Sources of bias when working with visualisations

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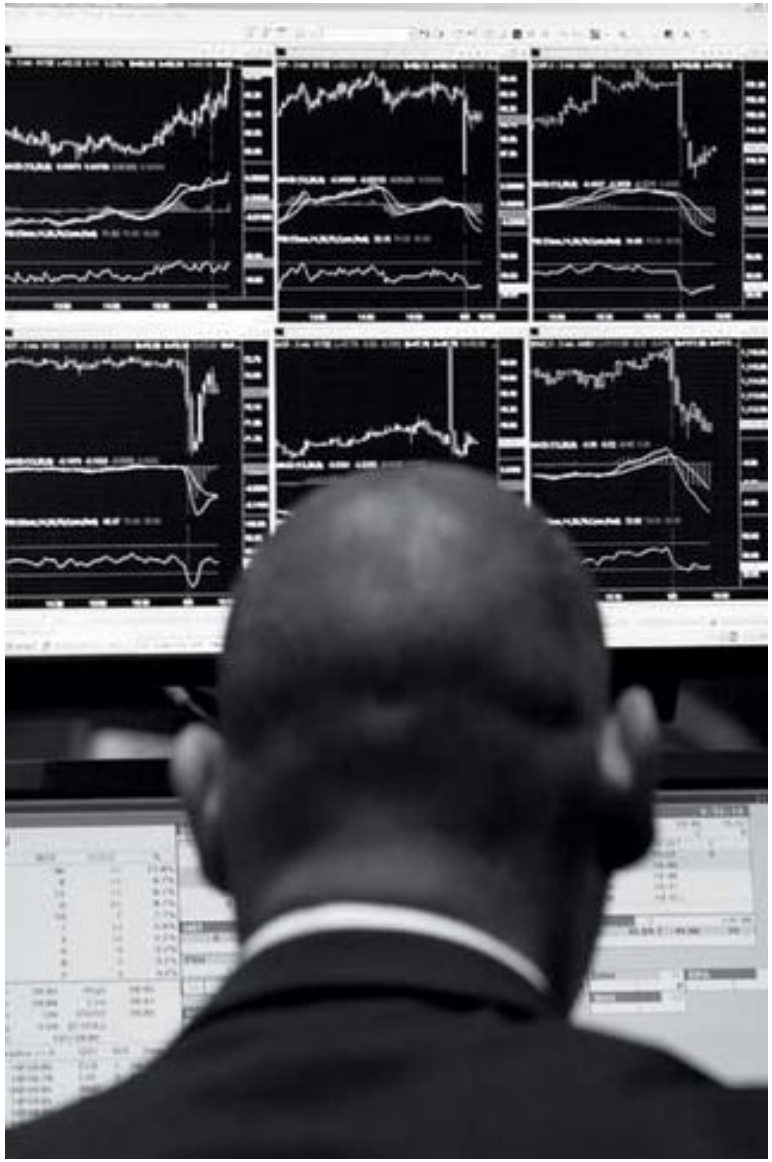
Where's the 'cognitive'?

Using visualisations prime example of 'embodied' cognition (Wilson, 2002).



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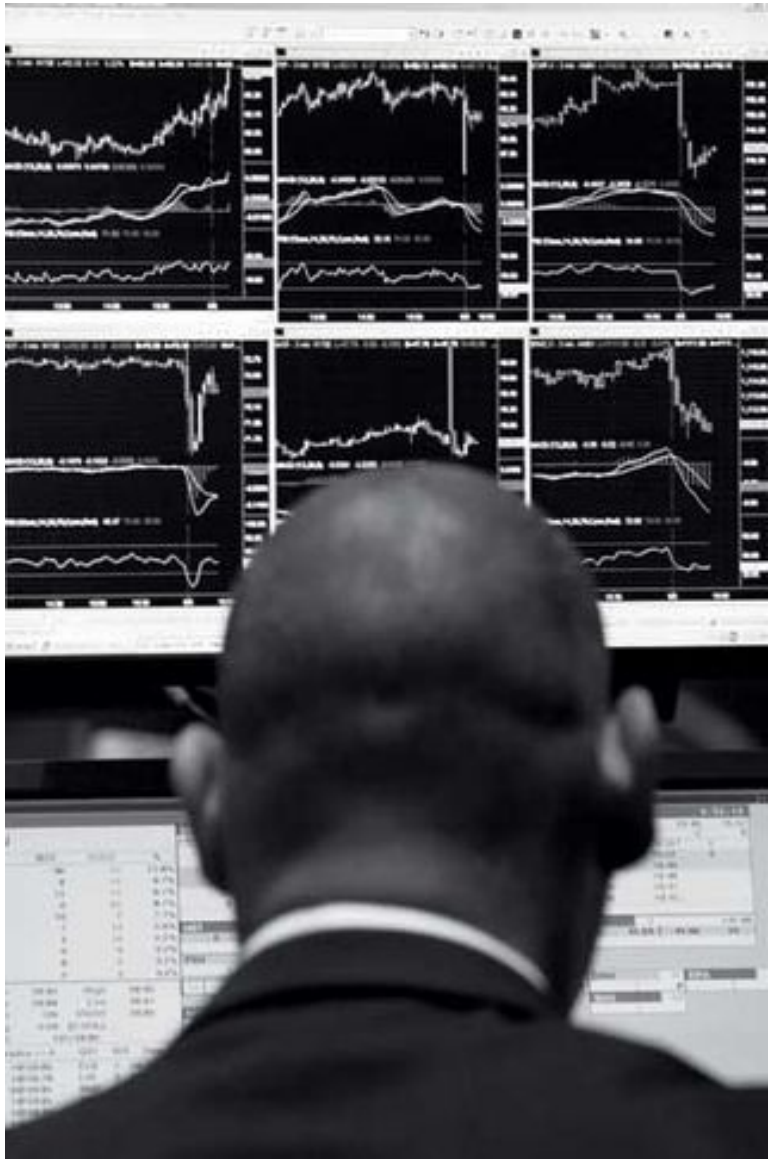

