A cognitive architecture-based model of expert graph comprehension

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Previous process models of graph use

GOMS-based task-analytic models:

- UCIE (Lohse, 1993)
- MA-P (Gillan, 1994)

Computational models:

- BOZ (Casner, 1991)
- CaMerA (Tabachneck-Shijf, Leonardo & Simon, 1997)
- ACT-R (Peebles & Cheng, 2003)

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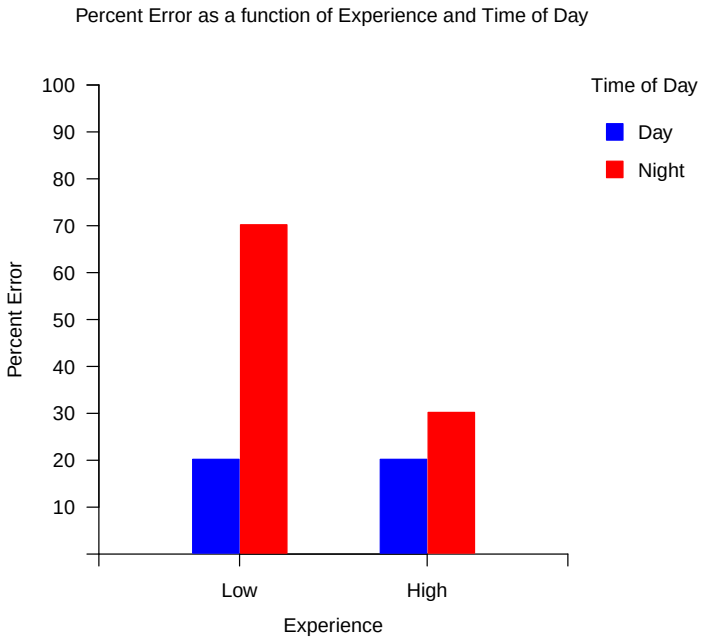
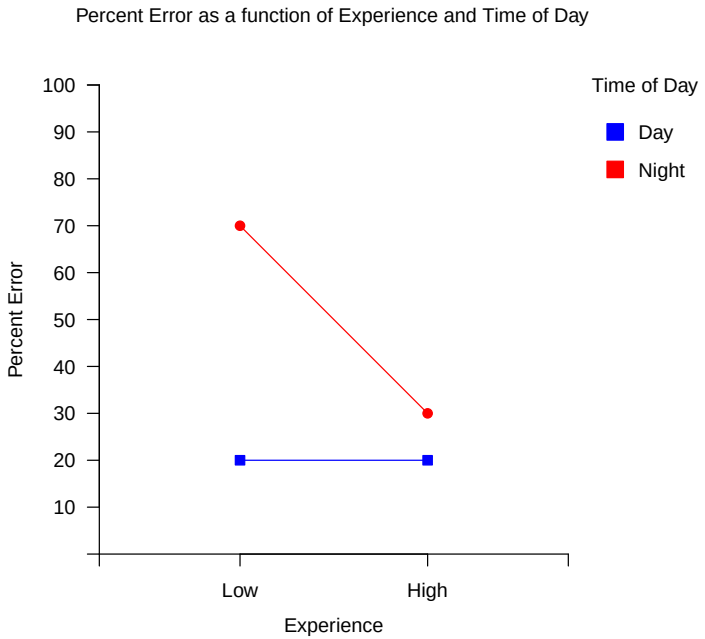
None of the above address graph *comprehension*

Graph comprehension

- Initial familiarisation stage prior to other tasks involving:
  - Identification & classification of variables into IV(s) and DV
  - Association of variables with axes and representational features (e.g., colours, shapes, line styles)
  - Identification of relationship(s) depicted
- May be an end in itself or a prerequisite for other tasks

