CREATIVITY IN HUMANS AND COMPUTERS

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Outline

1. Human creativity
2. Neural mechanisms
3. Computer creativity
4. Procedural creativity

What is Creativity?

Instead of a definition, a concept can be clarified by 3-analysis:

Exemplars: standard examples

Typical features: prototype

Explanatory roles: what creativity explains, and what explains creativity

Blouw, Solodkin, Thagard, and Eliasmith, forthcoming, Cognitive Science.

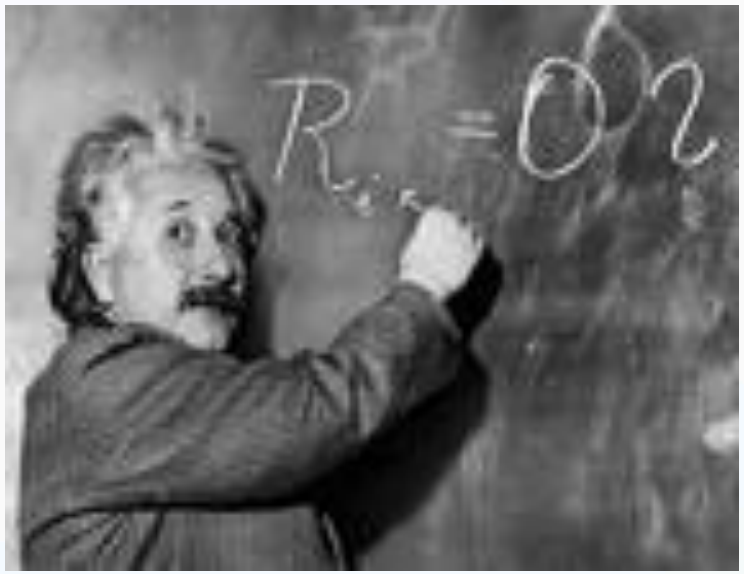
Creativity Exemplars

Scientific discovery

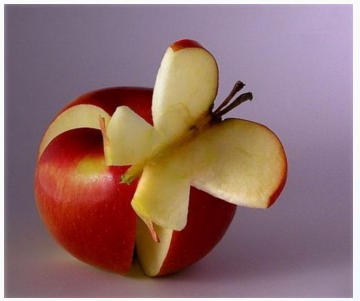
Technological invention

Social innovation

Artistic imagination



Creativity Features



A creative product is:

1. new (novel, original),
2. valuable (important, useful, appropriate, correct, accurate), and
3. surprising (unexpected, non-obvious).

Explanatory roles: Creativity explains individual and social success, but what explains creativity?

Products of Creativity

1. **Concepts**: atom, atomic bomb, hospital, cubism
2. **Hypotheses**: evolution, fission, public education, atonal music
3. **Things**: moons of Jupiter, wheel, University of Bologna, Mona Lisa
4. **Methods:** experimentation, computer programming, universal health care, impressionism

Human Creativity

1. **Combinatorial conjecture:** Creativity results from novel combinations of representations (Koestler, Boden, Dugald Stewart 1792, etc.). Thagard 2012, *The Cognitive Science of Science.*

2. Mental representations are patterns of neural activity. Multimodal: visual, etc.

4. All creativity results from combinations of semantic pointers.

Apple Creativity

Product	Year	Concepts	Images
Apple II	1977	Chip, motherboard, program, keyboard, television	Vision, touch, motion
Macintosh	1984	Computer, graphical interface, mouse, sound	Vision, touch, motion, sound
iMac	1998	Computer, translucent shell, egg-shaped, one-piece	Vision, touch, motion, sound
iPod	2001	Music player, small hard drive, iTunes, scroll wheel	Vision, touch, motion, sound
iPhone	2007	Telephone, music player, Internet appliance, multi-touch screen	Vision, touch, motion, sound

Creativity Results from:

1. Divine inspiration:
   Muses
2. Platonic apprehension
3. Computational
   generation
4. Neural mechanisms

The New Synthesis

Thesis (1950s): Intelligence results from the processing of physical symbols. (Herbert Simon, traditional AI)

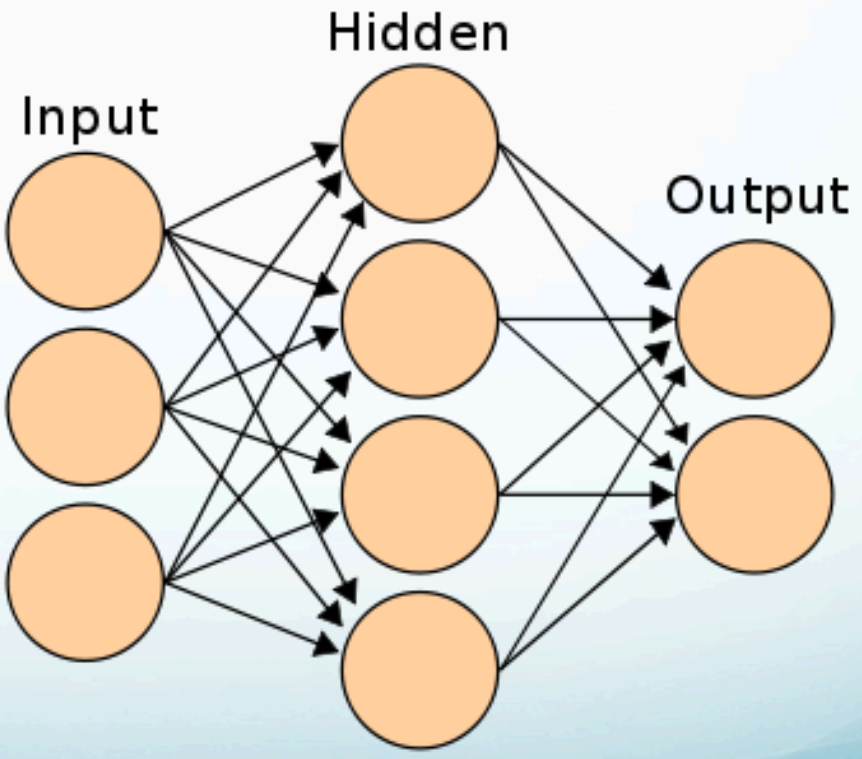
Antithesis (1980s): Intelligence results from sub-symbolic processes in neural networks, operating with distributed representations.

