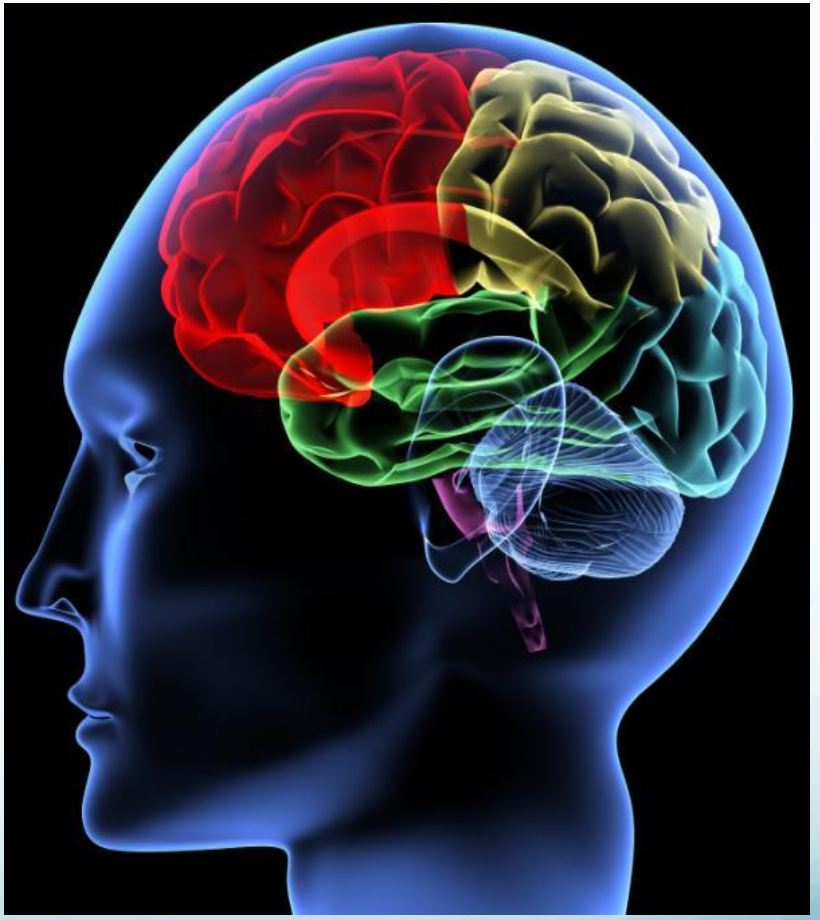
How Scientific Creativity Results from Three Brain Mechanisms

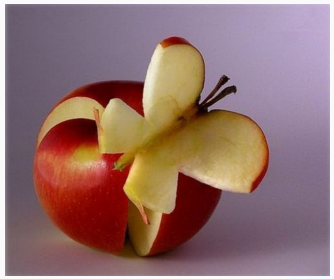
Paul Thagard
University of Waterloo

Outline

1. Self-consciousness of creativity
2. Neural representation
3. Recursive binding
4. Interactive competition
5. Consciousness
6. Procedural creativity



What is Creativity?



A creative product is:

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

Exemplars: relativity theory, television, public education, Starry Night

Typical features: new, valuable, surprising

Explanatory roles: Creativity explains success, etc.

Creative Intuition

Where does it come from?

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

Mechanistic Explanation

How does a bicycle move?

Parts: frame, wheels, gears, chain, pedals, etc.

Structure: e.g. pedal connected to gear.

Interactions: e.g. pedal moves chain.

Changes: e.g. wheels turn.

Self-consciousness of creativity

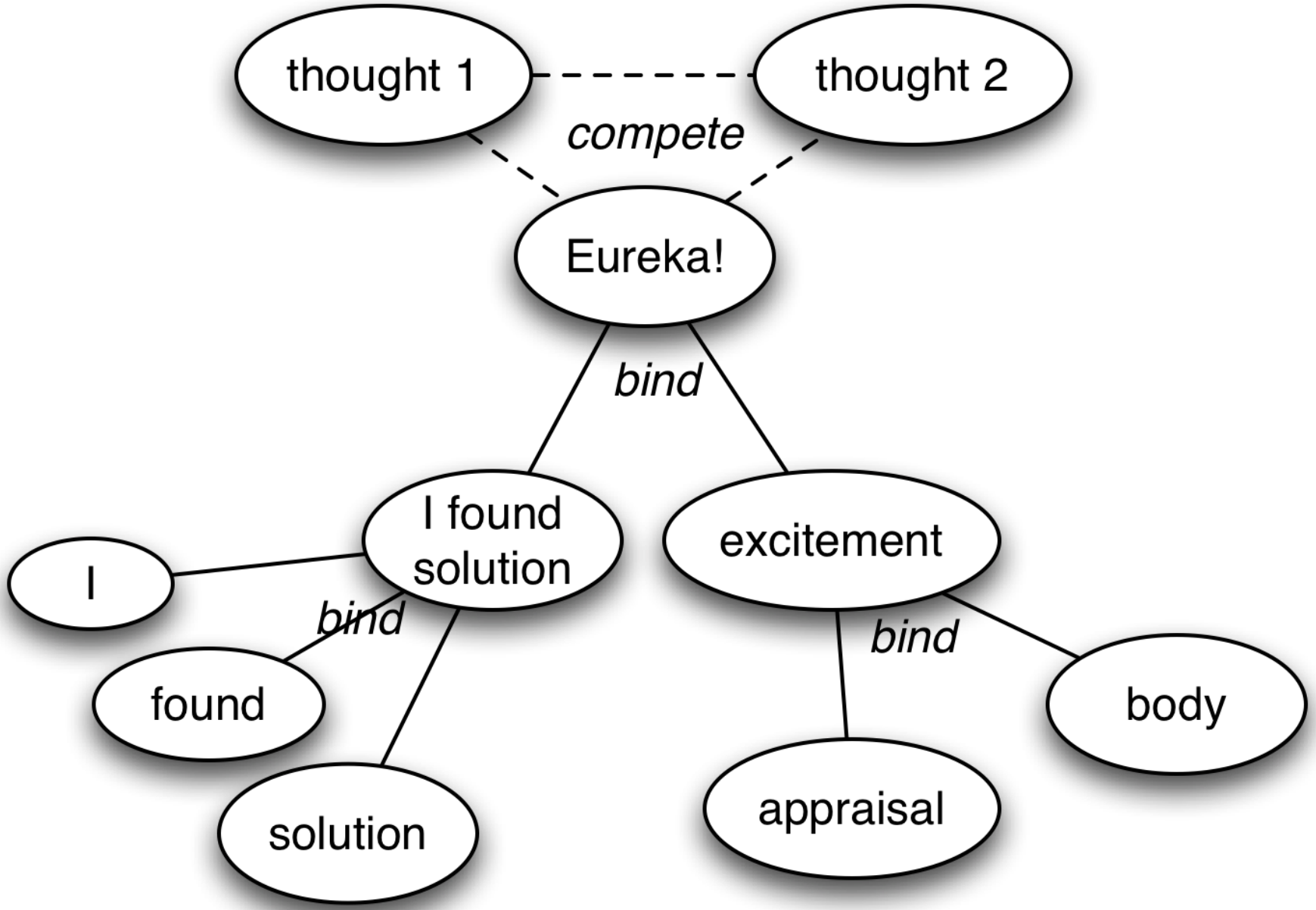
Eureka: I have found it.