Interaction graphs

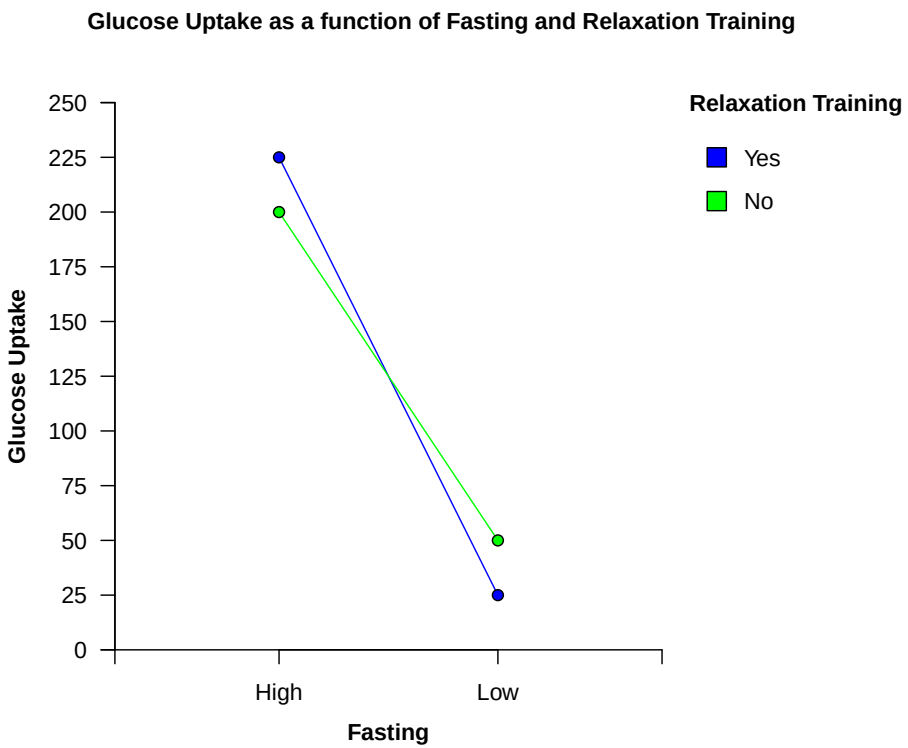




- Students more likely to misinterpret (Zacks & Tversky, 1999) or inadequately interpret line graphs (Peebles & Ali, 2009, Ali & Peebles, 2013)

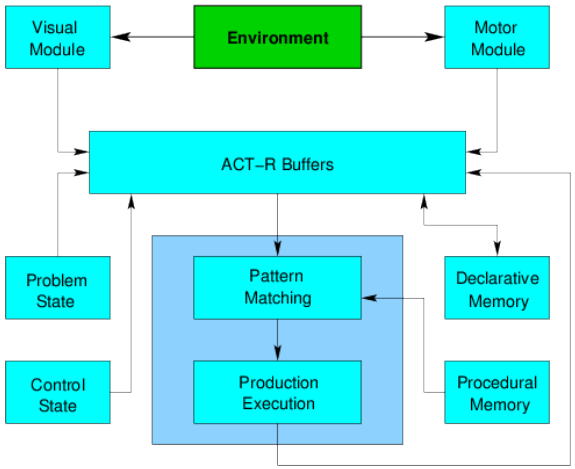
- Line graphs better at depicting common relationships for experts (Kosslyn, 2006)
- Interpretation facilitated by recognition of familiar patterns

An example expert verbal protocol



1. (Reads) "Glucose uptake as a function of fasting and relaxation training"
2. Alright, so we have. . . you're either fasting or you're not. . .
3. You have relaxation training or you don't. . .
4. And so. . . not fasting. . . er. . .
5. So there's a big effect of fasting. . .
6. Very little glucose uptake when you're not fasting. . .
7. And lots of glucose uptake when you are fasting. . .
8. And a comparatively small effect of relaxation training. . .
9. That actually interacts with fasting.

