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Cognitive Neuroscience of Utility: A Tutorial Review

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In this tutorial review, we discussed on the neural substrate of utility and the reason why decision-making often deviates from rationality, failing to serve people's best long-term interests. It was pointed out that there are two valuation systems in the brain, one cognitive and the other affective. These two valuation systems perform automatic computations of values based on knowledge (cognitive valuation) and past history of learning (i.e., instrumental conditioning) and evolution (affective valuation). In the instrumental conditioning a signal such as money comes to be associated with primary reinforcer like food and thus acquires reinforcing power. Utility in economics can be equated with expectation of this secondary reinforcer, especially monetary reward. Final decision is made under the control of supervisory control system in the prefrontal cortex. The decision may wander from rationality when affective valuation system demands its request too pressingly to resist or the supervisor controller is not efficient enough to handle the situation due to temporally distracted by other tasks or for some other reasons like age (being too young or too old to be equipped with an efficient supervisory controller) and individual difference in impulsivity.

KEYWORDS: utility, decision-making, valuation system

1. Introduction

Standard economic theories conceive *homo economicus* as a rational decision maker capable of maximizing utility (Lee, 2006). However, there are many examples in our daily experiences that tell us that we as living creatures do deviate from such a presumption of the theory-obsessed economists. It is important for deeper understanding of economic decision-making process to study actual human behavior. Objective action taken by an individual is usually accompanied by subjective feelings, which may be assessed as subjectively evaluated scores. Although they reflect inner state, still there remains some ambiguity. The same subjectively assessed strength of a feeling may be influenced by different factors depending on individual's current mood and past experiences. The same output does not guarantee that it is the result of the same internal processes. Measurement of the activities of the brain may be useful in disambiguating subjective states by illuminating the brain regions involved in those activities. To understand human decision-making processes in its totality it is a better research strategy simultaneously to study both behavior and neural processes that accompany it.

In a rapidly growing field of neuroeconomics, researchers in economics, psychology, and neuroscience are cooperating together to elucidate neural underpinnings of the economic behaviors engaged by the human beings (see for recent reviews of this emerging field, Camerer, Loewenstein, and Prelec, 2005; Glimcher and Rustichini, 2005). The goal of this discipline is "to understand the processes that connect sensation and action by revealing the neurobiological mechanisms by which decisions are made (Glimcher and Rustichini, 2005)."

It is easy to find in our daily activities evidence against the economist's assumption of rationality in the economic decision-making. For example, people often succumb to an option surging in them as an impulsive drive or emotion, while failing to consider or deliberately ignoring our long-term interests. Later on, to their great regret, they will realize that they have made a stupid choice. In a book titled "Self-control: waiting until tomorrow for what you want today," Logue (1995) states as follows: "People often do things that result in some immediate gratification, but which in the long run are not very beneficial." In such a situation there are at least two temporally separated alternatives, one is an immediate alternative, which like delicious sweets for a dieting woman and a glass of alcoholic beverage for an alcoholic addict, appears to be enticing or pleasant, and the other is a temporally distant one that is felt to be motivationally less urgent or more rationally evaluated necessity in accord with our long-term interests or goals. Self-control is an important endowment in inter-temporal choice, which differs from individual to individual and also is known to develop as one grows older.

One way to explain why people make this kind of hasty decisions of immediate gratification is to resort to temporal discounting of utility. Thus, a long-term option should be discounted in larger value relative to a more immediate one. If discount rate is steep enough, it is possible that an immediate option of smaller utility is judged to have greater value and thus decided to be better at the time of decision-making relative to a temporally distant option with larger utility.

Discounting of utility by hyperbolic function may work for this purpose, while traditionally assumed exponential discounting function won't do the job (Ainslie, 2001).

According to Lee (2006), utility has two different meanings in economics. One is experienced utility, which is the subjective pleasure one feels from a particular stimulus or event resulting from a given action. The second one is decision utility, which is an estimate of experienced utility that can be assessed during the process of decision making. In this latter meaning, utility is an expected value that would occur in future when people are to experience it. The estimation depends on their previous encounters with the reward situations or the sum of the experienced utilities they have undergone so far. In terms of learning theory, the decision utility is a result of learning in those opportunities that have brought us rewards in the past. In the course of learning people come to know the expected reward probability for a particular decision through exposure to a reinforcement schedule (see the next section for more details).

In this short review, we would like to depict utility by referring to three points concerning the neural basis of utility: first we will describe the neural basis of reward signaling system in the brain and secondly we will point out that there are more than one utility valuation system, one based on cognitive computation that forms the basis of rational decision-making and another one of emotionally driven system that evaluates a biological utility for a particular choice. This latter system is much older in its origin than the former, having been shaped in the long history of evolution. Contrary to its connotation, the emotional system is biologically adaptive. Otherwise it would not have evolved at all (Evans, 2001). Cultural constraints like mores, traditions and laws that have been formed in the human history, however, sometimes put the emotion-based system in conflict with the cognitive valuation system, which has been acquired during socialization process by adopting rules prevalent in the society. The third point we would like to make is the conditions in which decision-making process sometimes deviates from rationality. To anticipate the conclusion, a rational decision making is possible only when people are aware of totality of the influences they are subject to. Otherwise people are unconsciously biased in their decision making toward options suggested by the emotion-based valuation system (Wilson and Brekke, 1994).

