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Decision Neuroscience

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Abstract

This article presents an introduction to and analysis of an emerging area of research, namely decision neuroscience, whose goal is to integrate research in neuroscience and behavioral decision making. The article includes an exposition of (1) how the exponential accumulation of knowledge in neuroscience can potentially enrich research on decision making, (2) the range of techniques in neuroscience that can be used to shed light on various decision making phenomena, (3) examples of potential research in this emerging area, and (4) some of the challenges readers need to be cognizant of while venturing into this new area of research.

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† The genesis of this workshop session and article was a meeting that Dipankar Chakravarti, Antoine Bechara, and Baba Shiv had one balmy Iowa City summer afternoon in 2003. We coined the term Decision Neuroscience to describe the emerging stream of research outlined in this article.

Keywords: decision making, neuroscience

Introduction

While the field of decision making research continues to be vibrant and in excellent health, several researchers including Dawes (e.g., Hastie and Dawes, 2001), Loewenstein (e.g., Camerer et al., 2005), and Mellers (2000) have proposed that the next phase of exciting research in this area is likely to emerge from building on recent advances in the field of neuroscience. This enthusiasm for integrating neuroscience and decision making has partly been due to the exponential accumulation of knowledge about brain structures and neurological mechanisms since 1990 (the National Institute of Mental Health and the National Institutes of Health aptly labeled the 90's as the Decade of the Brain) and partly due to the increased availability of neuroscientific methods to investigate various decision making phenomena.

The objective of this article is to present an introduction to and analysis of this emerging area of research, namely decision neuroscience. To accomplish this objective, we first delineate ways in which neuroscience can potentially enrich research on decision making. We then discuss the range of techniques in neuroscience that can be used to shed light on various decision making phenomena. Subsequently we present examples of potential research in the area of decision neuroscience. Finally, we present some of the challenges one need to be cognizant of while venturing into this new area of research.

1. How Neuroscience can Enrich Research on Decision Making

In the sub-sections that follow, we highlight several broad ways in which neuroscience can potentially enrich our understanding of various decision making phenomena. Drawing upon diverse research domains for the purpose of illustrating these broad ways, we discuss how neuroscience can help by (1) providing confirmatory evidence about the existence of a phenomenon, (2) generating a more fundamental (i.e., a neural-level) conceptualization and understanding of underlying processes, (3) refining existing conceptualizations of various phenomena, and (4) providing methodologies for testing new as well as existing theories.

1.1. When Questions Arise about the Existence of a Phenomenon

It is not uncommon for researchers to face skepticism about the existence of a documented phenomenon. Take the case of the phenomenon of placebo analgesia, in which the mere belief that one is receiving an effective treatment has been shown to alleviate pain (e.g., Price et al., 1999). The very existence of this phenomenon has been widely questioned with researchers attributing placebo analgesia to a response bias rather than to an actual alleviation of pain (e.g., Hrobjartsson and Gotzsche, 2001). In other words, researchers have argued that placebos merely change our judgments of pain rather than alleviating pain. When faced with such skepticism, neuroscience can provide answers by examining whether the phenomenon in question is associated with localized neural activity. For instance, using functional magnetic resonance imaging (fMRI), Wager et al. (2004) found that placebo analgesia was associated with decreased brain activity in pain-sensitive brain regions, including

the thalamus, the insula, and the anterior cingulated cortex, thereby providing confirmatory evidence that placebos do alter the actual experience of pain.

1.2. More Fundamental Conceptualization of Underlying Processes

Psychologists, including behavioral decision making researchers, have traditionally relied on hypothetical constructs for developing theories to account for different phenomena. Going back to the phenomenon of placebo analgesia, for instance, psychologists have invoked the role of expectations, a hypothetical construct, in mediating the effects of placebos on the experience of pain. One of the major advantages of neuroscience is that it enables researchers to generate more fundamental (i.e., neural-level) conceptualization and understanding of various phenomena. For example, instead of relying on hypothetical constructs such as expectations to explain placebo analgesia, neuroscience enables researchers to develop a more fundamental conceptualization by specifying the areas of the brain that need to be activated should expectations indeed play a mediating role. Specifically, if expectations do indeed mediate the effects of placebos on the experience of pain, then one could now make (and test) the conceptual argument that activity in areas of the brain such as the prefrontal cortex (the dorsolateral aspect, in particular) which has been identified as being critical to maintaining and appropriately updating internal representations of goals and expectations should correlate with greater placebo-induced pain relief (see Wager et al., 2004).