The ACT-R cognitive architecture



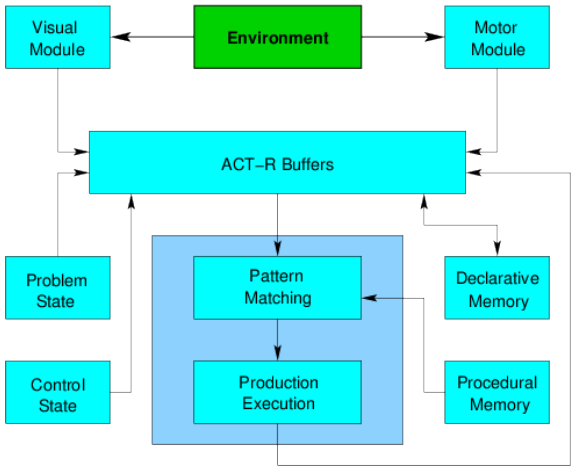
Elements of the architecture:

- *Hybrid* architecture with symbolic and subsymbolic components
- Production system model of procedural memory & cognitive control
- Semantic network model of declarative memory
- Activation-based learning, memory retrieval & forgetting mechanisms
- Simulated eyes & hands for interacting with computer-based tasks

Value for diagrammatic reasoning research:

- Allows modelling of complex tasks with graphical elements
- Imposes valuable cognitive constraints on models

The ACT-R cognitive architecture



Elements of the graph comprehension model:

- Prior graph knowledge (general and specific) required
- Information extracted and knowledge structures generated
- Sequence of cognitive & perceptual operations involved
- Strategic processes that control comprehension

Behavioural output to be compared with human data:

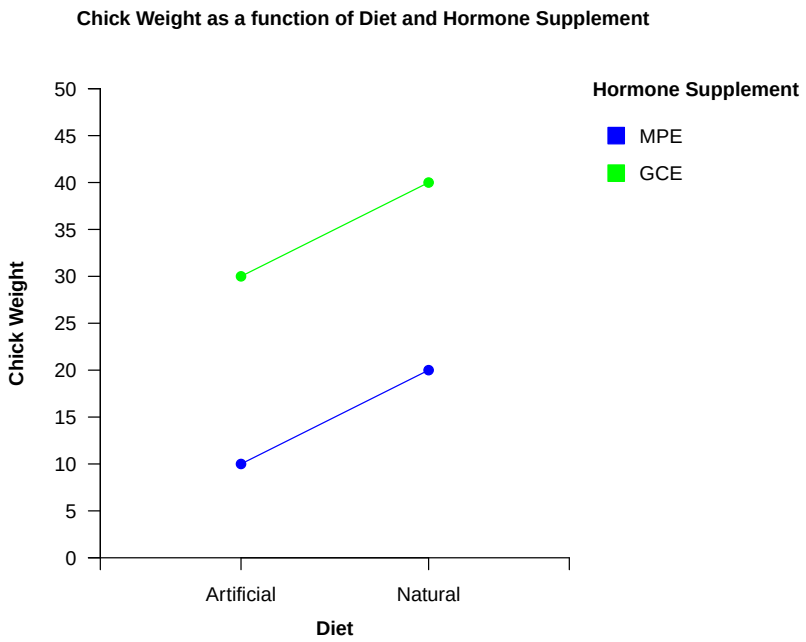
- Sequence of propositions to compare with expert verbal protocols
- Scan paths to compare with expert eye movements

Stages of comprehension

Comprehension proceeds in the following order:

1. Read title. Identify variable names and create declarative chunks.
2. Seek variable labels, identify what they are by their location and if required, associate with label levels
3. Associate variable levels with indicators (position or colour)
4. Look at plot region and attempt to interpret distances. If a highly salient pattern exists (e.g., cross, large gap) process that first
   - Individual production rule for each pattern
   - No production rule then pattern not processed
5. Continue until no more patterns are recognised

