Computational Modeling of Human Attentional Networks

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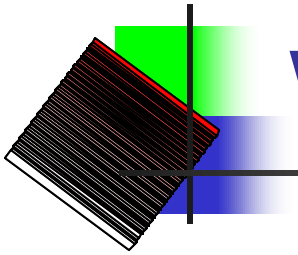


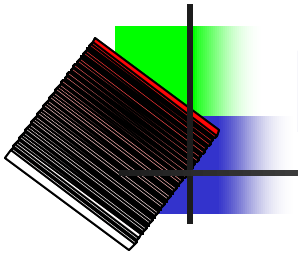
What is attention?

- “Everyone knows what attention is. It is the taking possession of the mind, in clear and vivid form, of one out what several simultaneous objects or trains of thought”.

  – William James, 1890

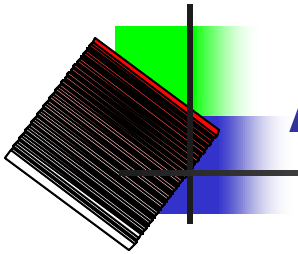
- “On attention itself, it is needless to discourse at length; its nature and conditions are familiar to every thoughtful student”.

  – Munsell, 1873



Many faces of attention

- Selectivity?
- Inhibition?
- State of arousal?
- Controlled and non-automatic process?
- Mechanism vs emergent property?

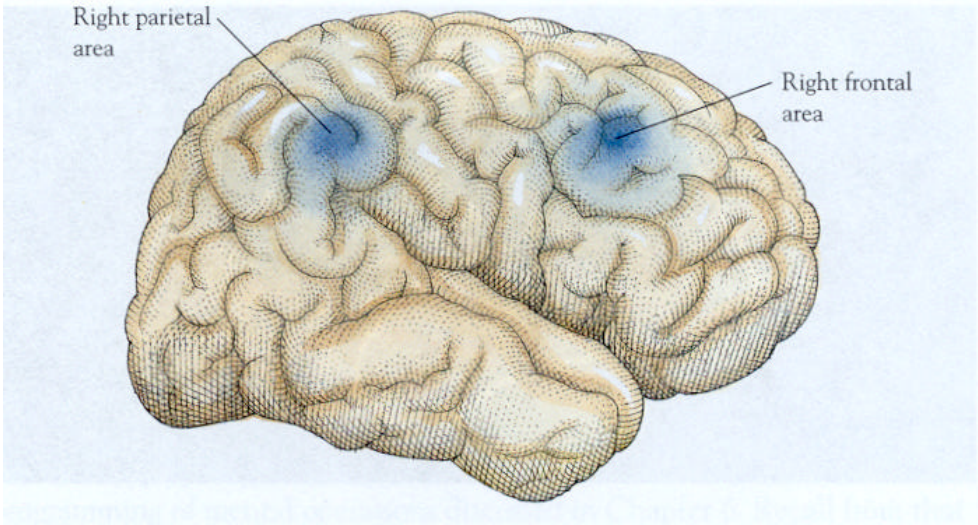


Attentional Networks

- Attention can be viewed as a system which consists of three specialized networks. In recent years three attentional networks have been defined in anatomical and functional terms (Posner & Petersen, 1990).
  - Alerting (general preparatory attention)
  - Orienting (to subset of input)
  - Executive control (Cognitive selectivity)

