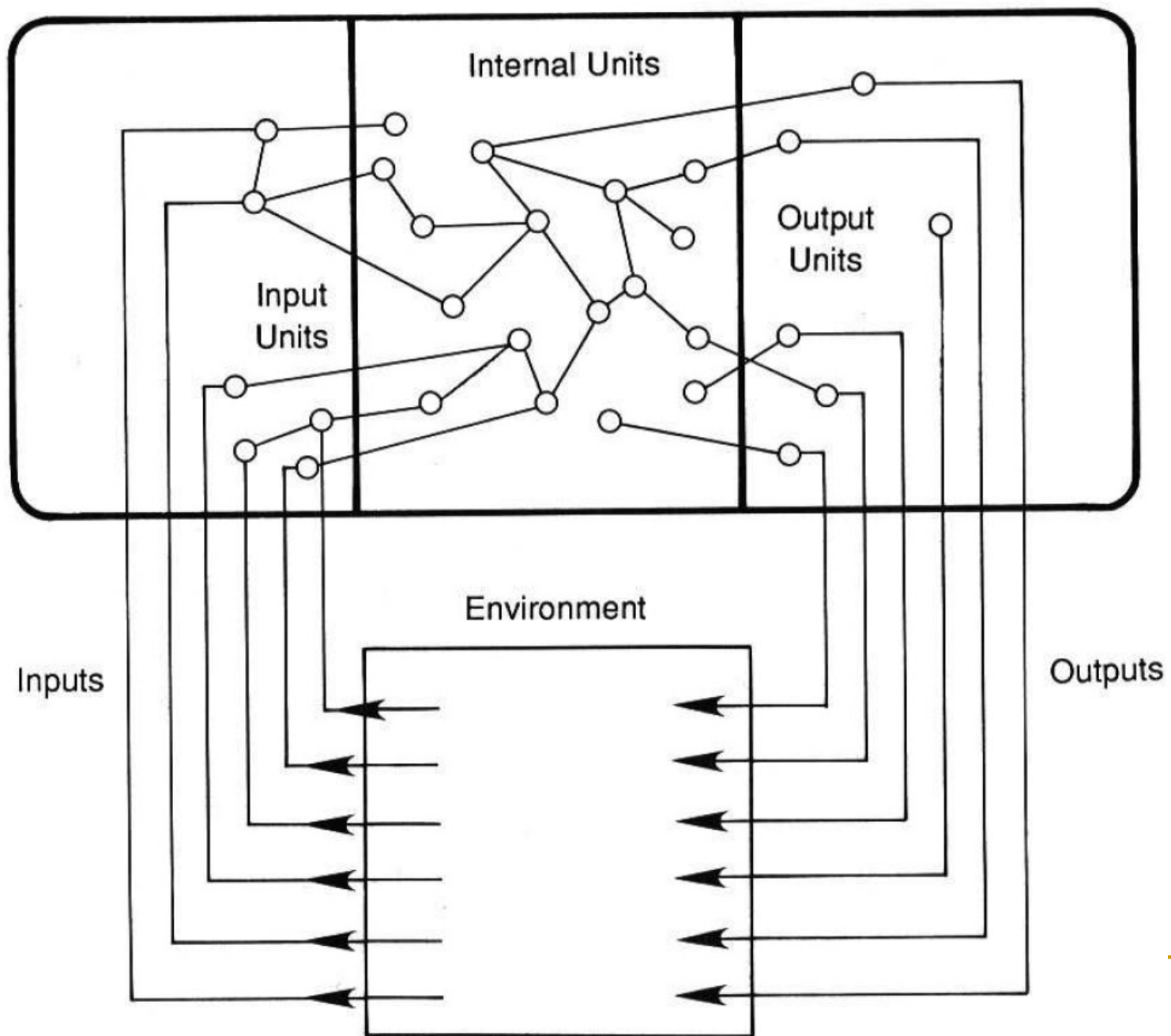
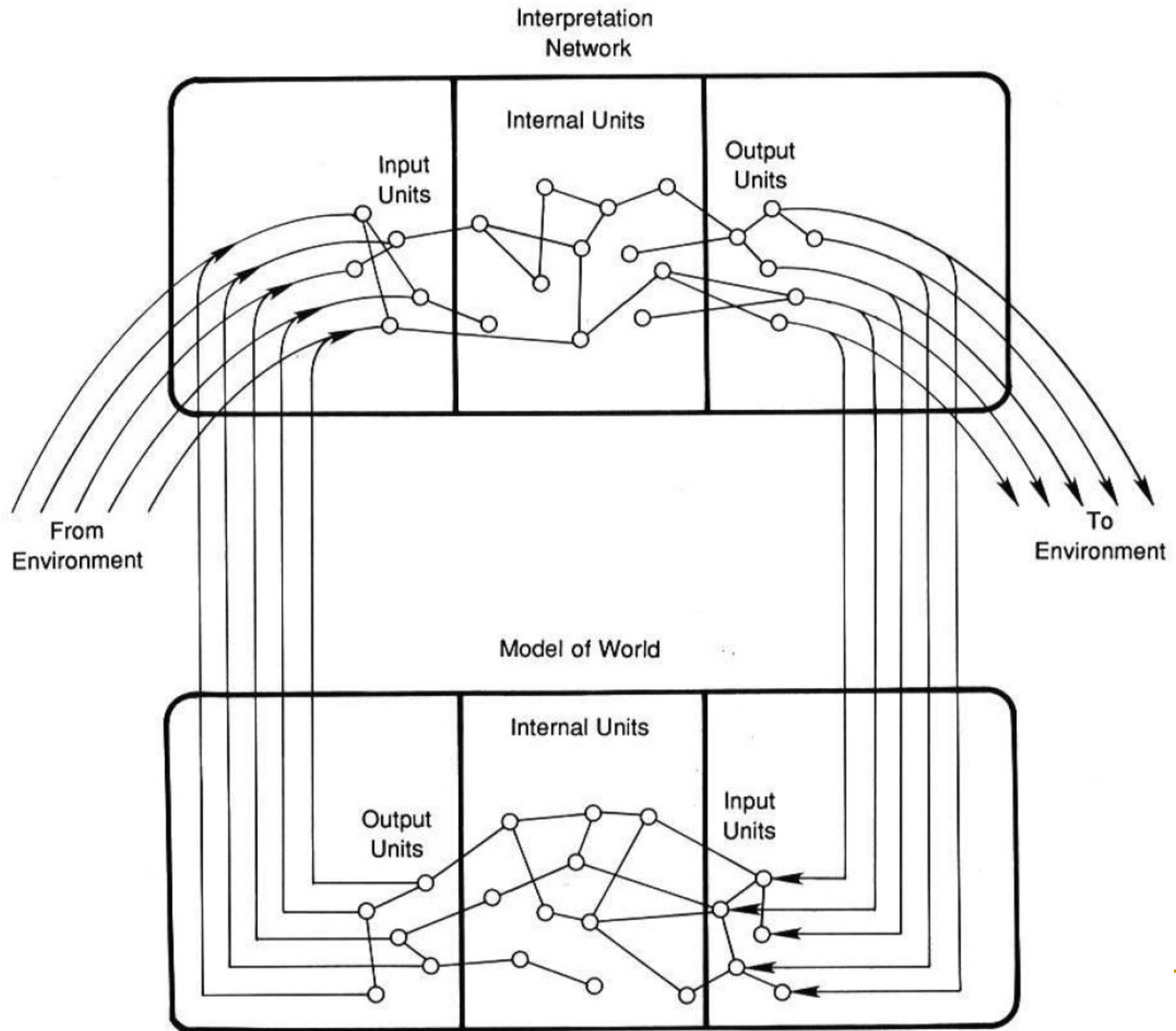


