PHIL 474/673 -NATURAL RATIONALITY – WEEK 9 – MARCH 8

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NEUROECONOMICS AND RATIONALITY

Men ought to know that from nothing else but [from the brain] come joys, delights, laughter and sports, and sorrows, griefs, despondency, and lamentations. And by this, in an special manner, we acquire wisdom and knowledge, and see and hear, and know what are foul and what are fair, what are bad and what are good, what are sweet and what unsavory. Some we discriminate by habit, and some we perceive by their utility.

- Hippocrates

A true theory of economy can only be attained by going back to the great springs of human action – the feelings of pleasure and pain.
(Jevons, 1866)

One may wonder whether Adam Smith, were he working today, would not be a neuroeconomist. (Rustichini, 2005)

1 A note on goals

1.1 Kinds of goal-orientation

- From (McFarland & Bösser, 1993)
- A system implements *goal-achieving* can recognize the goal or change its behavior when the goal is achieved
- A system implements *goal-seeking* when it is able to reach a goal (no representation needed)
- A system implements *goal-directed* when it entertains an explicit representation of the goal.

1.2 Rationality and goals

- Classical rationality: rational action is only *goal-directed*
- Bounded rationality (satisficing): *goal-achieving*
- Situated perspective: *goal-seeking*

2 Neuroeconomics

- The study of the neural mechanisms of decision-making *and* their economic significance

2.1 A very short history

2.1.1 Prehistory:

- Ramsey's psychogalvanometer
- *"it is, I suppose, conceivable that degrees of belief could be measured by a psychogalvanometer or some such instrument" (Ramsey, 1926, p. 161)*
- Edgeworth's hedononimeter:
- *"To precise the ideas, let there be granted to the science of pleasure what is granted to the science of energy; to imagine an ideally perfect instrument, a psychophysical machine, continually registering the height of pleasure experi- enced by an individual, exactly according to the verdict of consciousness, or diverging therefrom according to a law of errors. From moment to moment the hedonimeter varies; the delicate index now flickering with the flutter of the pas- sions, now steadied by intellectual activity, low sunk whole hours in the neighbor- hood of zero, or momentarily springing up towards infinity. The continually indicated height is registered by photographic or other frictionless apparatus upon a uniformly moving vertical plane. Then the quantity of happiness between two ep- ochs is represented by the area contained between the zero-line, perpendicular thereto at the points corresponding to epochs, and the curve traced by the index . . . The integration must be extended from the present to the infinitely future time to constitute the end of pure egoism." (Edgeworth, 1881/1961, p. 101)*
- (Hayek, 1952) "The Sensory Order": how the sensory order (mind) leads to social order (society)

2.1.2 Late Antiquity:

- Connectionism, Artificial Neural Networks ('90s)

2.1.3 Renaissance:

- (Damasio, 1994; Damasio *et al.*, 1996; Shizgal, 1997)

2.1.4 Modern times:

- (Platt & Glimcher, 1999),(McCabe *et al.*, 2001) (Glimcher, 2003a)
- Among the candidate for the Webster's Dictionary Word of the Year for 2006 (beaten by "CrackBerry")

2.2 Conceptual roots

- **Economics**: The *"science which studies human behavior as a relationship between ends and scarce means which have alternative uses"* (Robbins, 1932). Microeconomics: agent-based economics. Bentham's utility, Adam Smith's moral sentiments, (Bentham, 1789/2007; Smith, [1759] 2002)
- **Bioeconomics**: biological account of economic phenomena, synthesis of biology and economics. From Veblen (Veblen, 1898, 1899) to Ghiselin (Ghiselin, 1999; Landa & Ghiselin, 1999). Reward/fitness/utility.
- **Experimental/behavioral/cognitive economics**: descriptive and experimental account of economic phenomena (Smith, 1965, 1986, 1991a, 1991b)
- **Ethology/behavioral ecology:** modeling animal behavior as economic. Optimal foraging theory try to *determine "which patches a species would feed and which items would form its diet if the species acted in the most economical fashion" (MacArthur & Pianka, 1966, p. 603).* Neural computation for foraging (Gallistel, 1994). Ex: (Harper, 1982) Ducks that plays Nash Equilibrium (Ideal Free distribution).