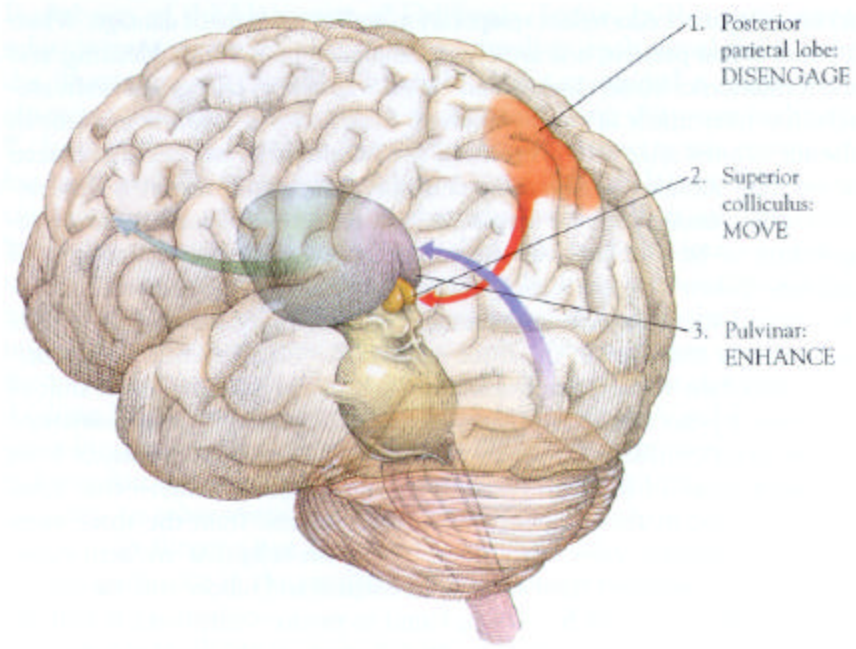
Alerting

- Alerting involves a change in the internal state in preparation for perceiving a stimulus. The alert state is critical for optimal performance in various cognitive tasks.
- The alerting network includes frontal and parietal regions particularly of the right hemisphere,



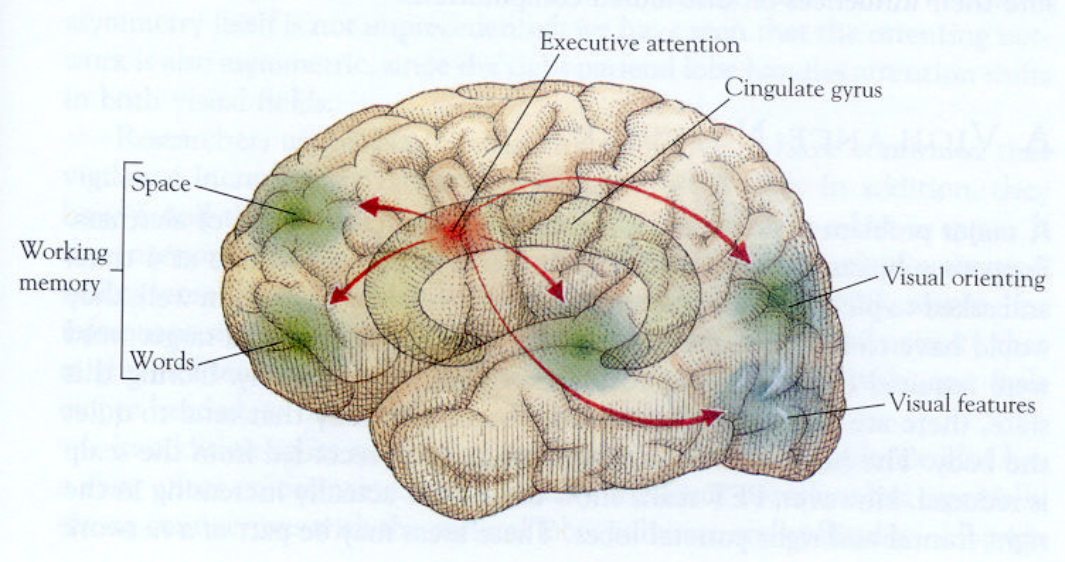
Orienting

- Orienting involves the selection of information from sensory input. It can be reflexive or voluntary, covert or overt.
- Sources of the orienting network include parts of the superior and inferior parietal lobe, frontal eye fields and such subcortical areas as the superior colliculus of the midbrain and the pulvinar and reticular nucleus of the thalamus.

