

# A THEORY OF CONSCIOUSNESS

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There are two problems about consciousness that I consider most difficult to answer. The first problem concerns with the fact that, although consciousness is related to the activities of a neural system, it can not be simply reduced to the whole set of ongoing activities in that system. There are many activities that occur in our neural systems and our consciousness seems to correspond to only a few of them. In later discussions, I shall refer to this problem as the *correspondence problem*. The second problem is concerning with the fact that there are many aspects of consciousness which do not seem to be functionally related. Consciousness appears to be there when we pay attention to something, when we intend to do something, when we talk to ourselves, or when we make a plan and carry it out. All of these aspects do not seem to have a functional relation to each other and yet they seem to be associated with the same consciousness. Thus, I shall refer to this problem as the *multi-presence problem*. It is the above two problems that I am going to address in this article.

## 1. The Correspondence Problem

Let me start to consider the first problem. What makes the problem puzzling is that consciousness corresponds to some of ongoing neuronal activities but not to all of them. When we open our eyes, for instance, a variety of visual information reaches our retina and gets processed and transformed into signals that are sent through nerve fibers to our brain. However, not all of those signals would result in things being seen by us. We can only see a few things, possibly only one thing at a time, and leave many others in an obscure background. That we seem to see all things at the same time is an illusion, since it can be easily demonstrated by experiments that, when items are briefly flashed on a screen, the tested subjects can only remember a few (four or five)

displayed objects and not all of them (Sperling 1960). It is also a common experience that, when we practice a new skill, we tend to be aware of our actions, but when we become well-trained on such a skill, we tend to be unaware of them. Presumably the same kind of information is sent from our sense organs to our brain, irrespective whether we are practicing a job skillfully or unskillfully, and yet there is a difference in our awareness of the activity between our doing it in one way and in the other way.

Thus, consciousness tends to make selective reading of the events that occur in our brain. We can make an analogy of consciousness by thinking of a filter that locates between all the activities in the brain and those that are read out by consciousness (Broadbent 1958). The filter is said to be limited in capacity, because it does not pass all the information to consciousness.

The filter model provides a functional view of consciousness. But if we think that there is a location in the brain which functions as a filter, then we would face a conceptual difficulty. Let us imagine that there is indeed a place in the brain for which many channels of information are competing to get through. Let us also imagine that the winner among them enters this place and the information it carries through is read out by consciousness. This is indeed a very peculiar picture about our brain, because it says that there is some special area of the brain whose function is to generate consciousness.

We know that each area of the brain consists of neurons. The firing of a neuron is caused by the firing of other neurons which send signals to it through their synapses. If consciousness is generated by the firing of neurons, then it is hard to see why only the firing of neurons in some special brain location serves this function. It is possible that some special neurons can activate a bodily machinery which is physically connected to them. For example, the neurons attached to our muscle can stimulate the muscle to stretch. But the stretch activity really occurs in the muscle, not in the neurons. This is not what we mean when we say that neural firing generates consciousness, since we believe that consciousness corresponds to the firing of neurons themselves.

In terms of firing of neurons in special location, one would face similar difficulty in accounting for an interesting phenomenon called "blindsight." Blindsight is caused by the severe damage to the primary visual cortex. Usually the patient, if requested, claims that he is unable to see the light that falls on the blind part of his visual field,

but when he is encouraged to make a guess, he can be fairly accurate in pointing to the direction of the light (Weiskrantz 1986). The usual explanation for this phenomenon draws from the fact that, although visual information do not reach the damaged part of the brain, they nevertheless flow through different pathway to certain area of the brain, enabling the patient to perform the right action. The difficulty with this explanation is again in the existence of a special area in the brain. One would wonder why the flow of information must reach this area to cause the visual awareness.

## **2. Consciousness and Memory**

Perhaps we can build an alternative point of view concerning consciousness. Consciousness, after all, is what we know about what we have just seen or done. So it takes a separate agent M to monitor and to talk about what agent A is doing. But doesn't M know exactly what A is doing? No, because when A is busy in doing its job, the minute details of A's work is not available to M. Instead, M only knows about the most consistent thing that is done by A. Thus, when M makes report, it only reports what is known to it about A.

Thus, the alternative view consists of the following elements. (i) It takes more than one agent to work in a subject's society of mind (Minsky 1986). (ii) While other agents are working towards certain goal, a monitor agent M collects information and also reports about them. (iii) M's report constitutes the content of the subject's consciousness.

