3D Interactive Visual Simulations (VR) as an aid to Learning in Africa

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The Human Brain and Mind

Dr RS Day

March 2003

VR in Africa – for Africa – by Africa

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1 PREFACE

UNESCO has, since 2000, supported a number of initiatives with the Naledi3d Factory that have explored the potential of Virtual Reality (VR) as a learning tool in Africa, to date in Ethiopia, South Africa and Uganda (summarized in the box).

In order to define a way forward in this project area, UNESCO commissioned this report, which evaluates the comparative advantages of applying multimedia and interactive 3D tools to the learning environment. This project was divided into two parts:

1. An overview of the general practices and approaches to the use of multimedia and interactive 3D tools as learning aids, and
2. An evaluation programme in South Africa and Uganda covering a number of schools and community telecentres.

The authors prepared the overview with the collaboration of three other specialists which were commissioned to prepare four original papers: "VR from an African educational perspective" (Dr Rita Kizito, Learning Developer, UNISA); "Overview of the Brain" (Dr R.S. Day, ICT Executive, UNISA); "The Global Approach to Teaching and Learning" (Dr R.S Day, ICT Executive, UNISA); "Comparison of and the learning characteristics of educational multimedia" (Mr J. Hugo, Usability Sciences). These papers can be obtained on the Naledi3d Factory Publications Archive (http://www.naledi3d.com/navpage.html).

For the evaluation programme, the support of the UNESCO National Commission for Uganda (especially Ms Anastasia Nakkazi, Secretary-General, and Mr Martin Nsubuga who was responsible for the logistical and operational support during the survey) and the University of South Africa - UNISA (particularly Dr Rita Kizito who developed the survey methodology and questionnaires) is gratefully acknowledged.

Appreciation is also due to the two Local Coordination Committees:

<u>Local Coordination - Uganda</u>

Professor Paul Mugambi	Chairperson National UNESCO IIP Committee
Mr Lawrence Ssenkubuge	St. Henrys' College Kitovu
	Kings' College Budu
Mr Daniel Kakinda	SchoolNet Uganda
Professor Albert Lutalo-Bosa	Principal, Kyambogo University
Mr Walugembe	Kyambogo University

To date, VR initiatives in Africa have resulted in:

- The development of a VR model addressing the learning points around basic hygiene in rural African communities. The main aim of this project was to use interactive visual simulation as a means of demonstrating basic hygiene to rural communities and to focus primarily on sanitation, water and the prevention of associated diseases (such as malaria, bilharzia, dysentery and cholera). The resulting model was piloted and used at the Nakaseke Telecentre in Uganda. A second goal of this project was to pilot and test the use of VR as a computerised interactive training method in African Telecentres. Nakaseke is approximately 40 miles north of Kampala.
- The training at the Naledi3d Factory in Pretoria of two VR developers from Uganda. Since the completion of the second training session in early 2002, other pilot VR models have been developed, including "DC motors" and "French for Ugandans", both of which have been used in Kings College Budu and St Henry's Kitovo, both Ugandan schools.
- The creation of a formal VR Committee in Kampala, established to co-ordinate VR initiatives in the country; with representation from two universities (Makerere and Kyambogo), SchoolNet Uganda, the Uganda National Commission for UNESCO, the Department of Education, the National Curriculum Development Centre, as well as a number of local schools.
- A VR workshop, sponsored by IICBA (International Institute for Capacity Building in Africa) and hosted by the Naledi3d Factory of Pretoria, in March 2002 with representation form Uganda, Ethiopia and Nigeria, resulted in pilot models to describe levers, relative velocity and chemical elements.
- A project using VR as an aid to helping young people of all ages in Alexandra (Johannesburg) understand better the job application process, how to keep a job and how to create your own employment space.
- A project to help educators in Ethiopia better understand and teach about HIV/AIDS, including the associated social, cultural and psychological issues.