Synthesis: Neural networks are capable of symbolic processes, using semantic pointers.

Chris Eliasmith: *How to Build a Brain*, Oxford U. Press, 2013. Eliasmith et al. (2012), *Science*.

Neural Representation

1. Local representation with individual neurons
2. Distributed representations
3. Pattern of spiking activity in neural population



Neural Representation in Theoretical Neuroscience

1. Neural populations have millions of neurons.
2. Firing patterns matter as well as rate of firing.
3. Populations are organized into brain areas whose interconnections matter more than modularity.
4. Neural populations encode sensory inputs and inputs from other neural populations. Multimodal.

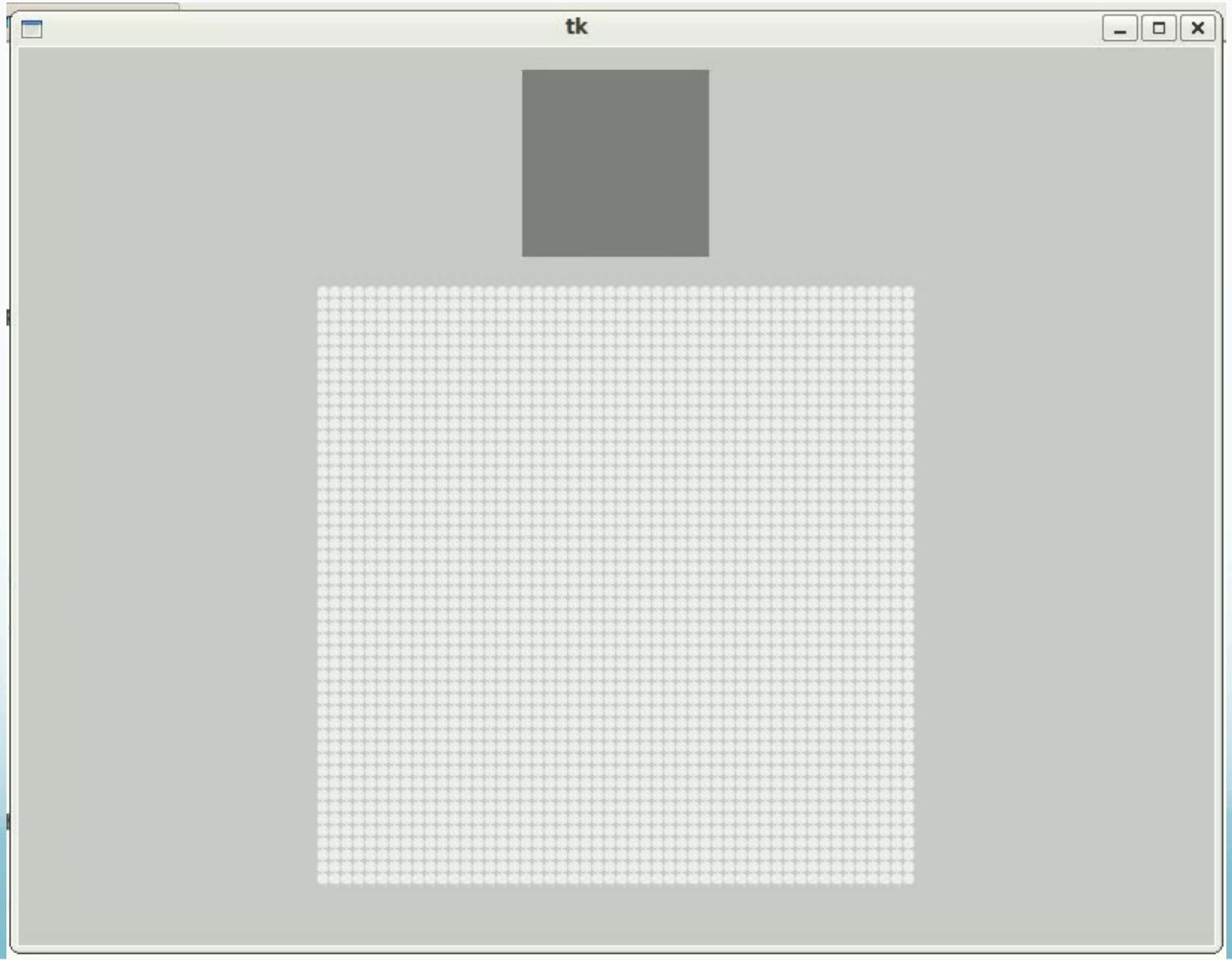
See Eliasmith & Anderson, *Neural Engineering,* 2003.