At first glance, this may look like nonsense. People feel that there is always a unity between what is known to the brain and what is done by the brain. But studies about split-brain patients reveal that this may not be always the case. The patient's one hemisphere usually does not know about the other hemisphere is doing. Thus, when it becomes necessary that the left hemisphere which controls the speaking has to explain the behavior controlled by the right hemisphere, it will make up explanation based on the information available to it (Sperry 1961).

Now let us consider the benefit of the alternative view. It allows the possibility that many agents do their jobs at the same time, but not all of the works get reported by the monitor agent M. M would report about an agent A, only if the information about A becomes available to M. Since A is working hard to complete its job, it would be too busy for A to send out the information at the same time. Most likely, M

has to collect the information by itself. But how does M do it? At the moment when M starts to look into A's activity, it has already been in the recent past. So the easiest way for M to get the information is to look at the trace that is left behind by A. But if the trace has been frequently erased or re-written, it would not be a reliable information. So most likely, only the sustained trace will be read by M.

Thus, I argue that it is the trace being written somewhere in our brain which makes it possible for us to keep track of what we have done. This view is promising, because it can explain why information has to reach certain locations to become consciously accessible. Presumably, there are certain areas in our brain into which the trace can be written down. If relevant information do not flow into these areas, due to damage to the areas or blockage of the pathways to them, then the information would not be read out by consciousness. Moreover, this view allows the possibility that some neural signals do not result in something in the consciousness and they can still impact on certain area in the brain. These two accounts taken together may help to explain why blindsight patients do not see light and yet are able to point to its direction.

This view may even offer an explanation for the fact that skillfulness reduces subject's conscious awareness of his actions. It is plausible to think that when the subject develops his skill, a detour is built within his neural system. While this detour serves to accelerate the information flow from one point to another point in the system, it also bypasses the area where memory trace can be laid down.

Thus, the alternative view asserts that conscious states are the remembered neural activities. Or put in different words, things become consciously accessible, because they are remembered as having been processed by the neural system. Thus, in order to explain various aspects of consciousness, it helps to analyze how they are related to the process through which things get remembered. Let us take attention as an example. Attention determines what is being admitted to consciousness. This is because the attended objects tend to be those that can be remembered with relative ease. Take voluntary control as another example. It is said that in the process of controlling one's actions, one is also conscious of the process. In fact, what is really involved here is that the so called "voluntary control" is processed by way of certain mechanism whose procedure can be easily recalled. Thus, "surely you can remember it, because it is your own decision" is nothing more than "surely you can remember it, because it is made out of a procedure which is well-recorded in your memory."

So the new view not only answers the correspondence problem, but also helps to answer the multi-presence problem, as mentioned in the beginning of this article. But before I extend my discussion to the latter point, let me first examine a few examples and use them to argue for the view that consciousness is about remembered neural activity.

## **2.1 Consciousness and Short-Term Memory**

People may feel uneasy about the above view, because they tend to think that whether they are conscious of something is independent of whether they can remember it later or not. However, Sperling's experiments, already mentioned in the above, demonstrated that the matter is not as simple as it looks. In his first experiment, three rows of four letters were flashed briefly on a screen and a subject was asked to report the displayed letters. Normally, the subject was able to remember only four or five of the letters. In a second experiment, the subject was asked to report only one line of letters, which was indicated to him immediately after the visual display had been terminated. Surprisingly, the subject was able to remember three of the four letters on any of the line indicated to him. Suppose that the three letters of each line had been rooted in his consciousness when he saw the display, he should be able to remember nine letters out of the total twelve letters in the first experiment, instead of only four or five letters as the outcome.

Thus, the two experiments suggested that the subject had to rely upon his memory to determine the content of his consciousness. Moreover, the content may vary according to the cue, in this case the indication of the line, by which his memory was guided. Sperling also demonstrated by experiments that the number of remembered letters decreased as the delay of the cue increased. This result suggests that the content of consciousness varied according to the time at which the subject was asked to report. It is conceivable that many other memory conditions could also affect the content of consciousness.

