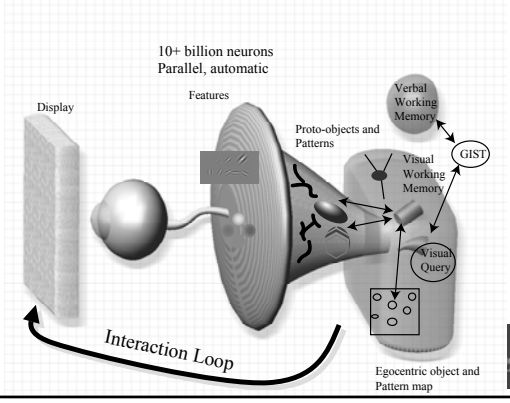
Thinking with Interactive Visualization

Colin Ware
Data Visualization Research Lab
University of New Hampshire

Outline

- The problem solving system
- Pre-attentive (what is low cost)
- Patterns
- 2D vs 3D?
- Visual thinking and the cost of knowledge

Architecture for visual thinking



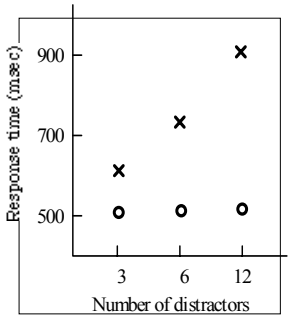
Pre-Attentive Processing

8973905709279405796297650982940802808508083080280985080280885678472988 72t y4582020947577200217898438 90r 455790456099272188897594797902855892594573979209

Color is Pre-Attentive (Pops out)

8973905709279405796297650982940802808508083080280985080280885678472988 72t y4582020947577200217898438 90r 455790456099272188897594797902855892594573979209

Generic Pre-Attentive Experiment



- Number of irrelevant items varies
- Pre-attentive 10 msec per item or better.

Preattentive popout cues

- Color
- Shape
- Motion
- Size
- Simple Shading
- Conjunctions do not popout

Conjunctions of motion and shape do pop out. (color also?)

- McLeod, P., Driver, J. and Crisp, J. (1988) Visual search for a conjunction of movement and form is parallel. Nature 332, 154-155.
- Driver, J., MacLeod, P. and Dienes, Z. (1992) Motion coherence and conjunction search: Implications for guided search theory. Perception and Psychophysics. 51, 1, 79-85.

MEGraph: Experimental system

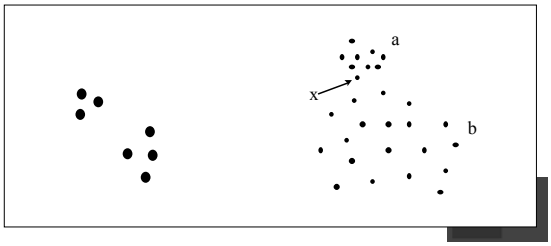
- Allows for various topological range highlighting methods