Eliasmith et al., *Science*, Nov. 30, 2012.

Eliasmith, *How to Build a Brain,* 2013.

Neural Representation

(Chris Eliasmith, Terry Stewart)



Binding in the Brain

Synchrony: neurons fire in temporal coordination

Syntax: e.g. Shastri, Hummel

Consciousness: e.g. Crick, Engel, Scherer

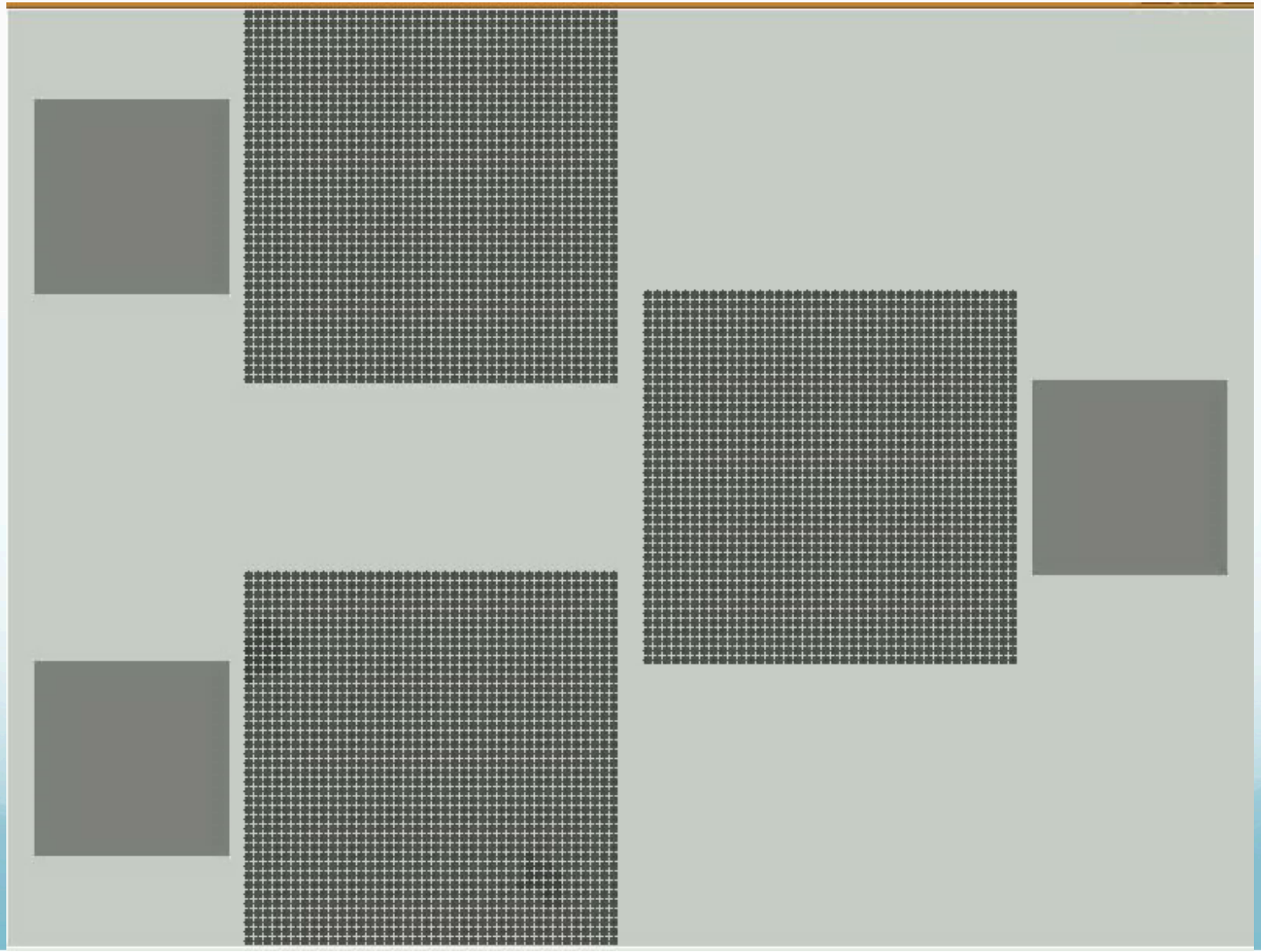
Convolution: activity of neural populations becomes "twisted together": convolve.

Representations are braided together.

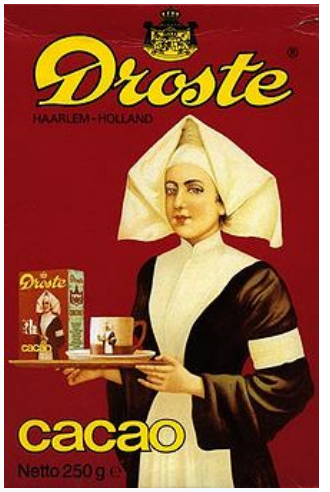
Eliasmith has shown how neural populations can perform convolution.

Convolution in Action

(Thagard & Stewart, AHA!, *Cognitive Science*, 2011)



Recursive Binding



Binding is recursive: binding of bindings of bindings ....

Binding using vectors can produce syntactic complexity (Eliasmith and Thagard, *Cognitive Science*, 2001).