- **Behavioral/cognitive psychology:** mechanisms and biases of decision-making (Ainslie, 2001; Kahneman *et al.*, 1982; Kahneman & Tversky, 1979)
- **Neuroscience**: scientific study of the nervous system. Interested in neural substrate of decision-making, neural representation of economic parameters (value, utility, probability, uncertainty, etc.) (Damasio, 1994; Damasio *et al.*, 1996; Montague & Berns, 2002)
- **Computer science**: neural modeling of decision-making, realistic algorithms.
- **Business/marketing**: prediction and understanding of consumer and economic behavior ("neuromarketing")(Lee *et al.*, 2007)

2.3 Three Definitions

- *"an emerging transdisciplinary field that uses neuroscientific measurement techniques to identify the neural substrates associated with economic decisions" (Zak, 2004, p. 1737)*
- *"Economics, psychology and neuroscience are converging today in to a single unified discipline with the ultimate aim of providing a single, general theory of human behavior. (…) The goal of this discipline is thus to understand the processes that connect sensation and action by revealing the neurobiological mechanisms by which decisions are made". (Glimcher & Rustichini, 2004, p. 447)*
- *"the program for understanding the neural basis of the behavioral response to scarcity" (Ross, 2005, p. 330)*

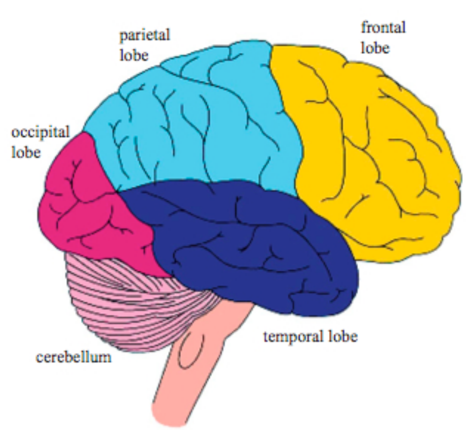
2.4 Research program

- *Standard View:* neuroeconomics explains how humans and other animals follow (or fail to follow) standards of rationality such as decision theory and game theory (Zak, 2004 : 1740). Neural mechanisms account for the formal rationality of irrationality of behavior.
- *Adaptive View*. Mechanisms uncovered by neuroeconomic researches are (or at least could be) adaptations to economic parameters. Neural mechanisms account for the natural rationality or irrationality of behavior. Just as a bird's wing embodies information about gravity and air viscosity, brain functioning embodies information about the social and physical environment. Thus, some robust findings in neuroeconomics can be construed as candidate for adaptive explanations. Neuroeconomics is thus the study of neural mechanisms by which biological agents find their way in the economy of nature (Hardy-Vallée, 2007, forthcoming-b).
- *Ex*: Probability matching as an adaptation to radical uncertainty: [partial observability and non-stationarity]. See (Hardy-Vallée, 2007, forthcoming-a)

3 The deciding organ

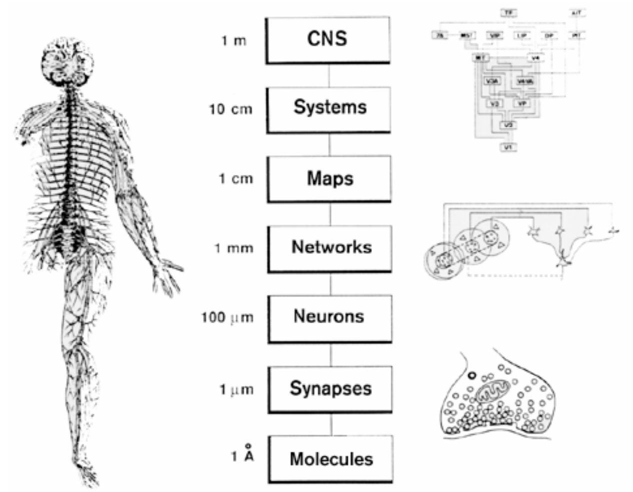
3.1 Basic facts

- 20-25% of the energy used by the body for about 3 pounds.
- 100 billion neurons in the human brain
- Each neuron is directly connected to between 1000 and 10 000 other neurons.