Stage 2 Pattern perception

- Gestalt principles
- Proximity
- Continuity
- Connectedness
- Closure

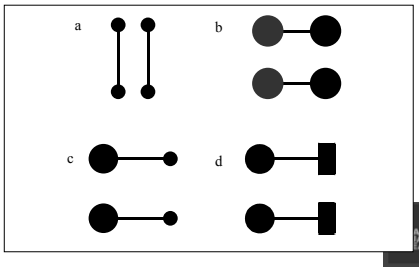
Proximity

- Emphasize relationship by proximity
- Spatial Concentration



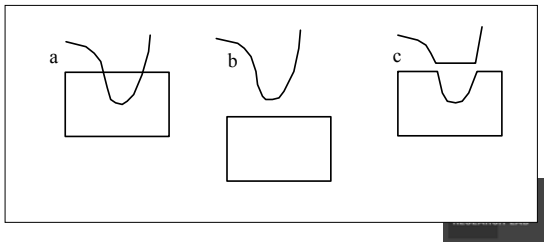
Connectedness

- Connectedness assumed in Continuity

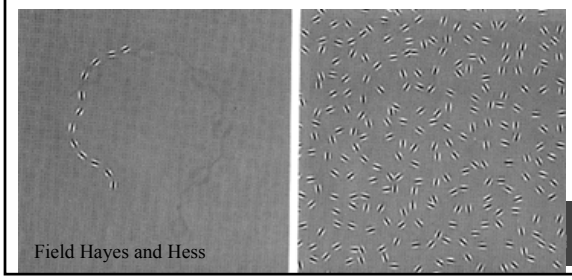


Continuity

- Visual entities tend to be smooth and continuous

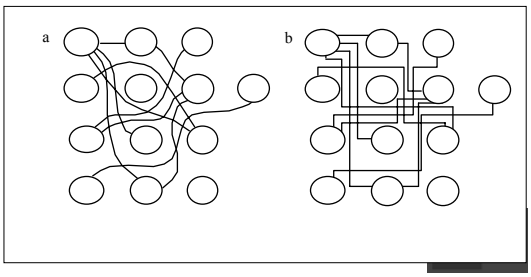


Neural basis



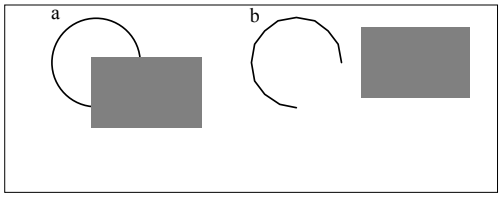
Continuity in Diagrams

- Connections using smooth lines



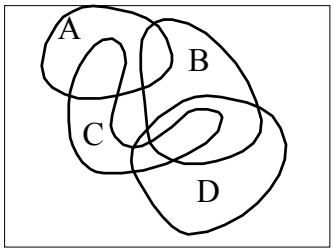
Closure

- Prefer closed contours



Closure (cont.)

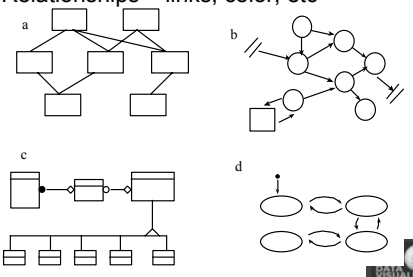
- Closed contours to show set relationship



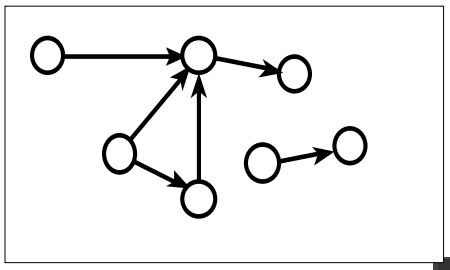
Extending the Venn-Euler Diagram

Patterns in Diagrams

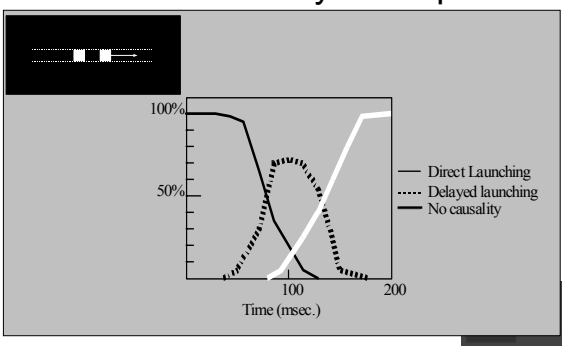
- Entities – objects
- Relationships – links, color, etc