## **2.2 Consciousness and Long-Term Memory**

It is not uncommon experience for some people that, after sufficient intake of alcohol, they could maintain normal actions (walking and driving) for a while, but are later unable to recall what they were doing in that period of time. Recent studies have revealed that ethanol (the major chemical factor of alcohol) inhibits the function of

NMDA receptors in hippocampal neurons (Lovinger et al. 1989). Since the activation of NMDA receptors in hippocampal neurons is involved in an important kind of memory mechanism called long-term potentiation (McNaughton and Morris 1987), the above finding provided a link between ethanol and some of its effects on long-term memory (Gonzales 1990). So it seems that overdrinking has the effect of inhibiting the normal function of long-term memory, and can leave a complete blank in a person's memory of his recent experience.

This fact leads us to an interesting question. Was this person conscious of what he was doing, about which his later memory fails to reveal anything? To infer from the fact that he acted like normal people, we might judge that he did. But from this person's own account, we would think that he did not. In some people's opinion, judging from the sheer performance of a working system, say a computer, is not a sound method for concluding whether such a system is a conscious being or not. But I wonder what those people would have to say in this case. Should the drunk man be taken as a walking robot or a truly conscious being who nevertheless loses his memory afterwards? I do not have an answer for this question myself.

This is a difficult question, because our normal notion of consciousness does not extend to the case in which a person's short-term memory works fairly well but none of its contents gets written into his long-term memory. Under the normal function of our neural systems, certain short-term memory will be transferred into our long-term memory. That is why we are not only aware of our conducts but also remember that we have such awareness. If, however, the linkage between short-term memory and long-term memory breaks down, causing all traces to be lost, then we tend to believe that we do not have consciousness in that period of time.

### **3. The Neural Basis of Consciousness**

It is argued in the previous section that consciousness has a lot to do with the memory process. How things become consciously accessible depends how they get remembered. The memory process is not a simple reflection of the information flow that enters into a particular region of our brain. In Sperling's (second) experiment, for example, what letters can be remembered by a subject depends very much on the line indicated to him, and also on the time the indication is given. Therefore, memory of the past has really been integrated into the conditions under which the memory is

formed.

Viewed from the level of neurons, the above conclusion is reasonable. The trace which is written down is nothing more than the facilitation of the connections between certain pairs of neurons. When some neurons start to fire later on, the firing would spread to the neurons whose connections to them have been facilitated. But which neurons will get activated depends very much upon which neurons are stimulated to fire initially. This explains why the content of our memory can be guided by certain cues. Moreover, not only recently facilitated connections (short-term memory) but many long-lasting facilitated connections (long-term memory) would also spread the firing. How do all the activated neurons maintain a coherence? Although this is far from clear, but a reasonable assumption can be given in the following.

Each activated neuron sends its signals to neighboring neurons, the neighboring neurons, if get activated, also send signals to their neighbors, etc. Suppose that in the neural system there is always a path for each neuron such that if one travels along it, one would eventually go back to the original neuron. Since in this system each neuron is in a process that sends and receives signals with the rest of the neural system, sooner or later such an iteration process is going to reach a steady state. Moreover, the steady state is reached by all the connected neurons.

In many areas of our brain, the situation is a little bit more complicated, because the signals sent back and forth between interconnected neurons are oscillatory. Oscillatory signal can be easily produced by a small group of connected excitatory and inhibitory neurons. If such groups take place for single neurons in a neural system considered in the above, then the steady state becomes not only oscillatory but also synchronous, that is, all signals maintain the same frequency of oscillation. This is what has been observed in rabbit's olfactory system (Freeman 1989) and also in cat's visual cortex (Gray and Singer 1989, Eckhorn et al. 1988).

The synchronous signals have been found to exist in different areas of the visual cortex whose functions are to analyze different features of the same object. I think this finding has something to do with the interesting discoveries of Treisman some years ago (Treisman and Gelade 1980). In her experiments, subjects have shown relative ease to pick an object which differed from background objects by a single feature, say color or shape. But when subjects were asked to pick an object (a red letter T) which differed from some background objects (green T's) by one feature (color) and also

differed from other background objects (red S's) by another feature (shape), their search time for the target object became longer.

It is very likely that the subjects' neural systems would have to use the synchronous signals as the clue for finding the target object. It is also likely that the subjects had to direct the focus of their eyes upon the target object, so as to prohibit the synchronous signals that represent background objects from spreading to those that represent the target object. I suspect that this is the reason for the longer search time.

