Decision Making in Robots and Autonomous Agents

A Brief Survey of Models from Neuroeconomics

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What is Neuroeconomics?

• Studies that take the *process* of choice seriously
• Studies that make use of data on the processes by which choices are made

Content of the science of Neuroeconomics:
• Locating correlates of economic (decision theoretic) concepts in the brain
• Causal studies
• A structural model of simple choice
Method: Locating Economic Concepts in the Brain

- Run a behavioral experiment to get people to exhibit some behaviour
  - e.g. Punishment
- “Scan” (e.g., using fMRI) brain while they are doing so
- Find areas of brain whose activity correlates with behavior
- Conclude that this is where the related preference lives
  - Preference for equality (or punishment)
Recall: Ultimatum Game
(Sanfey et al., *Science* Vol. 300, 2003)

- Player A (Proposer) has $10
- Makes an offer to player B (Responder) of the form “I will take x and you take $10-x”
- Player B can either accept offer, or reject offer in which case and both get $0
Experiment with Ultimatum Game

• Responder’s brain activations measured by fMRI in a $10 UG.
• A responder faces each of three conditions ten times.
  – Offers from a (supposed) human partner
  – Random offers from a computer partner
• Research Questions: Which brain areas are more activated when subjects face.
  – fair offers (3-5) relative to unfair offers (1-2).
  – the offer of human proposer relative to random computer offer
• Method (very simplified):
  – Regression of activity in every voxel (i.e., 3D Pixel) in the brain on the treatment dummy (i.e., unfair offer dummy, human proposer dummy)
Ultimatum Game Experiment

A

12 sec

Reveal Fixation

6 sec

Reveal Partner

6 sec

Reveal Offer

6 sec

Reveal Options

6 sec

Reveal Outcome

Subject Decides

Accept Reject

Kelly gets $8
You get $2

Kelly gets $0
You get $0

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Ultimatum Game Experiment
Ultimatum Game Experiment:
Differences in brain activity between unfair and fair offers from a human proposer
Ultimatum Game Experiment

![Graph showing the relationship between Right Anterior Insula (contrast values) and Acceptance rates (%).]
Ultimatum Game: Some Results

- Regions showing stronger activations if subjects face unfair human offers relative to fair human offers (the same regions also show more activation if the unfair human offer is compared to unfair random offers).
- Bilateral anterior Insula, anterior cingulate Cortex
  - Emotion-related region
  - Insula also has been associated with negative emotions such as disgust and anger.
- Dorsolateral prefrontal Cortex (DLPFC)
  - Cognition-related region
  - Associated with control of execution of actions
  - Associated with achievement of goals.
- Unfair offers are more likely to be rejected if insula activation is stronger.
Causal Studies...
Oxytocin, Trust and Trustworthiness
(Kosfeld et al., Nature Vol. 435, 2005)

• Step 1: Based on evidence from human and animal studies authors made an informed guess about how certain hormones may affect specific social behaviors in humans.
  – Oxytocin is a hormone, which induces labor in human and nonhuman mammals, during lactation of young animals and during mating.

• Step 2: Conduct a placebo-controlled hormone study that isolates the specific impact. This provides causal information about the impact of the hormone
  – Oxytocin is conjectured to play a key role in different social behaviors
Investor Trustee Game
Investor Trustee Game

• Both subjects receive an initial endowment of 12 monetary units (MU). The investor can send 0, 4, 8 or 12 MU to the trustee.

• The experimenter triples each MU the investor transfers.

• After the investor's decision is made, the trustee is informed about the investor's transfer. Then the trustee has the option of sending any amount between zero and his total amount available back to the investor.
Investor Trustee Game

• E.g., if investor has sent 12 MU, the trustee possesses 48 MU (12 MU own endowment + 36 MU tripled transfer) and can, therefore choose any back transfer from 0 to 48 MUs.

• The experimenter does not triple the back transfer.

• Investor's final payoff = initial endowment – transfer to trustee + back transfer from the trustee.

