A PROPOSED MECHANISM FOR ASSOCIATIVE MEMORY

Carl Pacifico

Introduction

To survive, every creature, from a microbe to a human, must respond appropriately to the objects it encounters in its environment. A person's response to these objects is more likely to be appropriate if he/she has correctly identified the object and its connections with other objects. These connections among objects in the real world exist whether or not anyone is aware of them or has identified them correctly. For example, as no one was aware of the existence of microbes before the invention of the microscope, people were unable to respond appropriately to their encounters with microbes, resulting in innumerable deaths from infections, smallpox, plague, etc.

A person's response to the stimuli he/she encounters is based entirely on the information that is already in his/her brain at that time. Every bit of information anyone has about the external world is detected by that person's senses. This information might have been obtained by direct detection of stimuli in the environment or it might have been detected in a communication, intended or unintended, from others. This sensory information is always in the form of neuronal impulses, which must be interpreted in order to identify the objects of the world and their connections. If a person does not detect an object or its connections, he or she has no way to know that they exist.

The brain of every creature, whether that of a mouse or a human genius, has no way to interpret the impulses it receives from its senses. All it can do is *assume* what these impulses represent in the real world. As a result, every mental image anyone has of some aspect of the real world is always an assumption, which might or might not be correct. So we often respond to stimuli without the information we need or with incorrect information.

Definitions

An "object" is defined as anything that exists physically in nature, such as a person, a flower, or a stone.

A "relationship" is a connection among two or more objects in nature. A relationship exists only at certain times and under certain conditions. For example, a relationship exists between a tree and its leaves under certain conditions, such as temperature. A relationship exists under certain conditions between a flower and the bird that sucks its nectar. However, the same relationship always exists among the same objects whenever the same conditions exist.

An "image" is the mental interpretation of sensory impulses in the brain of some person. It might be a mental representation of an object or a connection among two or more objects. An image can be formed by:

- Detection of an object in nature.
- Detection of the stimuli in a communication, intended or unintended, from others.
- Recollection of past detections (i.e., a memory)
- Some combination of these sources

An image might or might not be a correct interpretation of the sensory impulses in a person's brain, as with flying elephants or aliens from space.

An "association" is a connection among two or more images in a person's brain. However, the connection represented by the association might not exist among those objects in nature. Even when some connection does exist among these objects, the association might or might not represent it correctly.

An "item" is defined as any entity, tangible or intangible, real or imaginary. An item might be an object in nature or an image that represents, correctly or incorrectly, an object in nature. Items include objects, sounds, ideas, and imaginary events.

Any items, real or imaginary, can be associated, such as:

- Physical objects, such as a horse and a buggy.
- Intangible items, such as a person has first and last names.
- A combination of tangible and intangible items, such as a person and his or her name.

A "memory" is a retained image that can be recalled to consciousness under some conditions. A memory is usually recalled to consciousness by the detection or recollection of some item associated with it in that person's brain.

An association is "direct" when the detection or recollection of one item brings the other item to consciousness. An association is indirect when the detection of an item not directly associated with another item nevertheless recalls it through one or more intermediary direct associations.

Two or more items are said to be "associated" when the detection (or recollection) of one item also brings another item to consciousness. The classic example is the formation of an association between the sound of a bell and the odor of food in the mind of a dog in the experiments by Dr. Ivan Pavlov.

Associations among images are involved in almost every aspect of the human thinking process, yet very little is known about how they are formed and how the detection of one image in an association brings another image to mind. This paper proposes a mechanism that seems to account for what is known about associations.

Functions of Associations

Early warning for survival – Associations make a major contribution to survival by providing an early warning mechanism. For example, detection of the sound of a branch cracking, or an odor, or some dung, informs the creature of the presence of an otherwise undetected prey or predator.

Improving the response to stimuli – In advanced creatures, associations provide another essential contribution to survival. In the absence of associations, the only information a creature has to respond to a stimulus is that contained in its detection. This might be enough to identify the source of the stimulus, but provides little or no information on how to respond to it appropriately. In advanced creatures, the image of the stimulus is recirculated to assemble, through association, all information in that brain about the stimulus and how to deal with it. This additional information can then be used to respond to the stimulus in the way most likely to achieve that creature's survival.

