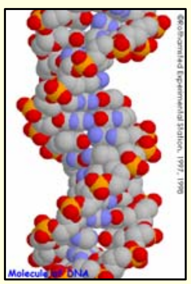
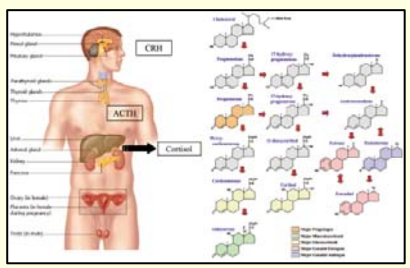
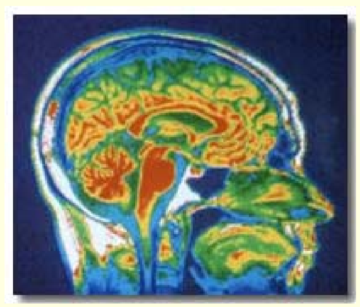
Resources for the Future
Frontiers of Environmental Economics Conference

Using Biomedical Technologies To Inform Economic Modeling:

Challenges & Opportunities for Improving Analysis of Environmental Policies

Brian Roe & Tim Haab

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THE OHIO STATE UNIVERSITY

Classical view of decision making

- Benthamite utility
  - "Mankind is governed by pleasure & pain"

Jeremy Bentham
1748-1832
Preserved at University College, London

Classical view of decision making

- Benthamite utility

  "Mankind is governed by pleasure & pain"

- Viner

  "Human behavior .. is the product of an unstable & unrational complex of reflex actions, impulses, instincts, habits, customs, fashions & hysteria."

Jacob Viner
1892-1970

Classical view of decision making

- Benthamite utility

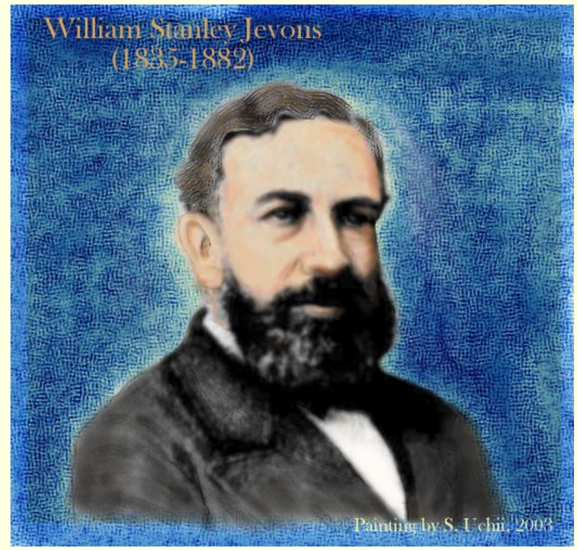
  "Mankind is governed by pleasure & pain"

- Viner

  "Human behavior .. is the product of an unstable & unrational complex of reflex actions, impulses, instincts, habits, customs, fashions & hysteria."

- Jevons' pessimism

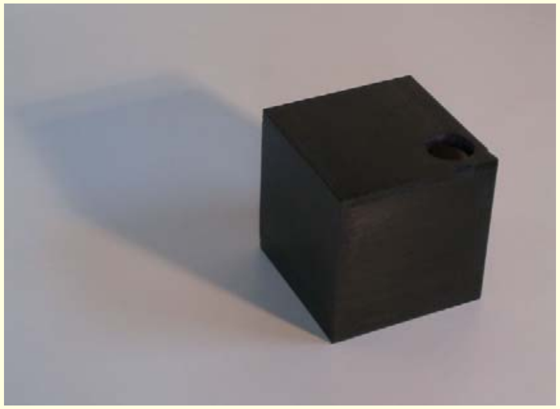
  "…it is impossible to measure the feelings of the human heart."



William Stanley Jevons
1835-1882

Views of Decision Making

- Neoclassical
  - Information about options →
  - Black box of preferences →
  - Resulting choices



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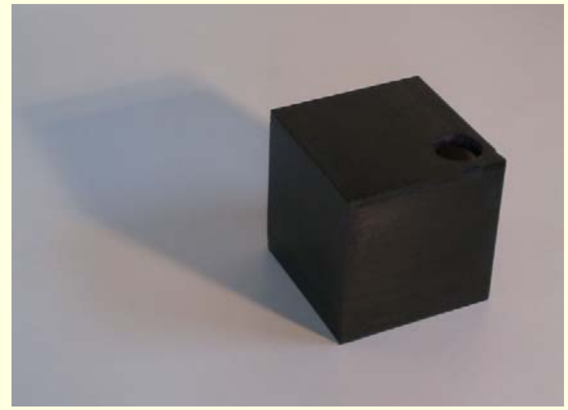


- Neuroeconomics

  Begins to articulate the *biological technology* that transforms environmental stimuli into actions

Welfare Analysis

… Relies on a well-structured black box

- Preferences
  - Coherent (transitivity, etc), complete, stable
- Rationality
  - Ability, information & motivation to optimize

…Experimental Social Sciences

- Provide one avenue to check for consistency of observed data with key economic axioms

…Biomedical Sciences

- A complementary approach to answering fundamental questions concerning the nature of human behavior

Overview

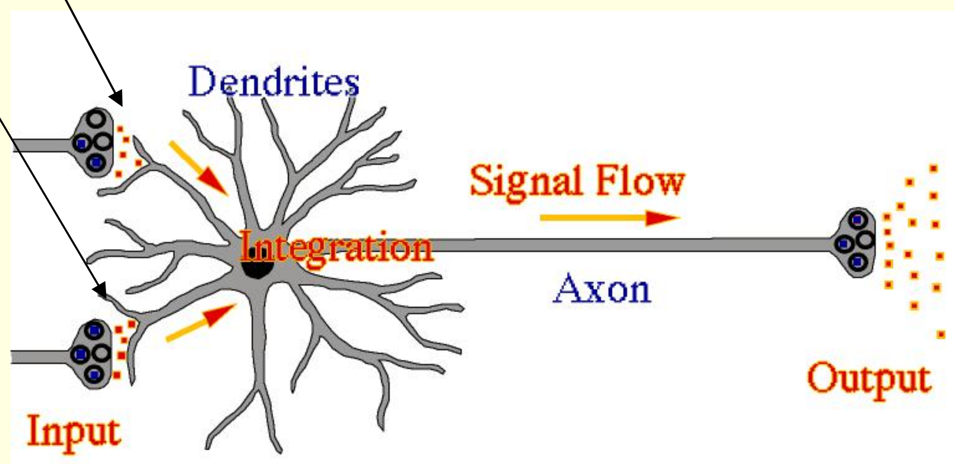
- Biomedical Methods
- Neural Foundations of Decision Making
- Re-examining Pillars of Welfare Theory
- Conclusions

Buffet of Methods

- Neural
  - Monitoring
  - Manipulation
- Genetic
  - Monitoring
  - Manipulation
- Body function monitoring

Neural Functioning

- The neuron in the basic unit of communication
- ~100 Billion neurons in adult humans
- Receive electrochemical signals across synapses from other neurons and generate electrical current



Neural Functioning

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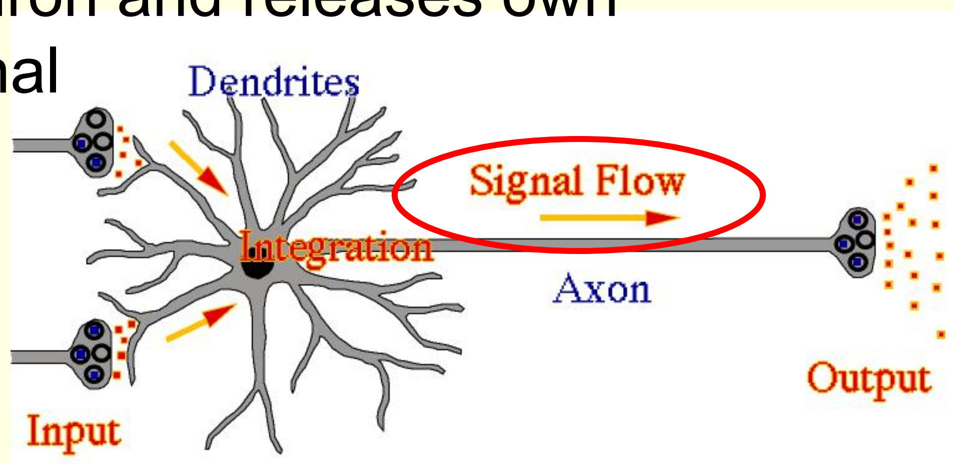
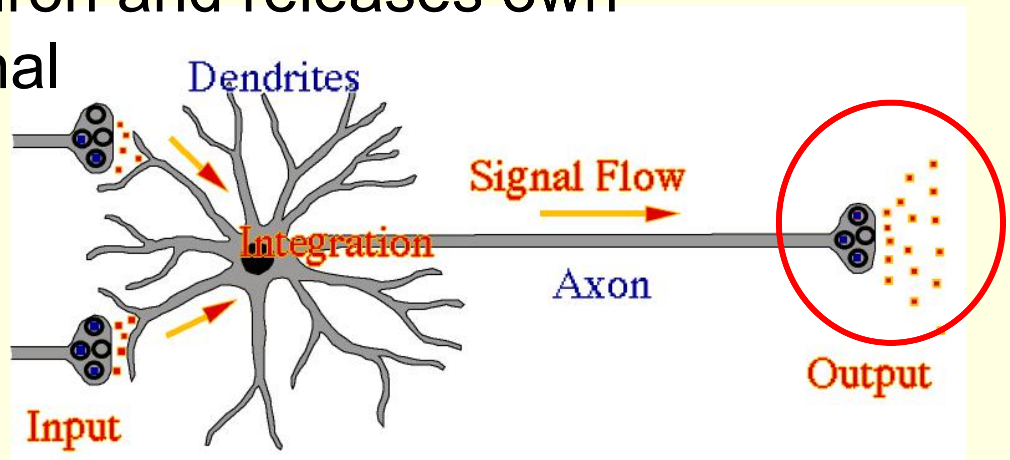


Neural Functioning

- The neuron in the basic unit of communication
- ~100 Billion neurons in adult humans
- Receive electrochemical signals across synapses from other neurons
- If current surpasses threshold → action potential travels length of neuron and releases own electrochemical signal
- Signal sent via a neurotransmitter
  - e.g., dopamine or serotonin



Monitoring Neural Activity

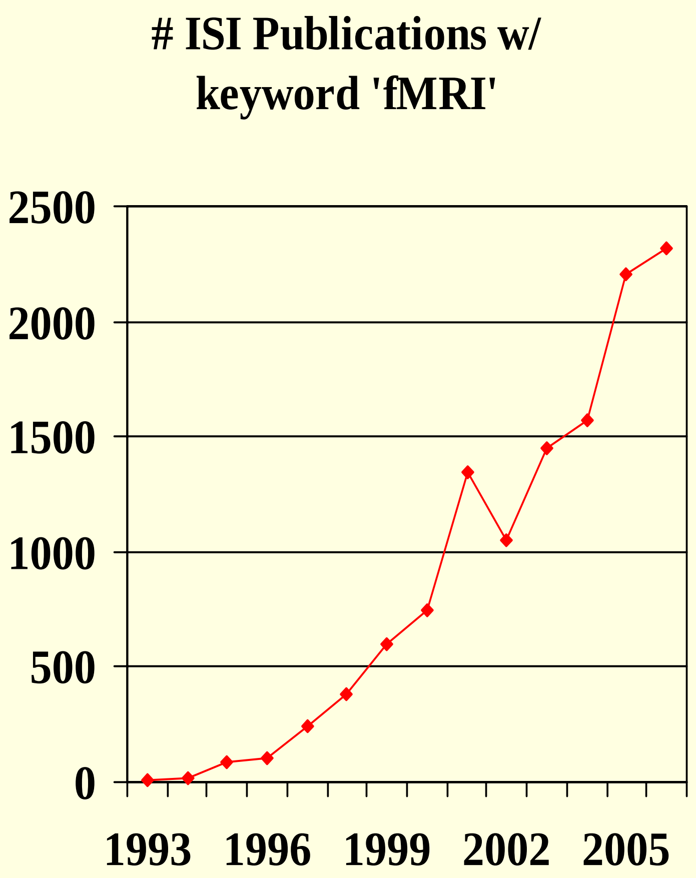
- Methods differ by
  - What they measure
    - Electrical current generated by neuron
    - Chemical release from neuron
    - Blood flow supporting neural activity
  - Spatial & temporal refinement
    - Spatial coverage also an issue
  - Invasiveness
    - Danger to patient
    - Allows ‘natural’ movement

Monitoring and Manipulation Methods

- **Functional Magnetic Resonance Imaging (fMRI)**
- **Single Unit Recording**
- Others discussed in paper
  - Electroencephalography of Event-Related Potentials (EEG of ERP)
  - Positron Emission Topography (PET)
  - Magnetoencephalography (MEG)
  - Functional Near-Infrared Spectroscopy (fNIR)
  - Single Photon Emission Computerized Tomography (SPECT)
  - Cyclic Voltammetry
  - Transcranial Magnetic Stimulation (TMS)
  - Lesion Studies (natural and induced)
  - Pharmacological manipulations
  - Electrical Brain Stimulation (EBS)
  - Dietary Depletion of Amino Acids
  - Genetic Manipulation
  - Autonomic Nervous System Monitoring
    - Heart rate, eye blink, pupil dilation, blood pressure, pulse, skin conductance, temp

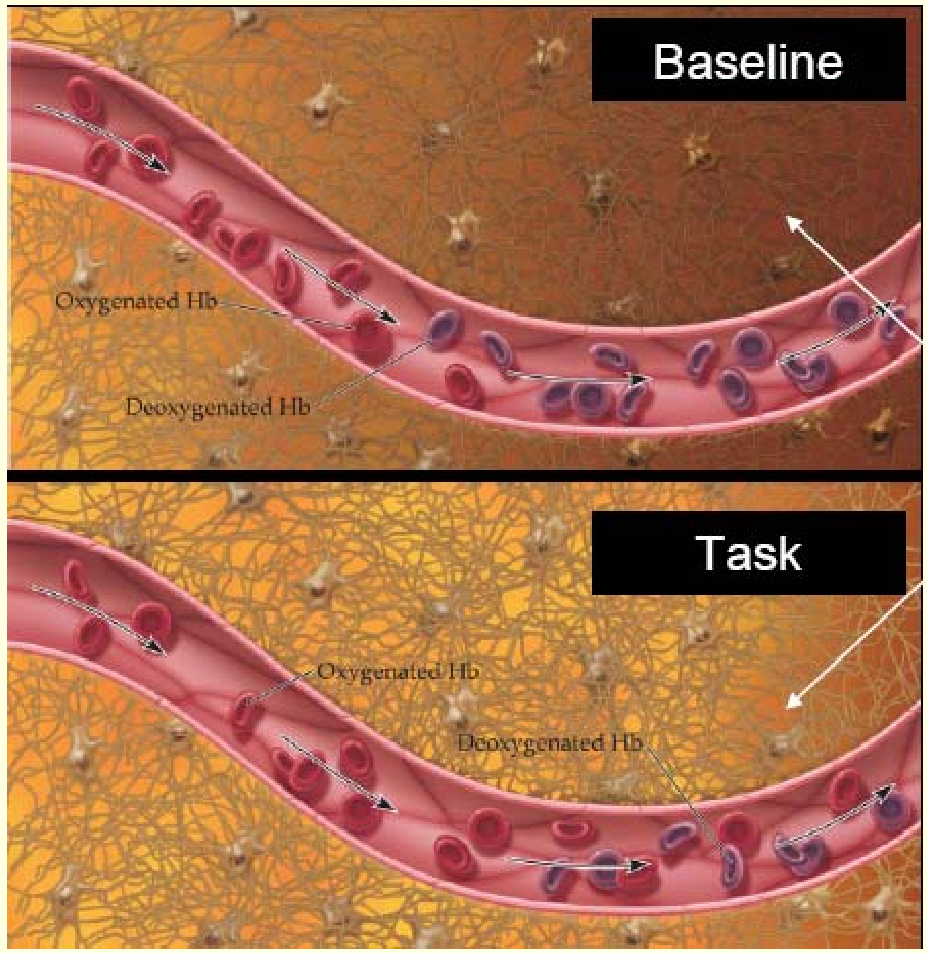
Functional MRI

- Increasingly popular over past decade



Functional MRI

- Increasingly popular
- Neural firings require energy supplied by blood
  - MR signal is sensitive to the oxygenation level in blood hemoglobin
  - Compare blood oxygenated level dependent (BOLD) signal between baseline & treatment