2. Neural Substrate for Reward

In psychology, behavior modification after some experience is called learning. In one class of learning that is called associative learning, an association is formed between one experience and another. One type of associative learning is classical conditioning, which was discovered by Russian physiologist I. P. Pavlov, and thus is also called Pavlovian conditioning. In this learning, an association is formed between one sensory event (which is called conditioned stimulus) and another sensory event (which is called unconditioned stimulus) that reflexively produces simple response. For example, in Pavlov's original study when a dog was exposed to metronome sound that was repeatedly paired with meat in its mouth, it started to salivate when hearing the metronome sound before actually tasting the food. Initially the animal did not salivate to the sound, so the association between sound and the taste of meat was acquired by repeated pairings of these stimuli.

In another form of associative learning, called instrumental or operant conditioning, learning starts with animal's spontaneous behavior. When an animal produces some response and it happens to lead to some result and the result is favorable for the animal, it increases the frequency of the response that has brought about the rewarding event. If the result is unfavorable then it decreases the frequency of the response. The fact that the resultant state is either good or bad for the animal constitutes reward. Something that increases animal's adaptability such as reducing hunger and thirst is endowed with positive reward value and other things that decreases its adaptability is endowed with negative reward value. In this way, spontaneous behavior may be associated with a particular reward and the acquired behavior is instrumental in bringing about the reward. In this learning, reward works as a feedback signal that helps animal modify its behavior (see Fig. 1 for schematic illustration of this learning process). This type of learning is prevalent in the animal kingdom. Even as simple an organism as a bumblebee which collects nectar and pollen for its colony can learn which flower is higher in utility by showing preference for a constant reward probability relative to a variable one, thus demonstrating loss aversion just like human being (Real, 1991).

Originally the instrumental conditioning was understood to be a purely behavioral phenomenon and the terms used in its description like reward and reinforcement were psychological constructs for the description with little understanding of underlying neural substrates. In 1954, a discovery brought about by two young psychologists, Olds and Milner, revealed the neural substrate for reward in the brain (Olds and Milner, 1954). They happened to come across with the brain's reward system when inserting a tiny electrode deep into a rat's brain. The rat, when electrically stimulated with the electrode implanted in its brain, increased frequency of the response that brought about the stimulation. It even crossed an electrified grid to obtain the stimulation. Thus, it appeared that the stimulation was highly rewarding. Subsequent researches indicated that the effective locations were found along a neural bundle called medial forebrain bundle. Running through the bundle are found dopamine neurons that originated in the midbrain areas and are projected to the striatum, the limbic system, and the prefrontal cortex. By the end of 1980's researchers studying the self-stimulation phenomenon came to the agreement that dopamine was the major constituent, if not the only one, of the brain's reward system (Wise and Rompre, 1989). According to subjective report artificial induction of this substance in

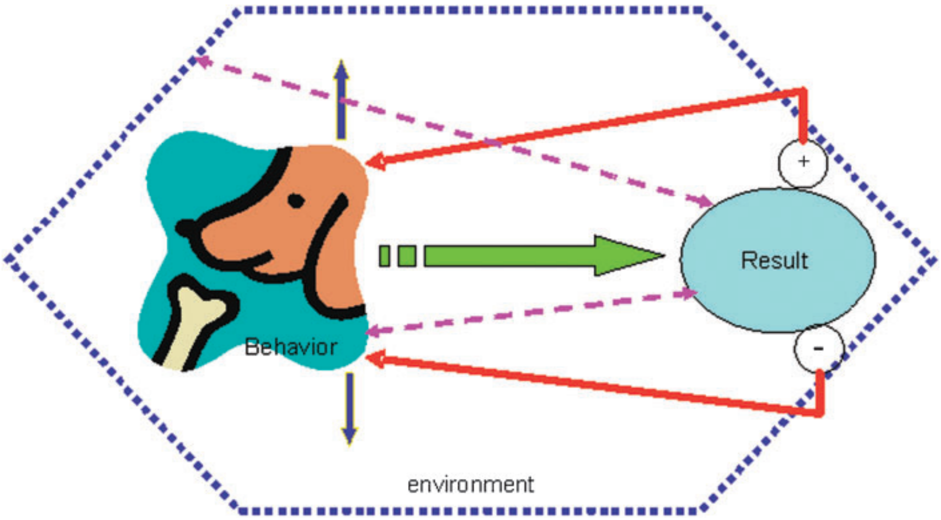

Fig. 1. Instrumental conditioning. Behavior of an organism, if encountered with some result (i.e., reward), modulates the frequency of that behavior. With positive reward, the frequency increases and with negative reward it decreases. Thus, the behavior becomes instrumental for obtaining reward. At the same time, environmental stimuli that signal the reward delivery come to acquire the rewarding property, which is called secondary reinforcer.

the brain is felt to be pleasurable and held to be responsible for the cause of addiction to many substance including alcohol, nicotine, and cocaine (Robbins and Everitt, 1999).

In the instrumental conditioning there are two types of associations. One is the association that was originally assumed to have occurred in this learning, namely the association between a response and a reward. Additionally animal also comes to associate the reward with a signal that informs its delivery. Thus, it becomes a secondary reinforcer. In this way, for example, people find money is rewarding because they learn that it enables them to obtain goods and services they need such as food and shelter. Although having no reward value originally, the association with reward imparts the rewarding power to money. This type of association is a source that generates an estimate of experienced utility in the real world. This can be seen in the experiments where a monetary reward was used in a speeded response task (Knutson, Adams, Fong, and Hommer, 2001) or a mock lottery game (Breiter, Akaron, Kahneman, Dale, and Shizgal, 2001). In these studies, neurons in the brain reward related regions including nucleus accumbens and part of the orbitofrontal cortex were found to increase activities with reward expectation or anticipation. Besides, subjectively felt pleasure was found to be correlated with the activities in the nucleus accumbens (Knutson, Adams, Fong, and Hommer, 2001).