Memory – Most memories are recalled through the detection or recollection of an associated item through a mechanism to be described later in this paper.

Communications – A sound or physical movement can be associated with the image of an object in the brain. A group of individuals might use the same sound or movement for the same mental image, so that the sound or action and the image become associated. When one person forms this sound or action, it triggers the image in the brains of other people who have this association. Indeed, the transfer of information from one person to another would be much more difficult, if not impossible, without these associations.

Identifying relationships – To respond appropriately to the source of the detected stimuli, it is necessary to know how the objects in nature are connected. To identify these relationships, it is necessary to associate the images of the items involved. For example, it is not possible to identify the relationship of making steel until that person has a mental image of both iron and carbon.

Causes and effects – The most difficult relationships to identify are those in which the items occur at different times, such as causes and their effects. Only forming a mental association of the images of all the causes and all their effects can identify these relationships correctly.

Memory aids – Although this use for associations is trivial, it does show how an associated item can recall a specific memory.

The Greeks and Romans used the numbered rooms of an imaginary building to remember a list of items in a given order. A modern example is based on the twelve avenues in New York. For example, to remember the fifth item on a

list, you think of the Empire State building on Fifth Avenue, which then brings to mind the object you mentally threw from its roof.

Proposed Mechanism for the Formation of an Association

Formation of a simple memory – This proposed mechanism for the formation of an association begins with the mechanism for the formation of a simple memory, such as that of a single object. All the information in the detection of a set of stimuli by a sensory organ is encoded as a series of nerve impulses with irregular intervals between them, rather like the bar code of a grocery product. Each different set of stimuli detected has a unique impulse pattern. This “sensory signal” is conducted through the brain structures along the route (i. e., “pathway”) determined by its impulse pattern to reach some set of neurons in the cortex. The set of cortical neurons stimulated simultaneously is interpreted in some way as representing an object in the environment.

A later detection of the same set of stimuli forms the same sensory signal that is conducted over the same pathway to reach the same set of cortical neurons, where it is interpreted in the same way as the earlier signal. In effect, this person “remembers” the item detected earlier. So recall of a memory does not occur by finding it in storage somewhere in the brain and then transferring it to some location where it is brought to consciousness but by re-stimulating the same set of cortical neurons. The set of cortical neurons stimulated simultaneously will be called a “thought pattern.”

Subsequent sensory signals – A sensory signal enhances all the synapses between the neurons along its route. A single use of a synapse causes only a minor increase in the quantity of neurotransmitter it discharges. This enhancement is lost in a few minutes. The more often a synapse is used, the greater its enhancement. A frequently used synapse retains its enhancement for days or weeks.

Similarity of sensory signals – What happens when a person detects a set of stimuli that is similar to, but not identical with, a set of stimuli detected frequently? Up to some unspecified degree of difference from the earlier signal, this new sensory signal is conducted over the established pathway for the earlier signal instead of forming a new one. It reaches the same set of cortical neurons as the earlier sensory signal and so is interpreted in the same way. As a result, a new set of stimuli that is similar to an earlier set is interpreted as being identical to it, despite their difference. A familiar example is not seeing the gradual changes in someone you meet frequently.

Types of differences in similar sensory signals – A similar but not identical sensory signal might differ from an earlier sensory signal that formed an enhanced pathway in three ways:

- It might be “incomplete;” that is, its impulse pattern is identical with most, but not all, of the earlier signal.
- It might contain some different information; that is, some part of its impulse pattern is different from the earlier impulse pattern.
- It might contain additional information; that is, its impulse pattern is identical with the entire earlier impulse pattern but contains some additional impulses.

An exploratory study was made to get some idea of the degree of similarity required for a later sensory signal to be conducted over an established pathway. Students were asked to identify a familiar word, given only the number of letters it contained. As all students knew the word, each had an enhanced pathway for its impulse pattern in his or her brain. The correct letters of the word in their correct locations were presented to the students in random order until the student recalled the target word. It was found that, for words with 6-12 letters, detection of about 75% of the letters were required to bring the target word to mind.

