Neural Basis of Analogical Processing

Yoonsuck Choe
Department of Computer Science
Texas A&M University
April 5, 2002

Paper is available under the topic Neural Basis of Analogical Processing at:
http://www.cs.tamu.edu/faculty/choe/publications/bytopic.html
The Question

What is the general principle underlying brain function?

- Computational device: traditional AI and Cognitive Science
- Reactive device: Embodied Robotics (Brooks)
- Evolutionary computation: Neural Darwinism (Edelman, Calvin)
- Active agents: Schema Theory (Arbib), Interactivism (Bickhard, Morrison)
- Active representations: Analogy (Hofstadter, Mitchell) and Metaphor (Naraynan)
Where to Begin?

First consider how the brain reflect the external world:

- Isomorphism: Locke
- Second-order isomorphism: Shepard and Chipman
Relation between:

- the objects and the events in the world, and
- internal representations
Relation between:

- the relations between objects and events in the world, and
- relations between the internal representations

Second-order isomorphism seems to be more plausible. However, common interpretations of this theory can cause problems.
Common Interpretations of S&C’s Theory

- Need an explicit comparison process, i.e. something needs to interpret and compare the internal representations.

- Problem of infinite regress can occur.
What if We Explicitly Represent the Relations?

- We still need an explicit evaluation process, to interpret the representation of relation.

- Thus, the possibility of infinite regress still remains.

The base of the problem is that representations are static. They sit there to be interpreted.
Similar Problems in Current Neuroscience

Research is focused on what kind of information neural spike trains encode, i.e. what they represent.

1. Neurons receive encoded signal.

2. Neurons decode and perform transformations.

3. Neurons transmit new information for further analysis.
Alternate Approach: Active Relations and Representations

The problem seem to be caused by representations being static. What if we make the representations **active**?

- Once a representation is activated, it **invokes** the other representation.
Active Units: They Are Just Like Neurons

One existential clue that the active approach can be better:

- Neurons in our brain do just that!
How Does the Active Approach Differ

- What other neurons a single neuron can invoke becomes important.

- That is, what action is taken by a neuron becomes important.

- With this, two things become equally important:
  1. the features a neuron is sensitive to (representation)
  2. what other neurons it can potentially invoke (relation)

The big question: What can it do? What principle can it embody?

Which neuron’s activity was not input-driven?.

- the Word–Orange detector.

Note that this is the exact answer to the analogical query above!
Collection of Active Units: Analogical Power

Big Apple : Small Apple = Big Orange :

Which was the least input-driven activity?

- the Small detector and the Orange detector.

Note that Orange-Color, Word-Red, Word-Orange can also be selected: to be discussed in Remaining Issues.
Active Units and Analogy

Required components:

- Analogical completion through relational links.
- Filtering for less input-driven cortical activities.

Surprisingly, a detailed circuitry that can implement such a mechanism exists in the brain!
Neural Basis of Analogical Processing

- Cortico-cortical connections: analogical **completion**
- Thalamo-cortical connections and **nRt**: analogical **filtering**
Summary

- Active approach leads to analogical power.

- Analogical function require active units that perform completion and a separate mechanism for filtering.

- Cortico-cortical and thalamo-cortical connections together with the nRt can actually implement such a mechanism.

- Thus, analogy may be at the basis of brain function: not only higher-level cognitive functions, but perception and motion as well.
Implications in Brain and Cognitive Sciences

- Neuroscience can focus on revealing the analogical aspect of brain function by adopting current advances in analogy research in cognitive science.

- Cognitive science can get a concrete understanding of analogical mechanisms from neuroscientific data, and build more elaborate theories.
Remaining Issues

- How to select from multiple candidate answers.

- Binding and order of query:
  Big Apple : Small Apple = Big Orange: and
  Big Big Small Apple Apple Orange return the same answer.

- How surrounding context can affect the answer?
  Apple : Orange = Word–Red : ? and
  Orange = ? return the same answer
Future Work

- **Solve the remaining issues**: a more elaborate scheme for filtering within the given circuitry needs to be developed.

- **How can structured information can be represented?**: cortical maps are topographically organized, and this may also be true for higher cognitive areas. Topology-preserving mapping between perceptual maps and cognitive maps can help elucidate the organization of cognitive areas.

- **Relation between natural sensory statistics and the brain structure**: the topographic nature of perceptual maps are largely due to non-accidental structure in nature. Understanding such structure in natural environment can help us infer the structure of brain circuits.

- Understand how **perception, cognition, and motor function** can interact with each other and with the natural world **within the analogical framework**.