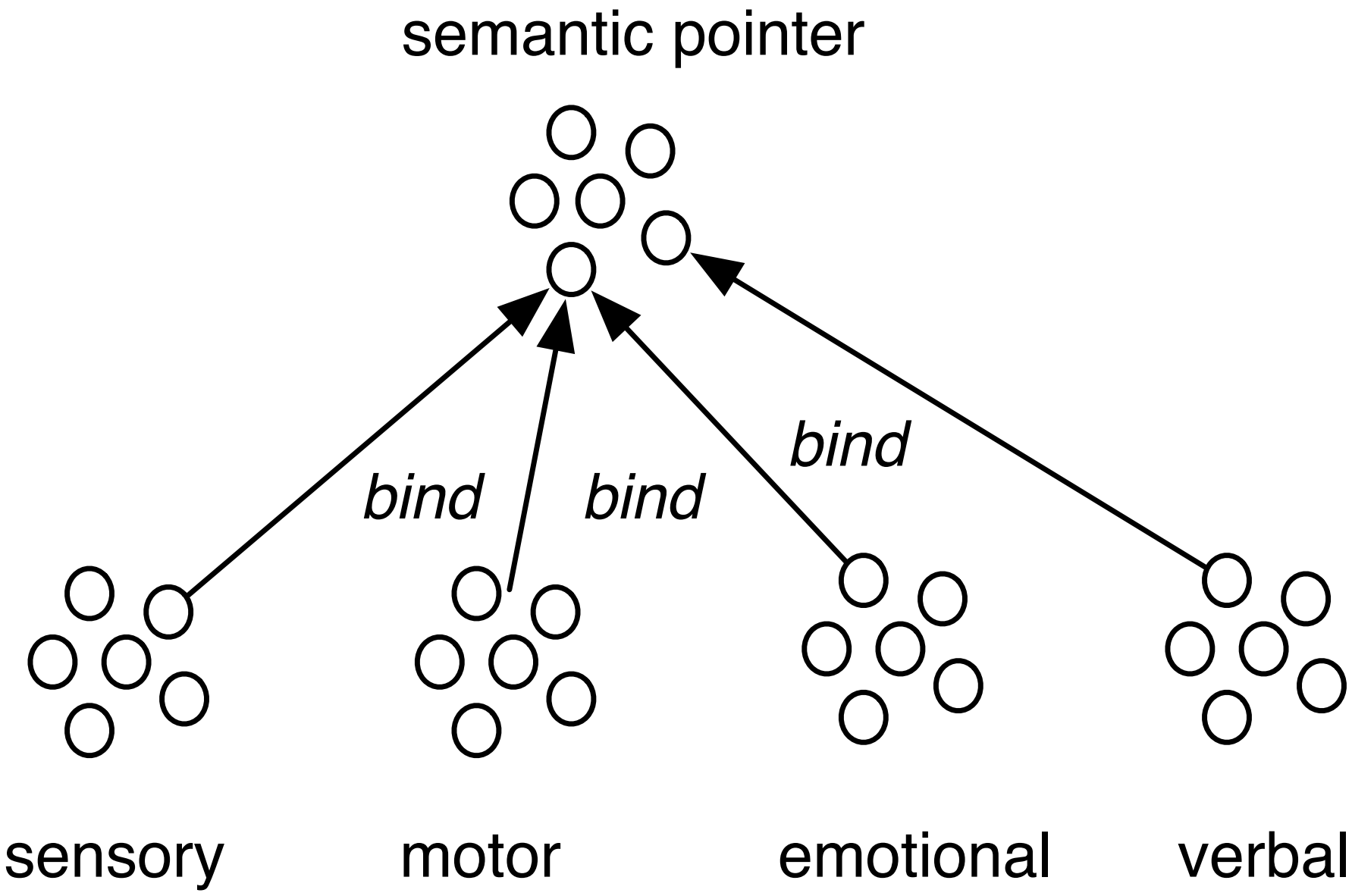
Binding (via convolution) can produce *semantic pointers* that function syntactically, semantically, and pragmatically, with properties akin to both symbols and distributed neural representations.

Semantic Pointers
(Eliasmith 2013)

