Distributed Cognition as a Theoretical Framework for Information Visualization

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Oct 19, 2008

A Science of InfoVis?

If there is something like a science of visualization, with what should it be concerned? Loosely defined, a scientific discipline should aim at a coherent set of theories, laws, and models that describe a range of phenomena, have predictive power, are grounded in observations, and that can be falsified.

[van Wijk, 2006]

Lack of Theory?

Information Visualization suffers from not being based on a clearly defined underlying theory ...There is much unease in the community as to the lack of theoretical basis for the many impressive and useful tools that are designed, implemented and evaluated by Information Visualization researchers.

[Purchase et al., 2008]

information visualization is the use of computer-supported, interactive visual representations of abstract data to amplify cognition

Representation

visual perception: eyes

- Semiology of graphics
- APT framework
- Taxonomies
- Attention, preattentive processing

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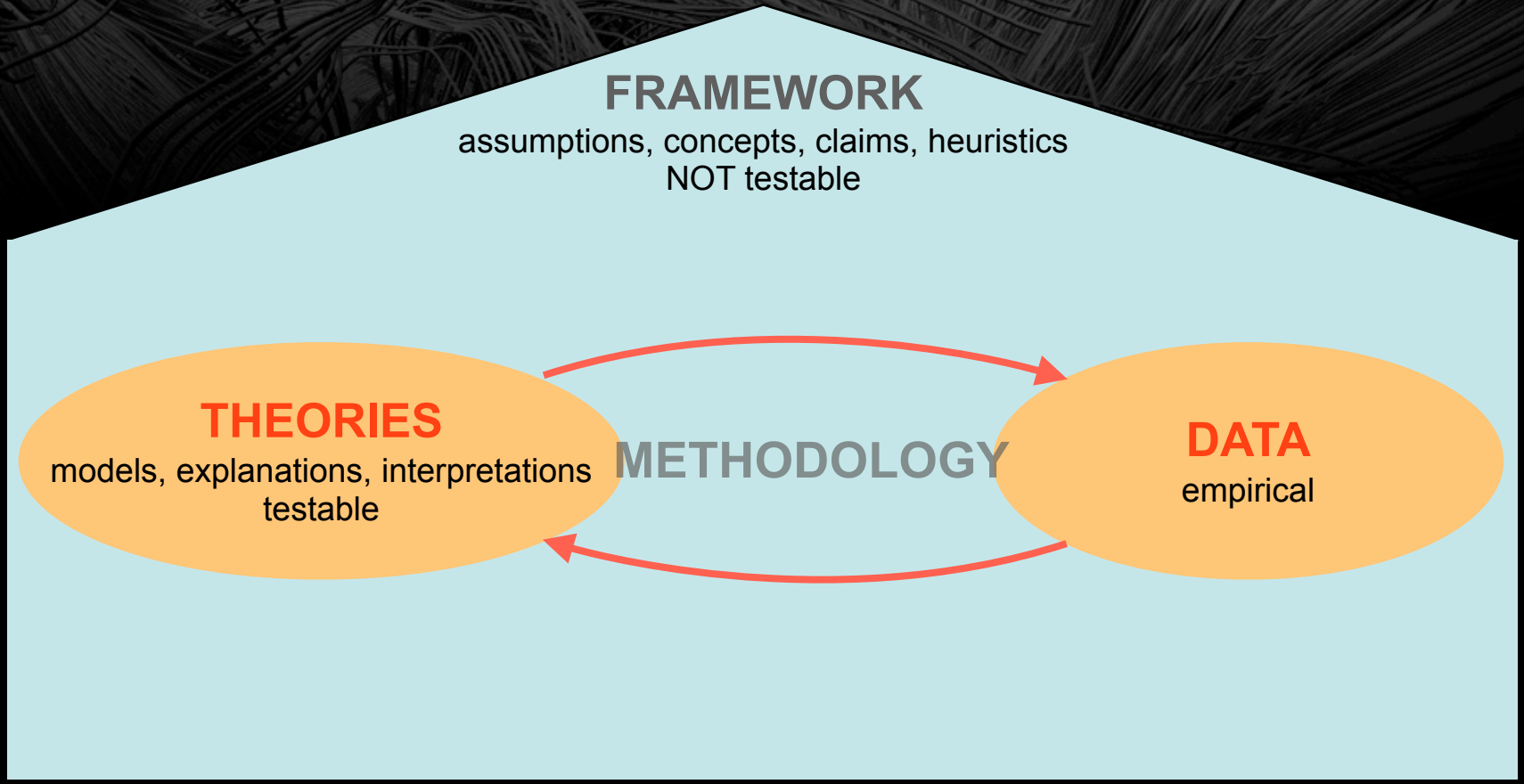
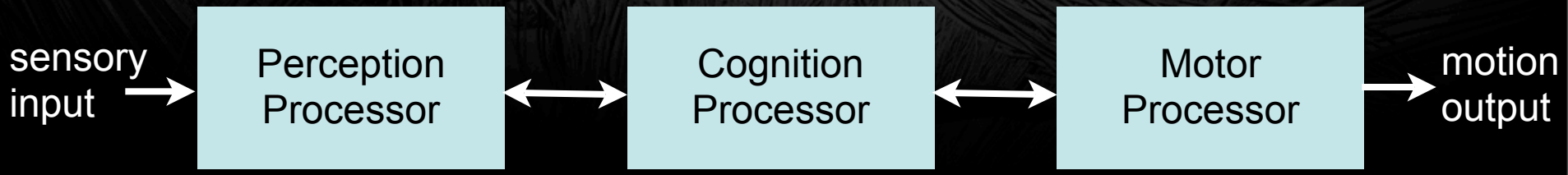
Cognition
mental operation: brain

