The Virtual Reality of the Mind

(*Short Version*)

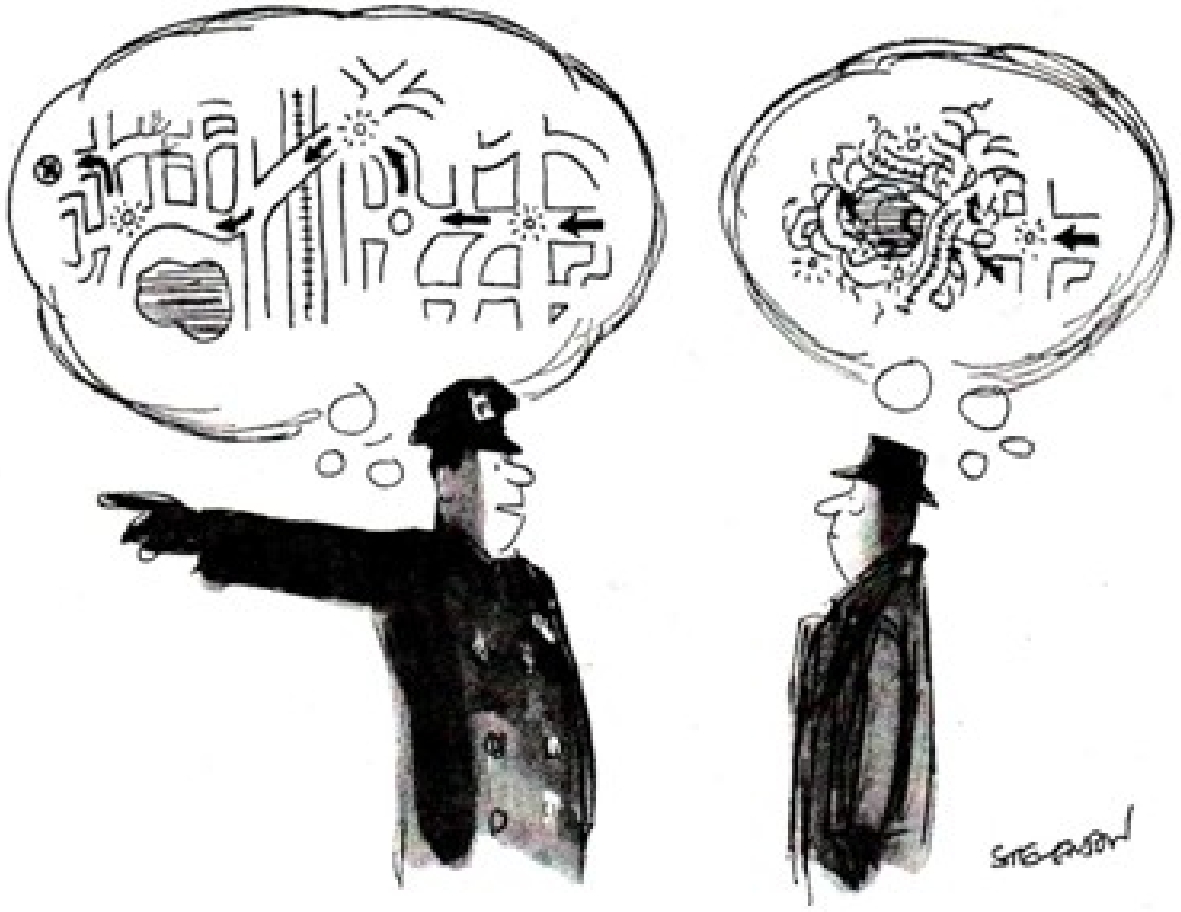
John F. Sowa

Kyndi, Inc.

15 July 2017

Full version: http://www.jfsowa.com/talks/vrmind.pdf

Communication



An image contains much more information than a string of symbols.

- **Expressing a mental image in language loses information.**
- **Reconstructing an image from language is a rough approximation.**
- **It's unlikely that a "language of thought" is the medium for reasoning about mental imagery.**
- **But how is the information processed, remembered, and used?**

Bird Nest Problem

Robots can perform many tasks with great precision.

But they don't have the flexibility to handle unexpected shapes.

They can't build a nest in an irregular tree with irregular twigs, straw, and moss.

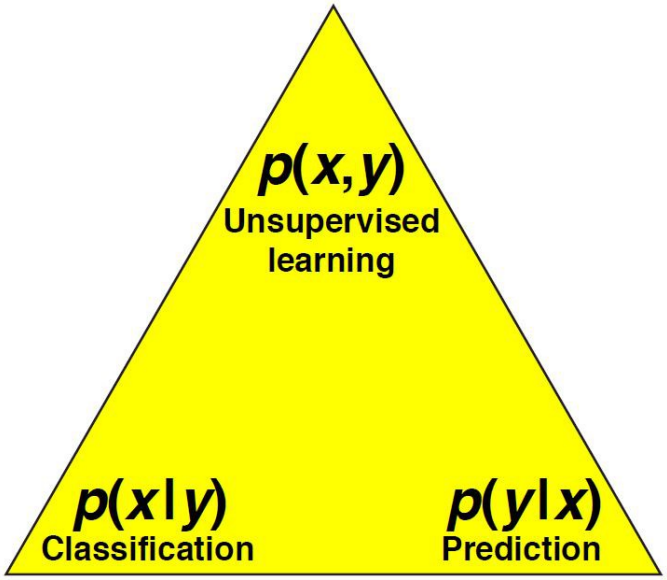
In terms of brain-body mass ratio, birds are comparable to mammals.