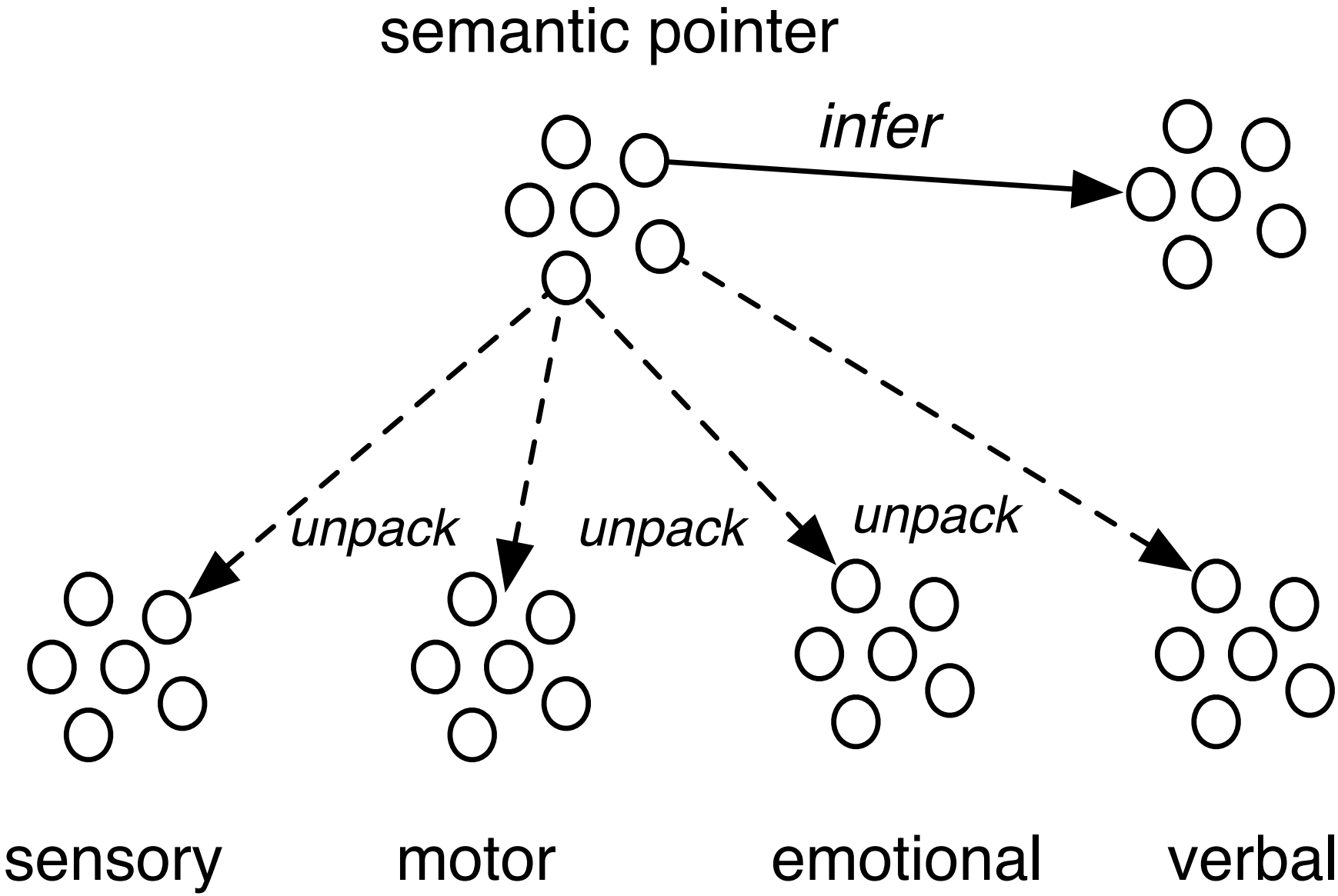
Semantic pointers are patterns of neural firing that:

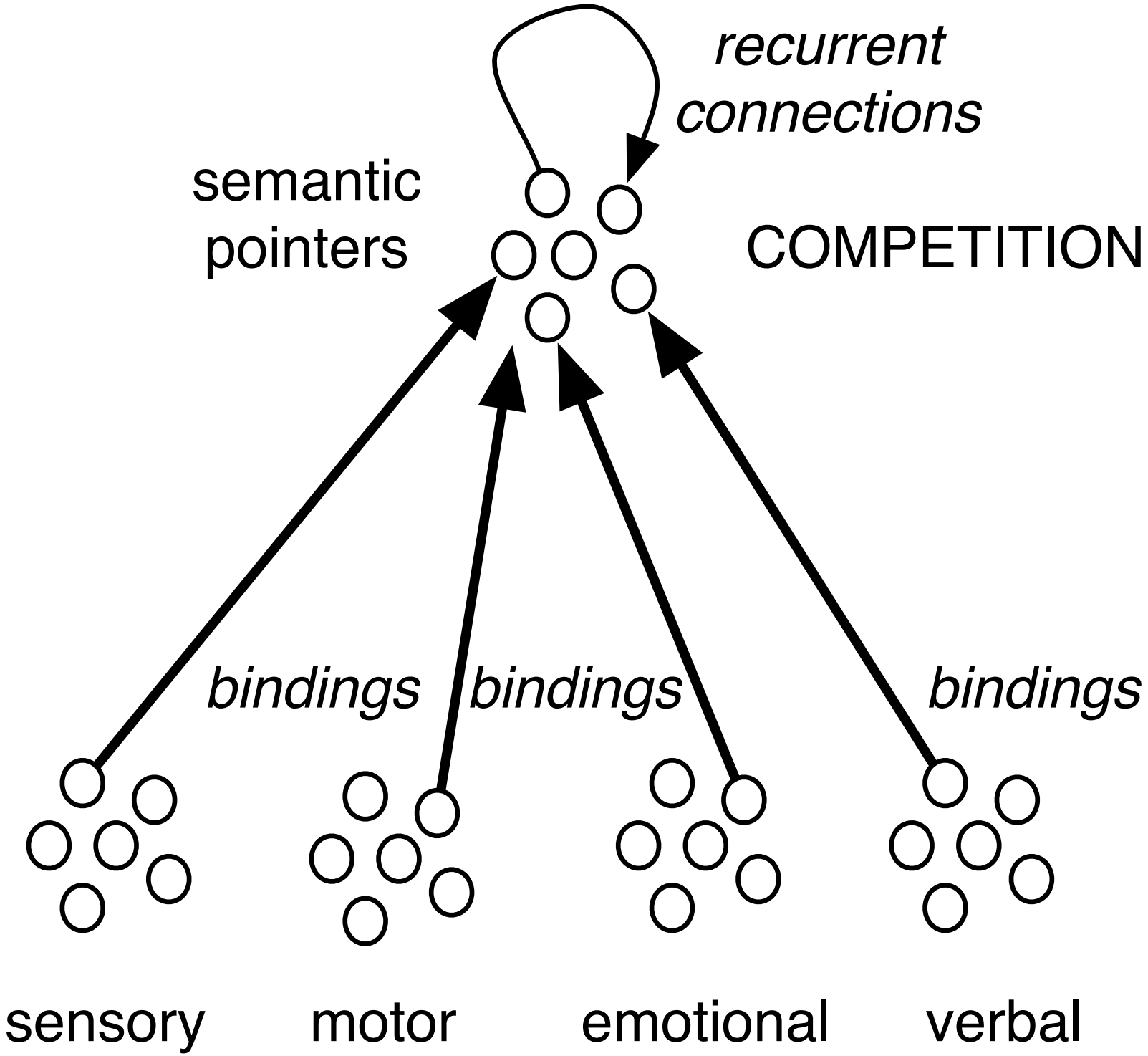
1. provide *shallow meaning* through symbol-like relations to the world and other representations;
2. expand to provide *deeper meaning* with relations to perceptual, motor, and emotional information;
3. support complex syntactic operations;
4. help to control the flow of information through a cognitive system to accomplish its goals.