Prediction and planning

- Networks and people are good at *prediction*
 - Temporal difference learning
 - Word segmentation
 - Sentence comprehension
- Forward modeling
 - Learn a model of the world
 - Use model to predict the consequences of actions
 - Select actions based on the best predicted outcome
- Can we use our ability to predict to aid in selecting the best response?

Interpretation Network





What is cognitive control?

- The models we've looked at are largely “recognition-based” (map input to corresponding output)
- These models ignore the human ability to *control* which response we produce (if we produce one at all)
 - Networks can't learn to produce different responses to the same input
 - Animals have trouble doing this, too
- Can PDP models account for the **flexibility** of human behavior?



What is cognitive control?

- We can override prepotent responses:
 - You're hungry. There's a sandwich on your roommate's desk, but you don't eat it.
- We can ignore things in the environment that aren't relevant for the task at hand:
 - You're at a busy train station looking for a friend wearing a red coat, and you only look at the faces of people who are wearing red. (Miller & Cohen, 2001)
 - The networks we've looked at process all input equally.
- We can perform multiple tasks at the same time:
 - You're writing an e-mail while listening to someone on the telephone.
 - Networks typically perform one tasks at a time.

What is cognitive control?

- What must cognitive control entail?
 - Select appropriate perceptual information for processing (e.g. only people wearing red)
 - Inhibit inappropriate responses (e.g. don't eat that sandwich)
 - Maintain relevant contextual information (e.g. *this* friend likes cream in his tea)
- Most of the networks we've seen can't do this.
 - Is cognitive control qualitatively different from other kinds of knowledge or processes?
- Example: Stroop task