As each letter was well known, it had its own enhanced sensory pathway in the brain of each student being tested. However, the impulse pattern for each letter is only a small part of the target impulse pattern, so that it was conducted over its own pathway and not over the enhanced pathway for the complete word. As a result, detection of one or a few letters of a word usually does not recall it. At some point, the combined impulse pattern for the letters detected, although still “incomplete” in comparison with the composite sensory signal, was sufficiently similar to it to be conveyed over its established pathway and so recalled the memory of the word.

No doubt the degree of difference in a sensory signal that is sufficient to recall a memory will be different for different types of stimuli. Nevertheless, this exploratory study does show that a sensory signal with a similar but “incomplete” impulse pattern is conducted over an established pathway to recall a memory. The mechanism described also accounts for recalling an object by catching only a glimpse of its form and would explain how a complete object is identified when part of it is occluded.

This study also investigated the effect of items that are different from those in the original sensory signal, in this case, the addition of letters that are not part of the target word. These extraneous items either prevented the sensory signal from reaching any thought pattern (i.e., no word came to mind) or required a much higher percentage of correct letters to do so. (Pacifico & Zillmer 1998)

Note that the ability to understand the following message is also based on the mechanism proposed above:

“Aoccdrnig to a reercheearch at Cmabrigde Uinervtisy, it deosn’t mttaer in what oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht the frist and lsat ltteer be at the rghit pclae. The rset can be a total mses and you can sitll raed it wouthit porbelm. Tihs is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe. Amzanig, huh?”

The message shows that the impulse pattern for a word is the summation of the impulse patterns for its letters. This somewhat different impulse pattern is conducted over the established pathway for the word, and so is interpreted in the same way as the impulse pattern that formed the pathway. This paragraph would be meaningless to someone who did not have established pathways for the correct words.

Composite Sensory Signals – The stimuli described earlier represented only a single item, such as a word, in the environment. However, each human sensory organ detects all the stimuli within its capability at each instant in time. These stimuli might represent a single object or several different objects.

All the stimuli detected simultaneously are encoded as a single impulse pattern. That is, the eye does not form a sensory signal for a horse and another sensory signal for its rider. The impulse patterns for all the objects detected simultaneously are combined into a single sensory signal. A sensory signal that represents stimuli that originated in two or more different sources will be referred to as a “composite” sensory signal. Nevertheless, a composite sensory signal is handled in the brain in exactly the same way as a simple sensory signal.

A composite sensory signal is conducted through the brain structures along the route determined by its impulse pattern to energize some set of neurons in the cortex to form a thought pattern.

After the pathway for this composite sensory signal has been sufficiently enhanced through use, this person detects the stimuli for only one of the items detected earlier. When the impulse pattern for this item is a sufficient part of the composite sensory signal, it is conducted over the composite pathway to re-form the thought pattern for the composite sensory signal. This brings to consciousness all the items in the composite thought pattern. As a result, detection of one item in an association brings the other items to mind.

Factors in the Formation of Associations

1. The essential requirement for the formation of an association is that the impulse pattern for stimuli representing two or more items are part of the same sensory signal. This can occur by:

    - Simultaneous detection of the stimuli representing two or more objects in the environment.

- Communication from others in which two or more items are part of the same sensory message.
- Under certain conditions, items detected within a very short time of each other become associated, as with the words in a sentence, a series of movements, or the sounds in a song.
- An earlier sensory signal for an item from memory can sometimes be associated with the present sensory signal formed by detection of stimuli, either in the environment or in a communication from others.
- Items detected at different times in different places can sometimes become associated through recirculating signals (by a mechanism not described here).
- Almost any set of items, whether related in nature or not, can be associated when the combination is detected repeatedly, as in some commercial advertisements.
- Items can be associated by commonality of a sufficient part of their sensory signals, such as trees or members of an ethnic group. (Association by commonality is not included in this paper.)
- There are direct associations between a thought pattern and its interpretation, between an object and its properties or attributes, between a word and its meaning, etc.
- There is an association between a group and its members, between a face and its components, etc.