Requires understanding of:

- Self
- Consciousness, including emotions
- Creativity

All of these involve mechanisms for:

- Neural representation
- Binding
- Competition


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

The New Synthesis

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

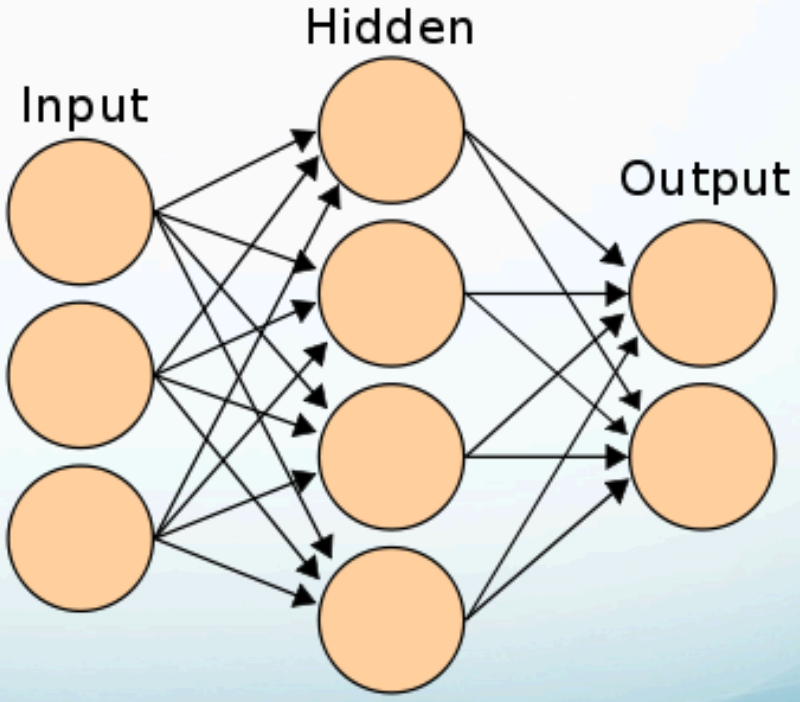
Antithesis (1980s): Intelligence results from sub-symbolic processes in neural networks, operating with distributed representations.

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.