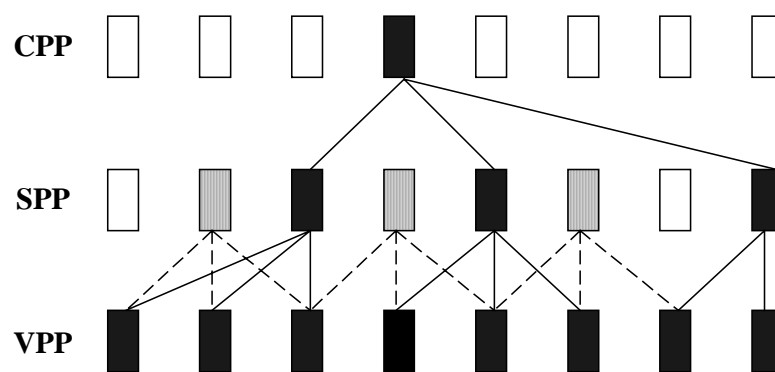
In general, even when no deliberate search is necessary, our consciousness remains to be selective in nature. This is because when a neural system reaches a steady state, it has the tendency to preserve the state until a significant change of external input has occurred. In fact, the resistance to change is so remarkable that a neural system exhibits a special effect called "hysteresis." That is, if it takes the input to increase to a level X for the system to reach a steady state S, then it takes the input to decrease to a level significantly lower than X for the system to leave away from S. There are several implications of this effect. First, the system tends to be selective, that is, it has limited capacity. Whatever input happens to induce the system to reach a steady state, it will lock the system in that state for a while. This system will resist possible changes induced by other inputs that occur during the same period of time. Secondly, the sustained steady state becomes the only detectable event, or the only consciously accessible event, in the system. Thirdly, the longer the duration of the steady state, the better is the chance for it to be written into long-term memory, and the better is the chance for it to be recalled afterwards. Furthermore, the more repetitious occurrence of the event, the more solid is the long-term memory associated with it.

#### **4. Coherence in Neural Systems**

The consolidation of neural system into a steady state is the key for the generation of a consciously accessible event. But it does not take the scrutiny of objects, as demanded by Treisman's experiment, to arouse our conscious awareness. When we enter a familiar environment, say an office room, we do not have to scrutinize each object, or even any single object, to realize that we are in the office. On the other hand, knowing the fact that we are in the office helps us to quickly



identify many objects within the room. In Biederman's experiment, a picture is cut into six pieces. Those pieces are jumbled randomly and re-assembled into a new but meaningless picture. Subjects were then asked to name one of the objects in the new picture (Biederman et al. 1973). The experiment demonstrated that some of the objects which would be easy to recognize in a normal picture became difficult to identify in the jumbled picture. It also demonstrated that global comprehension, that occurred when a normal picture is in view, can precede local comprehension and can even enhance the latter when further conditions are satisfied. This is a somewhat surprising result, for we feel that the former should come after the latter.



**Figure 1.** Three layers of neural processors.

How can we interpret the above result in terms a neural system? Let us consider this problem with a very simple neural architecture (Figure 1). I assume that there are three layers of neurons which process visual information. Neurons on the first layer process visual primitives, such as shape, orientation, texture, or lines that can be extracted from the visual world. For this reason, I shall name them as visual-primitive processor (VPP). The neurons on the second layers receive signals from those on the first layer. I assume that these neurons function as simple-pattern processor (SPP). The neurons on the third layer receive signals from SPP neurons and they function as complex-pattern processor (CPP).

The way that a SPP neuron works is very simple. It collects signals that are sent from neurons on the first layer and puts a weight to each of the received signal, which is determined as the synaptic strength of the sending neuron. If the sum of the weighted signals reaches a threshold value, then the SPP neuron fires and a pattern is supposed to have been detected by it. Since this process is so simple, it is possible that

many SPP neurons are activated, some of which may not be even compatible with each other.

The signals generated by SPP neurons are sent to neurons on the third layer whose function is to detect much more complex patterns than the second layer. The CPP neurons work in a similar way as SPP neurons, but they have much larger receptive field. This means that, in order to be activated, they must meet much more complicated conditions than SPP neurons. It follows that there is much less incompatibility generated on the layer of CPP neurons.