And their forebrain is so densely packed with neurons that it's comparable to a primate cerebrum.

A human brain has about 60 million neurons per gram. A macaw brain (21 g) or raven (14 g) have about 240 million per gram. *

*** See Suzana Herculano-Houzel et al. (2016).**

Machine Learning (ML)



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

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

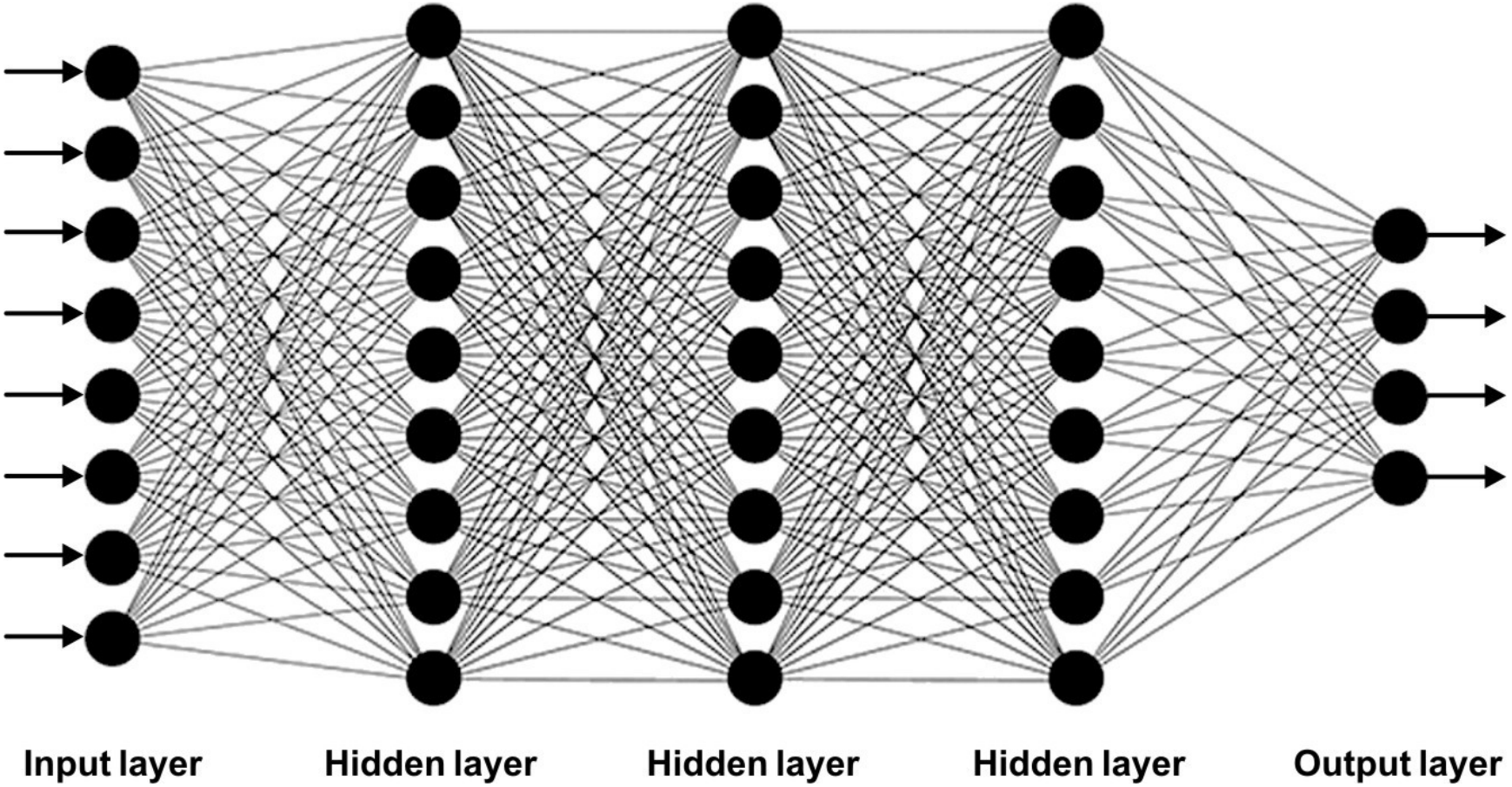
For prediction, $p(y \mid x)$ is the probability that a state described by a vector of features x will be followed by a state described by y.

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

But S-R theories could only explain the early stages of perceptual learning. They could not explain complex language and reasoning.