The Stroop task

Word reading or color naming

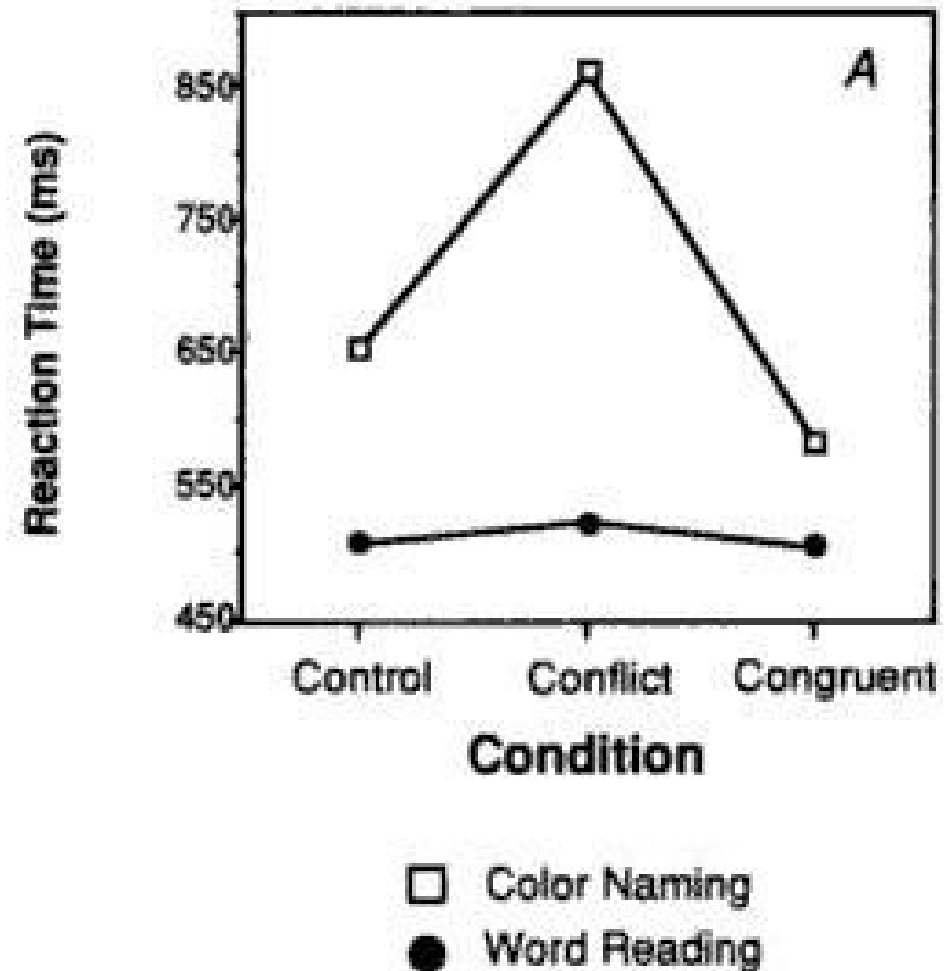
Control: **BLUE / XXXX**

Congruent: **RED**

Conflict: **GREEN**

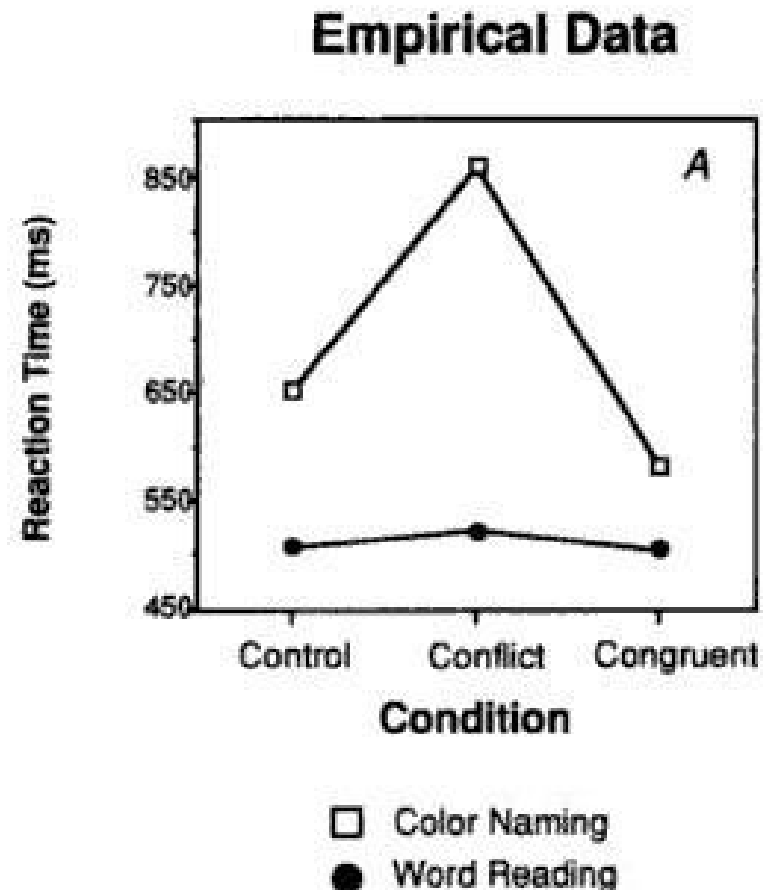
- No effect of ink color on word reading
- Color naming is slower than word reading
- When the color name conflicts with the word, reaction times are the slowest

Empirical Data

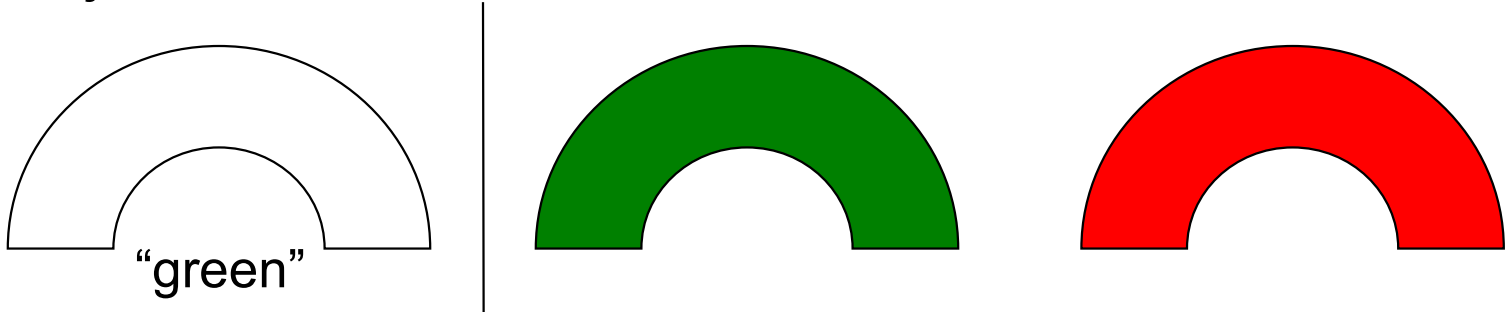


Automatic vs. controlled processes

- *Automatic*: fast, don't require attention for execution, can occur involuntarily
 - *Controlled*: slower, voluntary, require attention
-
- Word reading → automatic
 - Color naming → controlled
 - When outputs conflict, controlled process will be slowed