An example model protocol

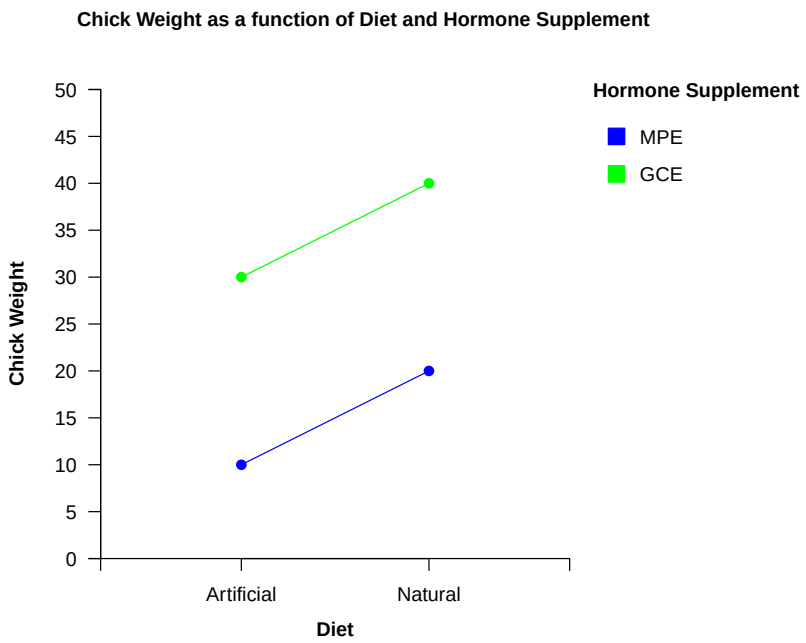


text at top of display. . .
[chickweight] [= variable]
[as] [a] [function] [of] [diet] [= variable]
[and] [hormonesupplement] [= variable]

text at bottom of display. . .
[diet] at [bottom] [= IV]
look to nearest text. . .
[natural] is a level of [diet]
[natural] is [right]
[artificial] is a level of [diet]
[artificial] is [left]

text at far right of display. . .
[hormonesupplement] at [far-right] [= IV]
look to nearest text. . .
[mpe] is a level of [hormonesupplement]
[gce] is a level of [hormonesupplement]

An example model protocol



objects in plot region. . .
a [green] [line]
no memory for [green] look to legend. . .
[green] [rectangle]. look for nearest text. . .
[green] represents [gce]
[blue] [rectangle]. look for nearest text. . .
[blue] represents [mpe]

text at far left of display. . .
[chickweight] at [far-left] [= DV]

look to pattern. . .
substantial difference between legend levels. . .
[0.2] diff [blue] = [small] effect [mpe]
[0.2] diff [green] = [small] effect [gce]

compare [blue] and [green] levels. . .
[moderate] diff: [gce] greater than [mpe]
[moderate] [main] effect [hormonesupplement]

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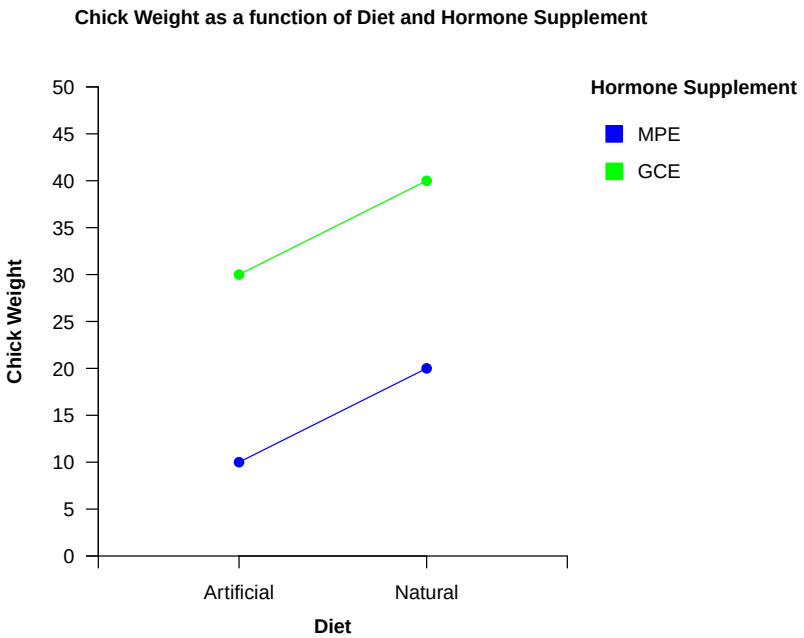

identify x-axis levels. . .
[0.4] diff [left] = [moderate] effect [artificial]
[0.4] diff [right] = [moderate] effect [natural]

compare [left] and [right] levels. . .
[small] diff [natural] > [artificial]
[small] [main] effect [diet]

compare left and right patterns. . .
[0.0] diff between points. [neither] bigger
[no] diff & [same] order = [no-interaction]
for [artificial], [gce] > [mpe]
for [natural], [gce] > [mpe]