As depicted in Figure 1, I assume that there is only one CPP neuron (the dark square on the third layer) activated, and it receives signals from three SPP neurons (dark squares on the second layer). There are three other SPP neurons (gray squares) that are also activated, but they do not send signals to any CPP neuron, because they do not correspond to any familiar complex pattern. If no further arrangement in this system is introduced, then we are left with one activated CPP neuron and six activated SPP neurons. The three dark SPP neurons are compatible with the dark CPP neuron, but the three gray SPP neurons are incompatible with it. This is a rather unwelcome result.

I shall then make some extra assumptions. First, I assume that reciprocal excitatory connections exist between SPP and CPP neurons so that if a cluster of SPP neurons send signals to a CPP neurons, then the CPP neuron would also send signals back to them. Secondly, I assume that reciprocal inhibitions exist among those competitive SPP neurons, i.e., those neurons which receive signals from same VPP neurons.

Given the two new assumptions, the dark SPP neurons now receive signals from three sources. (1) The excitatory signals that come from the first layer. (2) The excitatory signal which is sent from the dark CPP neuron. (3) The inhibitory signals that are sent from some possible local competitors. These neurons still fire, because they receive not only the bottom-up support from lower layer but also the top-down support from upper layer. The latter signals are very strong in character, because they are sent from a CPP neuron which receives signals from a cluster of SPP neurons. On the other hand, the gray SPP neurons receive signals from two sources. (1) The excitatory signals that come from the first layer. (2) The inhibitory signals that come from the local competitors. These neurons cease to fire, because they are not boosted

up by any upper-layer support, and thus lose its fight against local inhibitory forces. As a consequence, the top-down signals sent from the activated CPP neuron serve as a force which boosts up the compatible SPP neurons and suppresses the incompatible neurons on the same layer.

It is possible that the CPP neuron would still fire even when a few subordinate SPP neurons do not fire, since the former has large receptive field and can afford losing a few bottom-up support. This explains why we can be aware that we have entered an office room without paying scrutiny to the minute details within the room. Moreover, knowing that we are in an office room helps to identify the things that we are encountering there. On the other hand, if we are given a screwed-up context, such as the jumbled picture in Biederman's experiment, then our SPP neurons would not receive any top-down support, and may result in firing failure.

## **5. Regulation of Actions**

As we have seen in the previous section, the development of higher-level neurons that respond to complex pattern is very important for a neural system to achieve coherence. This means the ability of the system to boost up the firing of neurons that respond to mutually compatible patterns and to suppress the firing of neurons that respond to patterns incompatible with them. The formation of complex pattern processor does not need to be long term in character. We often have the need of temporarily identifying a collection of images or symbols as the sign for the coming of an expected event. Sometimes, this can even be done by linguistic instructions. For example, we could be instructed to wait for a bus which is red in color and is expected to arrive in approximately five minutes.

How can language help to quickly establish a complex pattern processor? I think this can in principle be done in the following way. First, there exists in our brain a special set of neural structures that can serve as a link between concept and language processing. It can take a concept and stimulate the production of word-forms, and it can also receive words and cause the brain to evoke the corresponding concepts (Damasio and Damasio 1992). When an oral instruction is mediated via this set of structures to create appropriate concepts in our brain, the concepts in turn would evoke some responses in our brain. For example, they may generate certain signals constituting our mental imagery, which would also facilitate certain neural pathways.

This initial response, possibly very weak and stereotyped in nature, can nevertheless bias neural systems in our brain towards expected signals. That is, the brain becomes more readily engaged in a state which is compatible with the initial state that is set up in the appropriate neural systems. Furthermore, the brain becomes much less sensitive to other distracting signals that are incompatible with the initial setting.

Traditional account for the mental expectation usually makes the assumption that the brain creates a role model and uses it for comparing coming signals. According to this account, the brain will enhance the signals that are compatible with the model and suppress those that are irrelevant to it. My explanation given in the above has made the same prediction, but it avoids the presupposition of a role model for performing the signal comparison. Instead, it assumes a modulation process which induces neural systems to establish, upon the arrival of expected signals, a steady state which is compatible with the initial setting of the systems.

