Automaticity and Control

- Definition & Background
- Contemporary Theory of Cognitive Control
- Challenges
- Formal / Normative Theories of Control

Attention

Watch the following….


PATISSIER
LA MERE MITRON
BAR
LE BISTROT

← Group A | **Group B →**

Everyone Close Your Eyes

Oliva & Alvarez

Buildings

People

Oliva & Alvarez

Oliva & Alvarez


PATISSIER
LA MERE MITRON
BAR

Oliva & Alvarez

Oliva & Alvarez

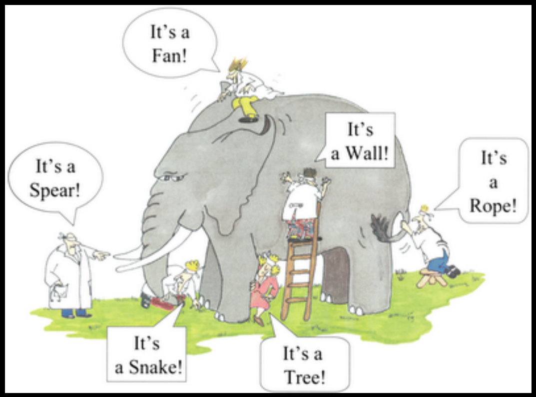
Traditional Theories of Attention

Traditional Theories of Attention

- **Filter theories**
  - **Attention selects information early** *(Broadbent)*
  - **Attention selects information partially** *(Treisman)*
  - **Attention selects information late** *(Johnston)*
- **Integration theory**
  - **Attention serves to integrate information into meaningful representations** *(Treisman)*
- **Capacity/Resource theories**
  - **Attention reflects a single, limited capacity resource** *(Kahneman)*
  - **Attention reflects constraints on local resources** *(Allport; Navon & Gopher)*

Traditional Theories of Attention

- **Filter theories**
  - **Attention selects information early** *(Broadbent)*
  - **Attention selects information partially** *(Treisman)*
  - **Attention selects information late** *(Johnston)*
- **Integration theory**
  - **Attention serves to integrate information into meaningful representations** *(Treisman)*
- **Capacity/Resource theories**
  - **Attention reflects a single, limited capacity resource** *(Kahneman)*
  - **Attention reflects constraints on local resources** *(Allport; Navon & Gopher)*



Control

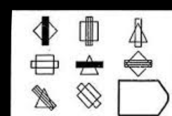
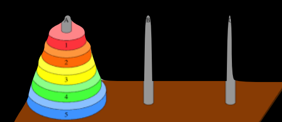
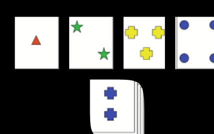
Control ?

Cognitive Control

Cognitive Control

- Uniquely developed in humans:
  - Can be flexibly deployed in nearly arbitrary ways at a moment's notice

Cognitive Control

- **Uniquely developed in humans:**
  - Can be flexibly deployed in nearly arbitrary ways at a moment's notice
  - **Fundamental to most (all?) characteristically human behaviors:**
    (and the tasks near and dear to us that we use to study them)
    - **reasoning** 
    - **problem solving** 
    - **planning** 
    - **symbolic language** "The horse raced past the barn fell"
    - **"executive function"** 

Cognitive Control

Cognitive Control

- Intellectual foundation for understanding human behavior:
  - Distinction between controlled and automatic processing is:
    - a theoretical cornerstone of psychological theory

Cognitive Control

- Intellectual foundation for understanding human behavior:
  - Distinction between controlled and automatic processing is:
    - a theoretical cornerstone of psychological theory
    - the antecedent (and isomorphic) to distinctions in behavioral economics:
      - System 1 vs. System 2 processes
      - “Deliberative” vs. “reflexive” behavior
      - “Thinking fast” vs. “thinking slow”

Cognitive Control

- Intellectual foundation for understanding human behavior:
  - Distinction between controlled and automatic processing is:
    - a theoretical cornerstone of psychological theory
    - the antecedent (and isomorphic) to distinctions in behavioral economics:
      - System 1 vs. System 2 processes
      - "Deliberative" vs. "reflexive" behavior
      - "Thinking fast" vs. "thinking slow"
    - closely related (also isomorphic?) to distinction in computer science:
      - interpreted vs. compiled procedures

Cognitive Control: A Brief History

Cognitive Control: A Brief History

- **Formal heritage**
  - **Control Theory** *(Maxwell, 1868)* **and Cybernetics** *(Weiner, 1948)*

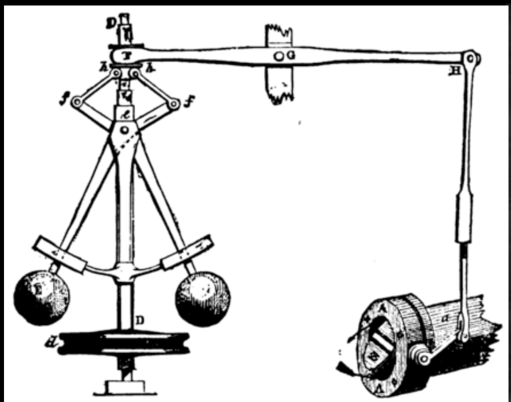
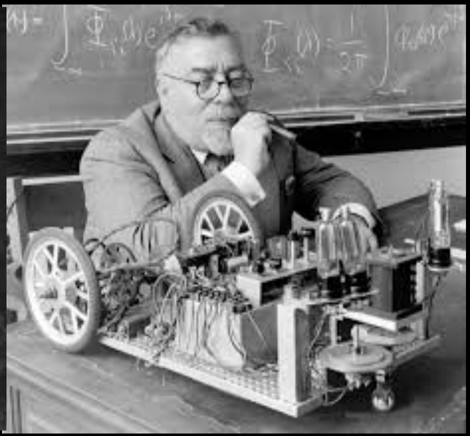
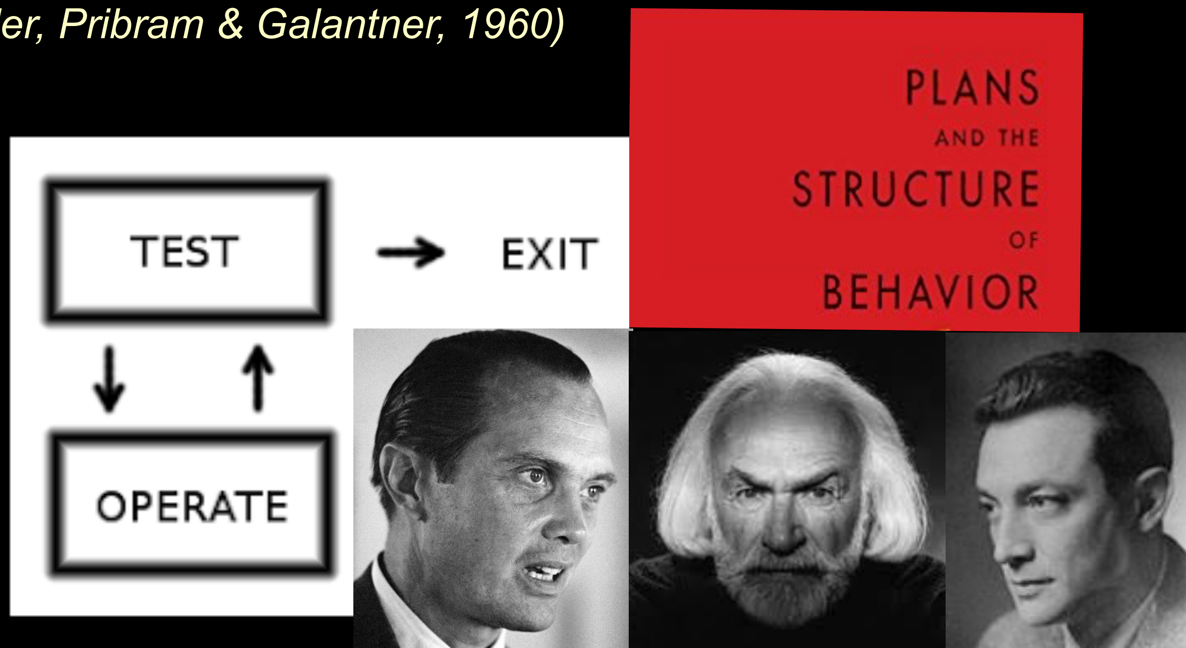


FIG. 4.—*Governor and Throttle-Valve.*



Cognitive Control: A Brief History

- **Formal heritage**
  - **Control Theory** *(Maxwell, 1868)* **and Cybernetics** *(Weiner, 1948)*
  - **TOTE model** *(Miller, Pribram & Galantner, 1960)*



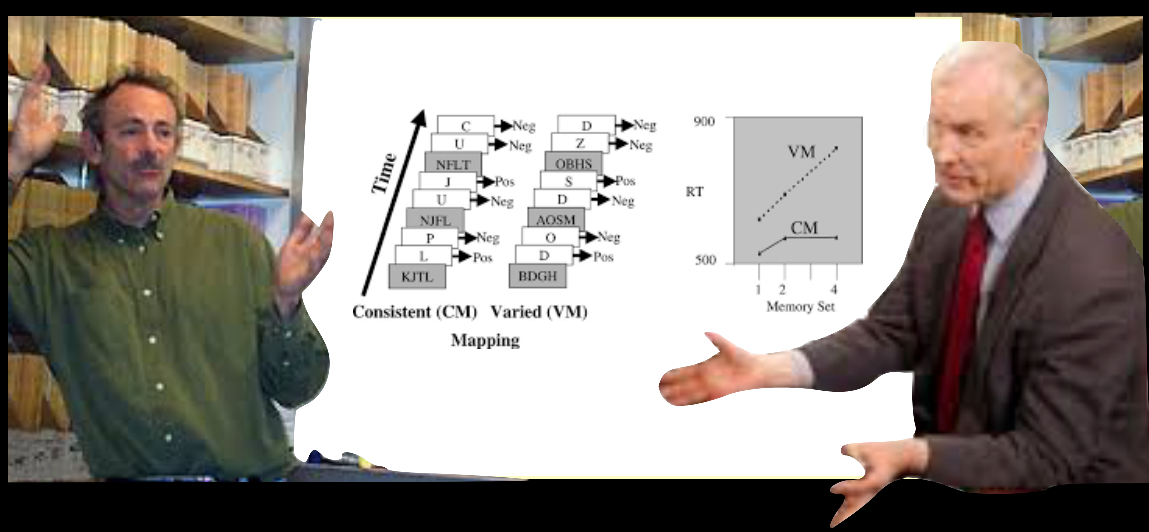
Cognitive Control: A Brief History

- Formal heritage
  - Control Theory *(Maxwell, 1868)* and Cybernetics *(Weiner, 1948)*
  - TOTE model *(Miller, Pribram & Galantner, 1960)*
- Cognitive Psychological Tradition
  - Cognitive Control
    - qualitative definition *(Posner & Snyder, 1975)*

GREEN

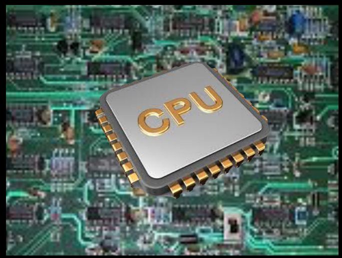
Cognitive Control: A Brief History

- **Formal heritage**
  - **Control Theory** *(Maxwell, 1868)* **and Cybernetics** *(Weiner, 1948)*
  - **TOTE model** *(Miller, Pribram & Galantner, 1960)*
- **Cognitive Psychological Tradition**
  - **Cognitive Control**
    - **qualitative definition** *(Posner & Snyder, 1975)*
    - **rigorous empirical characterization:** *(Shiffrin & Schneider, 1977)*



Cognitive Control: A Brief History

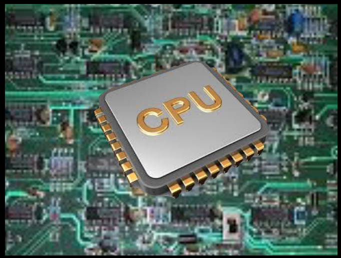
- **Formal heritage**
  - **Control Theory** *(Maxwell, 1868)* **and Cybernetics** *(Weiner, 1948)*
  - **TOTE model** *(Miller, Pribram & Galantner, 1960)*
- **Cognitive Psychological Tradition**
  - **Cognitive Control**
    - **qualitative definition** *(Posner & Snyder, 1975)*
    - **rigorous empirical characterization:** *(Shiffrin & Schneider, 1977)*
  - **Central assumption: central limited capacity processor (~CPU)**