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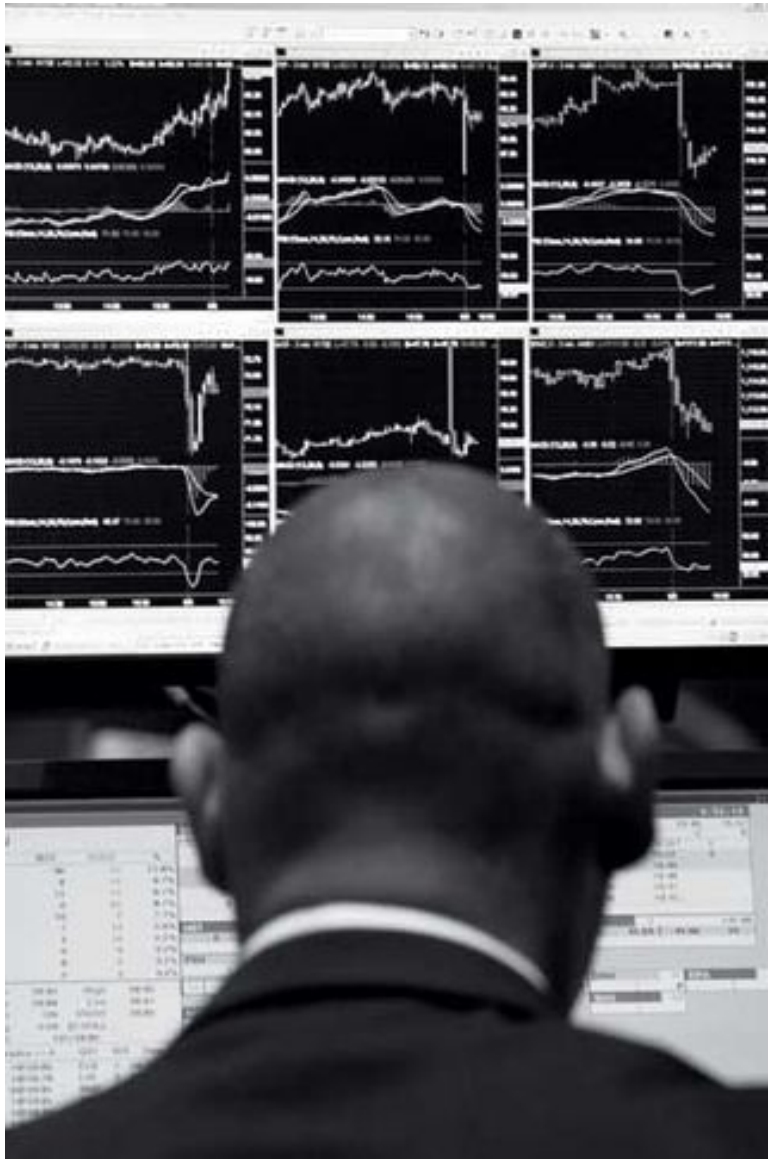

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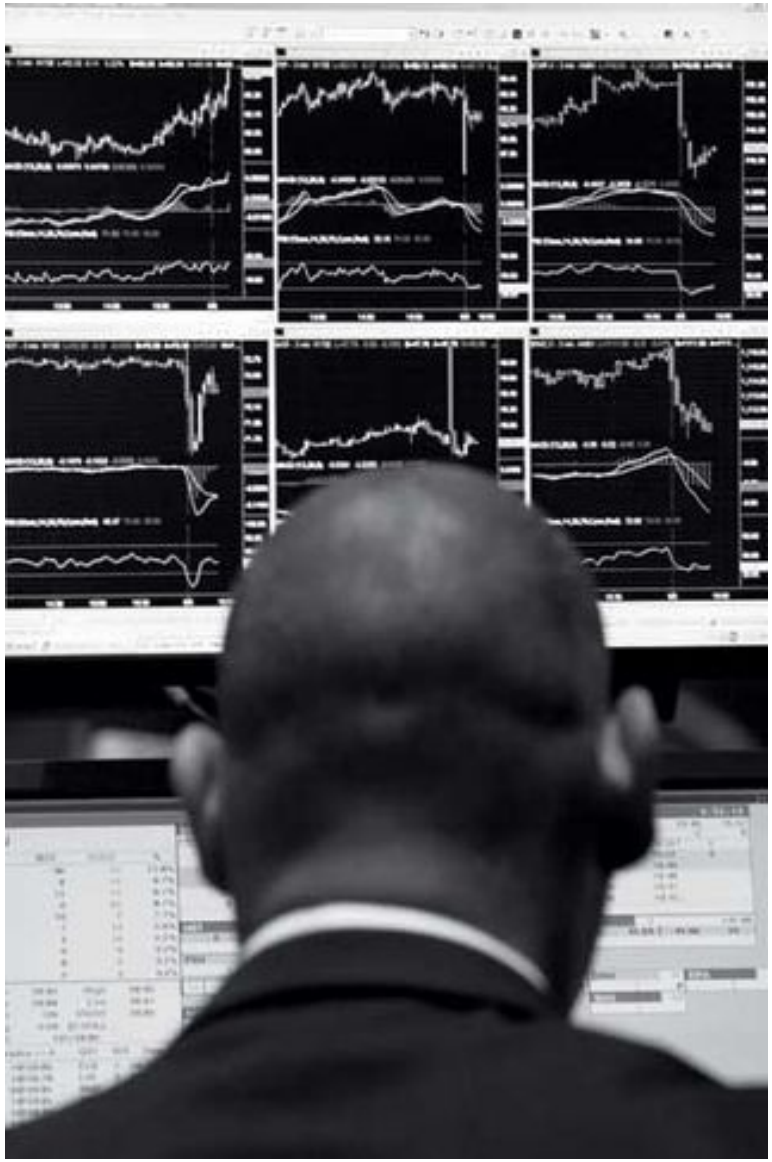
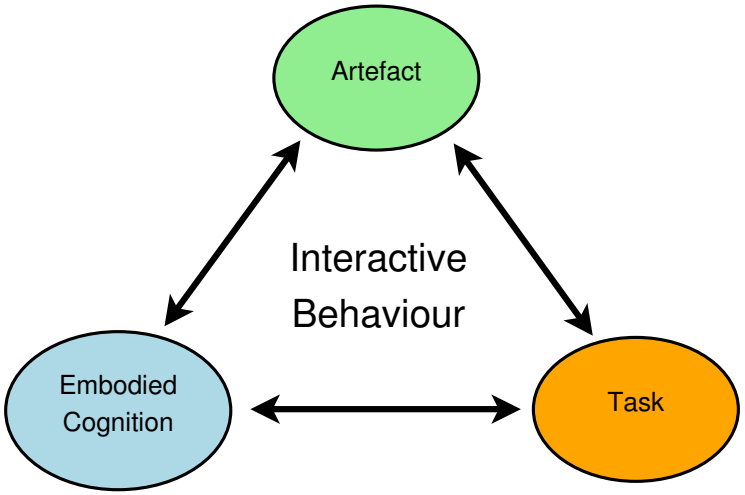
Using visualisations prime example of 'embodied' cognition (Wilson, 2002).

