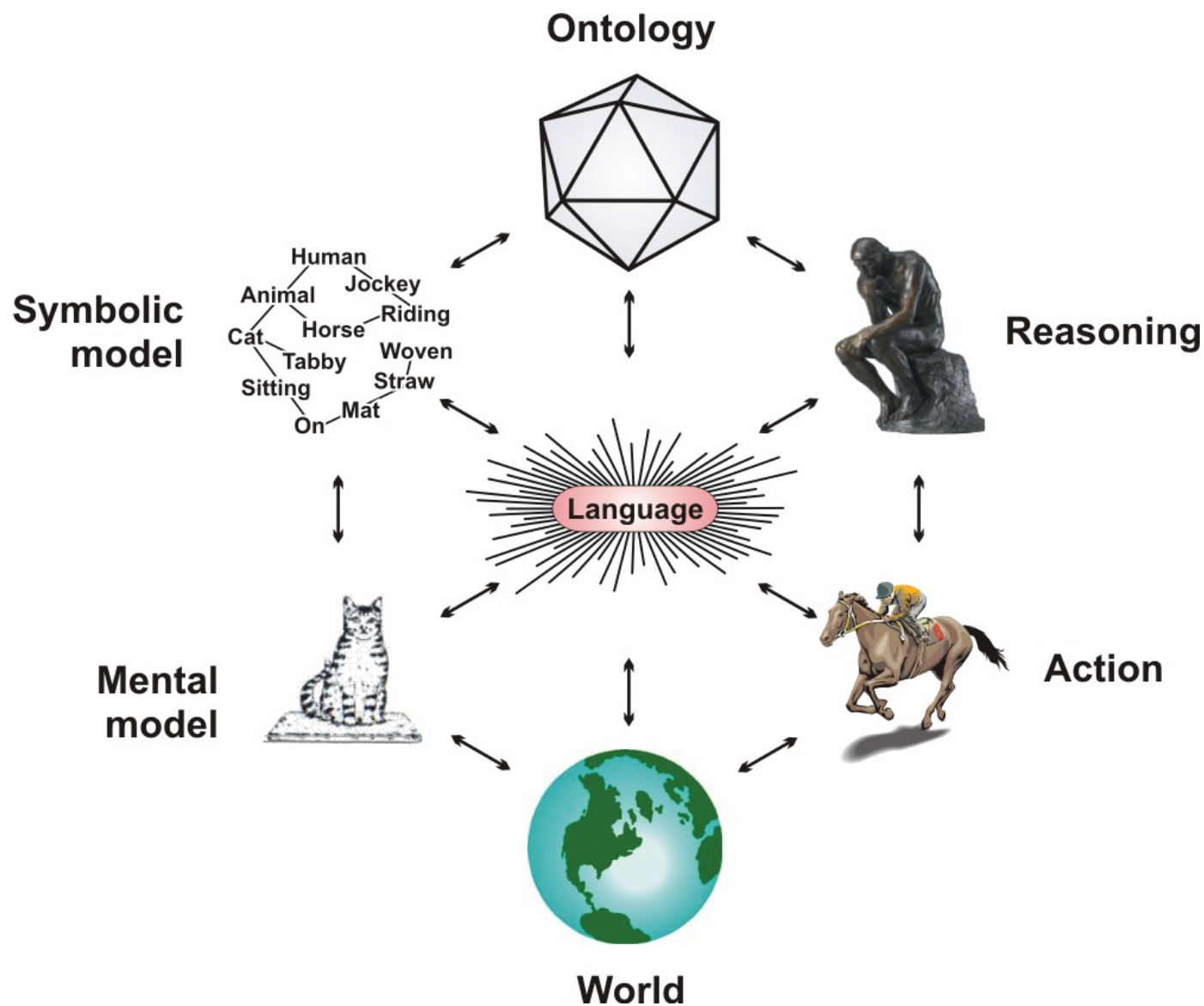
Neurocognitive Computation With the Logic Virtual Machine

Part 1: John F. Sowa

Part 2: Arun K. Majumdar

Part 3: Open discussion

31 August 2022



Challenge: Every aspect of AI has different kinds of data and operations. And they must all be mapped to and from one another and the natural languages that people speak.

Implementing the Hexagon

The corners of the hexagon represent aspects of knowledge.

- 1. The world is everything we encounter in space and time.**
- 2. Mental models represent everything we experience or imagine.**
- 3. Symbolic models consist of words related by words to other words.**
- 4. Ontology is a catalog of words and the kinds of things they refer to.**
- 5. Reasoning includes all our ways of thinking about anything.**
- 6. Action is what our thinking leads us to do in and on the world.**

Natural languages represent conscious knowledge.

- They can represent and relate all six corners of the hexagon.**
- Every artificial language, notation, or diagram is a simplified or stylized version of something that could be said in a natural language.**
- But the nervous system contains an enormous amount of unconscious knowledge that supports the basic operations of the human body.**

Challenge: Implement AI tools to support all the above.

VivoMind (2000 to 2010)

Cognitive Memory: a key component of VivoMind technology.

- Approximate pattern matching for analogies and metaphors.
- Associative storage and retrieval of graphs in $\log(N)$ time.
- Precise pattern matching for logic and mathematics.

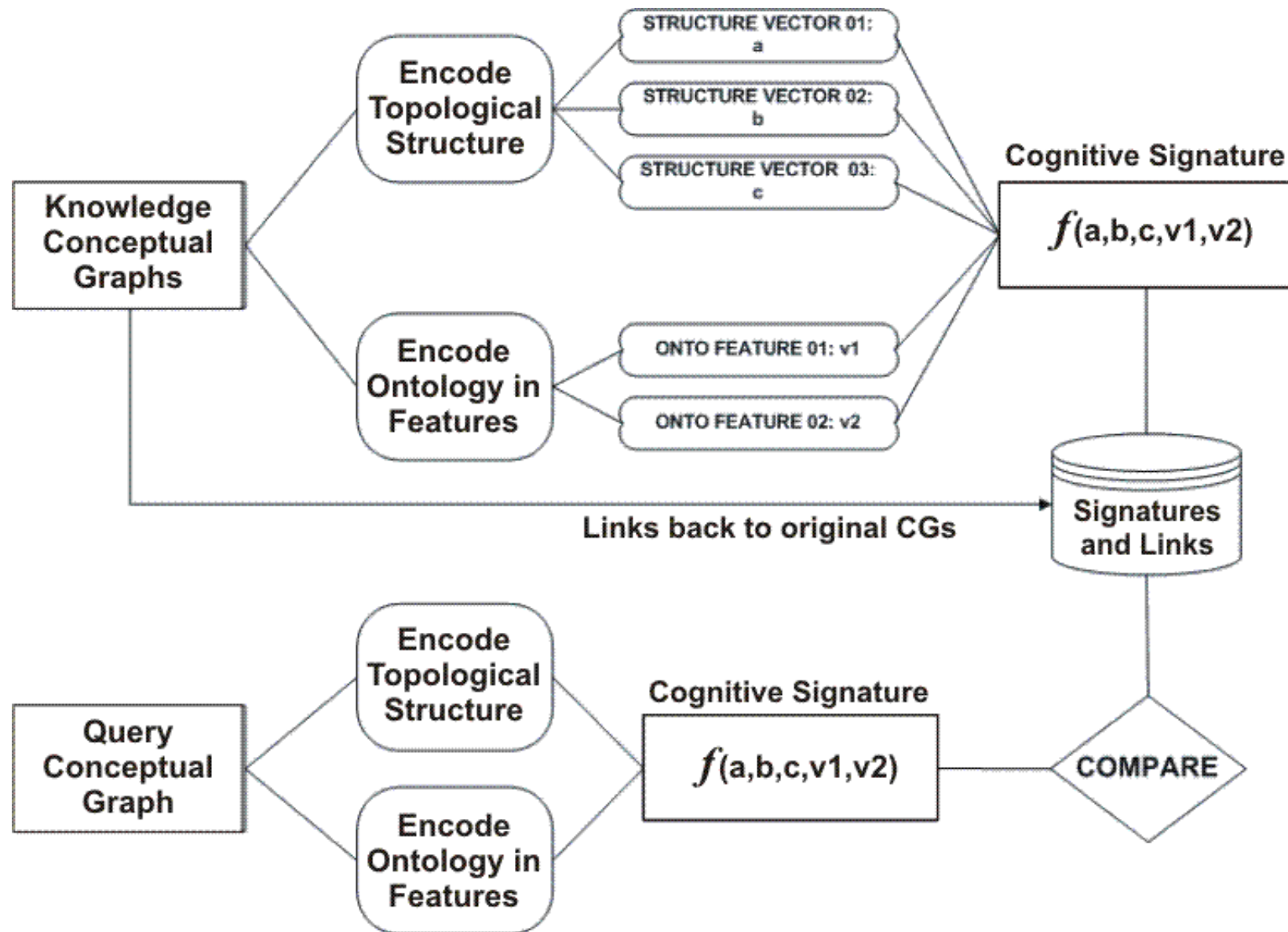
Analogies can support informal, case-based reasoning:

- CM can store large volumes of previous knowledge and experience.
- Any new case can be matched to similar cases in long-term memory.
- Close matches are ranked by a measure of semantic distance.

Formal reasoning is based on a disciplined use of analogy:

- Induction: Generalize multiple cases to create rules or axioms.
- Deduction: Match (unify) a new case with part of some rule or axiom.
- Abduction: Form a hypothesis based on aspects of similar cases.

Cognitive Memory™



High-speed associative memory for conceptual graphs 5

Application to Legacy Re-engineering

Analyze the software and documentation of a corporation.

Programs in daily use, some of which were up to 40 years old.

- **1.5 million lines of COBOL programs.**
- **100 megabytes of English documentation — reports, manuals, e-mails, Lotus Notes, HTML, and program comments.**

Goal:

- **Analyze the COBOL programs.**
- **Analyze the English documentation.**
- **Compare the two to determine:**
 - Data dictionary of all data used by all programs.**
 - English glossary of all terms with index to the software.**
 - Evolution of terminology over the years.**
 - Structure diagrams of the programs, files, and data.**
 - Discrepancies between programs and documentation.**

An Important Simplification

An extremely difficult and still unsolved problem:

- **Translate English specifications to executable programs.**

Much easier task:

- **Translate the COBOL programs to conceptual graphs (CGs).**
- **Those CGs provide the ontology and background knowledge.**
- **The CGs derived from English may have ambiguous options.**
- **In parsing English, use CGs from COBOL to resolve ambiguities.**
- **The COBOL CGs show the most likely options.**
- **They can also provide missing information or detect errors.**

The CGs derived from COBOL provide a formal semantics for the informal English texts.

Excerpt from the Documentation

The input file that is used to create this piece of the Billing Interface for the General Ledger is an extract from the 61 byte file that is created by the COBOL program BILLCRUA in the Billing History production run. This file is used instead of the history file for time efficiency. This file contains the billing transaction codes (types of records) that are to be interfaced to General Ledger for the given month.

For this process the following transaction codes are used: 32 — loss on unbilled, 72 — gain on uncollected, and 85 — loss on uncollected. Any of these records that are actually taxes are bypassed. Only client types 01 — Mar, 05 — Internal Non/Billable, 06 — Internal Billable, and 08 — BAS are selected. This is determined by a GETBDATA call to the client file.

Note that none of the files or COBOL variables are named.

By matching graphs derived from English to graphs derived from COBOL, all names of files and COBOL variables were determined.

Interpreting Novel Patterns

Many documents contain unusual or ungrammatical patterns.
They may be elliptical forms that could be stored in tables.

But some authors wrote them as phrases:

- 32 — *loss on unbilled*
- 72 — *gain on uncollected*
- 85 — *loss on uncollected*

The dashes were represented by a default relation (Link):

[Number: 32]→(Link)→[Punctuation: “–”]→(Link)→[Loss]→(On)→[Unbilled]

This CG, which was derived from an English document, matched CGs derived from COBOL programs:

- The value 32 was stored as a constant in a COBOL program.
- The phrase “loss on unbilled” was in a comment that followed the value 32 in that program.

Results

Job finished in 8 weeks by Arun Majumdar and André LeClerc.

- **Four weeks for customization:**
Design, ontology, and additional programming for I/O formats.
- **Three weeks to adapt the software that used Cognitive Memory:**
Matches with strong evidence (close semantic distance) were correct.
Weak matches were confirmed or corrected by Majumdar and LeClerc.
- **One week to produce a CD-ROM with the desired results:**
Glossary, data dictionary, data flow diagrams, process architecture diagrams, system context diagrams, and list of errors detected.

A major consulting firm estimated that the job would take 40 people two years to analyze the documentation and find all cross references.

With Cognitive Memory, the task was completed in 15 person weeks.

Information Extraction Project

The next slide shows a table derived from research reports.

To extend the semantics, an ontology for chemistry was added to the VivoMind ontology.

Then for each report,

- Map each sentence to a conceptual graph (CG). *
- Analyze anaphoric references to link pronouns to named entities.
- The result is a large CG that represents every sentence in the document.
- Store that graph (including subgraphs) in Cognitive Memory.
- Query Cognitive Memory for the data in each row of the table.
- Store the answers in the table.

In a competition among twelve NLP systems,

- The VivoMind system got 96% of the entries correct.
- The second best score was 73%. Most scores were below 50%.

* For an overview of CG methods, see <http://www.jfsowa.com/pubs/template.pdf>

Information Extracted from Documents

DOE BREMS PROJECT.xlsx

Search in Sheet

Home Layout Tables Charts SmartArt Formulas Data Review

Edit Font Alignment Number Format Cells Themes

Paste Fill Calibri (Body) 24 abc Wrap Text General Conditional Formatting Styles Insert Delete Format Themes Aa