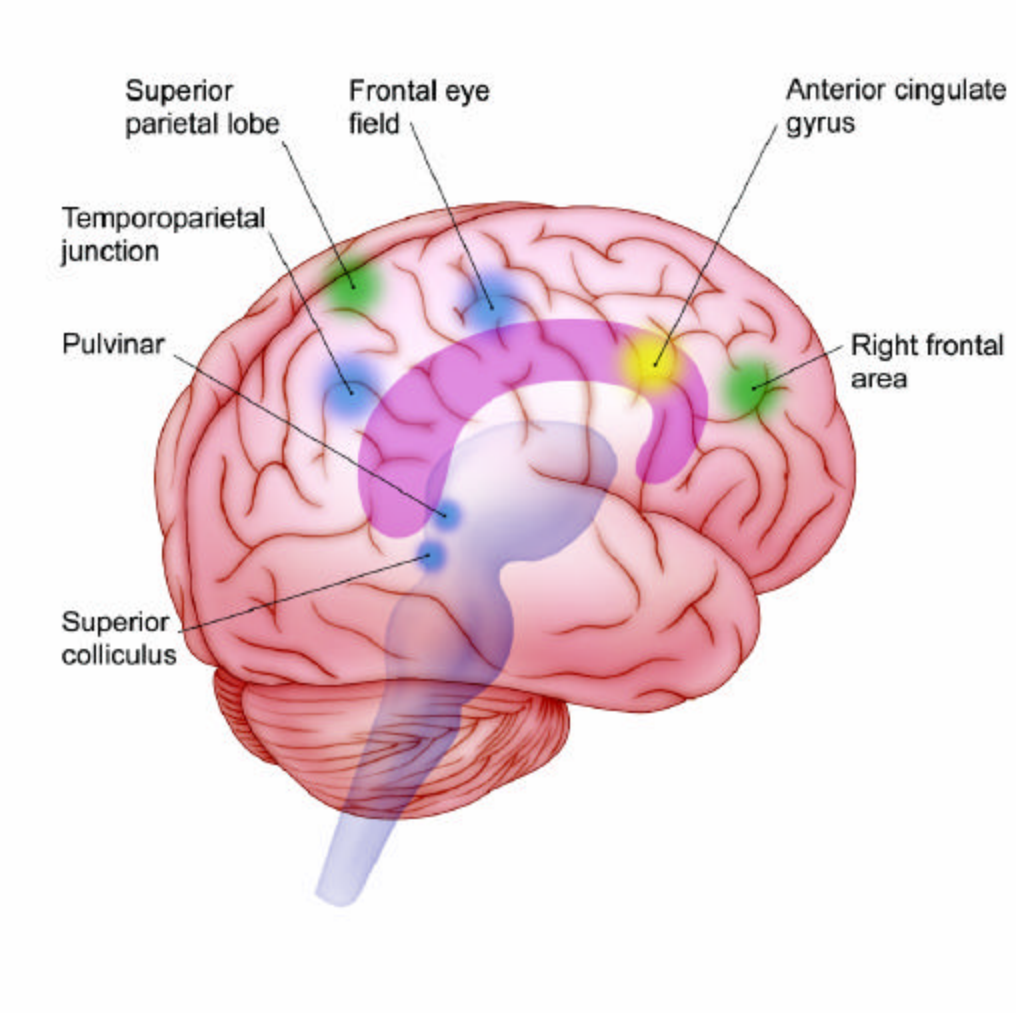


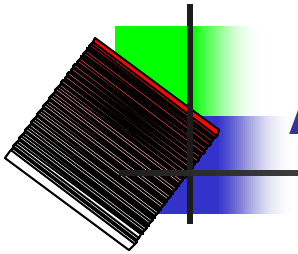
Executive Control

- Executive control of attention involves more complex mental operations in monitoring the resolving conflict between computations occurring in different brain areas, such as planning, decision making, error detection, novel or not well-learned responses, and overcoming habitual actions.
- The network involves midline frontal areas (anterior cingulate), lateral prefrontal cortex, and the basal ganglia.