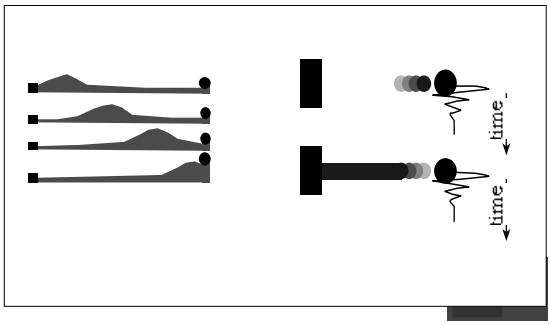
A causal graph



Michotte's Causality Perception

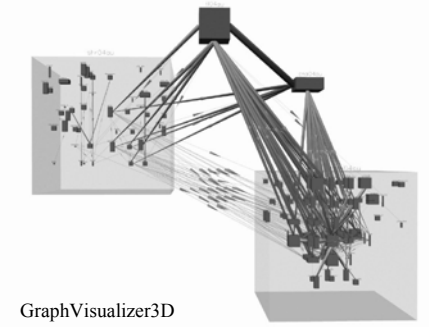


Visual Causal Vectors

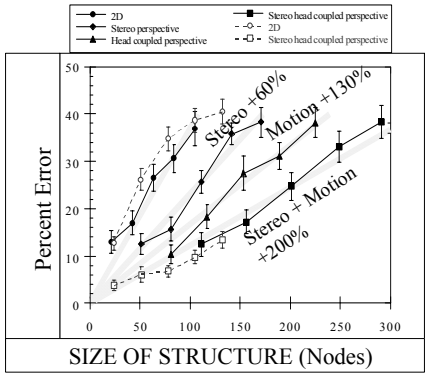


3D pattern perception

- Use 3D?



GraphVisualizer3D

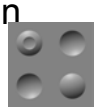


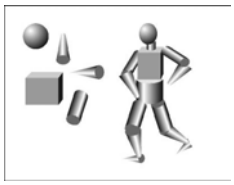
DATA VISUALIZATION RESEARCH LAB

Issues

- Can see a larger graph
- Must have stereo and motion
- But consider the cost of interaction

Another form of 3D Structured Object Perception





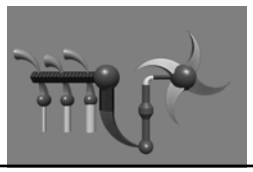
3D Primitives "Geons"
Structural skeleton

Shape from shading
is also primitive

Color and texture are
Secondary attributes

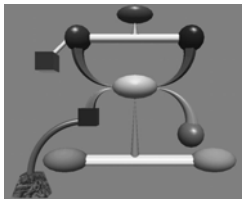
Geon Diagram (Pourang Irani)

- Major entities should be represented with simple 3D shape primitives
- Links can be represented by connecting geons (the structural skeleton)
- Geons should be shaded to make 3D shape visible
- Secondary attributes -> color and surface texture
- Layout of structure should be primarily in 2D plane



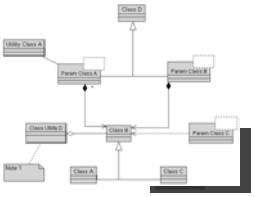
Structure diagrams (UML)