At the start of learning an animal knows nothing about reward contingency. Thus, any delivery of reward should be a surprise for it. As the learning process proceeds, however, the animal gradually understands the contingency between response it emits and the resultant reward. Then, it comes to form an expectation that a particular behavior would bring about a particular reward. It also associates a particular constellation of stimuli with the reward. After the formation of this initial expectation, the learning is driven by the error signal generated by the discrepancy between the reward expectancy and the actual reward delivered. This prediction error is a central element of modern theory of instrumental conditioning (Schultz, 2002).

For groups of neurons to form association it is necessary for them to find themselves in nearby locations since long-range interactions are limited in the brain due to slow transmission of neural signals. Consequently, we should search for the formation of such an association between some representation of a reward and a sensory signal in a converging area of the brain. The candidate area must be innervated by the dopamine neurons because it is the transmitter that signals contingency of learning. One such area is found in the orbitofrontal cortex where sensory signals like taste, olfaction, vision, and touch converge (Rolls, 2000) and where rich dopaminergic innervation has been reported to exist. Anatomically, the orbitofrontal area is a suitable convergence zone for the formation of association between primary reward signal like taste and a secondary signal like visual shape (Rolls, 2000). Another important area for the instrumental conditioning is the striatum which is responsible for automatic control of response. This region is suitable for the formation of association between an instrumental response and a reward with its rich dopaminergic innervation and its role in the response control (Schultz, 2002).

A recent fMRI study (Erk, Spitzer, Wunderlich, Galley, and Walter, 2002) with human male participants confirms findings reported in the animal studies that the orbitofrontal cortex is important in the formation of association between sensory signals and reward. In this study, people were shown cultural objects (i.e., cars) that signaled wealth and social dominance. It was found that when exposed to pictures of cars the orbitofrontal and the ventral striatum areas were found to increase activities. The response was stronger to the sports car relative to limousines, which then produced higher activation than small cars. This finding demonstrates that the brain responds to the culturally conditioned reward like luxury cars which act as a symbol of social dominance. Thus, the association learning between reward and sensory signal is a key component of the second type of utility (i.e., estimate of expected utility).

3. Two Valuation Systems

That there are more than one valuation systems in us is not a new idea. A well-known Vienna psychiatrist S. Freud, who is the founder of psychoanalysis, proposed such a dual-drive system in the early part of the 20th century. In his model of ego system Freud assumed two drive forces. One is called *id* or *es* and is regarded by Freud as a sexually motivated instinctive drive. The other is called superego, which is a corpus of internalized social rules and moral obligations. These two drives are often in conflict because *id* demands immediate gratification based on pleasure principle, while superego commands us to do what we are supposed to do. To reconcile these two drives, a third component called ego works as a mediator. It attempts to find a socially acceptable solution for these two conflicting demands. The main function of ego is reality-testing and impulse-control.

At the time of his theorization (Freud wrote the book *The Ego and the Id* that explained this ego system in 1923), little was known on the brain processes he assumed to be involved in the ego's decision-making. Consequently, his theory was constructed on the basis of his clinical observations of the neurotic patients he attempted to treat and on speculations derived from these observations.

Amazing to the modern eyes with better knowledge of the functioning of the brain, the Freud's idea on the ego system can find corresponding functional equivalents in the brain. *Id* can be regarded as a reflection of working of motivation and emotion, which can be mapped onto the orbitofrontal-limbic system. These neural structures process our internal needs that were subjectively felt as emotion and motivation and help us survive in the non-friendly environment. Emotion functions to evaluate our current status in the environment; is it dangerous? Is it pleasant and safe for satisfying our needs? Is there anything that interferes with our intended action? and so on. Motivation functions to assess the status of our internal world; does it need food? Is it time for finding a mate? Do we need a rest? et cetera, et cetera. This is affective valuation system in the brain (see Fig. 2 for the approximate locations of these regions).

Superego is an internalized corpus of rules that we are supposed to follow in a society. These rules are somewhat arbitrary, reflecting long history of cultural traditions. We have acquired them during our development. Freud assumed that they are internalized because children, especially boys, want to be like their fathers and wish to marry their much loved mothers. Thus, they come to identify themselves with their fathers. Therefore, they mimic their fathers' behaviors, which help them to internalize the rules their fathers appear to obey. These rules are stored in the semantic memory located in the temporal cortices (Graham and Hodges, 1997; Mummery, Patterson, Wize, Vandenbergh, Price, and Hodges, 1999). This constitutes cognitive valuation system.

Ego is an arbitrator, which tries to reconcile conflicting demands from *id* and superego to find out an acceptable solution, acceptable from the view point of the real world constraints or reality principle. Thus, ego is a kind of