2. The items in an association might be detected by different senses, as in associating an odor with the image of an animal.

3. Associations can be formed among tangible and intangible items, as in associating a certain conduct with a physical reward.

4. Some items are indirectly associated through a succession of intermediary associations.

5. Items associated in one person's brain are not necessarily associated in any other brain.

6. As with all memories, the strength of an association changes with time. Some get stronger through frequent recall while others become weaker through disuse. An association is forgotten if its sensory pathway is not re-enhanced through use periodically.

7. Some items are associated with many different items. Which of these items is brought to mind when the central item is re-detected or recalled is determined by:

- The relative degree of enhancement of each sensory pathway for its associated items at that time.
- The impulse pattern of some items detected will be a larger percentage of the composite impulse patterns than others.
- Minor stimuli might cause one set of stimuli to trigger an association. An example is returning to the location where an event occurred. The minor stimuli detected might be sufficient to recall the memory of the original event.

Obstacles to the Recall of an Associated Item

Some conditions interfere with the formation of the composite sensory pathway that is required for an association. Other conditions interfere with the recall of an existing association.

1. Strongly enhanced pathways for the individual items – Pavlov was able to form an association between the sound of a bell and the smell of food in dogs. Why didn't the simultaneous detection of these items by the people present form this association?

Most people already have a strongly enhanced pathway for the sound of a bell and another one for the odor of food. When these items are detected simultaneously, the impulse pattern for the sound goes over its pathway and that for the odor goes over its pathway. The composite pathway, if any, is weak compared with the pathways for the individual items. When one of these items is detected later, its sensory signal is conducted over its own pathway instead of the weak composite pathway and so does not recall the other item.

Effect of repetition – Despite this obstacle, a composite pathway is sometimes formed even when strongly enhanced pathways for the individual items already exist. This occurs through frequent simultaneous re-detection of the items, as occurs in commercial advertisements, such as those associating after-shave lotion with sexual attraction.

Novelty – Occasionally the combination of stimuli detected are so unusual that the brain does not recognize that they represent a combination of familiar items. For example, the ancient Greeks had strongly enhanced pathways for "horse" and for "man," but had never seen a man on a horse. They first detected Scythian horsemen in the heat of battle. This composite sensory signal formed a new pathway that was interpreted as a single object, a "centaur." (A centaur is an imaginary creature with the head of a man and the body of horse.)

2. Number of items in the association – Some sets of stimuli represent many different items, including extraneous "background" items. The impulse pattern for any one item in the association might not be a sufficient part of the

composite impulse pattern to reach its thought pattern and so recall the other items. As a result, most associations consist of only a few items.

It is fortunate that the sensory signal for a minor item in a composite sensory signal is insufficient to recall the other items, or our minds would be constantly filled with a jumble of associations.

3. Number of associations – Some items are associated with many different items while others have only a few associations. For example, there might be a composite pathway for horse-and-buggy. Because the signal for "horse" has many more enhanced connections, it is unlikely to bring "buggy" to mind. Nevertheless, "buggy" readily brings "horse" to mind.

Changes in Associations

As associations are composite memories, they are subject to the same changes that occur in simple memories:

1. The entire association is forgotten if the synapses in the composite sensory pathway are not re-enhanced.

2. Part of the association is forgotten through failure to use that part of the composite sensory pathway. For example, there might be an association between the appearance of an acquaintance and his full name. Someone who uses only that person's first name will forget the association between that person's appearance and his last name.

3. Substitution of other associated items occurs rather frequently. For example, a little girl who was angry at a playmate named Tommy Rice, said, "I'm not going to play with you anymore, Tommy Krispies!"

4.Some associations become obsolete in the sense that the connection among the objects that formed them no longer exists. For example, seeing Bob brings Betty to mind, even though they are no longer married.

Carl Pacifico
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References

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