Cognitive Control: A Brief History

- Formal heritage
  - Control Theory *(Maxwell, 1868)* and Cybernetics *(Weiner, 1948)*
  - TOTE model *(Miller, Pribram & Galantner, 1960)*

- Cognitive Psychological Tradition
  - Cognitive Control
    - qualitative definition *(Posner & Snyder, 1975)*
    - rigorous empirical characterization: *(Shiffrin & Schneider, 1977)*
  - Central assumption: central limited capacity processor (~CPU)
    - paradigmatic operationalization — dual task design



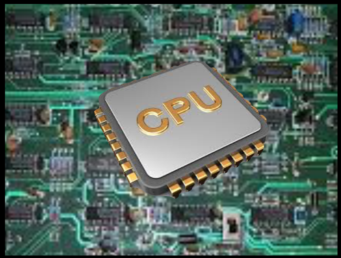
Cognitive Control: A Brief History

- Formal heritage
  - Control Theory *(Maxwell, 1868)* and Cybernetics *(Weiner, 1948)*
  - TOTE model *(Miller, Pribram & Galantner, 1960)*
- Cognitive Psychological Tradition
  - Cognitive Control
    - qualitative definition *(Posner & Snyder, 1975)*
    - rigorous empirical characterization: *(Shiffrin & Schneider, 1977)*
  - Central assumption: central limited capacity processor (~CPU)
    - paradigmatic operationalization — dual task design
    - mechanistic realization — ACT-R *(Anderson, 1983)*

Cognitive Control: A Brief History

- **Formal heritage**
  - **Control Theory** *(Maxwell, 1868)* **and Cybernetics** *(Weiner, 1948)*
  - **TOTE model** *(Miller, Pribram & Galantner, 1960)*

- **Cognitive Psychological Tradition**
  - **Cognitive Control**
    - ♦ **qualitative definition** *(Posner & Snyder, 1975)*
    - ♦ **rigorous empirical characterization:** *(Shiffrin & Schneider, 1977)*
  - **Central assumption: central limited capacity processor (~CPU)**
    - ♦ **paradigmatic operationalization — dual task design**
    - ♦ **mechanistic realization — ACT-R** *(Anderson, 1983)*
    - ♦ **empirical validation — PRP** *(Welford, 1952; Pashler, 1994)*



Automatic vs. Controlled Processing

Automatic vs. Controlled Processing

- **Some processes don't seem to require attention:**
  - scratching an itch
    perceiving one's own name *(Cocktail party effect, Moray, 1959);*
    processing some meaning *(Lewis, 1970; MacKay, 1973);*
    perceiving simple features *(Pop-out effect; Treisman & Gelade, 1980);*

Automatic vs. Controlled Processing

- **Some processes don't seem to require attention:**
  - scratching an itch
    perceiving one's own name *(Cocktail party effect, Moray, 1959);*
    processing some meaning *(Lewis, 1970; MacKay, 1973);*
    perceiving simple features *(Pop-out effect; Treisman & Gelade, 1980);*

- **Others do:**
  - *not* scratching an itch
    retrieving information from visual memory
    noticing someone else's name
    searching for a conjunction of features *(Treisman & Gelade, 1980);*

Automatic vs. Controlled Processing

- **Some processes don't seem to require attention:**
  - scratching an itch
    perceiving one's own name *(Cocktail party effect, Moray, 1959);*
    processing some meaning *(Lewis, 1970; MacKay, 1973);*
    perceiving simple features *(Pop-out effect; Treisman & Gelade, 1980);*
  - **these are *automatic:***
- **Others do:**
  - *not* scratching an itch
    retrieving information from visual memory
    noticing someone else's name
    searching for a conjunction of features *(Treisman & Gelade, 1980);*

Automatic vs. Controlled Processing

- **Some processes don't seem to require attention:**
  - scratching an itch
    perceiving one's own name *(Cocktail party effect, Moray, 1959);*
    processing some meaning *(Lewis, 1970; MacKay, 1973);*
    perceiving simple features *(Pop-out effect; Treisman & Gelade, 1980);*
  - **these are *automatic:***
    - fast
    - involuntary
    - do ***not*** require "*capacity*"
- **Others do:**
  - *not* scratching an itch
    retrieving information from visual memory
    noticing someone else's name
    searching for a conjunction of features *(Treisman & Gelade, 1980);*

Automatic vs. Controlled Processing

- **Some processes don't seem to require attention:**
  - scratching an itch
    perceiving one's own name *(Cocktail party effect, Moray, 1959);*
    processing some meaning *(Lewis, 1970; MacKay, 1973);*
    perceiving simple features *(Pop-out effect; Treisman & Gelade, 1980);*

  - **these are *automatic:***
    - fast
    - involuntary
    - do ***not*** require "*capacity*"

- **Others do:**
  - *not* scratching an itch
    retrieving information from visual memory
    noticing someone else's name
    searching for a conjunction of features *(Treisman & Gelade, 1980);*

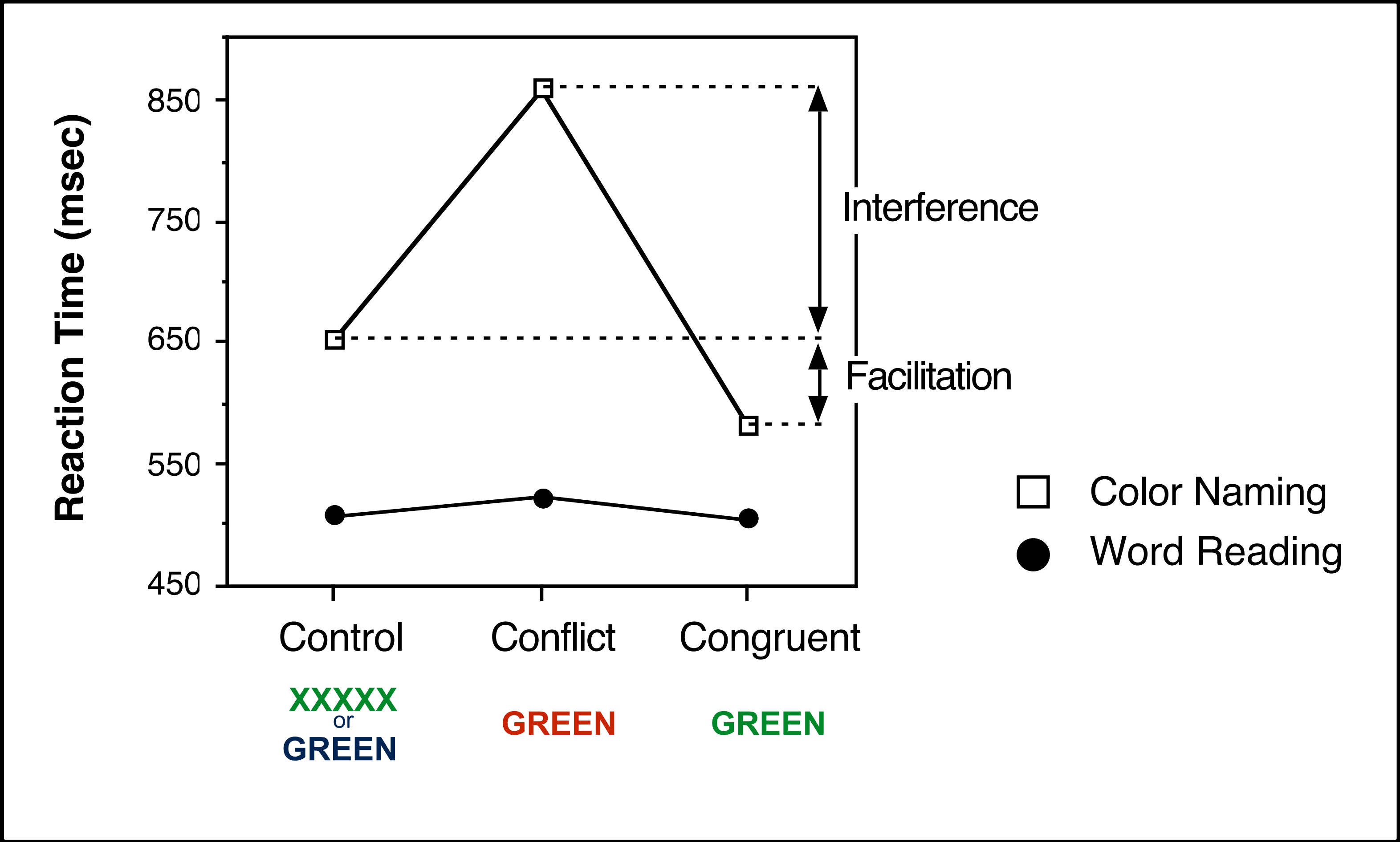
  - **these are *controlled***

Automatic vs. Controlled Processing

- **Some processes don't seem to require attention:**
  - scratching an itch
    perceiving one's own name *(Cocktail party effect, Moray, 1959);*
    processing some meaning *(Lewis, 1970; MacKay, 1973);*
    perceiving simple features *(Pop-out effect; Treisman & Gelade, 1980);*
  - **these are *automatic:***
    - fast
    - involuntary
    - do ***not*** require "*capacity*"
- **Others do:**
  - *not* scratching an itch
    retrieving information from visual memory
    noticing someone else's name
    searching for a conjunction of features *(Treisman & Gelade, 1980);*
  - **these are *controlled***
    - slower
    - require effort
    - ***do*** require "*capacity*"

GREEN

Stroop Effects

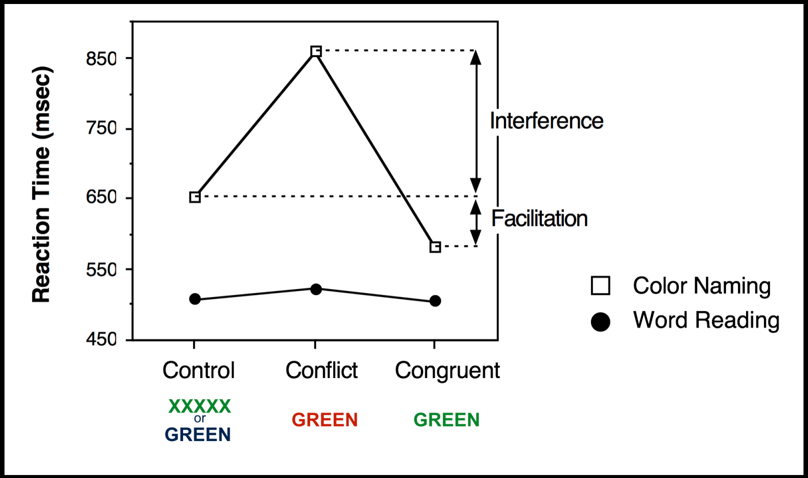


Underlying Mechanisms?

- **Stroop Task:**
  brings the questions of attention and control together
  canonical example of controlled vs. automatic processing
  (Posner & Snyder, 1975)

  – ***Word reading* is automatic:**
    - fast
    - involuntary (can produce interference)
    - does not require capacity

  – ***Color naming* is controlled:**
    - slower
    - requires effort (subject to interference)
    - requires capacity



Problems with Automaticity

- "Fast"
- "Involuntary"
- "Does not require capacity"
- Is automaticity a cardinal attribute?