- **Situated** in real-world environment. Inherently involves perception/action.
- **Time pressured**. Under pressure of real-time interaction with environment.
- **Exploits task environment** to reduce cognitive workload by holding, representing, and manipulating information. Knowledge in world combines with knowledge in head.



The embodied cognition-task-artefact triad



- **Interactive behaviour:**
  - Emerges from dynamic interaction of goal-directed, task-driven cognition/perception/action with designed task environment.
  - A complex combination of bottom-up stimulus driven and top-down goal and knowledge driven processes.
- Makes little sense to consider and investigate cognition in isolation.

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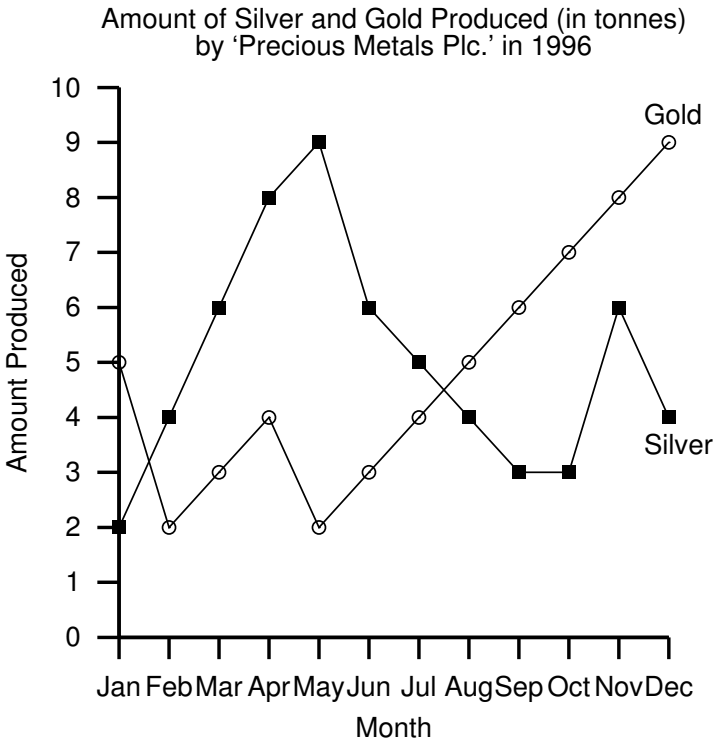
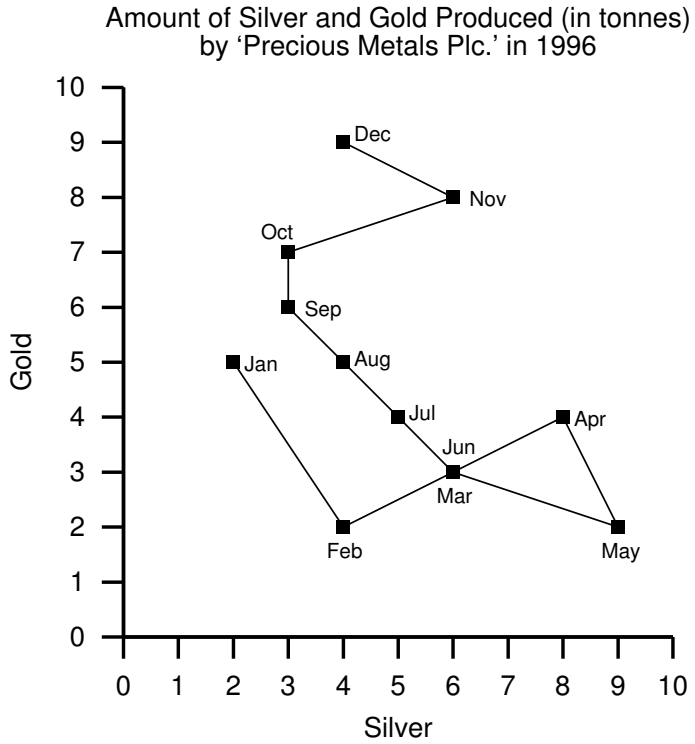
Four sources of bias:

- Computational affordances
- Emergent/salient features
- Gestalt principles of perceptual organisation
- Adaptive behaviour

Computational affordances (Peebles & Cheng, 2003)