Mr David Kalanzi	Uganda National Commission for UNESCO
Mr Micheal Galiwago	Educational Consultant
Mr Musa Luyinda	Nakaseke MCT
Mr John Ssenkunja	Ndejje Senior Secondary School
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2 The Human Brain and Mind

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2.1 Summary

Many believe that, to move towards an ideal world, every human mind should be given the opportunity for optimal life-long learning, and there is a growing related belief that this represents a basic human right.

The human brain is by far the most complex device on the planet, and yet most of us take it for granted. We humans have some 100 billion neurons (10 times more than the apes), and these neurally active cells (perceiving, thinking, learning, etc) are connected by an amazing *1.5 million kilometres* of nerve fibres. Over the past 2 million years (a very short period in evolutionary terms), the hominid brain-body weight ratio has almost quadrupled, with most of this unprecedented growth being in the cerebral cortex. This article emphasises the dynamic, “under-construction” nature of the brain/mind of homo sapiens sapiens. Although we have been around for about 150,000 years, it is only in the past approximately 50,000 years that a dramatic growth in artefacts beyond stone tools appeared. Why did it take man 100,000 years to develop these abilities? What does it tell us about the mind, intelligence and learning?

The human mind is not the brain but what the brain does. It is not a single organ, but a system of modules and organs whose operation was shaped by natural selection. They can be thought of as psychological faculties, each with a specialised design that makes it an expert in one arena of interaction with the world. These interactions enter through the windows of the body’s five senses, which do not have equal standing in humans. It is the interaction between vision, touch and sound that is of most importance in enabling humans to understand and learn about the universe around them, their society, and themselves.

Vision is man’s primary sense around which his mind has evolved. This remarkable sense has the largest cortical area (almost 50%) devoted to its activities. The visual cortex is split into many areas, each processing an aspect of sight such as colour, shape, size, stereo, depth, etc. Observed images are reflected by matching patterns of neuronal activity on the surface of the visual cortex which are then converted into higher level abstract mental models. The visual system as a whole is not dedicated to any one kind of behaviour, but instead creates abstract representations of the world (mental images rather than retinal images), and inscribes them on a ‘mental commons’ for general use by *all* the mind’s mental modules. A mental image is simply a pseudo-3D sketch that is loaded from long-term memory rather than from the eyes.

Sound has changed the human brain radically because complex language has recently annexed large parts of the left hemisphere (previously given over to visuo-spatial functions), thereby creating the asymmetry not found in any other animal. The implication is that, in evolutionary terms, human language is very young, is still ‘under construction’, and is far from being fully integrated into the brain. Although analysing a stream of spoken words is highly complex, infants do not need to be taught the basics of hearing and speaking language. By contrast, reading and writing are difficult to learn at any age. Printed text is only a few hundred years old, and therefore, on the evolutionary time scale, reading has not even begun to become an innate ability. Hence, the unnatural nature of reading and writing has serious implications for learning. Even for the literate people on this planet, in cognitive terms, text is the least efficient and effective of all the available communications media.

Memory is not a fixed thing or singular skill, but rather is a process where a transient stimulus creates a persistent change in the brain. A complex set of multiple memory locations and systems are responsible for our best learning and recall. The variety of ways in which information is stored and retrieved provides a better platform for understanding memory. *Explicit/Declarative Memory* comes in several forms, including the more word-based semantic memory (by far the weakest of our retrieval systems) and the event-type episodic memory (unlimited capacity, and used naturally by everyone). *Implicit memory* includes both the procedural and reflexive retrieval pathways. *Working memory* comprises a central executive and two subsidiary slave systems; i.e. the visuo-spatial sketch pad and the phonological loop. Working memory's role in human cognition and learning could hardly be more important, since it integrates and coordinates memory, attention and perception.

Natural Learning is what the human brain does best. There are predetermined sequences of development in early childhood, including windows of opportunity for laying down the basic hardware necessary for later learning. All babies are born with the innate potential to learn and speak any language and many languages. Natural selection also shaped man to be intuitive physicists, biologists, engineers, psychologists, and mathematicians so that he could master his local environment. Although these different ways of knowing are innate, this does NOT mean that knowledge is innate. The key to getting smarter is growing more dendrites and synaptic connections between neurons. The brain's architecture has the inherent capacity for every individual to significantly increase their intelligence. The mind learns optimally when it is appropriately challenged in an environment that encourages taking risks. Humans have survived by trying out new things, usually in small groups, NOT by always getting the 'right', tried-and-true answer - that's not healthy for growing smart, adaptive minds.