Pattern finding & Recognition



13% errors: 4.3 sec sub-structure

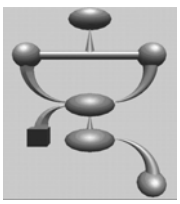
22% memory errors



26% errors 7.1 sec sub-structure

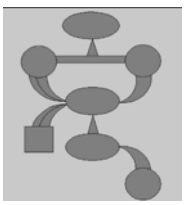
42% memory errors

3D versus 2D



11.4% errors 3.7 sec sub-structure

20% memory errors

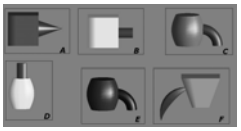


21% errors 5.1 sec sub-structure

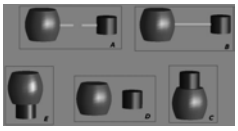
34% memory errors

Natural semantics

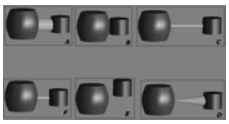
Instances



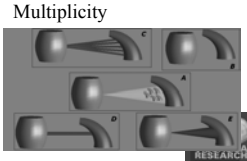
Dependency



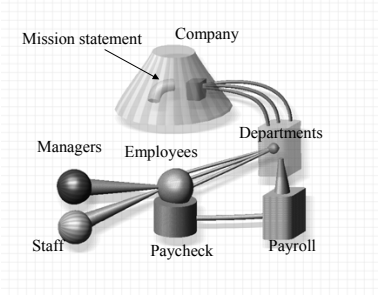
Strength of Relationship



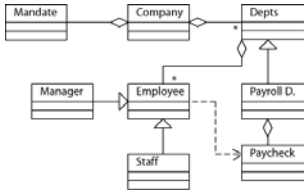
Multiplicity



Geon Diagram with semantics



UML MODELING

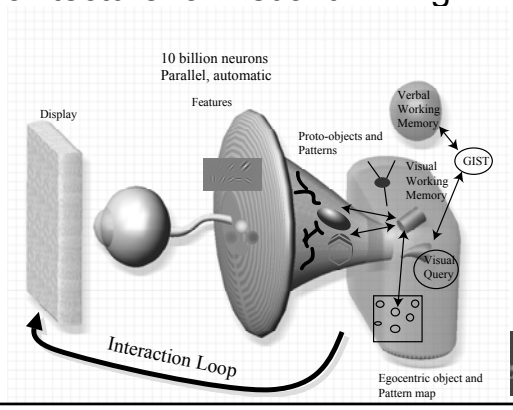


Geon Diagrams

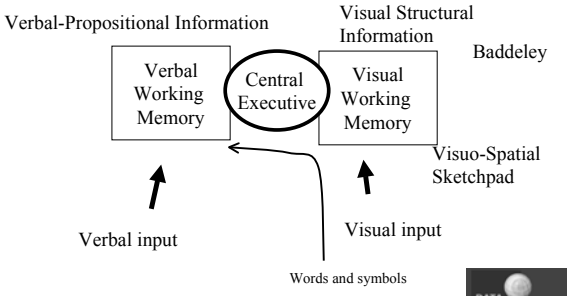
Geon Diagrams

- Advantages
  - More memorable
  - Easier to interpret
- Disadvantages
  - Do not work well with text
  - Inflexible wrt layout

Architecture for visual thinking



Dual Coding Theory

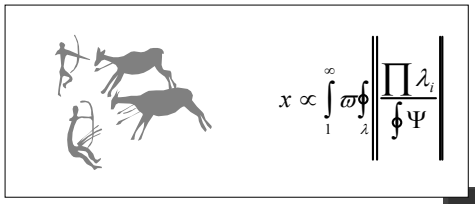


Pictures and Words

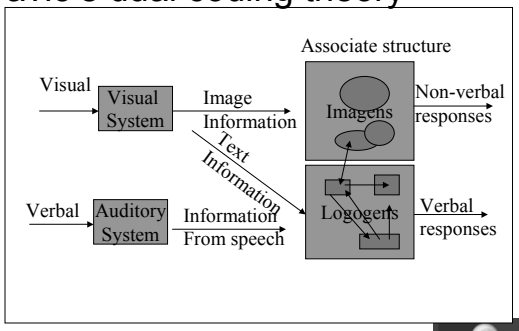
- When should we use a visual display?
- What is a visual language?
- Dual coding theory?
- How to integrate images and words

Consider that hieroglyphs gave way to more abstract symbols

- Why turn back the clock?



Pavio's dual coding theory



Theory: Graphics and Words

- Graphics for structural logic
- Words for procedural logic: conditionals, qualifiers, if-then else, while.

The nature of language

- Chomsky, innate deep structures.
- Common to computer languages
- Critical period for language development
- But being verbal is not essential to language development
- Sign languages for the deaf are the most perfect examples of visual language

What is language

- Description
- Communication of intention
- The ability to communicate procedures and sequences of operations – including logic – if, but, causes, do ***a*** then ***b*** then ***c***
- ***Thus far we have only dealt with description***

Sign languages

- Are true languages
- Developed spontaneously
- Developed independently
- Start as representations
- Become more abstract over time

Can there be a true visual language?

Yes,
But not for most of us!!