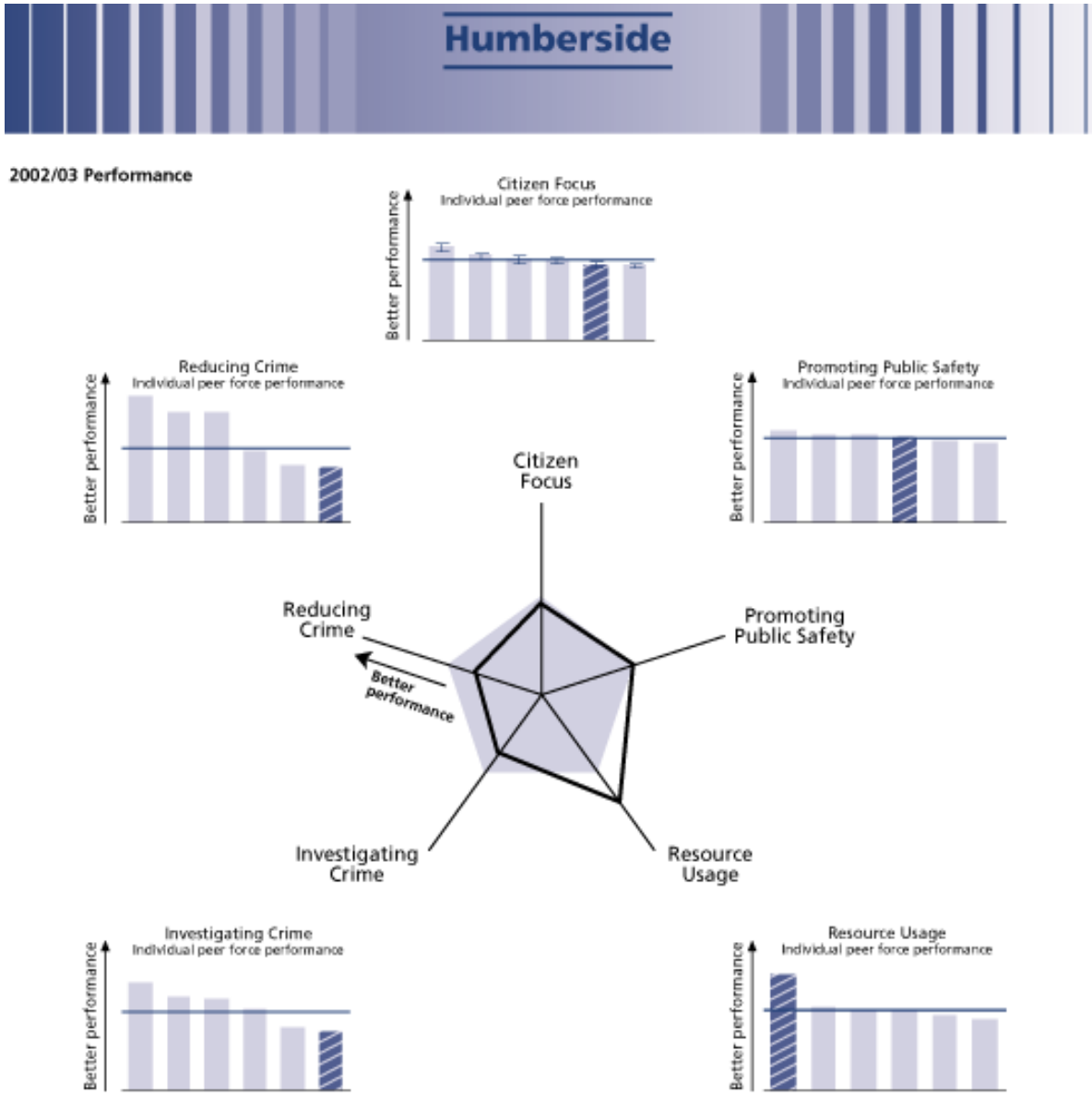




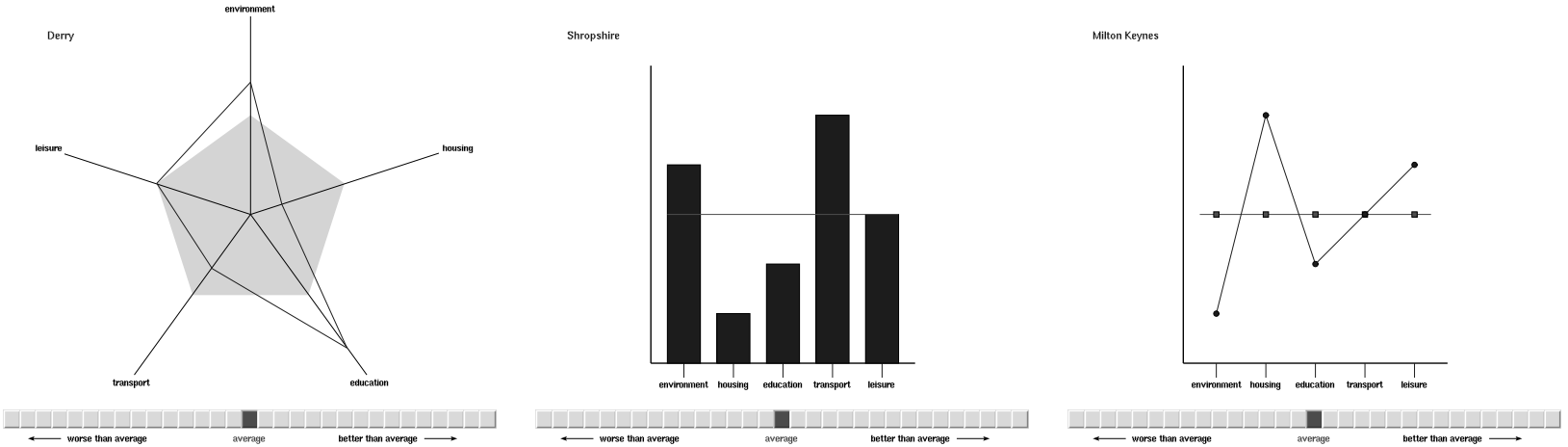
- *Informationally* equivalent
- *Computationally* inequivalent.
- Require different procedures.

- "When *gold* is 4, what is the value of *silver*?
- "Which two months have the same values of silver and gold?