2.2 Overview of the Brain

We each have our brains, use them mercilessly, take them for granted in a wide variety of ways, and seldom stop to think what unique devices they are. It is generally agreed that the human brain is by far the most complex device on the planet. According to Rita Carter[1]:

"The human brain is made of many parts. Each has a special function: to turn sounds into speech; to process colour; to register fear; to recognise a face or distinguish a fish from a fruit. But this is no static collection of components - each brain is unique, ever changing and exquisitely sensitive to its environment. Its modules are interdependent and interactive and their functions are not rigidly fixed.... The whole is bound together in a dynamic system of systems that does millions of different things in parallel. It is probably so complex that it will never succeed in comprehending itself. Yet it never ceases to try."

Figure 9: The human brain

[1]Carter, R.; "Mapping the mind". Phoenix, p 8, 1998.

The adult human brain weighs about 1350 grams. Whereas this represents about 2% of an adult human's weight, the brain accounts, on average, for 20% of our energy consumption. Surprisingly, the brain needs 8 to 12 glasses of water a day for optimal functioning, hence dehydration is a common problem. The cerebral cortex, the most recently evolved component, constitutes the highly folded outer region of the brain. The folds maximise the brain's surface area, but if laid flat on a surface, the cortex has the size of a large napkin. The brain is made up of cells, 90% of which are gill cells which give the brain structure, and handle the boring administrative duties. The 'exciting' cells which are actively involved in perceiving, thinking, learning, etc., (the neurons) take up the remaining 10%. Fruit flies have 100,000 neurons, monkeys have 10 billion neurons, whilst we humans have some 100 billion neurons. On average, adults lose about 10,000 neurons per day, and have half the number of a 2 year old.

The content of brain activity lies in the patterns of connections and patterns of activity among neurons. In particular, learning is a critical function of neurons that cannot be accomplished individually - it requires groups of neurons[2].

Neurons have very specialised cell shapes, with a cell body, one axon, and many dendrites. Each axon usually splits to connect, via synapses, with thousands of dendrites from many other neurons (see Figure 10).

To help understand the amazing level of connectivity this produces, it is useful to know that each brain's nerve cells are connected by *1.5 million kilometres* of nerve fibres[3]. Neurons are electro-chemical devices, converting chemical and electrical signals back and forth, as they integrate, generate and process information. The information impulse always flows from the cell, to the axon, then via the synapse to the dendrites of the next cells. Whether or not a particular part of the brain is 'active', all normal neurons are continuously firing.

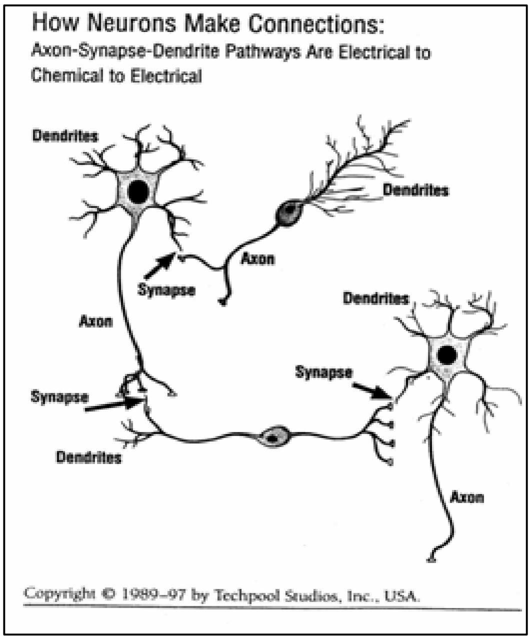

Figure 10: Neuron structure and connections

2.3 Overview of Brain Evolution

The first "brains" are thought to have emerged about 500 million years ago. These were very simple compared with the wide range of such organs which abound on the planet today - brains have proved beneficial for survival, and so have developed dramatically!