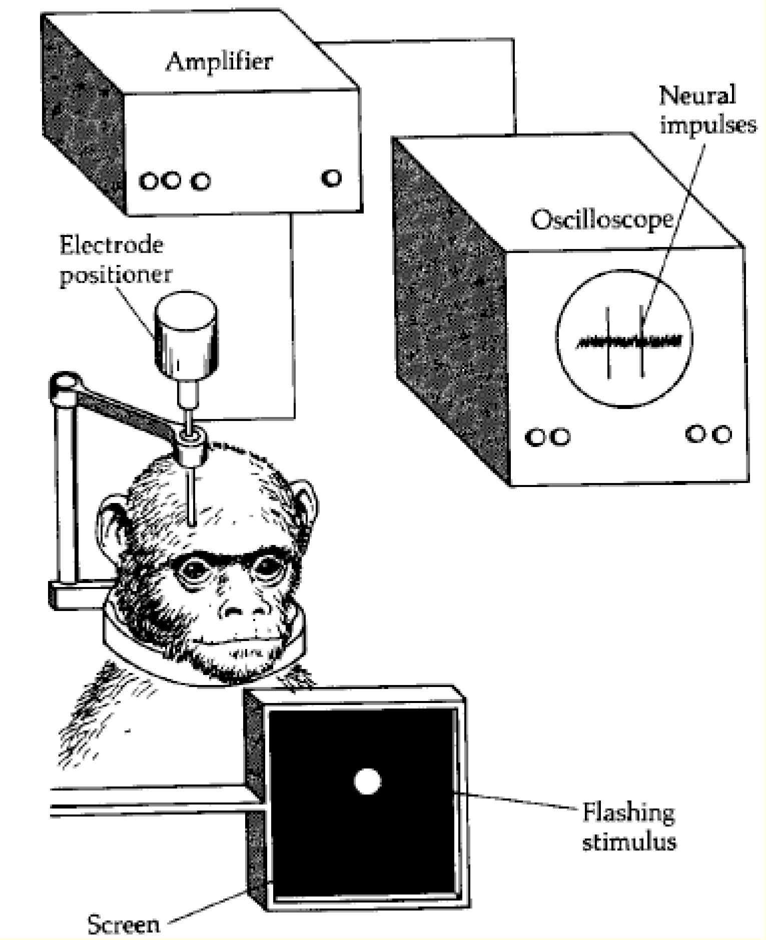


Functional MRI

- Increasingly popular
- Measures blood oxygen level
- Spatial
  - Resolution: good (mm)
  - Coverage: whole brain
- Temporal resolution
  - Good (seconds)
- Non-invasive
- Restricts movement

Single Unit Recording

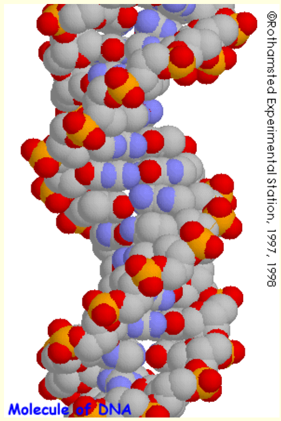
- Animal technique
- Place very small electrode
  - Through cranial hole
  - Near neuron of interest
  - Measures Δ's in elec current
    - Best temporal resolution
    - Only measures one neuron
  - Non-fatal
    - Kills some neurons



Neural Manipulation

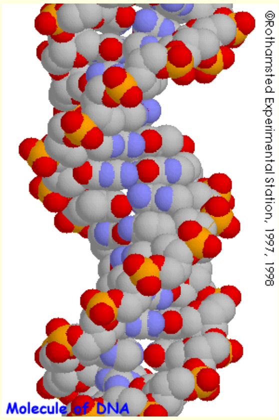
- Transcranial Magnetic Stimulation (TMS)
- Lesion Studies
  - Natural and induced (animal only)
- Electrical Brain Stimulation (EBS)
- Pharmacological Manipulation
- Dietary Depletion of Amino Acids

Genetic Methods



Variation in one or more genes - ***Genotype***

Genetic Methods



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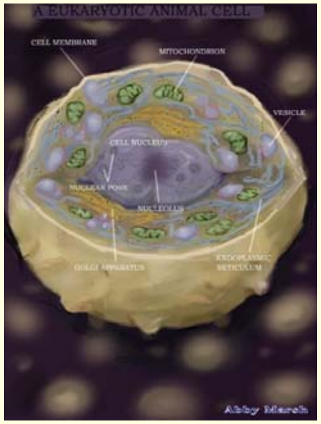
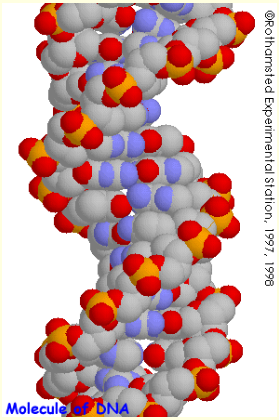


differences in cellular function

Genetic Methods



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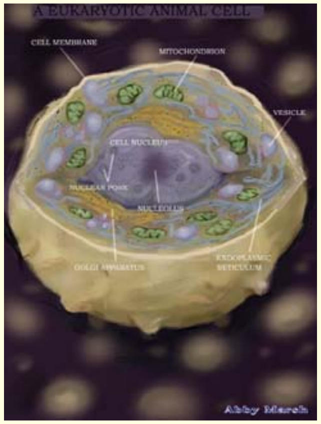
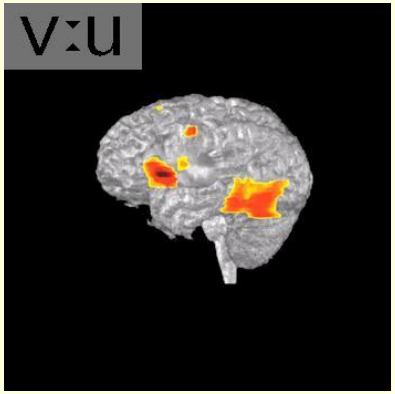
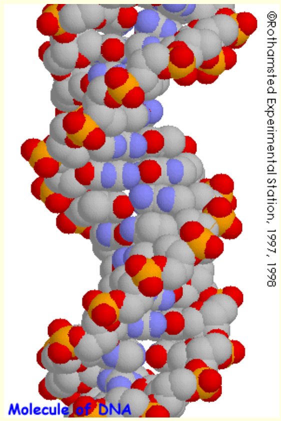


differences in cellular function

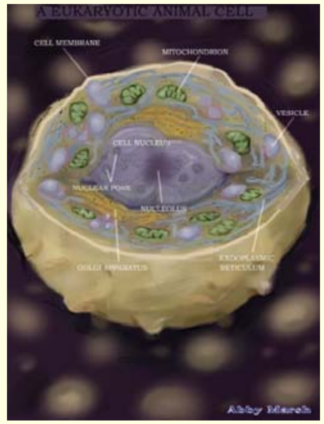


differences in system response

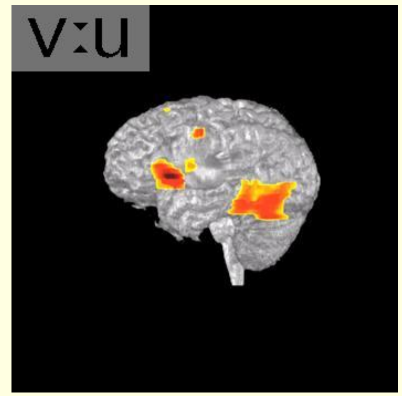
Genetic Methods



Variation in one or more Genes - ***Genotype***



differences in cellular function



differences in system response

Understanding how ***genotype*** is related to ***phenotypes*** relevant to economic decisions

differences in decision behavior - ***Phenotype***

Genetic Methods

- Fundamental and functional unit of heredity
- An ordered sequence of nucleotides
  - In a particular position on a particular chromosome
  - Encodes a specific functional product (e.g., protein)
- 1 gene carries the directions for making 1 protein
- We have many genes (20,000 – 25,000)
- Genes do not encode behavior
  - They impact the way certain cells and molecules act/work
  - Some genes have common variations
    - Called Polymorphisms

~~Nature vs. Nurture,~~ Nature + Nurture

- Common perception of genes as blueprints
- But genes do not produce (express) their protein all of the time
  - Genes are switched on and off
    - By chemical regulators
    - By external stressors
- Leads to genetic ‘predisposition’
  - Must be turned on/off
  - Means analysis must be informed by individual’s past activities/stressors

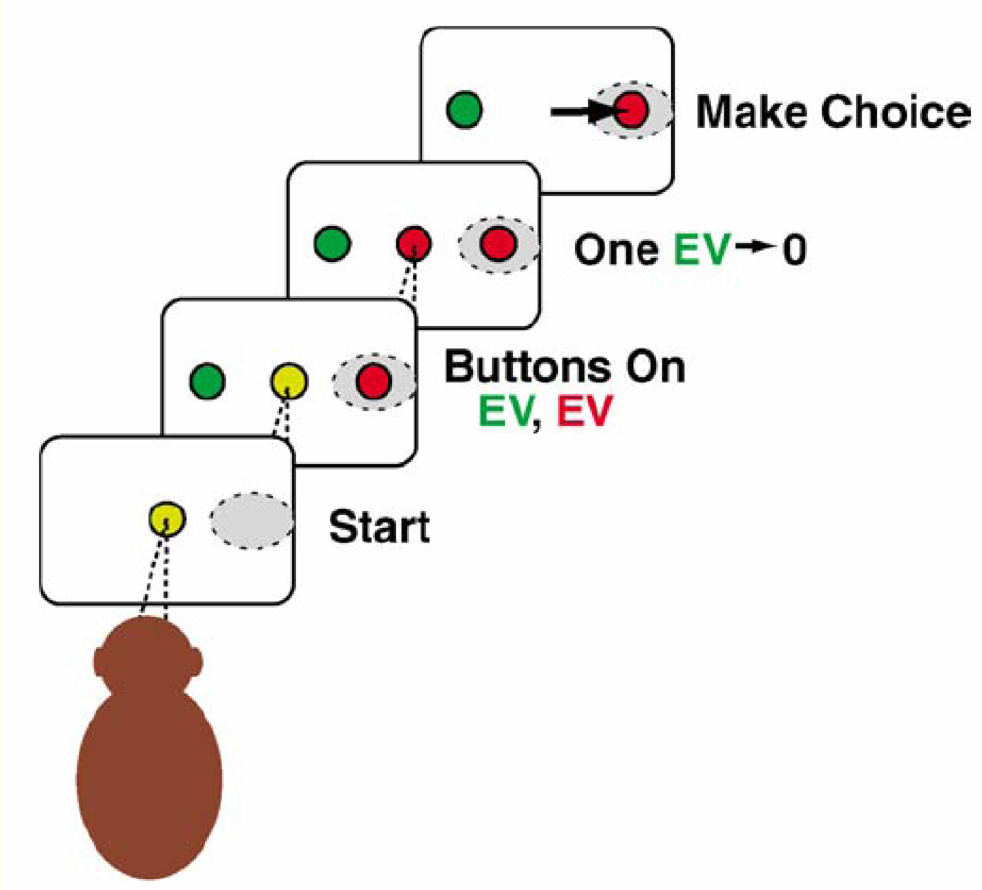
Genetic Methods

- Association Studies
  - Phenotype – Genotype
  - Endophenotype – Genotype
    - Behavior of a system (e.g., region of brain)
  - Each can involve controls for environmental influence
- Linkage Studies
- Whole genome and phenome studies
- Genetic manipulation (animals)

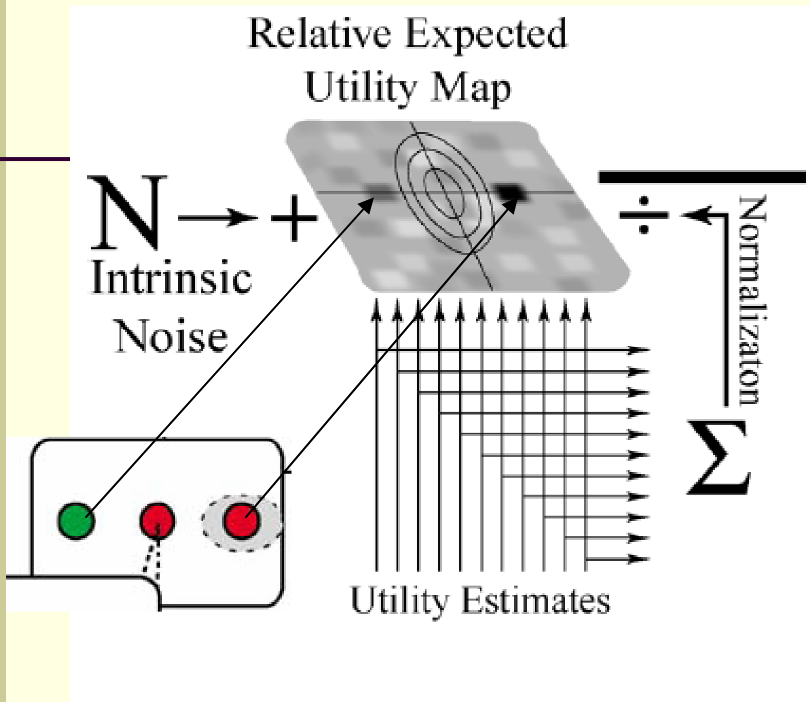
Neural Basis of Decision Making

- RUM in the LIP
  - Random utility model is executed for a simple choice
    - Thirsty monkeys choosing among visual targets
      - Select via shifting eye gaze
      - Trained to realize some target provide juice
    - Single unit recording in several regions
  - Identify physiological counterparts for
    - Estimated relative utility for each option
    - Identification of utility maximizing option