A1 fx

	A	B	C	D
	COMPOUND	CURIE TEMP.	SOURCE	
1				
2	Mn3[Cr(CN)6]2 ·16H2O	89 K	A solid-state hybrid density functional theory study	
3	Sr3Ir2O7 in Sr3Ir2O7 single-cr	~ 280 K	Canted antiferromagnetic ground state in Sr3Ir2O7	
4	PrPt2B2C	6 K	Coexistence of superconductivity and magnetic ord	
5	La0.3Nd0.7Pt2:1-	2.8 K	Coexistence of superconductivity and magnetic ord	
6	NdPt2:1B2:4C1:2	3 K	Coexistence of superconductivity and magnetic ord	
7	NdPt1:5Au0:6B2C	3 K	Coexistence of superconductivity and magnetic ord	
8	SmNiC2	= 17.7 K	Commensurate charge-density wave with frustrate	
9	Co0.2Zn0.8Fe2O4. in CdxCo1-	~ 780 K	Does Ti+4 ratio improve the physical properties of C	
10	Zn0.88Co0.12O in ZnO	~ 540 K	Effect of Co doping on the structural; optical and m	
11	La in Sr2-xLaxFeMoO6	425 K	Effect of La doping on the properties of Sr2-xLaxFe	
12	Fe in Sr2-xLaxFeMoO6	~ 1040 K	Effect of La doping on the properties of Sr2-xLaxFe	
13	FeSe	~ 305 K	Electronic and magnetic properties of FeSe thin film	
14	Ni-Mn-Ga	= 376 K	Electronic and structural properties of ferromagnet	
15	LaFexSi1 - x13 in La1-zPrz(Fe	~ 190 K	Enhancement of magnetocaloric effects in La1-zPrz	
16	LaFe0.88Si0.1213 in La1-zPrz(	= 195 K	Enhancement of magnetocaloric effects in La1-zPrz	
17	Co2MnGa in Co2MnGa	600 K	Ferromagnetic resonance in Co2MnGa films with va	
18	HoCrO4 in HoCrO4	17.6 K	Ferromagnetism vs. antiferromagnetism of the dim	
19	Mn3(HCOO)6 in Mn3(HCOO)6	8.0 K	Guest-induced chirality in the ferrimagnetic nanop	
20	NaZn13- in La0.5Pr0.5(Fe0.88	range from 195 K to 185 K	Large isothermal magnetic entropy change after hy	
21	La2/3Ba1/3MnO3 in La2-3Ba1	range from 300 K to 250 K	Magnetic and neutron diffraction study of La2-3Ba1	
22	CuMnSb in Co1-xCuxMnSb	range from 476 K to 300 K	Magnetic properties of half-metallic semi Heusler C	
23	Nd2 in Nd2-yDyyFe17-xSix	range from 61.46 °C to 236 °	Magnetic properties of iron-rich Nd2-yDyyFe17-xSix	
24	Tb2Fe17 in Nd2-yDyyFe17-xS	~ 80 °C	Magnetic properties of iron-rich Nd2-yDyyFe17-xSix	

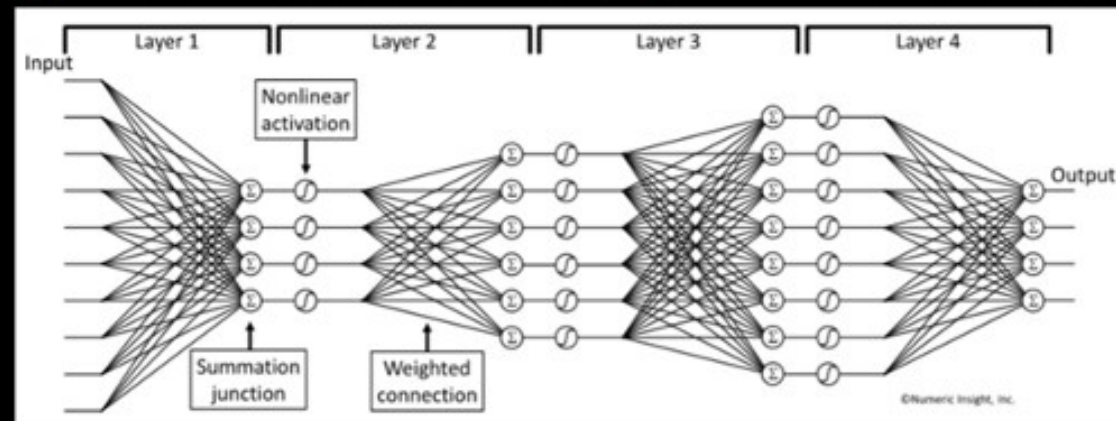
Sheet1

Multi-Layer Neural Nets

Deep Learning



Geoffrey Hinton: co-inventor of the backpropagation and contrastive divergence



Biomimicry of the human cortex

Deep neural nets (DNNs) are superior to earlier versions, but they must be supplemented with symbolic AI methods.

Machine Learning (ML)

Most ML methods learn to approximate a function $f: x \rightarrow y$, where x and y are vectors of observable features or attributes. *

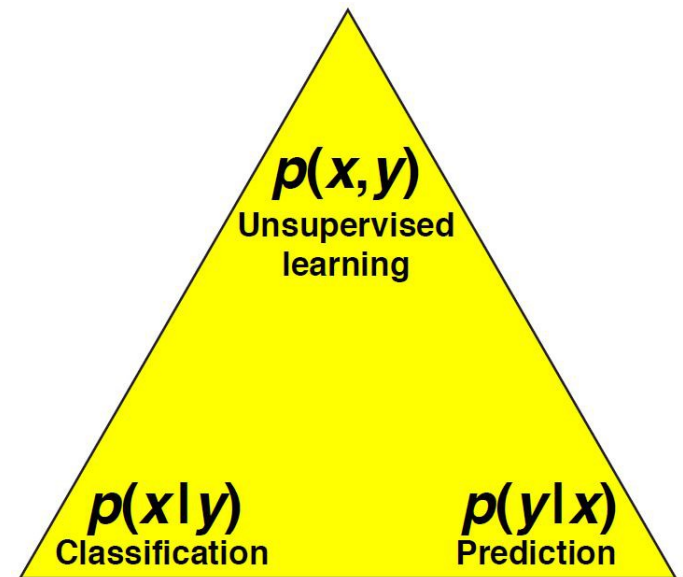
Unsupervised learning begins with a set of pairs of the form (x,y) and computes an estimated probability $p(x,y)$ for any x and y .

For classification, $p(x | y)$ is the probability that something described by the feature vector y belongs to a class x .

For prediction, $p(y | x)$ is the probability that a state described by a vector of features x will be followed by a state described by y .

Such functions represent the kind of learning that psychologists analyzed and described by stimulus-response (S-R) theories.

But S-R theories could not explain novelty, discovery, intentionality, or the open-ended diversity analyzed by Minsky and Barsalou.



* Henry Lin & Max Tegmark (2016) [Why does deep and cheap learning work so well?](#)