• Trustee's final payoff = initial endowment + tripled transfer of the investor – back transfer to the investor.

• Each subject made 4 decisions in the same player role while paired with 4 different, randomly selected interaction partners.
Does Oxytocin Affect Reciprocity/Inequality aversion?

Answer: NO
Does Oxytocin Affect Investor Behaviour?

Answer: YES
Is Risk Aversion the Cause?

Risk experiment: Replace trustee by a random choice.

NO. Oxytocin seems to increase trust of first mover in the game.
Structural Model of Simple Choice

Choice

Stochastic Process

Valuation of options in “Common Neural Currency”

Memory

Reward Prediction Error

• A monkey is offered the choice between different amounts and types of juice
• For example 3 ml of water or 1 ml of Kool Aid
• Record choices from different pairs
• Record activity from neurons in orbitofrontal cortex (OFC)
Calculate Behavioural Tradeoff Between Different Types of Juice
Some Results
Some Results

• OFC neurons record ‘value’ of chosen option on a single scale
• Regression of activity on ‘utility’ of chosen object gives r-squared of 0.86
  – Better fit than just amount of juice.
• Other studies show this area (striatum) values other items
  – Choosing between gambles [Tom et al 2007]
  – Current vs delayed monetary rewards [Kable and Glimcher, 2007]
    – Food items [Plassman et al. 2007; Hare et al. 2009]
• Activity in this area can (weakly) predict choice between consumer goods (Levy et al. 2011)
Methods: What do we Learn about Human/Animal Choice?

Lesions, localized damage, gene knockout…

- e.g., experimental destruction of both amygdalas in an animal tames the animal, making it sexually inactive and indifferent to danger like snakes or other aggressive members of its own species
- e.g., humans with lesions of the amygdala lose affective (i.e. emotional) meaning
- e.g., knocking out the gene that makes a key protein for amygdala function makes rats relatively fearless
- e.g., hippocampus removal prevents experiences from being encoded in long-term memory
More Methods

• Brain stimulation (e.g., electrical stimulation of the amygdala elicits violence and aggressivity; at special loci, electrical brain stimulation is highly reinforcing)

• Single neuron measurement (e.g., track high frequency dopamine release in animal models, Schultz et al, Glimcher)

• Transcranial magnetic stimulation (TMS)

• EEG, PET, fMRI... (taking pictures of the active brain; e.g., McCabe, Houser, Ryan, Smith, and Trouard 2001).
Interesting Findings

Brain activity in the frontoparietal system and mesolimbic dopamine reward system predict behavior.
Variety of Neuroimaging Methods

- Electroencephalography (EEG)
- Magnetoencephalography (MEG)
- Transcranial Magnetic Stimulation (TMS)
- Positron Emission Tomography (PET)
- Structural Magnetic Resonance Imaging (MRI)
- Functional Magnetic Resonance Imaging (fMRI)
Critique: Why Neuro?

• Inspiration
  – Little new theory, except maybe optimal coding

• Breaking up the problem
  – e.g., relation between oxytocin and trust game

• Ruling out all mechanisms that could generate a mapping
  – Hard, few examples include eye tracking and backwards induction

• Robustness/Out of Sample Predictions
  – Issues such as selection of priors makes this hard too

• Creating a Brain Map
  – We are still far from being able to establish any of this conclusively
An eminent philosopher of science once encountered a noted decision theorist in a hallway at their university. The decision theorist was pacing up and down, muttering, “What shall I do? What shall I do?”

“What’s the matter, Howard?” asked the philosopher.

Replied the decision theorist, “It's horrible, Ernest – I’ve got an offer from Harvard and I don’t know whether to accept it.”

“Why, Howard,” reacted the philosopher, “you’re one of the world’s great experts on decision-making. Why don’t you just work out the decision tree, calculate the probabilities and expected outcomes, and determine which choice maximizes your expected utility?“

With annoyance, Howard replied, “Come on, Ernest. This is serious.”
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