Experimental Stimuli



Source: Glimcher, Dorris and Bayer, *Games & Economic Behavior*, 2005



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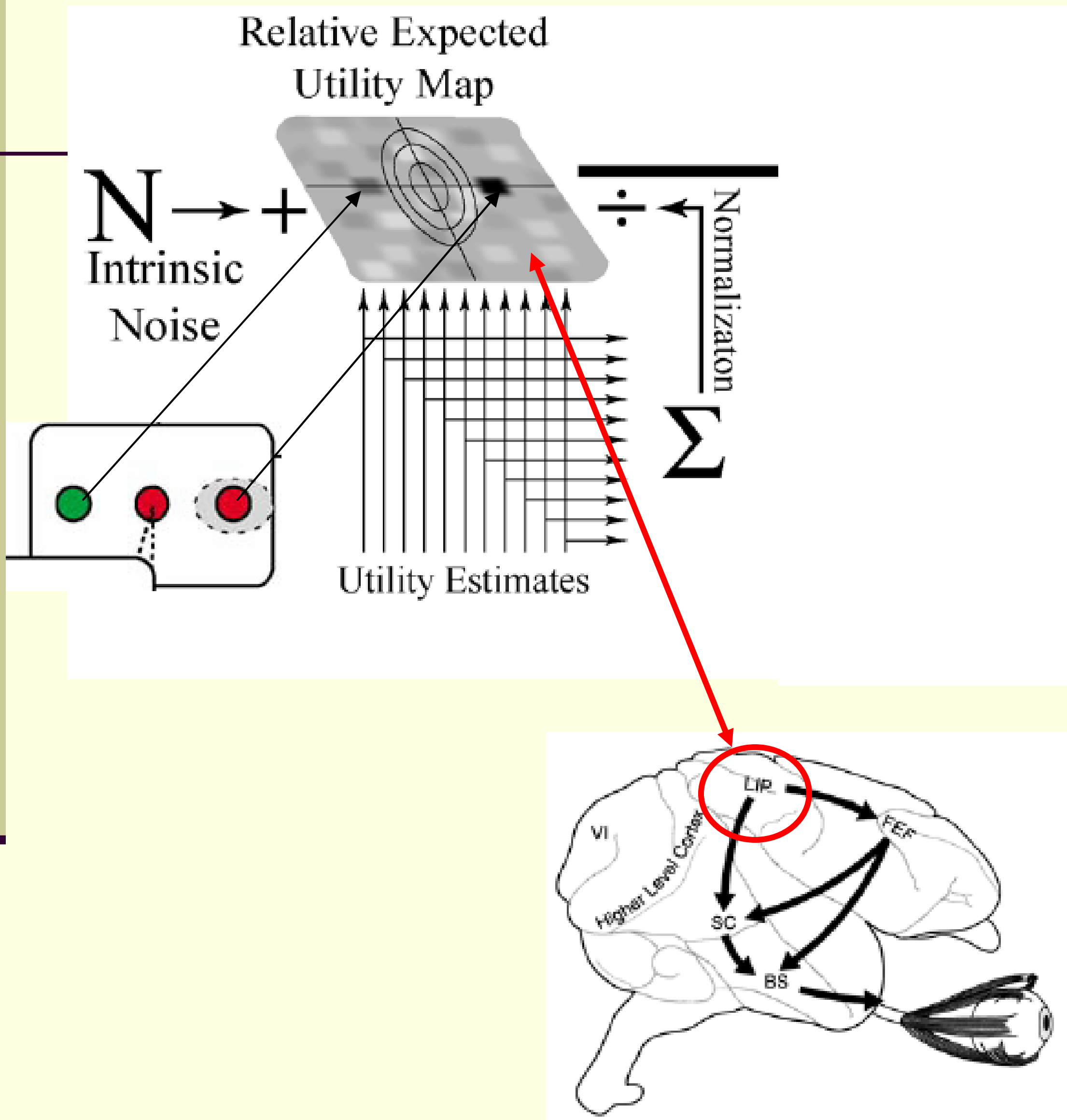

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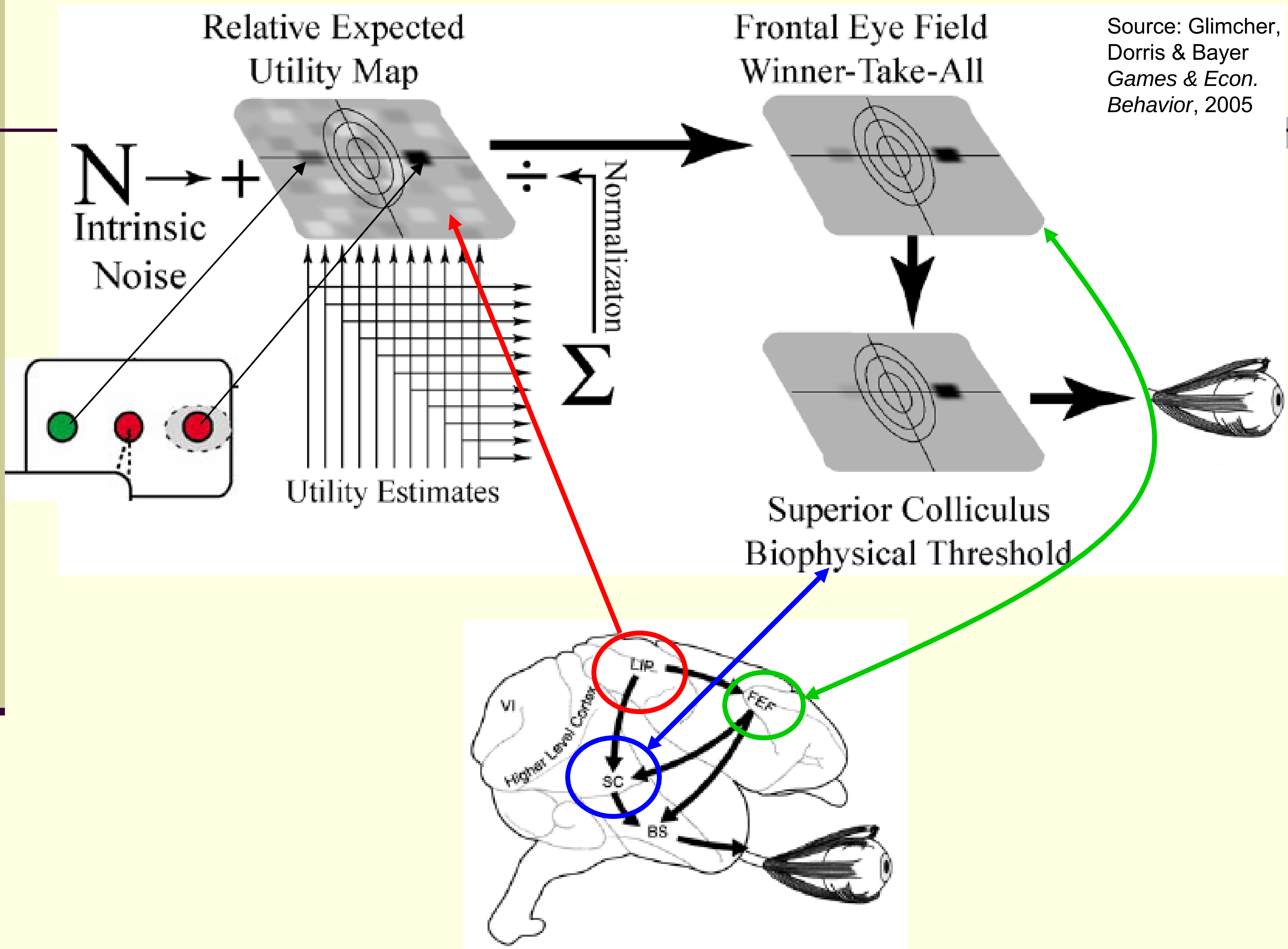
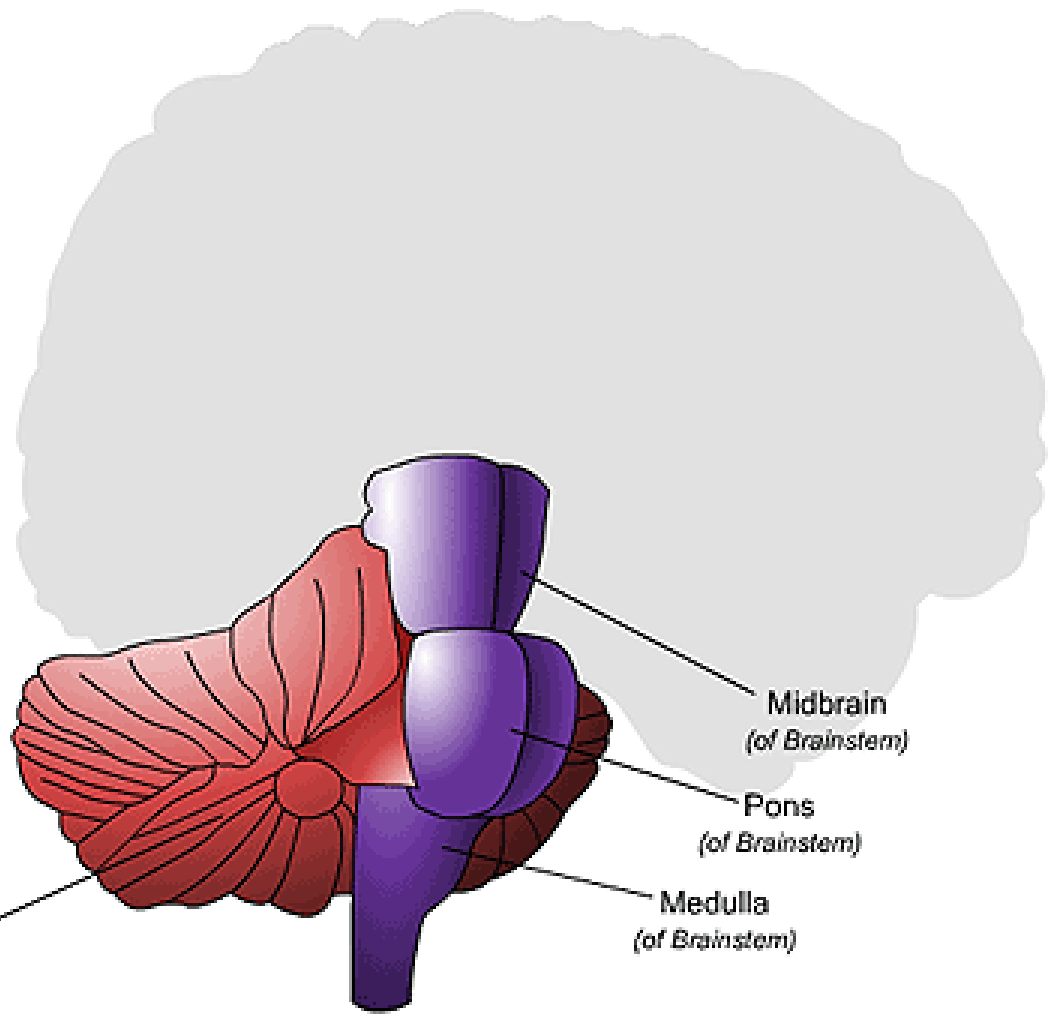