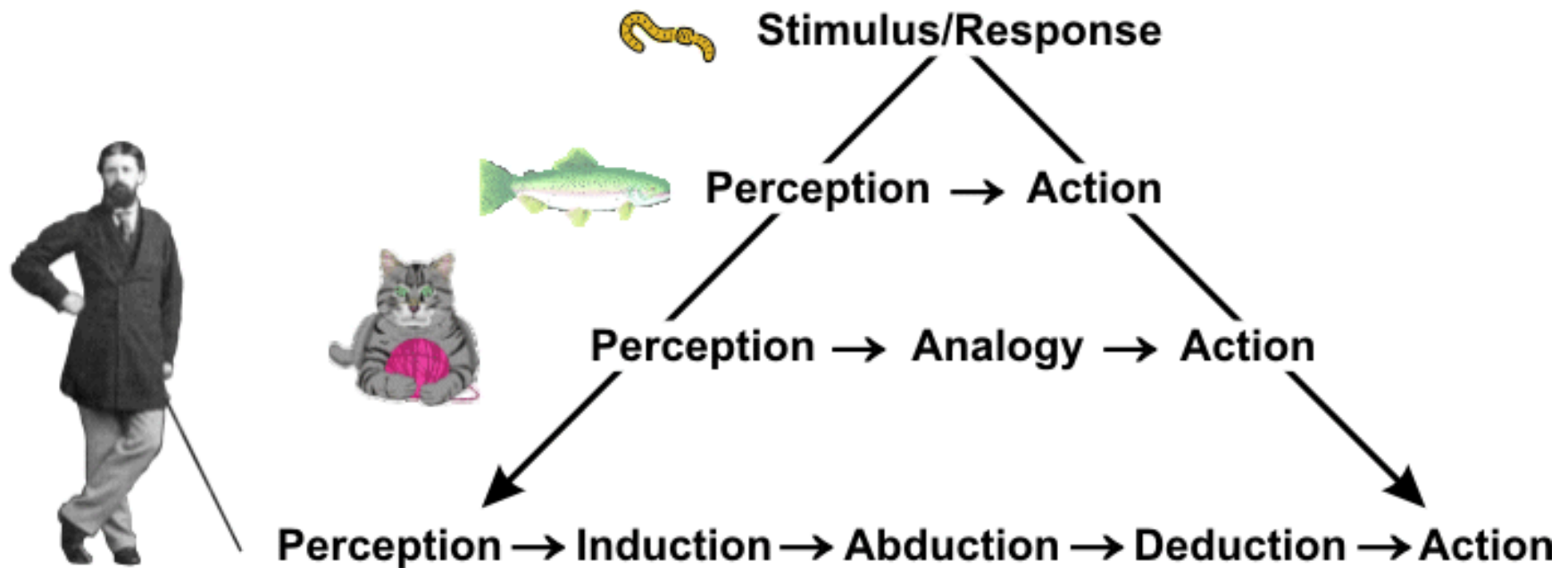
Applications of Machine Learning *

Stimulus x	Response y	Application
Picture	Are there human faces? (0 or 1)	Photo tagging
Loan application	Will they repay the loan? (0 or 1)	Loan approvals
Ad plus user information	Will user click on ad? (0 or 1)	Targeted online ads
Audio clip	Transcript of audio clip	Speech recognition
English sentence	French sentence	Language translation
Sensors from hard disk, plane engine, etc.	Is it about to fail?	Preventive maintenance
Car camera and other sensors	Position of other cars	Self-driving cars

Learning a function $f: x \rightarrow y$ is the basis for perception.

- **Observation by Andrew Ng: Current ML methods automate tasks that take less than one second of mental effort by humans.**
- **Every one of Ng's examples recognizes a pattern.**
- **None of them do complex reasoning or language understanding.**

Thinking Beyond the First Second



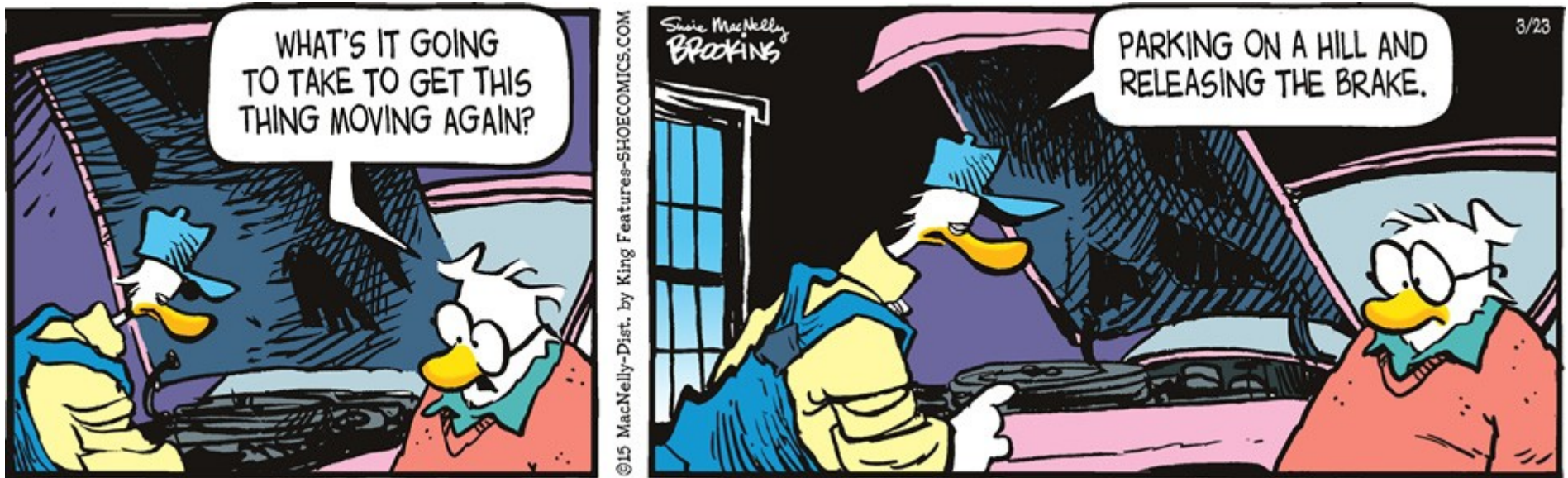
Perception and classification take one second or less.

- Neural nets are valuable for learning and recognizing patterns.
- By themselves, NNs support a fish level of intelligence.
- With analogies, NNs can support a cat level of intelligence.

Analysis, planning, discovery, and innovation take more time.

- They require cycles of induction, abduction, deduction...

Context and Purpose



Syntax is easy: Parse the question and the answer.

Semantics depends on context and background knowledge:

- Interpret the meaning of *thing*, *take*, and *move* in this situation.
- Apply the laws of physics to understand what would happen.

Pragmatics depends on the intentions of the participants.

- No computer system today can understand that cartoon.
- Computers should ask people about purpose or intentions.

* Source of cartoon: search for 'moving' at <http://www.shoecomics.com/>

What is Cognition?

Lawrence Barsalou's answer: coordinated non-cognition. *

- Cognition is “embedded in, distributed across, and inseparable from” the “processes of perceiving, acting, and emoting.”
- Visual and motor simulations are essential to language understanding.
- When people view a static object, they anticipate working with it.
- When people view food, they anticipate its taste when eating it.
- Musicians identify their own performances by recognizing the fingering.
- Affect, feelings, rewards, and value judgments are fundamental to all aspects of reasoning and decision making.
- No single aspect is cognition, but all of them together are cognition.
- Social interactions facilitate learning by stimulating more aspects.

Barsalou's answer resembles Minsky's Society of Mind.

- They both emphasized an open-ended variety of cognitive processes.
- The society must relate all aspects of the mind and the body.

* Barsalou, Breazeal, & Smith (2007) [Cognition as coordinated non-cognition](#).

Semantics of Natural Languages

Human language is based on the way people think about everything they see, hear, feel, and do.

And thinking is intimately integrated with perception and action.

The semantics and pragmatics of language are

- **Situated in time and space,**
- **Distributed in the brains of every speaker of the language,**
- **Dynamically generated and interpreted in terms of a constantly developing and changing context,**
- **Embodied and supported by the sensory and motor organs.**

These points summarize current views by psycholinguists.

Philosophers and logicians have debated the issues:

- **A continuum between natural languages and formal logics or a sharp dichotomy between NLs and logic.**

Continuum Between Logic and Language

Richard Montague (1970): A continuum with logic as primary.

“I reject the contention that an important theoretical difference exists between formal and natural languages.”

Hans Kamp (2001): A qualified continuum.

“The basic concepts of linguistics — and especially those of semantics — have to be thought through anew... Many more distinctions have to be drawn than are dreamt of in current semantic theory.”

Barbara Partee (2005): More qualifications.

“The present formalizations of model-theoretic semantics are undoubtedly still rather primitive compared to what is needed to capture many important semantic properties of natural languages...”

Peirce and Wittgenstein: A continuum with NLs as primary.