Problems with Automaticity

- **“Fast”**
  - how fast is fast?
  - is it really just speed (Glaser & Glaser, 1982)
- **“Involuntary”**
- **“Does not require capacity”**
- **Is automaticity a cardinal attribute?**

Problems with Automaticity

- **“Fast”**
  - how fast is fast?
  - is it really just speed (Glaser & Glaser, 1982)
- **“Involuntary”**
  - how involuntary is involuntary?
- **“Does not require capacity”**
- **Is automaticity a cardinal attribute?**

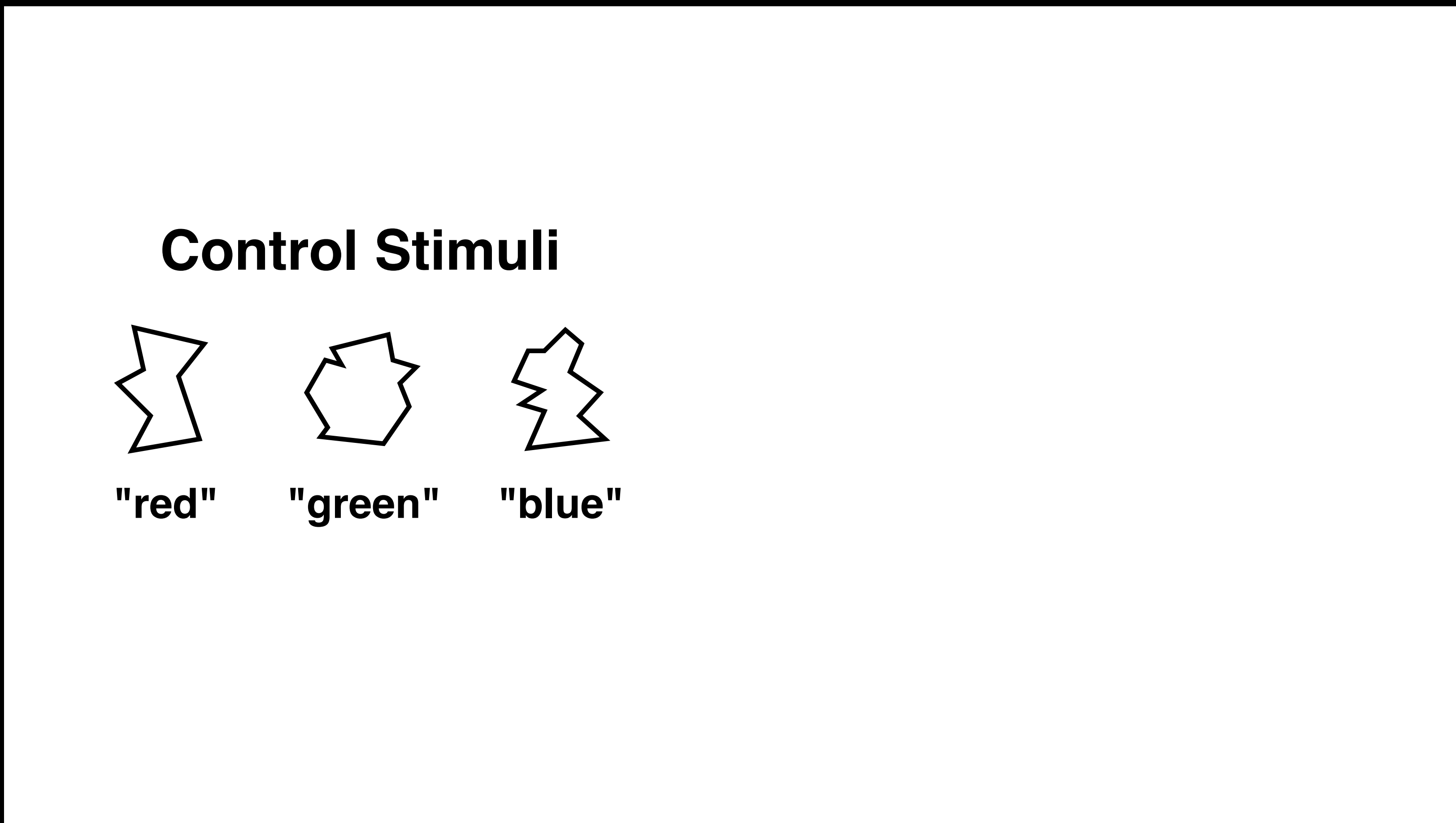
Problems with Automaticity

- **“Fast”**
  - how fast is fast?
  - is it really just speed (Glaser & Glaser, 1982)
- **“Involuntary”**
  - how involuntary is involuntary?
- **“Does not require capacity”**
  - how little is “does not” *(Kahneman & Henik, 1983)*
- **Is automaticity a cardinal attribute?**

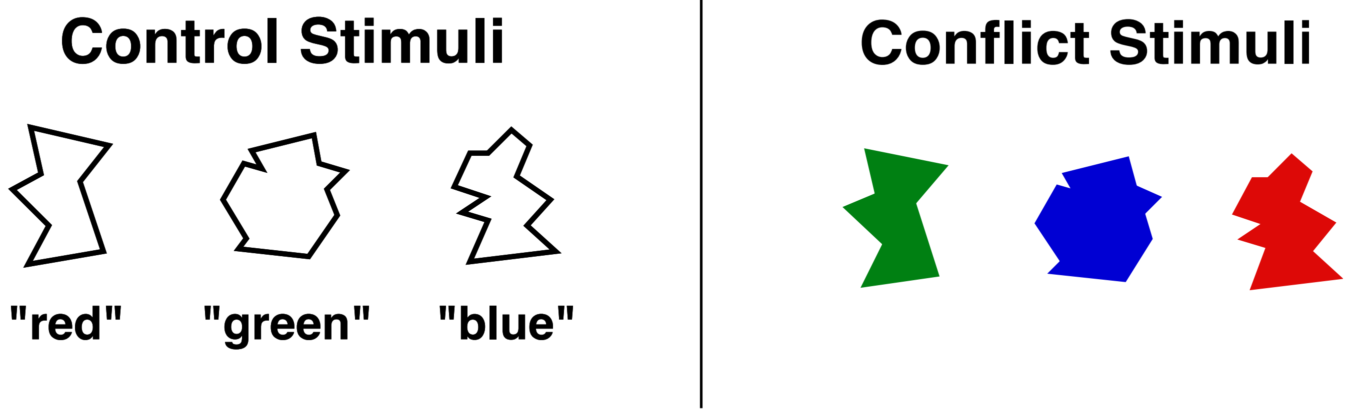
Problems with Automaticity

- **"Fast"**
  - how fast is fast?
  - is it really just speed (Glaser & Glaser, 1982)
- **"Involuntary"**
  - how involuntary is involuntary?
- **"Does not require capacity"**
  - how little is "does not" *(Kahneman & Henik, 1983)*
- **Is automaticity a cardinal attribute?**
  - is it a dichotomous attribute? (MacLeod & Dunbar, 1988…)

MacLeod & Dunbar *(1988)*

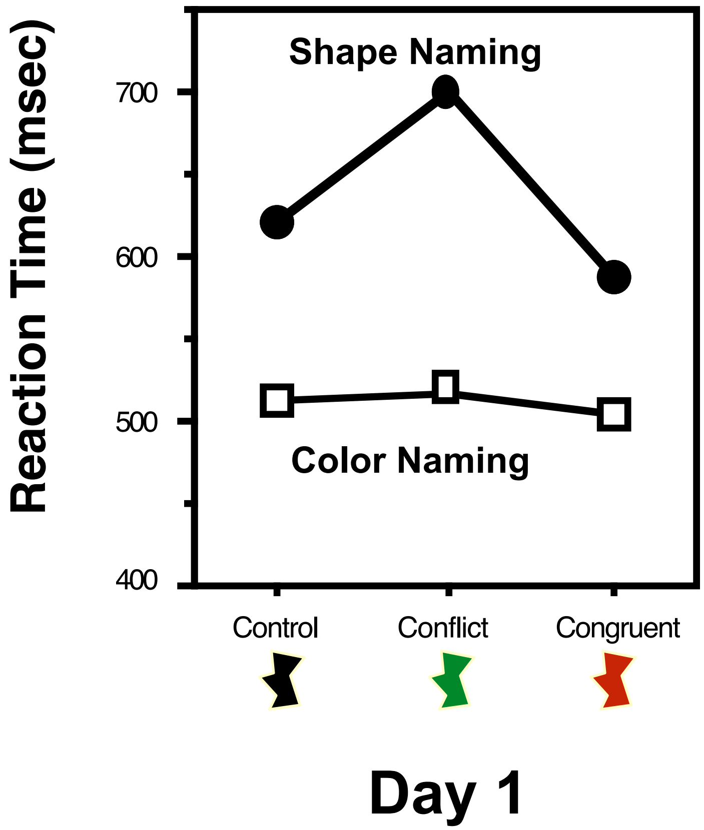


MacLeod & Dunbar *(1988)*



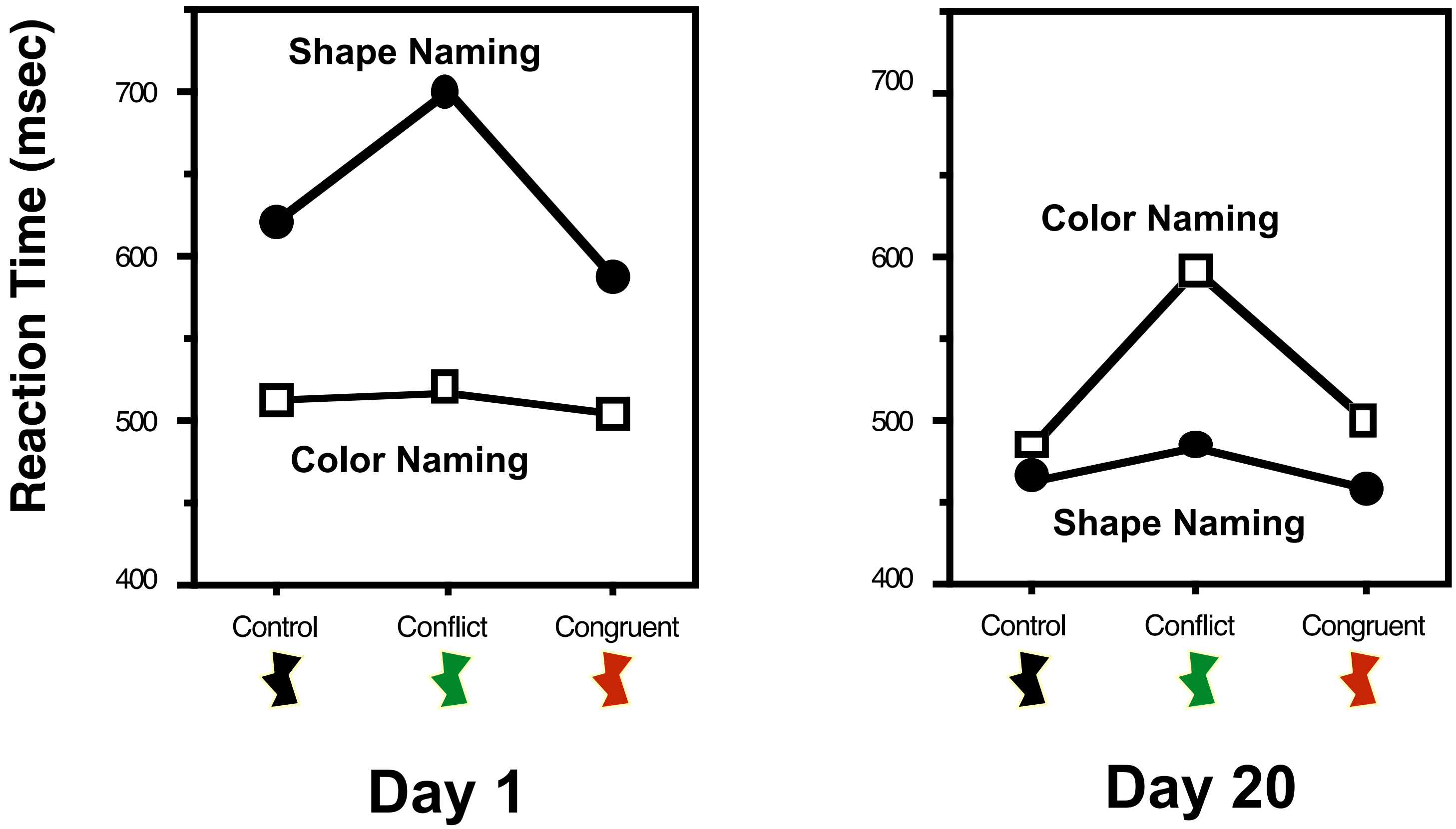
Shape Naming Findings

(MacLeod & Dunbar, 1988)



Shape Naming Findings

(MacLeod & Dunbar, 1988)