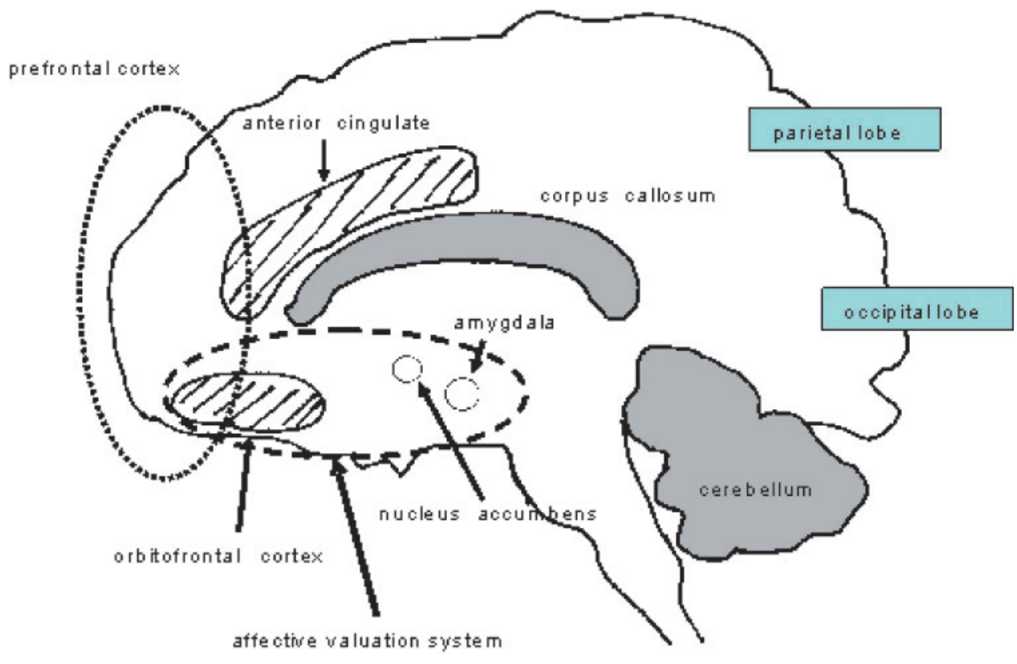

Fig. 2. Brain's affective valuation system. Orbitofrontal-limbic system is the neural substrate of this valuation system with the amygdala for affective computation and the nucleus accumbens involved in signaling reward. Supervisory controller resides in the dorsolateral prefrontal lobe (not shown here).

supervisor system which controls or integrates brain's semi-independent modules (Fodor, 1983). This component can be mapped onto the prefrontal lobe, to which both cognitive and emotional processing modules send their outputs. Supervisory module is located in the dorsolateral prefrontal cortex and corresponds to the executive part of the working memory system (Baddely, 1992). This module controls our cognitive operations, like thinking, calculating, and remembering. Deliberate thinking process executed by the supervisory module is required in a highly complicated decision-making people often encounter in their daily life.

This supervisory controller is activated when subordinate modules cannot handle situation in its usual, well-learned ways (Paus, 2001). There are three major categories of such emergencies: First case is cognitive conflict, in which more than one response requests are activated simultaneously. A well known example is Stroop effect (Stroop, 1935). In this situation, people are required to name colors of color words (e.g., red, green, blue, yellow, etc.). When the colors and the color words are not concordant in response (e.g., when word RED is colored in blue), one feels two competitive response tendencies, one deriving from well-learned or automatic reading of the color word and the other from naming its color. Response latency is known to become slower in this competitive condition relative to a simple condition of naming colors of non-word letter string like XXXX.

Second case of emergency is malfunctioning of some part of our body. We perceive this situation as painful. Pain is called nociception, which means that some part of our body is damaged or almost so. The situation needs immediate attention with priority over other ongoing activities. Thus, it has a drive quality. Third case is emotion. Emotion arises when circumstance does not match to our current needs. For example, when their intention is interfered with by some obstacle people feel anger, which drives them to get rid of it. Emotion generates in them a signal or request to change their behavior in the way that help fix current non-optimal state they find themselves in.

These emergency situations are signaled to the supervisory controller through the anterior cingulate, which situates in the medial part of the frontal lobe. Different anterior cingulate cites are activated when people are in one of these emergency situations (Bush, Luu, and Posner, 2000; Drevets and Raichle, 1998). That the anterior cingulate is important in generating attention request signal is suggested by the damage inflicted on it. Thus, bilateral lesions to this region causes akinetic mutism (Tibbetts, 2001), a symptom in which the patient is unable to voluntarily initiate response even though sensorimotor and vigilance functions such as orienting to external stimuli are preserved. According to Damasio (1994, p. 73):

> [The patient's] mind had not been imprisoned in the jail of her immobility. Instead it appeared that there had not been much mind at all, no real thinking or reasoning...Nothing had forced her not to speak her mind. Rather, as she recalled, "I really had nothing to say." I would say her will had been preempted, and that seems also to have been her reflection. It appears that there had been no normally differentiated thought and reasoning in Mrs. T's mind, and naturally no decisions made and even less implemented.

A dramatic illustration of the malfunctioning of the reconciliation of affective and cognitive valuation systems can be found in the patients whose ventromedial prefrontal cortex is damaged due, for example, to cerebrovascular accident and neurosurgical operation (Damasio, 1994). Perhaps, the best known example of the disorder is a 19th century American railroad construction worker, Phineas Gage, who due to an accident inflicted on him while he and his men were attempting to blow up a huge rock, had his prefrontal lobe damaged by a pointed iron bar that penetrated his skull. After the accident, he could no more work as a foreman because he lost temper easily and behaved as if a young child ignoring others' opinions and needs. Based on the preserved skull of Phineas Gage, Damasio and his associates estimated the lesion site (Damasio, Grabowski, Frank, Galaburda, and Damasio, 1994), which turned out to be the region surrounding the left ventromedial prefrontal cortex including the orbitofrontal region.