FORMATION


semantic pointer
bind
bind
bind
sensory
motor
emotional
verbal

FUNCTION


semantic pointer
infer
unpack
unpack
unpack
sensory
motor
emotional
verbal

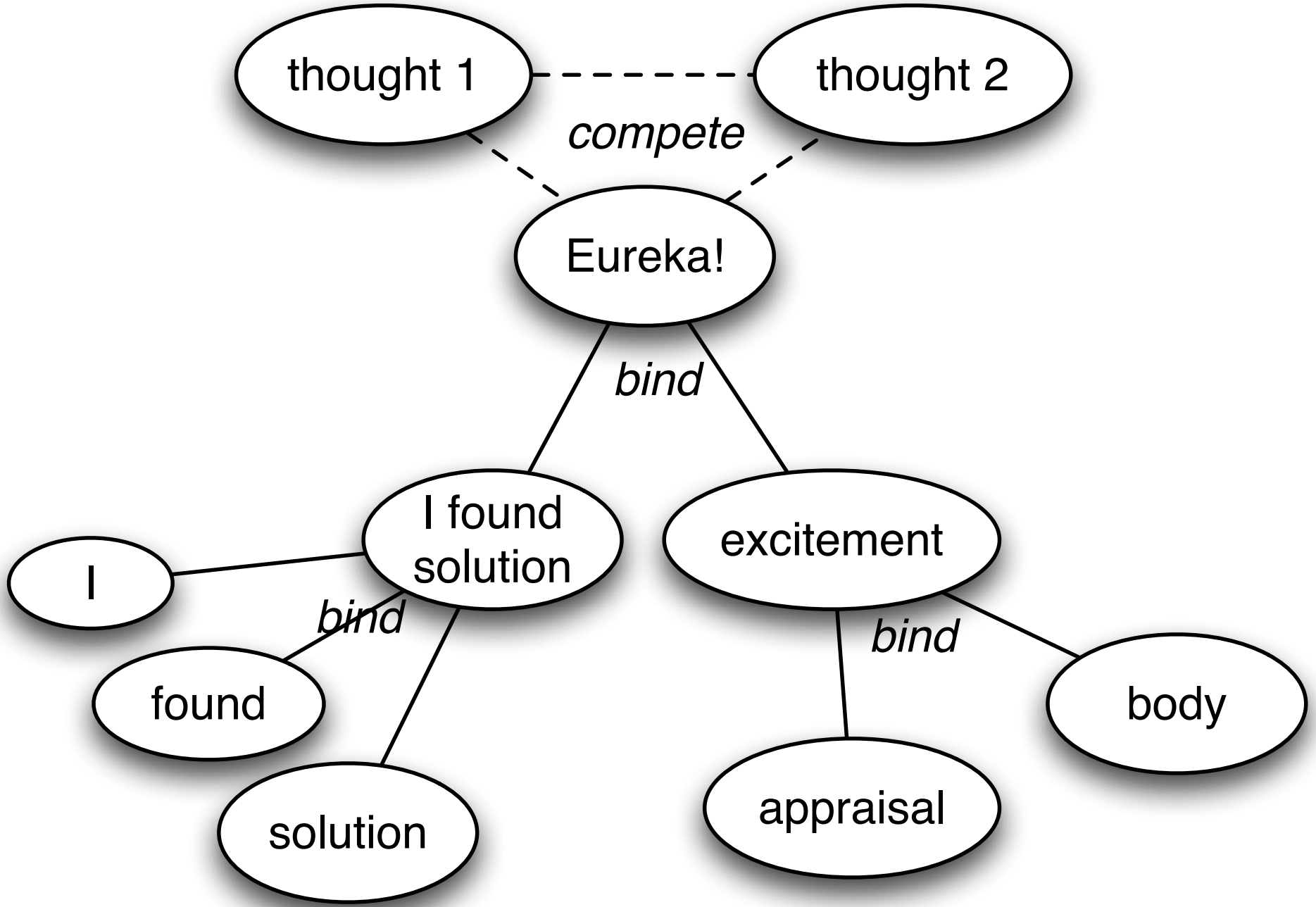

recurrent
connections
semantic
pointers
COMPETITION
bindings
bindings
bindings
sensory
motor
emotional
verbal

Binding Procesess

Discovery results from binding representations (Thagard & Stewart, *Cognitive Science, 2011;* Thagard, *The Cognitive Science of Science,* 2012; Thagard, artistic genius, 2014; Jiang and Thagard, social innovation, 2014).

