The 7±2 Urban Legend

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1 Introduction

In 1956 George Miller published a paper entitled "*The magical number seven, plus or minus two: Some limits on our capacity for processing information*" and the integrated circuit [1] had not yet been invented.

In the 47 years since the publication of this paper, knowledge of the workings of the human mind has moved on and the invention of the integrated circuit has led to the wide spread use of computers, with a corresponding need for reliable software. However, perception of the 7 ± 2 urban legend as being a scientifically proved fact remains and it continues to be used to inform decisions on the maximum complexity of coding constructs. The purpose of this paper is to dispell the urban legend that has grown up around 7 ± 2. While no other rules, based on the workings of human memory, are yet available to replace it, people should at least stop taking false comfort from this bogus model.

What is the 7 ± 2 urban legend? A common model of human memory divides it into two units; a short term memory and a long term memory. The short term memory is a limited capacity store for holding temporary information. The long term memory is usually treated as an infinite capacity store capable of holding information throughout a persons life. Information is held in short term memory before being transferred (or not) to long term memory. The 7 ± 2 urban legend is that the capacity of short term memory is seven plus or minus two items of information (some people being able to only hold five or six items, while others can hold eight or nine). The extent to which short term and long term memory really are different memory systems, and not simply two ends of a continuum of memory properties continues to be researched and debated.

Millers original paper is available on line at `www.well.com/user/smalin/miller.html`. Readers will be surprised to find that Miller never proposed 7 ± 2 as the capacity of short term memory; he simply made the observation that this range of values fitted the results of several recent, 1950's, experiments.

Readers might like to try measuring their short term memory capacity, with one of the techniques used in early memory studies. The lists of digits in the margin can be used. Slowly and steadily read the digits in a single row, out loud. At the end of each row close your eyes and try to repeat the sequence of digits back, in the same order. If you make a mistake go onto the next row. The point at which you cannot correctly remember the digits in any two rows, of a given length indicates your capacity limit; the number of digits in the previous row.

8704
2193
3172
57301
02943
73619
659420
402586
542173
6849173
7931684
3617458
27631508
81042963
07239861
578149306
293486701
721540683
5762083941
4093067215
9261835740

Measuring short term memory capacity using sequences of digits relies on several assumptions. It assumes that short term memory, STM, treats all items the same way (what if letters of the alphabet had been used instead?), and that individual concepts are the unit of storage. Subsequent studies have shown that both these assumptions are incorrect.

Any Chinese (or Welsh) speaking readers might like to do the exercise twice; once using English words and once using Chinese (Welsh) words for the digits. Use of Chinese (Welsh) should enable readers to apparently increase (decrease) the capacity of STM to an average of 9.9 digits [HS88] (5.8 in Welsh [EH80]).

How can a persons native language affect their STM capacity? It turns out that the kind of STM people use for remembering digits is based on the sound of those digits. A person has a two second, approximately, capacity limit [BTB75] on the amount of sound they can hold in STM. Approximately 7 ± 2 English digit words can be spoken in approximately 2 seconds. The difference is caused by people having different speech rates. The Chinese spoken words for the digits are shorter than the corresponding English spoken digit words, which in turn are shorter than the Welsh spoken digit words. This difference in sound length is what causes the difference in these speakers digit storage capacity.

2 A model of working memory

In the 1970's Alan Baddeley asked what purpose short term memory served. He reasoned that its purpose was to act as a temporary area for activities such as mental arithmetic, reasoning, and problem solving. The

[1] This is a correction to the paper presented at the conference, which used the transistor as a parallel. The transistor was invented in 1947 (thanks to D. Sawyer for pointing out the error).

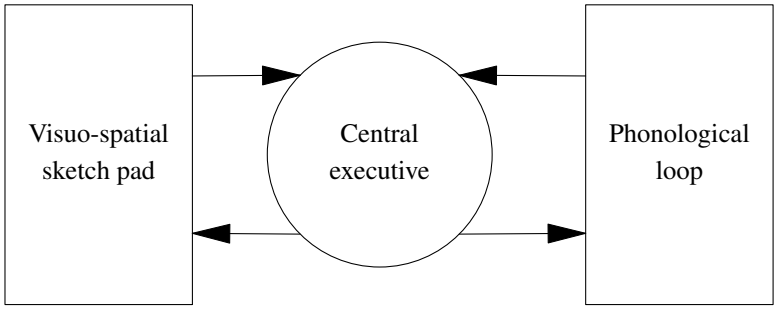

Figure 1: Model of working memory. From Baddeley [Bad99].

model of working memory he proposed [Bad99] is shown in Figure 1. Note that this model uses the term '*working memory*' to refer to the three components as a whole. There are three components, each with its own independent short term memories, and each holding a particular representation of information.

The central executive is assumed to be the system that handles attention, controlling the phonological loop, the visuo-spatial sketch pad and the interface to long term memory. The central executive needs to remember information while performing tasks such as text comprehension and problem solving.