Are we on the right track?

The Birth and Development of Theories



Traditional Cognitive Science Framework



Assumptions:

- Cognitive processing is completely inside the brain
- Cognitive processing is internal symbol manipulation

Implications on the nature of representation and interaction in InfoVis

- Representation
  - Visualizations are scaffolds for cognition
    - memory aid, improve search / abstraction efficiency, make information explicit
  - All visual information is abstracted as symbols for cognitive processing

- Interaction
  - Interaction is soliciting information and carrying out cognitive decisions
  - “Pragmatic actions”

Distributed Cognition

- Developed primarily by Edwin Hutchins and colleagues at UCSD

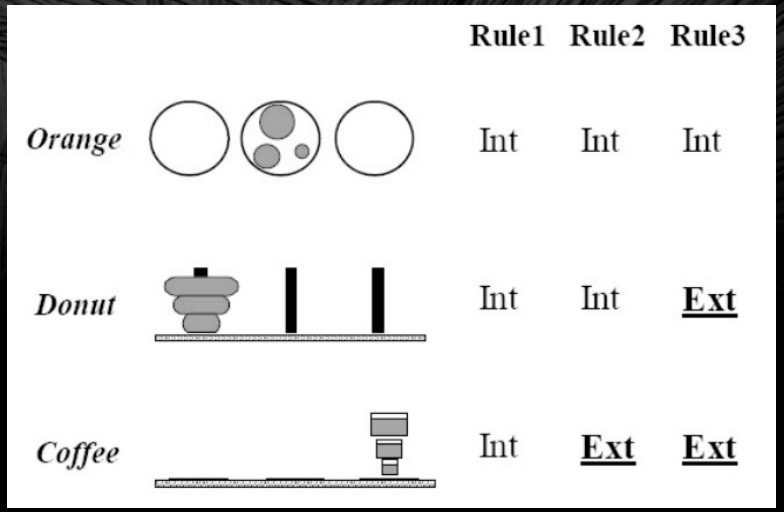
- Part of a larger movement in contemporary cognitive science
  - distributed, situated, embodied, enculturated

Distributed Cognition: Some Observations (1)

Rule 1: only one disk can be transferred at a time

Rule 2: a disk can only be transferred to a pole on which it will be the largest

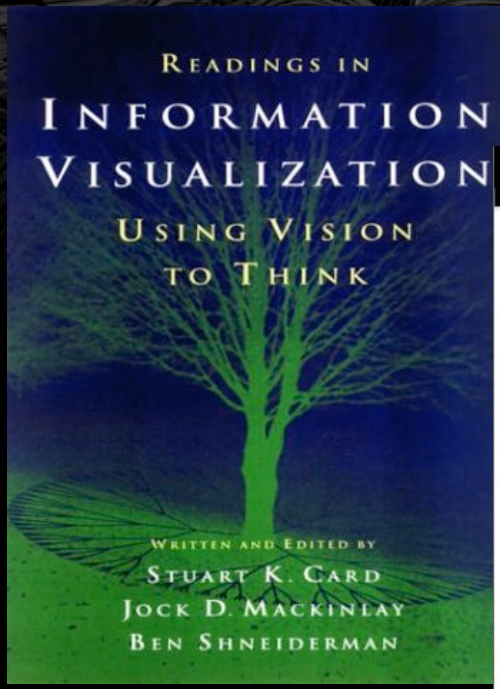
Rule 3: only the largest disk on a pole can be transferred to another pole.



