The Bottleneck a New Perspective

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In the past there have been two main theories about the nature of the bottleneck, The first, predicated on the concept of a Production System, assumed a size limit to the Short Term Memory, and the Second, The approach taken by the Global Workspace Theory, assumed a Bandwidth limit to the Network connecting the elements of the mind. In this article I introduce a third theory, predicated on the characteristics of the Phenomenal Implicit Memory, which blames the bottleneck on the need to redescribe a phenomenally implicit memory in order to make it accessible. The problem with using computer models to implement implicit memory is the temptation to cheat and use the memory addressing of the computer, as a result, a paradigm shift is missed that is important to understand the nature of human memory.

George A. Miller [Miller 1956] noted a distinct limit to the size of Short Term memory. However he was not able to narrow it down, because there was a distinct range of capability. This indicated that there was some other reason besides memory size for the limitation. It took until nearly 1990 [Gathercole 1996] for scientists to track that variability down to a serial dependency in the rehearsal process necessary for holding short term memories in the mind for periods longer than about 3 seconds. It is not surprising therefore that Bernard J. Baars [Baars 1993] who authored the Global Workspace Theory was not aware of this science at the time he wrote his book.

Instead Bernard J. Baars, cited work suggesting that it might be the Global Network that was limiting bandwidth, illustrating his model with the idea of a T.V. network where programming of many different types competed for a single channel network. This multiple agent architecture was taken up by A.I. Researchers, and has evolved into the Independent Distribution Agent Architecture of Stan Franklin.

We don’t know exactly why there is a bottleneck where a massively parallel perception system, is narrowed down to a very small number of elements, but, we suspect that there is a search involved, and that that search cannot be done in parallel despite an otherwise massively parallel brain. I will leave that point unresolved for now, and get into Phenomenally Implicit Memory.

It has been said, with some correctness that the term implicit in regards to memory is overutilized and has too many meanings. That is why, I have chosen to use a more complex, and hopefully more exacting label, for a subset of the range of types of memory that have been labeled implicit by one researcher or another.

Phenomenally Implicit Memory, is memory that results in a Phenomenal output, and is implicit in its nature. To explain, one of the problems with neural networks, which was brought to my attention by Jerry Fodor [Fodor 2000] when he noted that one of the characteristics of Neural Networks was that the network as a whole determined the storage location of a specific memory, and so it was a phenomena of the network, where it was stored.

We now know that certain types of networks will result in the reinforcement of location within the network, thus encouraging the network to have a tendency to locate memories where they are most likely to be reinforced, but the actual location of a memory is opaque to us, even in these localized networks. When we add the uncertainty inherent in the opportunistic growth of neural fibrils, we end up with a memory that has location, but not a predictable address for that location.

This means that phenomenally implicit memory is quite difficult to convert from an implicit form to an explicit form, and the only way to achieve it, is to do redescription between the two representational forms, the implicit form, and the explicit form that can be accessed in a demand fashion. If we accept this, then we can see that implicit memory is stored in a manner that has no access, and the explicit form is accessible.

To explain what use an inaccessible form of memory has, to us, we need to understand a little more about the nature of the Cerebral Cortex. To understand the nature of implicit memory we have to reach back to David Marr [Marr 1970] who theorized that the cerebral cortex was organized into a "self-classifying content addressable memory" Theoretically there are only two ways to address memory, by place code as in computer addressing and by content. What Marr suggested was that the cerebral cortex memory was addressed by the second mechanism. There have been attempts in the past to prove him wrong, but these have themselves been subject to interpretation in light of our current knowledge of the nature of the function of the Cerebral Cortex.

Content addressability is a natural mode for a neural network where every neuron is not only a memory but also a processor, and a transport/distribution mechanism. If you consider, each neuron as being sensitive the most to the pattern that activates it, then you can clearly see that given any stimulus a number of neurons are bound to fire whenever anything close to that stimulus is presented to them. This creates a field of data, which has to be sifted for any particular memory, because the individual memories are buried in the bulk of the output field.

I call this a Volunteer memory, where a number of answers are put forward to contrast it to a Demand Memory where you have to demand a specific memory in order to access it. It is the voluntary nature of the implicit memory that makes the concept of a Quale seem familiar enough to use, so I have affectionately named the field of output data of the whole cerebral cortex, a Quale. When people ask me how we have such a rich experience from a single memory, I point out that the Quale is information rich, just interpretively poor to work with. The problem is that there is so MUCH information, that separating out a specific element to concentrate on, is improbably complex.

Because Implicit memory is information rich, but interpretively poor, we can't separate out a specific memory, all we can do is filter some of the outputs, so that we can concentrate on other outputs. Ideally we need some processing technique that infers salience on the Quale in some sort of zoned manner, and a way of filtering the quale for the zones to isolate them. That is about all we can expect from phenomenally implicit memory, the ability to zone rough areas of the quale according to saliency. To get anything more, we have to redescribe the memories, into a form that at least we can access more than once. The problem is, that to go on from here we have to do a search, because the memories while localized are arbitrary in location.

Previously we attempted to work from the top down and found that we suspected a search was required to explain the bottleneck in memory, now we work our way from the bottom up, and we find a search is required to convert between phenomenally implicit form and some sort of explicit form that we can at least focus on memory elements with. Is it the same search? Well let us see.

The problem is how to convert from a content addressed Phenomenally implicit memory to a place-code addressed explicit form. We have already looked at the nature of the quale and found it uninformative, with only the ability to cluster vague zones of the output together to form functional clusters, and we know that because of the locality of certain types of networks, we can define a network that allows us to select particular memories, but what is missing is the bridge from improbably complex data field to discrete memory. what is missing is the redescription process.