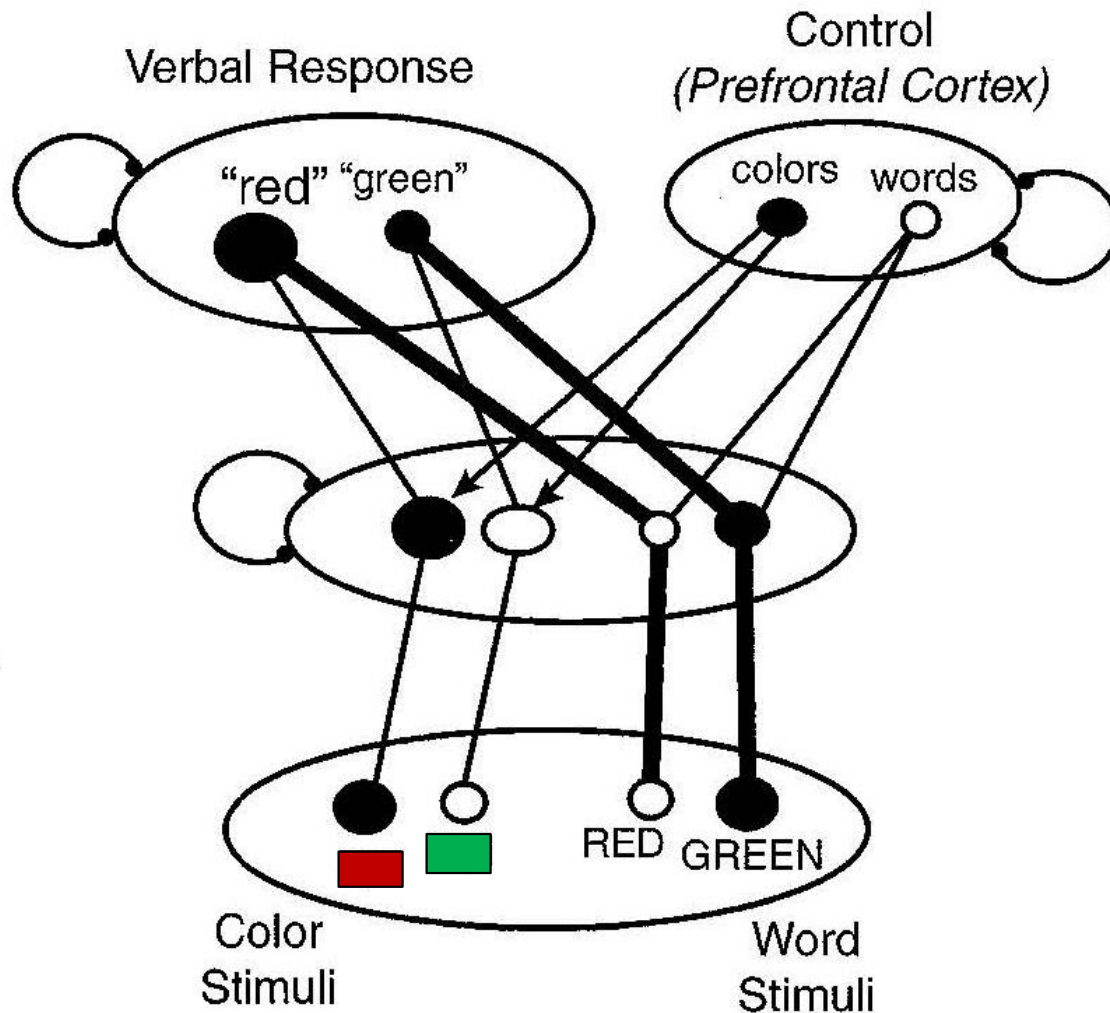


MacLeod & Dunbar (1988)

- Is there really a dichotomy between automatic and controlled processes?
 - Taught subjects to use color names as names for neutral-colored shapes
 - Initially, color naming interfered with shape naming
 - With extended training on shape naming, effects reversed
- Speed of processing and interference depend on the degree of automatization (due largely to practice)
- Graded nature of effects suitable for connectionist modelling

PDP model of Stroop task (Cohen et al., 1990)

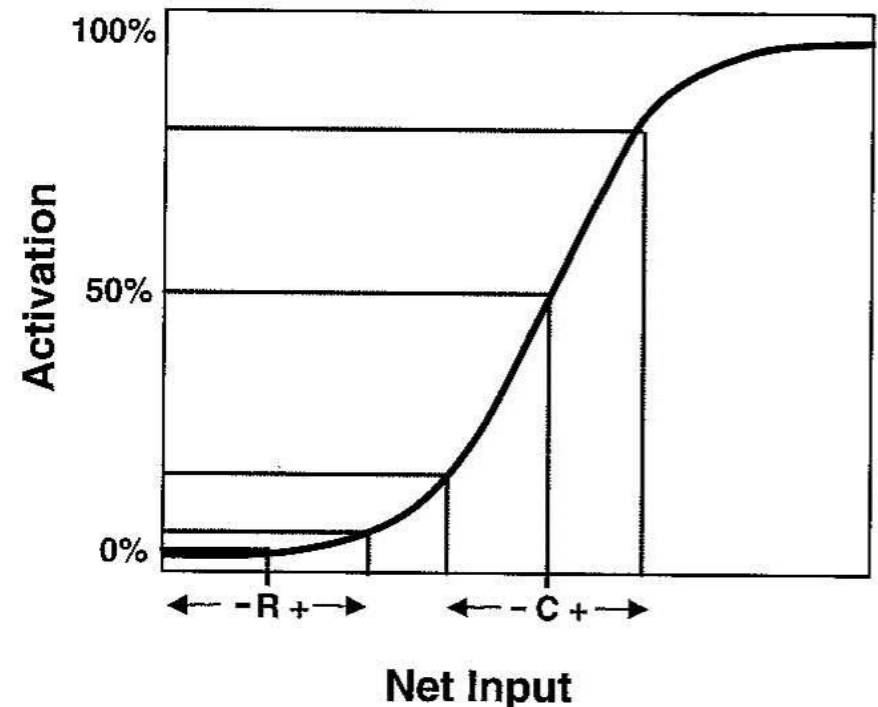
B. Color Naming



- Separate pathways for word reading and color naming; Word reading pathway is stronger
 - More practice, more systematic task; doesn't need top-down support
- Presence of a conflicting color produces no interference
- Color naming requires top-down support (control) to override "prepotent" response from word pathway

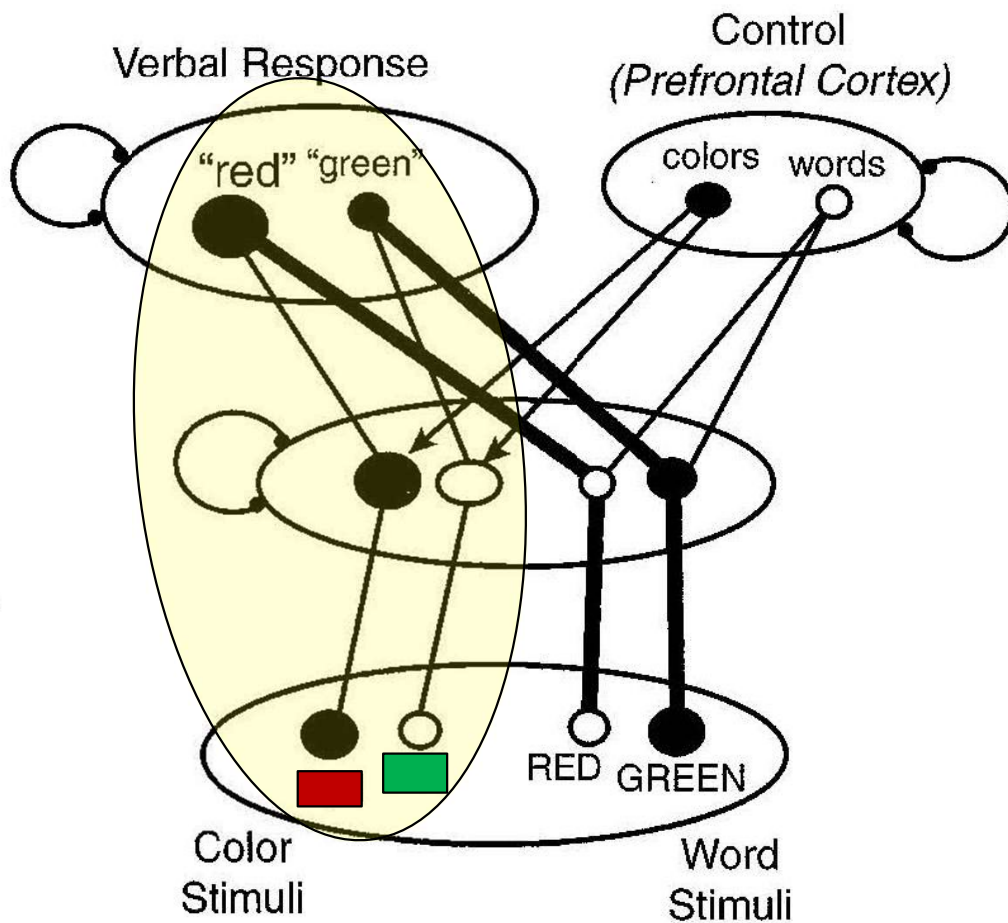
PDP model of Stroop task (Cohen et al., 1990)