[Zhang and Norman, 1994]

- External representations can be coupled directly as an information source without requiring the explicit formulation of an internal representation of the information provided in them

External Cognition



To understand something is called "seeing" it. We try to make our ideas "clear," to bring them into "focus," to -arrange' our thoughts. The ubiquity of visual metaphors in describing cognitive processes hints at a nexus of relationships between what we see and what we think. When we imagine someone hard at mental work, we might picture a scholar drawing a diagram, a book of sources open at her side. Or we might imagine a stockbroker, watching computer displays of financial data, rushing to act on events. Whatever the activity, mental work and perceptual interactions of the world are likely to be interwoven.

This interweaving of interior mental action and external perception (and manipulation) is no accident. It is the essence of how we achieve expanded intelligence. As Norman says,

> The power of the unaided mind is highly overrated. Without external aids, memory, thought, and reasoning are all constrained. But human intelligence is highly flexible and adaptive, superb at inventing procedures and objects that overcome its own limits. The real powers comefrom devising external aids that enhance cognitive abilities. How have we increased memory, thought, and reasoning? By the invention of external aids: It is things that make us smart. (Norman,1993, p. 43)

An important class of the external aids that make us smart are graphical inventions of all sorts. These serve two related but quite distinct purposes. One purpose is for communicating an idea, for which it is sometimes said, "A picture is worth ten thousand words."[1] Communicating an idea requires, of course, already having the idea to communicate. The second purpose is to use graphical means to create or discover the idea itself: using the special properties of visual perception to resolve logical problems, as Benin (197711981) would say. Using vision to think. This second sense of graphics is the subject of this book.

Graphic aids for thinking have an ancient and venerable history. What is new is that the evolution of computers is making possible a medium for graphics with dramatically improved rendering, real-time interactivity, and dramatically lower cost. This medium allows graphic depictions that automatically assemble thousands of data objects into pictures, revealing hidden patterns. It allows diagrams that move, react, or even initiate. These, in turn, create new methods for amplifying cognition, new means for coming to knowledge and insight about the world. A few years ago, the power of this new medium was applied to science, resulting in scientific visualization. Now it is possible to apply the medium more generally to business, to scholarship, and to education. This broader application goes under the name of information visualization. The purpose of this book is to introduce information visualization, to collect some of the important papers in the field, and to give samples of some of the latest work,

EXTERNAL COGNITION

To understand the intuition behind information visualization, it is useful to gain an appreciation for the important role of the external world in thought and reasoning. This notion is sometimes called external cognition (Scaife and Rogers, 1996) to express the way in which internal and external representations and processing weave together in thought. As Norman suggests, the use of the external world, and especially the use of cognitive artifacts or physical inventions to enhance cognition, is all around us.

Multiplication Aids

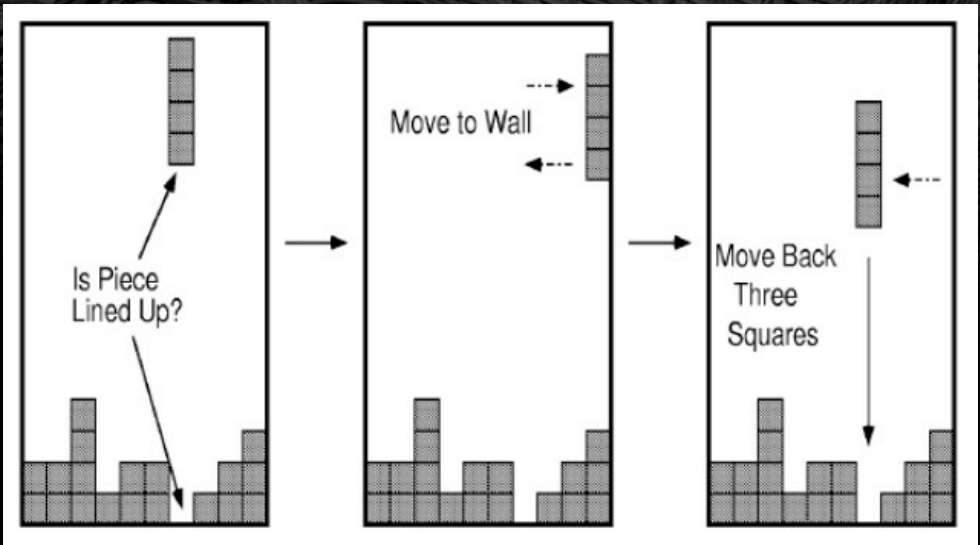
Take multiplication, one of the most mental of activities. Have a person multiply a pair of two-digit numbers, such as **34 x 72**, in his or her head and time how long it takes. Now repeat the experiment with another pair of numbers, in longhand using pencil and paper.