While remembering the digit sequences above, readers may have noticed that the sounds used for them went around in their heads. [2] In the Baddeley model the working memory area responsible for these sounds is known as the phonological (or articulatory) loop. This kind of memory can be thought of as being like a loop of tape. Sounds can be recorded onto this tape, overwriting the previous contents, as it goes around and around. An example of the functioning of this loop can be found in trying to remember lists of words that vary by the length of time it takes to say them.

Below are some lists of words. [3] Those above the dashed line contain a single syllable, and those underneath it contain multiple syllables. Readers should have no difficulty remembering a sequence of five single syllable words, while a sequence of five multi-syllable words should prove more difficult. As before, read each word slowly, out loud.

```
one             cat           card          harm          add
bank            lift          list          bank          mark
sit             able          inch          view          bar
kind            held          act           fact          few
look            mean          what          time          sum
-------------------------------------------------------------------
ability         basically     encountered   laboratory    commitment
particular      yesterday     government    acceptable    minority
mathematical    department    financial     university    battery
categorise      satisfied     absolutely    meaningful    opportunity
inadequate      beautiful     together      carefully     accidental
```

List of words with either one, or more than one, syllable (and thus varying in the length of time taken to speak).

The visuo-spatial sketch pad holds visual information. This kind of short term memory decays very rapidly. Experiments have shown that people can recall four or five items immediately after they are presented with visual information, but that this recall rate drops very quickly after a few seconds.

[2] Where possible the digits were chosen so that the most common acoustic confusion, that between five and nine in English [MCM73], does not occur. Also, recall error rate is higher for lists containing duplicate entries [Hen98], and so to help readers each list only contains one instance of any digit.

[3] Recall performance is affected by word frequency [MK96] and so the words were choosen to approximately have the same high frequency of occurrence, for native English speakers [LRW01].

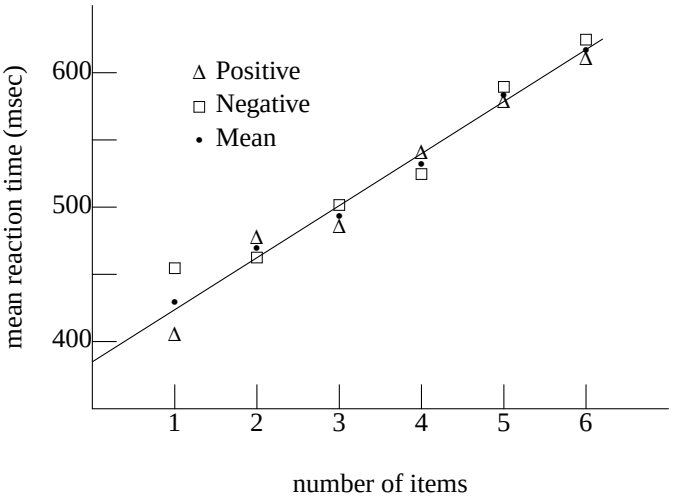

Figure 2: Judgment time as a function of the number of digits held in memory. From Sternberg [Ste69].

A good example of using the different components of working memory, is mental arithmetic. For example, multiply 23 by 15 without looking at this page. The numbers to be multiplied can be held in the phonological loop, while information such as carries and which two digits to multiple next, can be held within the central executive. Now perform another multiplication, but this time look at the two numbers being multiplied, see Table .

26
12

Two numbers to multiply.

While performing this calculation the Visuo-spatial sketch pad can be used to hold some of the information, the values being multiplied. This frees up the phonological loop to hold temporary results, while the central executive holds positional information (used to decide which pairs of digits to look at). Carrying out a multiplication while being able to look at the numbers being multiplied seems to require less cognitive effort.

3 Locating information

The loop of tape in a tape recorder analogy, for the '*phonological loop*', suggests that it might only be possible to extract information as it goes past a '*read-out point*'. A study by Sternberg [Ste69] looked at how information in the phonological loop could be accessed. Subjects were asked to hold a sequences of digits, for instance 4185, in memory. They were then asked if a particular digit was in the sequence being held. The time taken to respond yes/no was measured. Subjects were given sequences of different length to hold in memory. The results showed that the larger the number of digits subjects had to hold in memory, the longer it took them to reply, see Figure 2. The other result was that the response time was not affected by whether the answer was yes or no. It might be expected that a yes answer would enable the search to be terminated. This suggests that all digits are always compared.

A study by Cavanagh [Cav72] found that different kinds of information, held in memory, has different search response times (see Figure 3).