Humans and chimpanzees appear to have had a common ancestor between 6 and 9 million years ago, when the hominid line broke away. Over the past 50 million years of primate evolution, the brain-body weight ratio of all off-shoots of our common lineage remained within a fairly small range (see fig 11).

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[2]Greenfield, S.; 'Journey to the Centres of the Mind'. New York: WH Freeman Company, 1995.

[3]Jensen, E.; "Teaching with the brain in mind". Association for Supervision and Curriculum Development (ASCD) Publications, pp1-3, 1998.

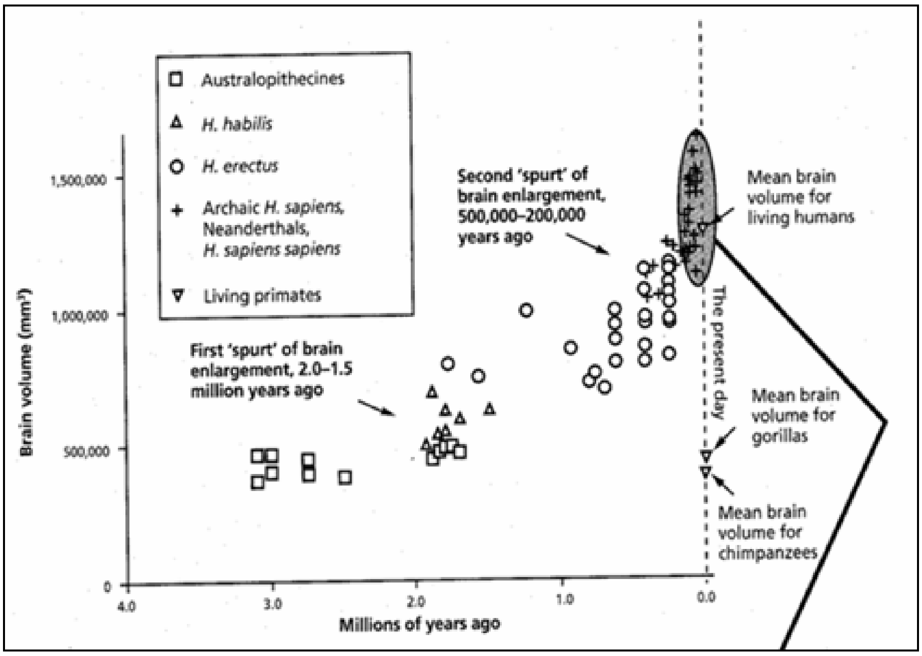

Figure 11: Evolution of the Human brain

This was also true of the early hominids, until over the past 2 million years (a very short period in evolutionary terms), the hominid brain-body weight ratio almost quadrupled[4]. Most of this growth was in the cerebral cortex, where humans have developed the largest area of uncommitted cortex of any species on earth[5]. No specific function has been identified so far, so it is sometimes referred to as the 'association cortex'.

Man's outsize brain is, by any standard, an extraordinary adaptation from our common ape ancestors. Controversy is rife around a range of interesting theories to explain this phenomenal growth. One such theory postulates that complex human language emerged first, and stimulated the growth. However, as described below, this is highly unlikely. Complex human language appears to be a recent emergent property of the fully *physically* grown brain of homo sapiens sapiens. Complex language appears to have emerged as the human mind developed within that brain.

Homo sapiens sapiens, with the current brain size, appeared on the planet only about 150,000 years ago. In evolutionary terms, this means that the human brain is very young, and the mind even younger. These facts raise two fascinating, fundamental questions:

- In the longer term, over the next 2 million years, will the brain continue to grow at the current accelerated rate? Why should it stop with the current version of humans?
- In the shorter (but still quite long) term, over the next 150,000 years (and with our current brain size), how much more will the human mind develop? How will our consciousness, intelligence, and learning grow?