- At rest (R), a change in the net input has little effect on activation
- After modulation by task units (C), a change in the net input has a larger impact on activation
 - Task information *sensitizes* these units to external input
- All units in pathway activated equally
 - No specific information about the correct response



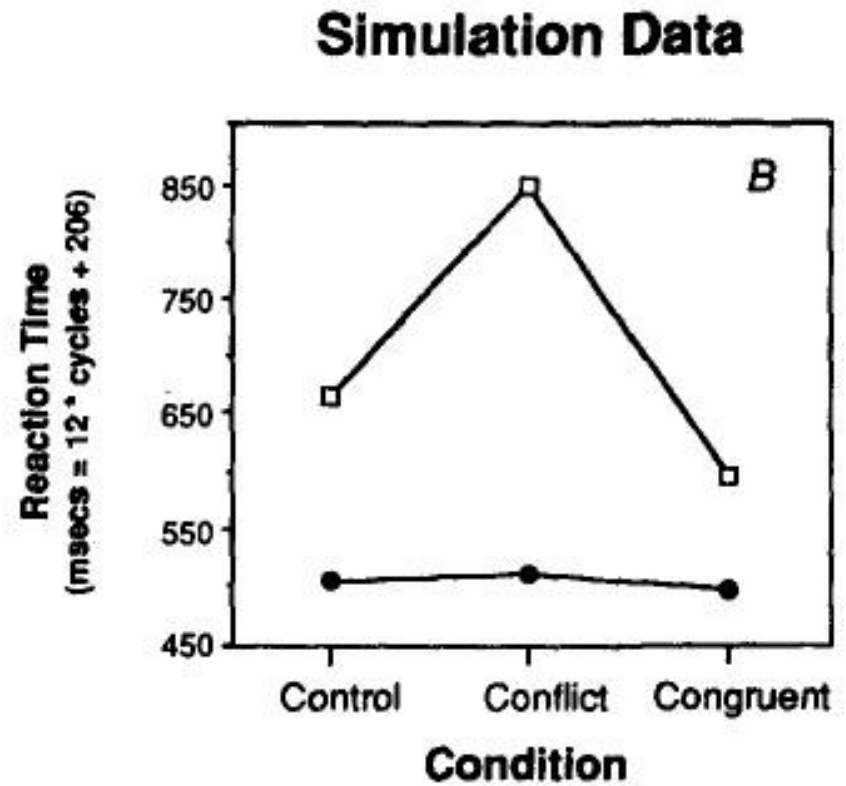
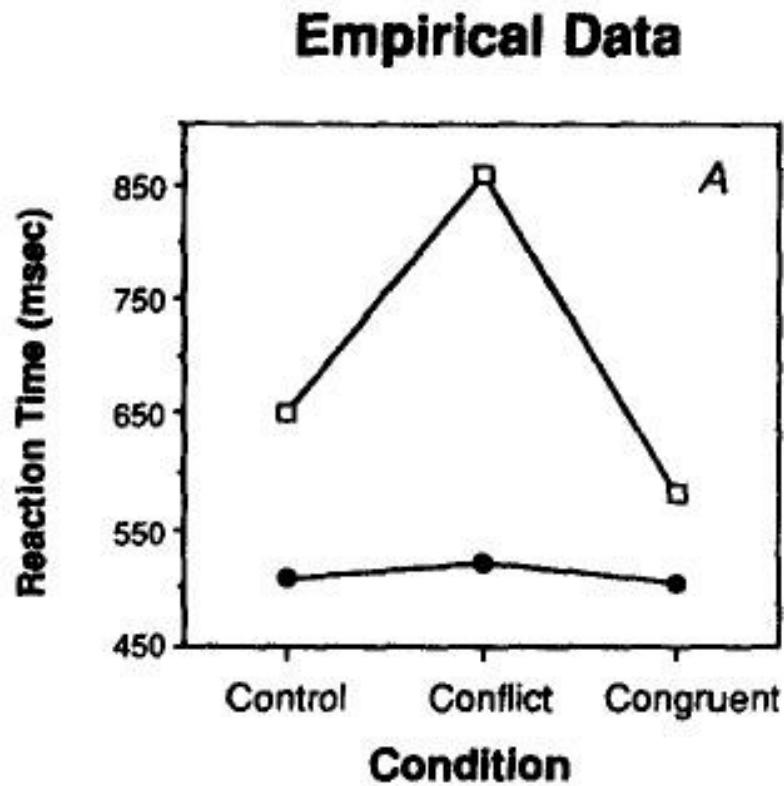
PDP model of Stroop task (Cohen et al., 1990)

B. Color Naming



- Task demand units *bias* processing in favor of the weaker pathway
- These units “guide” (or implement) attention to overcome the dominant response

PDP model of Stroop task (Cohen et al., 1990)



□ Color Naming
● Word Reading

PDP model of Stroop task (Cohen et al., 1990)

- Automaticity is a continuum of strength of processing
 - No qualitative distinction between “controlled” vs. “automatic” processes
- Same kinds of processing and representation used for word reading and color naming participate in “cognitive control”

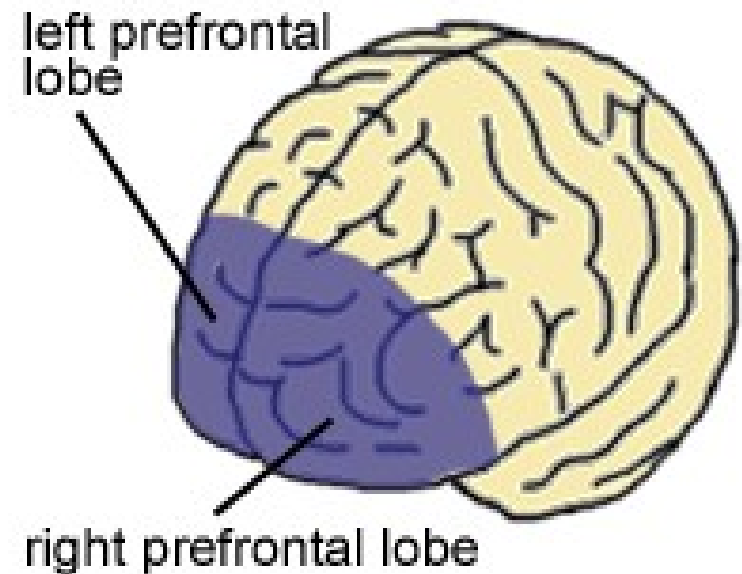
Attention & cognitive control

- In the Stroop case, the task demand units are guiding attention to enable cognitive control
- Attention is:
 - “... the modulatory influence that representations of one type have on selecting which (or to what degree) representations of other types are processed...” (Cohen et al., 2004)
- Attention biases competition between representations competing to generate response
 - Bias can be “bottom-up” or “top-down”
 - In the Stroop case, it’s top-down (instructions given by the experimenter to color name)