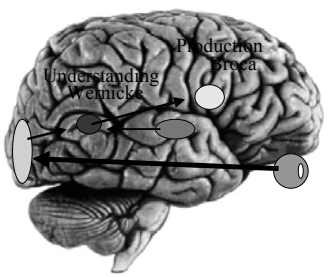
Consider verbal language

A critical period

Abstraction, logic
(if, while, perhaps)

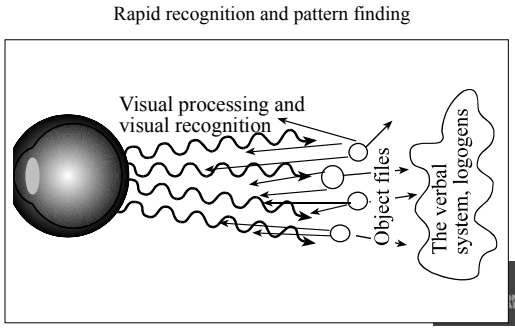
Based on speech

Sign languages are true
Visual languages



To be fluent in visual language we should be trained from early in life

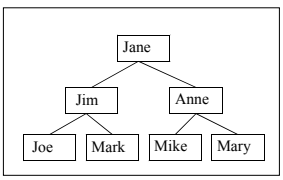
The visual system gives us



Abstraction

- Jane is Jim's boss
- Jim is Joe's boss
- Anne works for Jane
- Mark works for Jim
- Anne is Mary's boss
- Anne is Mike's boss

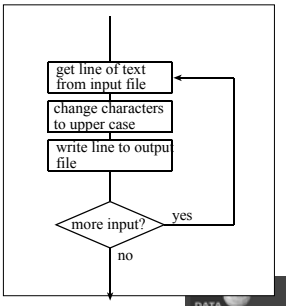
Pattern



Visual and verbal pseudo-code

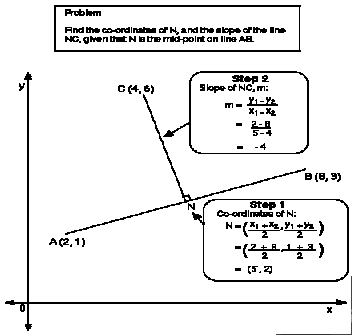
- While letters in stack
  - Take a letter
  - Put a stamp on it
  - Put it in the 'out tray'

Visual programming languages have a history of failure

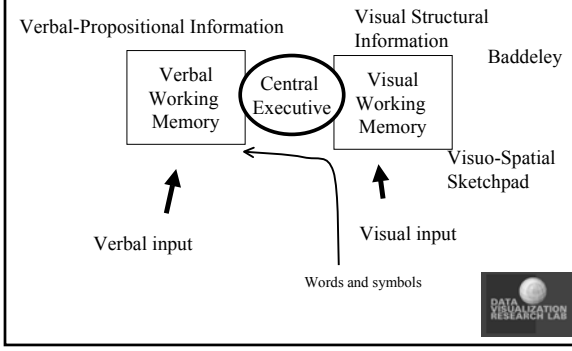


Data flow diagrams are defined

Integrated pictures and words more Effective: Chandler and Sweller 1991



Working memory capacities ~ 3

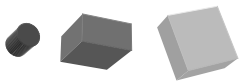


Capacity of verbal working memory

- Used to be though of a 7 +/- 2
- It is now thought of as more a duration of proto-verbal codes.

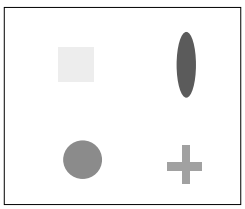
Capacity of visual working memory (Vogal, Woodman, Luck, 2001)

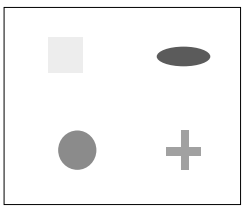
- Task – change detection —— 1 second
- Can see 3.3 objects
- Each object can be complex