1.3. Refining Existing Theories

Neuroscience can help refine existing theories in several ways. Take for instance the enduring theory of cognitive dissonance which proposes that a discrepancy between an individual's attitudes and behavior creates cognitive dissonance, an aversive state that, in turn, prompts the individual to remove the discrepancy by altering his or her attitudes to fit with the behavior. Most accounts of the dissonance-reduction process imply that explicit memory is involved in the behavior-induced attitude change (i.e., attentional resources are needed for the dissonance-reduction process to ensue). Lieberman et al. (2001) examined whether explicit memory is necessary for the dissonance-reduction process or whether the process occurs in a relatively automatic fashion. Their findings suggest the latter—amnesics in their study showed no memory for the dissonance-arousing source, yet showed as much dissonance reduction as did normal individuals. From a broader perspective, Lieberman et al. (2001) used existing knowledge of brain structure and function to refine the theory of cognitive dissonance.

Neuroscience can also help tease apart alternative accounts for a phenomenon. Take the case of a well-documented finding related to ethical dilemmas, the "trolley-footbridge" set of moral dilemmas. The trolley dilemma is one where a runaway trolley is headed for five people who will be killed if it proceeds on its present course. The only way for you to save them is to hit a switch that will turn the trolley onto another set of tracks where it will kill one person instead of five. The question is, will you hit the switch to turn the trolley and, thereby, save five people at the expense of one? Most people say yes to this

question. Now consider a similar problem, the footbridge dilemma. As before the trolley threatens to kill five people. You are standing next to a large stranger on footbridge that spans the tracks. The only way you can save the five people is to push the stranger off the bridge onto the tracks below. He will die in the process, but his body will stop the trolley from reaching the others. The question again is, will you push the stranger to save the other individuals? Most people say no to this question. That is, unlike the trolley dilemma, where most people indicate that they are willing to sacrifice one person to save five, most people are reluctant to sacrifice one individual to save five in the case of the footbridge dilemma.

Two competing explanations can be put forward to account for these puzzling findings (see Greene et al., 2001). One explanation invokes the role emotions in giving rise to the discrepant responses across the two dilemmas. Specifically, according to this explanation, the thought of pushing someone to his death is more emotional than the thought of hitting a switch that will cause the trolley to produce similar consequences. It is this differential emotional reaction that causes individuals to respond differently to the two dilemmas. A second explanation is devoid of emotions; rather it invokes cognitive processes related to justificatory processes. Specifically, according to this account, the decision to push an individual to his death in order to save five (footbridge dilemma) is more difficult to justify than the decision to hit a switch to turn a trolley onto a different set of tracks (trolley dilemma). It is this differential justificatory cognitions that causes individuals to respond differently to the two dilemmas. Using methods of neuroscience (fMRI, in this case), Greene et al. (2001) provided support to the former explanation—brain areas associated with emotion were found to be more active during contemplation of dilemmas such as the footbridge dilemma as compared to during contemplation of dilemmas such as the trolley dilemma.

1.4. Providing Methodologies for Testing Theories

As the reader might have gleaned from the discussion thus far, an obvious advantage of integrating research in neuroscience with that in decision making is that neuroscientific methods offer the promise of localizing neural activity that is associated with various phenomena and, thereby, offer the advantage of providing direct tests for existing as well as new theories. In the next section, we discuss the various neuroscientific methods, highlighting the advantages as well as inherent disadvantages of the different methodologies.

2. Neuroscience Methods

In this section, we briefly discuss three techniques that continue to provide the bulk of brain localization data: singe-cell measurement studies, studies with individuals who have impairments in specific areas of the brain, and functional imaging studies (for greater detail on these techniques and on their relative merits and demerits, (see, e.g., Cacioppo et al., 2000; Savoy, 2001).