- White matter (axons and dendrites) + grey matter (neurons) 40% of the brain, 94% of the brain's oxygen
- Cortex: outer surface of the brain used for information processing and higher mental functions
- Four cortical lobes: the frontal, temporal, parietal and occipital
- Hypothalamus controls *autonomic nervous system*

3.2 Hierarchical system: ➔



3.3 Limbic system

- Primary emotional responses emanate from the brain's limbic structures.
- Located in the medial temporal lobe
- *Amygdala* (associated with positive and negative emotions)
- *Hippocampus* (associated with long-term memory),
- *Cingulate cortex* (attention and error detection)

3.4 Measurement of brain activity

- PET, fMRI, EEG/ERP, intra or extracellular recording of electrical activity of single neurons, blood samples, lesions, rTMS.

4 Two persepectives on neuroeconomics: neural economics and economic neuroscience

4.1 Neural economics

- Economic modeling uses a single-system perspective: utility maximization.
- Precise concepts of utility, value, uncertainty, risk, probability, formal models (RCT)
- <u>But</u>, classical economics lacks mechanistic descriptions and causal models.
- "Inferring preferences from a choice does not tell us everything we need to know"(Camerer *et al.*, 2004, p. 563).
- Neural economics: neural substrates for RCT-like cognition, mechanistic account, realistic, causal (not purely logical).

4.2 Economic neuroscience

- Neuroscience: multiple-system perspective (Against the sense-model-plan-act)
- More reliable measurement techniques than surveys
- Ex. Automatic (fast, parallel, domain-specific, robust) vs. controlled processes (slower, serial, domain-general, flexible).
- Affective (subcortical) and cognitive (prefrontal) systems

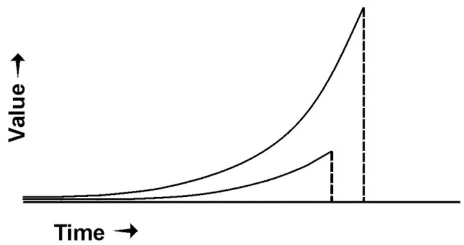
- (Rudebeck *et al.*, 2006): separate systems for effort (ACC) vs. delay (orbitofrontal cortex, OFC) decision costs.
- Economic neuroscience: highlight the need for the values of each alternative action to be mapped onto a single dimension (a currency, such as utility).

4.2.1 Ex: the Ultimatum Game (Sanfey *et al.*, 2003)

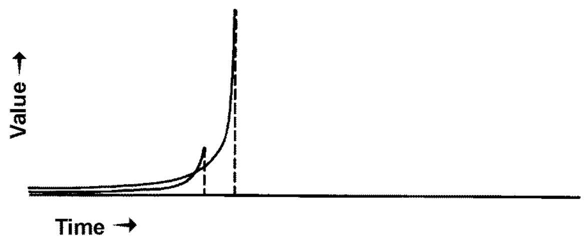
- In the UG (Güth et al., 1982), a first player (the Proposer) offers a fraction F (>0) of a money amount M; the second player (the Responder) may either accept or reject the proposal. If the Responder accepts, he keeps F while Proposer keep the difference (M-F). If he rejects, both players get nothing. According to game theory, the subgame perfect equilibrium (a variety of Nash equilibrium for dynamic game) prescribes that the rational agent must behave as following:
- 1) The Proposer should offer the smallest F possible (in order to keep as much money as possible)
- 2) The Responder should accept any F (because a small amount should be better than nothing)
- **Behavioral data**
- While Proposers offer about 50% of M, Responders tend to accept these offers while rejecting most of the "unfair" offers (less than 20% of M).
- **Neural data**
- "Moral disgust": activation of **anterior insula (AI),** associated with negative emotional states like disgust or anger. More active when unfair offers are proposed, significantly lower when the proposer is a computer
- Offers and their rejection are associated with greater skin conductance (van 't Wout et al., 2006)
- Correlated with the degree of unfairness and with the decision to reject unfair offers
- Non-invasive lesions of the vMPFC augment acceptance of unfair offers (Koenigs & Tranel, 2007). Thus without emotional modulation, subjects feel less 'moral disgust'.
- **Dorsolateral prefrontal cortex (DLPFC)**, associated with cognitive control, attention, and goal maintenance;
- **Anterior cingulate cortex (ACC)**, associated with cognitive conflict, motivation, error detection and emotional modulation
- *Neural economics* perspective: interaction between cognitive (DLPFC), affective (AI), and "mediator" (ACC) system.
- *Economic neuroscience* perspective: one can graph the utility functions of proposers/responders (greediness is unvalued, fairness is valued)