- **Every artificial notation is an abstraction from some aspects of NLs.**
- **No version of logic has all the semantic properties of NLs.**
- **Any formal logic is just one among many possible language games.**

Relating Language to Logic

Peirce wrote a succinct summary of the issues:

“It is easy to speak with precision upon a general theme. Only, one must commonly surrender all ambition to be certain. It is equally easy to be certain. One has only to be sufficiently vague. It is not so difficult to be pretty precise and fairly certain at once about a very narrow subject.” (CP 4.237)

Implications:

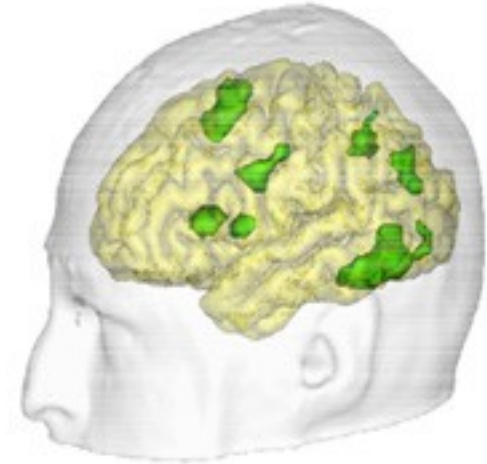
- A precise formal ontology of everything can be stated in logic, but it’s almost certainly false in critical details.**
- A looser classification, such as WordNet or Roget’s *Thesaurus*, can be more flexible for representing lexical patterns.**
- A specification in logic can be “pretty precise and fairly certain” only for a very narrow subject.**

A formal logic cannot be vague. But no finite set of symbols can precisely describe every aspect of a continuous world.

Signatures of Consciousness

Dehaene (2014) on introspection:

- People can't observe their own brains.
- But introspection is data about experience.
- At the right is an fMRI scan of Dehaene's own brain while he was reading concrete words.
- He calls the patterns of neural activity *signatures of consciousness*. *
- “These signatures are remarkably stable and can be observed in a great variety of visual, auditory, tactile, and cognitive stimulations.” (p. 13)

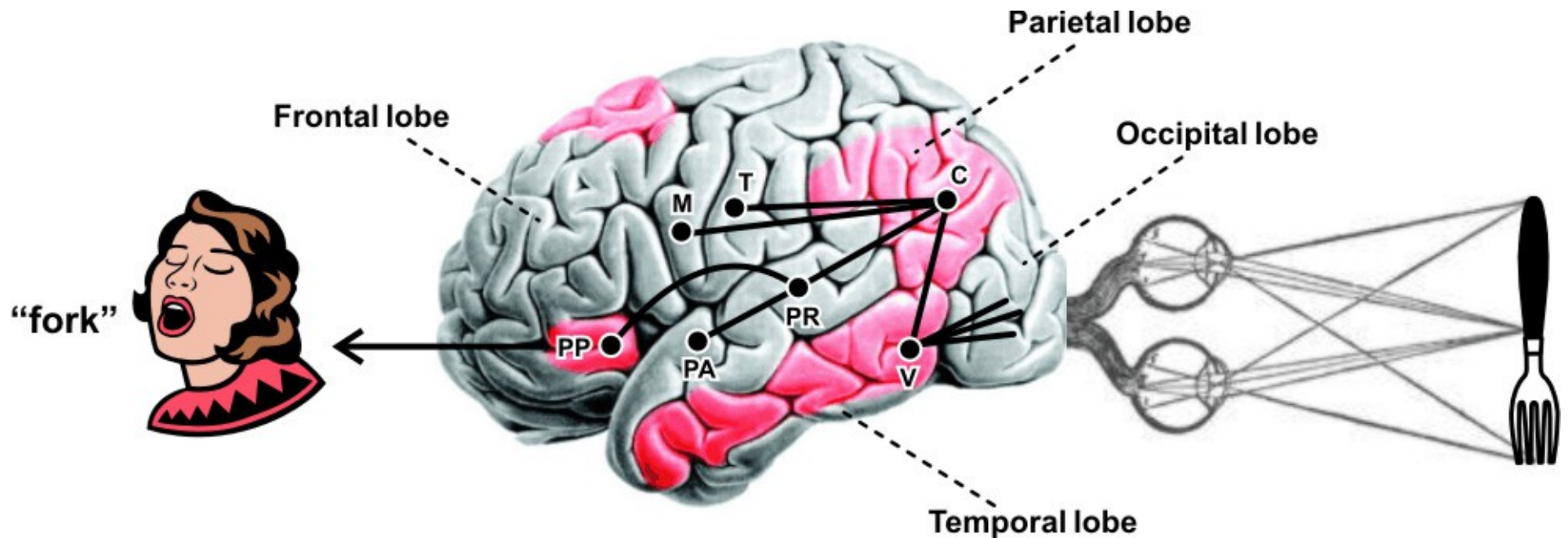


Example: signatures for numbers and computation:

- Mathematicians treat numbers and arithmetic as a unified system.
- But people learn, use, and experience numbers in a variety of ways: verbal, computational, spatial (diagrams), and temporal (counting).
- By examining the neural signatures, the experimenters can distinguish which versions the subjects are thinking about.

* Stanislas Dehaene (2014) *Consciousness and the Brain*, New York: Viking.

Neurocognitive Networks



Sydney Lamb (1999, 2010, 2016) developed **neurocognitive networks**:

- Node C represents a *cortical column* for the concept of a fork.
- V has links to the occipital lobe for visual percepts of forks.
- T has links to afferent nerves for the tactile sensation of a fork.
- M has links to motor nerves for manipulating a fork.
- PR in Wernicke's area represents the word 'fork'.
- PA represents the auditory percept of the word.
- PP in Broca's area links to motor nerves for pronouncing the phonemes.
- Pink areas in the diagram are active in semantics (Binder et al. 2009).

Meaning in a Network

How can a network of links define the categories of a language?

- **The network is not based on a “code” defined by rules or axioms.**
- **It just links patterns of nodes to other patterns of nodes.**
- **Nodes may link to anything: images, sounds, feelings, muscles...**

Lamb’s principles of categorization: *

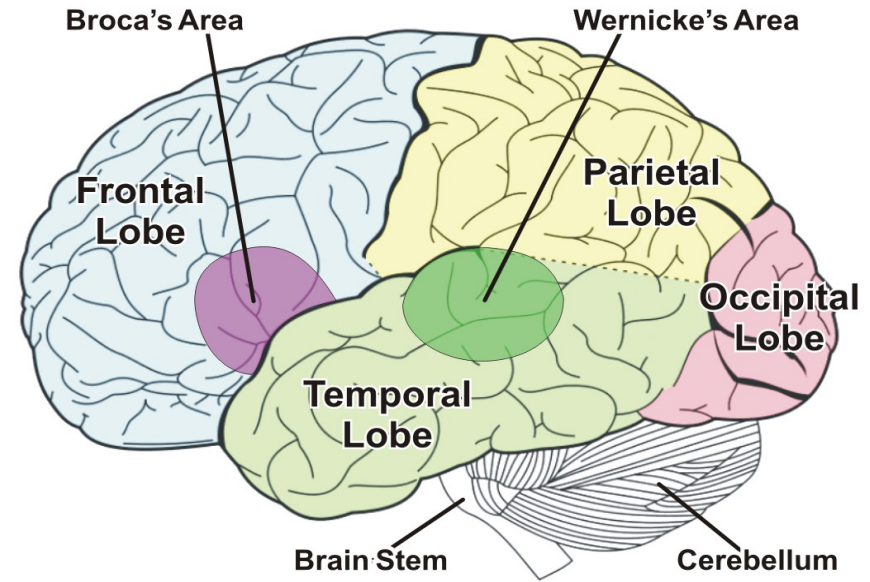
- 1. No small set of defining features (except for special purposes).**
- 2. Fuzzy boundaries.**
- 3. Prototypical members and peripheral members.**
- 4. Subcategories, and sub-subcategories, in hierarchical chains.**
- 5. Categories are in the mind, not in the real world.**
- 6. Categories and their membership vary from one language or cultural system to another.**
- 7. Categories influence thinking, in both appropriate and inappropriate ways.**

* From slide 85 of <http://www.ruf.rice.edu/~Ingbrain/categories.ppt>

Cognitive Learning

The areas of the cerebral cortex are highly specialized.