2.1. Single-Cell Measurement

In single-cell measurement, brain activity is measured at the level of an individual neuron or a small group of neurons by placing a probe at the brain location of interest. Because single-cell neuron measurement involves surgically implanting a probe in the brain, it is almost always restricted to nonhuman animals. The basic assumption behind single-cell measurement studies is that studying animals is informative because humans share many of the same brain structures and functions of nonhuman animals. Using this technique, neuroscientists have been able to shed light on basic that humans seem to share with other animals. For example, using this technique, Hubel and Wiesel (1959) identified a set of neurons in the primary visual cortex that is maximally responsive to the perception of simple lines and line intersections. Another set of neurons in the temporal sulcus has been identified as being responsible for coding facial gestures that carry information such as fear or threat (Hasselmo et al., 1989). Schulz and Dickinson (2000), using the single-cell measurement technique, showed that monkeys that expected to receive a tasty reward showed maximum activation of dopamine neurons in the animal's ventral stratiatum, which has been shown to play a significant role in motivation and emotion. (What is significant about this study's findings is that the dopamine neurons were responding not to the reward per se, but to expectations of receiving the reward.) A limitation of this technique arises from the fact that it is restricted to nonhumans and, therefore, cannot be used to infer higher-order neural processes that humans don't share with nonhuman animals including language, consciousness, long-term planning, and complex decision-making.

2.2. Studies with Brain Damaged Individuals

Localized brain damage produced by accidents, strokes, or diseases provides neuroscientist with another technique to infer neural activity accompanying different phenomena. The logic behind this technique is as follows: if patients with known damage to a brain area A perform a specific task differently than "normal" individuals, and do other tasks equally well, one can infer than area A is used in performing the task. That is, if patients with brain damage in the dorsolateral prefrontal cortex, for instance, show deficits on a working memory task but not on a task involving a test of verbal skills, it is inferred that the dorsolateral prefrontal cortex contributes to working memory.

An example of the use of this technique is the work by Bechara and his colleagues to examine the role of emotions in decision making (Bechara et al., 1997). It is a well-documented fact that patients with damage to the ventromedial prefrontal cortex (VMPFC) tend to be inappropriately emotional, impulsive, and apathetic, and display a diminished capacity to respond to punishment. The emotional responses that people ordinarily generate in response to emotional situations are often abnormal in these patients. Bechara and his colleagues examined the consequences of these deficits for decision making by having participants engage in the Iowa Gambling Task, where participants have to choose among 4 decks of cards. Unbeknownst to the participants, two of the decks (A and B) yield high immediate gain but larger future loss and the other two decks (C and D) yield lower immediate

gain but smaller future loss. Further, participants have no way of predicting when a penalty will arise in a given deck, no way to calculate with precision the net gain or loss from each deck, and no knowledge of how many cards they must turn to end the game (the game is stopped after 100 card selections). The goal in the task is to maximize profit on a loan of play money.

Two groups of participants engaged in the task: normal individuals and VMPFC-damaged patients. As the trials progressed, normal participants were found to avoid the disadvantageous decks (A and B) and prefer the good decks (C and D); by contrast, VMPFC patients did not do so. Moreover, when sampling from the decks, patients failed to generate anticipatory skin conductance to rewards and punishment that, in normal participants, signals anticipation of a possible gains or losses. From these results, Bechara and his colleagues concluded that decision making is guided by emotional signaling generated in anticipation of future events. Without the ability to generate these emotional signals, the patients fail to avoid choices that lead to losses, and instead continue to sample from the disadvantageous decks until they go broke in a manner that is akin to how they behave in real life. (Readers interested in a different interpretation of these findings and in the rejoinder by Bechara and his colleagues may refer to Maia and McClelland (2004) and Bechara et al. (2005).)

While the use of this technique requires access to patients with localized brain lesions, a relatively new noninvasive method called repetitive transcranial magnetic stimulation (rTMS) offers the promise of using this approach on normal individuals (for an example of the use of rTMS, see Kosslyn et al. (1999)). rTMS involves using pulsed magnetic fields to temporarily disrupt brain function in specific regions. In essence, rTMS creates a temporary, reversible "lesion," and the difference in performance on tasks before/after the temporary disruption and during the disruption can be examined to provide clues about which brain regions control which neural functions. A limitation of TMS is that its use is currently limited to the cortical structures of the brain and is somewhat controversial because its safety has not been established.