$$\begin{array}{r} 34 \\ \times\, 72 \\ \hline 68 \\ 23^{1}80 \\ \hline 24^{1}48 \end{array}$$

[1] According to Paul Martin Lester, professor of communications at the University of California at Fullerton, this quotation was simply made up by ad writer Frederick R. Barnard and included as an invented "Chinese proverb" in a streetcar advertisement for Royal Baking Powder. The ad writer wanted to make the point that pictures can attract attention faster than other media. See *http://www5.Fatterton.eduAes/iad.html* and Printers' Ink, March 10, 1927.

What is the nature of interaction?

Distributed Cognition: Some Observations (2)



[Kirsh and Maglio, 1994]

- Interaction is more than “pragmatic action”
- Epistemic action: human’s reflective and creative ability to use external actions to save internal computational resources

Distributed Cognition: A Framework

- Push the boundary of the unit of cognitive analysis beyond a human individual
- Cognition is an emergent property of interaction
- Interaction is more than changing representations to get closer to a goal : coordination

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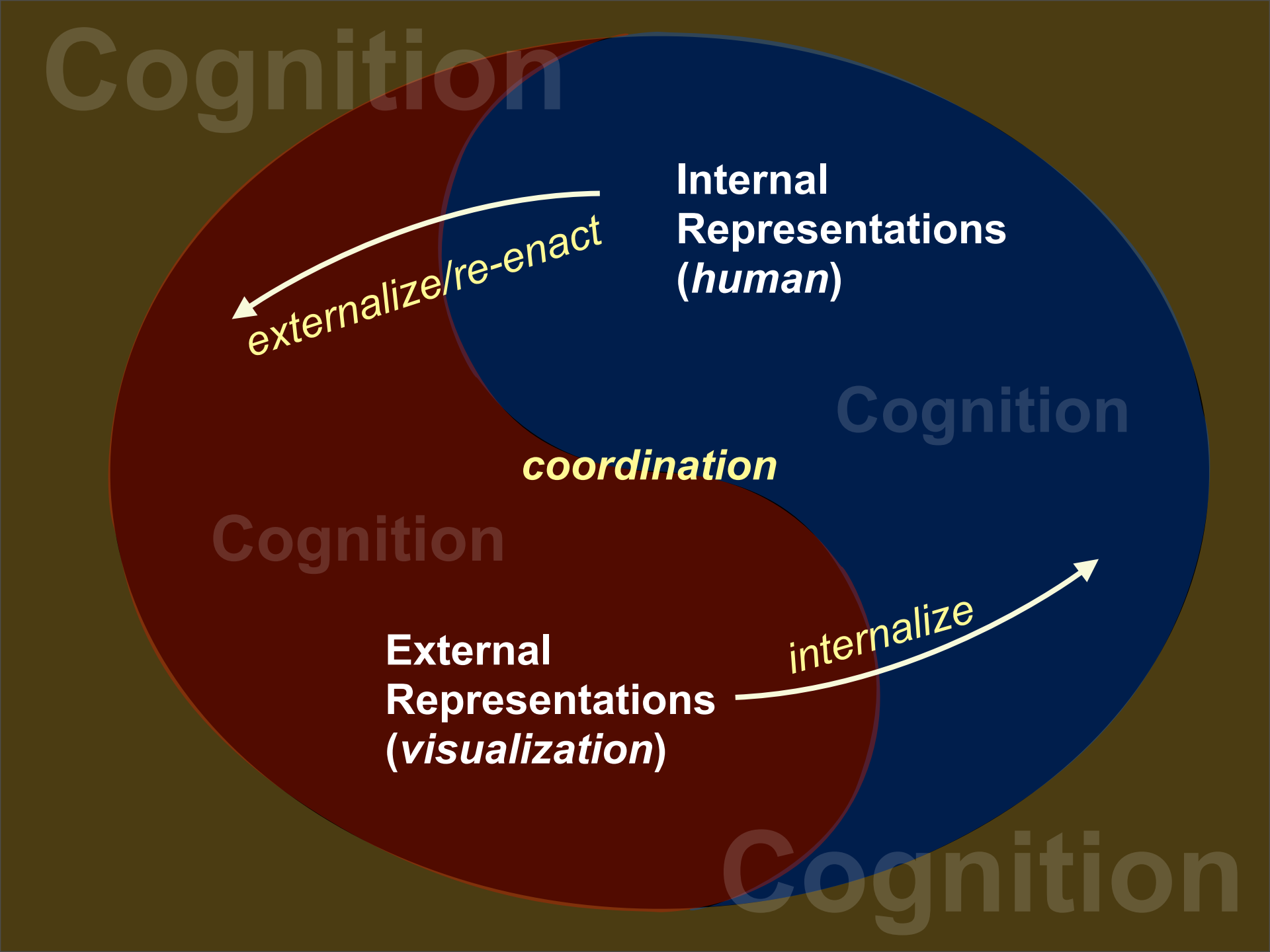
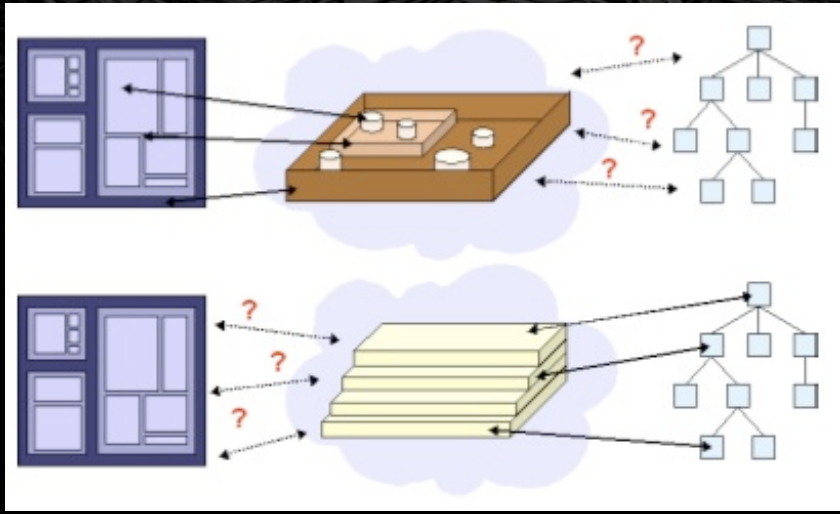

Cognition
Internal
Representations
(*human*)
externalize/re-enact
Cognition
coordination
Cognition
External
Representations
(*visualization*)
internalize
Cognition

Implications for InfoVis: Design



The Shaping of Information by Visual Metaphors

"The process of understanding a visualization therefore involves an *interaction* between these *external* visual metaphors and the user's *internal* knowledge representations."

[Ziemkiewicz and Kosara, 2008]

“Users may not only need to learn how to read a particular visualization in order to use it,

but also to *incorporate* its particular metaphors into their own thinking”

Interaction is more than internalizing external representations and acting on them

It also involves externalizing mental models that helps reducing internal cognitive load

- Designers' mental models are not users'
- Designers' externalizing actions may not be identical to users'

Implications for InfoVis: Design

- Could some of the current InfoVis systems inhibit users from developing coordination strategies when performing a task?

- Design to support coordination and easy cognitive coupling
  - allow users to make easy customizations or appropriations
  - allow users to create visualizations by externalizing their mental models directly

Implications for InfoVis: Theories

With DCog as a theoretical framework....