A study with fMRI scans showed which areas are active at various stages of learning. *



14 participants studied how four devices work: bathroom scale, fire extinguisher, automobile braking system, and trumpet.

Cognitive learning is much deeper than deep neural nets:

- 1. Occipital lobes are active in recognizing shapes and patterns.**
- 2. Parietal lobes become active in learning mechanical structures.**
- 3. All lobes become active as participants are “generating causal hypotheses” about how the system works.**
- 4. Finally, the frontal lobes anticipate “how a person (probably oneself) would interact with the system.”**

Areas Active in Cognition

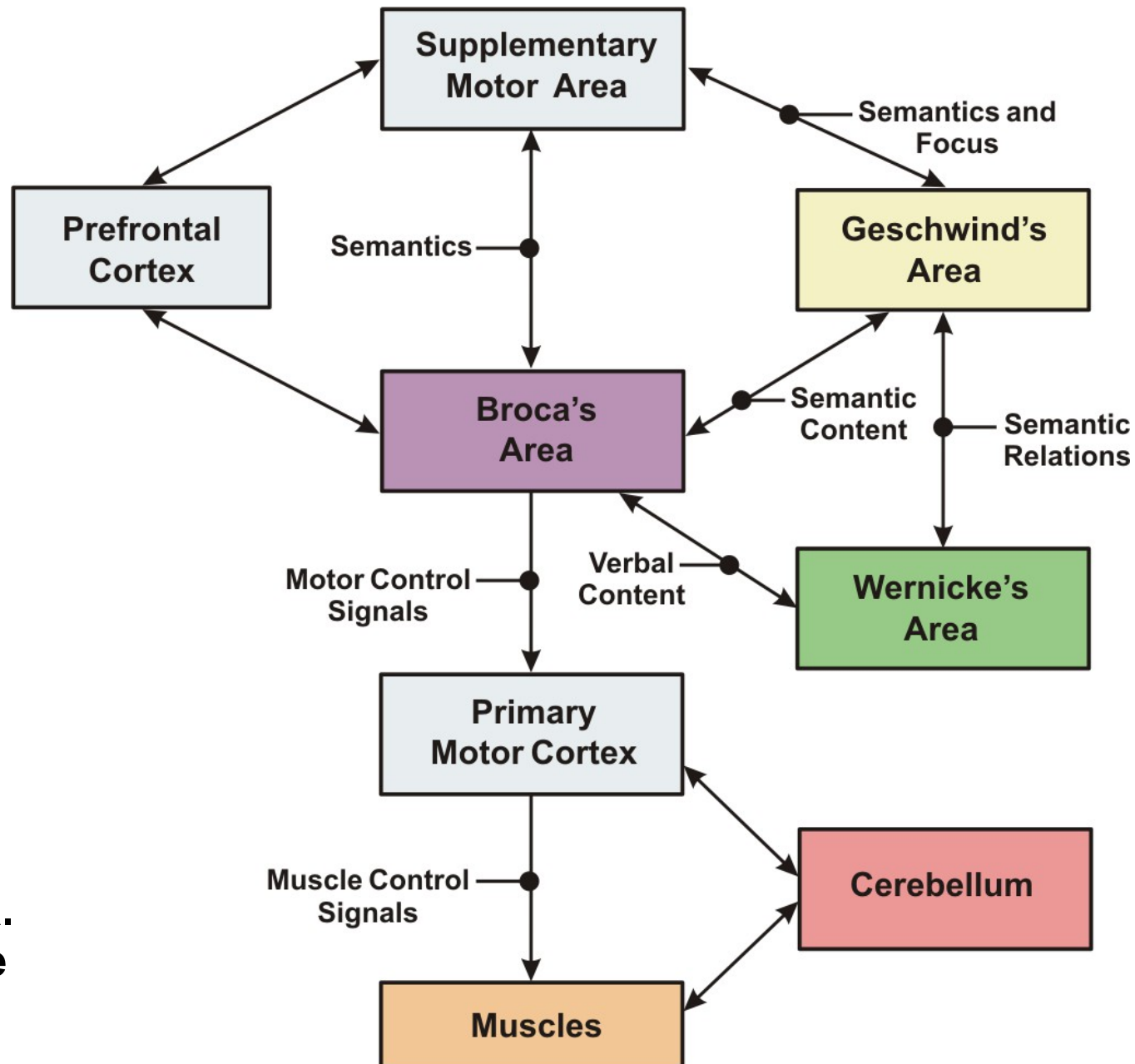
Most neurons have short links to nearby neurons.

But others make long-distance connections from one lobe to another.

The diagram shows connections among areas of the brain involved in language. *

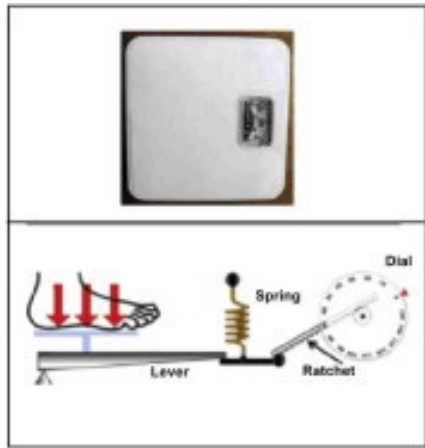
The colors of the boxes correspond to the colors of the brain areas in the previous slide.

Patterns can be learned and recognized in one area. But cognition links diverse areas across the brain.



* Diagram adapted from MacNeilage (2008).

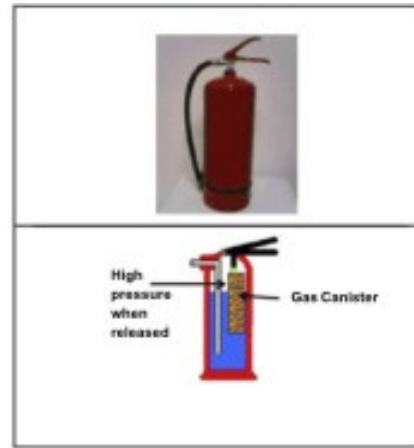
Perceptual and Cognitive Learning



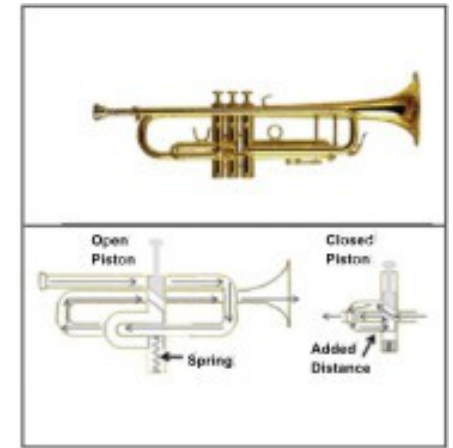
Bathroom Scale



Disc Brake System



Fire Extinguisher



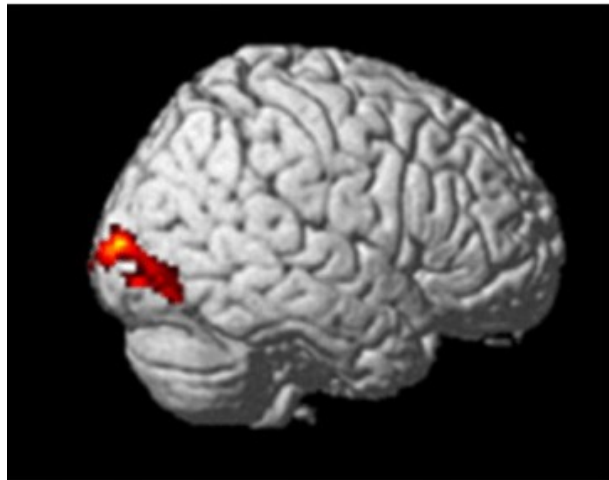
Trumpet

14 participants studied how four devices work: bathroom scale, fire extinguisher, disc brake system, and trumpet. *