Emergent/salient features

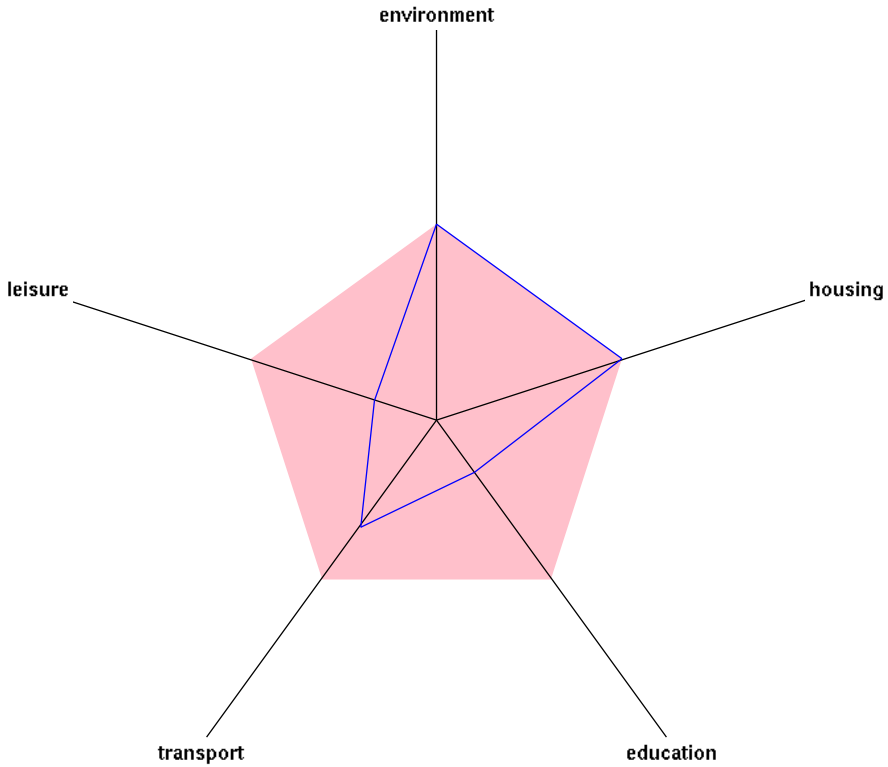


Emergent features (Peebles, 2008)

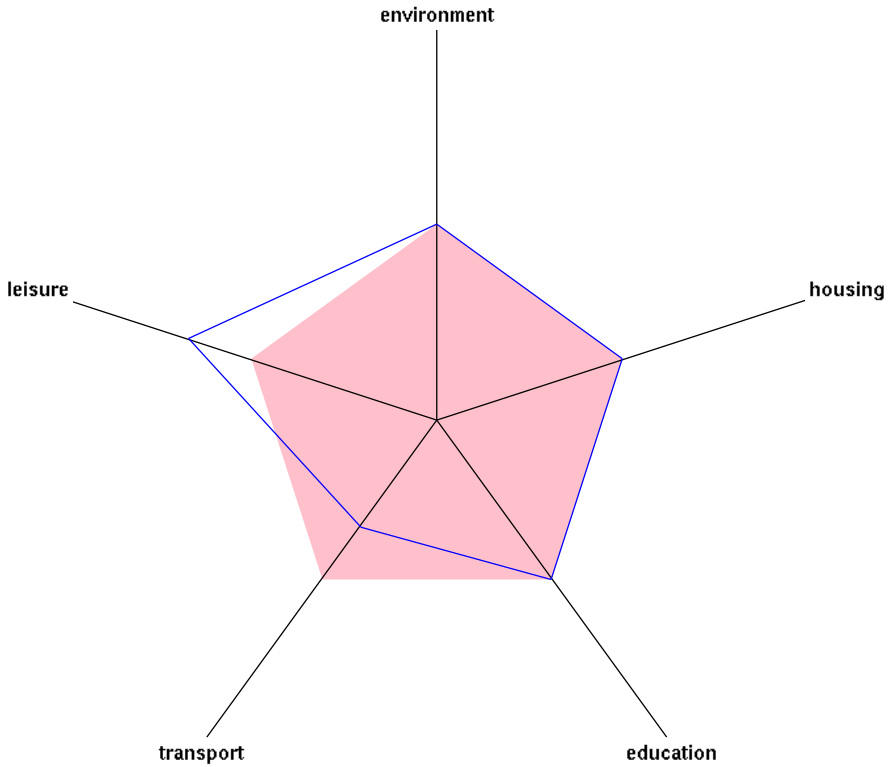


- Tasks: *local* (1 feature) and *global* (all features) comparison.
- Accuracy and latency of comparison judgements affected by:
  - Representation used.
  - Value being compared.
  - *Emergent features* created by arrangements of values.