Source: Glimcher, Dorris and Bayer, *Games & Economic Behavior*, 2005

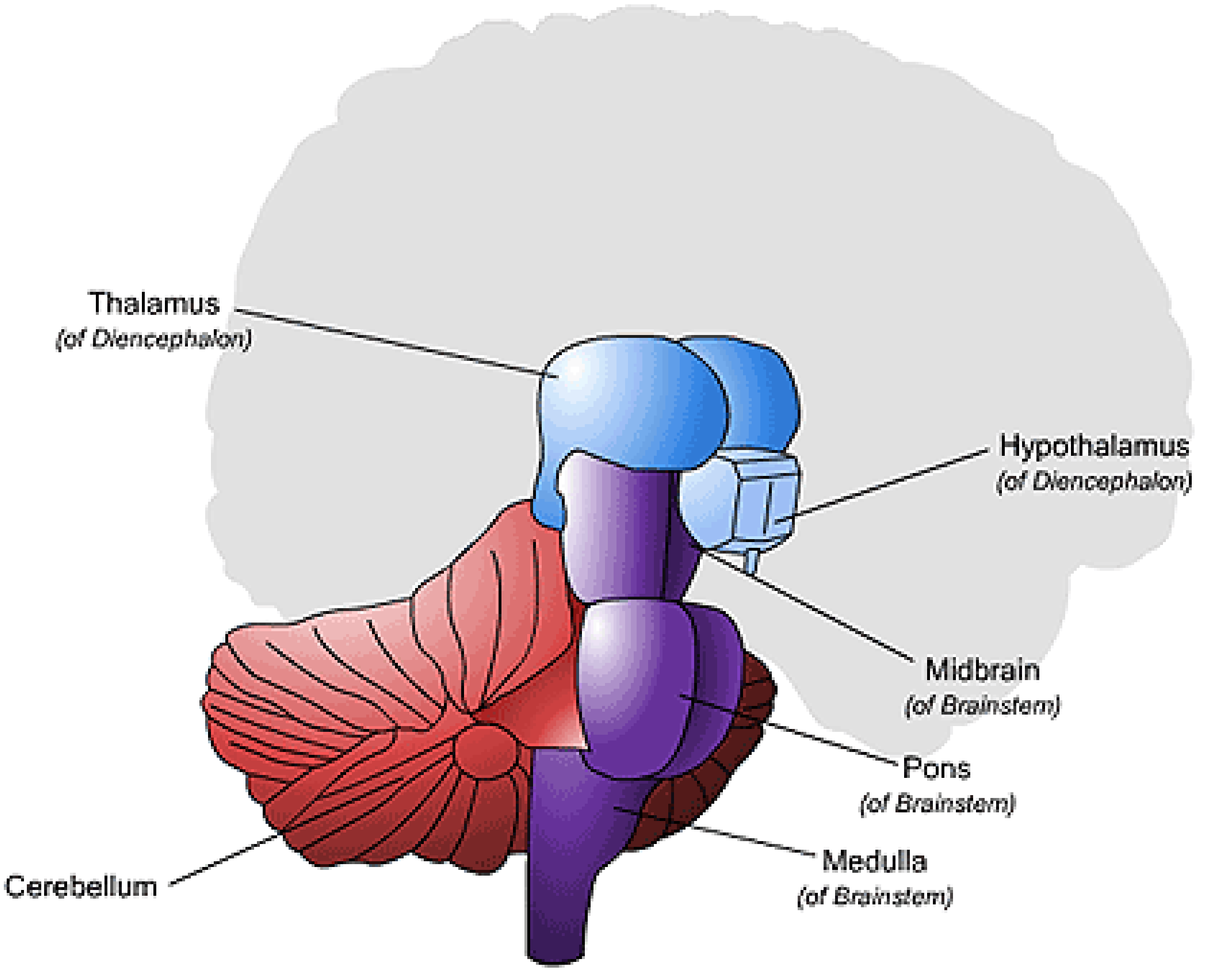
Neurological Rewards

Figure AB-28: Build A Brain, Step 3



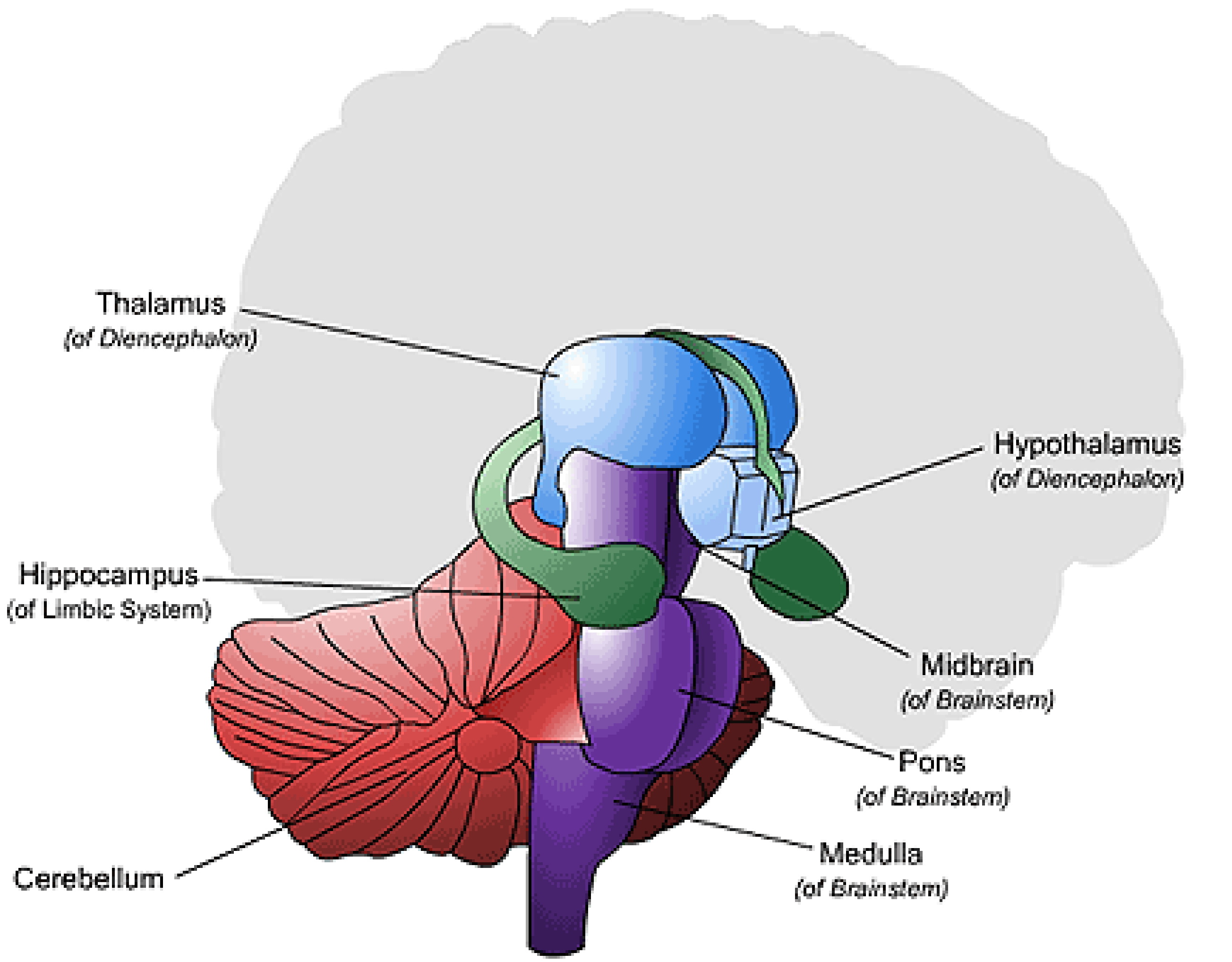
Neurological Rewards

Figure AB-30: Build A Brain, Step 5



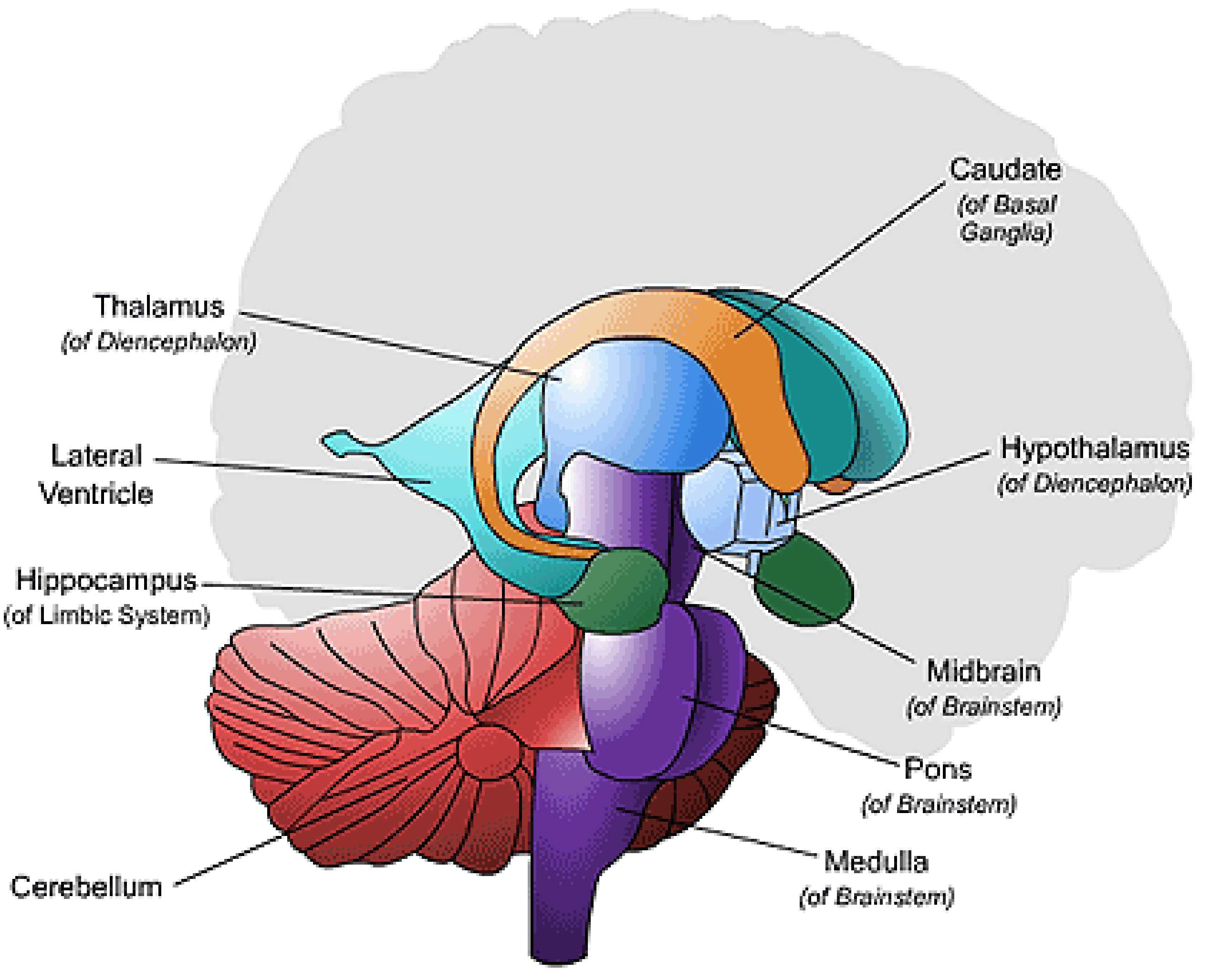
Neurological Rewards

Figure AB-31: Build A Brain, Step 6



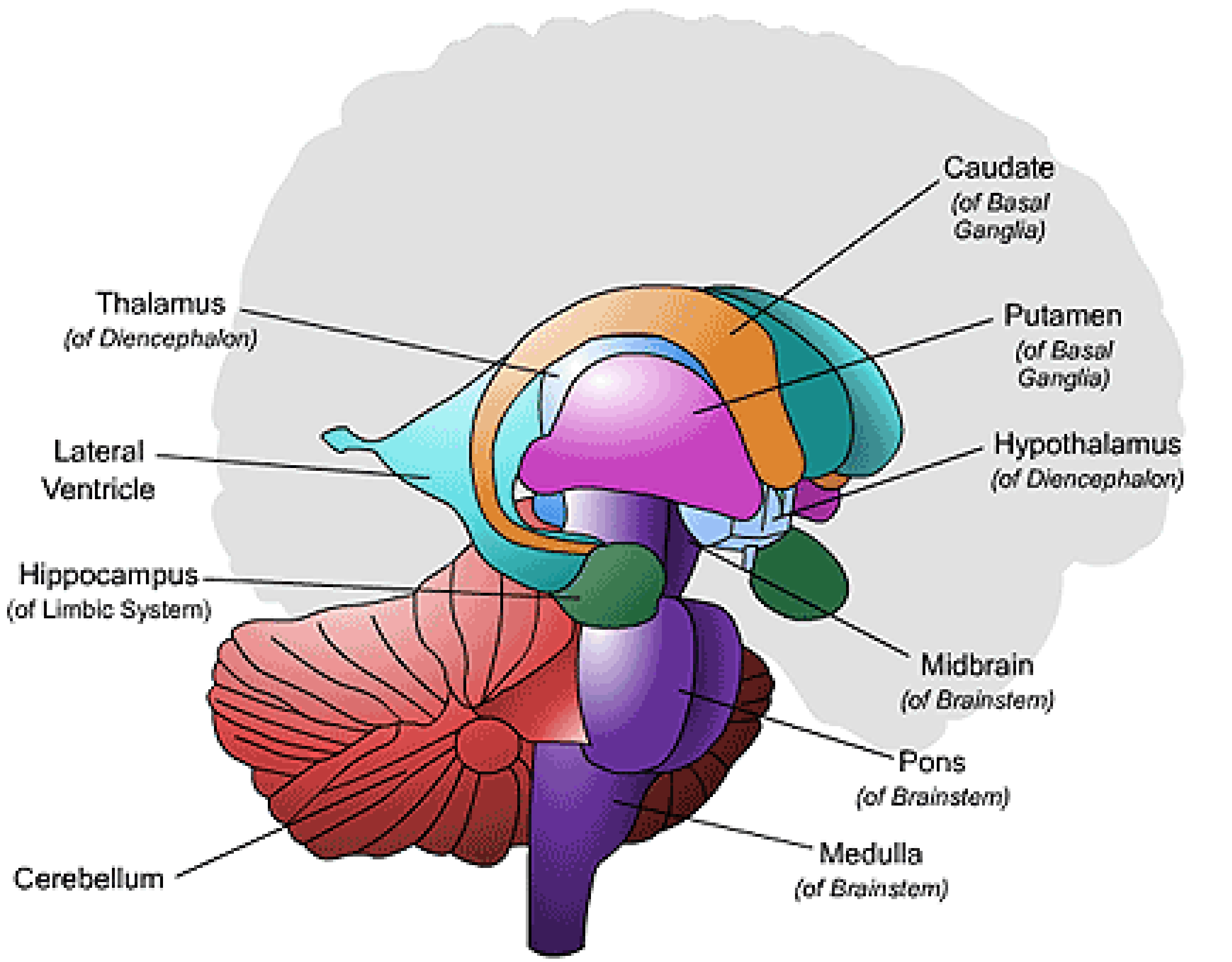
Neurological Rewards

Figure AB-33: Build A Brain, Step 8



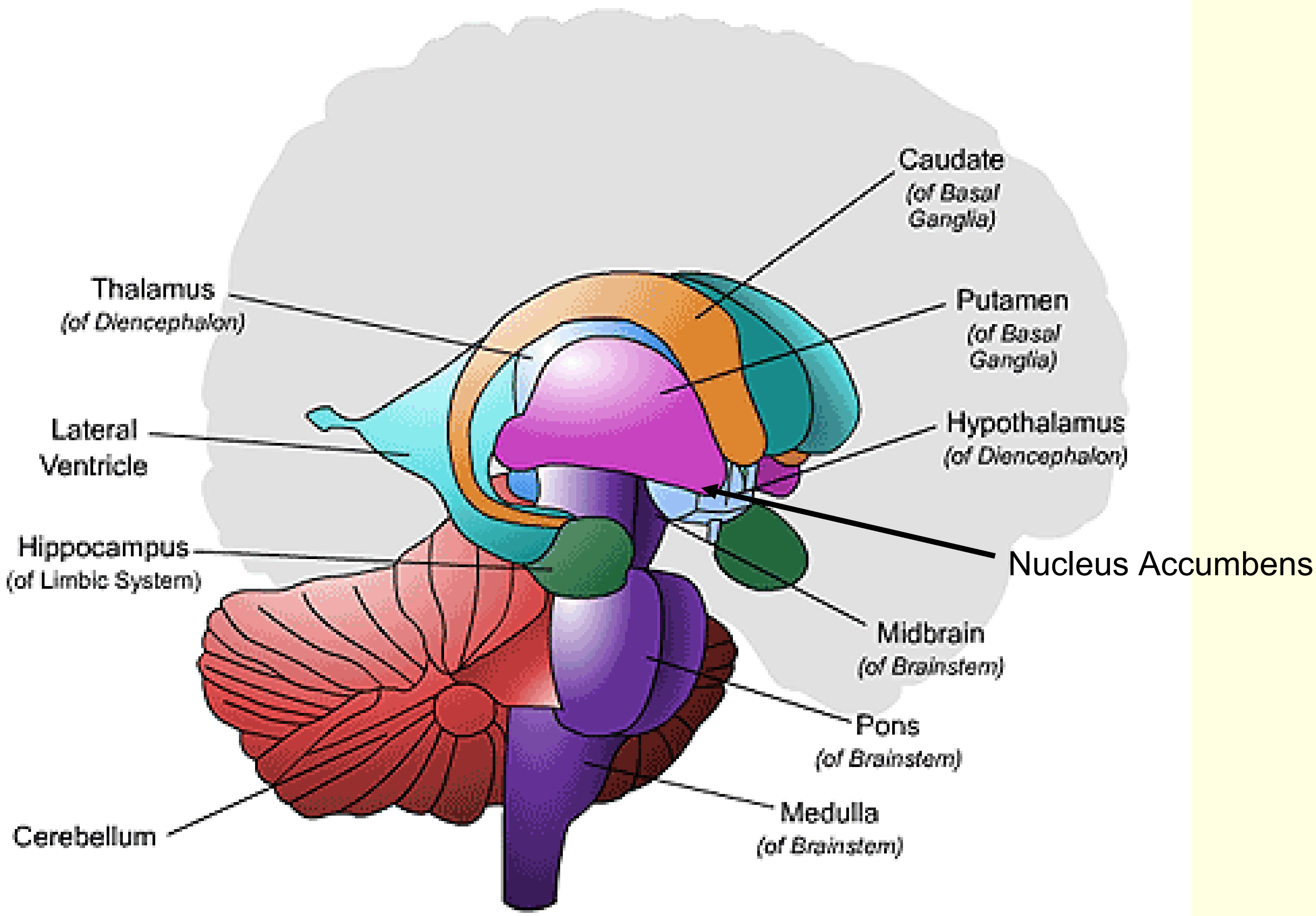
Neurological Rewards

Figure AB-34: Build A Brain, Step 9



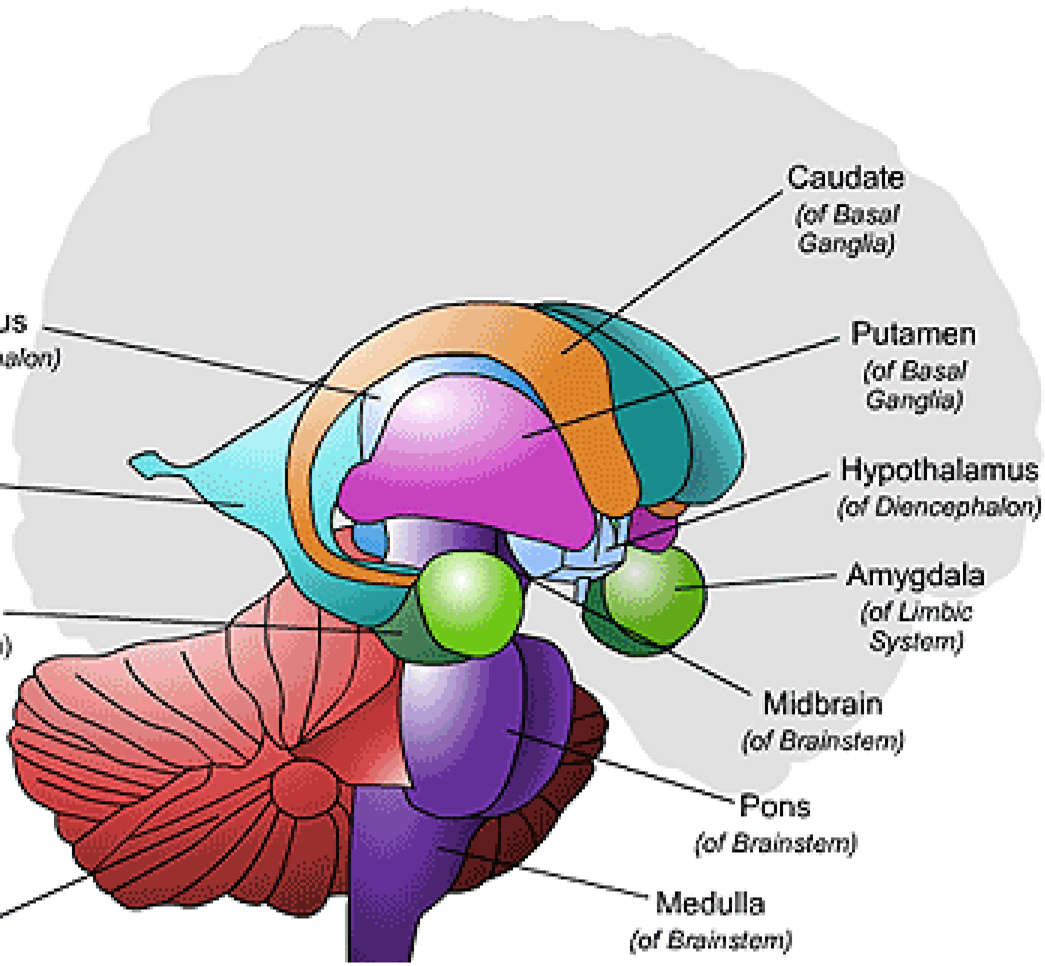
Neurological Rewards

Figure AB-34: Build A Brain, Step 9



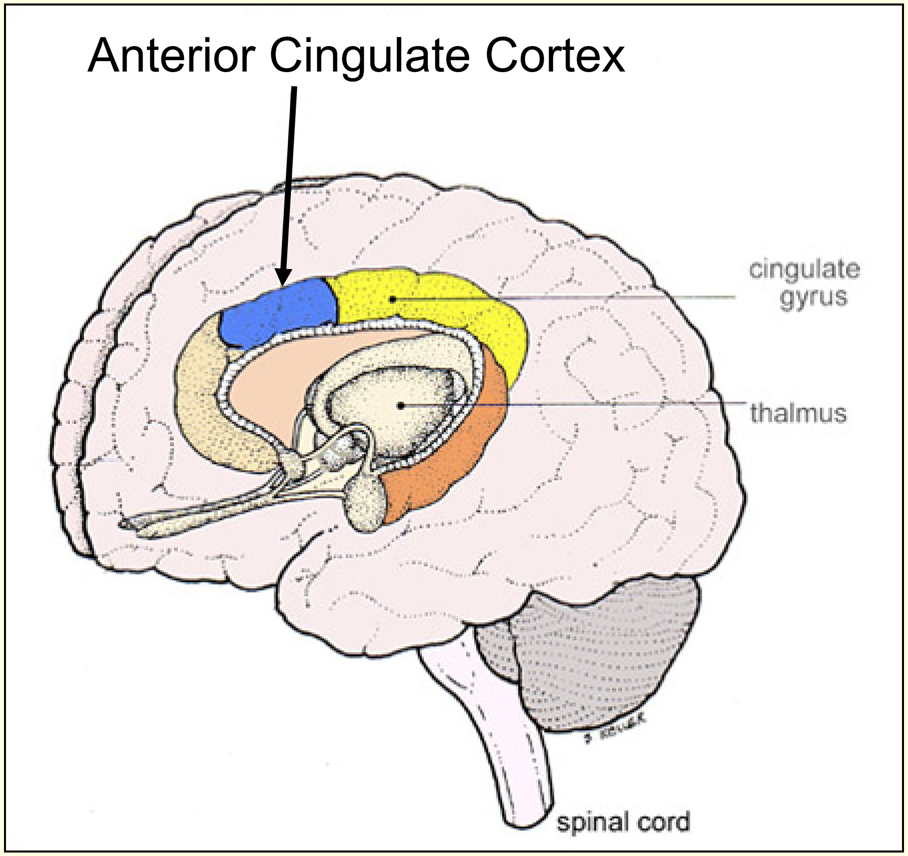
Neurological Rewards

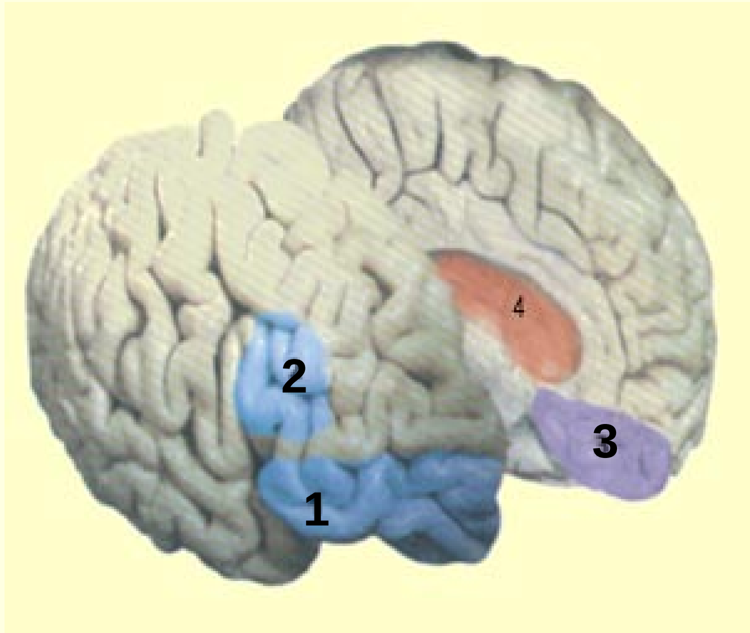
Figure AB-35: Build A Brain, Step 10



Source: Huntington's Outreach Project for Education , Stanford University