Here is where we need to accept another paradigm shift. We need to accept that we can address the same memory in two different forms, but there is no quick conversion between the two forms. Our only choice is to convert the whole functional cluster, the whole quale once the functional cluster has been filtered out of the rest of the quale, and scan Place-code addresses of individual locations looking for points that are common to both.. We are essentially doing a search, but the essence of that search is that the quale for the functional cluster has to be isolated from all the other possible quales. The only way to do that, is to suppress everything that isn't the functional cluster we want, and scan that for place-code addresses. And, as a side effect of that isolation step, we have to accept that only one quale can be redescribed at a time. In other words, we have arrived at the bottleneck by finding the serial dependency from the bottom up.

Ok, now we know that we are talking about the same bottleneck search whether we are talking about something that limits the number of rehearsals, or something that isolates a specific functional cluster so we can redescribe the phenomenally implicit form of the memory into a place-code addressed explicit form.

The next thing is to determine what the representational form of the Place-code equivalent of a functional cluster is. The most likely representation is something that has been called a Clump, Originally clumps were designated by Miller and his contemporaries as registers containing references to long-term memory. But what we have described in the process of redescription is a list of place-code addresses that correspond to localities within the greater Cerebral network. When we match up a locality with a functional cluster, we just transfer the address into the equivalent clump. This means that the clump contents, contain just the addresses, and not any of the data, that is stored in the functional cluster. In order to get at the data, we have to rehearse the clump, and we get a phenomenally implicit quale as our output.

However, although we can't digest this quale any easier than the original, we can suppress some of the place-code addresses, and in doing so, derive from the quale other less fulsome qualia, that when projected onto the Basal Ganglia, can be found to have greater or lesser salience. So despite the fact that there is no direct location, sub-elements of the functional cluster can be identified if they have some salience.

With this type of filtering, it is possible to eventually begin to build an index of salient elements within our environment, even if the strategy for finding them is to suppress random place-codes. When a salient element has once been found, it can be tracked even though it moves through different configurations of the analysis elements that make up the cerebral cortex.

Thus sub-elements within the larger field of data begin to precipitate out of the chaotic signal clutter, and are eventually indexed so that they can be found faster the next time. Evidence is that the nature of the cerebral cortex, is partially defined by DNA, and partially defined by precipitation of certain types of order as the brain develops. This means that at certain times in the development of the brain, certain types of analysis become more possible and as a result, the development of other areas of the brain is guided.

At each step in the process, more order is precipitated out of the neural structure, converting what seems to be chaotic connections at the neural level, into vaguely consistent mappings of functions at the gyrus and sulcys level. As a result of this development, and the ability to detect salience at each step of processing and feed that back into the development of the analysis engine, the index becomes gradually more and more capable of describing signals that are more and more sophisticated information sources about the environment.

But to get this feedback loop to work, we need to be able to suppress individual Localities in place-code addresses of the clump. And we need to be able to redescribe the quales we create by doing so, into new clumps by passing them again through the bottleneck. Thus the process of rehearsing involves a more complex mechanism than just presenting the clump back to the place-code addressing mechanism in parallel.

This suggests that isolation of a specific memory, is not nearly as simple as it might seem when we implement it in a computer system, since the same quale may pass multiple times through the editing stage. It is only once we have found the sub-elements of the functional cluster, that we quit passing it through the bottleneck, and store them as entries in an index, making them not only explicit but declarative. It is only once they are indexed that they become really explicit.

For this reason, there is a grey area, in writings about implicit memory. Some assume that there are only two types of representations, implicit, and declarative, others like myself can trace three distinct representations, but there is still discussion as to where the boundaries lie between implicit and explicit memory. The problem comes with the definition of explicit. The midline condition between implicit and declarative memory in this model is memory that because of it's place code addressing is demand memory, but is not yet entered into the index.

Because it is not yet entered in the index, it can't be declarative memory, and some who demand declarative aspects for explicit memory therefore would call it implicit memory still. I liken this to those who believe in early redescription and late redescription, Early redescriptionists like myself, call the midline condition explicit memory while late redescriptionists, call it implicit memory. Potatoes Potahtoes, the main difference is the recognition that there needs to be an intermediate state between phenomenally implicit memory and Declarative Memory, what we call it, is arbitrary.

I have modeled for you a system where the nature of the bottleneck has a distinct impact on the nature of the redescription process in the shift between phenomenally implicit memory and the midline state that lies between it and Declarative memory and I have shown that the nature of the representation shifts again between the first explicit clumps and the clumps that get represented in Declarative Memory. It is because this process is sensitive to the sophistication of the existing memory system, that there is such a range of values in even such simple memory measurements as digit span, so sensitive in fact, that the phonological nature of the language the test is done in skews the results [Gathercole 2000] and changes the number of digits that a person of the same age and intelligence in other measures can claim. The difference comes down to a simple factor of how long it takes to search for a digit in a specific language and taking into account other factors that affect the search strategy. That is why Miller's Magic number is Seven Plus or Minus 2, and Chinese University Students can claim digit spans of up to 13 digits. This is why even intelligent children have a lower digit span than Mediocre University Students, and why Welsh speakers have a lower digit span than English or Japanese speakers. It is the combination of multiple strategic parameters that determines the length of time it takes to isolate a digit, and thus there is a significant range to the size of short term memory. A range that wouldn't be found, if either the production system theory or the Global Workspace Theory were accurate.

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