More recent cases that exhibited the non-rationality like Phineas Gage are found in the patients who had cerebrovascular accidents in this region or who underwent neurosurgical operations to remove tumors or other diseases. Systematic neuropsychological testing of these patients revealed a dramatic dissociation of the functions of the two valuation modules, with the intact cognitive valuation module and the awfully malfunctioning affective valuation module (Eslinger and Damasio, 1985; Damasio, Tranel, and Damasio, 1990). Among them there was a patient known as EVR (Eslinger and Damasio, 1985), who had led a decent life as an accountant with a wife and children. After the surgery he quitted his job and started unsuccessful business, divorced his wife and then married another woman. Many of these patients became sociopaths, turning from well-adapted, decent citizens to problematic characters or even wicked persons. Although a moral judgment test showed that they were quite normal in their moral judgments and the profiles of a personality test indicated that they were within the range of normal personality, which were presumably ascribed to normal functioning of the cognitive valuation module, it turned out that they could not learn from the past reward history to choose wiser options. This was revealed in a gamble game devised by Damasio and his associates. In this game there were four decks of cards from which the patients had to select a card in each turn. The card when laid face up revealed either a gain or loss of some amount. Two of the decks were made to be profitable in the end with small gains and losses. The other two decks were made not to be so because while majority of the cards of the latter decks returned large gains this was more than offset by larger losses of small portion of the cards, resulting in an overall loss in the end. Normal people could learn the different payoffs of the four decks, gradually shifting their choices to the good decks. In contrast, the patients could not learn the trick of the game, and resorted to the bad decks now and then until the end of the game.

It has been shown that two valuation systems show different sensitivities to the probabilities of possible prospects. In the estimation of utility, the value of a prospect is equal to the sum of the utilities of outcomes that could be experienced, weighted by their likelihood of occurrence. Probabilities and outcomes thus have symmetrical effects on evaluations. This, however, is the case only for the cognitive valuation. For the affective valuation, changes in probability within some broad range of values have been found to influence very little on its estimation, to which only outcome matters. For example, when asked to indicate the largest amount of money they would be willing to pay to avoid an undesirable outcome with different levels of probability, people were insensitive to the probability in the amount of money they are willing to pay when it is related to receiving electric shock (which would be emotion-provoking experience) but were quite sensitive to it when the loss is not so shocking (i.e., paying $20). In this latter case, the amount of money they answered to pay was in proportion to the probability ranging from $1 ($p = .01$) to $18 ($p = .99$) (Loewenstein, Weber, Hsee, and Welch, 2001).

With neuroimaging technique it is possible to illuminate independent working of these two valuation systems in the intact brain. In a recent study (McClure, Laibson, Loewenstein, and Cohen, 2004), Loewenstein and his associates used fMRI to probe the brain's valuation systems in a temporal discount choice task. Participants of this study were given a task of choosing between two temporally separated reward options. As usually the case in this type of temporal discounting, a temporally nearer option was made to bring about less reward than the temporally more distant reward option. Measuring brain activities during this temporal choice task, they demonstrated that there are two separate systems operating in this decision task. When a temporally nearer option was chosen the participant's orbitofrontal cortex and limbic structures were found to be activated. In contrast, when a temporally more remote option was chosen s/he seemed to use the lateral prefrontal and the parietal cortices, which were known to be involved in higher cognitive functions like executive attention and working memory. These findings suggest that selection of a remote reward was decided by the cognitive valuation system and selection of a nearer reward was driven by the affective valuation system. Since, although larger in actual reward value, a remote reward was an event that would occur in distant time it may have been felt to be less appealing emotionally. Consequently, when the participant chose this option their cognitive valuation system was dominant in the decision-making process. Suppressing lower level drive generated by the affective valuation system and resorting to "more recently evolved, uniquely human capacity for abstract, domain-general reasoning and future planning" (McClure, *et al.*, 2004) may be regarded as a manifestation of rational decision-making capacity which Freud ascribed to ego.

4. Failures in Rational Control of Decision Process

Why do people sometimes fail to make decisions in a rational way? As mentioned in the previous section, there are two independent valuation modules in the brain. The cognitive valuation module is responsible for making decisions in a way that is in harmony with individual's long-term interest. To achieve this purpose it resorts to the knowledge database stored in the semantic memory system. The affective valuation module reports the current status of the inner world that is expressed as emotion and motivation. This evaluation also reflects individual's past reinforcement history. A consonant working of these two valuation modules allows an individual to make a rational decision that serves the best interest of her/his long-term prosperity. Since these two modules work semi-independently, each module does not know what is going on in the other module until final reports are submitted.

If the two modules reach the same conclusion on a particular decision, that's OK, since there is no conflict in the decision making process. The decision will be implemented as soon as circumstances allow it. However, when they do not reach an agreement some reconciliation must be made between the two, which Freud assumed to be the role of ego. Without somewhat finding a compromise, actual implementation is not possible. When agreement or compromise is not possible, only way for avoiding deadlock is to let one valuation module take possession of the entire decision-making process. Whichever wins the contention, a bill would have to be paid in the future for this type of solution. For instance, if you refuse an unreasonable order of your boss under the influence of lost temper, you will find out later that your chance of promotion is jeopardized by your emotion-driven decision. On the other hand, if you obey the order, rationally calculating your long-term interest but ignoring the voice of the affective valuation module, your mental health may deteriorate in the long run from the stress you feel when you suppress your anger.

Control of actions is usually performed as an automated sequence of individual acts. Any relatively simple action will eventually become automatic as people perform it repeatedly. An automatically performed action requires little supervisory cognitive control. This can be felt when you compare the cognitive control you had to exert when you started to drive a car with that you now feel (assuming that you are good at driving). After having practiced a lot behind wheel, you can now do many other things while driving, like listening to radio, talking to a passenger, watching billboards on the roadside, and so on. The supervisory controller is called upon when circumstance arises where well-practiced actions are not able to handle the situation, such as driving a car on a road with heavy traffic.