Three Attentional Networks

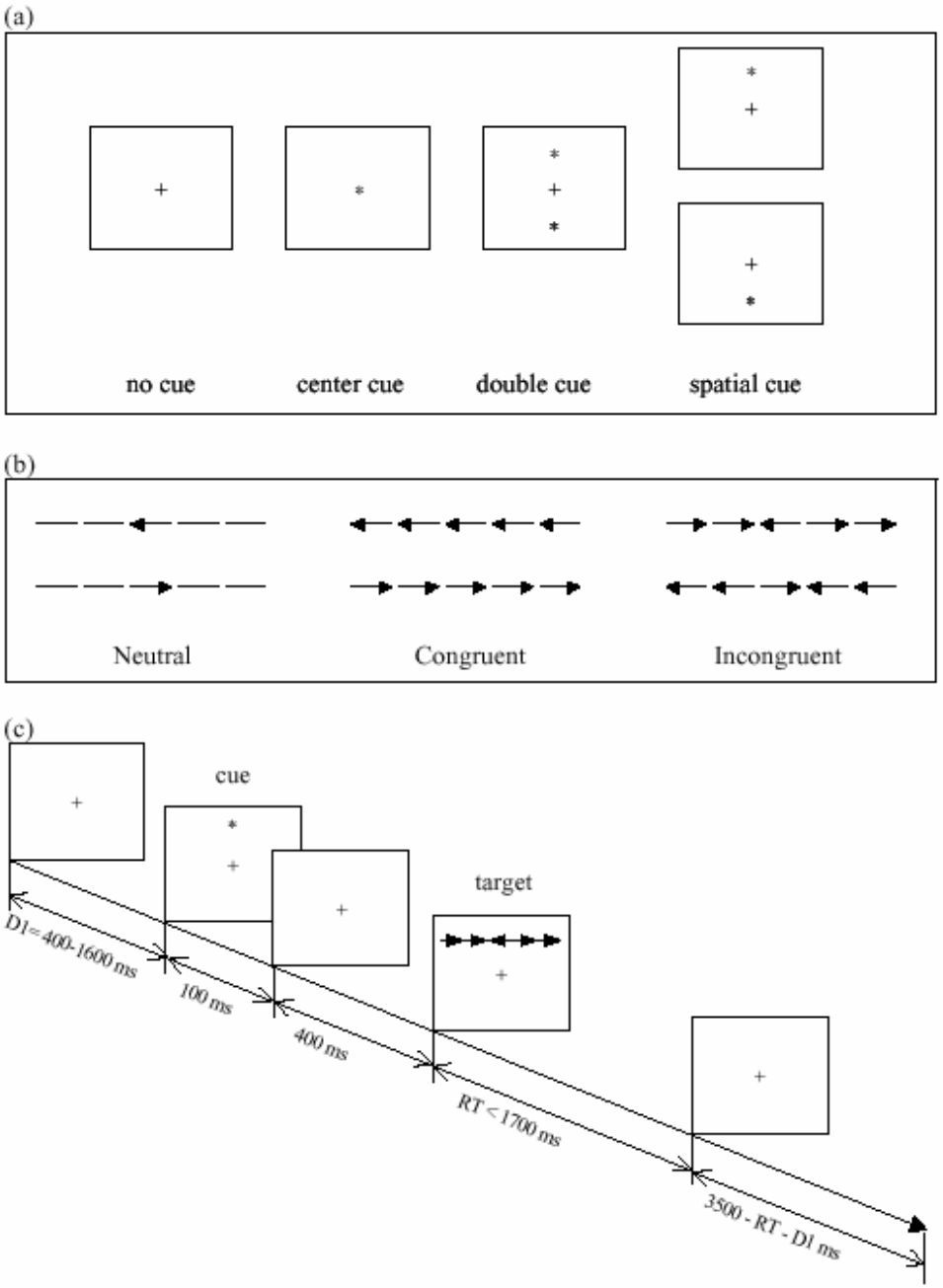




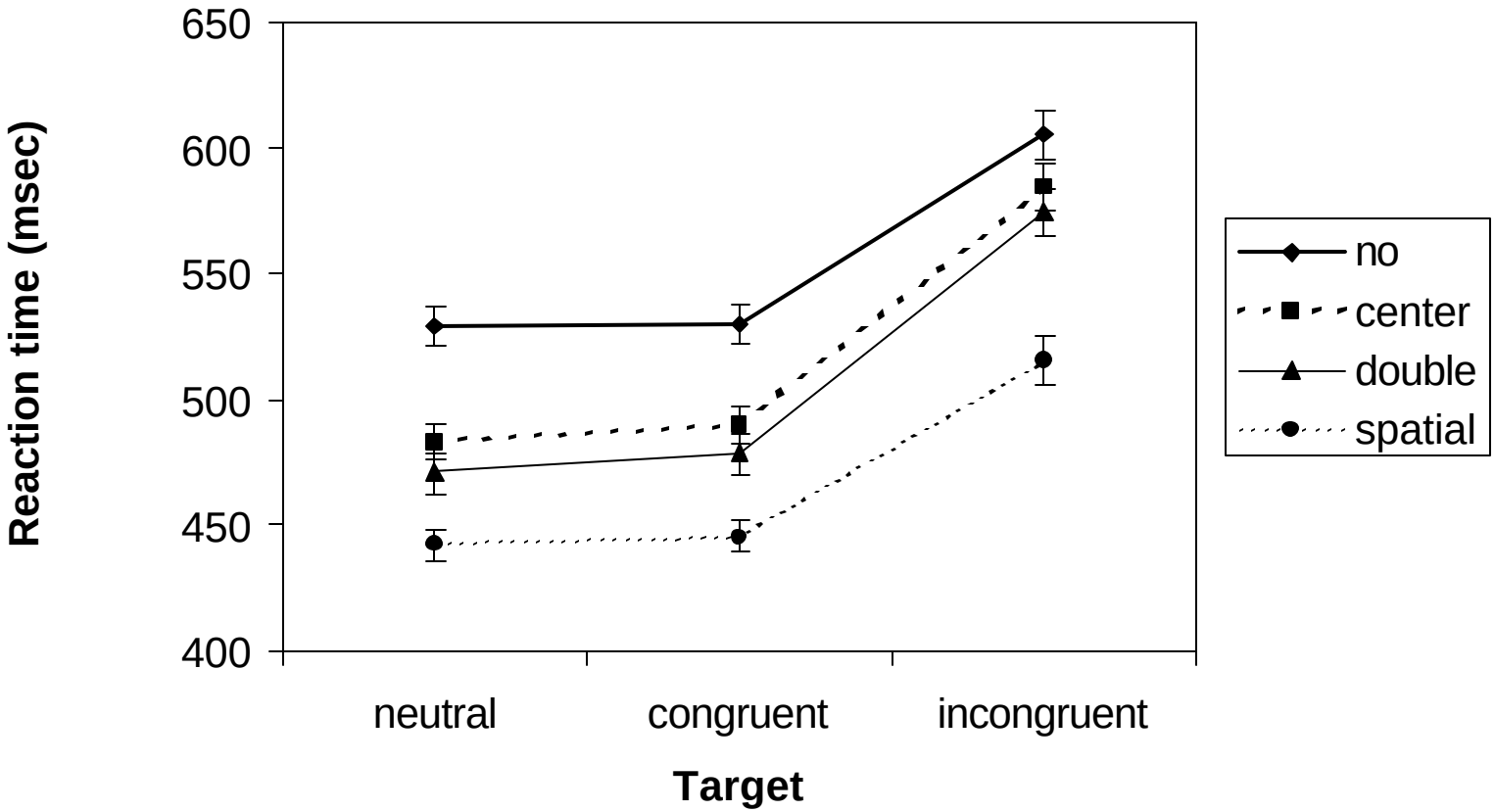
ANT (Attentional Network Test)

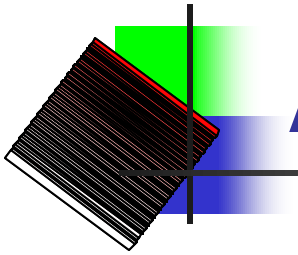
- Fan, Posner, et al (2002)
- Features
  - Involves all three ANs.
  - Can be used to obtain a measure of the efficiency of each AN.
  - Is simple and quick (30 mins) enough to obtain data from children, patients, and animals.
- Purposes
  - Test functional independency
  - Functional imaging & EEG
  - Pharmacological intervention
  - Genetic basis?