Emergent features affect distance perception



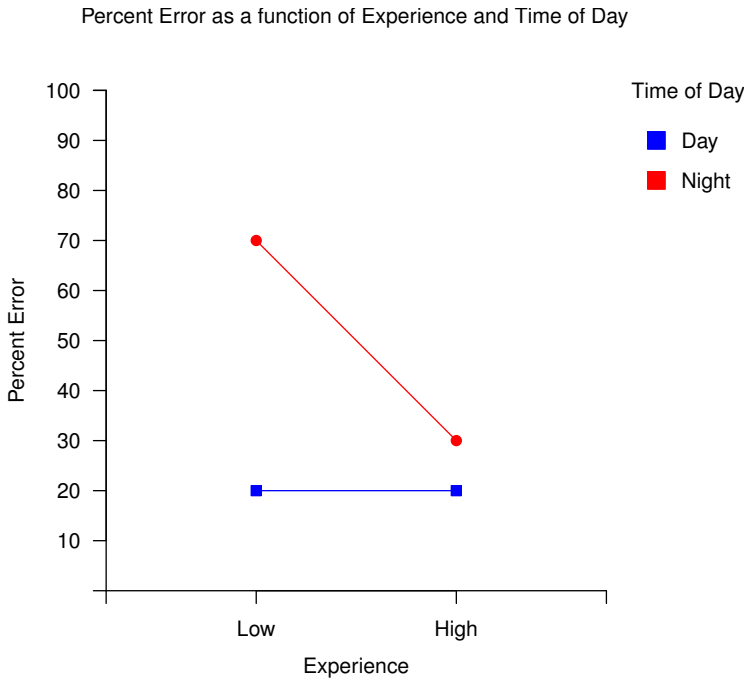
(a) Transport = 1.91

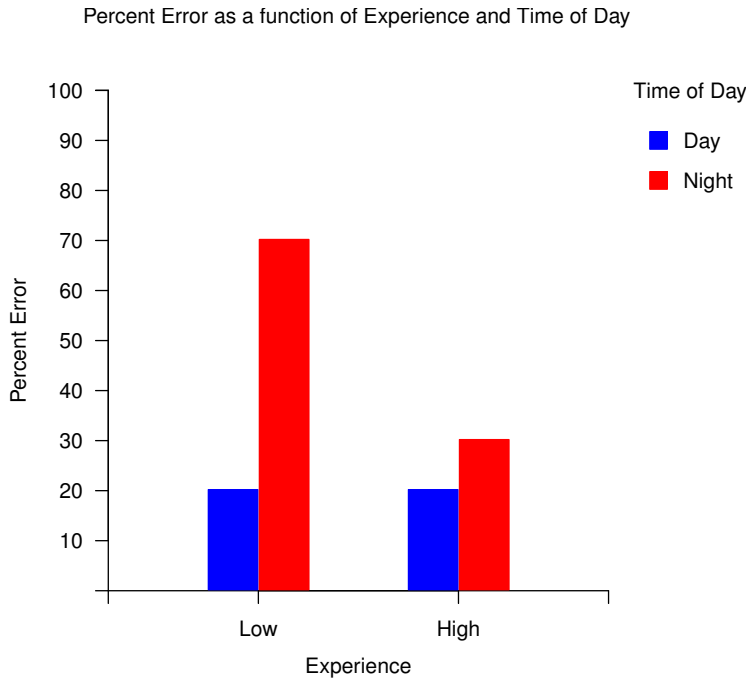


(b) Transport = 2.14

Gestalt principles (Ali & Peebles, 2013)

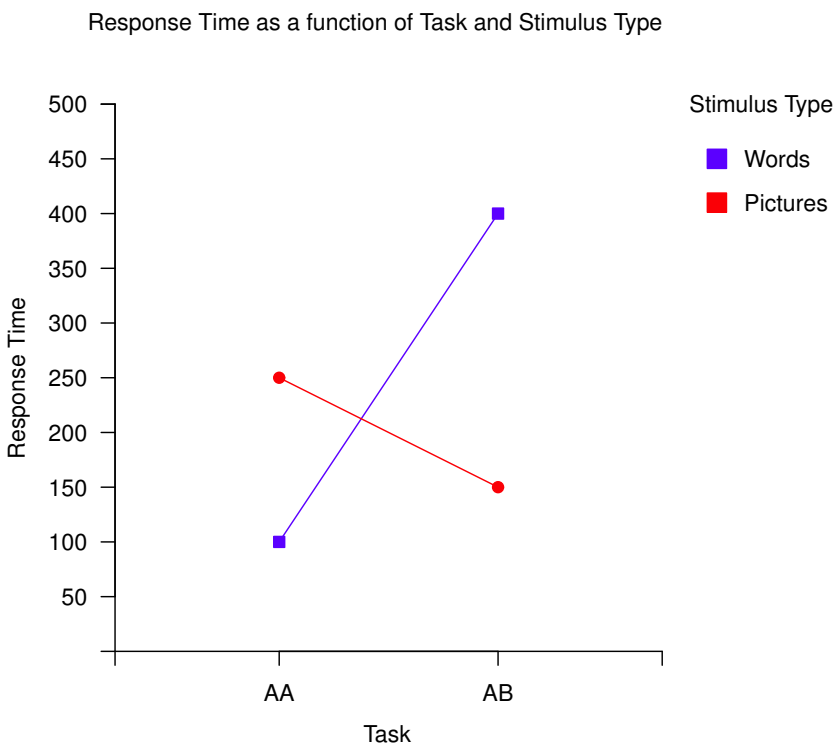
- Laws of perceptual organisation (e.g., proximity, similarity, continuity, connectedness, common fate) affect grouping of graphical elements.



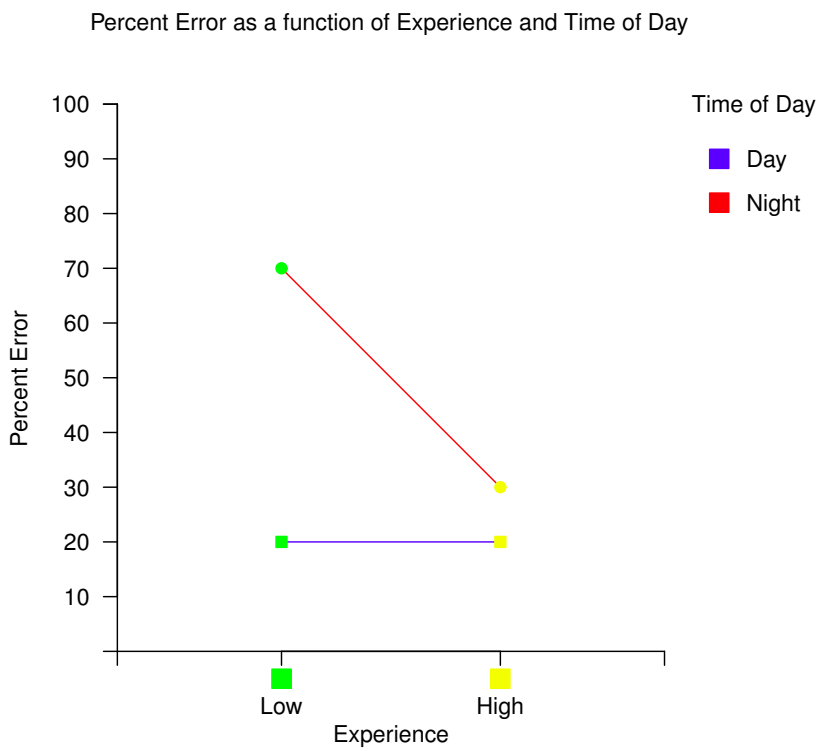


- **Line:** Novices focus primarily on legend variable (connectedness and similarity).
- **Bar:** Novices' attention balanced between legend and x-axis variables.

Using emergent features and Gestalt principles



(a) "Crossover" interaction



(b) "Colour-match" graph

(a) Experts learn emergent features for rapid pattern recognition.

(b) Knowledge of Gestalt principles can be used to design more effective representations (Ali & Peebles, 2013).