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

Deep Neural Networks



DNNs are highly efficient versions of artificial neural networks.

- **Early ANNs with multiple hidden layers were very slow to learn the weights on the links that define the functions.**
- **The improved algortihms for DNNs enable them to learn complex functions from larger volumes of data in much less time.**

Machine Learning Applications

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 only one aspect of intelligence.

- **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 learns to recognize a pattern.**
- **None of them do cognitive reasoning or language understanding.**

*** Andrew Ng (2016) https://hbr.org/2016/11/what-artificial-intelligence-can-and-cant-do-right-now**

What is Cognition?

Barsalou's answer: coordinated non-cognition. *

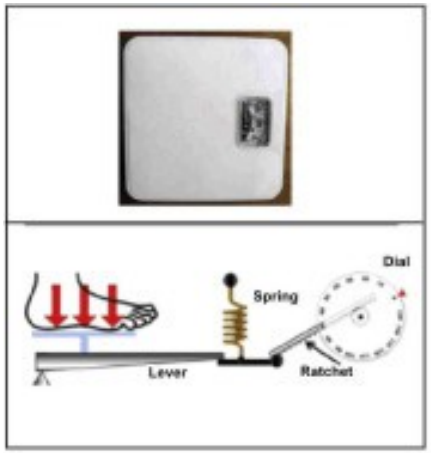
- Cognition is "embedded in, distributed across, and inseparable from" the "processes of perceiving, acting, and emoting."
- Visual and motor simulations are essential to language understanding.
- When people view a static object, they anticipate working with it.
- When people view food, they anticipate 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 is compatible with the Society of Mind.

- But Minsky, in 1986, was still emphasizing symbolic reasoning.
- The society must integrate the mind and body at every level.

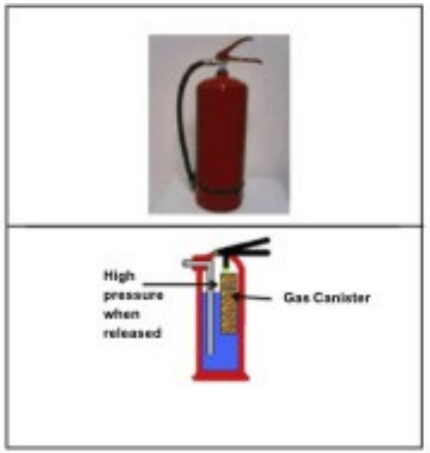
* Barsalou, Breazeal, & Smith (2007) Cognition as coordinated non-cognition.

Perceptual and Cognitive Learning

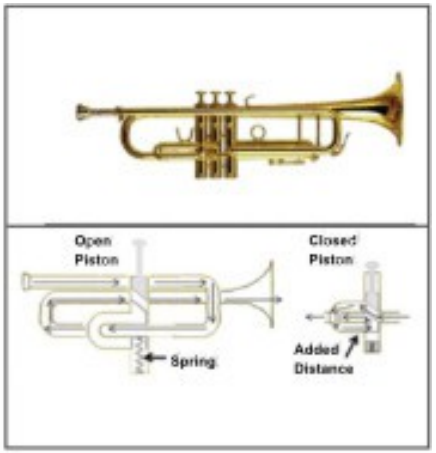


Bathroom Scale

Disc Brake System



Fire Extinguisher



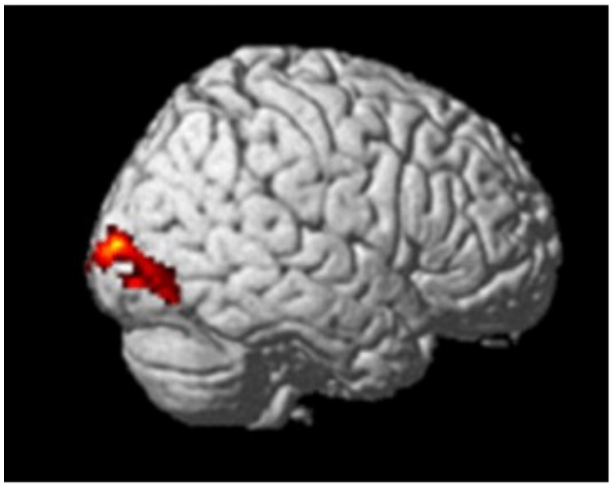
Trumpet

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

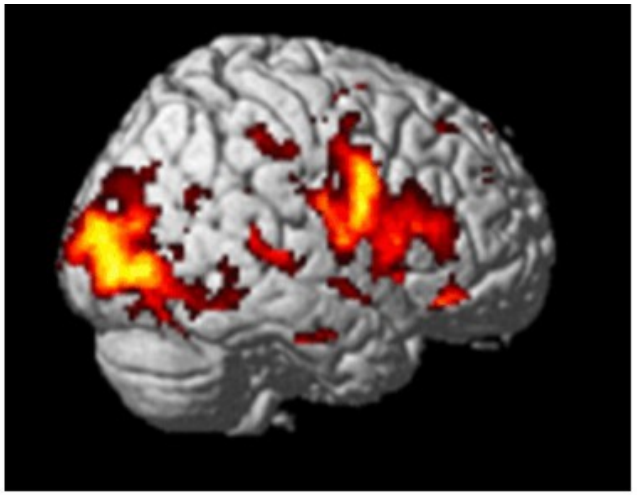
- **Subjects: college students who were not science or engineering majors.**
- **Mutiple training sessions and test sesions with each of the four devices.**
- **During test sessions, an fMRI scanner recorded patterns of brain activity.**
- **An early training session just showed pictures and named the 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.**