Cognitive control and the PFC

(Cohen et al., 2004)

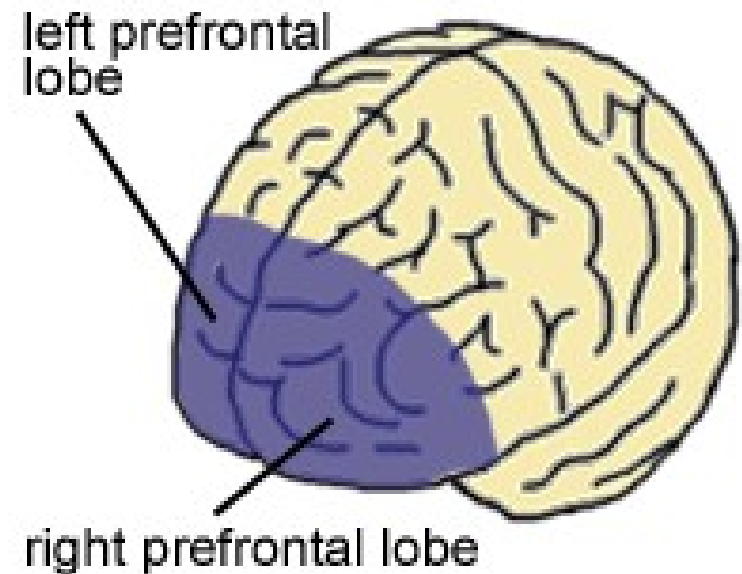
- Prefrontal cortex (PFC) subserves the function of the “task demand” units
 - Can sustain the activation of representations that “bias the flow of activity along task relevant pathways”
- Models of PFC use recurrent connections
 - “Attractor dynamics”
 - Units with mutually excitatory connections can actively maintain themselves without external input



Cognitive control and the PFC

(Cohen et al., 2004)

- Lesions to parts of the PFC can produce deficits in “working memory”
 - Patients are unable to maintain task relevant information
- Patients are also easily distracted during a task



Cognitive control and the PFC

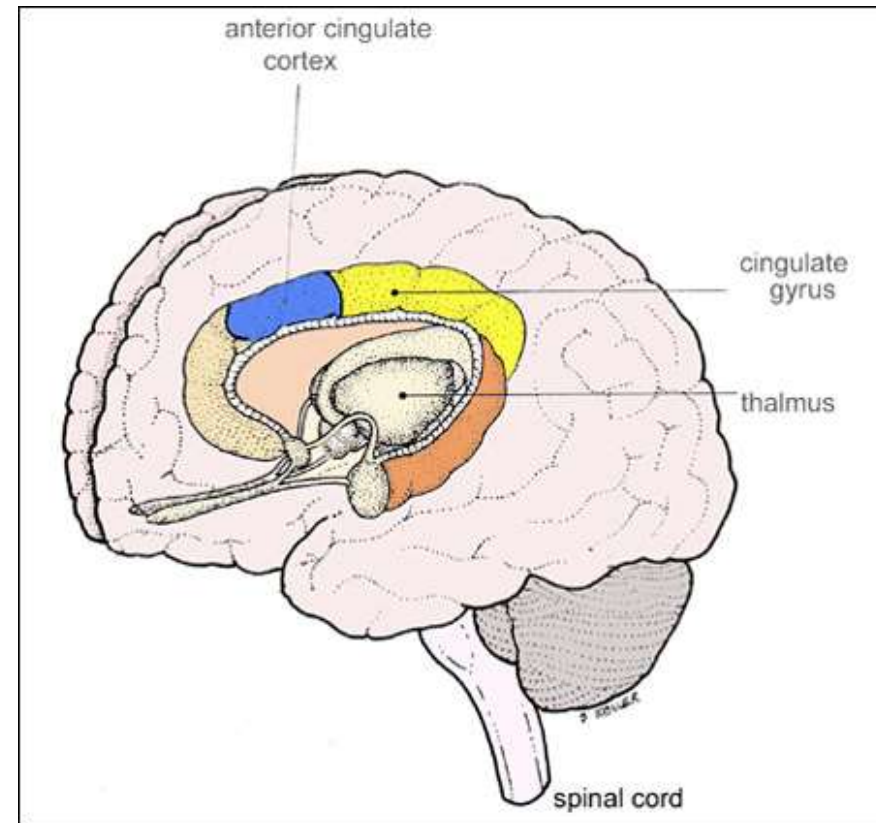
(Cohen et al., 2004)

- PFC must also be able to *update* task representations
 - New input may signal a change in task or need to be ignored
 - The current degree of control may be insufficient to do the task
 - PFC needs to increase amount of “biasing”
- Patients with lesions to the PFC may *perseverate*
 - Continuing to produce a response even when inappropriate or not relevant to the task
- How does the PFC know when to alter the current amount of control?