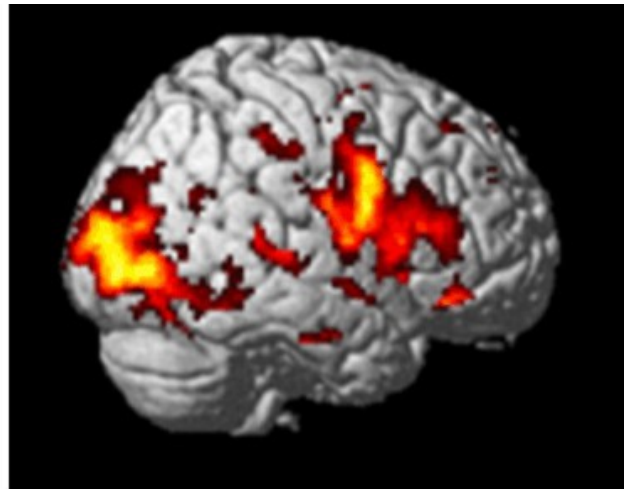
- **Subjects:** college students who were not science or engineering majors.
- They had multiple training sessions with each of the four devices.
- During test sessions, an fMRI scanner recorded patterns of brain activity.
- An early training session just showed pictures and named the parts: *A bathroom scale consists of a spring, a lever, a ratchet, and a dial.*
- Later sessions explained structural and causal relations: *The spring pulls a ratchet which rotates a gear attached to a measurement dial.*

* R. A. Mason & M. A. Just (2015) [Physics instruction induces changes in neural representation.](#)

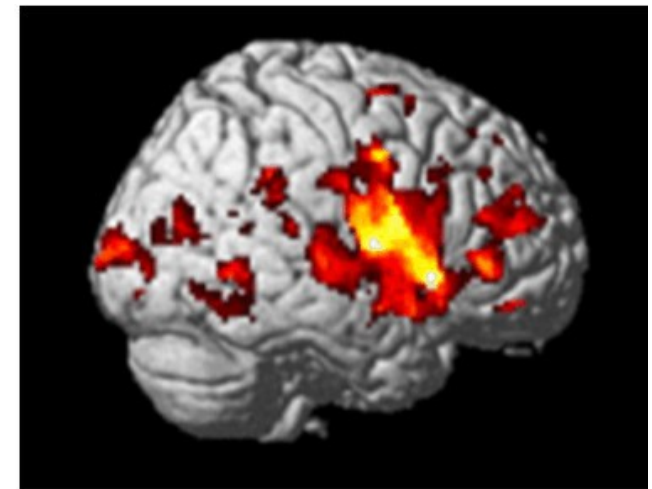
Cognitive Learning



1. Visual perception



2. Thinking about structure



3. Thinking about causality

Neural activity in the right hemisphere during test sessions:

- All 14 students showed similar neural activations.
- Questions about the objects and parts activated the visual cortex, the occipital lobes in the back of the brain (fMRI image #1 above).
- Questions about structural relations activated the parietal lobes, which link vision to all sensory and motor regions (image #2).
- Questions about the causal effects of someone operating the system activated the frontal lobes and connections across the brain (image #3).
- Summary: Cognitive learning involves structural and causal relations that link and coordinate perception, action, and reasoning.

Intentionality

Without life, there is no meaning in the universe.

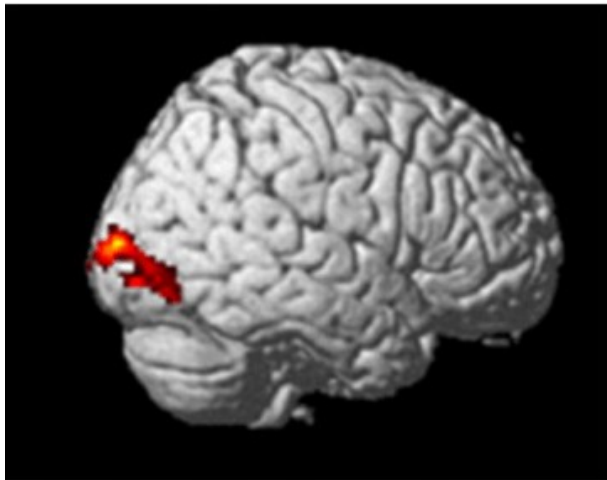
- **Philosopher Franz Brentano:** Intentionality is *“the directedness of thought toward some object, real or imagined.”*
- **Biologist Lynn Margulis:** *“The growth, reproduction, and communication of these moving, alliance-forming bacteria become isomorphic with our thought, with our happiness, our sensitivities and stimulations.”* *
- **A bacterium swimming upstream in a glucose gradient marks the beginning of goal-directed intentionality.**

In Peirce’s categories, intentionality is a mediating Third.

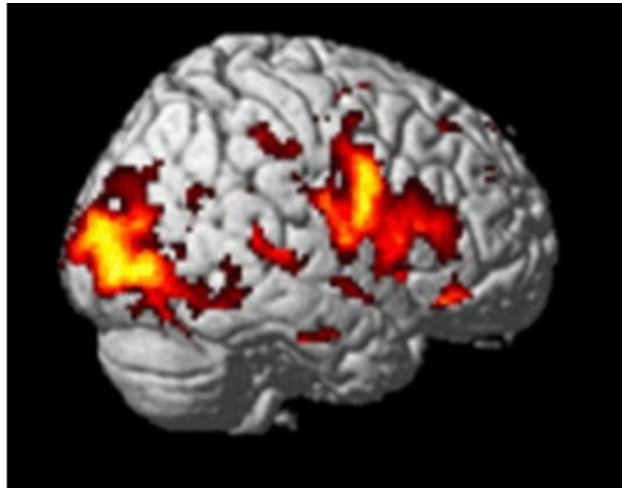
- **It’s the reason why some mind or quasi-mind directs attention toward some mark, which it interprets as a token of some type.**
- **Some interpretation by some agent makes some mark (an aspect of the universe) meaningful in some way for that agent.**
- **All laws, communications, explanations, value judgments, and social relations depend on the intentions of some agent.**

* Margulis (1995) Gaia is a tough bitch, <http://edge.org/documents/ThirdCulture/n-Ch.7.html>