4.2.2 Hyperbolic discounting

- Hyperbolic discounting = subjects generally prefer smaller, sooner payoffs to larger, later payoffs when the smaller payoffs would be imminent; when the same payoffs are distant in time, people tend to prefer the larger, even though the time lag from the smaller to the larger would be the same as before. Associated with Impulsivity, lack of free will. From (Ainslie, 2001):



Conventional (exponential) discount curves from a smaller-sooner (SS) and a larger-later (LL) reward. At every point their heights stay proportional to their values at the time that the SS reward is due.



Hyperbolic discount curves from an SS and an LL reward.. The smaller reward is temporarily preferred for a period just before it's available, as shown by the portion of its curve that projects above that from the later, larger reward.

- Neuroeconomic explanation: (McClure *et al.*, 2004a) "Limbic grasshopper" and "prefrontal ant".
- Parts of the limbic system associated with the midbrain dopamine system, including paralimbic cortex, are preferentially activated by decisions involving immediately **available rewards**. In contrast, regions of the lateral prefrontal cortex and posterior parietal cortex are engaged uniformly by **intertemporal choices** irrespective of delay.
- Implication for policy-making: *"Rather than asking people if they want to start saving right away, companies should ask people if they want to opt into a savings plan that begins in a few months' time. This allows people to make decisions about the future without contemplating the present, bypassing our irrational emotions. (…) After three years, average savings rates jumped from 3.5% to 13.6%."* (Lehrer, 2006)

5 Important findings

5.1 General

- Importance of emotions, as guide for actions: the "Affect Heuristics" (Slovic *et al.*, 2002)
- Human and computer partners do not elicit the same neural-affective reactions (Rilling *et al.*, 2004).
  - Ex: in a Prisoners' Dilemma, the anteroventral striatum, rACC, and OFC were activated more by reciprocated social cooperation than by a $2 reward in a nonsocial context.

- Social emotions and moral attitudes are important in economic interactions: cooperation, fairness, altruism and trust. Markets are "morality in action" (Zak, 2007)
- Dissociations of decision-making processes.
- Interactions between affective/cognitive systems, Prefrontal/subcortical systems (e.g.: Risk as feeling, Risk as analysis)
- Neuroeconomic data explain "paradoxes" and "violations of rationality".

5.2 Individual rationality

5.2.1 Purchasing (Knutson *et al.*, 2007)

- 3 areas:
- nucleus accumbens (anticipation of pleasure)
- medial prefrontal cortex (balancing gains and losses)
- insula (pain registration).
- Product desirable: nucleus accumbens
- 'Fair' price: more activity in medial prefrontal cortex, less in the insula
- 'Unfair price': more activity in the insula, less in medial prefrontal cortex
- High medial prefrontal cortex activation predict purchase
- High insula activation predicts no-purchase.

5.2.2 Preferences for cultural goods

- Coke vs. Pepsi: Coke labels make drinks tasting better (McClure *et al.*, 2004b).
- *"The receipt of cultural objects such as art cannot be considered a primary reward, yet these objects nonetheless elicit activity in the in the same neural structures also activated by receipt of primary reinforcers."*(Montague *et al.*, 2006, p. 420)
- Loss of money can be aversive: stimuli that acquire reinforcing properties through social communication and interaction, such as money, can effectively influence aversive learning (Delgado *et al.*, 2006)

5.2.3 Perception as decision

- Lateral intraparietal area (LIP) activity predicts *visual-saccadic decision-making, encode the desirabilities of making particular movements.* (Glimcher, 2001, 2003b; Platt & Glimcher, 1999)
- Compare with Tversky and Kahmenan: decision as perception

5.2.4 Payoff and outcomes

- Attitudes about payoffs (gain/loss) and beliefs about the likelihood of outcomes (risk and ambiguity) interact (risk-aversion in gains and risk-seeking in losses) "*the brain does not honor a prevalent assumption of economics—the independence of the evaluations of payoffs and outcomes."* (Smith *et al.*, 2002)