Basic elements of visualisation behaviour

- **Cognitive processes:**
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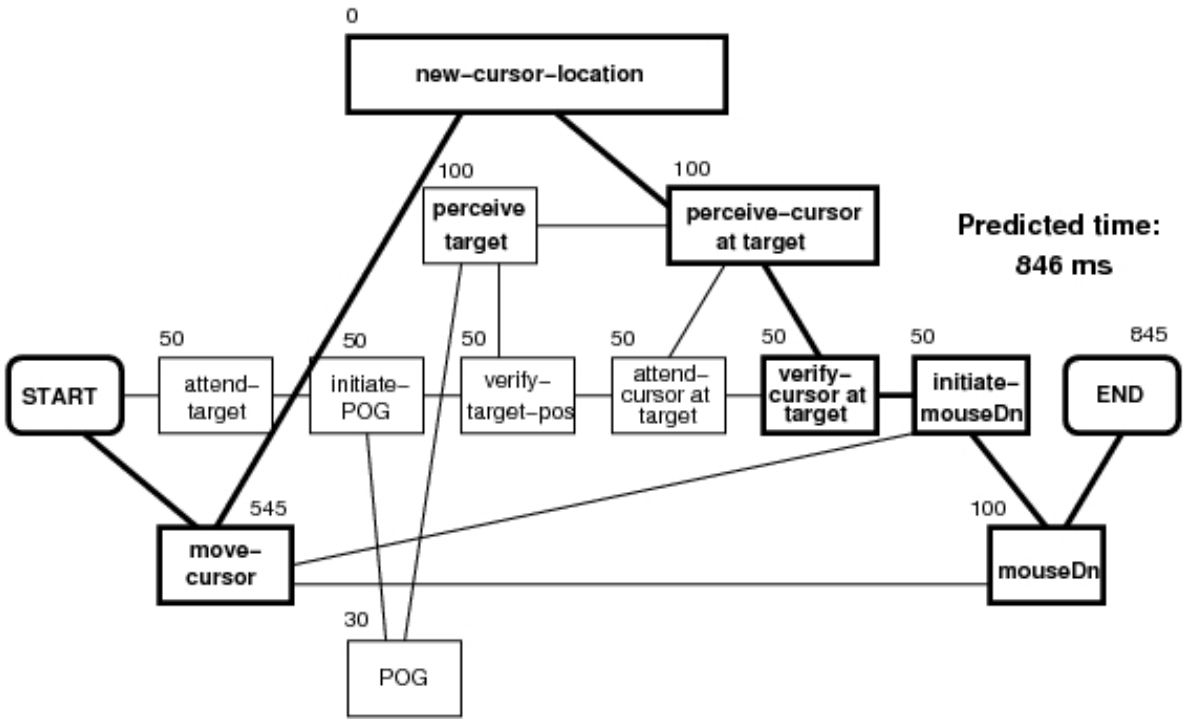
- **Physical actions:**
  - Eye movement saccades and fixations, mouse clicks and cursor movements, finger taps and pinches etc.
  - Interface manipulations: Selection/highlighting with mouse; dragging, realigning, rotating, deleting; zooming in and out

Interactive routines

Basic cognitive, perceptual and motor operators combined into **interactive routines** that take between 0.3 to 1 second to execute:

- Direct attention to object and encode features/location.
- Move mouse cursor to graphical object and click on it (see CPM-GOMS model below; Gray & Boehm-Davis, 2000).

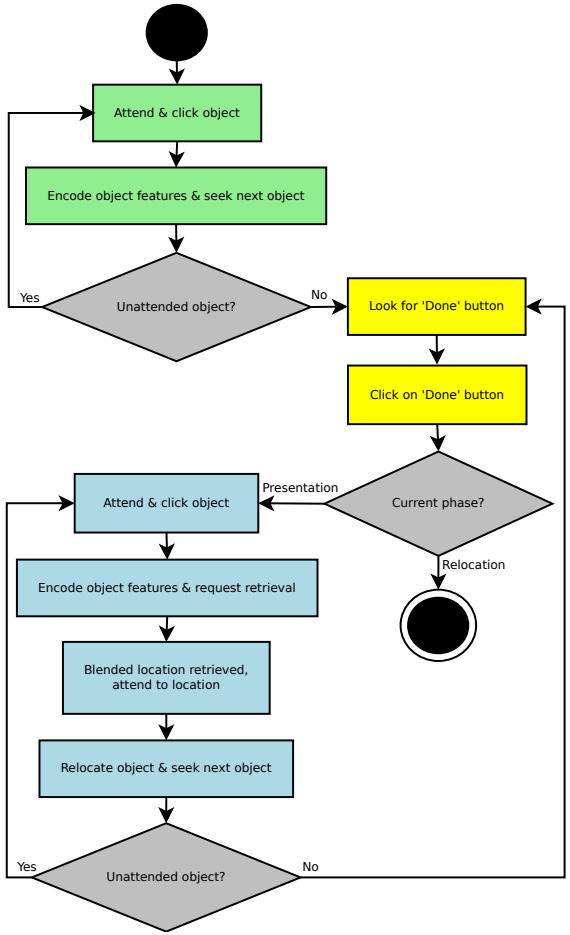


Unit tasks and strategy selection

Unit tasks: Combinations of interactive routines that perform subtasks.

Typical execution time: between 3s and 30s.

- Select and visually mark subset of data.
- Locate variable value(s) according to some criterion (e.g., max, min, median etc.).