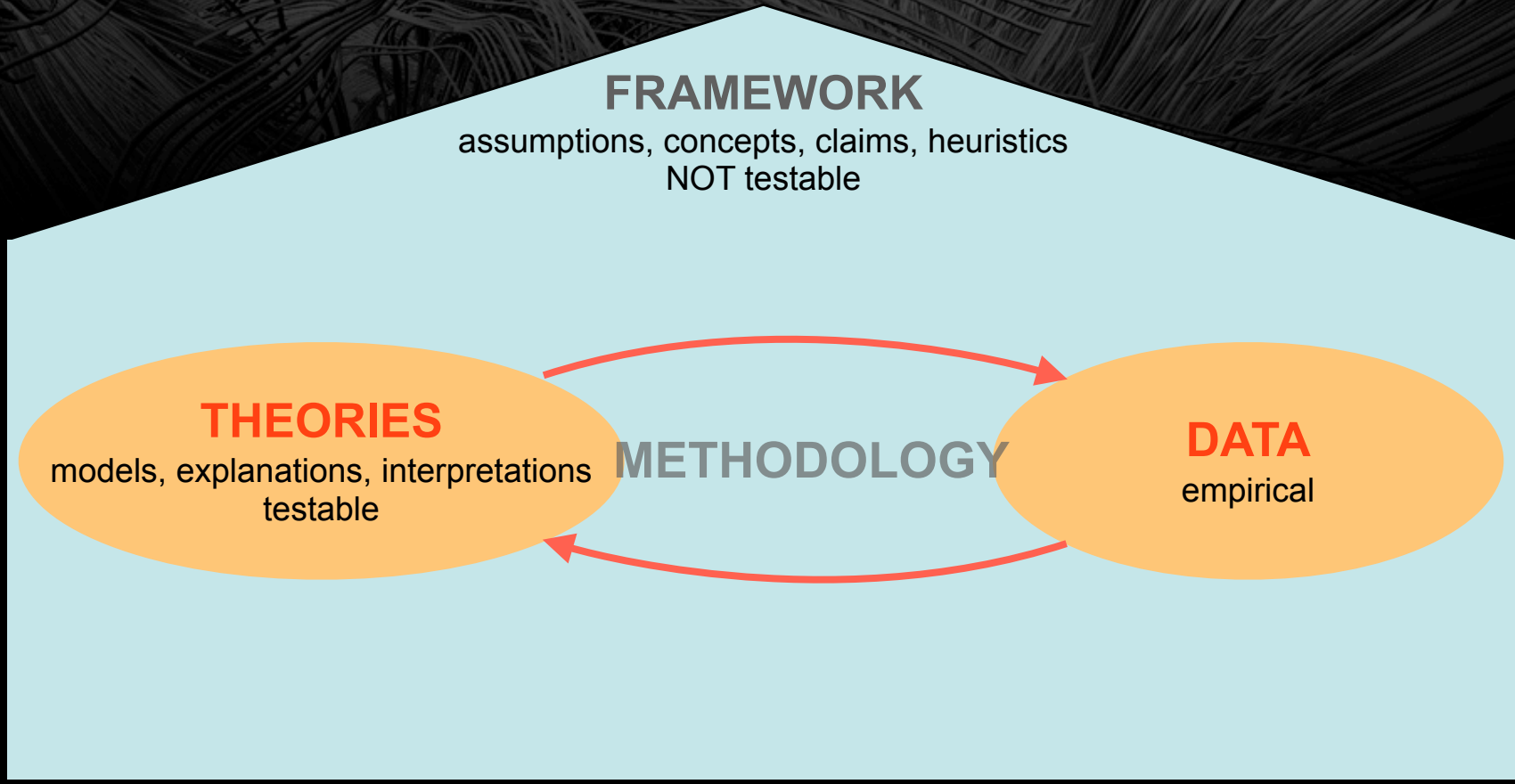
We can try to develop theories about cognition

as an emergent property of interaction

Cognition as a Research Agenda

- What are the nature and mechanisms of coordination and cognitive coupling?
- How do people develop interaction strategies during sense-making and analytical reasoning?
- How are external representations created and how do they evolve?
- How does interaction with visual structures enable turning information into meaningful understanding?