Cognitive control and the ACC

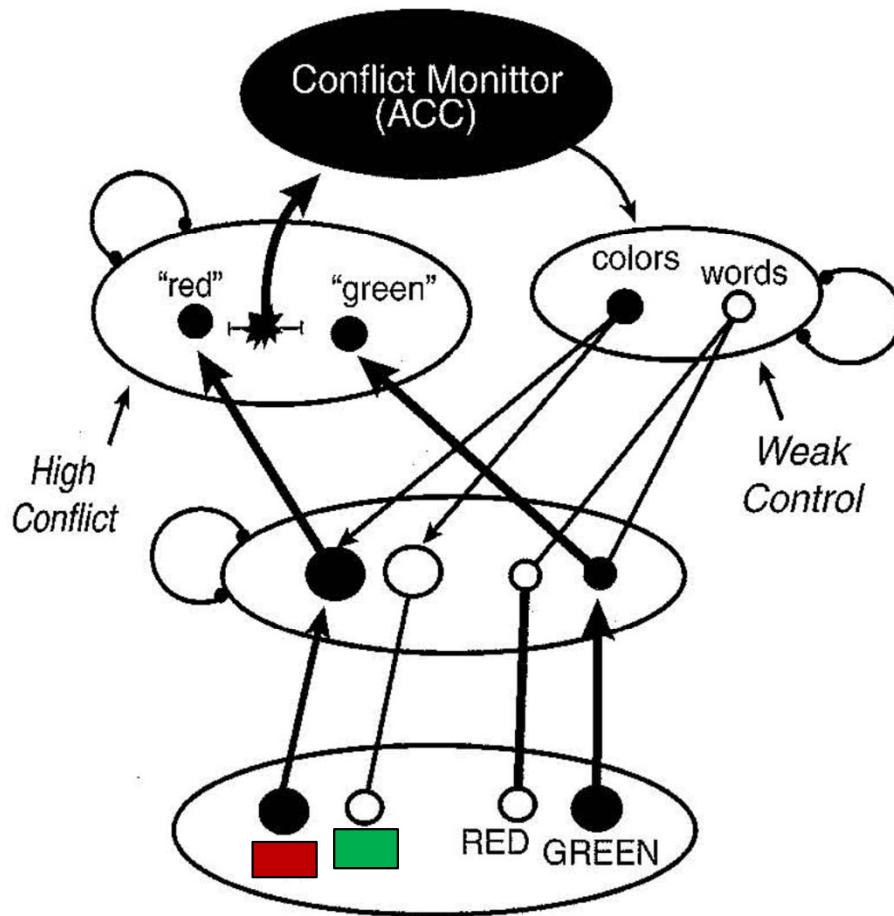
(Cohen et al., 2004)

- Attention reduces conflicts in processing
- Occurrence of conflict signals need for *more* attentional control
- **Anterior cingulate cortex (ACC)** appears to respond to conflict in processing pathways and/or response representations
- Lesions to the ACC result in an inability to detect errors and severe difficulty with Stroop task

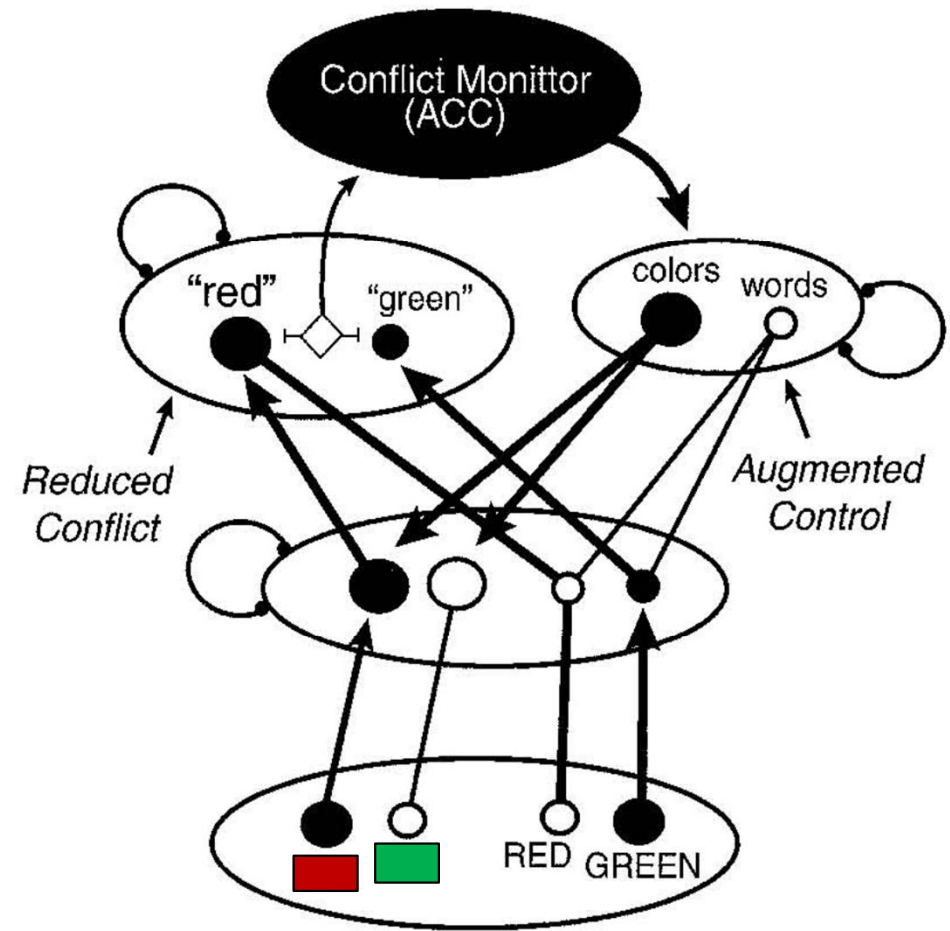


(Cohen et al., 2004)