Studies on brain lesions have revealed that prefrontal cortex is involved in forming mental expectation and performing many types of complex mental operations. Prefrontal cortex is known as the part of the brain that has rich reciprocal connections with major sensory, limbic, premotor and speech areas of the cerebral cortex. Thus, it is an ideal place in the brain for the establishment of CPP neurons, which are discussed in the previous section. The function of CPP neurons is to send boosting force to its subordinate neural systems to get hold of a complex pattern, or a context. The CPP neurons do not have to be activated by signals from sensory cortical areas. They can be activated by linguistic instructions, or various types of chain reactions that are established in the past learning processes. It seems that the prefrontal cortex has so clever a design that enable some of the neurons to function as context holder even when the corresponding context in the outside world has vanished, and this is demonstrated in the following discovery.

In a delay-response task set up by Goldman-Rakic and her colleagues, one of eight small squares on a television screen is flashed and vanished. A monkey is then instructed to move its head to the target at the end of a delay of three to six seconds. Using the eye-movement experiment, Goldman-Rakic's team is able to demonstrate that certain neurons in the prefrontal cortex respond to the appearance of the target. There are other neurons responding to the disappearance of the target and they remain activated until the end of the delay, when the monkey makes its eye movement

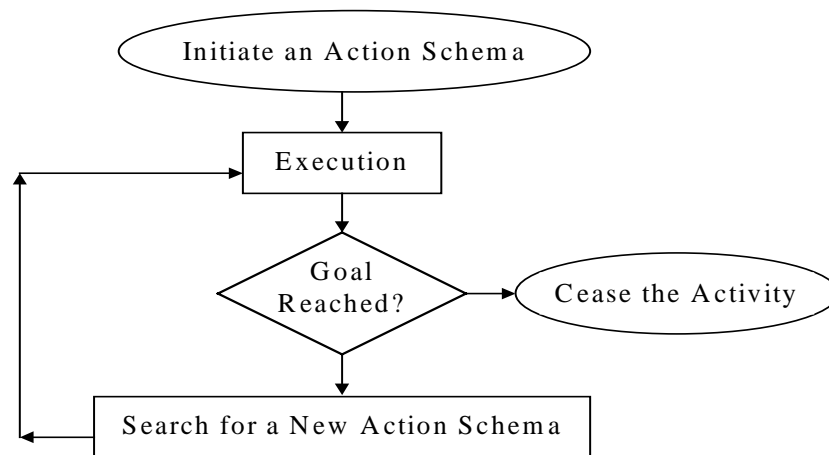
(Goldman-Rakic 1992).

Lack of knowledge about the detailed design of neural circuits in the prefrontal cortex, I am not able to guess why it takes one set of neurons to respond to the appearance of target and another set to its disappearance. Perhaps this outcome should be expected, since the first set of neurons can not continue to react when they lose the support from outside stimuli. The turn on of the second set of neurons is perhaps by way of other means, for example, the concentration of certain kind of neural transmitters. But I suspect the two sets of neurons put together would constitute the CPP neurons as discussed in the previous section: one set of them reacts to the occurrence of a context, while the other set preserves the context, even when the outside correspondence has already vanished.

If the prefrontal cortex can preserve a context, it can certainly switch contexts. This can be easily done, since the change of input from either the external or the internal environment can stimulate a neural system to migrate from one steady state to another steady state. The prefrontal cortex, again, is the ideal place to serve as context switchboard, due to its rich connections with many other cortical areas. Putting together the two functions, preservation and switching of contexts, the prefrontal cortex becomes the most ideal place to monitor and regulate the progress of a complex program. Here I quote the words of Luria to illustrate what prefrontal cortex would do when it engages in a complex action program.

In the case of the simplest or the most usual voluntary action, when the necessary movement is determined unambiguously by the aim of the action and the external situation, the role of the speech components is limited simply to formulation of the idea and the triggering of the appropriate motor stereotypes. In more complex cases, when formulation of the motor task no longer ensures the unambiguous appearance of the required action, the role of the speech components of the voluntary motor action is more complex. In such cases, speech participates in the recoding of information reaching the subject, the distinguishing of its most important features, and the inhibiting of irrelevant possible courses of action arising either under the influence of direct environmental stimuli or as a result of inert traces of previous experience (Luria 1980, p. 292).

The emphasis in this passage is the important role which is played by language in initiating an action program, monitoring the progress of the subsequent actions which carry out the program, correcting the errors made by the actions, and ceasing the activity when the aim has been achieved, or otherwise resuming the activity.