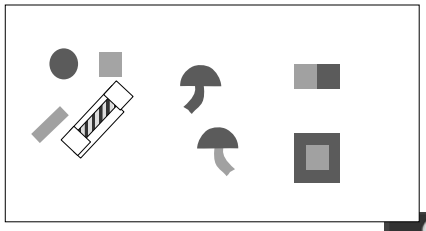


Sequential comparison task

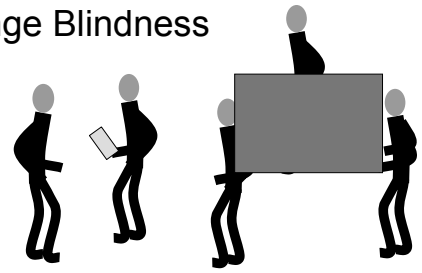
1 sec delay





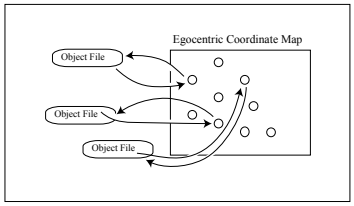


Change Blindness



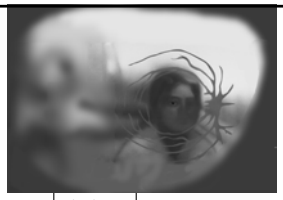
- Triesman serial processing of non-pre-attentive object (40 msec/item)
- Kahneman and Triesman “object files”
- Rensink - Fingers of attention reach into pro-object flux

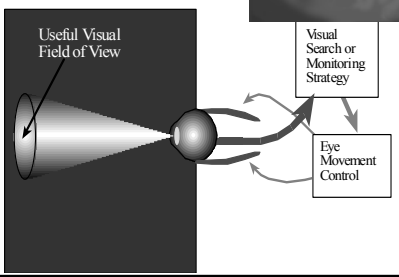
Other components of working memory



Gist Semantic content

Visual search



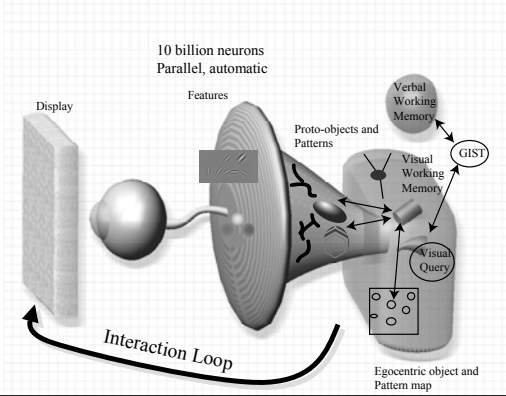


Eye movements

- Two or three a second
- Preserves Context

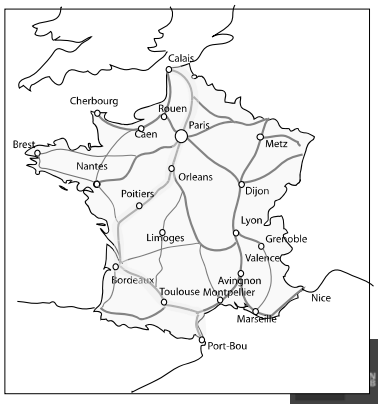
- The screen is a kind of buffer for visual ideas – we cannot see it all at once but we can sample it rapidly

Architecture for visual thinking



Thinking visually
Embedded processes

- Define problem and steps to solution
  - Formulate parts of problem as visual questions/hypotheses
    - Setup search for patterns
      - Eye movement control loop
        - IntraSaccadic Scanning Loop (form objects from proto-object flux



Problem

- Trip Port Bou- Calais (5 days 3 citise)
  - Visual Problem Mayor Highways
    - Distance < 1.2 min = red smooth path
    - Eye movements to identify major candidate pathways
      - Pattern Identification: smooth, red, connected segments / reject non-red-wrong direction
- Part solutions into vwm – spatial markers
- Parts may be handed to verbal wm

Software Engineering Example - with Graph Representation

- Segment Big Module into parts
  - High Cohesion (semantics)
  - Low Coupling
    - Find highly connected subgraphs with minimal links
      - Scan for candidate patterns
        - Look for Low connectivity
        - Look for Semantic similarity (symbols)
- Important question: what are relevant pattern that can fit in vwm

Cost of Knowledge

- How do we navigate.
- Intra-saccade (0.04 sec)
- An eye movement (0.5 sec)
- A hypertext click (1.5 sec but loss of context)
- A pan or scroll (3 sec but we don't get far)
- Walking (30 sec. we don't get far)
- Flying (faster can be tuned)
- Zooming, fisheye, DragMag

Walking Flying (30 sec +)

Naïve view that does not take perception or the cost of action into account.