Bind images into new images, concepts into new concepts, concepts into hypotheses.

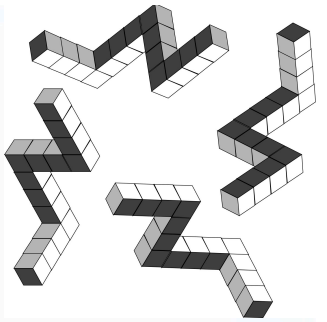
Emotion results from binding cognitive appraisal and physiological perception (Thagard & Aubie, 2008; Thagard, *The Brain and the Meaning of Life*, 2010; Thagard & Schröder, 2014).


thought 1
thought 2
compete
Eureka!
bind
I found solution
excitement
I
bind
bind
found
body
solution
appraisal

Emotions and Creativity

1. Emotions provide motivation. James Watson: never do anything boring.
2. Emotions provide evaluation: excitement, elegance, disgust, etc.
3. Emotions communicate motivation and evaluation in social groups, including scientists.

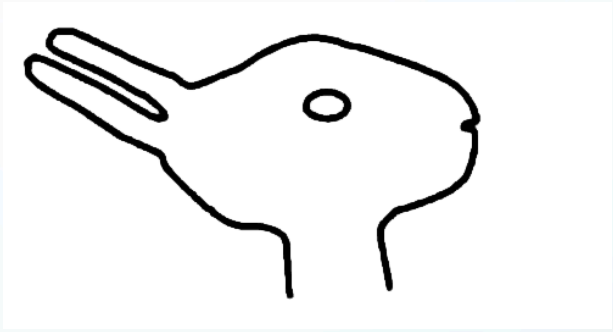
Imagery Operations



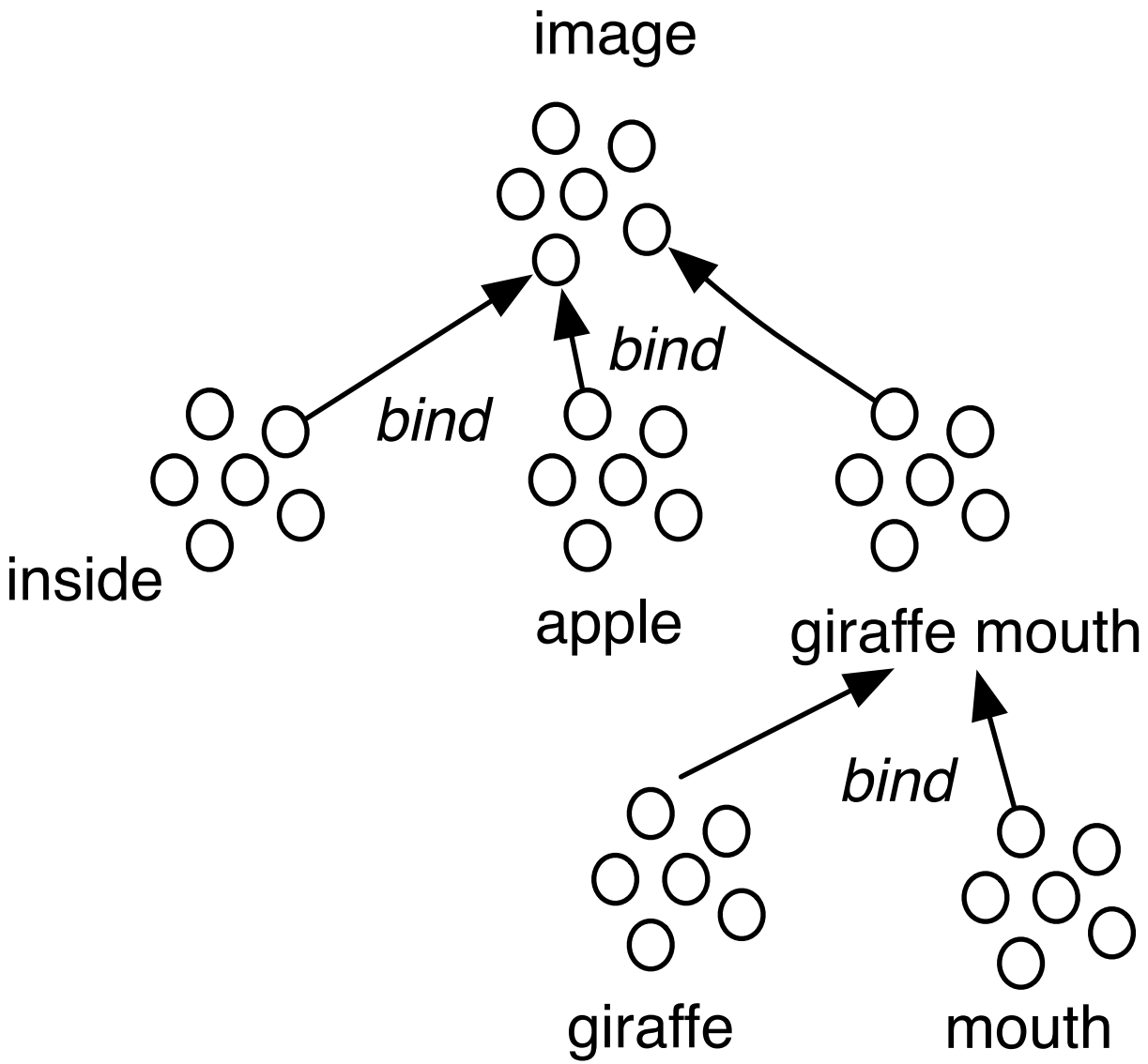
1. Intensify: make stronger, e.g. louder sound
2. Focus: concentrate, e.g. zoom in
3. Combination: put together, e.g. sweet + salty
4. Juxtaposition: join in space or time, e.g. jump shot
5. Decomposition: take apart, e.g. song