5.2.5 Risk and ambiguity

- decision making under ambiguity does not represent a special, more complex case of risky decision making; instead, these two forms of uncertainty are supported by distinct mechanisms. (Huettel *et al.*, 2006)

5.2.6 TD-learning predict dopaminergic activity.

- See (Montague & Berns, 2002; Montague *et al.*, 2004; Montague, 2006)
- midbrain dopaminergic pathways broadcast in different brain areas an error signal similar to those displayed by temporal difference (TD) algorithms (Sutton & Barto, 1987, 1998).
- Imaging studies indicates that short, phasic activations of DA neurons respond selectively to prediction errors:
- TD model uses sensory inputs to predict a discounted sum of all future rewards.
- The difference between successive value predictions is computed and constitutes an error signal.
- The learning rule updates the value function (the function that maps state-action pairs to numerical values) according to the prediction error

5.3 Social rationality

5.3.1 Institution matters

- Different kinds of auctions modulate heart rates differentially. The economic behavior of individuals in English (ascending) auctions is less mediated by emotional factors than in Dutch (descending) auctions (Smith & Dickhaut, 2005). Heart rate reflects anticipation of bad outcomes.

5.3.2 Cooperating

- people enjoy cooperation in Prisoner's Dilemma. Rewarding effects of arranging and/or experiencing a mutually cooperative social interaction.

5.3.3 Trust

- Rules of the trust game:
  - In a two players, one-shot Trust Game (Berg *et al.*, 1995) DM1s (Decision-Makers one) decide how much, if any, of a certain amount of money they would like to transfer to DM2s. The transferred money is tripled, and DM2s decide how much, if any, they give to DM1s.
- Game-theoretical norms:
  - Game Theory states that as rational agents, DM1s anticipate that DM2s are greedy; hence, they would keep all transferred money. Thus DM1s should send nothing to DM2s, and would they send anything, DM2s should keep all of it.
- Behavioral results:
  - DM1s invest about 50% of their money and get more or less what they invest (Camerer, 2003). In double-blind condition, about one third of the DM2s reciprocated and sent back more than what DM1s give them (Berg *et al.*,

1995). The more they reciprocate, the more trust they build, and conversely, less reciprocity entails less trust.

- Cognitive processes:
  - trust and reciprocity (TR) hypothesis (McCabe *et al.*, 2003): Agents really have the intention to trust, to reciprocate and to be trustworthy, they have beliefs that the others will be so, and they interpret them as intentionally trustworthy
  - "intention to trust", or benevolent reciprocity send signal of trustworthiness. Players build models of other players, based on repeated interaction (King-Casas *et al.*, 2005).
- Neuronal processes
  - The trust game activates the head of the caudate nucleus (King-Casas *et al.*, 2005). Signals in the caudate reflect the development of a model of the other DM. (from reactive signal to anticipatory signals).
  - increased activity in the caudate nucleus — a region involved in the brain's reward pathway — of the trustee was directly correlated with the trustworthiness of the investor's behaviour.
  - medial prefrontal regions are differentially activated when cooperative DMs face other human vs. computer DMs (more activation for humans), while low-cooperative subjects have similar activation (McCabe *et al.*, 2001)
- Molecular processes:
  - Trust is increased by oxytocin (Zak *et al.*, 2005). There is also an increase in oxytocin in DM2 if DM1 "trusts" her by investing a lot. Oxytocin levels are higher in subjects who receive a monetary transfer that reflects an intention of trust relative to an unintentional monetary transfer of the same amount.
  - 2% of subjects studied are pure non-cooperators (keep everything)
  - Neuroactive hormone involved in bonding, attachment, recognition. Modulates social cognition and increase social competence in autistic subjects (Hollander *et al.*, 2006; Kirsch *et al.*, 2005).

5.3.4 Costly punishment

- "revenge tastes sweet": in the trust game, players are ready to “invest” in punishing untrustworthy player, and this punishing activated the nucleus accumbens (associated with pleasure), while at the same time activating prefrontal cortex and orbitofrontal cortex (cost evaluation).