The supervisory controller can deal only with those signals that are consciously perceived. However, there is circumstances in which people are under the influence of signals that they are not aware of, be it cognitive or emotional. The phenomenon is called priming in psychology. To be more specific, when the signal is not strong enough or otherwise interfered with by other signals as is the case in masking (i.e., when two stimuli are presented in close temporal succession), signal may be passed directly to response controller without being checked by the supervisory controller (Wilson and Brekke, 1994). In fact there are many demonstrations in cognitive psychology that people are under the influence of stimuli that they are not aware of. One interesting example is the mere exposure effect (Zajonc, 2001). In this experimental paradigm, participants are repeatedly exposed to novel stimuli and later their preference for these stimuli is evaluated. In proportion to the number of exposures they show increased preference for them. Interestingly, the effect is still found when the stimuli are subliminally presented (that is, stimulus presentations were made suboptimal for one to consciously perceive them). In effect, the mere exposure effect is more pronounced when obtained under subliminal condition than when people are aware of the repeated exposures. In such a condition, since they are unaware of the influence people come to like them without knowing that their preference is influenced by repeated exposures. Repeated presentation of a new product through media is the well-known technique utilized in the advertisement industry when people in the industry want consumers to come to prefer it. For advertisement to be effective, it is not consumer's recognition that matters, but the repeated exposures themselves, which are the stealthier the better.

Second case of the failure in monitoring of unintended influences occurs when the supervisory controller is engaged with other activities or its normal functioning is impaired by other causes like fatigue and pharmacological agents like alcohol, or in an extremely high emotional activation. When it is occupied by another task, the monitoring and checking processes cannot be mobilized for this monitoring purpose, allowing the influence to control actions without going through the cross-checking by the supervisor controller.

For example, in an interesting study conducted by Shiv and Fedorikhin (1999) the participants were asked to go from one room to another. In the middle of the corridor there was a cart on which two snacks were displayed. They were allowed to choose one of the two foods for later consumption. One of the snacks was a piece of chocolate cake with cherry topping and the other was a dish of fruit salad. When their supervisory controller was made busy by being forced to remember 7 digits until they reach the second room, about two thirds (63%) of the participants chose affectively good but cognitively bad (from the viewpoint of health and dieting) option of the cake. When cognitive load was low (i.e., remembering two digits) majority (59%) chose cognitively better option of the fruit salad. When two options were displayed as photographs rather than as real foods, the cognitive load had little effect on the choice of the snacks with about two thirds of the participants choosing the salad.

Thus, the choice may be a rational one if and only if the supervisory controller has enough spare capacity (i.e., is not busy with other tasks) and time (i.e., there is no time pressure for reaching a decision) to examine the outputs from the two valuation modules and at the same time has the power to suppress loud voice of the affective valuation module (when it is loud). Paradoxically, if the output of the affective valuation module is not loud enough and therefore does not reach the supervisory controller (i.e., is not perceived consciously), its influence may appear in the final decision without being detected by the supervisory controller. This is called mental contamination, a "process whereby a person has an unwanted judgment, emotion, or behavior because of mental processing that is unconscious or uncontrollable" (Wilson and Brekke, 1994).

5. Inhibition and the Supervisory Control

As our understanding of the brain functions deepens, our intuitive notion of how mind works comes to face a new challenge because it is found not to be consonant with the actual working of the brain. One such challenge is the notion of free will. Since our legal system is firmly based on this notion of free will, any challenge to it causes deep penetrating repercussions not only among researchers in the field of cognitive neuroscience, but also among philosophers and jurists.

Such a challenge was thrown by an American physiologist Benjamin Libet, who with his associates demonstrated in a simple but elegant experiment that brain process involved in controlling finger flexion starts well before our perceived conscious intention (Libet, Gleason, Wright, and Pearl, 1983). In his experiment, participants were asked to monitor a clock-like dial on which light spot moved around the periphery. Their task was to flex their fingers as they felt like to do so, that is, by their free will. They were asked to remember the position of the light spot that was moving around the dial surface at the moment when they felt the intention, on which they had to report later. At the same time, brain activities related to the motor control was monitored with electroencephalography. Motor control is known to generate a brain potential called readiness potential. This potential is a reflection of the ongoing neural activities in the motor regions of the brain.

What he found was this: the readiness potential generated by the brain when the participants moved their fingers at the command of their free will actually preceded their intention by about 300 msec. This and related observations demonstrating that people are not accurate in their perception of the cause of their actions led Wegner to suggest that "conscious will is an illusion" (Wegner, 2002). Libet himself is skeptical of this total negation of free will and claims that although conscious intention may not be a real initiator of action people can still veto their action. Libet maintains that in this sense there is still a free will (Libet, 2005).

As suggested by the Libet's finding, decisions people make may be a direct product of their brain, rather than their mind or self. According to his opinion people can still say no to the voice generated by a part of the brain. Freud