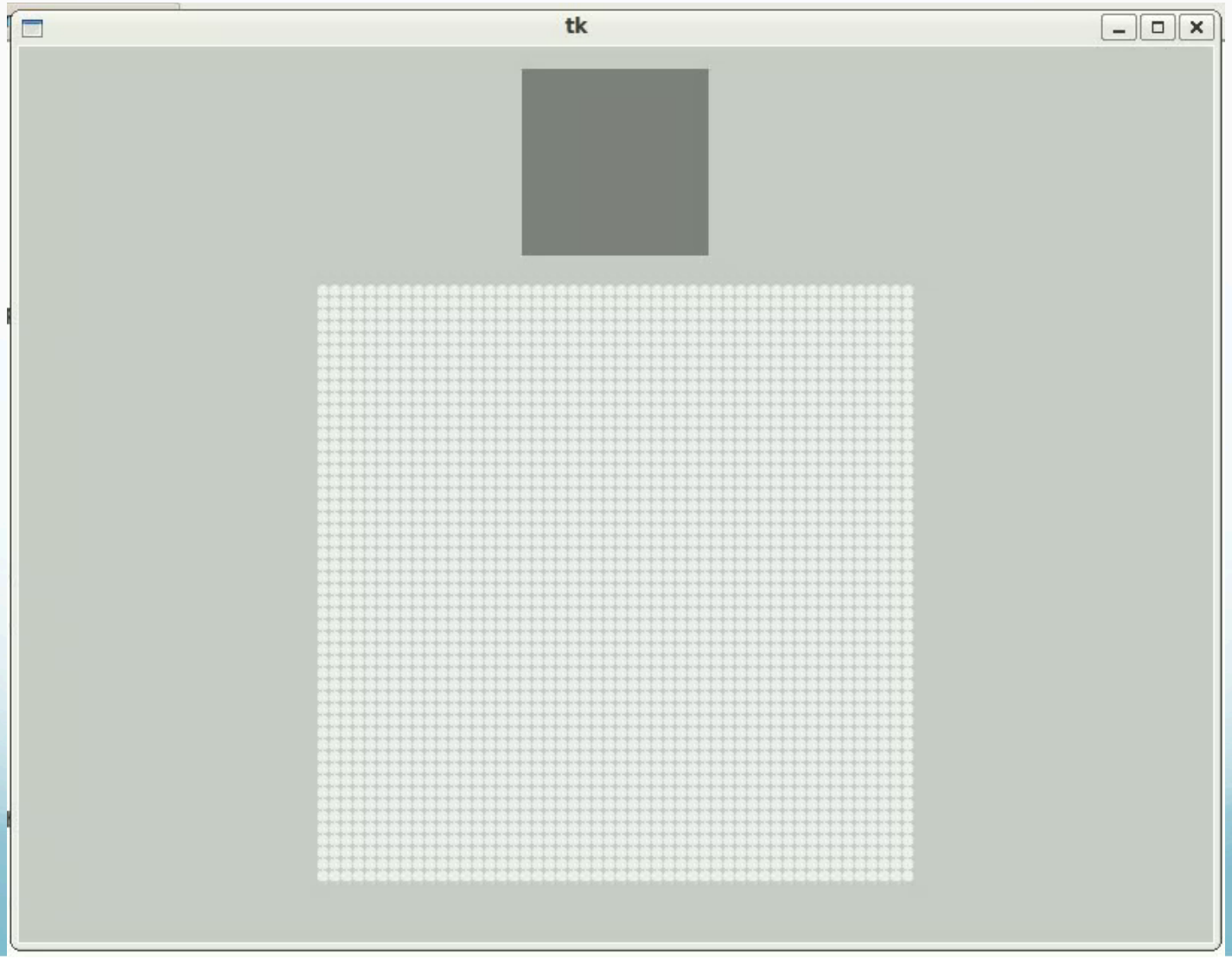
See Eliasmith & Anderson, *Neural Engineering,* 2003.

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

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

Neural Representation

(Chris Eliasmith, Terry Stewart)

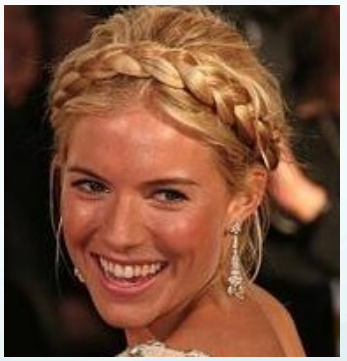


Binding in the Brain

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.