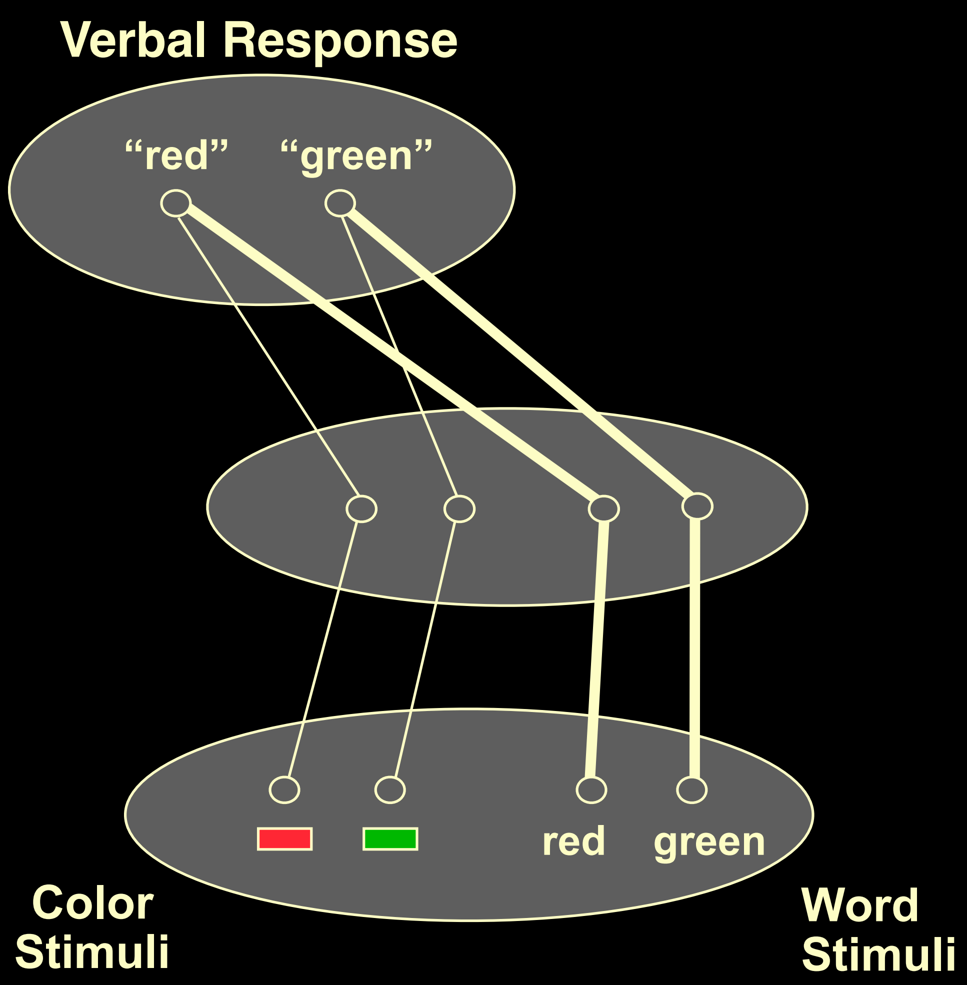
Elementary Mechanism of Control

Representation of context information

(goal / intention / task set / instructions)

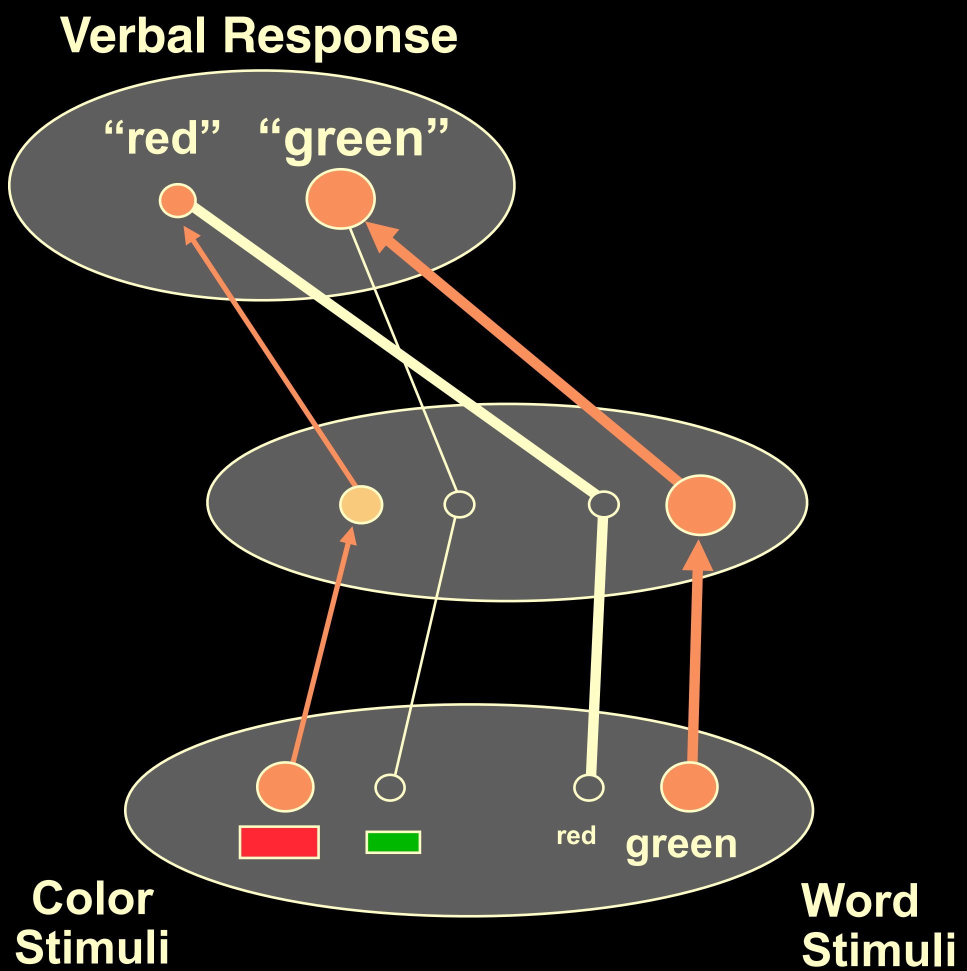
Model of the Stroop Task

Cohen et al. (1990)



Model of the Stroop Task

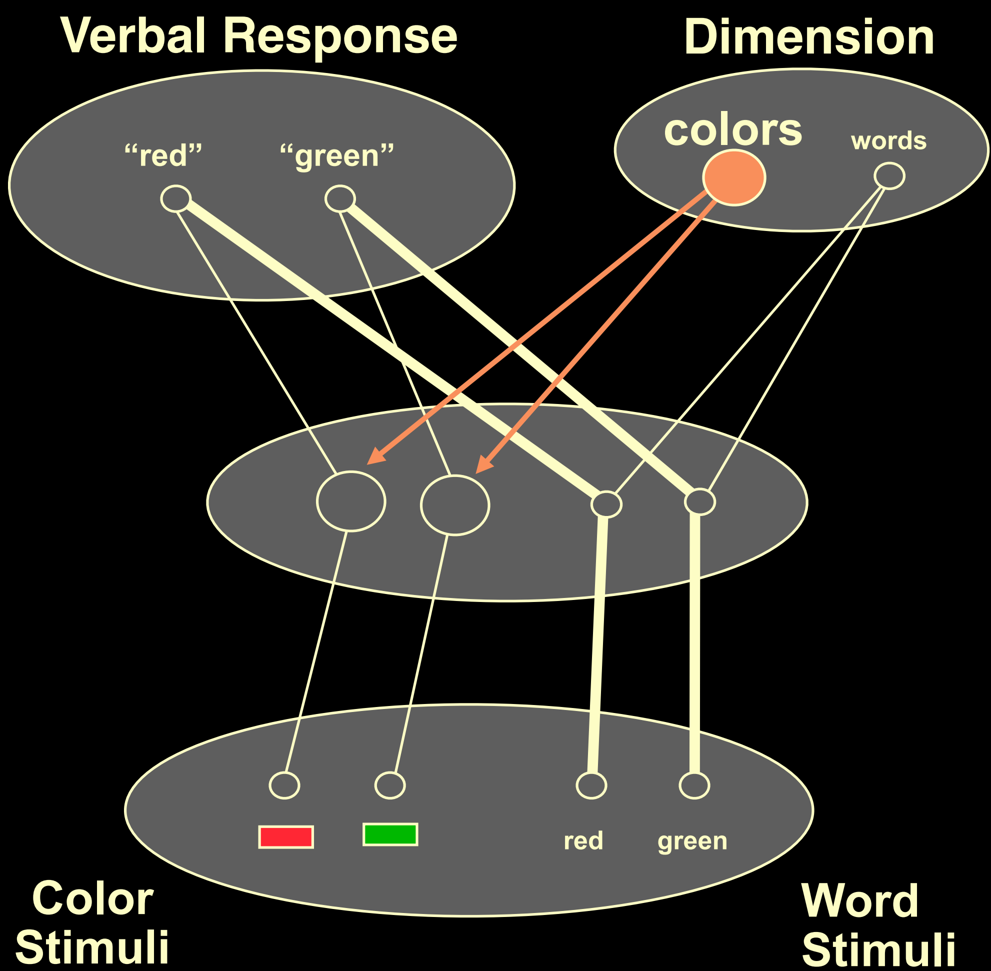
Cohen et al. (1990)



Stimulus: GREEN

Model of the Stroop Task

Cohen et al. (1990)

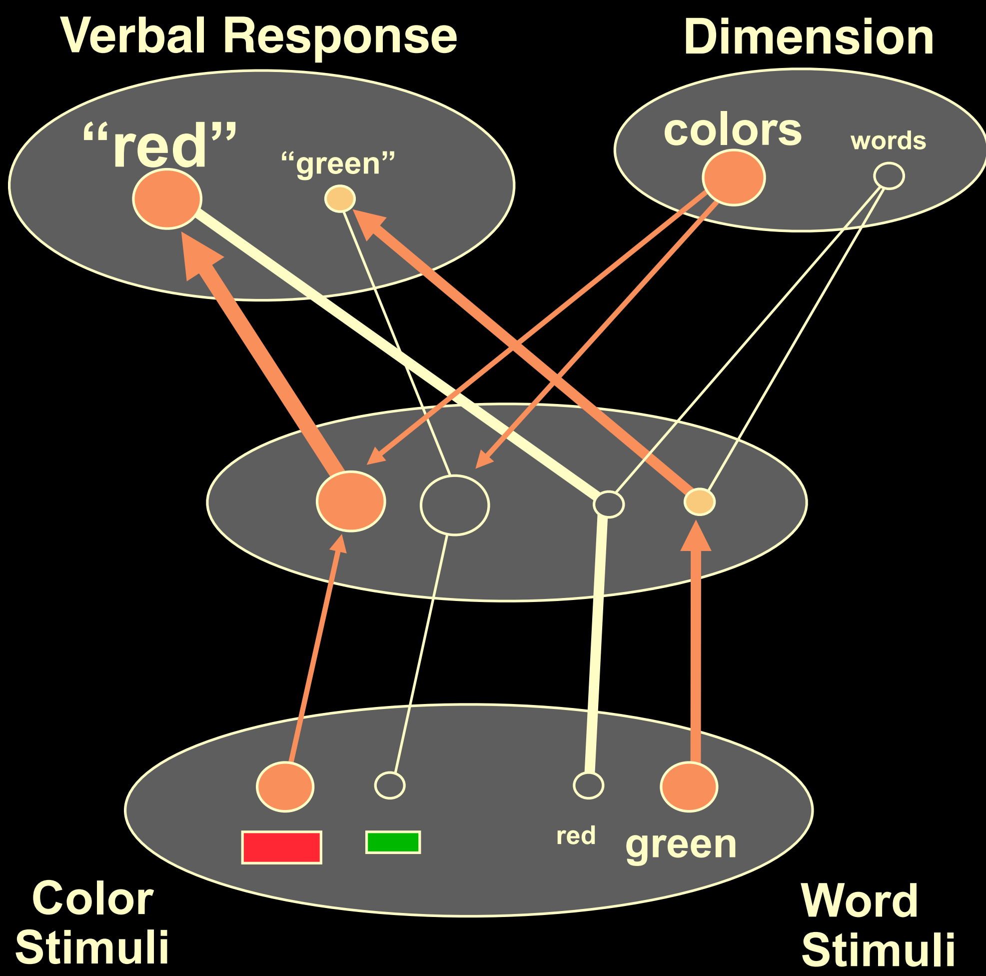


Context:

“Attention”
“Intention”
“Control”
“Instruction”
“Task”

Model of the Stroop Task

Cohen et al. (1990)



Stimulus: GREEN

Processing Functions

Activation Function

net input: $net_j(t) = \Sigma a_i(t) w_{ij} + \sigma$

time-averaged net input: $\overline{net_j}(t) = \tau\, net_j(t) + (1-\tau)\, \overline{net_j}(t-1)$

time-averaged net input: $a_j(t) = \dfrac{1}{1+e^{-\overline{net_j}(t)}}$

Response Function

$r_i(t) = rate \cdot a_i(t) + \sigma + r_i(t-1)$

A *response occurs when the difference between the largest r_i and the next largest r_j exceeds the response threshold*

Processing Functions

Activation Function

net input: $net_j(t) = \Sigma a_i(t) w_{ij} + \sigma$

time-averaged net input: $\overline{net_j}(t) = \tau \, net_j(t) + (1-\tau) \, \overline{net_j}(t-1)$

time-averaged net input: $a_j(t) = \frac{1}{1+e^{-\overline{net_j}(t)}}$

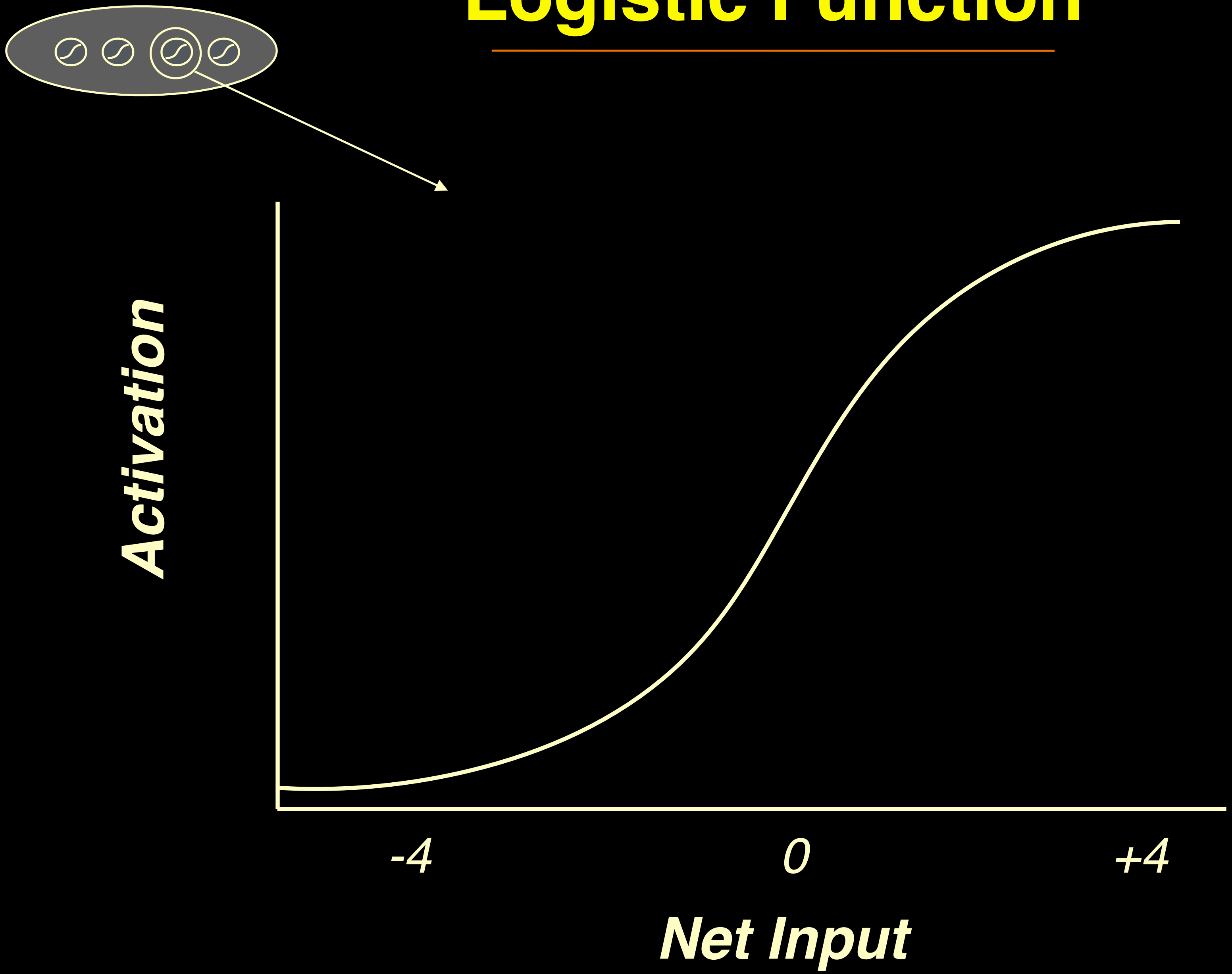
Response Function

$r_i(t) = rate \bullet a_i(t) + \sigma + r_i(t-1)$

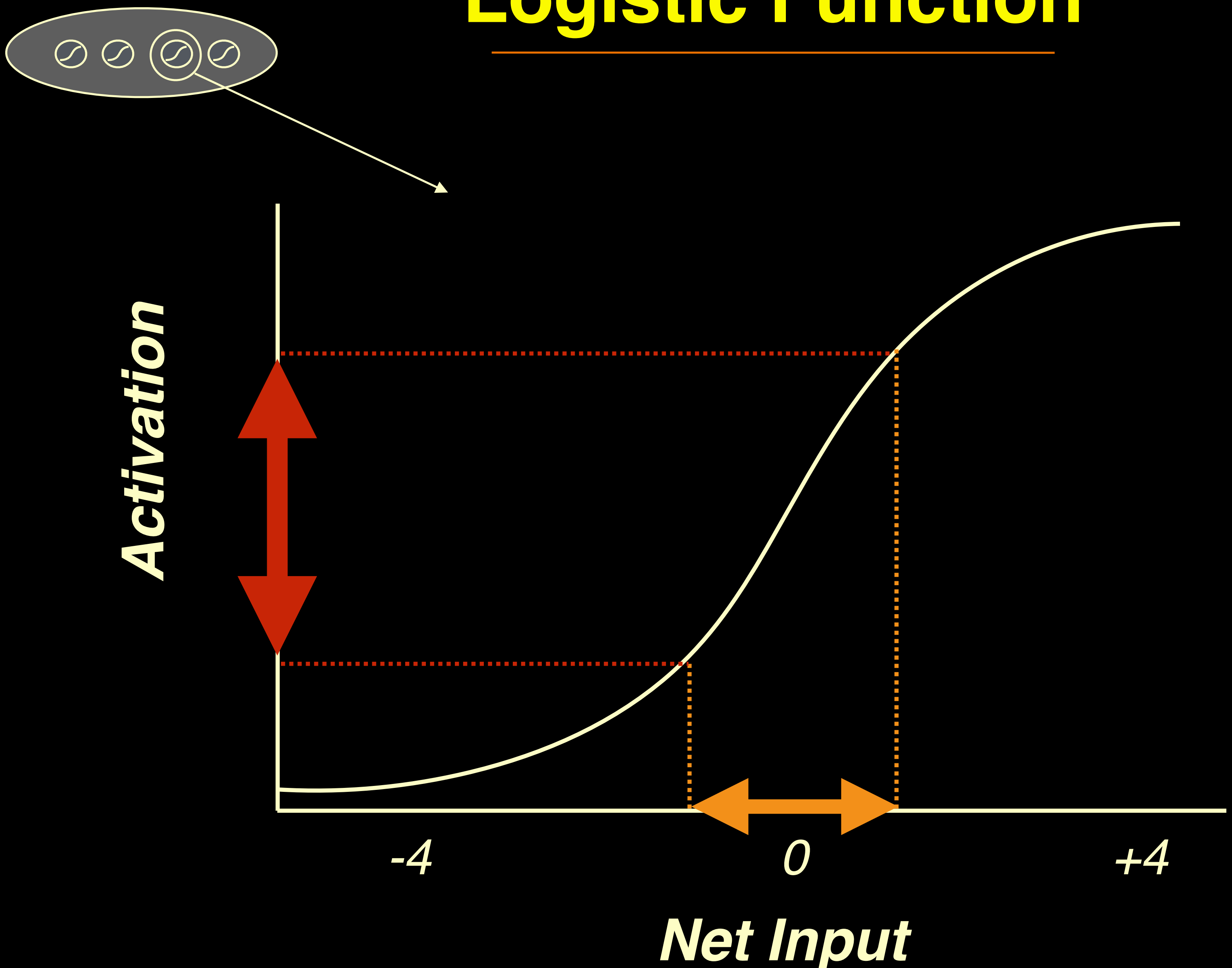
A *response occurs when the difference between the largest* r_i *and the next largest* r_j *exceeds the response threshold*