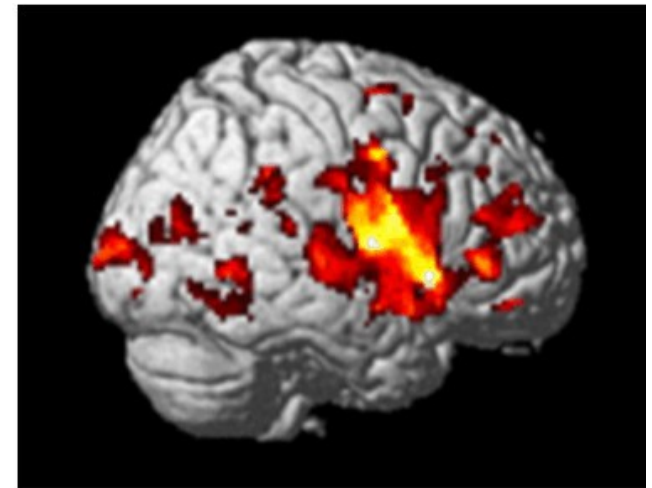
Monadic, Dyadic, and Triadic Relations



1. Visual perception



2. Thinking about structure

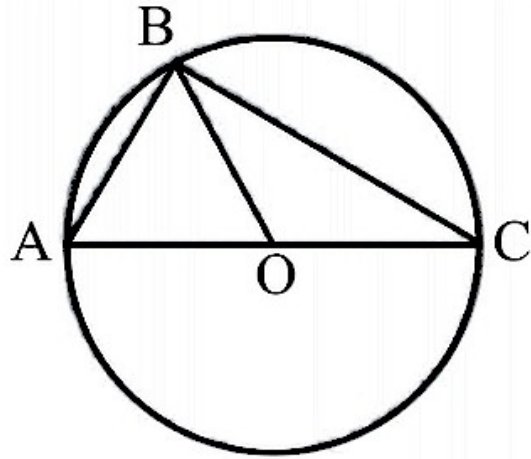


3. Thinking about causality

Neural correlates of Peirce's First, Second, and Third:

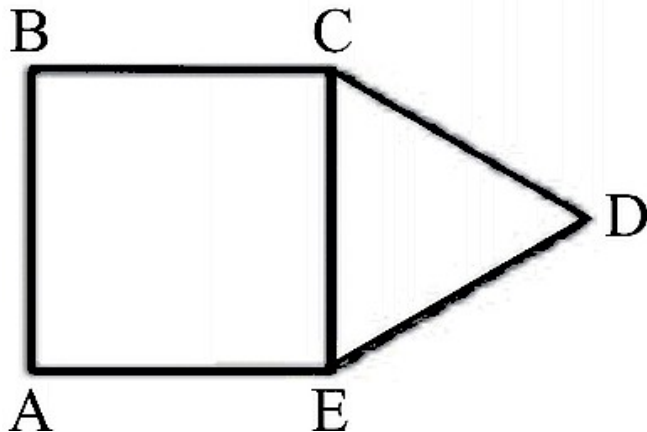
- Perception is based on localized percepts or prototypes. It classifies phenomena by monadic predicates (fMRI image #1).
- Long-distance connections in the parietal lobes support dyadic relations that connect all sensory and motor modalities (image #2).
- The frontal lobes process the mediating triadic relations in reasoning, planning, causality, and intentionality (image #3).
- Much more detail must be analyzed and explained, but these examples suggest promising directions for future R & D.

Relating Images to Language



In the figure to the left, triangle ABC is inscribed in the circle with center O and diameter AC. If $AB=AO$, what is the degree measure of angle ABO?

- (A) 15°
- (B) 30°
- (C) 45°
- (D) 60°
- (E) 90°



In the figure to the left, CDE is an equilateral triangle and ABCE is a square with an area of 1. What is the perimeter of polygon ABCDE?

- (A) 4
- (B) 5
- (C) 6
- (D) 7
- (E) 8



A program that solves problems on the Geometry SAT exam uses information from the images to interpret the questions. *

* Developed by the [Allen Institute for AI](#) and the [University of Washington](#).

Spoken and Signed Language

The same neural mechanisms are used to produce and interpret spoken and signed languages. (Petitto 2005)

Studies of bilingual infants of parents with different languages:

- **All pairs of four languages: English, French, American Sign Language (ASL), and Langue des Signes Québécoise (LSQ).**
- **Monolingual and bilingual babies go through the same stages and at the same ages for both spoken and signed languages.**
- **Hearing babies born to profoundly deaf parents babble with their hands, but not vocally.**
- **Babies bilingual in a spoken and a signed language babble in both modalities – vocally and with their hands.**
- **And they express themselves with equal fluency in their spoken and signed language at every stage of development.**

Petitto's conclusion: Any hypothesis about a Language Acquisition Device (LAD) must be independent of modality.

American Sign Language



MANY

DEAF

LEARN

AGENT



ENTER



SPEAK



COLLEGE

Many deaf students enter hearing colleges.

**The order of signs in ASL is similar to English word order.
But many syntactic features are absent; others are different.**

Diagram adapted from Lou Fant (1983) *The American Sign Language Phrase Book*.

Spatio-Temporal Syntax

Signed and spoken languages have a time-ordered sequence.

But signed languages take advantage of 3-D space:

- **For anything visible, pointing serves the role of pronouns.**
- **But references to people and things that left the scene are also possible by pointing to where they had been.**
- **The signer can also introduce new characters and things, place them in fixed locations in the air, and refer to them by pointing.**
- **For spatial relations, signing is more “natural” than spoken language.**

Observation: The index finger is the most natural indexical.

Some theoretical questions:

- **Must a language of thought include geometry of the environment?**
- **If so, should it still be called a “language” of thought?**
- **A better term might be “cognitive map” or “mental model.”**

Mental Models

Hypothesis of “artificial causation” by Kenneth Craik (1943):

If the organism carries a ‘small-scale model’ of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and future, and in every way to react in a much fuller, safer, and more competent manner to the emergencies which face it. (p. 61)

Proposed as a basis for AI by Marvin Minsky (1963).

Widely accepted, but with different interpretations:

- **GOFAI:** The models are constructed from patterns of symbols (chunks, frames, or schemata) and processed by symbolic rules or procedures.
- **Embodied cognition:** The models are analog simulations, represented in patterns that have a direct (topographic) mapping to sensory input.
- **Dual coding:** Both kinds of representations occur in the brain, and both must be integrated for human-level cognition. But how?

These options have been actively debated for half a century.

Mental Maps, Images, and Models

Quotation by the neuroscientist Antonio Damasio (2010):

“The distinctive feature of brains such as the one we own is their uncanny ability to create maps... But when brains make maps, they are also creating images, the main currency of our minds. Ultimately consciousness allows us to experience maps as images, to manipulate those images, and to apply reasoning to them.”

The maps and images form mental models of the real world or of the imaginary worlds in our hopes, fears, plans, and desires.

Words and phrases of language can be generated from them.

They provide a “model theoretic” semantics for language that uses perception and action for testing models against reality.

Like Tarski's models, they define the criteria for truth, but they are flexible, dynamic, and situated in the daily drama of life.

Feelings and Emotions

Damasio and Carvalho (2013),

- **“Feelings are mental experiences of body states.”**
- **“They signify physiological need, tissue injury, optimal function, threats to the organism, or specific social interactions.”**
- **“Feelings constitute a crucial component of the mechanisms of life regulation, from simple to complex.”**
- **“Their neural substrates can be found at all levels of the nervous system, from individual neurons to subcortical nuclei and cortical regions.”**

Damasio (2014), *

- **“I’m ready to give the very teeny brain of an insect – provided it has the possibility of representing its body states – the possibility of having feelings.”**
- **“Of course, what flies don’t have is all the intellect around those feelings that could make use of them: to found a religious order, or develop an art form, or write a poem.”**

* Interview, <http://www.technologyreview.com/qa/528151/the-importance-of-feelings/>

The Role of Empathy

Observation by the linguist Zellig Harris:

“We understand what other people say through empathy – imagining ourselves to be in the situation they were in, including imagining wanting to say what they wanted to say.”

That sentence shows a deeper understanding of language than anything that his star pupil, Noam Chomsky, ever wrote.

Subsets of language that map to formal logics are mainly used for mathematical precision in science and engineering.

Baby talk is a dialect that mothers develop through empathy with their babies. People also develop special dialects through empathy with their pets and other animals.

In fact, communication among all higher animals is based on sounds or signs learned through empathy.

Conclusion: Robots will never fully understand human language unless and until they develop empathy with humans.