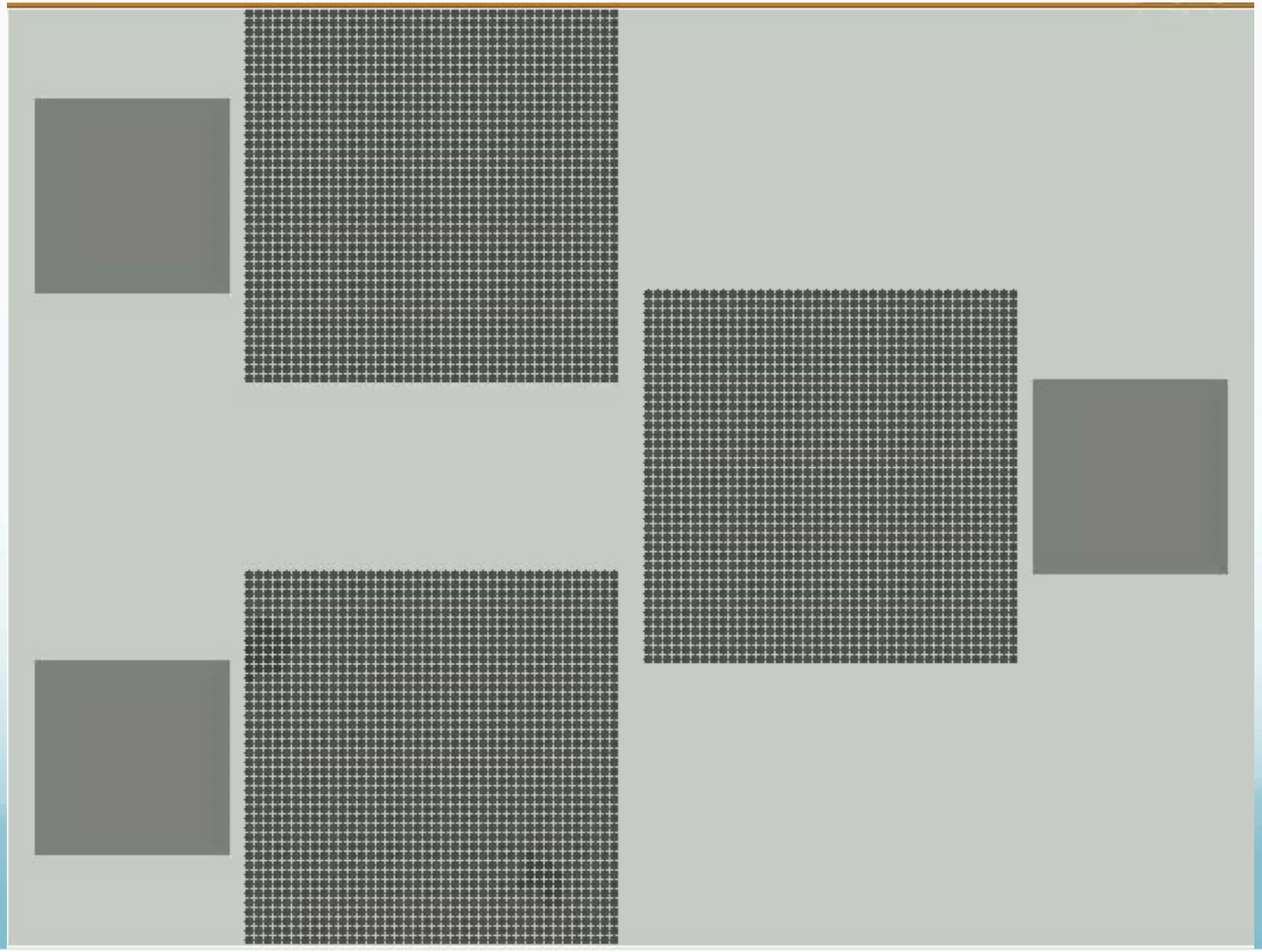


Representations are braided together.

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 ....

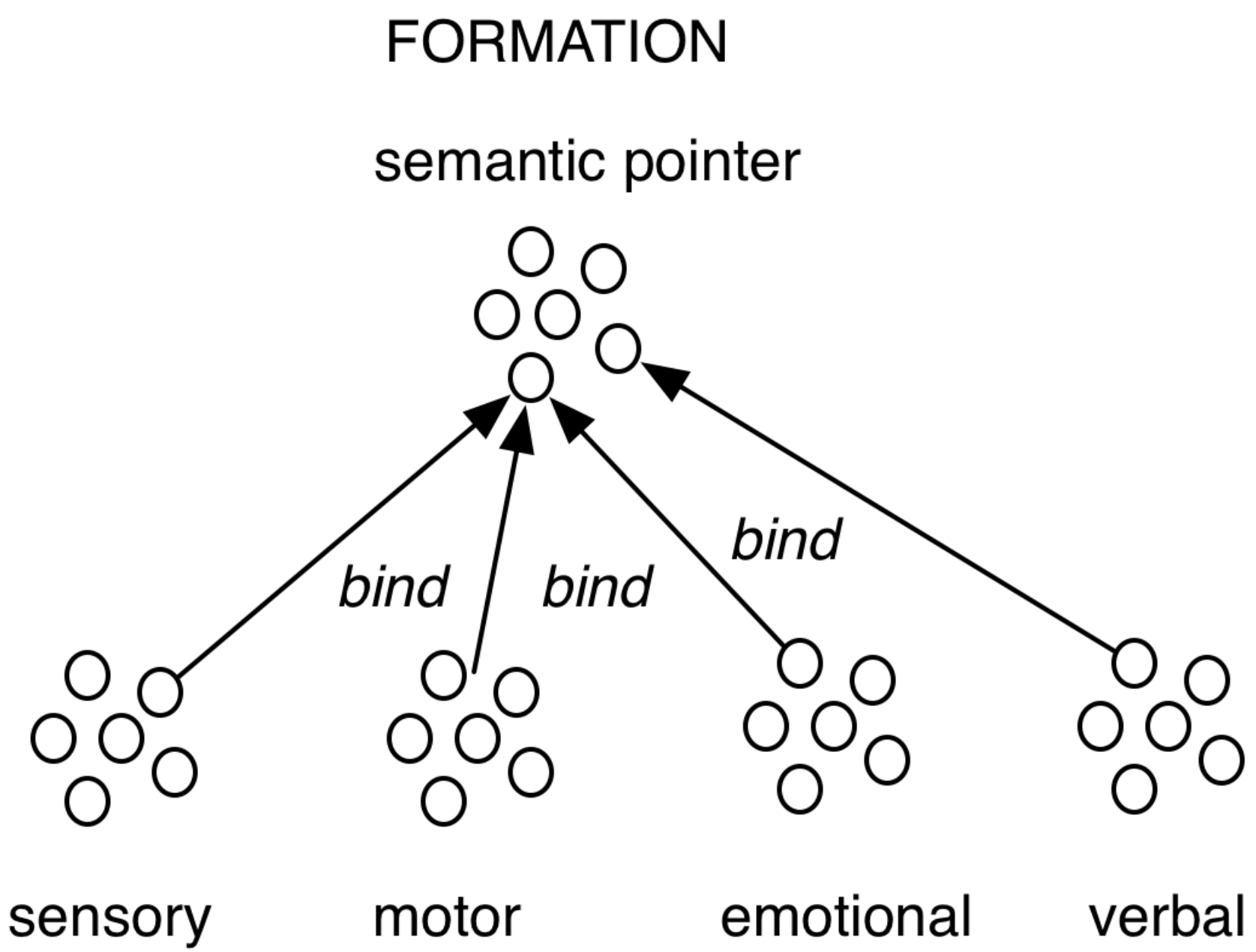
Binding using vectors can produce syntactic complexity (Eliasmith and Thagard, *Cognitive Science*, 2001).