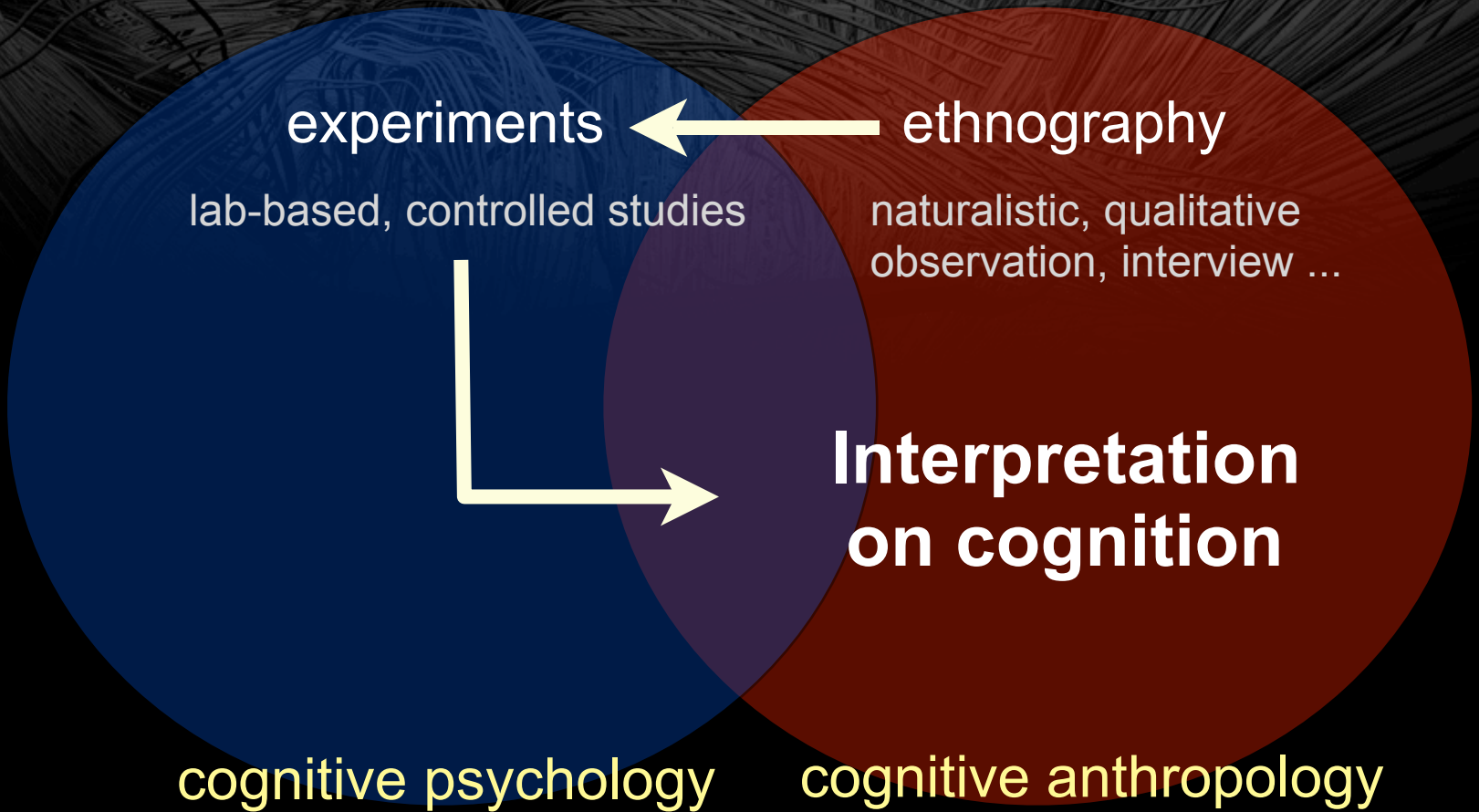
Where does the data come from?



Implication for InfoVis: Evaluation

- Traditional evaluation goal: Validation / Comparison
- With an overarching theoretical framework like DCog, we can develop theories from empirical data collected during evaluation

Methodology



Conclusion

- The Distributed Cognition Framework
  - Internal vs. external Representation
  - Interaction as coordination between internal and external representations
  - Cognition as an emergent property of interaction

- Implications on InfoVis Research
  - design: support people developing coordinative strategies
  - theories: cognition as a research agenda
  - evaluation: interpreting empirical data to theorize about cognition

Questions?

This research is supported by the National Science Foundation via Award IIS-0414667 and the National Visualization and Analytics Center (NVAC™), a U.S. Department of Homeland Security Program, under the auspices of the Southeast Regional Visualization and Analytics Center