A. Detection of Conflict



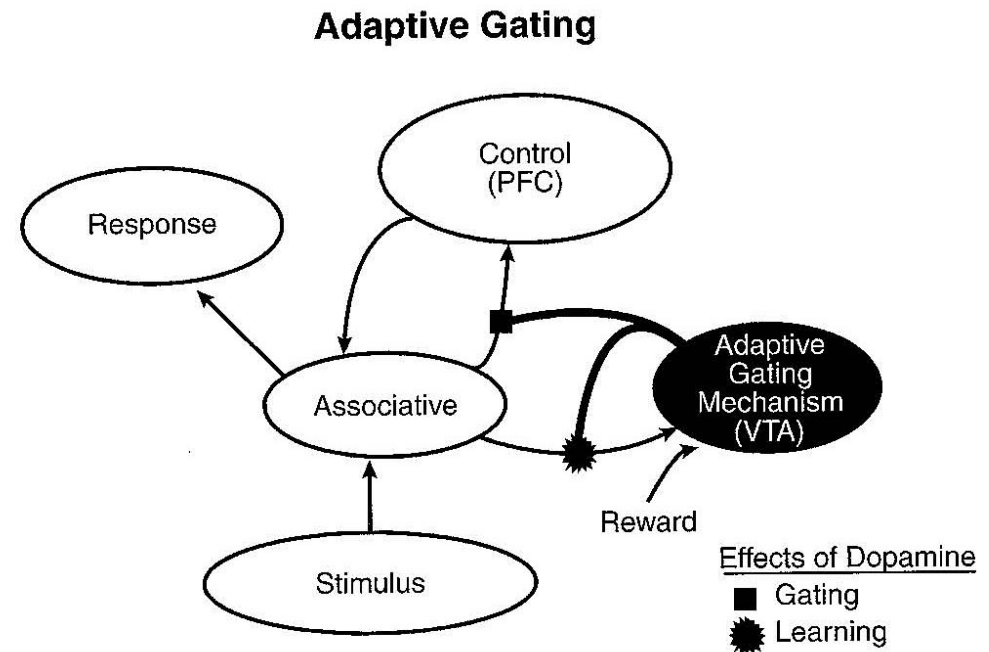
B. Recruitment of Control



Cognitive control & the VTA

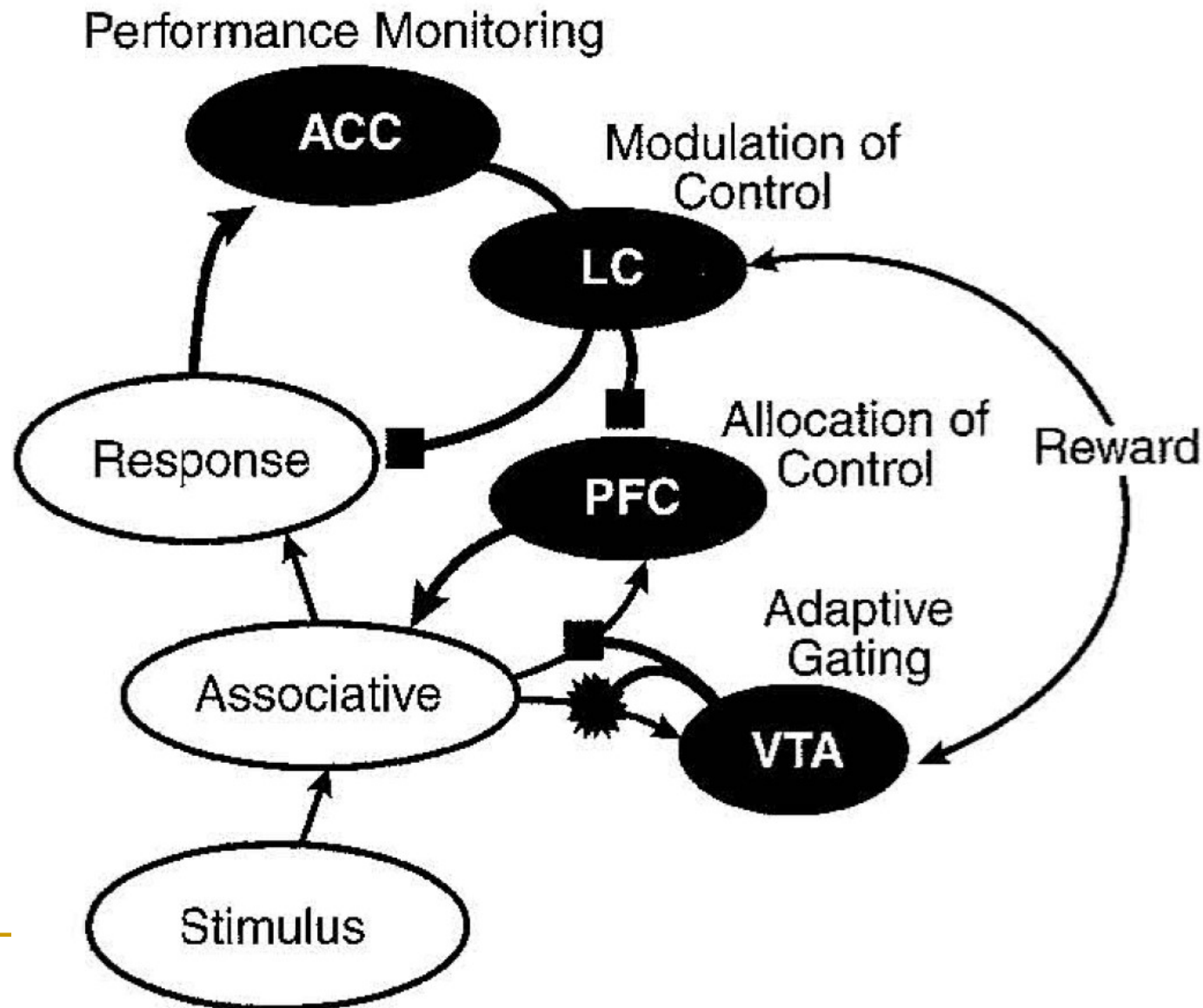
(Cohen et al., 2004)

- How is a task representation selected from many possible representations?
 - Maybe via temporal difference learning
 - **Ventral Tegmental Area (VTA)** responds to errors in predicted reward (Schultz et al., 1997) and communicates with PFC
 - If a response is associated with reward, ensure that relevant external cues signal a task change to the PFC in the future



Cognitive control: Summary

(Cohen et al., 2004)



Cognitive control & expertise

- Strong cognitive control (e.g. color naming in the Stroop task) is effortful and errorful
 - We can do it, but it's not easy
- How can we reduce the cognitive demands of a difficult task?
 - Novice chess players must study the board at length before selecting a move, but experts “see” the move immediately
- Learn to place more of the burden on the “recognition” side of things
 - Humans and networks are inherently good at pattern recognition

Cognitive control & expertise

- Experts encode perceptual input differently than novices
 - ❑ Chase & Simon (1975): participants viewed a chessboard with pieces on it for 5 seconds
 - ❑ Later, they were asked to recall the positions of the pieces
 - ❑ Experts were better at recall when the pieces were in legal configurations
 - ❑ No difference between experts and novices with the pieces were placed randomly on the board



Cognitive control & expertise

- The experts had become better at recognizing the relevant aspects of the input
 - They could attend to the important details rather than all information available
- Another example: face processing
- Experience guides attention, reducing the required degree of top-down cognitive control
 - e.g. word reading in the Stroop task required less activation from the task units

Summary

- “Control processes” need not be different than any other kinds of processing and representation
 - Amount of control depends on strength of the relevant task
- Networks (and humans) can be more flexible than simply “input → response”
 - Can learn to produce the appropriate response given a particular task instruction, a context, a reward, etc.
 - Can either maintain that response or switch to produce a new one
 - Can use prediction of reward or outcomes to learn when to use appropriate task representations