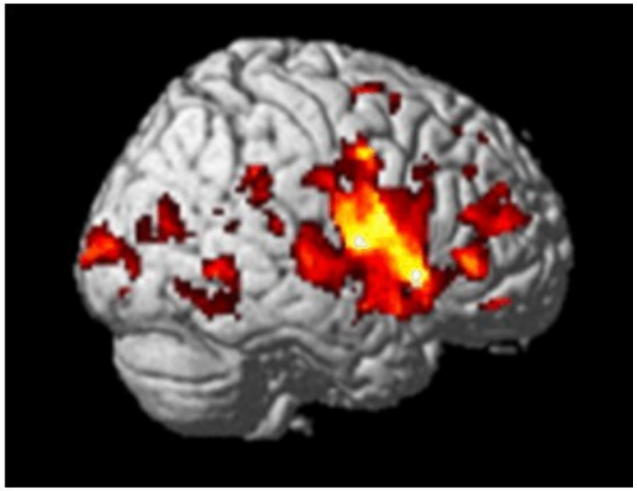
Cognitive Learning



1. Visual perception



2. Thinking about structure



3. Thinking about causality

Neural activity in the right hemispehre 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 (image #1).
- 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.

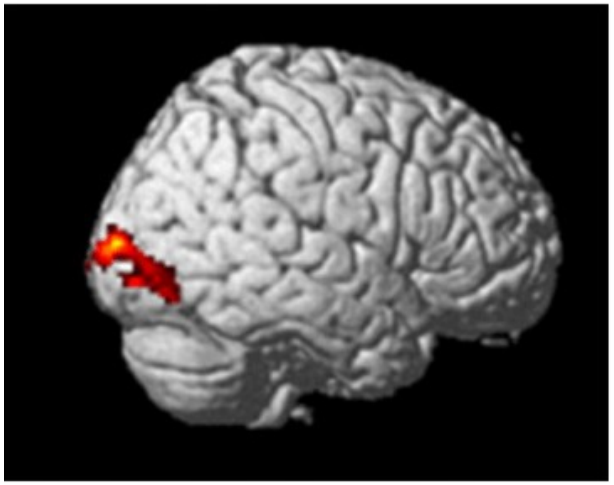
- **Philosopher Franz Brentano: Intentionality is "*the directedness of thought toward some object, real or imagined*."**
- **Biologist Lynn Margulis: "*The growth, reproduction, and communication of these moving, alliance-forming bacteria become isomorphic with our thought, with our happiness, our sensitivities 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.

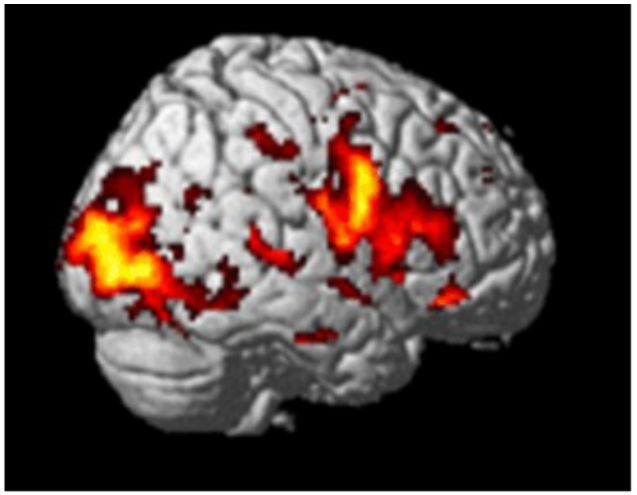
- **It's the reason why some mind or quasi-mind directs attention toward some mark, which it interprets as a token of some type.**
- **Some interpretation by some agent makes some mark (an aspect of the universe) meaningful in some way for that agent.**
- **All laws, communications, explanations, value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