5.3.5 Neuroscience in economics: four advantages (from Camerer, 2004)

- neuroscientific measurements are "asking the brain, not the person"
- neuroeconomics research will ideally be able to link hypotheses about specific brain mechanisms (location, and activation) with unobservable intermediate variables (utilities, beliefs, planning ahead), and with observable behavior (such as choices).
- may reveals that economic choices which are considered different in theory are using similar brain circuitry. (Ex: hyperbolic discounting and non-reciprocal altruism (Takahashi, 2006)).

- add precision to functions and parameters in standard economic models.

6 Kinds of utility

"the notion of value is to our science as that of energy is to mechanics" (Jevons, 1905)

6.1 Economics

- Kahneman, Wakker, and Sarin (1997) distinguish between
- **Experienced** utility: hedonic content, moment-to-moment flow of pleasure or pain
    - **Instantaneous** : continuous experienced utility from sensory input, the way people feel about experiences in real-time
    - **Remembered**: memory of experienced utility, utility, which influences post-decision evaluations (e.g., regret and disappointment with a decision outcome);
    - **Predicted**: anticipation or prediction of experienced utility
- **Decision** : the utility influencing (or revealed by) the actual decision
    - Unclear notion: sometimes it means rational-choice theory value, sometimes objective gains and loss, sometimes the internal representation of gain vs. loss, sometimes the motivation, sometimes the value (as opposed to reward).

6.2 Neuroeconomic perspective: (Tom *et al.*, 2007b)

- **Predicted**: neural activity involved in the anticipation of immediate outcomes
- **Experienced**: neural representation of actual experience of gains or losses
- **Decision:** brain systems that represent potential losses versus gains when a decision is being made (the computation of 'what to do')
- **Multiple utility functions**: depending on the task, economic value can be represented in different areas. ('look on your left' and 'buy this shirt' can be processed by different areas).

6.2.1 Example: loss-aversion

- vmPFC: anticipation of emotional impact (*anticipated* utility) (Naqvi *et al.*, 2006)
- Amgydala: registering emotional impact (*experienced* utility) (Ibid.)
- midbrain dopaminergic neurons: computing the value of reward (*decision* utility) (Tom *et al.*, 2007a)

6.3 Reward: three functions

- 1) elicit approach and consummatory behavior. (*motivation*)
- 2) increase the frequency and intensity of behavior leading to such objects and they maintain learned behavior by preventing extinction. (*learning*)
- 3) induce subjective feelings of pleasure and positive emotional states (*hedonic affect*)

6.4 Reward vs. value (from Montague *et al.*, 2006)

- **Reward**: refers to the immediate advantage accrued from the outcome of a decision (e.g., food, sex, or water)
- **Value**: estimate about how much reward (or punishment) will result from a decision, both now and into the future.
- *"value incorporates both immediate and long-term rewards expected from the decision. So reward is more like immediate feedback, whereas value is more like a judgment about what to expect."* (Montague *et al.*, 2006, p. 419)
- Maybe value is empty without reward, while reward is blind without value…

6.5 Reward, value and goals

- Goal-achieving: reward / experienced utility
- Goal-seeking: value / predicted + decision utility
- Goal-directed: Desire (cognitive value) / cognitive representation of predicted + decision utility. Goal can behave as higher-order rewards

7 Main references:

- First experiments: individual decision-making (Platt & Glimcher, 1999) and social exchange (McCabe *et al.*, 2001)
- Conceptual foundations: (Glimcher, 2003a; Glimcher & Rustichini, 2004)
- Individual decision-making: (Glimcher *et al.*, 2005)
- Trust/investment game: (King-Casas *et al.*, 2005; Zak *et al.*, 2004)
- Prisoner's dilemma: (Rilling *et al.*, 2002)
- Ultimatum Game: (Sanfey *et al.*, 2003)
- Molecular: (Zak *et al.*, 2005)
- TD Learning/dopaminergic neurons: (Bayer & Glimcher, 2005; Egelman *et al.*, 1998; Montague *et al.*, 2004; Schultz, 2001; Waelti *et al.*, 2001)
- Economics and Neuroeconomics: (Camerer *et al.*, 2005; Camerer *et al.*, 2004)
- General Review: (Sanfey *et al.*, 2006)

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