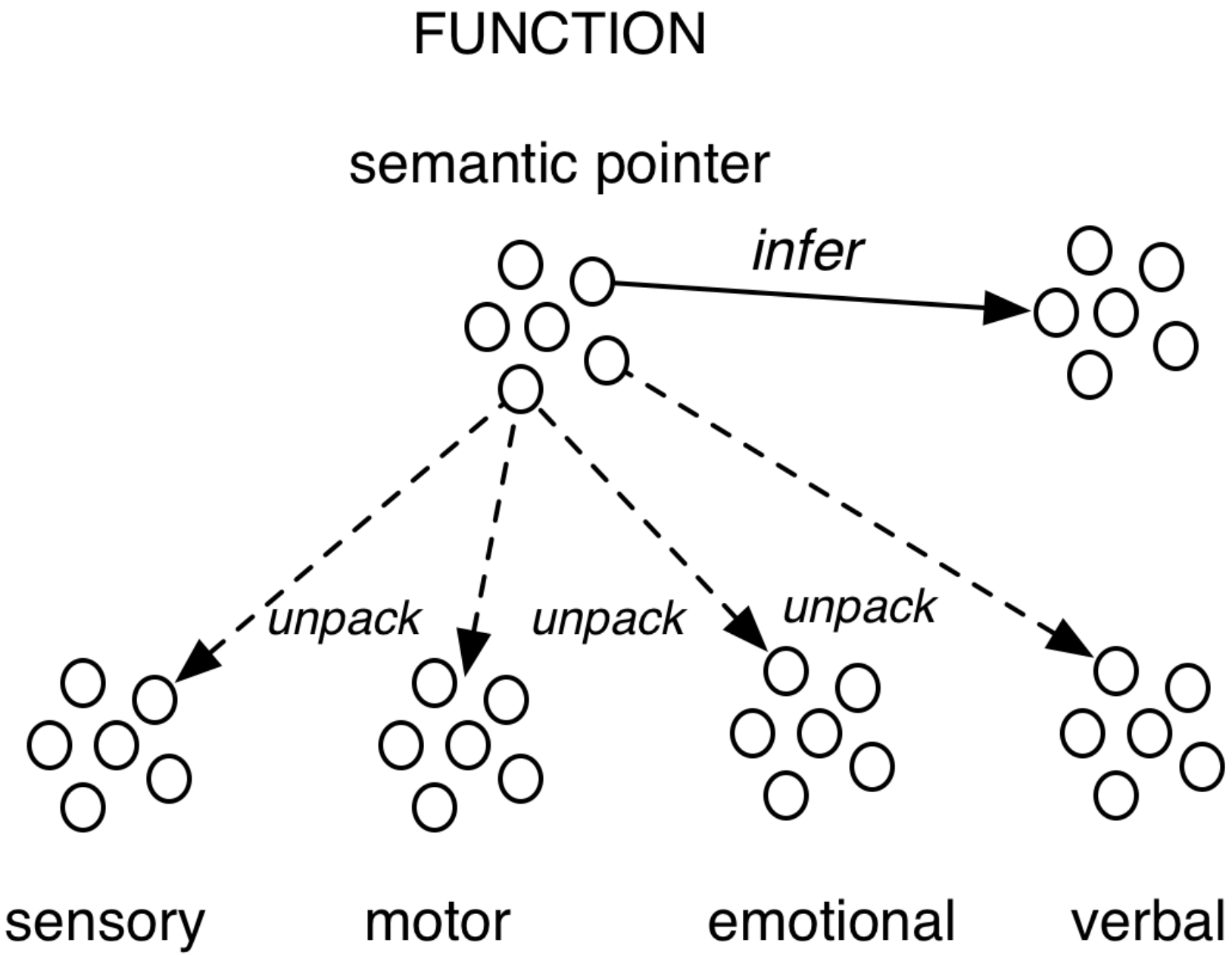
Binding (via convolution) can produce *semantic pointers* that function syntactically, semantically, and pragmatically, with properties akin to both symbols and distributed neural representations.

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

Binding Processess

Self-consciousness of creativity requires:

BIND (self, discovery, emotional reaction)

Discovery results from binding representations (Thagard & Stewart, *Cognitive Science, 2011;* Thagard, *The Cognitive Science of Science,* 2012).

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

Self as Semantic Pointer

Self-representation binds:

- Current experiences: sensory, bodily
- Memories
- Concepts of self and others

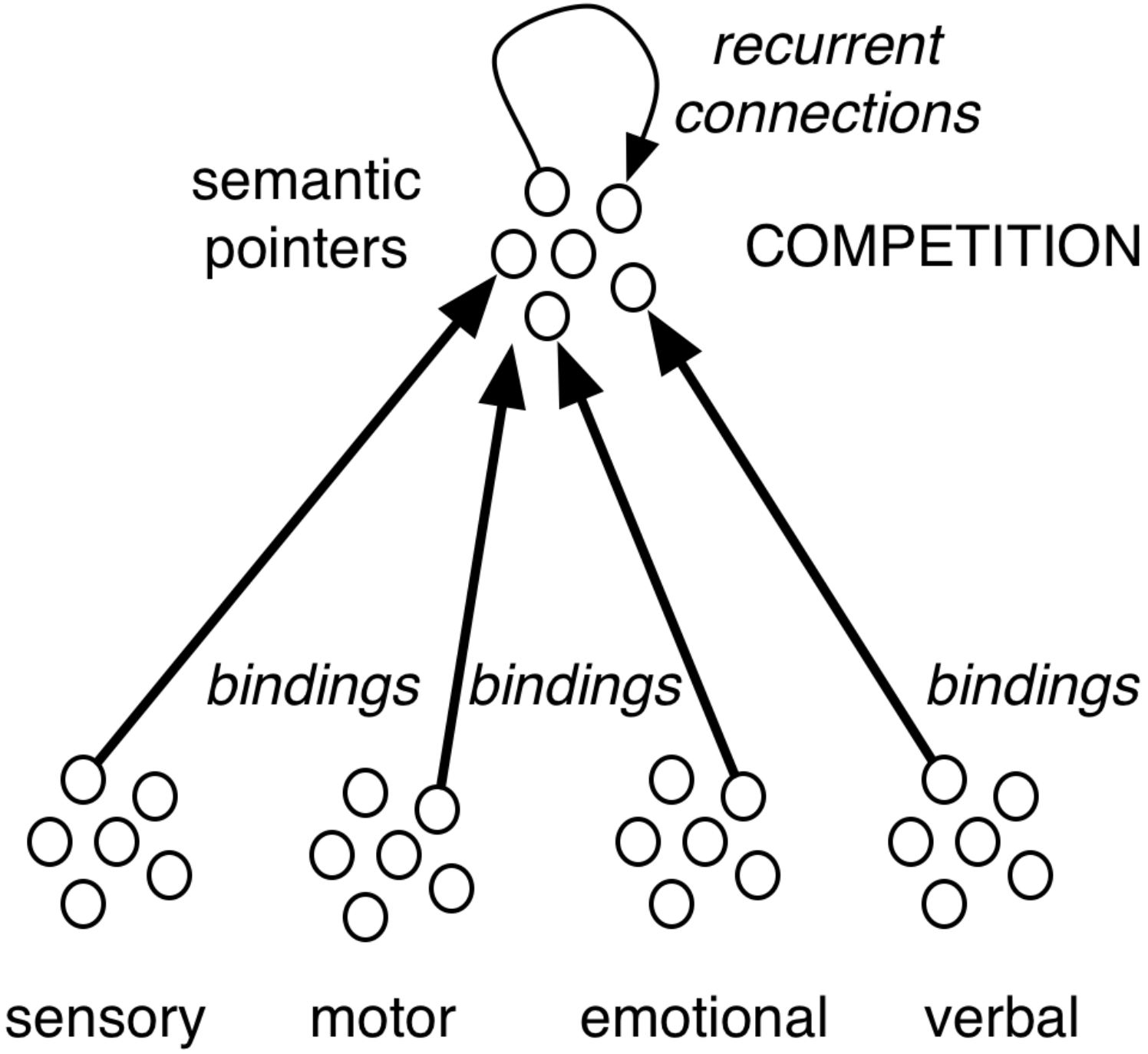
Result is a self-representation produced by recursive bindings. Unity and diversity.

Interactive Competition

Rumelhart & McLelland: Many processes, e.g. language result from interactive activation and competition in neural networks.

Smith & Kosslyn (2007): interactive competition model of attention.

Hypothesis: consciousness of all sorts results from interactive competition among semantic pointers!


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

Consciousness Evidence

Simulations (NENGO) of:

1. Qualitative differences in experience, e.g. vision vs. smell
2. Onset and cessation, e.g. sleep
3. Shifts of consciousness, e.g. cocktail party
4. Kinds of consciousness, e.g. self
5. Unity and disunity, e.g. drugs

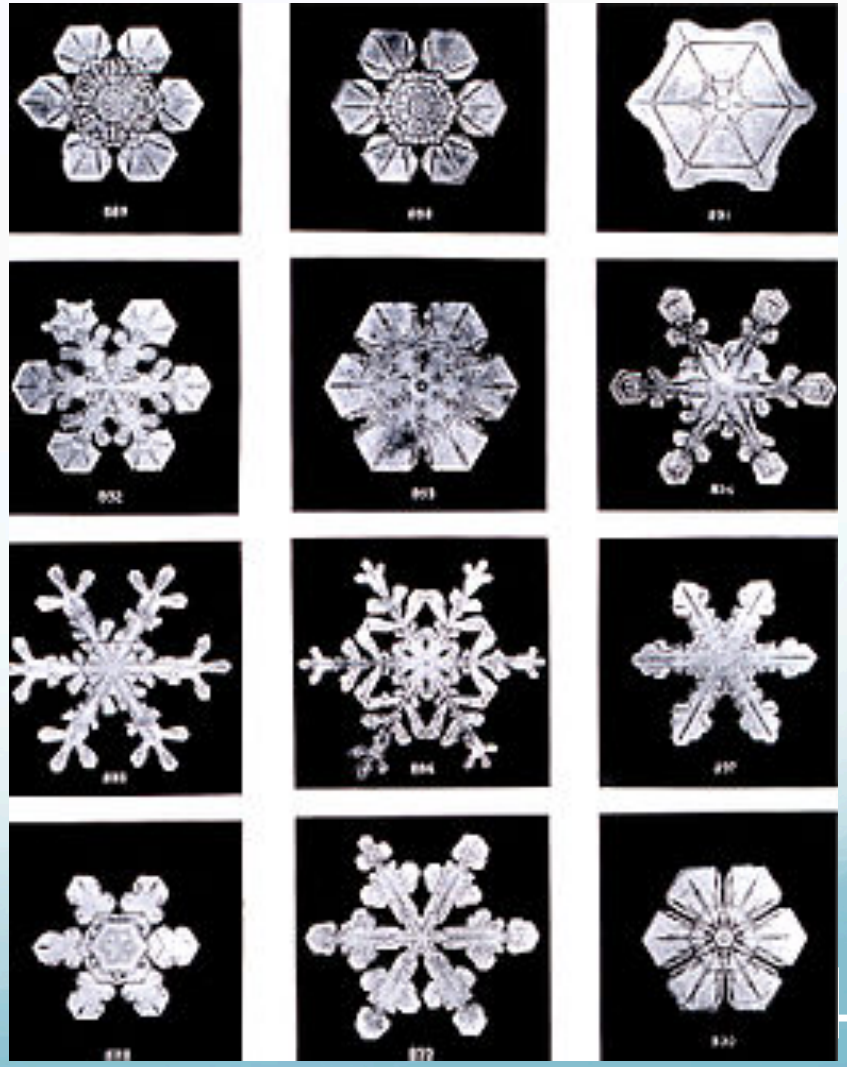
Thagard & Stewart, Two Theories of Consciousness, in press, *Consciousness and Cognition*.