Logistic Function

$$a_j(t) = \frac{1}{1+e^{-\overline{net}_j(t)}}$$

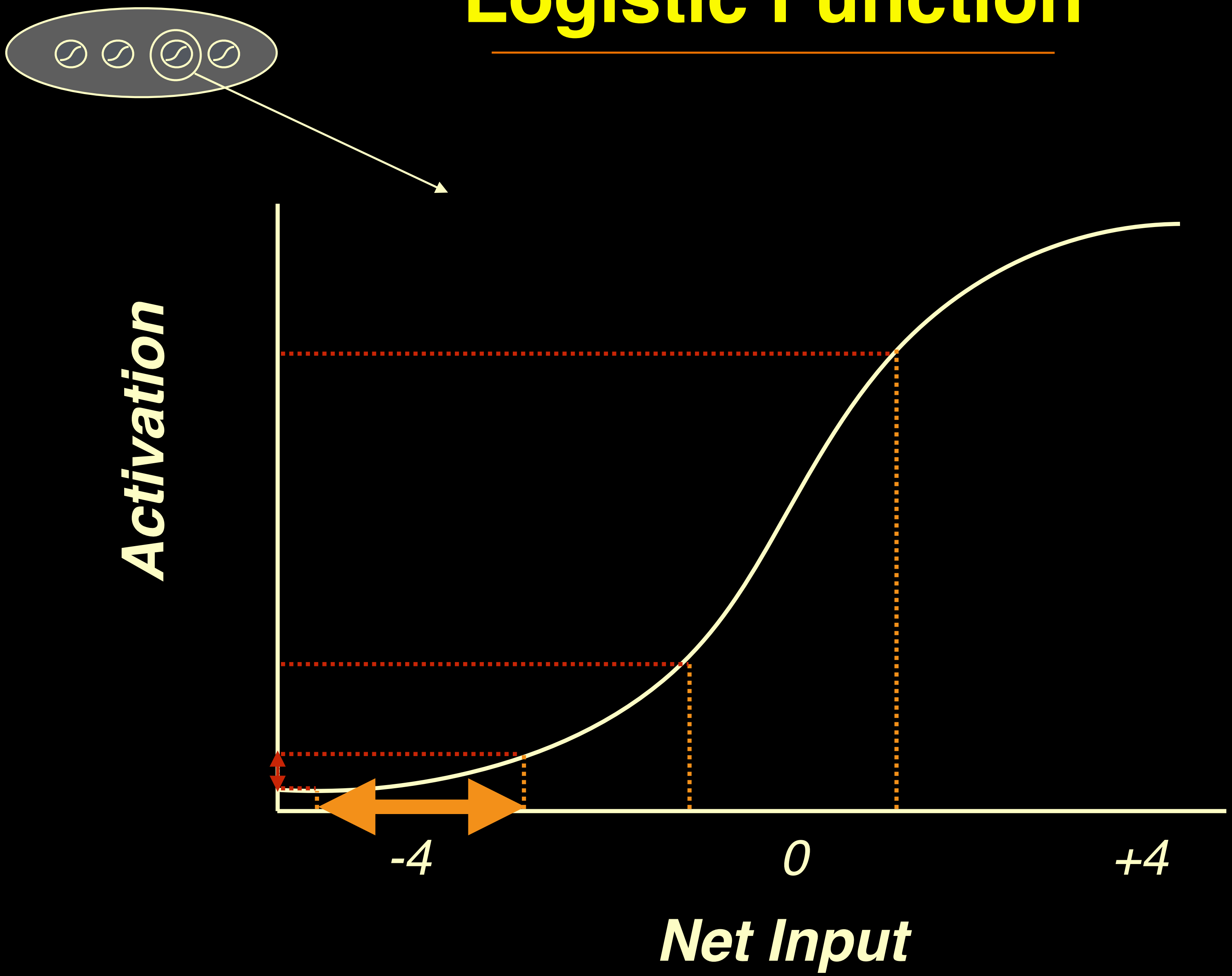


Logistic Function



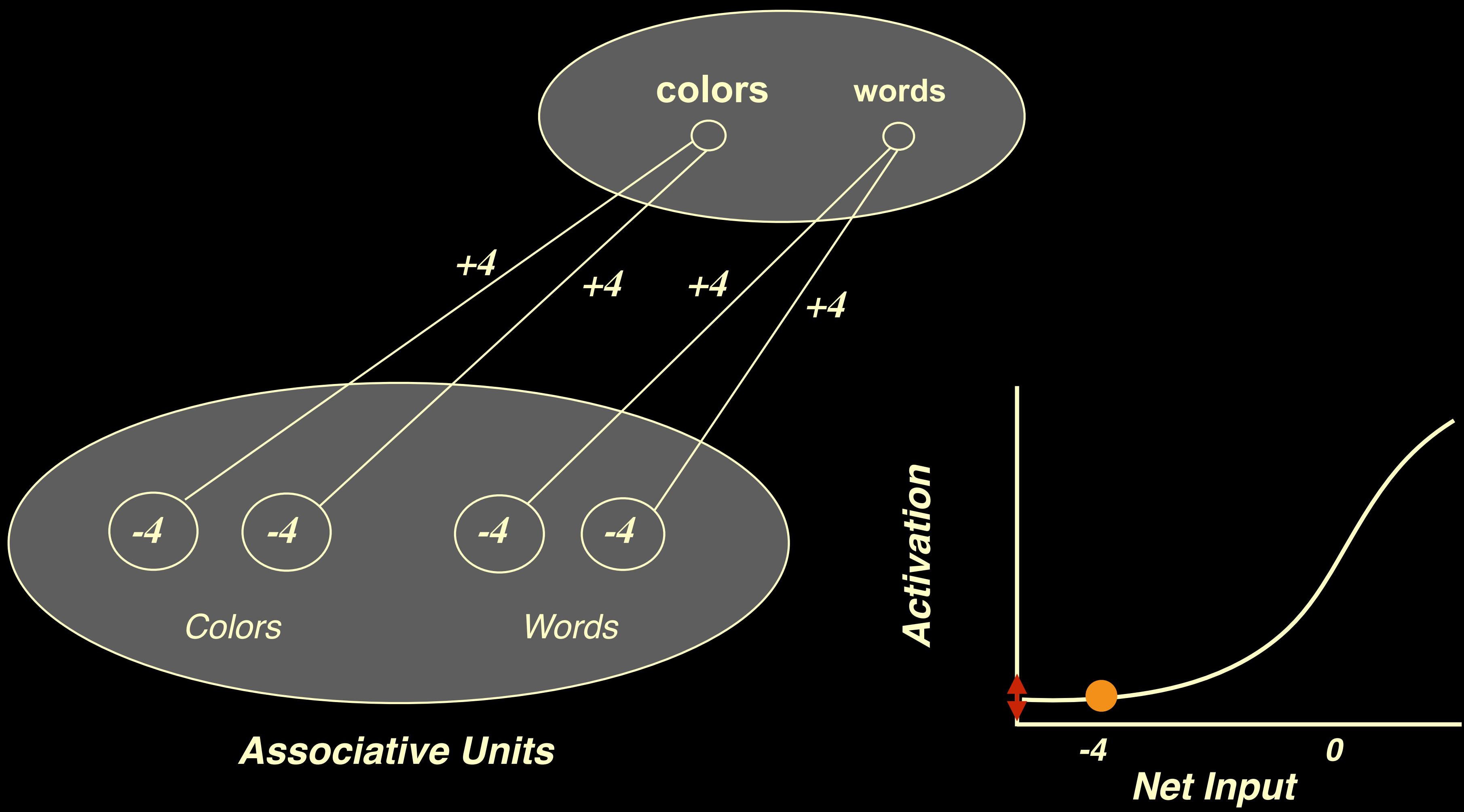
$$a_j(t) = \frac{1}{1+e^{-\overline{net}_j(t)}}$$