Neurological Rewards

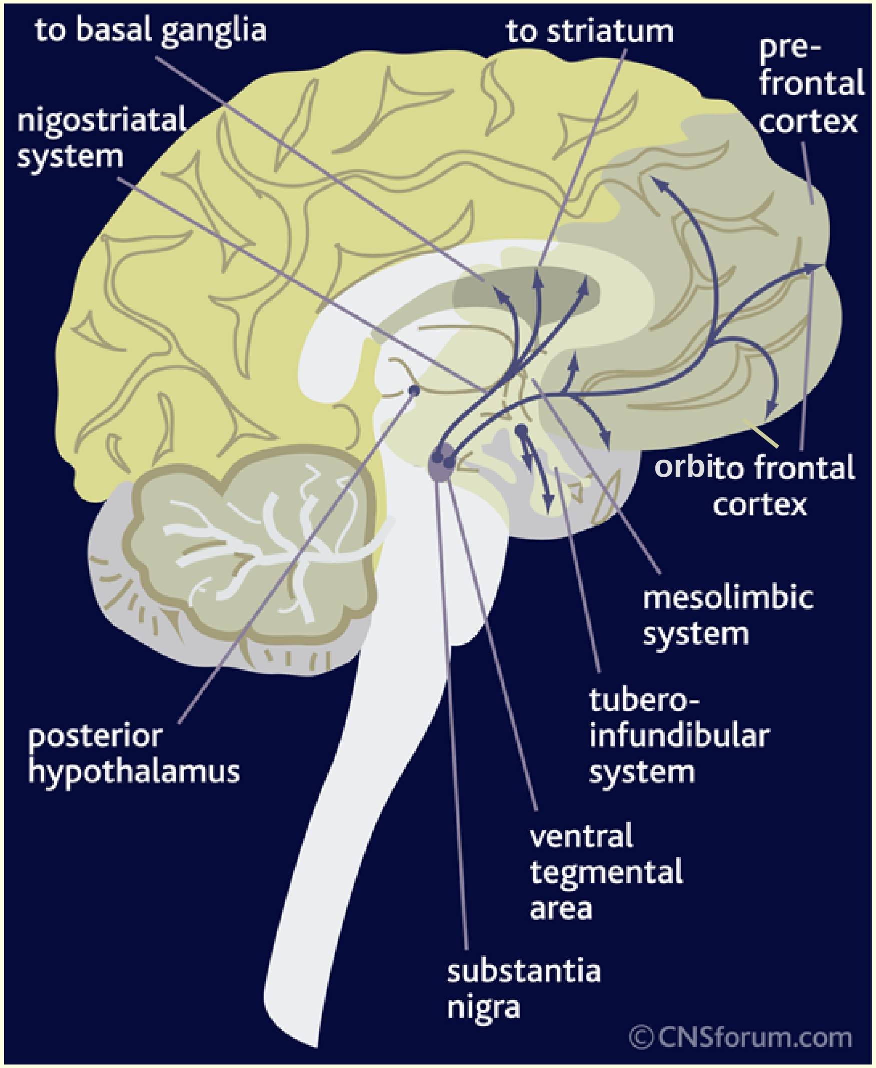




<u>Frontal Cortex Regions</u>

1. Orbitofrontal
2. Dorsolateral
3. Ventromedial

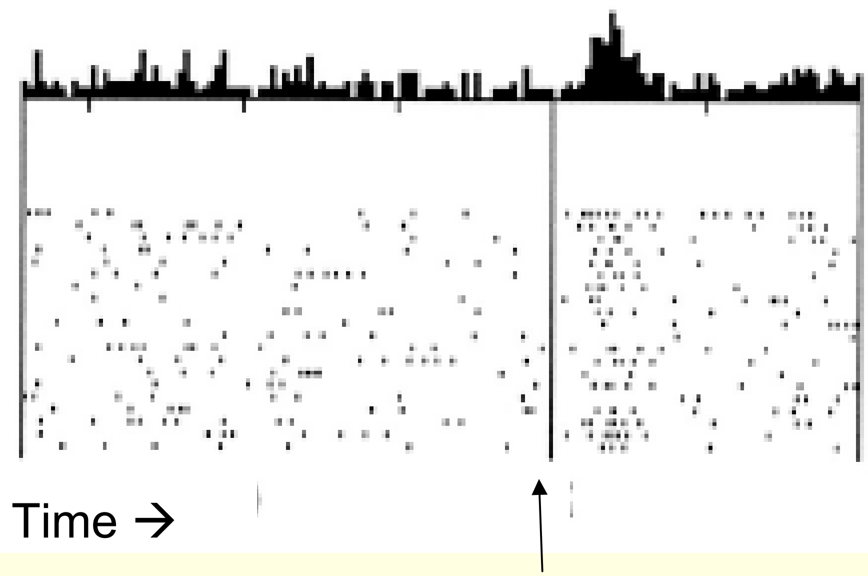
Dopamine Pathways



Dopamine Learning

Single unit recording, midbrain dopamine neuron, monkey

Each dot = 1 firing
Each line is one trial
Top bars = sum of trials
@ each time



Source: Schultz, Dayan, Montague, *Science*, 1997

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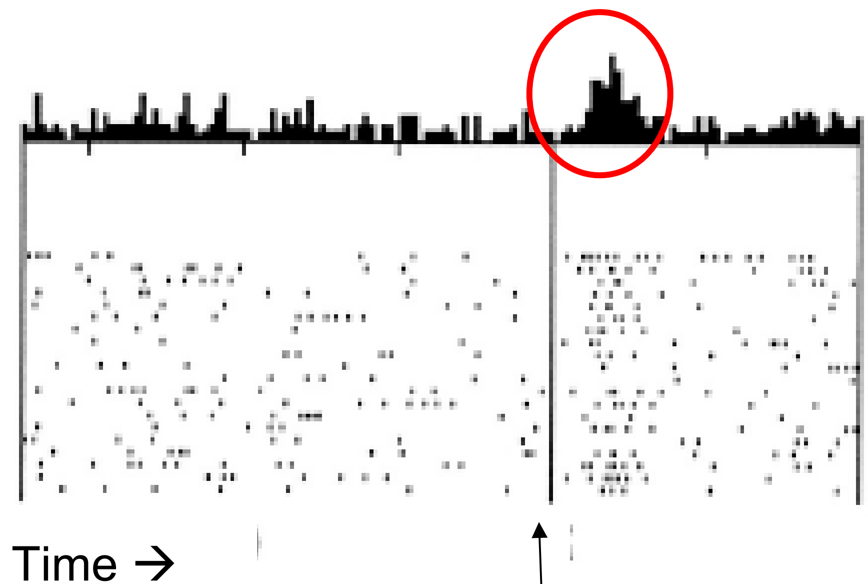

Each dot = 1 firing
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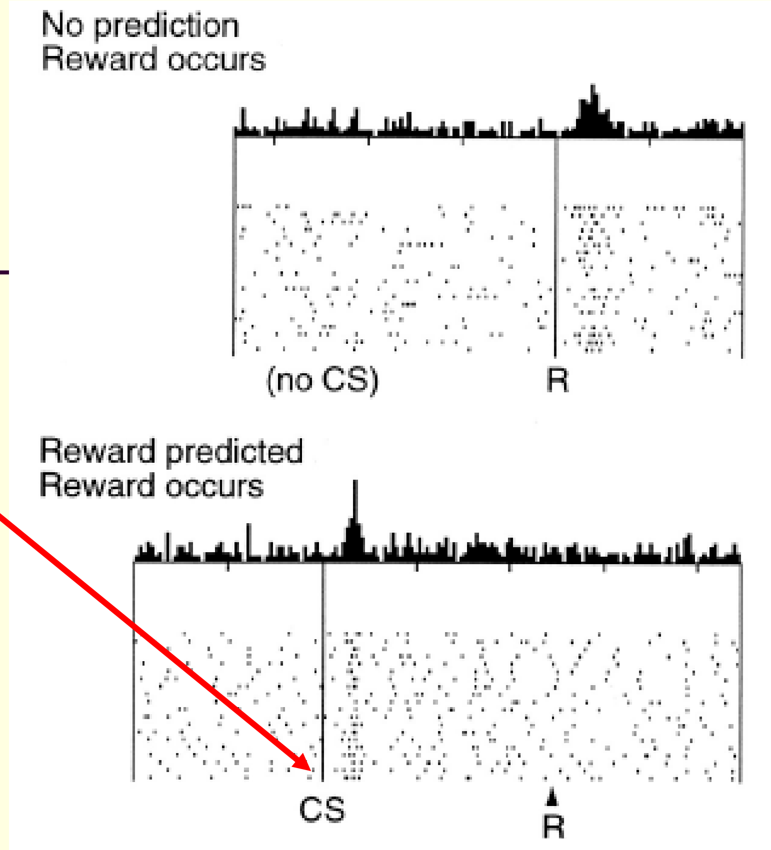
Top bars = sum of trials
@ each time

Reward delivered (R)

Source: Schultz, Dayan, Montague, *Science*, 1997

When reward preceded by a signal…



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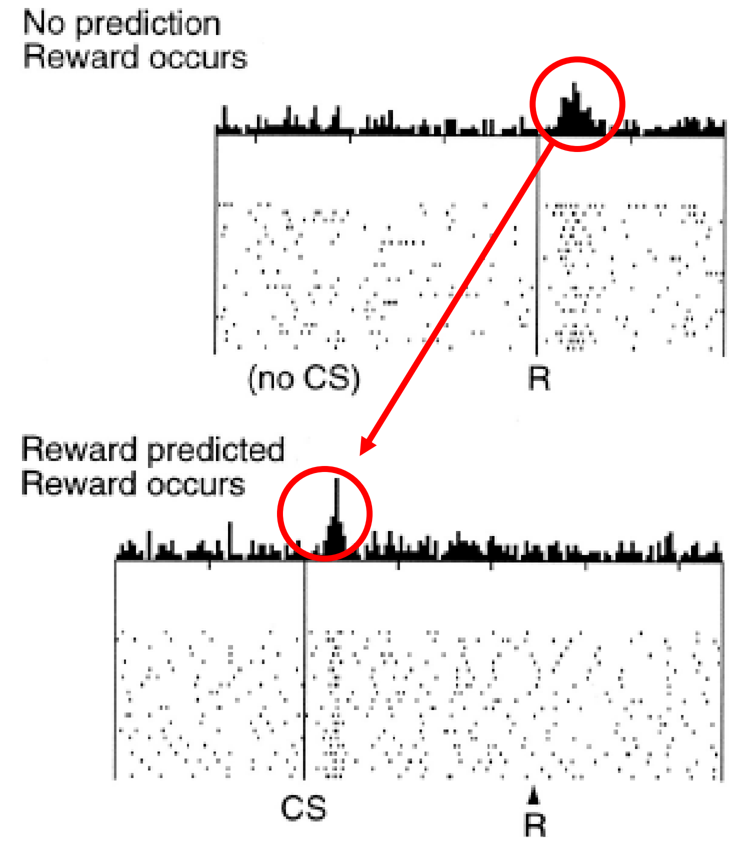
When reward preceded by a signal…