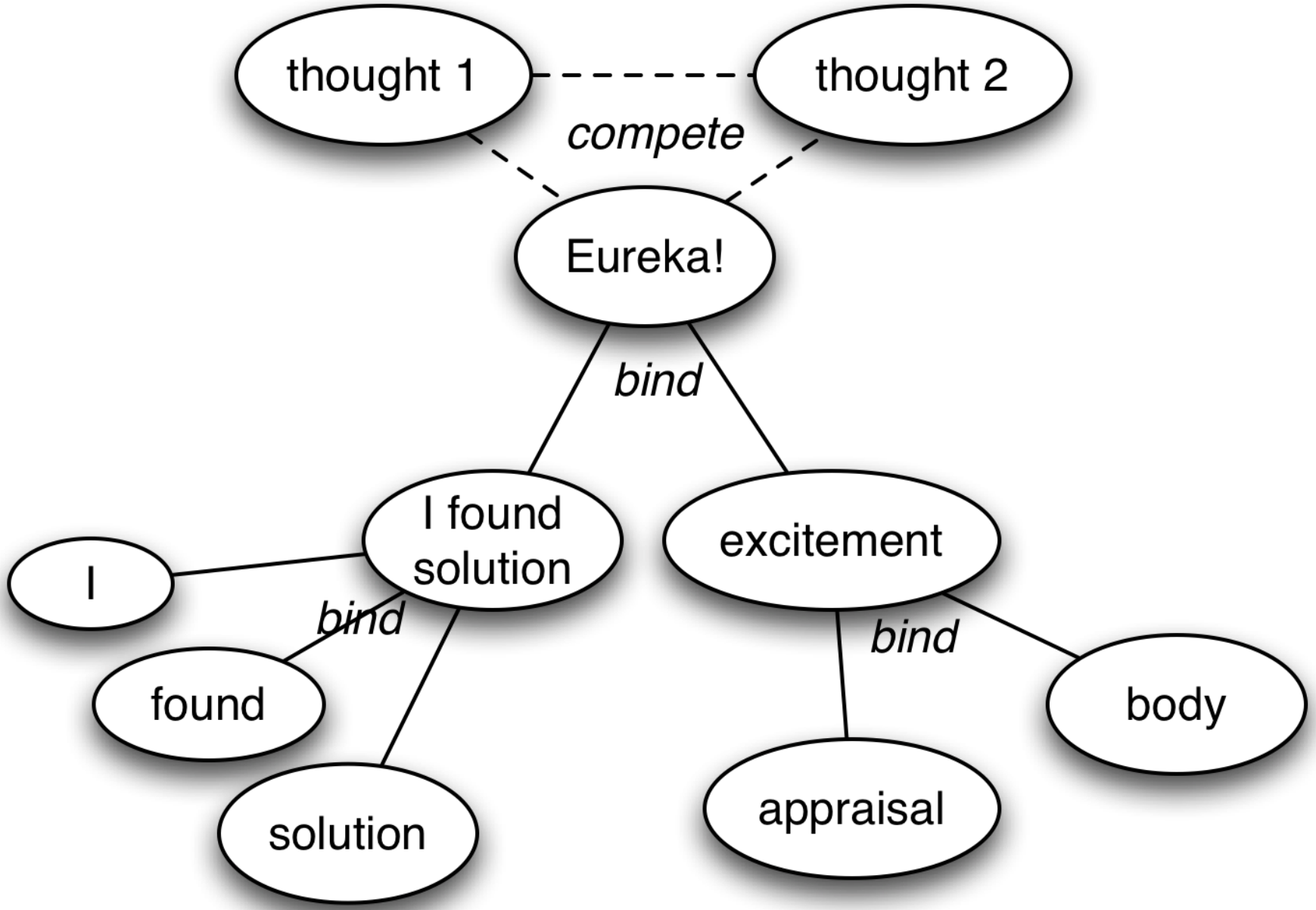
Three Mechanisms

Parts	Interactions	Emergent result
Neurons	Excitation, inhibition, synaptic connections	Representation by firing patterns
Neural populations	Recursive binding	Semantic pointers
Semantic pointers	Interactive competition	Conscious experience

Emergence

Emergent properties are possessed by the whole, not by the parts, and are not simple aggregates of the properties of the parts because they result from interactions of parts.