2.3. Functional Imaging

The third technique that has grown in popularity in recent years is functional brain imaging, including positron emission tomography (PET), fMRI, electroencephalography (EEG), which falls in a broader category of techniques involving event-related brain potentials (ERPs), and magneto-encephalography (MEG). PET and fMRI provide indirect measures of blood flow and relies on the assumption that any mental activity increases demand for oxygen or glucose at active regions in the brain, which is met by increased blood flow to the region. EEG and MEG, on the other hand, measure products of brain activity, either electric (EEG) or magnetic (MEG).

PET involves the inhalation of a radioactive gas or the injection of a radioactive solution that is metabolized by various areas of the brain. The greater the activity in a brain region, the more the radioactive tracer that is present in that region, and the greater the PET signal at that location of the brain. Unlike the other imaging techniques, which are used predominantly to measure neural activation, PET has been used to measure all aspects of the physiology

of brain function including protein synthesis and activity at dopamine receptor sites. Apart from an inherent limitation arising from the use of radioactive substances (governmental guidelines limit the total radiation dose per year per volunteer), the main limitation is that the temporal resolution is relatively poor because it takes time before enough radioactive "ticks" can be counted. As a result, one can typically get only one picture per minute of brain activity and, thus, all one gets at is an averaged brain activity over that period. The spatial resolution of PET is quite good—one cubic centimeter is a good rough estimate of the best that PET is likely to yield—which is substantially better than EEG or MEG, but worse than what fMRI is likely to yield.

fMRI is currently the most popular neuroimaging technique for cognitive neuroscience research in healthy humans and is beginning to used by consumer researchers as well (e.g., Yoon et al. forthcoming). It uses powerful magnetic fields to alter the orientation of atoms in the brain and measures signals given off by these atoms as they return to their normal orientation. Simply stated, brain areas that are active in performing a given task use more blood and, therefore, produce a stronger signal than other brain areas. The advantages of fMRI compared to PET are that (1) it does not require the use of radioactive substance, and (2) it offers better spatial resolution (in the order of 1–5 mm.). A limitation of fMRI is that, though very much better than with PET, the temporal resolution is poor when compared to EEG or MEG. Typically, the temporal resolution of fMRI is in the order of seconds (2–8 s) and is dependent on the strength of the magnetic field and the design of the experiment (e.g. in so-called event-related designs, the effects can be separated to the extent of about 2 s). Fundamentally, the temporal resolution of fMRI is limited by the underlying physiological blood flow response since blood-flow to active brain areas occurs with a stochastic lag in the range of 2–4 s. Another limitation is that it is susceptible to artifacts induced by subject movement (there are motion-detection and motion-correction algorithms that can be applied to the image data, but he algorithms work best if there is minimal motion to begin with).

EEG is an imaging technique that falls in a broader category of methods involving the measurement of event-related potentials (ERPs). The major advantages of ERP methods lie in the high temporal resolutions they afford and their relatively low cost. ERPs have been studied for a long time particularly in the study language processing, providing potentially interesting avenues for studying consumer behavior. For example, the N400 of the event-related potential is a very well established measure of semantic mismatch. It is a negative potential that occurs after 400 ms if two words are incongruent (semantic violations). This ERP component could be used for measuring brand associations: brand attributes that fit worse with a brand name would yield a larger N400 component in the brain. Another well known ERP component is the P600, which is a late positive potential (LPP) that occurs after 600 ms and that has been shown to be linked to stereotypes and prejudice (e.g., Cacioppo et al., 1996; Osterhout et al., 1997).

MEG is another technique that is similar to EEG in that it is non-invasive, offers excellent temporal resolution (in the range of milliseconds), and can be used to measure neuronal activity continuously (a limitation of PET and fMRI). On the other hand, EEG and MEG are limited in terms of three-dimensional spatial resolution because they can only measure signals outside the surface of the head (any 3-dimensional localization of brain activity within the head has to be generated based on data collected at or just outside the scalp). The

major differences of EEG and MEG are (1) MEG machines are much more expensive and are, therefore, much less readily available to researchers, and (2) EEG can be cumbersome to use because of the need to attach many electrodes to the scalp.