… dopamine release follows the signal

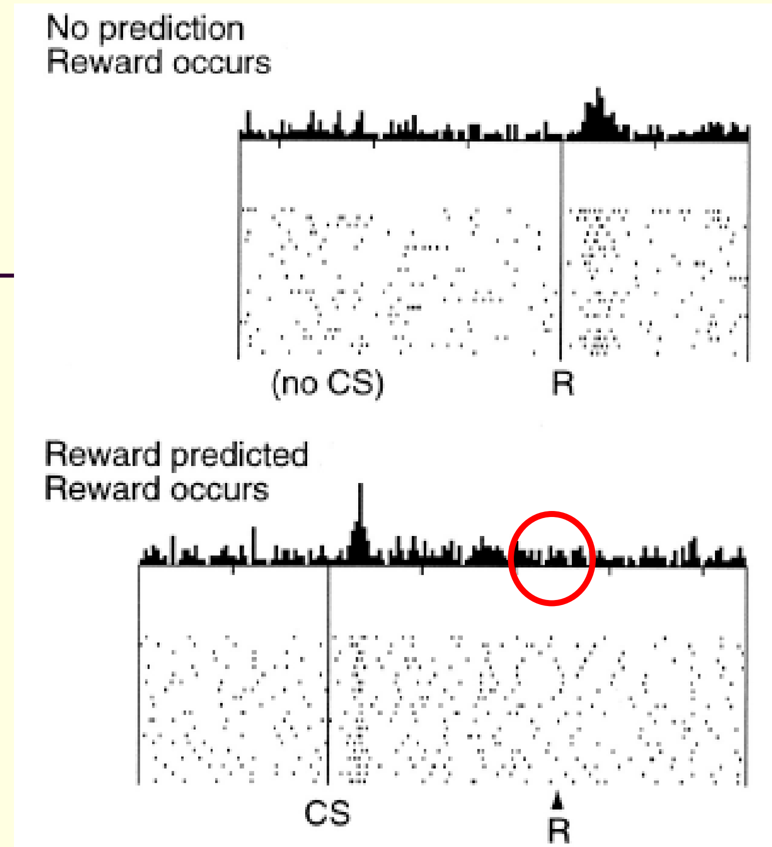


Source: Schultz, Dayan, Montague, *Science*, 1997

When reward preceded by a signal…

… dopamine release follows the signal

… dopamine firing after reward returns
to baseline levels



Source: Schultz, Dayan, Montague, *Science*, 1997

When reward preceded by a signal…

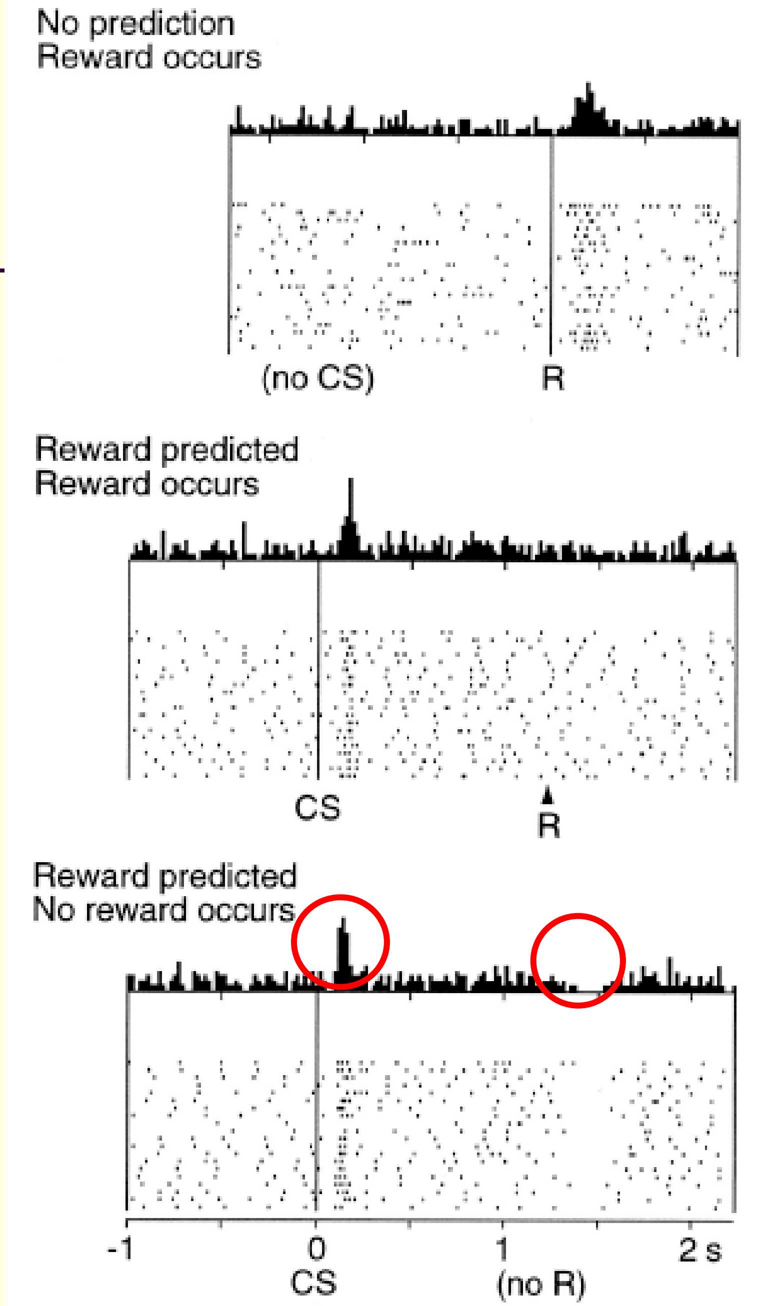
… Dopamine release follows the signal

… Dopamine firing after reward returns to baseline levels

When signal is not followed by reward…

…. Still get spike at signal

…. But firing dips below baseline at time when reward would normally appear



Source: Schultz, Dayan, Montague, *Science*, 1997

Role of Dopamine

- The ‘rush’ of dopamine

  Does not directly signal the magnitude of a reward…

  … but rather the deviation of reward from its expected value

Role of Dopamine

- The 'rush' of dopamine

  Does not directly signal the magnitude of a reward, but the deviation from expected value

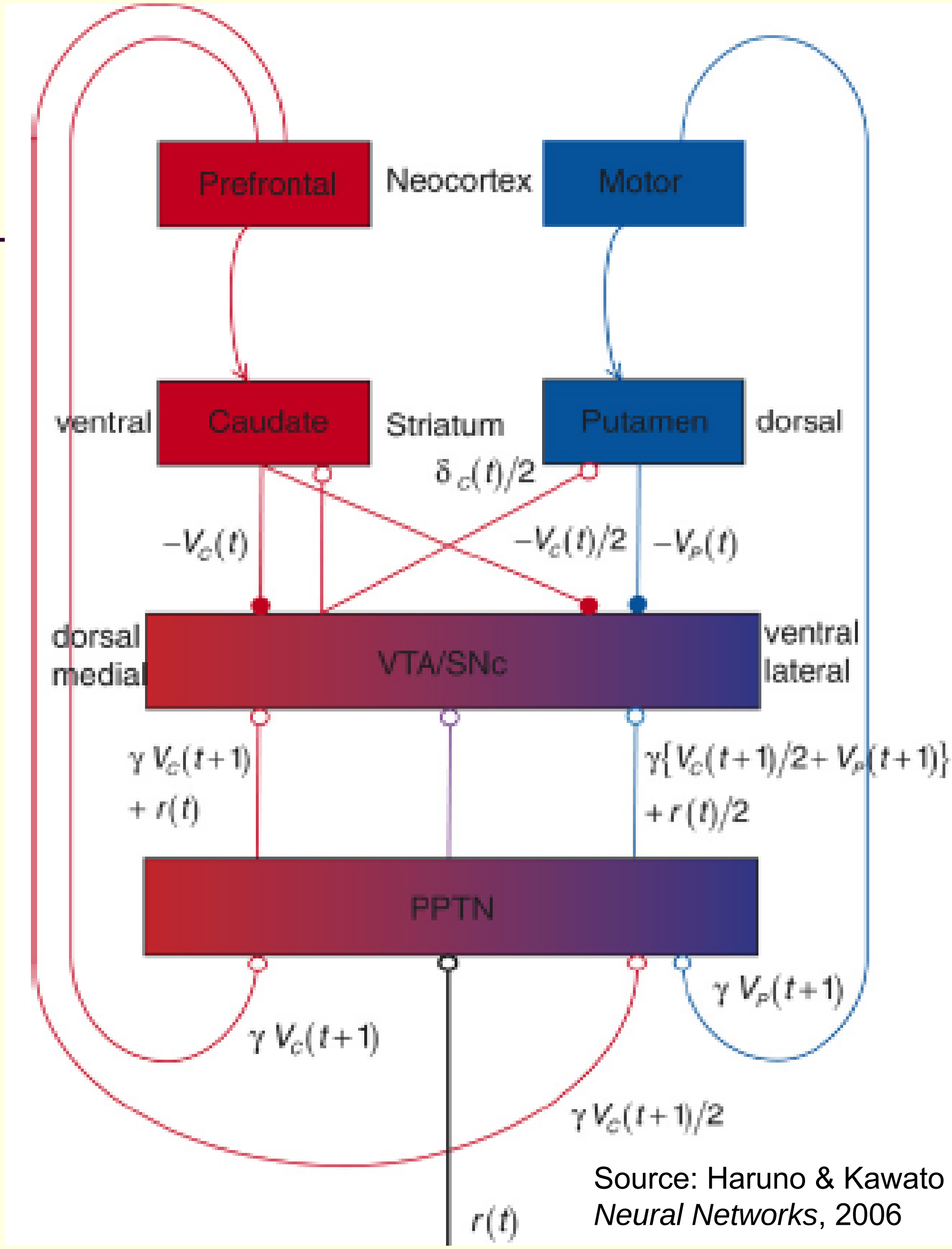
  - "Nearly all the best things that come to me in life have been unexpected." Carl Sandburg

  - "A man's delight in looking forward to and hoping for some particular satisfaction is a part of the pleasure flowing out of it, enjoyed in advance." Arthur Schopenhauer

Role of Dopamine

- Insights from such experiments led to development of formal models of reward learning
  - Early, simplest models
    - Temporal difference models
    - Dopamine response = Reward – E{Reward}
  - More recent models
    - Integrate several sources of learning in the brain
    - Increasingly formal, mathematical models of function
    - Used to generate predictions tested via monitoring methods

Leading to more formalized modeling of neural reward evaluation
and decision making



Source: Haruno & Kawato
Neural Networks, 2006

Neoclassical Pillars Revisited

- Rewards Expected vs. Rewards Received
  - Anticipated vs. Experienced utility
  - Hypothetical bias / consequentiality
- Context Dependent Preferences
  - Counterfactual information
- Malleable Preferences
  - Advertising & Promotion
  - Macro feedback to preferences via genetic predisposition
  - Therapeutic approaches to preference change

Utility: Anticipation vs. Actual

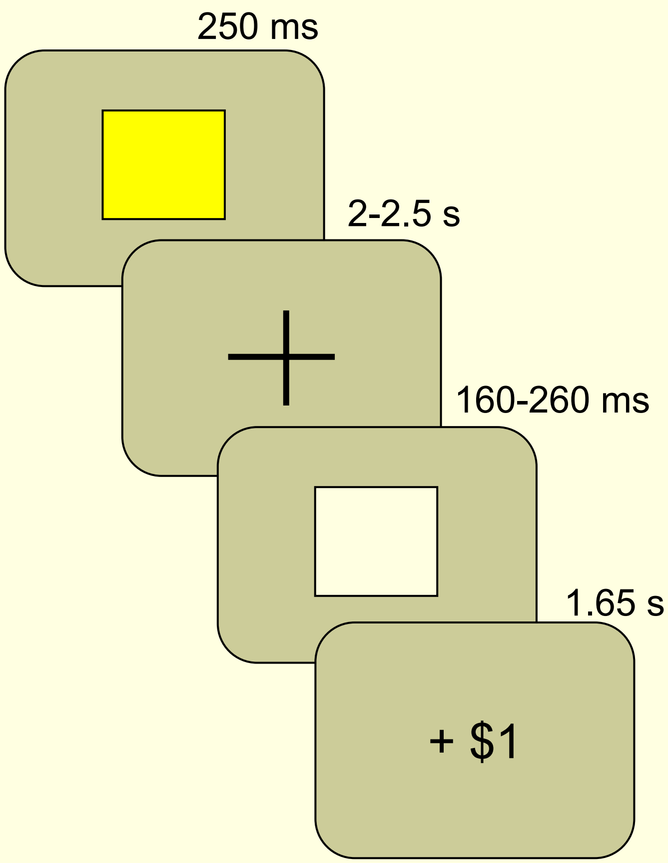
- Decisions driven by anticipated/expected utility
  - May deviate from actual experience
- Knutson et al. (2001 *NeuroReport*), O'Doherty (2004 *Curr. Opin. Neuro*)
  - Regions such as striatum, OFC, amygdala
    - Engage during anticipation, not receipt, of reward
      - Direct dopamine pathways
  - Ventral Medial Prefrontal Cortex
    - Engages during reward receipt

Hypothetical vs. Consequential

- Long-standing debate in environmental econ
  - Contingent valuation
  - Stated preferences more generally
  - Bias
  - Increased variance
- Study differences in neural activation patterns
  - If none, greater confidence in hypothetical
  - If different
    - Degree of difference
    - Source of difference
    - Questioning methods that minimize difference

Knutson et al. 2001

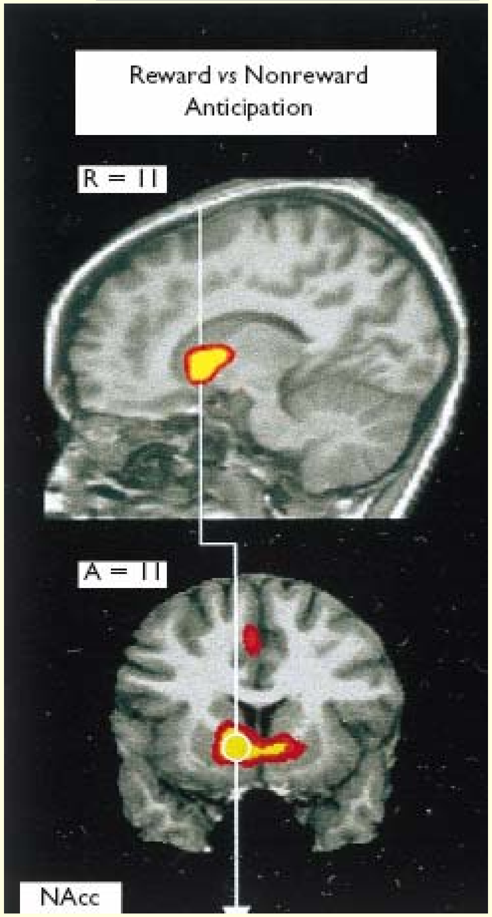
- If yellow square
  - Given $1 if press button quickly enough when white square appears
- If a blue square
  - No reward, but told to try to press the button before white square disappears



Differences in neural activity

When trials are rewarded..