ANT


(a)
no cue
center cue
double cue
spatial cue
(b)
Neutral
Congruent
Incongruent
(c)
cue
target
D1=400-1600 ms
100 ms
400 ms
RT < 1700 ms
3500 - RT - D1 ms

ANT: Results


650
600
550
500
450
400
Reaction time (msec)
neutral
congruent
incongruent
Target
no
center
double
spatial



ANT: Efficiency Measures

- Alerting = RT(no cue) – RT(double cue)

  47ms +- 18ms

- Orienting = RT(center cue) – RT(spatial cue)

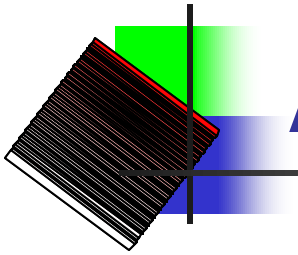
  51ms +- 21ms

- Executive Control = RT(incongruent) – RT(congruent)

  84ms +- 25ms

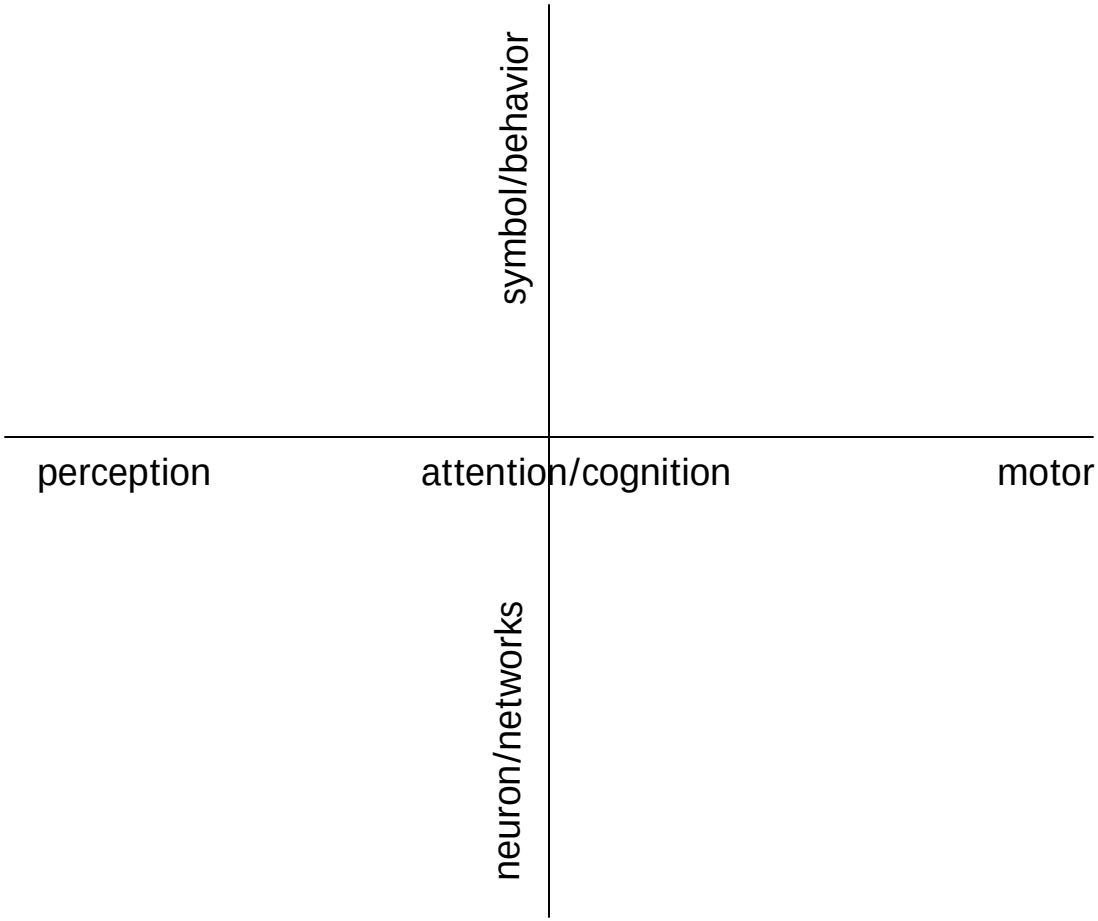
- Correlation test shows independence.