Recent research on working memory has began to question whether it does have a capacity limit. Many studies have shown that people tend to organize items in memory in chunks of around three or four items. The role that attention plays in STM, or rather the need for STM in support of attention, has also come to the fore. It has been suggested that the focus of attention is capacity limited, and the other temporary storage areas are time limited (without attention to rehearse them, they fade away). Cowan [Cow01] proposed that:

1. the focus of attention is capacity-limited,

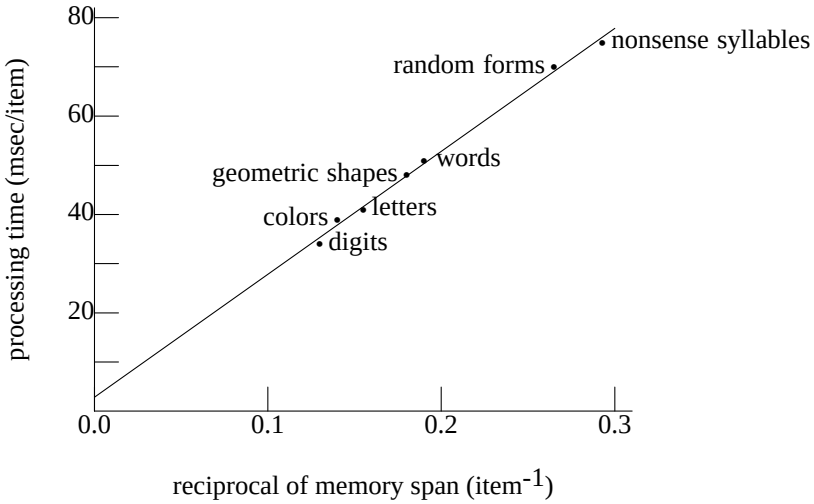

Figure 3: Judgment time as a function of the number of different items held in memory. From Cavanagh [Cav72]

2. the limit in this focus averages about four chunks in normal adult humans,
3. no other mental faculties are capacity-limited, although some are limited by time and susceptibility to interference,
4. that any information that is deliberately recalled, whether from a recent stimulus or from long-term memory, is restricted to this limit in the focus of attention.

Are there any characteristics of short term memory that coding guidelines can make use of?

Chunking is a common technique used by people to help them remember information. A chunk is a small set of items (the value 4 ± 1 is seen in many studies) having a common, strong, association with each other (and a much weaker one to items in other chunks). For instance, Wickelgren [Wic64] found that peoples recall of telephone numbers is optimal if numbers are grouped into chunks of three digits. The random letter sequence "*fbibbcibmirs*" is much easier to remember when it is noticed that it can be chunked into a sequence of well known acronyms (fbi, bbc, ibm, and irs). These three characters are culture specific, a non-US reader is unlikely to strongly associate the letters '*irs*' with '*internal revenue service*'. Several theoretical analyses of memory organizations have shown that chunking of items improves search efficiency ([Dir72] optimal chunk size 3-4), ([Mac87] number of items at which chunking becomes more efficient that a single list, 5-7).

An example of chunking of information in long term memory is provided by a study performed by Klahr, Chase, and Lovelace [KCL83], who investigated how subjects had stored the letters of the alphabet in memory. Through a series of time to respond measurements, where subjects were asked to name the letter that appeared immediately before or after the presented probe letter, they proposed the alphabet storage structure shown in Figure 4 (they also proposed two search algorithms describing the process that subjects used to answer the before/after question).

The results of the Klahr et al study show that deducing the details of how people organize information in memory is a non-trivial exercise.

4 Conclusion

As its name suggests, short term memory does not last very long. Anybody who has tried to remember a telephone number while performing other tasks will be aware of how quickly the digits are forgotten. Coding

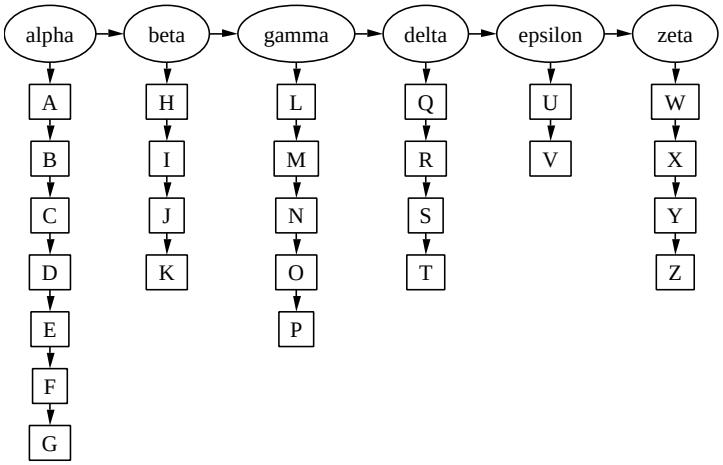

Figure 4: Semantic memory representation of alphabetic letters (the Greek names assigned to nodes by Klahr are used by the search algorithm and are not actually held in memory). Derived from Klahr [KCL83].

guidelines based on human memory performance need to take a lot more into account than the characteristics of one subsystem. A person existing beliefs are a very important factor when needing to recall recently read information while reading a section of code.

The value 7 ± 2 as a measure of short term memory is an urban legend. It only applies to speakers of English attempting to remember a sequence of digits. Actual human memory performance depends on many factors and cannot be approximated by a numeric value.

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