- Anticipation phase
  - More activity in striatum for rewarded trials
    - Region w/ many dopamine neurons
    - Reward error signaling
  - Several other regions also different
    - Mesial frontal cortex (absolute reward values)
    - Amygdala (emotional)

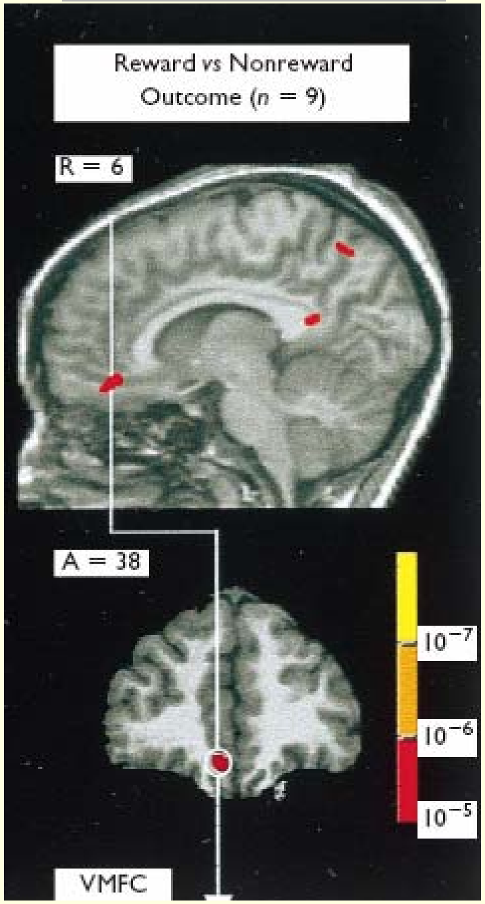


Source: Knutson et al. *Neuroreport*, 2001

Differences in neural activity

When trials are rewarded..

- Outcome phase
  - Fewer differences than anticipation
    - Less activity in orbitofrontal cortex
      - Relative reward magnitudes
    - Less activity in putamen
- Together suggests different pattern of neural engagement when rewards are not paid
  - Not the same task as most CV work



Source: Knutson et al. *Neuroreport*, 2001

Context Dependence

- Neoclassical theory posits utility as a function of absolute values
  - Experimental research suggests decisions interpret raw outcomes in context
    - Past outcomes and baseline position (gains vs. losses)
    - Peers, reference groups (The Joneses)
    - Counterfactual outcomes (regret & relief)
  - Inspired significant theoretical work
    - Khaneman & Tversky, Sugden, Koszegi & Rabin
- Dopamine learning models pave the way
  - Dopamine release impacted by reward expectation
    - Context can greatly impact expectation
      - → subsequent dopamine release

Coricelli et al. (2005 *Nat. Neuro*)

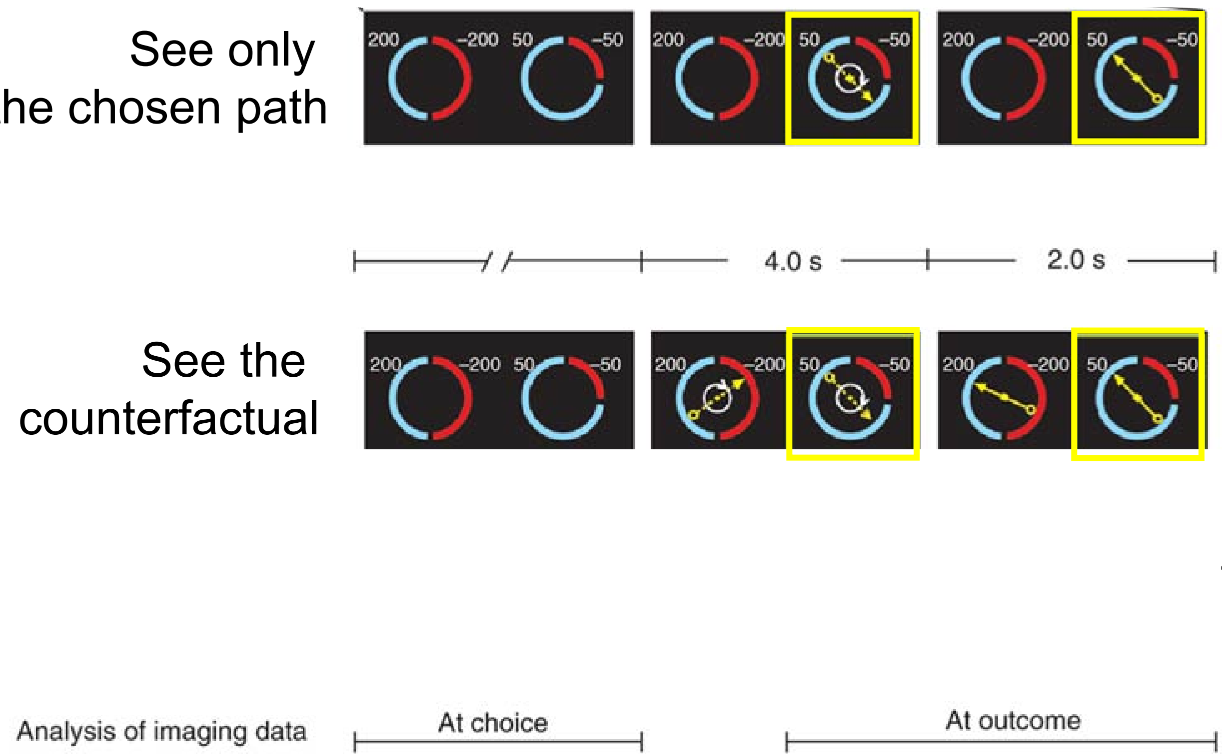
Choose b/w gambles

Watch spinner

Observe Outcome(s)

See only the chosen path

See the counterfactual

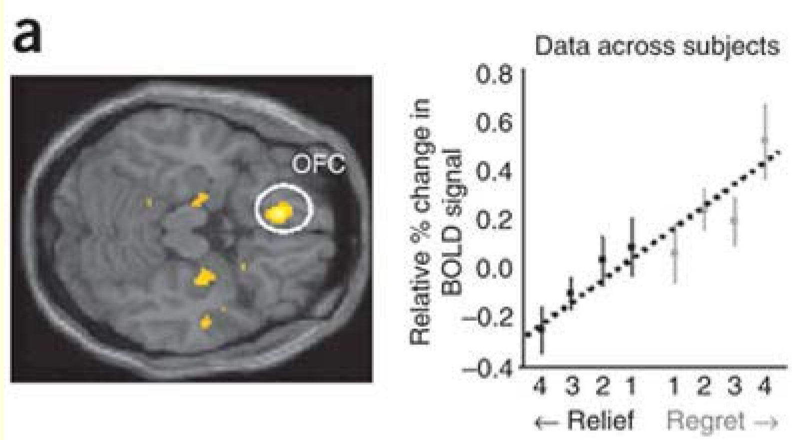


Happy – you won!

Regret – missed 4x the payout

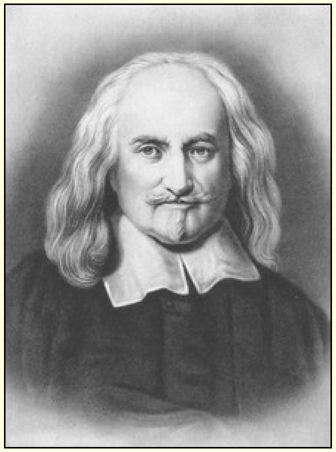
Counterfactual impacts activity

- Activity
  - Scales w/ degree of regret vs. relief
    - In OFC, ACC & hippocampus
- For decisions following ‘regretful’ outcomes
  - DLPFC & amygdala become more active



Preference Malleability

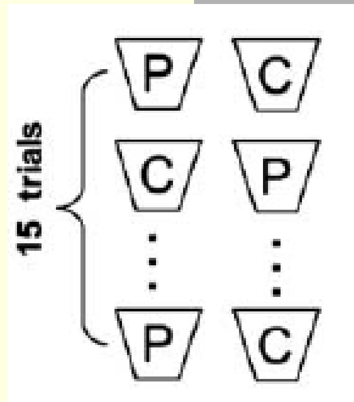
- Neoclassical econonomics treats preferences as complete & stable
  - "…consider men as if but even now sprung out of the earth, and suddenly (like mushrooms), come to full maturity, without any kind of engagement with each other." – Hobbes
- Simplifies welfare analysis
  - Evaluate proposed policies using existing, stable preferences to infer benefits and costs
- If proposed policies shift preferences
  - Incidentally or intentionally
  - Positive basis of welfare analysis becomes murkier

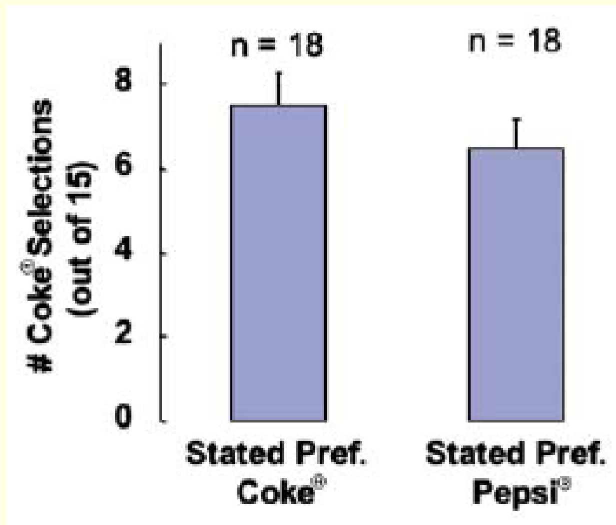


Thomas Hobbes
1588-1679

Preference Malleability

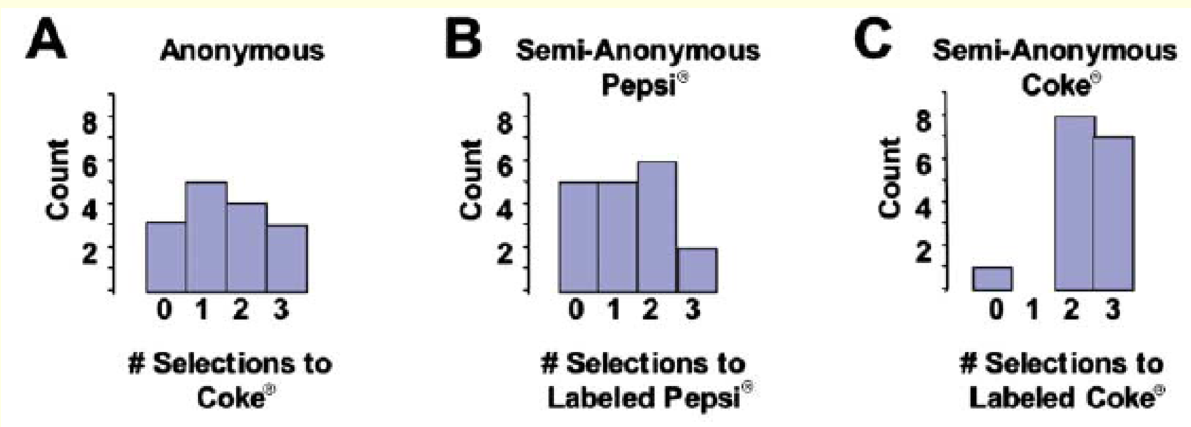
- McClure et al. (*Neuron* 2004)
  - Rework the Pepsi Challenge
  - Asked preference
    - Half preferred coke
  - Conduct blind taste test
    - Choices uncorrelated to stated preference





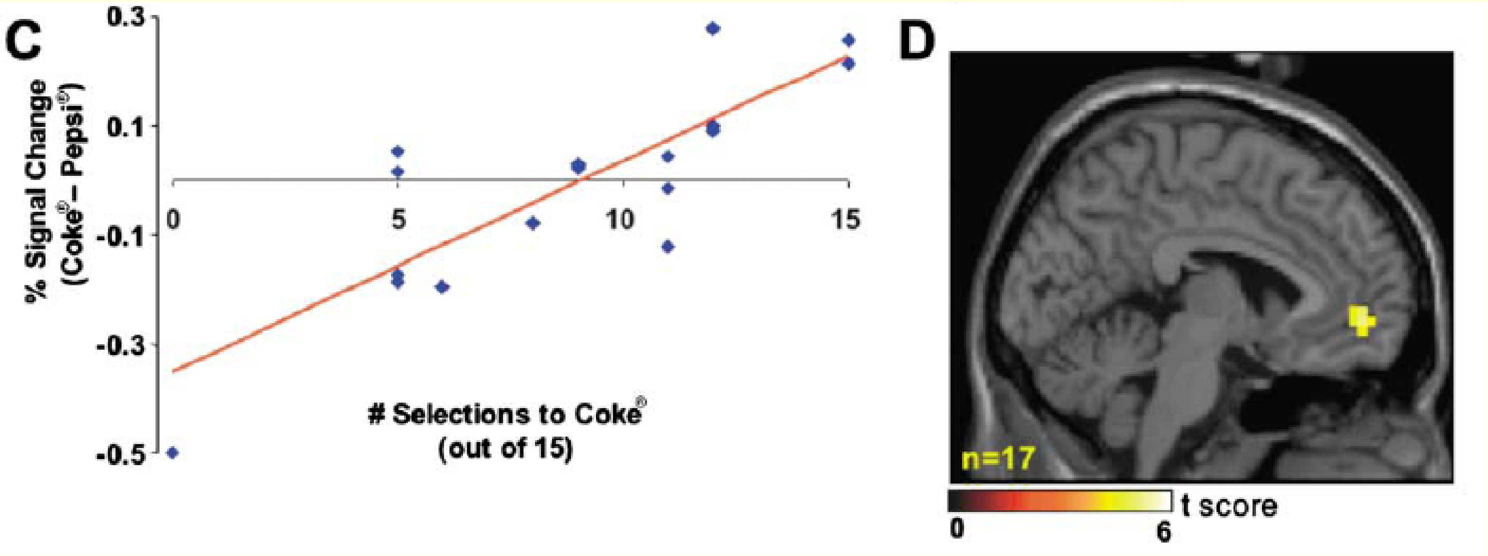
McClure et al. (2004)

- Then conduct 'semi-blind' test
  - 1 is clearly labeled with brand name
  - Subject told other could be Coke or Pepsi
    - It's always the same product
      - E.g., subject tastes labeled and unlabeled Coke



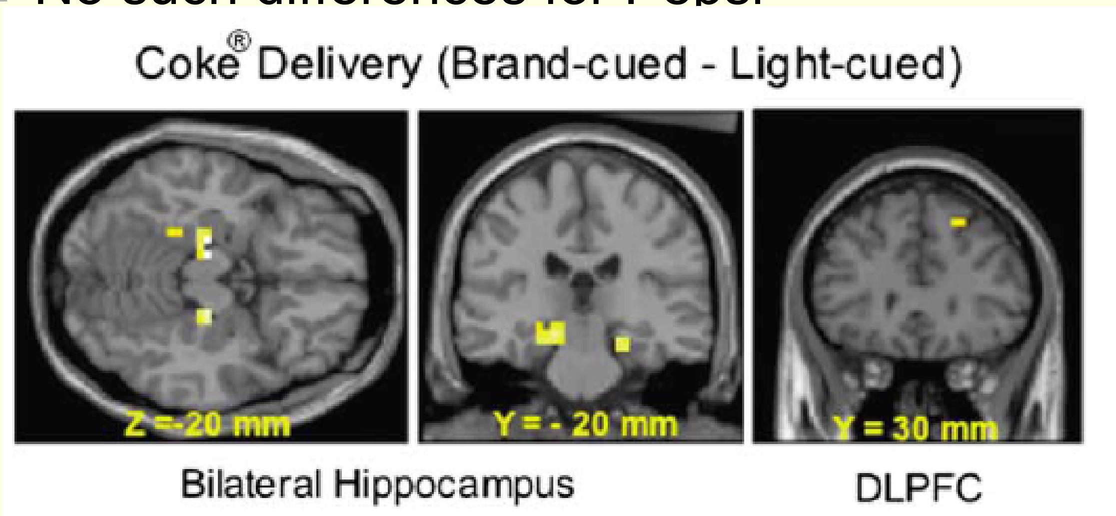
Pepsi Challenge in MRI

- Repeat blind & semi-blind treatments in MRI
  - Tube feeds soda into MRI
- Blind (Coke vs. Pepsi)
  - Activity in VMPFC higher for the brand preferred in blind taste test