Multilevel Modeling of Attentional Networks

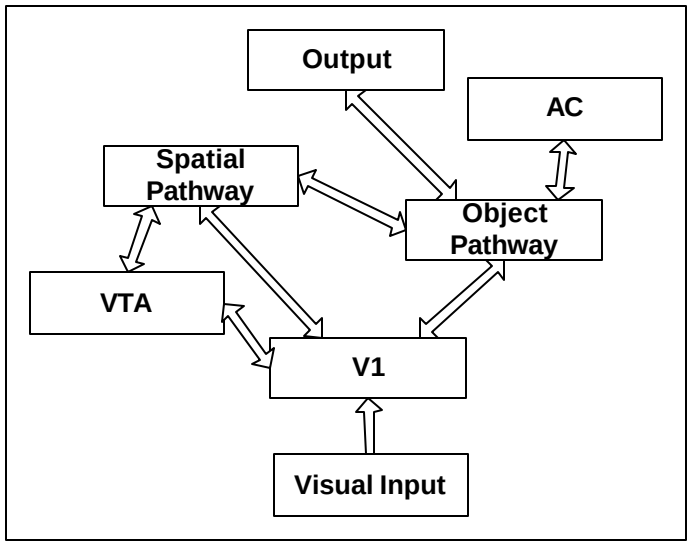


- Develop computational models, at both subsymbolic and symbolic levels, to simulate the three attentional networks and the ANT results.
- Provide computational links between biological reality and cognitive behavior.
  - Connectionist models typically have solid neural foundations and excel in providing robust and brain-based explanations of cognition. But their connections to empirical behavior are often unclear and ad hoc
  - Symbolic models excel in providing explicit and symbol-based explanations of cognition but often lack the necessary neural level support.

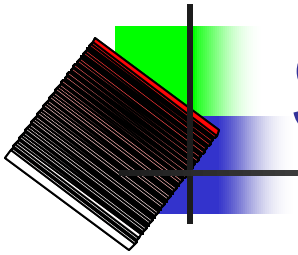
Towards a horizontally and vertically unified theory of cognition



Subsymbolic modeling in leabra (PDP++)

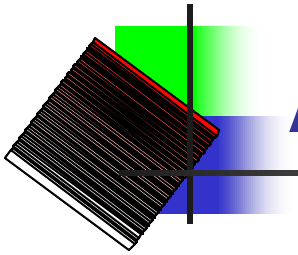


QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.



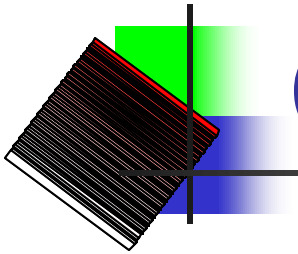
Symbolic model in ACT-R/PM

- Demo?



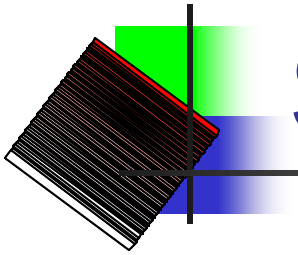
ACT-RPM Model of ANT

- No cue
  - Attend to fixation point
  - Expecting cue
  - Buffer stuffing delivers target
  - (50ms) “Surprise” production notices target and switches goal state to process target



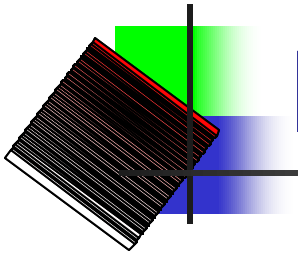
Center and Double Cue

- Buffer stuffing always delivers cue location
- Center Cue
  - Process cue
  - Change state to expect target
  - Attention remains in center
- Double Cue (Uses a betting strategy)
  - Randomly attend to top or bottom stimulus
  - Search for other cue and Switch attention
  - 50% chance of attending to target location
  - Prepare for target



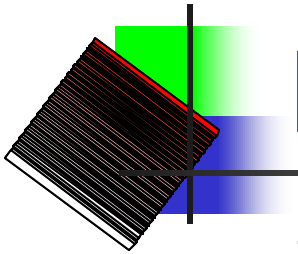
Spatial Cue

- Same mechanism as double cue, but only one cue (top or bottom)
- Switch attention to cue
- Look for other cue, but none found
- Prepare for target
- 100% chance of attending target location



Processing target

- If attending to target location, no attentional switch needed
- Otherwise, find target and switch attention
- Chance of attending to flanker arrow (incongruent condition): Must notice incorrect location and switch to center arrow