The second of these questions is particularly relevant to this article, which emphasises the dynamic, 'under-construction' nature of the human brain/mind. Although we have been around for about 150,000 years, it is only in the past approximately 50,000 years that a dramatic growth in artefacts

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[4]Mithen, S.; ' The Prehistory of the Mind'. 1997.

[5]Howard, P.; 'Owner's Manual for the Brain'. Austin, Tex: Leornian Press, 1994.

beyond stone tools appeared. Why did it take 100,000 years to develop these abilities? Were we physically able, but not yet mentally ready? At that stage, did we *consciously realise that we can learn* (rather than the automatic learning that all animals experience), and find that to pass on this learning to other humans, we needed to leave some kind of record in the form of cave paintings, artefacts, etc.?

2.4 The Mind

The relationship between the human brain and mind is thought by many to be one of the oldest and most fundamental of mysteries. The mind is not the brain but what the brain does (in particular, the brain processes information), and not even everything it does, e.g. metabolising fat and giving off heat.

The mind is not a single organ, but a system of modules and organs whose operation was shaped by natural selection to solve the problems of the hunting and gathering life led by our ancestors throughout most of our evolutionary history. Whether or not we establish exact boundaries for each module, it is clear that the mind has a heterogeneous structure of many specialised parts. These modules or organs can be thought of as psychological faculties or 'mental modules', each with a specialised design that makes it an expert in one arena of interaction with the world.

The human mind is a product of evolution, so the basic logic of our mental modules (and their combinations as 'mental organs') is specified by our genetic programme. The mental modules are either present in the minds of apes (and perhaps other mammals and vertebrates), or arose as further adaptations of the minds of the common ancestors of humans and chimpanzees that lived in Africa between 6 and 9 million years ago.

A remarkable feature of the mind/brain is its capacity to function as a complex adaptive system on many levels and in many ways simultaneously. There are emergent properties of the mind as a whole system that cannot be recognised or understood when the parts alone are explored[6]. Underlying this, thoughts, emotions, imagination, predispositions, and physiology operate concurrently and interactively as the entire system interacts and exchanges information with its environment. But how does it sense its environment?

2.5 An overview of the senses

For the mind to function, it must take in data that it can use for its processing. The only way the mind can do this is through the sensory perceptions that enter through the windows of the body's five senses. These senses do not have equal standing in primates or humans. What is sensed, how quickly does it reach our senses, how useful is it to the human mind throughout its development and learning?

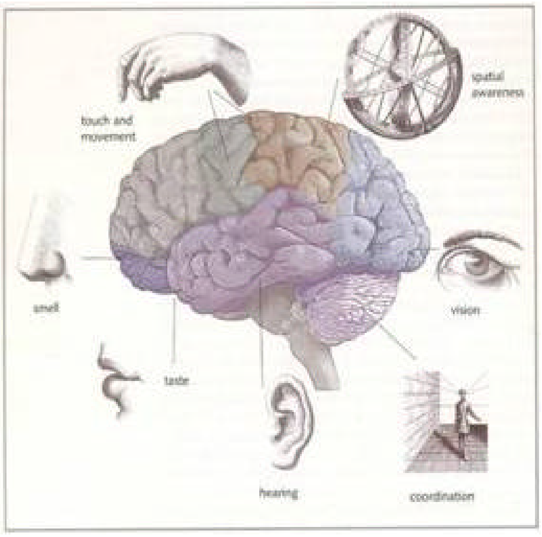

Figure 12: The human senses

2.5.1 Touch

Touch involves physical contact with the environment using the entire surface of our body as the sense organ (but with dramatic variations in sensitivity in different regions of the body). It

[6]Caine, RN. & Caine, G.; "Education on the Edge of possibility". ASCD Publications, p104, 1997.

happens as quickly as the contact process involved, whether we are being touched (a handshake, a bullet), or we are touching (a footstep, typing). It is particularly important during infant development, with much of its activity becoming subconscious with frequent repetition. It retains its importance throughout life by confirming our immediate surroundings, what is happening to us, what we are doing, and providing feedback on what we have just done. But it tells us little of our more distant surroundings, and provides little information on what might be about to happen, both in the short and longer terms. Of particular importance is its collaboration with visual perception ('touch-eye coordination', and especially 'hand-eye coordination'), which will be shown to be of major importance to learning, memory, and retrieval.