3. Potential Research in Decision Neuroscience

In this section, we discuss some examples of potential research in the emerging area of decision neuroscience. Across these examples, we highlight ways in which one can develop a more fundamental conceptualization of the phenomenon of interest and how neuroscience methods can be brought to bear in testing the conceptualization. We begin with a potential study on the well-documented asymmetric dominance and compromise effects. We then propose a study related to ultimatum games, the goal being to investigate the neural processes that underlie allocators' decisions. Finally, we present a research idea relating aesthetics and neuroscience.

3.1. Asymmetric Dominance and Compromise Effects

Context effects (the fact that the choice frequency of any given option may vary depending upon the specific set of other options available) are among the most documented findings in research on choice. Two of the most important context effects are asymmetric dominance and compromise. Consider two options A and B defined on two attributes x and y. Assume that A is better than B on attribute x, but B is better than A on attribute y. The asymmetric dominance effect refers to the finding that the relative probability of choosing A over B can be increased by introducing a third option C ("decoy") that is worse than A on both attributes x and y (that is, A dominates C) but is not worse than B on both attributes. The compromise effect says that the relative probability of choosing A over B is increased by adding a third option C such that A is the middle option between B and C.

Although the asymmetric dominance and compromise effects are both "relational" heuristics that depend upon relationships among the available options, recent research suggests that these two heuristics may fundamentally differ in the processing that characterizes each. In particular, asymmetric dominance may be more automatic and perceptual in nature, whereas compromise may be more controlled and cognitive. Dhar and Simonson's (2003) results support this distinction. When a no-choice option is made available as a way to resolve choice conflict, the asymmetric dominance effect increases in size, whereas the compromise effect decreases. Shafir et al. (2002) show that asymmetric dominance effects can be obtained with honeybees and gray jays; these results are consistent with the idea that asymmetric dominance effects may be more automatic and not require higher-order cognition for their occurrence.

Based upon these and other results, we hypothesize that the nature of the processing underlying asymmetric dominance and compromise effects differs; hence, the regions of the brain active during asymmetric dominance choices and compromise choices should differ systematically. In particular, we believe that compromise effects will be

characterized by more controlled processing, in particular conflict resolution and cognitive control. Thus, we expect more activation of the anterior cingulate cortex, insula, prefrontal cortex, and orbito-frontal cortex for compromise choices relative to asymmetric dominance choices. There may be more amygdale activation for asymmetric dominance choices relative to compromise choices. These predictions can be tested in a study using fMRI.

3.2. Role of Emotions in Ultimatum Games

Whenever a theory rests on the premise that people are selfish, one shouldn't be surprised to find violations in situations that involve fairness. Obviously, we care about fairness for ourselves, our friends, and our families. But what happens when the other person is a complete stranger and that stranger will never know the identity of the decision maker? This is the question that economists asked when they first ran an empirical experiment known the ultimatum game (see, e.g., Thaler, 1988). Two players are randomly paired. One is assigned the role of the allocator, and the other is the receiver. The allocator makes an offer about how to divide $ 10. The receiver can either accept the offer (and the money is divided accordingly) or reject the offer. If the offer is rejected, both players get nothing. The solution to the ultimatum game from rational choice theory is for the allocator to offer the smallest sum of money possible to the responder and for the responder to accept this offer. However, hundreds of studies have demonstrated violations of rational choice theory. First, allocators typically offer about 40–50% of the pie. Second, receivers tend to reject offers that fall below 30%.

Why do most allocators offer even splits? One hypothesis that has been offered in the literature is more cognitive in nature and proposes that that people might be selfish, but they are not idiots. They realize the receiver might reject their offer, so they maximize their expected profits, and 40–50% of the pie has that property. We propose a second hypothesis to account for allocators' behaviors. According to this hypothesis, allocators make choices based on emotions—fear of rejection or the pleasure from being selfish/fair. If this emotions-based conceptualization is valid, then one could argue that specific components of a neural circuitry that includes the amygdala, the orbitofrontal cortex, and the right insular/somatosensory cortex, which have been shown to be critical for the processing of emotions (Damasio, 1994; Sanfey et al., 2003) should be active when allocators make their decisions.