Imagery Mechanisms

1. Intensify: increase firing in neural groups
2. Focus: competition among semantic pointers
3. Combination: binding
4. Juxtaposition: binding with spatial/temporal relations
5. Decomposition: decompress (unbind) semantic pointers



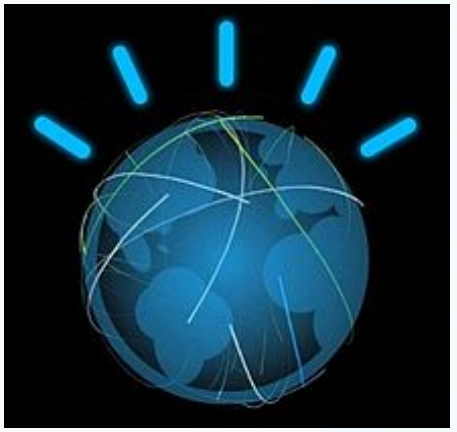
Juxtaposition



Computer Creativity

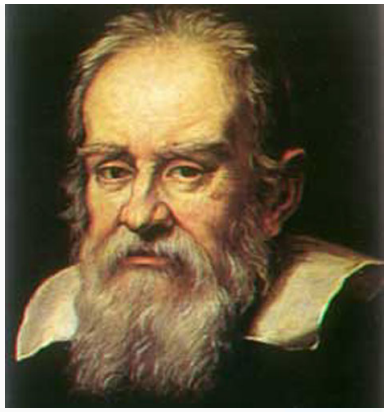
1. Painting: AARON (Harold Cohen)
2. Music: David Cope
3. Heuristics: Lenat's Eurisko
4. Recipes: Chef Watson
5. Image processing and voice recognition: e.g. Google brain and deep learning - AlphaGo

Increasing Computer Creativity



1. Multimodal representations
2. Recursive binding
3. Analogy: driven by semantics and pragmatics, not just syntax
4. Pragmatic evaluation by something like emotion
5. Procedural creativity: new methods

Procedural Creativity: Scientific Examples



Naturalistic explanation (Thales, c. 600 BC).

Experimentation (Ibn al-Haytham, 1021).

Mathematical science (Galileo, 1590).

Telescope (Galileo, 1609). Microscope (Malpighi, 1660).

Calculus (Newton, 1666). Statistical inference (Bernoulli, 1689).

Taxonomy (Linnaeus, 1735).

Spectroscopy (Kirchoff and Bunson (1859).

Polymerase chain reaction (Mullis, 1983).

Procedural Creativity: Other Examples

Technology: measuring density, movable type, lightning rod, vaccination, photography, Morse code, antiseptic surgery, FORTRAN, email, Web.

Art: perspective, opera, science fiction, impressionism, jazz, stream of consciousness, abstract sculpture, modern dance

Social: hospice, Facebook, prison reform, Habitat for Humanity, microfinance, distance learning, universal health care, affirmative action, pensions

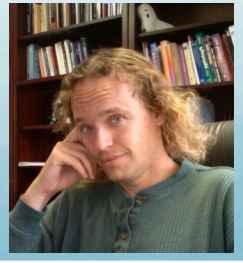
Procedural Creativity: Cognitive Representation

Methods can be represented as rules: IF you want to accomplish goal G, THEN follow procedure P.

Goals and procedures are not just verbal, but can be multimodal (visual, kinesthetic, auditory, touch, taste, smell, etc.).

So the IF and THEN parts of some rules need to be represented by neural patterns, or vectors as an approximation. E.g. <*move mouse*> -> <*cursor*>.

See the Semantic Pointer Architecture of Eliasmith (2013) *How to Build a Brain.*



Cognitive Process: Goal Driven

Procedural generalization:

Inputs: Goal and a problem solution showing that using steps leads to accomplishment of the goal.

Output: A method with the structure: If you want to accomplish the goal, then use the steps.

Process: Identify the steps that led to the goal, and generalize them into the method, with multimodal representations.

Additional Topics

1. Values as emotional cognition
2. Multimodal rules
3. Analogy and metaphor
4. Emotions and evaluation
5. Inference
6. Communication and collaboration: social mechanisms

Conclusions

1. Humans are creative because of brain mechanisms.
2. Neural binding of semantic pointers generates new images, concepts, etc.
3. Computer creativity can be enhanced.

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THE BRAIN AND THE MEANING OF LIFE

The Cognitive Science of Science

Explanation, Discovery, and Conceptual Change

Paul Thagard