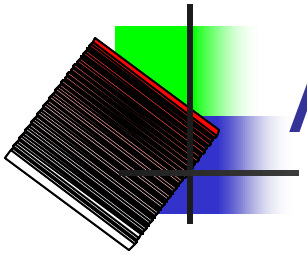
Effects in ACT-R/PM

;;;Alerting (nocue-doublecue):
;; exp: 47ms+-18ms
;; model: about 75ms. A surprise production costs 50ms for the nocue condition;
Betting strategy (doublecue) can save 25ms

;;;orienting (centercue-spatialcue):
;; exp: 51+-21ms
;; model: about 50ms. An additional +visual-location> is needed in the centercue condition, which costs 50ms.

;;;executive control (incongruent-congruent):
;; exp: 84+-25ms
;; model: about 90ms. The selected target can be wrong and must be reselected if so in the incongruent condition, which costs time.

;;;10ms effect
;; exp: doublecue condition is 10ms less the the center cue condition.
;; model: about 25ms. This is due to the bet strategy in doublecue condition.

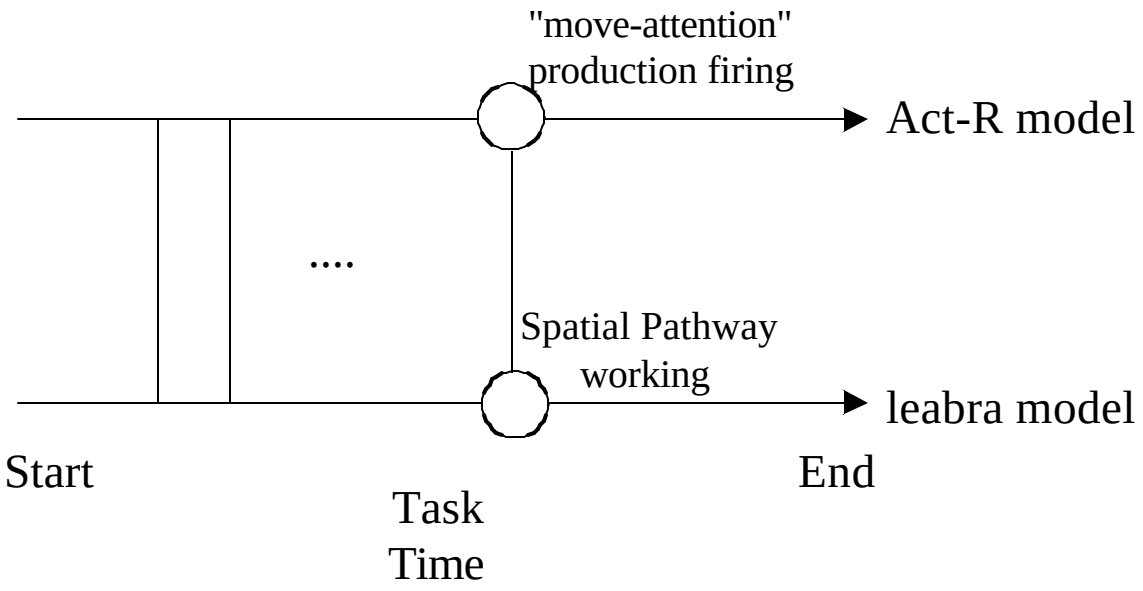


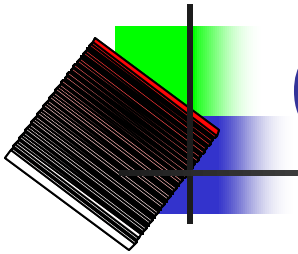
ANT modeling results

cue	target	leabra	act	ant
nocue	neutral	44	545	525
nocue	congruent	45	580	528
nocue	incongruent	54	686	605
center	neutral	41	495	480
center	congruent	39	526	485
center	incongruent	45	615	570
spatial	neutral	38	445	440
spatial	congruent	36	478	445
spatial	incongruent	41	525	505

R = 0.94, 0.94, 0.98

To link/contrast multiple levels





Conclusion

- Human attention is a complex construct and involves multiple components, at both brain/networks and behavioral/functional levels.
- Multiple models provide a principled computational link between neural activities and cognitive behaviors.