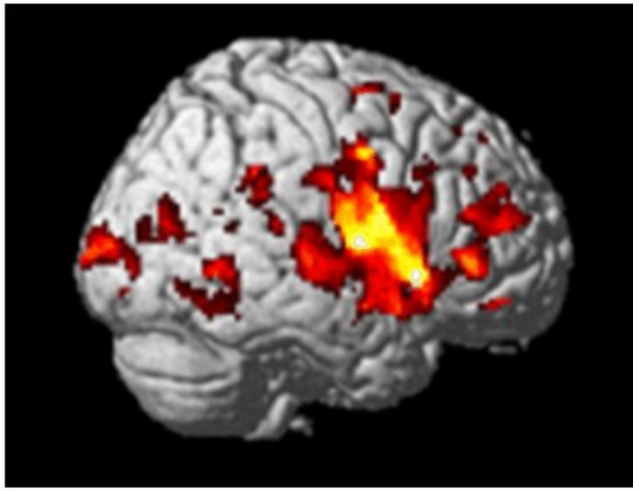
Neural Correlates



1. Visual perception



2. Thinking about structure

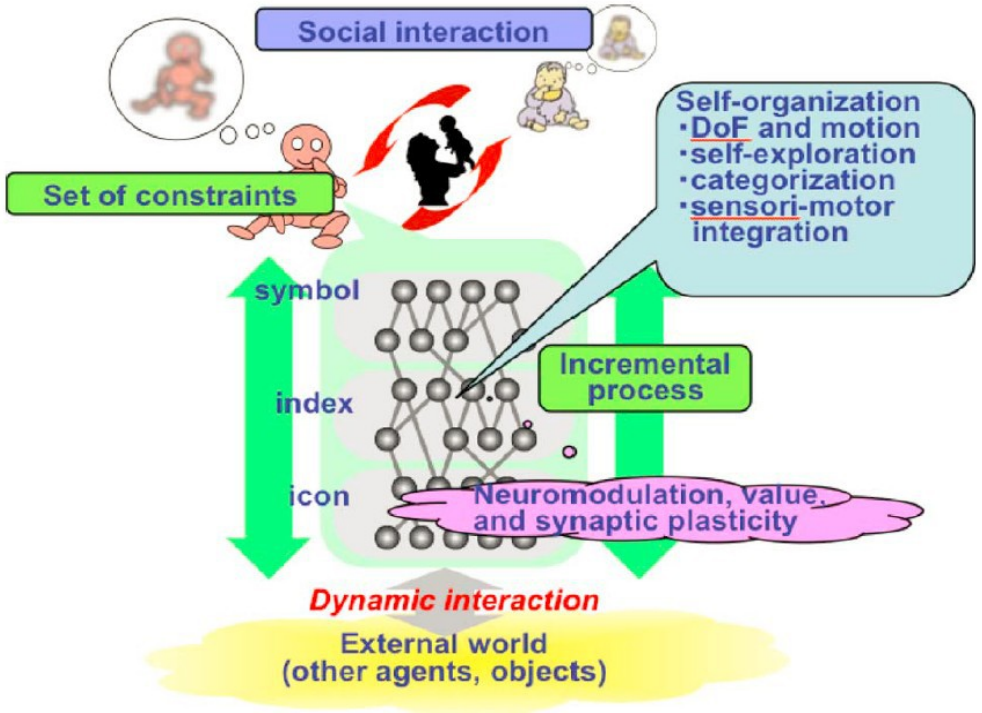


3. Thinking about causality

Neural correlates of Peirce's semiotic categories:

- Perception is based on localized percepts or prototypes. It classifies phenomena by the monadic predicates of Firstness (fMRI image #1).
- Long-distance connections in the parietal lobes support dyadic relations that connect all sensory and motor modalities. They represent the structures of Secondness (image #2).
- The frontal lobes process the mediating Thirdness in reasoning, planning, causality, and intentionality (image #3).
- Much more detail must be analyzed and explained, but the examples in slides 8, 9, and this one illustrate promising directions to explore.

Cognitive Development



Can or should robots learn to think and talk like children? *

- **Piaget's stages: Sensorimotor (0-2 years old); preoperational (2-7); concrete operations (7-12); formal operations (12-adulthood).**
- **Even adults go through similar stages when they encounter something new (see previous slide).**
- **ML algorithms can often beat humans in learning patterns from large data sets, but they are not as general, flexible, or extendible.**
- **Major weakness of ML: Explaining causality and intentionality.**

*** See the review article (Asada et al. 2009) and slides (Asada 2012).**

Classification of Signs

	1. Quality	2. Indexicality	3. Mediation
1. Material	**Mark** *A quality which is a sign.*	**Token** *An actual existent thing or event which is a sign.*	**Type** *A principle, habit, or law which is a sign.*
2. Relational	**Icon** *Refers by virtue of some similarity to object.*	**Index** *Refers by virtue of being affected by object.*	**Symbol** *Refers by virtue of some law or association.*
3. Formal	**Predicate** *A sign of qualitative possibility.*	**Proposition** *A sign of actual existence.*	**Argument** *A sign of law.*

Peirce's three basic triads (the *triple trichotomy*):

- **Living things from bacteria to humans perceive and communicate via signs in the material triad.**
- **Birds and mammals appear to use relational signs.**
- **Formal signs are used by animals with language (*zôa logon echonta*).**
- **Other kinds of signs are derived by combinations of these nine.**

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.**
- **A formal logic is just one among many possible language games.**

Relating Language to Logic

Peirce summarized the issues:

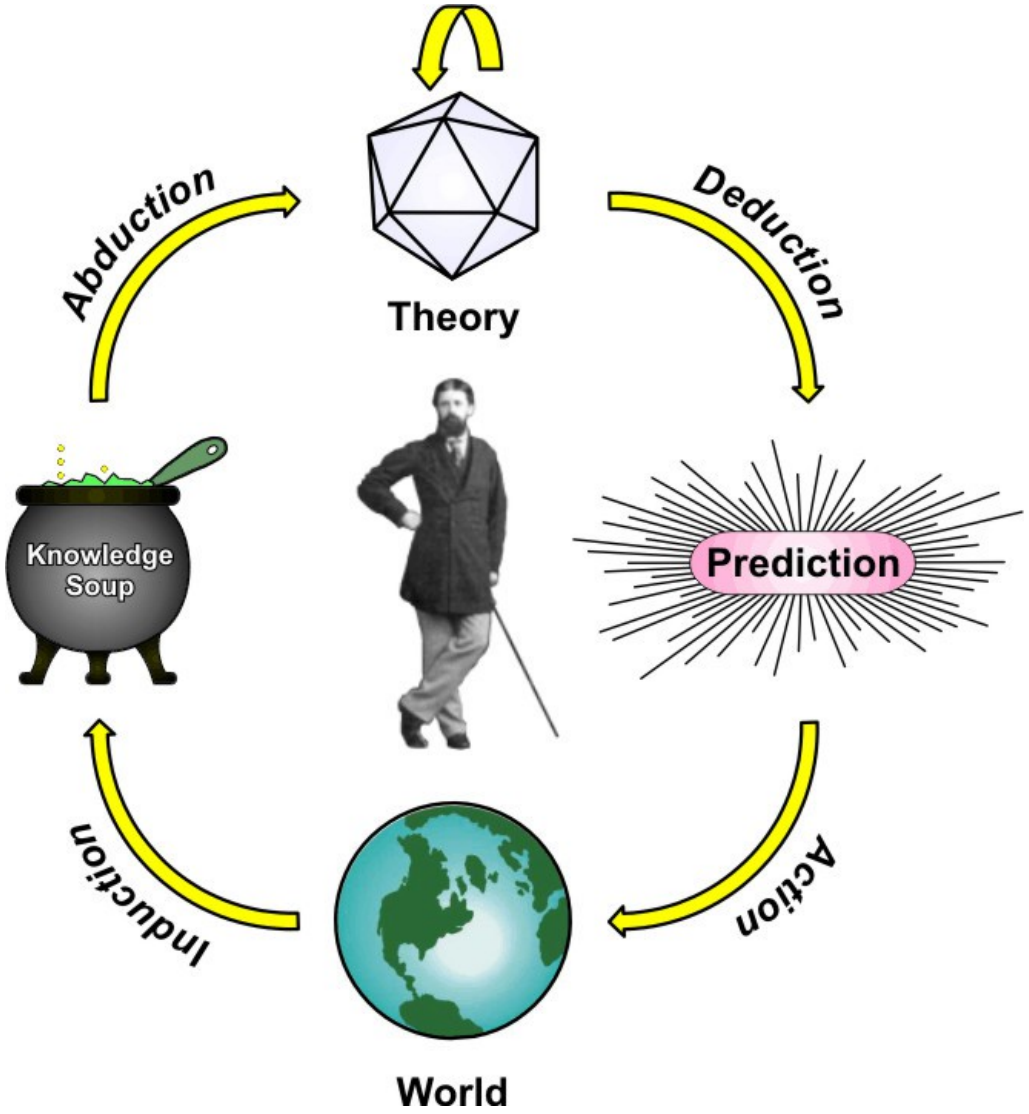
> ***"It is easy to speak with precision upon a general theme. Only, one must commonly surrender all ambition to be certain. It is equally easy to be certain. One has only to be sufficiently vague. It is not so difficult to be pretty precise and fairly certain at once about a very narrow subject."***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

The Cognitive Cycle



The logic of pragmatism by Charles Sanders Peirce.

Similar cycles occur in science and everyday life.

Knowledge Soup

A heterogeneous, loosely linked mixture: *

- **Fluid, lumpy, and dynamically changing.**
- **Many lumps are or can be structured in a computable form.**
- **But they may be inconsistent or incompatible with one another.**

In anybody's head, knowledge soup is

- **The totality of everything in the brain, including the cerebellum, the brain stem, and all signals from and about the body.**

In the WWW, knowledge soup is

- **The totality of everything people downloaded from their heads, recorded automatically, or derived by any computable method.**

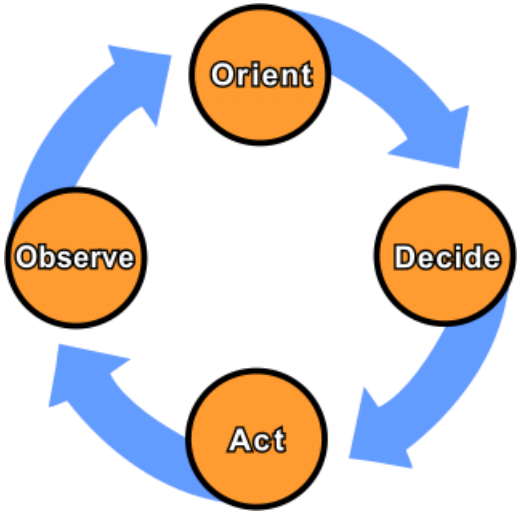
Linked Open Data is useful for finding and classifying anything in the soup – whether loose items or structured lumps.