2.5.2 Taste and smell

Taste and smell also involve physical contact, but at the molecular level, coupled with sophisticated chemical analysis within highly specialised (and related) parts of the body (mouth/tongue and nose). Smell provides some indirect information on what may be happening even in our more distant surroundings, but it arrives very slowly and with no clear directional data. Hence smell relies on touch, sound and vision to give better quality backup information based on its initial input. Taste plays a crucial role in our primary process of life sustaining energy provision, but tells us almost nothing about the dynamics of our external environment. Neither sense appears to play a significant role in our conscious understanding of and learning about the world about us, especially after early development.

2.5.3 Sound

Sound, again, involves physical contact, but this time by sensing pressure variations in the air via the diaphragms in two highly sensitive and specialised organs (the ears). It provides a great deal of information about the dynamic external environment, but of varying quality (due to many disturbances of the medium, distortion, interference, and falling off significantly with distance). The two ears provide directional and distance information fairly quickly (at the speed of sound), but of fairly poor quality so that the mind usually transfers attention to touch and particularly, vision. Sound is good for monitoring the dynamics of our near to medium environment (stationary, inert objects create no sound, and we do not project clicks to investigate the environment, unlike bats and cetaceans for whom sound is the primary sense). Unlike touch, taste and smell, sound provides a great deal of information that allows creatures to anticipate what might be about to happen, particularly in the short term. Sound appears to have several unique strengths, including its obvious value at night (not just for nocturnal creatures), as well as being the primary medium used by creatures that have developed the wish to express themselves (especially consciously). Emitting sound provides a much wider spectrum (amplitude, frequency, types) than touch or smell, and with a sustainably low energy bill. Emitting light of sufficient intensity and variability for day time broadcast has proved too energy expensive for most animals to date, although some nocturnal (e.g. fireflies), and aquatic (e.g. angler fish, squid) creatures have developed very limited capabilities.

2.5.4 Vision

Vision, unlike the other four senses, is non tactile, since photons of light are discrete quanta of energy, with no mass. In the other senses, the stimulus interacts indirectly with the brain via intermediary sense organs, which inevitably reduces the quality and speed of the impulse. But, since the retina is an integral component of the brain, light is unique in that it interacts directly with the mind as each photon is absorbed by a rod or cone in the retina. Vision provides a flood of information of excellent quality, under normal daylight conditions, about both the dynamic and the inert external environment, and virtually instantaneously (at the speed of light!). The two eyes provide immediate and highly accurate directional and distance information, as well as shapes, colour, orientation, shading, relative size, relative speed, and much more. Vision is excellent for monitoring most aspects of the near, medium and distant environment - most sound waves are dissipated over a few hundred metres, but photons can and do reach us from the horizon, and even the edge of the universe! Vision provides an order of magnitude more information than sound, thereby allowing creatures to anticipate what might be about to happen, not only in the short term, but also in the medium and even long terms. It is clear that for daytime, land based creatures, vision is uniquely powerful amongst the five senses. But it cannot do everything alone. We have already mentioned the crucial role of 'touch-eye' coordination, and that sound ably supplements vision's weaknesses (at night, when something happens behind us, etc.). But it will be shown below that visual perception relies on a wide range of inputs from all the other senses (but particularly touch and sound) to complete the mental models we use to think.

It is the interaction between vision, touch and sound that is of most importance in enabling humans to understand and learn about the universe around them, their society, and themselves. How well are we mixing the combination of these to satisfy the learning needs of the world's wide variety of learners, particularly the billions in the disadvantaged world with the greatest need?

2.6 Vision and Perception

Man, like all primates, is primarily a visual creature, and his mind has evolved around this remarkable sense[7]. Vision is the sense which has the largest cortical area devoted to its activities, and is referred to as the 'senior sense'[8].