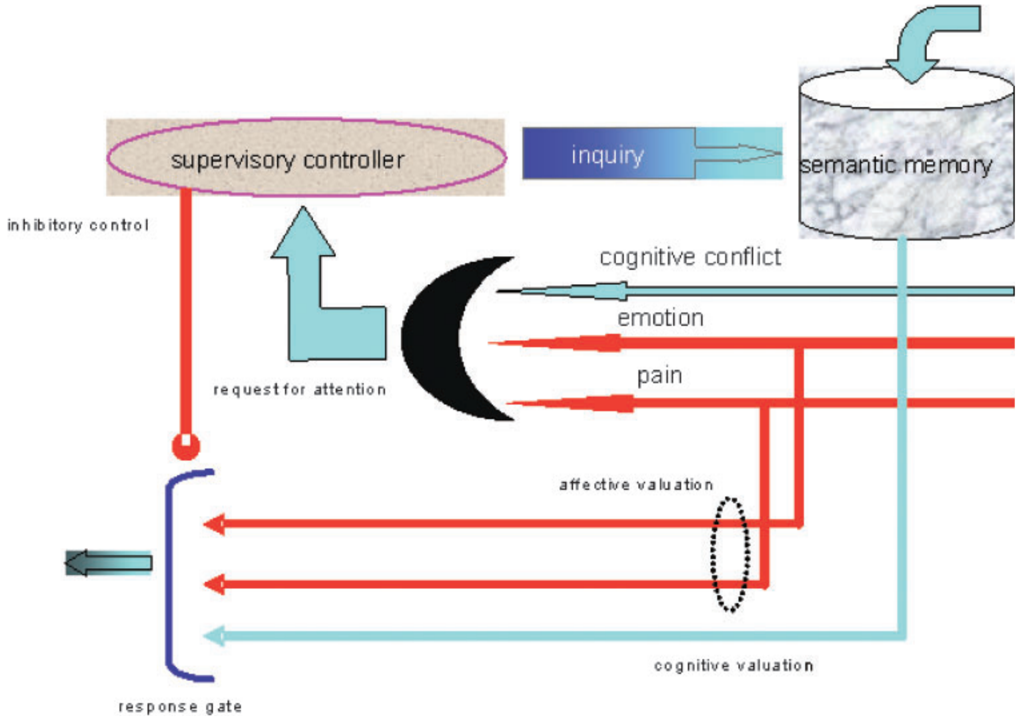

Fig. 3. Schematic illustration of neural substrate of decision-making. Perceptual processing activates information stored in semantic memory and automatically triggers cognitive valuation signal. Emotion and pain generates affective valuation signals. These signals are allowed to control response if the inhibitory gate is opened by the supervisory controller. When automatic response control is not possible (i.e., when there is a cognitive conflict or the situation provokes emotion and pain), the supervisory controller is summoned by the attention request signal generated by the anterior cingulate.

proposed that the urge that is incompatible with superego's moral standard is repressed into unconscious part of mind because people hate to admit that they can ever conceive such an unmoral desire. If less morally unacceptable, the urge may just be inhibited and no overt behavior appears while its presence is consciously felt.

That people can control their emotion (to some extent) is shown in a recent study (Levesque, Eugene, Joanette, Paquette, Mensour, Beaudoin, Leroux, Bourgouin, and Beauregard, 2003). These researchers showed female participants a sad film and asked them to suppress their emotion. It was found that reported strength of sadness was related to the activities in the right dorsolateral prefrontal cortex and the right orbitofrontal cortex, suggesting that these regions are involved in the suppressive control of emotion (see Fig. 3 for schematic illustration on these points).

That people have the capacity for inhibitory control and that there are individual differences in the degree of this control can be seen in the studies of personality trait known as impulsivity. Inhibitory control is a function of the supervisory controller and is known to reside in the frontal lobe (Engle, 2002). The frontal lobe is the last sector of the brain to develop both in terms of evolution and of individual development (Harnishfeger and Bjorklund, 1994). Relative immaturity or dysfunction of this part of the brain is known to lead to defective inhibitory control, which in turn is a cause of various problems like attention deficit hyperactivity disorder and conduct disorder in children and many dysfunctional behaviors like drug addiction, binge eating, and antisocial behaviors in adults.

Good functioning of inhibitory control enables delay of gratification. It is important for individual's cognitive and social functioning. This point was demonstrated in a study conducted in the Stanford University (Mischel, Shoda, and Rodriguez, 1989). In this study, 4-year old children were tested on how long they could postpone immediate gratification for later larger reward. For this purpose, an experimenter first showed the children some toys, explaining they would play with them later (so that ending the delay led to uniform positive consequences). Next, the experimenter taught a game to the children where he or she had to leave the room but came back immediately when the children summoned her or him by ringing a bell. Then each child was shown a pair of treats (such as snacks, small toys, or tokens) which differed in value, established through pretesting to be desirable and of age-appropriate interest (for example, one marshmallow versus two; two small cookies versus five pretzels). The children were told that to get their favorite they had to wait until the experimenter would return. They were also told that they were free to end the waiting period whenever they wanted by signaling it; if they did so, however, they would only get the less preferred object and had to give up the other, favorite one. After children understood the rule, they were left on their own during the delay period, and the duration of their delay was recorded until they terminated or the experimenter returned (typically after 15 min). With this method, "self-imposed delay of gratification" was investigated both as a psychological process in experiments that manipulated reward values in the delay situation and as individual differences in inhibitory control that examined the relation between children's delay behavior and their social and cognitive competencies.

The experiment found that children who tended to prefer delayed rewards also tended to be more intelligent, more likely to resist temptation, to have greater social responsibility and higher achievement strivings. Furthermore, in a follow-up study of a sample of these children found that those who had waited longer in the above mentioned situation at 4 years of age were described more than 10 years later by their parents as adolescents who were more academically and socially competent than their peers and more able to cope with frustration and resist temptation. These findings thus suggest that there is clear individual difference in the inhibitory control capacity at the age of 4 and the control capacity also has long-term consequences in terms of cognitive and social competence.