But understanding the contents of the LOD poses the same challenge as understanding natural language.

*** Sowa (2004) The challenge of knowledge soup.**

Boyd's OODA Loop

John Boyd drew a four-step diagram for training fighter pilots to observe and respond rapidly.



The first two steps – Observe and Orient – involve the occipital, parietal, and temporal lobes.

The next two steps – Decide and Act – involve the frontal lobes for reasoning and motor control.

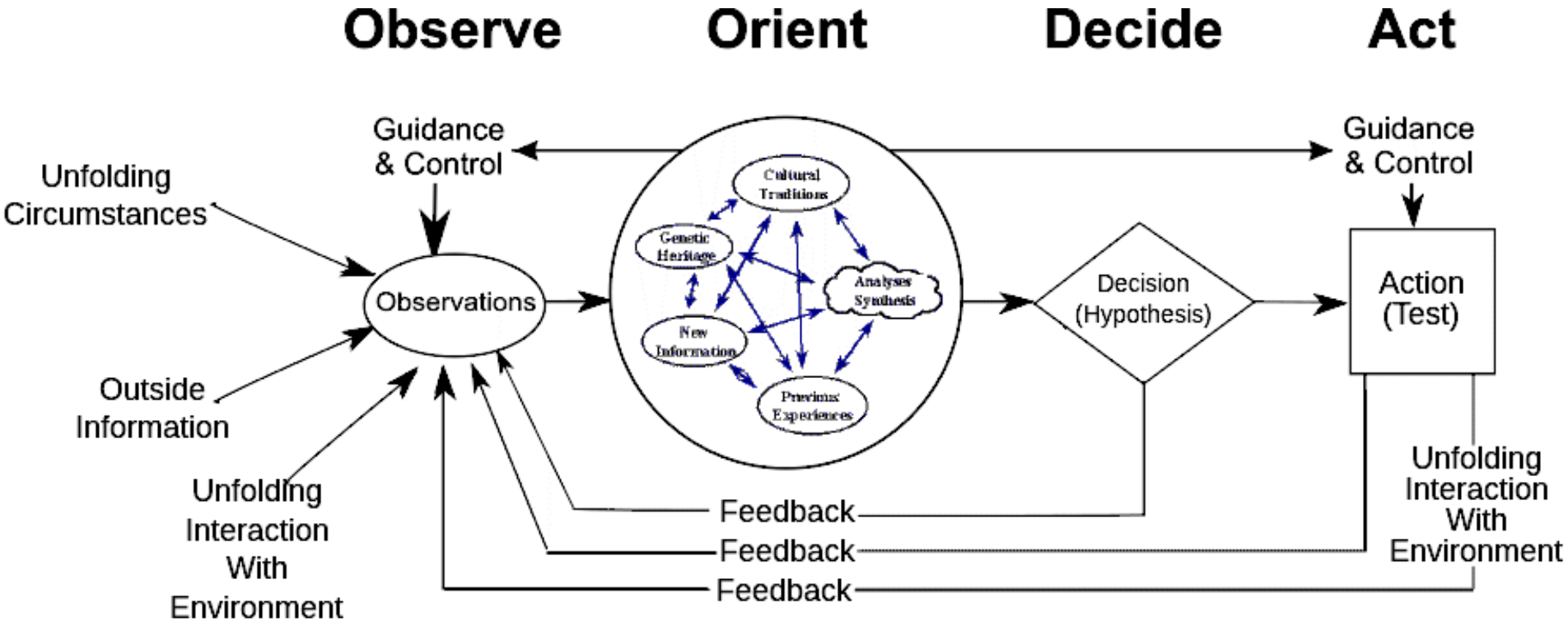
The four steps and the associated brain areas:

1. Observe: Visual input goes to the primary visual cortex (occipital lobes), but object recognition and naming involve the temporal lobes.
2. Orient: Parietal lobes relate vision, touch, and sound in "cognitive maps."
3. Decide: Reasoning is under the control of the frontal lobes, but other areas store the "knowledge soup" and the "mental models."
4. Act: "Action schemata" are patterns in the premotor cortex of the frontal lobes. Signals from the motor cortex go to the muscles.

In emergencies, each step must be traversed in milliseconds.

The fastest responses are controlled by the cerebellum. But conscious decisions require the cerebral cortex.