Logistic Function

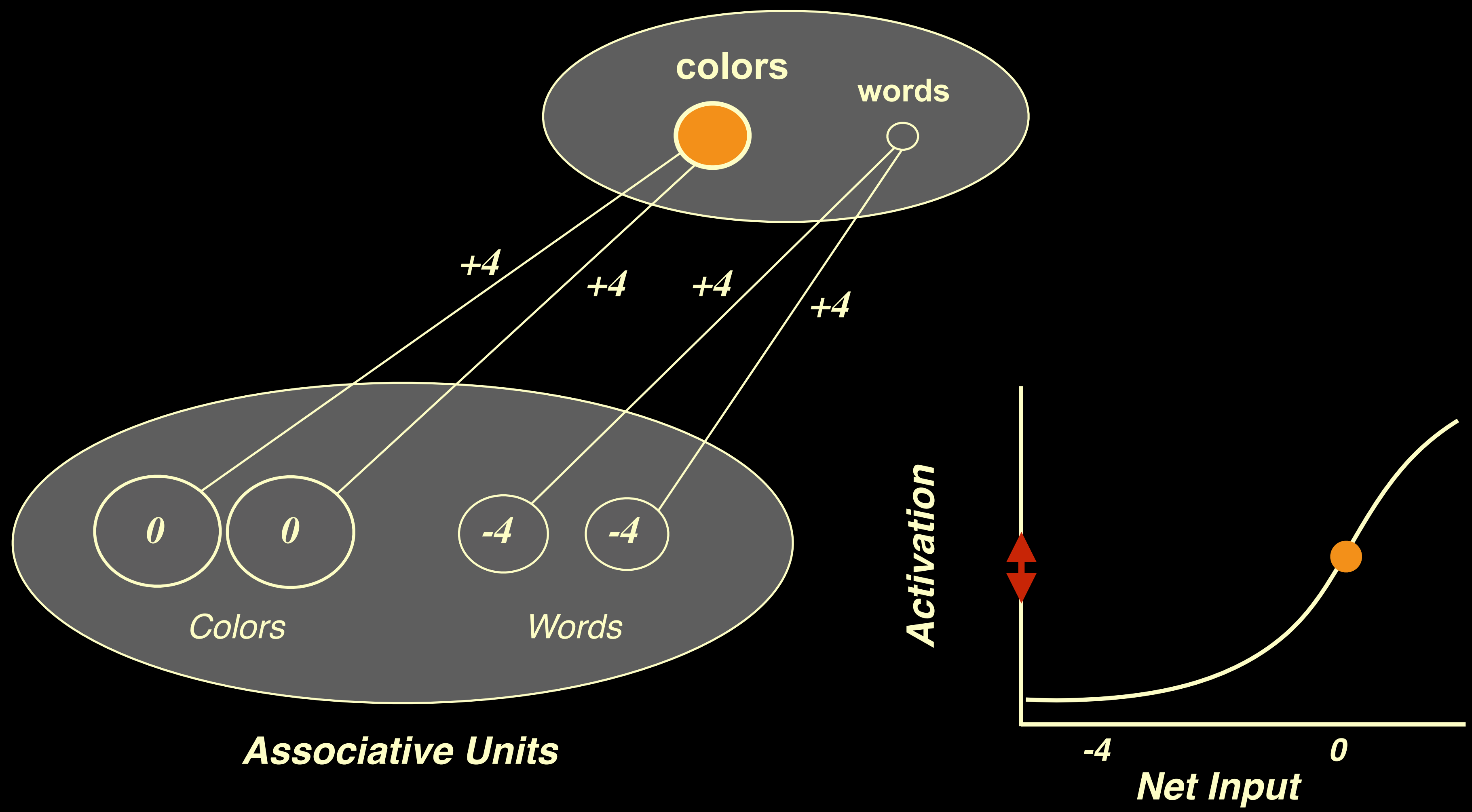


$$a_j(t) = \frac{1}{1+e^{-\overline{net}_j(t)}}$$

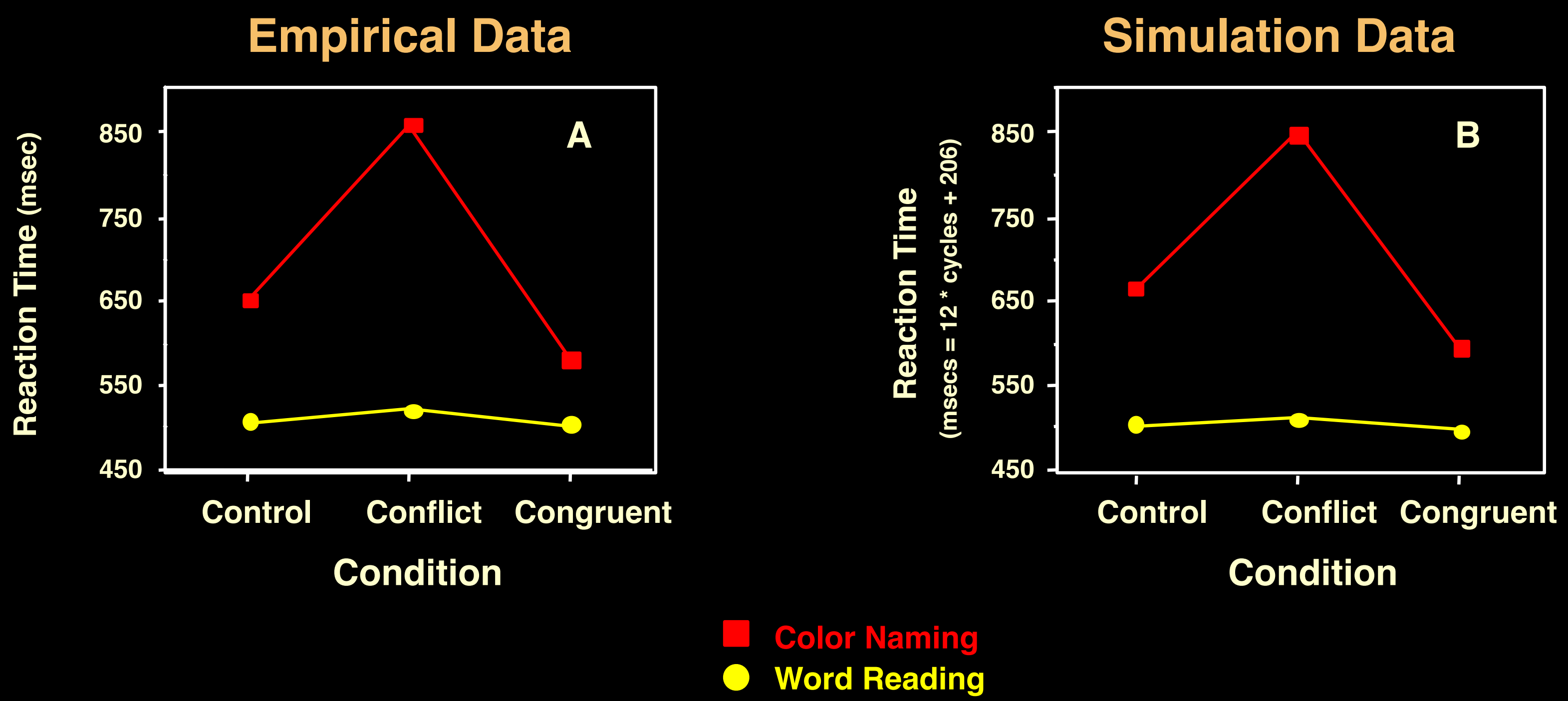
Effect of Attention



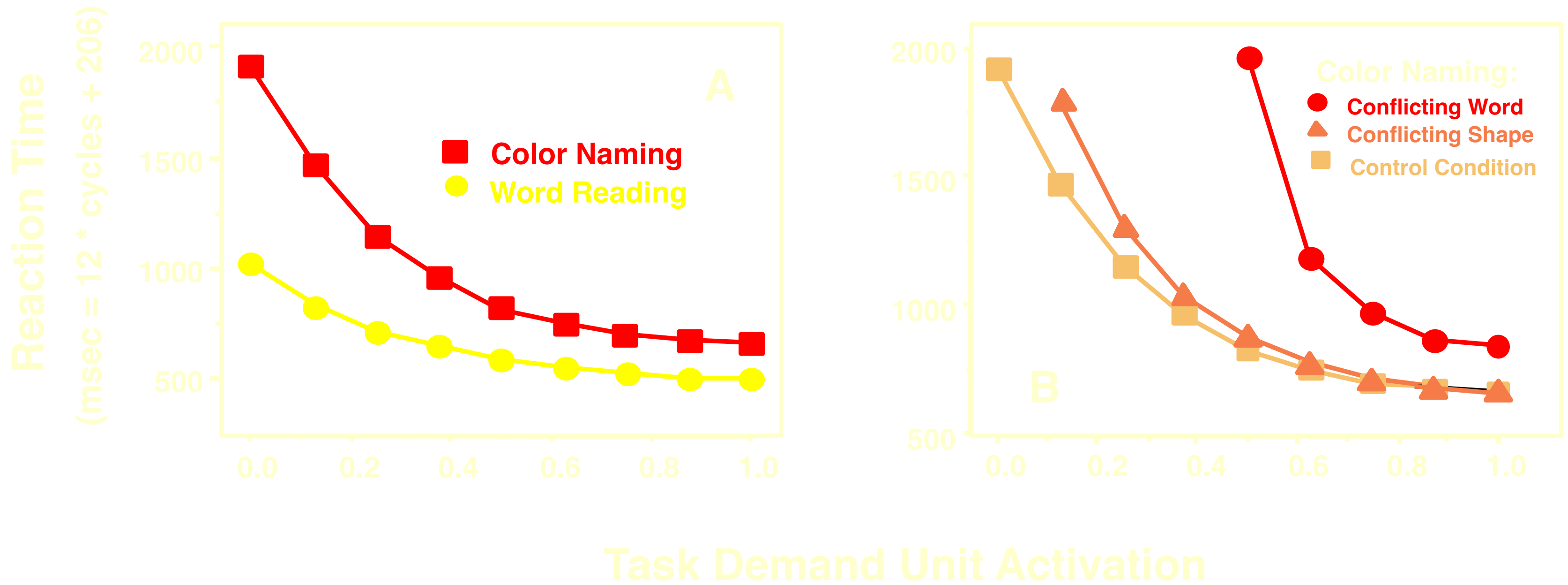
Effect of Attention



Simulation Results

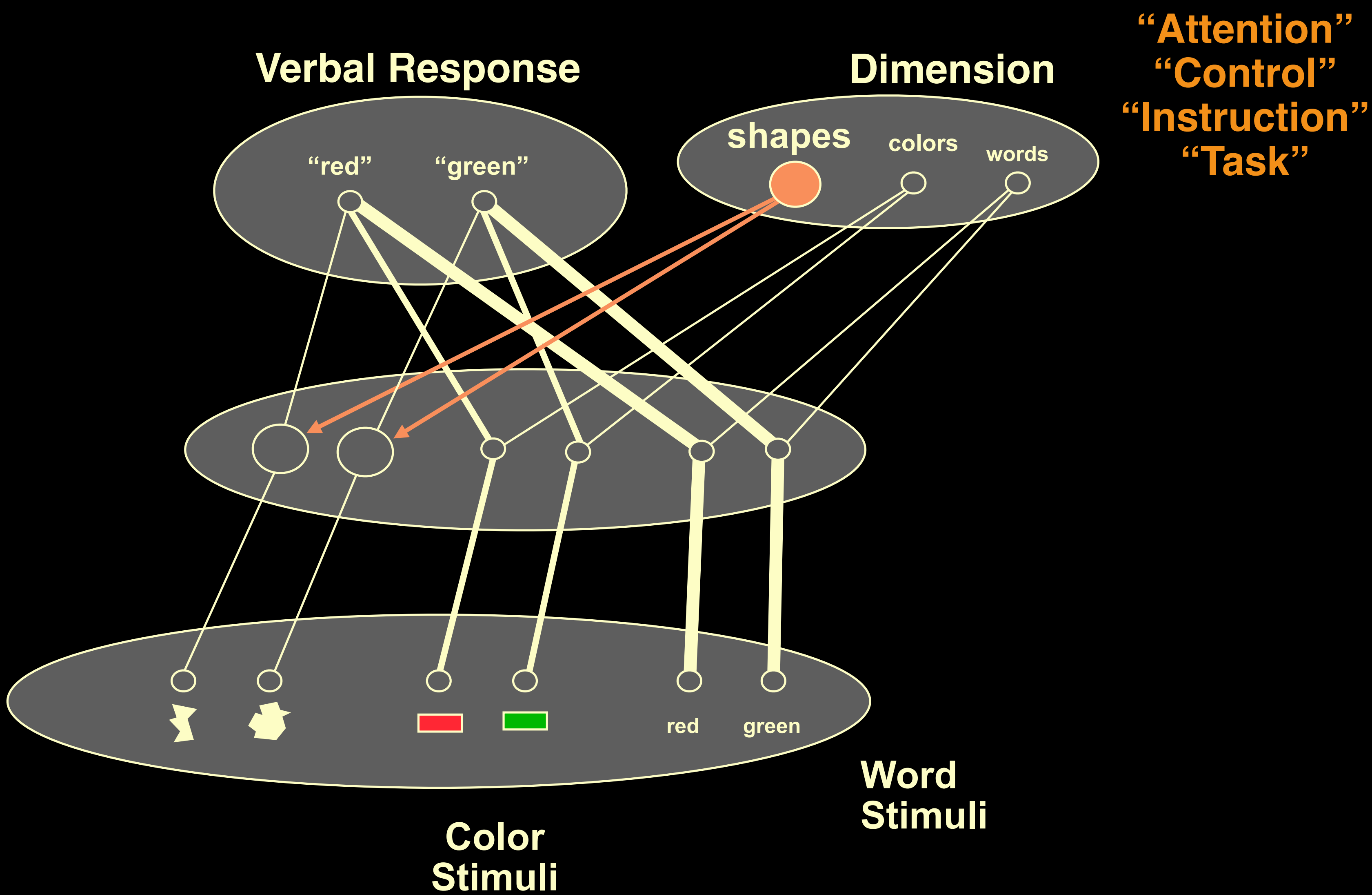


Influence of Attention on Processing

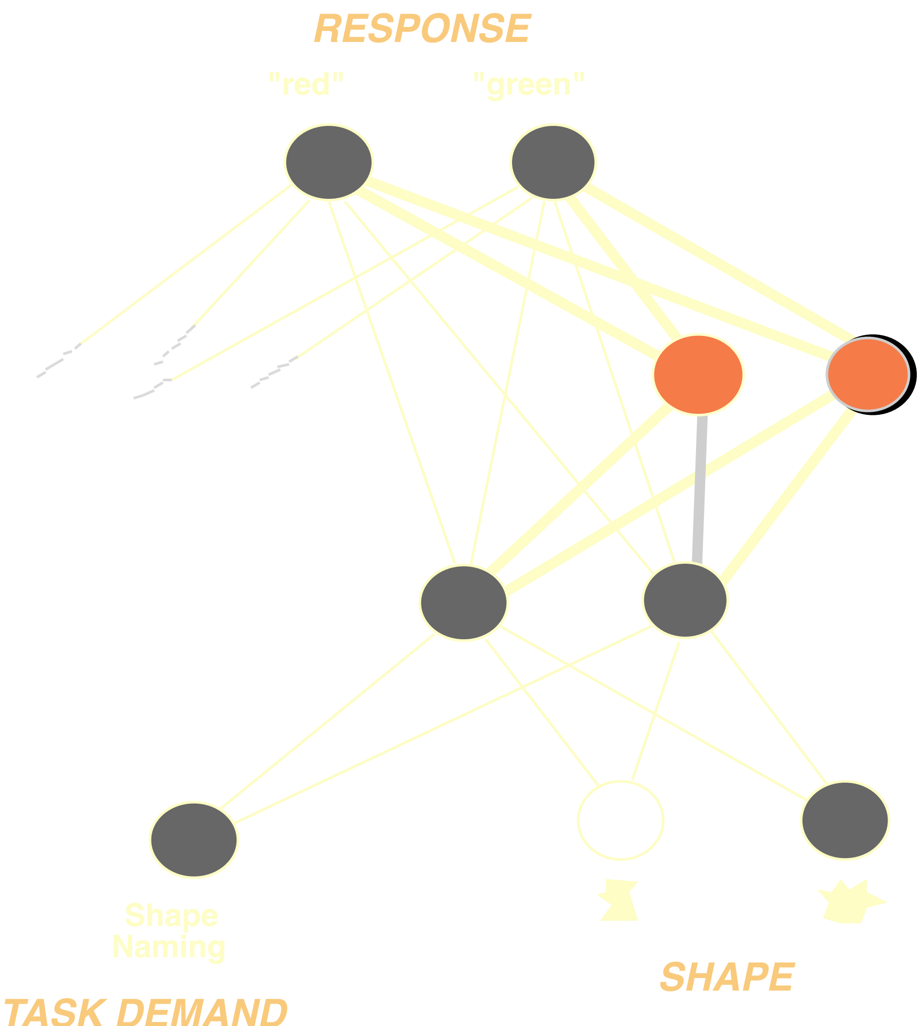


Shape Naming

Cohen et al. (1990)