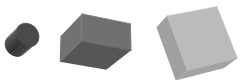
How to navigate large 21/2D spaces?
Zooming Vs Multiple Windows

- Key problem: How can we keep focus and maintain context.
- Focus is what we are attending to now.
- Context is what we may wish to attend to.

- 2 solutions: Zooming, multiple windows

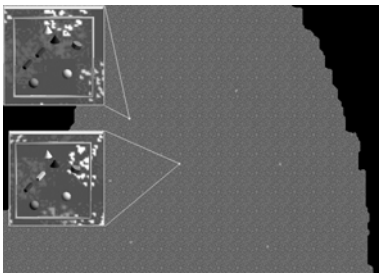
When is zooming better than multiple windows (Matt Plumlee)

- Key insight: Visual working memory is a very limited resource. Only 3 objects



GeoZui3D

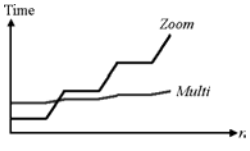
Task: searching for target patterns that match

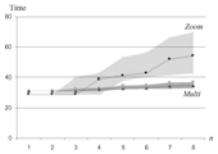


Cognitive Model (grossly simplified)

- Time = setup cost + number of visits*time per visit
- Number of visits is a function of number of objects (& visual complexity)
- When there are too many multiple visits are needed

Predictions

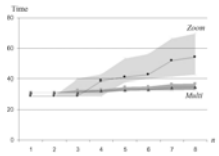




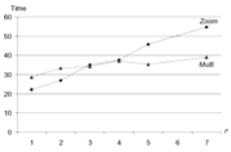
Time =

As targets (and visual working memory load) increases, multiple Windows become more attractive.

Prediction



Results



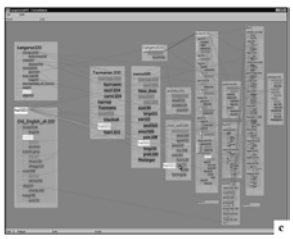
Critical issues: Cognitive costs

- Clickless queries and cognitive costs
- Medium level – pattern perception
- High level vwm and cognitive costs

- Assumption: topologically close nodes are more important

Need low cost and low cognitive cost interactions

Constellation: Hover queries (Munzer)



Lessons for design

- Low level- what stands out
- Medium level – pattern perception
- High level vwm and cognitive costs

A large high resolution screen may be the best alternative - because of eye movement

Interactive techiques hold promise

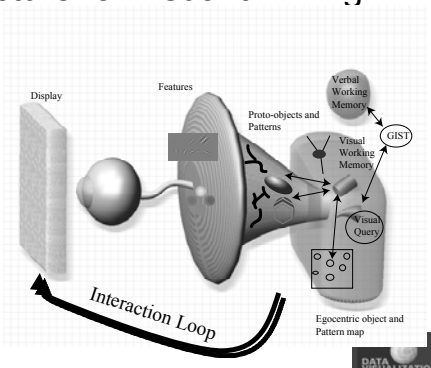
Implications for design of information spaces

- Design for pattern perception, three chunk patterns
- Consider attention
- Implications for navigation
  - Make all navigation devices visible.
  - Do not ever make people walk
  - Maintain context
  - Minimize cognitive load of navigation
  - Use multiple linked views for more complex pattern integration

Research topic
What are easy visual queries

Easy= single object comparison in vwm

Architecture for visual thinking



Cognitive Systems

- Humans with cognitive tools functioning groups
- Visualization for pattern finding
- Coding for pre-filtering
- Slogan: “Tighten the loop”

- Large displays – interactive diagrams

Acknowledgements

- NSERC (Canada)
- NSF (USA)
- NOAA
- ARDA