Extended OODA Loop



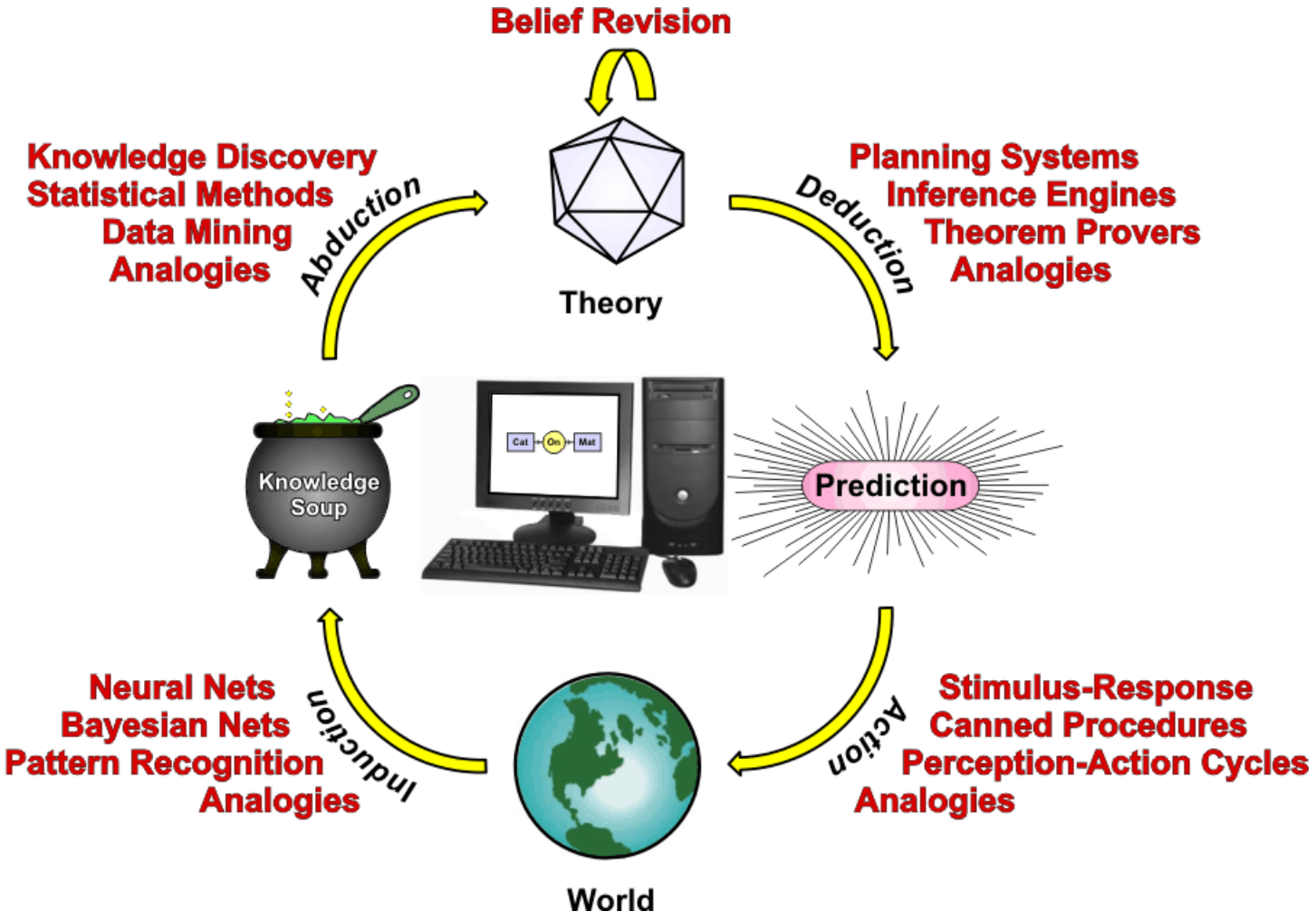
Cycles are self-correcting: Any error in one cycle can be detected and corrected in later cycles.

Over the years, Boyd added more detail to the OODA Loop and applied it to decision-making processes of any kind.

Both versions are compatible with Peirce's cycles.

Diagram adapted from http://en.wikipedia.org/wiki/OODA_loop

Implementing the Cycles



An open-ended variety of methods for learning and reasoning.

Conclusion

Many theories capture important aspects of cognition:

- Symbolic methods support formal deduction and computation.
- Embodied theories emphasize the dependence of mind on body.
- Dual coding theories relate the symbolic and embodied methods.
- The cerebellum supports virtual reality as a foundation for cognition.
- Artificial neural networks are valuable for pattern recognition.
- Cognitive linguistics relates language to all of the above.
- Biosemiotics emphasizes the continuity from bacteria to humans.
- Philosophers have analyzed and debated these issues for millennia.

Peirce's semiotic relates and integrates everything:

- Signs are the basis for all aspects of perception, learning, cognition, reasoning, communication, and action by all living things.
- His research in logic, philosophy, science, mathematics, lexicography, psychology, and early computing devices gave him the insights. *

* See http://www.jfsowa.com/pubs/csp21st.pdf