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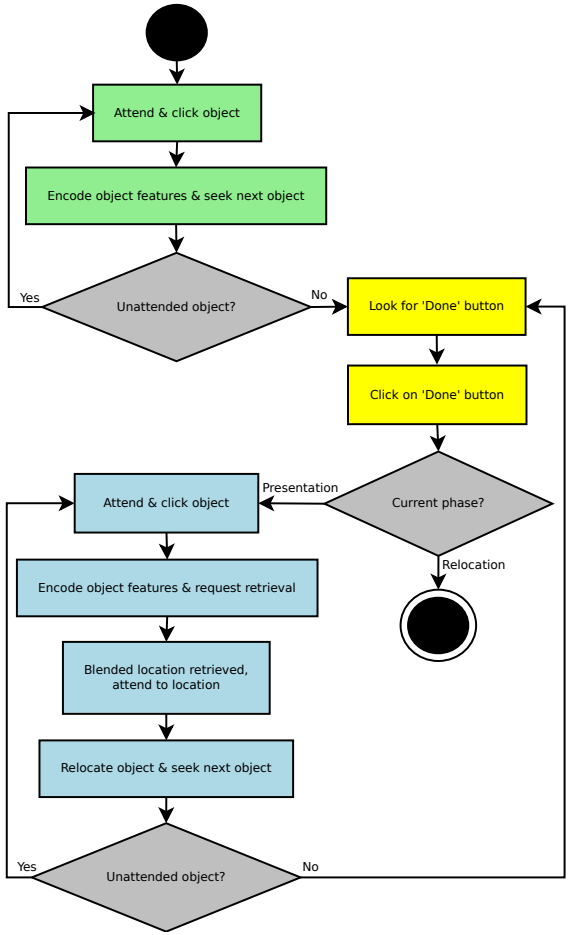
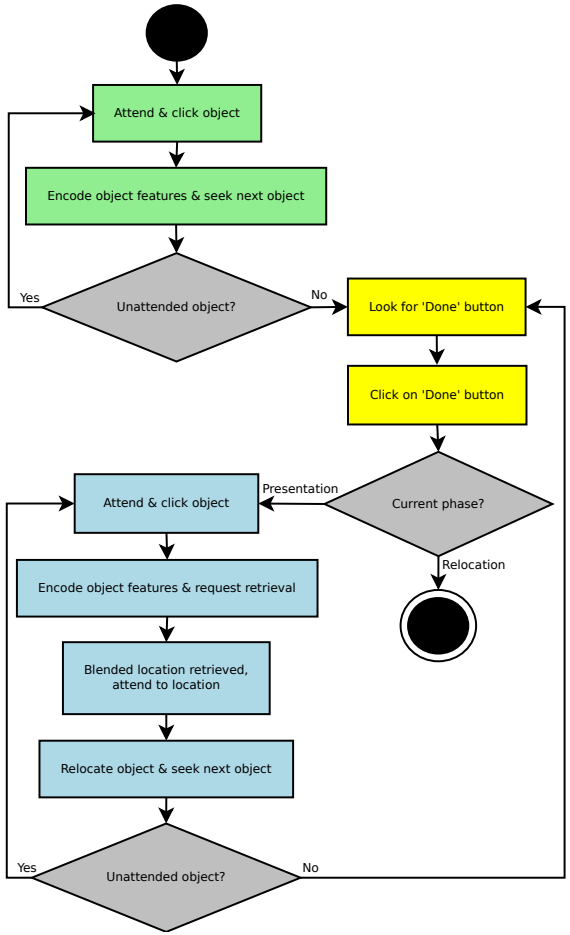
Strategies: Sequences of unit tasks.



Adaptive behaviour

- Interactive routine changes reduce interaction cost & optimise control system resource allocation. *Milliseconds matter* (Gray & Boehm-Davis, 2000)



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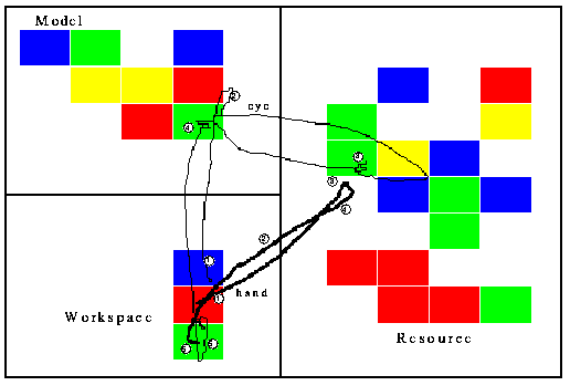
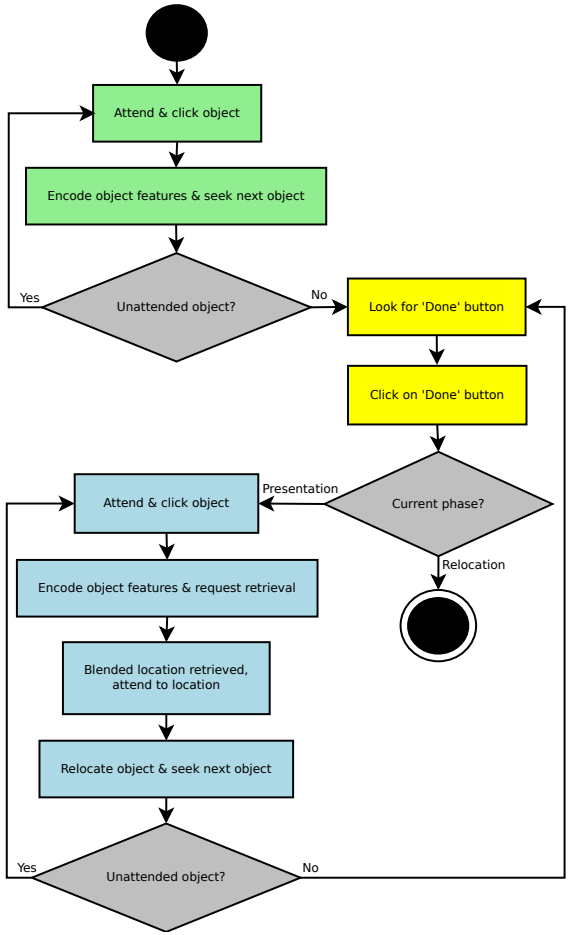
- Ballard et al. (1995) increased information access cost from eye movement to head movement – users shifted from display based access to memory retrieval.





Adaptation as a source of bias

Adoption and adaptation determined by:

- Cost structure of the task environment (i.e., how quick/easy is it to execute the task).
- The representational efficiency of the visualisation.
- History of success with the strategy.
- Adaptation typically beneath conscious awareness and deliberate control.

Do users always adapt to an optimal interaction?

- Not necessarily – only when local (interactive routine level) optimum coincides with global task level optimum (Fu & Gray, 2004).

Suboptimal interaction and interpretation may result from strategy selection pressures resulting from unconscious choices made at the embodiment level.

Summary

- **Interpretation of data graphics can be shaped/biased by number of factors:**
  - Visual and computational properties of the representation.
  - Adaptive behaviour of the user seeking to minimise effort.
- **Research on simpler data graphics must be extended to:**
  - Larger and more complex data sets.
  - Broader class of visualisations.
  - Cover the increasing variety of interactions and manipulations that are being developed.
- **Vital for design of most appropriate representations/task environments for different users and tasks and to reduce error.**
- **Important role for cognitive science theories and methods in this research (e.g., computational cognitive modelling)**