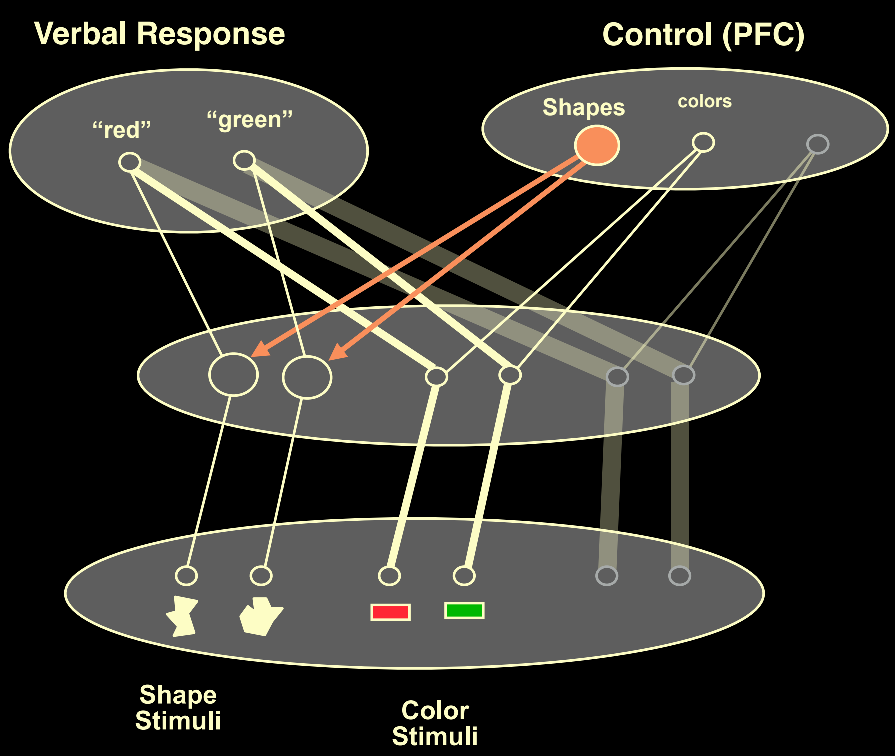
"Indirect" pathway

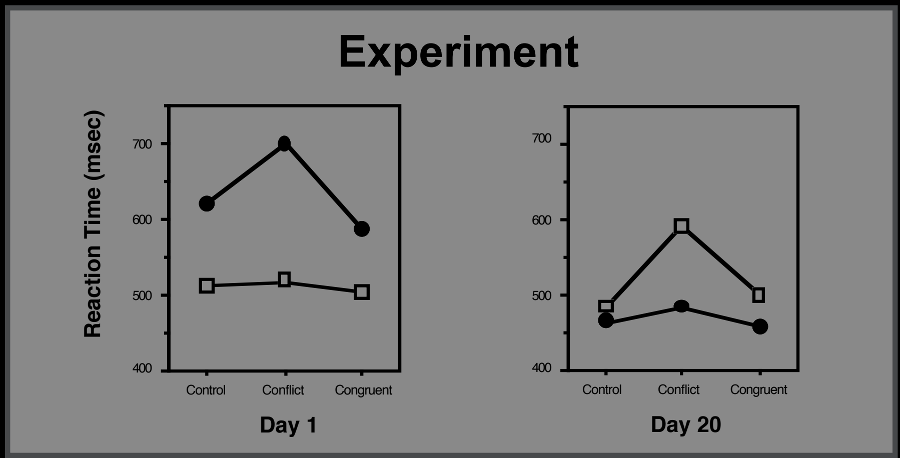


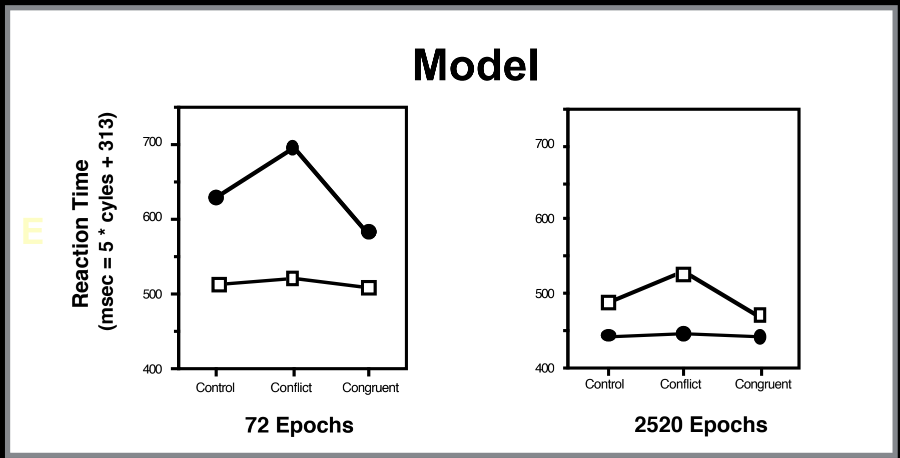
"We will call this new pathway the indirect pathway, to distinguish it from the usual "direct" pathways used by the network. The indirect pathway was meant to represent the involvement of a general purpose module (or even set of modules) that has been committed to the shape naming process for the current task. The connections in the indirect pathway were assigned a set of strengths that allowed it to be used for shape naming, before the effects of training had accrued in the direct pathway. This captured the assumption that such a mechanism can be rapidly programmed to perform a given task. Because the indirect pathway relied on an extra set of units, processing was slower than in the direct pathway. This conforms to the common assumption that processing relying on general purpose mechanisms is slower than automatic processing (e.g., Posner & Snyder, 1975)."

Simulation of Shape Naming Experiment

(MacLeod & Dunbar, 1988)







Interpretation

Interpretation

- **“Fast”**
  - ***Strength*** is what matters
  - That leads to speed

Interpretation

- **“Fast”**
  - ***Strength*** is what matters
  - That leads to speed

- **“Involuntary”**
  - Strong processes can “leak" through and compete with “selected” process(es) without (as much) top-down support

Interpretation

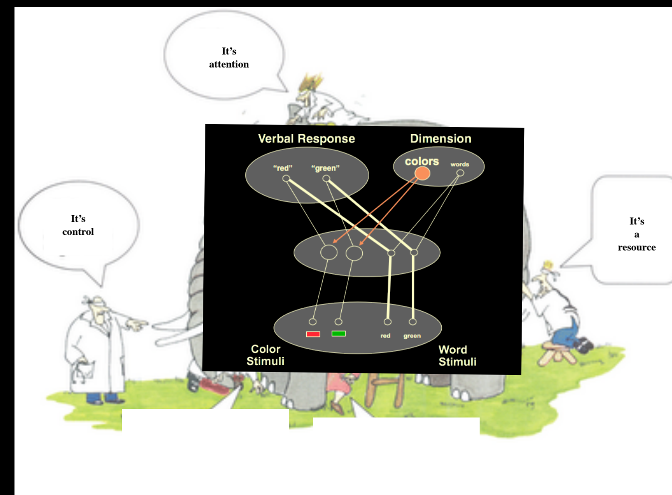
- **“Fast”**
  - ***Strength*** is what matters
  - That leads to speed
- **“Involuntary”**
  - Strong processes can “leak" through and compete with “selected” process(es) without (as much) top-down support
- **“Does not require capacity”**
  - Depends on strength *and* ***circumstances*** *(what competitors are in play)*
  - All tasks demand *some* control

Interpretation

- **“Fast”**
  - ***Strength*** is what matters
  - That leads to speed
- **“Involuntary”**
  - Strong processes can “leak" through and compete with “selected” process(es) without (as much) top-down support
- **“Does not require capacity”**
  - Depends on strength *and* ***circumstances*** *(what competitors are in play)*
  - All tasks demand *some* control
- **Is automaticity a cardinal attribute?**
  - is it a dichotomous attribute? No! It is a ***relative, context-dependent*** attribute

Interpretation

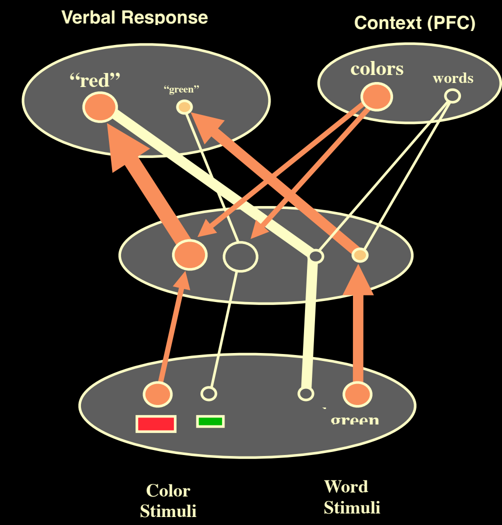
- **"Fast"**
  - *Strength* is what matters
  - That leads to speed



- **"Involuntary"**
  - Strong processes can "leak" through and compete with "selected" process(es) without (as much) top-down support
- **"Does not require capacity"**
  - Depends on strength *and* ***circumstances*** *(what competitors are in play)*
  - All tasks demand *some* control
- **Is automaticity a cardinal attribute?**
  - is it a dichotomous attribute? No! It is a ***relative, context-dependent*** attribute

Guided Activation Theory of PFC and Control

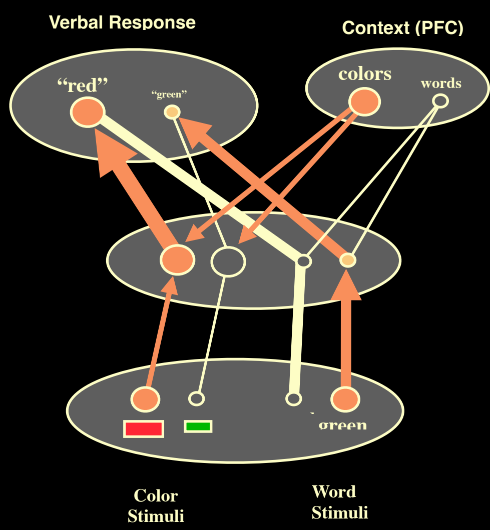
Cohen & Servan-Schreiber (1992); Miller & Cohen (2001)



Guided Activation Theory of PFC and Control

Cohen & Servan-Schreiber (1992); Miller & Cohen (2001)

- Representations in PFC bias decision processes to establish a task set: mappings between input, memory, and output representations
  - Ties control of decision making to working memory, attention and inhibition



Guided Activation Theory of PFC and Control

Cohen & Servan-Schreiber (1992); Miller & Cohen (2001)

- **Representations in PFC bias decision processes to establish a task set: mappings between input, memory, and output representations**
  - **Ties control of decision making to working memory, attention and inhibition**

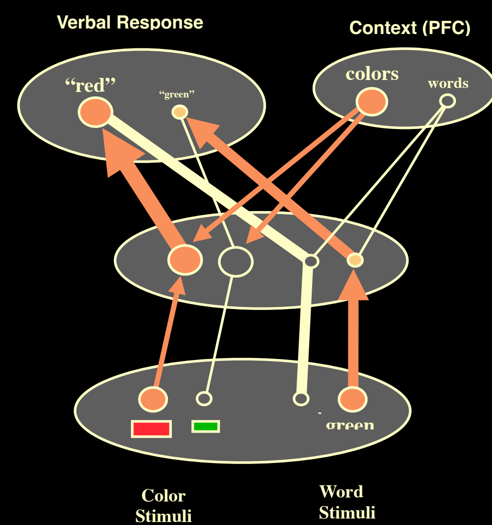
- **Accounts for psychological / behavioral data:**

  Normal performance in a variety of cognitive tasks:

  - **Stroop inhibition paradigm** (Cohen et al., 1990; Phaf et al., 1990)
  - **Eriksen flanker task** (Cohen et al., 1993)
  - **Spatially-cued reaction time task** (Mozer, 1988; Cohen et al., 1994)
  - **Delayed response tasks** (Dehaene & Changeux, 1989)
  - **Continuous performance test** (Braver et al., 1996)
  - **Wisconsin Card Sort Task** (Dehaene & Changeux, 1992)
  - **Lexical disambiguation tasks** (Cohen et al., 1992)

  Neuropsychological deficits in such tasks

  (e.g., Cohen & Servan-Schreiber, 1992; Cohen et al, 1994; Kerns et al., 2004)



Guided Activation Theory of PFC and Control

Cohen & Servan-Schreiber (1992); Miller & Cohen (2001)

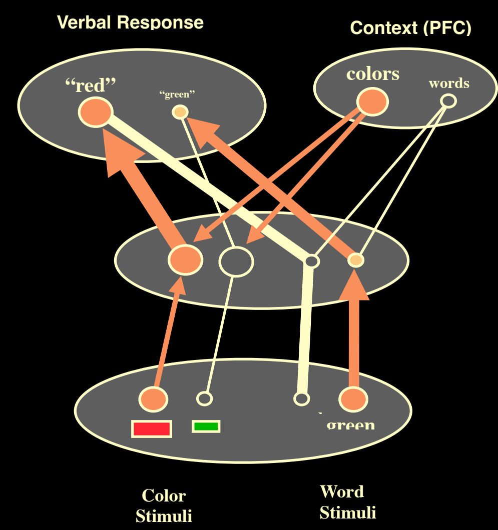
- **Representations in PFC bias decision processes to establish a task set: mappings between input, memory, and output representations**
  - **Ties control of decision making to working memory, attention and inhibition**

- **Accounts for psychological / behavioral data:**

  Normal performance in a variety of cognitive tasks:
  - **Stroop inhibition paradigm** (Cohen et al., 1990; Phaf et al., 1990)
  - **Eriksen flanker task** (Cohen et al., 1993)
  - **Spatially-cued reaction time task** (Mozer, 1988; Cohen et al., 1994)
  - **Delayed response tasks** (Dehaene & Changeux, 1989)
  - **Continuous performance test** (Braver et al., 1996)
  - **Wisconsin Card Sort Task** (Dehaene & Changeux, 1992)
  - **Lexical disambiguation tasks** (Cohen et al., 1992)

  Neuropsychological deficits in such tasks

  (e.g., Cohen & Servan-Schreiber, 1992; Cohen et al, 1994; Kerns et al., 2004)



- **Accounts for neurobiological data**
  - **Single unit recordings from PFC in non-human primates**

    (e.g., Miller, Erickson & Desimone, 1996; Rainer et al., 1998; Asaad, Rainer & Miller, 2000)
  - **Neuroimaging findings in humans**

    (e.g., e.g., Jonides & Smith, 1993; Barch et al., 1998; MacDonald et al., 2001; Yeung et al., 2006)