Semi-blind Tests

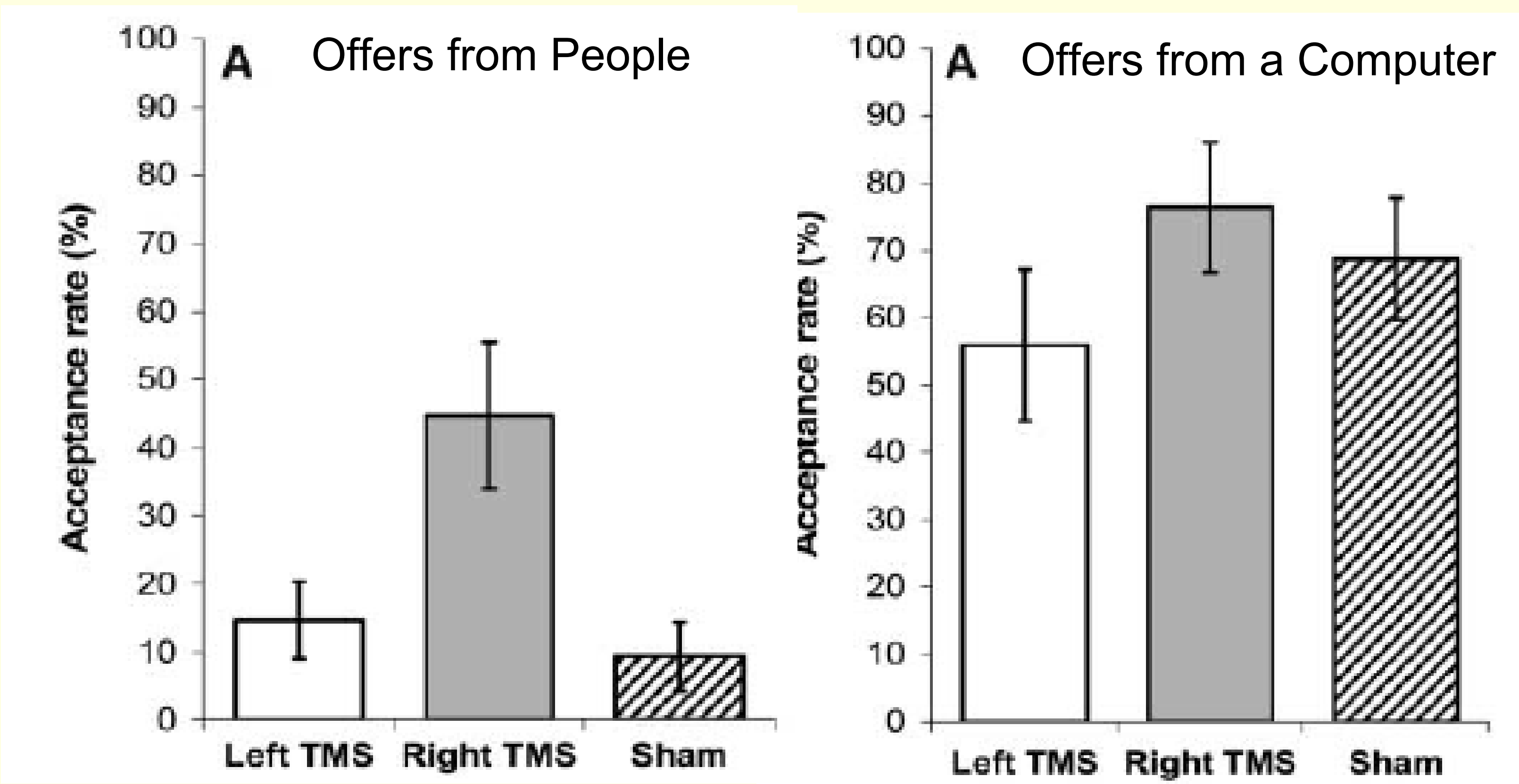
- Not surprisingly, no difference in VMPFC activity
  - For both Coke and Pepsi
- Compared to unlabeled Coke
  - Labeled Coke increases activity in
    - Hippocampus (memory center)
    - DLPFC (impulse control region)
  - No such differences for Pepsi



Therapeutic Preference Change

- Knoch et al. (2006, *J. Neuroscience & Science*)
  - Apply TMS to the right DLPFC
    - Control – apply to left DLPFC, apply a sham
  - Two experiments
    - Choose between more and less risky gambles
    - Respond to unfair ultimatum offers

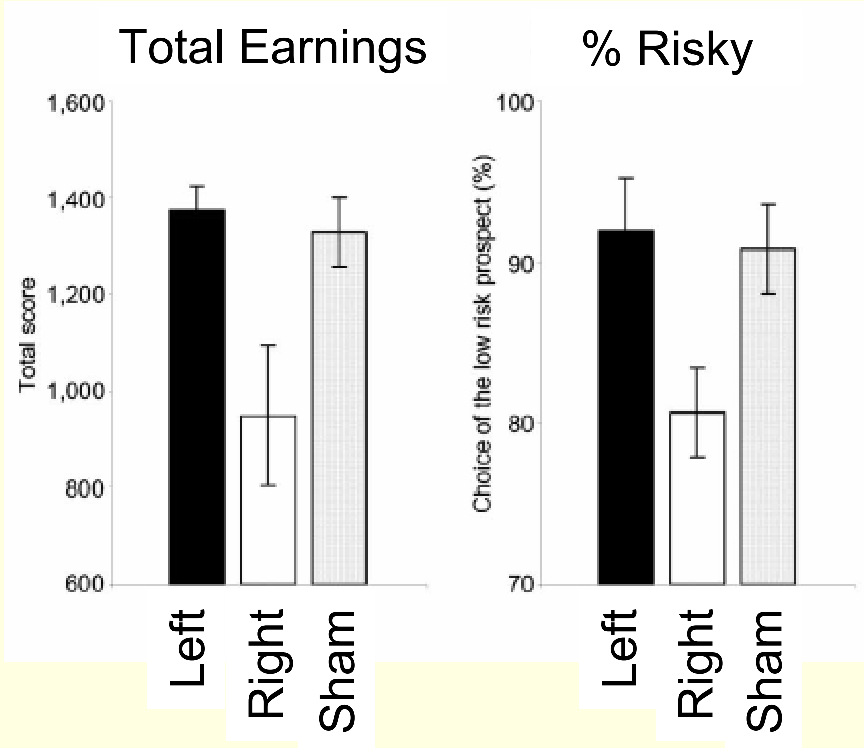
Ultimatum Responses



Source: Knoch et al. (2006, *Science*)

Risk Responses

- TMS of right DLPFC
  - Significantly more risky choices
  - Significantly realized earnings



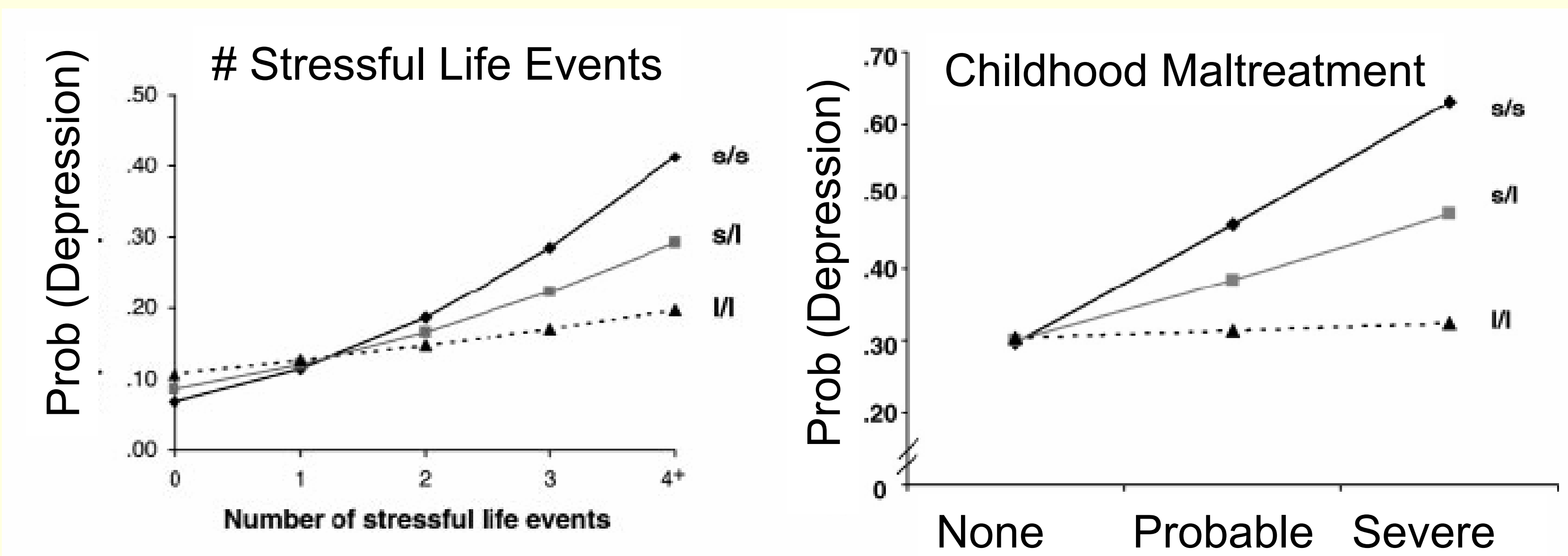
Source: Knoch et al. (2006, *J. of Neuroscience*)

Genetic Predisposition to Preference Δ

- Genotype-phenotype relationships in literature often fail to replicate
  - Environmental factors may mitigate gene function
- Caspi et al. (2003, *Science*)
  - Genotype: Serotonin polymorphism (5-HTT)
    - Affects how much serotonin stays in synapses
    - 2 long alleles (31% of population) vs. s/s (17%) & s/l (52%)
  - Phenotype: Major Depression or not @ age 26
    - Onset of depression = change in preference
  - Environmental factors: Stressful Life Events
    - Employment, financial, housing, health & relationship events
      - Measured from age 21 – 26
      - No difference in # of events by genotype
      - Excluded those with depression prior to age 21
    - Childhood maltreatment measured from 3 – 11

Caspi et al. (2003) results

- Stressful life events mitigate prob of depression
  - Macroeconomic feedback to preference structure
  - Economic depression ↔ neural depression loop?



Caspi et al. (2003) results

- Stressful life events mitigate prob of depression
  - Macroeconomic feedback to preference structure
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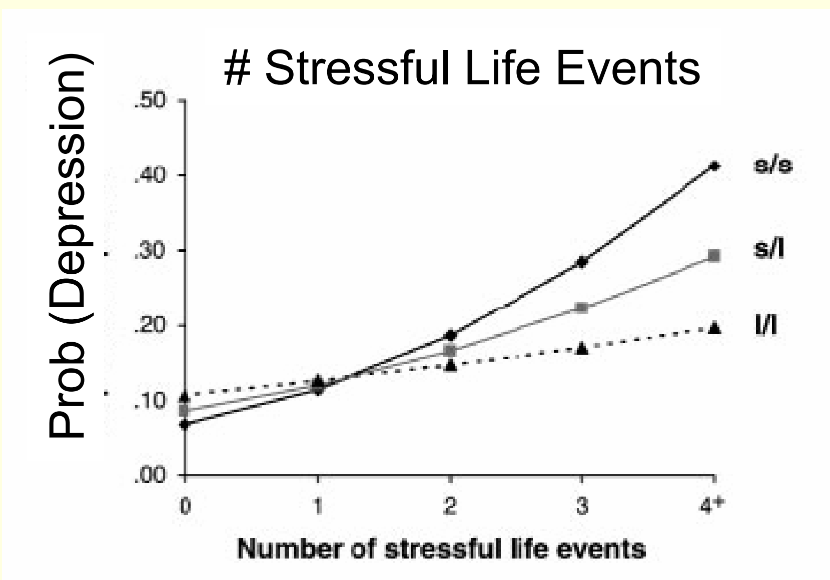
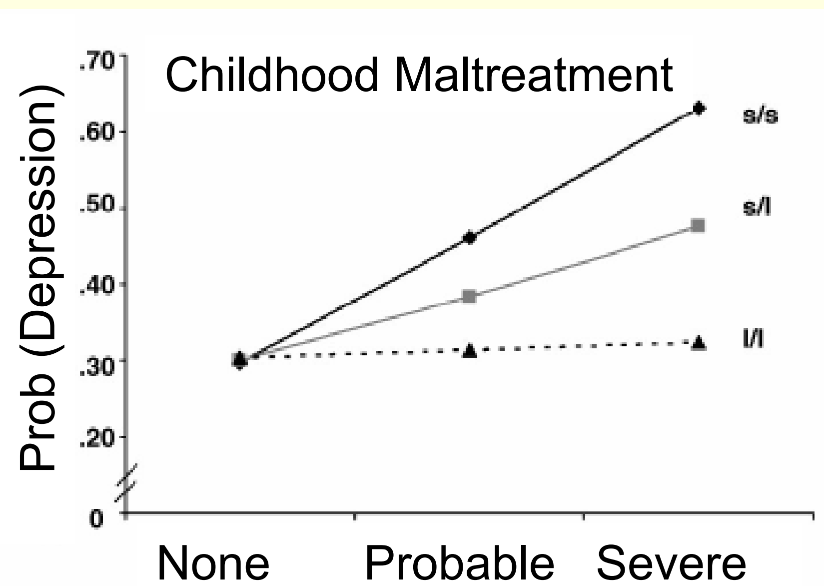
- Hariri et al. (‘02 *Science*) shows 5-HTT variation
  - Correlated to amygdala response to emotive stimuli





Welfare Thought Experiment

- Suppose a generic cola exists ….
  - Gov’t distributes to all citizens to satiation
  - No close substitutes or productivity effects (no caffeine)
  - Freely disposable (no pollution)
  - Perfect information (no cancer threats)

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- Suppose a generic cola exists ….
  - Gov't distributes to all citizens to satiation
  - No close substitutes or productivity effects (no caffeine)
  - Freely disposable (no pollution)
  - Perfect information (no cancer threats)
- Proposed Policy
  - Spend $1 billion on a promotional campaign
    - Pictures of beautiful people having fun w/ soda in hand
  - Traditional Cost – Benefit Analysis
    - Costs - $1 billion
    - Benefits - ??
      - Preferences assumed well defined & stable – promo useless
      - Information is perfect – no adjustments to fixed preferences
  - If campaign is effective as Coke advertising …
    - Is this a realistic analysis?

Thought Experiment (continued)

- Suppose gov't considers banning this now-beloved cola….
  - Estimate lost surplus from ban is $1 billion/yr
  - Cost of providing soda is $800 million/yr
    - Wouldn't appear to pass benefit-cost test

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- Suppose gov't considers an aversion campaign followed by a ban
  - Pictures of drab people @ econ conferences w/ soda in hand
  - Drives surplus to from $1 billion to $100 million
  - Aversion campaign costs $250 million
  - Campaign costs + lowered surplus levels < soda provision

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  - Campaign costs + lowered surplus levels < soda provision
- Many policy proposals may feature intentional or incidental effects on preferences
  - Can traditional welfare analysis still provide an appropriate ranking of possible policy options?

Conclusions

- Elegant symmetry consumer & firm problems in microeconomic theory
  - Firm behavior shaped by technology
  - Consumer behavior shaped by preferences

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- Theory of the firm
  - Great attention to how technology changes
    - Induced innovation to change technology
  - Measurement issues have led to a reticence to explore similar themes for consumer preferences
    - You can count output
    - You can't count utils
      - This may be slowly changing
      - The capability to measure physiological utility is arriving

Future of Env Policy Evaluation

Three possible paths could be followed …

1. Stick with the neoclassical approach
2. Start over with a decision framework derived from neuro-biological principles
3. Amend and augment neoclassical approach using insights from biomedical research

Thanks and Ongoing Work

- Thanks to ….
  - Resources for the Future
  - Ohio Agricultural Research & Development Center for financial support
  - Dan Burghart, David Beversdorf & Michael Tilley for feedback on paper
- Author's Related Multidisciplinary Work:
  - Understanding Human Response to Risk: A Multidisciplinary Approach
  - http://aede.osu.edu/people/roe.30/index.htm