Another interesting point of this study is the finding that the self-control was found to be easier when children did not face the reward objects. They could wait an average of 11 min when they did not see the rewards, but could wait less than 6 min on average when any of the rewards were in front of them during the delay period. Furthermore, observation of the children during the delay period suggested that those who were most effective in sustaining delay seemed to avoid looking at the rewards deliberately. For example, they covered their eyes with their hands or rested their heads on their arms. Many children generated their own diversions like talking quietly to themselves, singing, creating games with their hands and feet, and some children even tried to go to sleep during the waiting time.

These observations of young children suggest that even as young as 4 years old children can use cognitive strategy to prevent less desirable reward from dominating their choice. Seeing reward object directly seemed to induce in them a potent drive force (generated by the affective valuation system), which they found difficult to resist. By diverting their attention from them their mental representation must have been based on some memorized symbol of the reward objects, which may have stimulated the affective valuation system less, making it easier for the 4-year olds to inhibit urge for immediate gratification, thus leading to longer waiting time. In a similar vein, in the above mentioned study reported by Shiv and Fedorikhin (1999) undergraduates were less tempted by chocolate cake when it was presented to them as a photograph rather than as a real object.

That paying attention to cognitive or symbolic representation of reward object is an important step forward to prevent less desirable but quicker gratification from controlling behavior can be seen in a simple game taught to a pair of chimpanzees. The two chimps had been taught to use symbols for Arabic numerals and could do simple numerical additions. The rule of the game was to select a dish by pointing to it. One of the two dishes contained 7 gumdrops, while the other only one. The gumdrops on the designated dish were given to the partner. Surprisingly to Sarah Boysen, the psychologist who conducted this research, they could not master the game, even though they could count the numbers. However, when symbols of the two numbers that corresponded to the number of gumdrops rather than gumdrops themselves were placed on the dishes, they could play the game well by always pointing to the dish that contained the symbol of smaller number (Fischman, 1993). Thus, the rule of the game itself was not the obstacle for them to master it. What was difficult for them to overcome was the urge welling up from the real reward objects.

6. Conclusion

Standard economic theory of constrained utility maximization is interpreted either as the result of learning based on consumption experience or careful deliberation characterizing complex decisions like planning for retirement, buying a house, or hammering out a contract (Camerer, Loewenstein, and Prelec, 2005). In either way, maximization of utility is assumed to be a result of rational decision-making. Observation of individual decision-making process, however, suggests that the internal working of our mental processes is not so cool. Sometimes, emotion steps in. This can be seen, for example, in ultimatum bargaining game. The rule of the game is like this: one offers some portion of a fixed amount of money to the other and if the partner accepts the offer, the money is divided between the two but if the partner refuses the offer, both can receive nothing. Since something is better than nothing, rational calculation would suggest that you should always accept the offer, if it is not zero. In reality, however people are not so rational. They often choose to receive nothing rather than accepting an unfair offer, that is, when the offered money deviates widely from even split of the total money. The decision seems to be made under the influence of negative affect, perhaps disgust, because their insula increased activities when people rejected an unfair offer (Sanfey, Rilling, Aronson, Nystrom, and Cohen, 2003).

In this tutorial review, we have argued that there are two valuation systems in the brain. One is the cognitive valuation system, which is the basis of rational deliberation assumed by the economists. The other one is the affective valuation system, which, although less rationally and more emotionally inclined than the cognitive valuation system, actually has higher affinity with the definition of experienced utility since this contains the term pleasure, which is a positive affect people feel when they receive a reward.

These valuation systems functions as subsystems, which produce automatically the results of their computations when appropriate inputs are given. The supervisor controller usually inhibits immediate gratification of their requests and if necessary re-examine them by consulting knowledge data-base stored as a semantic memory. This is rational decision making. When such a deliberate process involving the supervisor controller is not engaged owing either to other task has already occupied it or to its impaired functioning because one is under the influence of alcohol or stress.

Cognitive valuation works best when all the material is prepared as cognitive representation, which is more abstract (i.e., symbol-like) and less pressing in terms of bodily felt drive or urge. Affective valuation is an evolutionarily older system that assesses the current status of an organism *vis-a-vis* surrounding environment and steers it in the best interests of its survival and preservation of its genes. A complex social interaction among a large number of people is a relatively new phenomenon, which probably goes back less than ten thousand years in the human history, may have made it necessary to establish a complicated corpus of regulations and laws. Maximization of utility should be pursued within the allowance of these rules. In terms of evolution the period of ten thousand years is too short for any creature to incorporate these "modern" rules within the affective valuation system. Assessments reported by these two valuation systems are thus often contradictory. Therefore it is necessary to make some arbitration to find an acceptable solution. This is the function of the supervisory controller residing in the prefrontal lobe. This schematic depiction is not a new one, but is virtually identical with the Freud's famous Ego model.

Most of the internal working of our mind is automatic and inaccessible to introspection. Psychological understanding of these processes has been hampered by this impenetrability of the mental processes. A recent advance in the neuroimaging techniques has done a great service for solving the riddles that have long remained to be unsolvable with purely behavioral approaches by illuminating the brain regions involved in mental processes. The rapidly accumulating evidence in this field of cognitive neuroscience within less than two decades has shown that the internal working of our mind as seen through functions of the brain is much more complex than our mental power can imagine. Top-down cognitive effort for understanding mind is clearly limited, because logical thinking develops in linear and serial production steps, each of which is represented one by one, whereas any mental operation is a product of massive parallel working of tens of thousands of neurons. Therefore, there would be so many intermediate states that are generated in the process, which are mostly outside of our conscious recognition and are unreachable for the top-down cognitive effort.

Through collaborative work with psychologists and neuroscientists economists can gain new insights into the hidden processes behind our economic activities, as we psychologists are enjoying now in every realm of the research in human behaviors.

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