**Figure 2.** Monitor and regulation of an action program.

In Figure 2, I have drawn a simplified diagram that shows the process in which an action program is executed. The prefrontal cortex is involved at the transition from each step to the next step. At the beginning, it has to look for an action schema to start with the activity. In order to do this, it has to look into both the external and internal environment to find available tools and means. How does the brain know what the right schema is for the current problem situation? If fact, it may not know. So what it can do is to activate whatever strategy that has been associated with the similar problem situation.

At the end of the execution of the schema, it has to evaluate the consequence with the goal. If there is a match, it ceases the program. If not, it looks for a new action schema and thus calls forth a new loop. Sometimes, we find ourselves hopelessly trapped in the same loop, because we can no longer come up with any new schema but randomly repeat any of the used ones. As a consequence, we may pause at this point, and start to reason with ourselves, trying to find what has been missed by us, or we look around, trying to be inspired by the external environment.

The prefrontal cortex is involved in a variety of activities in the above process because of the following advantages. First, its rich connections with almost all important cortical areas enable it to engage many areas into building a stable steady state, although this may not be the most desirable state at each moment. Secondly, it engages the speech areas in monitoring the execution of action schema, evaluating its consequence, and modifying the state by evoking new action schemes. The language area is frequently engaged in the carrying through of a voluntary control of actions, since the brain does not always know in advance what is the best strategy for

accomplishing a goal. When it fails at such a mission, it has to appeal to the language area to re-examine the environment, to look for new strategy, and sometimes even to play the role of a supervisor, exerting appropriate encouragement or threat to refrain the brain from getting lazy.

## **6. The Multi-Presence Problem**

Why are we conscious of our voluntary actions? The common-sense view assumes that there is a self which is in voluntary control of the actions. According to this view, the self is also the subject which senses what is happening in the inner and the external world. Thus concludes the view that the self must be consciously aware of what it is in control of.

To coalesce the common-sense picture with the neurological reality, I find it very shaky to assume that the control and sensing of our voluntary actions are made by the same neural entity in our brain. In the previous section, I do away with this assumption by postulating that there are many different areas which participate in the carrying through of a voluntary control at different time. Some areas participate in preserving a goal context so that when an action has been performed, the consequence can be evaluated. Some of the areas participate in switching contexts, so that the action program can be modified and previous errors can be corrected. Furthermore, I assume that the preservation and switching of contexts can be made in a self-organized manner, that is, the participating neural systems can adjust themselves to maintaining a steady state, or toppling an old steady state and migrating into a new one. If all of these activities can be carried through while no neural entity has participated throughout the whole process, how can those actions be consciously accessible? Or, to put the question in a different way, who is becoming conscious of them?

If there is no neural entity which is involved throughout the whole process, it make less sense to hypothesize that there is one which is sensing the whole process. Thus, it is more urgent to hypothesize that consciousness is through a memory process, that is, it arises when some monitoring agent starts to examine what has just happened from the trace that is left somewhere in the brain.

But why are voluntary activities particularly easy to remember? I think this is due to the following reasons. (1) The very stable steady state achieved by the participation

of many cortical areas has rendered long duration of the state, and thus the durability of its memory trace. (2) The participation of a large set of neural entities also renders the retrieval of their activities very easy. (3) The participation of language area, particularly in setting a goal context and also in the assessment of results and re-examination of environment, has made it possible that the knowledge about the situation be summarized in highly condensed form, and can thus be remembered with much more easy.

It may be argued that when we are conscious of our actions, not only the actions appear in the consciousness, but also the feeling that there is an I who is possessing the consciousness. Indeed, the question concerning how a concept of self is formed in our life experience is hard to answer, and it is not a problem that I want to address in this article. But I think we can at least get a clue from what has already been hit upon in the explanation of the voluntary control of our actions.

Language plays a great role in our voluntary control, because through the use of it opens the rich repertoire of concepts, schemes, and memories. Thus, although there is no neural entity which is active for all of the time, there is nevertheless a memory bank, stored with knowledge and life experience, organized in a highly condensed form and easily retrievable manner, into which our new knowledge and experience is being constantly written. When an agent has the need for retrieving the past memory from this bank, it sees that the records are organized in reasonably chronological order, and the events embedded in the records can be easily reconstructed with the help of knowledge and common sense. The agent then feels that there is a continuation of its past lying within the memory. This is perhaps why the feeling of a self is concomitant with the consciousness.

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