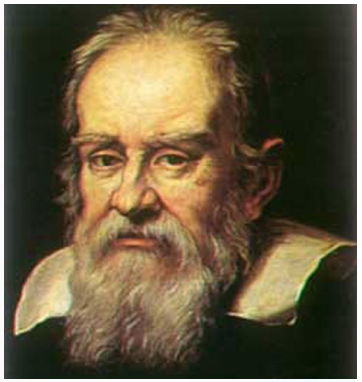

thought 1
thought 2
compete
Eureka!
bind
I found solution
excitement
I
bind
bind
found
body
solution
appraisal

Products of Creativity

Domains: scientific discovery, technological invention, social innovation, artistic imagination

1. **Concepts**: atom, atomic bomb, hospital, impressionism
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

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).

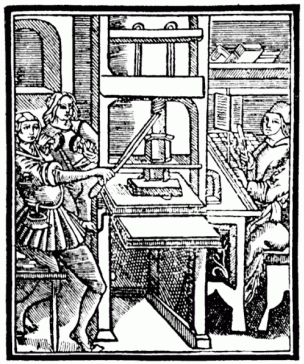
Calculus (Newton, 1666). Statistical inference (Bernoulli, 1689).

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

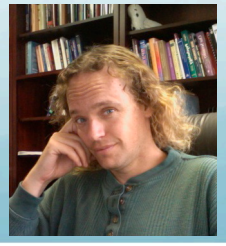
Procedural Creativity: Cognitive Representation

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.

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



Cognitive Process: Goal Driven

Procedural generalization:

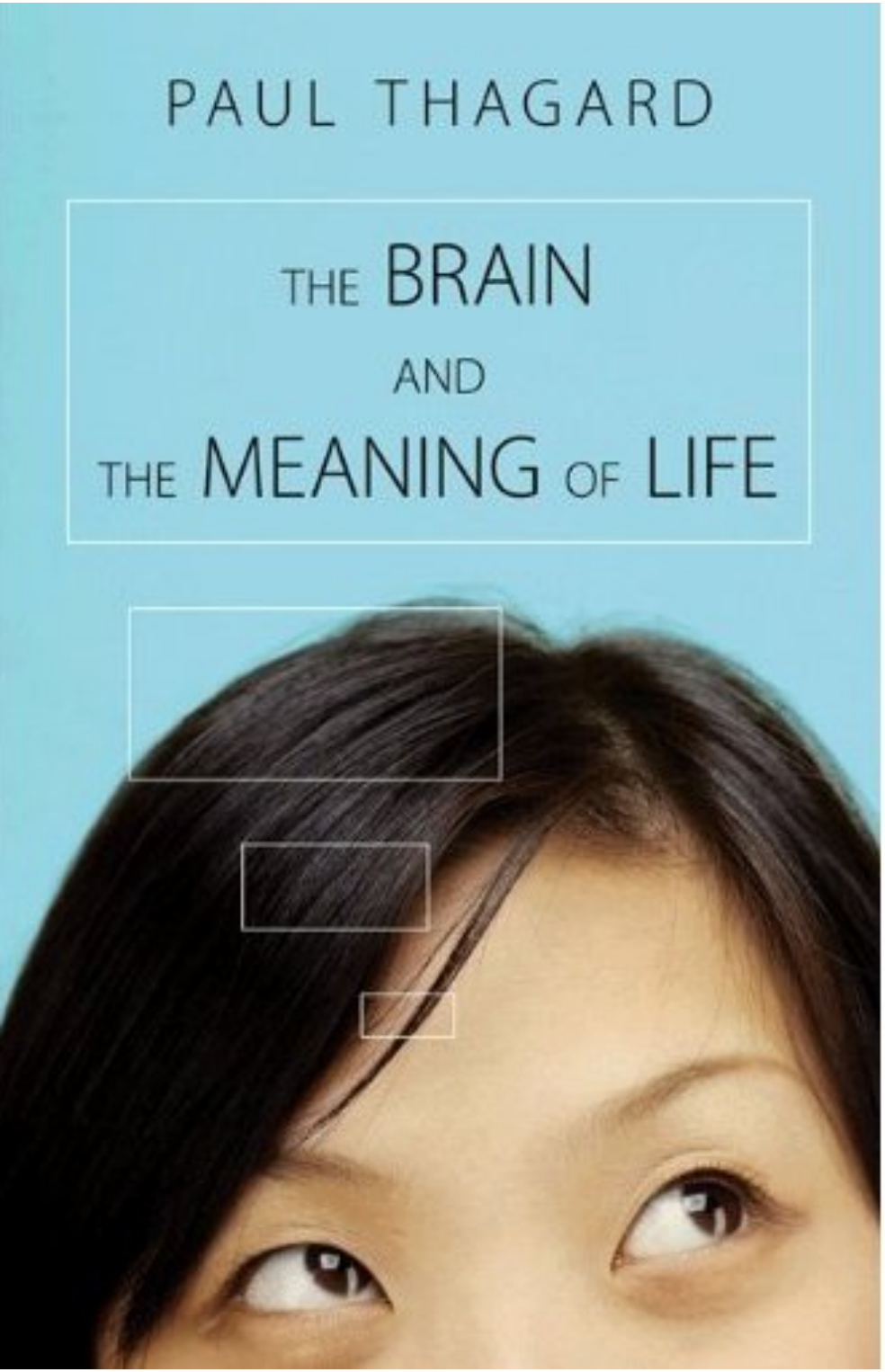
Inputs: Goal and a problem solution showing that using steps leads to accomplishment of the goal.

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.

Conclusions

1. Eureka experience is self-consciousness of creativity.
2. Key mechanisms are neural representation, recursive binding, and competition among semantic pointers.
3. Consciousness is a brain process.



The Cognitive Science of Science

Explanation, Discovery, and Conceptual Change

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