As with the earlier example, this prediction can be tested using fMRI. A second approach to testing this prediction would be to have three groups of participants play the role of allocators in the ultimatum game: individuals with stable focal lesions in either the amygdala, orbitofrontal cortex or the right insular/somatosensory cortex (target-patient group), individuals with stable focal lesions in areas such as the dorsolateral sector of the prefrontal cortex that are not involved with emotional processing (patient-control group), and normal participants (normal-control group). If our prediction is valid, then the findings in the literature on allocators' decision ought to be replicated in the patient-control and normal-control groups, but not in the target-patient group.

3.3. Aesthetics and Decision Making

A noncontroversial assertion is that aesthetics will drive brand choice, ceteris paribus (see, e.g., Norman, 2004). Further, though neurological research on aesthetics is sparse, there is some evidence that idiosyncratic perceptions of artistic beauty are associated with cerebral activity in areas associated with rewarding stimuli, particularly the orbitofrontal cortex (Kawabata and Zeki, 2004). The question, however, is will aesthetics influence decisions when it is pitted against attributes that are more determinative of product utility? For example, will choices between two brands of cars, one with a more appealing print advertisement but less favorable ratings on mileage be systematically biased in favor of the first option? And, if (or when) these biases do occur, what are the potential neural correlates of the biases?

Two competing neural-level hypotheses can be put forward to account for the biasing effects of aesthetics (assuming the bias exists) and tested using neuroscientific methods (e.g., fMRI). First, aesthetics and the more determinative attribute give rise to a conflict that is accompanied by activity in areas that are related to conflict resolution (e.g., the anterior cingulate cortex). Second, the neural activity related to aesthetics result in a pre-decisional distortion of information on the more determinative attribute, in which case one should see less activity in the anterior cingulated and a stronger relationship between activity in the orbitofrontal cortex and participants choices (the greater the activity in this region is, the greater the probability that the individual will pick the option with the more aesthetically appealing advertisement).

4. Integrating Neuroscience and Decision Making Research—Challenges

In this concluding section, we present some of the challenges one need to be cognizant of while venturing into research in the area of decision neuroscience.

4.1. Attention to the Task, Design, and Stimuli

Several of the challenges arise from the methods of neuroscience. For example, when one plans to use functional imaging to test predictions, one needs to develop several hundred stimuli across the treatment and control conditions, differing only in their reliance on the specific processes hypothesized to occur across the conditions. For example, Kawabata and Zeki (2003), in their study of the neural correlates of beauty, had a simple one-factor repeated-measures design with three levels (paintings classified as beautiful, neutral, or ugly), yet had to use 192 paintings as stimuli in order to measure activation. This is because functional imaging involves very low signal-to-noise ratios—effect sizes are often very small compared to random variations in the data and, therefore, necessitates averaging across a large number of trials so that the signal can be detected from the noise.

Similarly, studies using patients with stable lesions in specific neural areas require repeated-measures designs since the number of patients are likely to be very low (often 7 to 10 patients). Further, issues related to random assignment become relevant in lesion studies and often color the interpretation of data.

Care also needs to be taken that, as with any research in decision making, the task is designed appropriately to test a theory. For example, there have now been several studies done with ventromedial prefrontal cortex (VMPFC) patients to test Damasio's (1994) Somatic Marker hypothesis, albeit with mixed results. Studies using the Iowa Gambling Task have generally confirmed the Somatic Marker hypothesis. Leland and Grafman (2003), however, were unable to find a difference between patients and controls in response to a battery of questions that included assessment of attitude toward risk. To account for their "null" results, Leland and Grafman propose that their task did not tap into emotional components of decision making since, unlike the Iowa Gambling Task, their task had no real consequences in terms of the outcomes of choices. Thus, this is an example where an inappropriate design of the task can lead one to wrong conclusions.

4.2. "Big Science" Model for Conducting Research

Owing to its interdisciplinary nature, research in decision neuroscience is likely to entail interdisciplinary collaboration, a norm in areas such as medicine and neuroscience, but not common in decision making. Further, conducting research in decision neuroscience is likely to be very expensive compared to traditional studies in decision making (e.g., the cost of using functional imaging can total more than $ 1000 per participant in terms of charges for scanning, analyzing the data, etc.). Therefore, research in decision neuroscience is likely to entail applying for large grants from institutions such as the National Institute of Health.

Despite the challenges discussed above, we believe that integrating neuroscience with decision making offers tremendous potential for future research in decision making.

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