2.6.1 Seeing

Each visual stimulus, having been converted to electric signals in the retina, is shunted on to the visual cortex at the back of the brain. The visual cortex (see figure 13) is split into many areas, each processing an aspect of sight such as colour, shape, size, stereo, depth, etc. The heart of the visual cortex, V1, mirrors the world outside in which each point in the external visual field matches a corresponding point on the V1 cortex[9]. Hence, when simple shapes (e.g. a honeycomb) are observed, the image is reflected by a matching pattern of neuronal activity on the surface of the visual cortex. The centre of the retina, the fovea, is much more densely packed with neurons and therefore captures far more detail. As a result, the cortical 'map' is distorted, as the neurons responding to the dense central area of the visual field take up a much greater cortical area, i.e. the 'picture' produced on V1 is a little like that seen through a fish-eye camera lens.

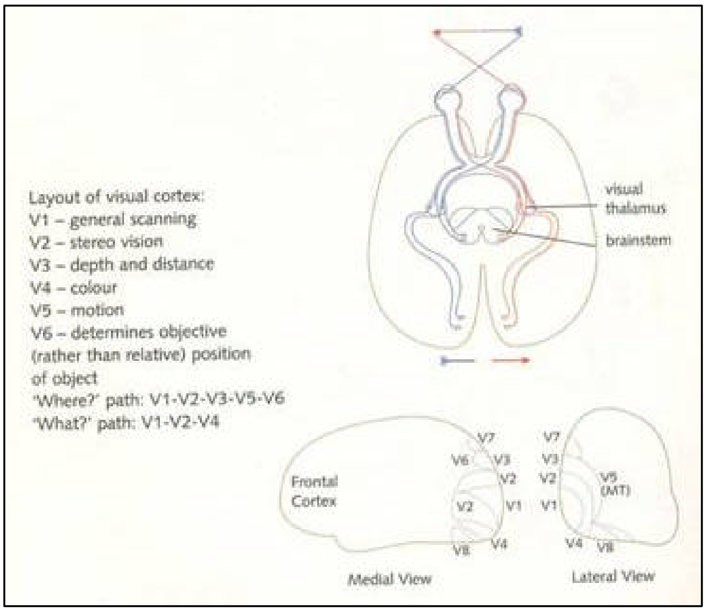

Figure 13: The visual cortex

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[7]Pinker, S.; "How the Mind Works". Penguin, p211-20, 1997.

[8]Cotterill, R.; "Enchanted Looms: Conscious Networks in Brains and Computers". Cambridge University Press, p 384, 1998.

[9]Carter, R.; "Mapping the mind". Phoenix, pp 184-5, 1998.

Vision is much more than the capturing of these cortical 'maps'. Hubel and Wiesel proposed their classic theory which provides a credible mechanism for how the visual system goes to the next level, and detects patterns[10]. Following their lead, other researchers have proposed that groups of cells in the V1 visual cortex are at the bottom of a hierarchy of feature detectors. The idea is that a cluster of these cells feed into a single higher-level pattern detector, or complex cell, in another part of the visual cortex; and, similarly, many of these complex cells feed into a hyper-complex cell. It is argued that these high-level cells fire only in response to a very specific feature or stimulus, such as a face, a car, a deer, or a tree.[11]

Visual perception is one of the most complex processing tasks that the brain is called upon to perform. It is not surprising, therefore, that when it goes wrong, the results can be dramatic. It is significant that unlike 'seeing disorders', which may cause degradation of the image, blurring, loss of colour vision and so on, 'visual perception disorders', e.g. agnosia, cause only gross errors in perception (sufferers are unable to identify objects as a whole, e.g. a face, a deer..). This suggests that perception works through a higher level 'language' that can be compared with the written word in its level of specificity. Our visual perception seems to work in the same way, by 'seeing' or perceiving objects as complete forms, not as sums of their constituent parts.

2.6.2 Visual perception and the mind's eye

Intuitively, it seems unlikely that analysis of lines and curves can fully account for the richness of our perceptions, which involve knowing what the patterns represent - recognising what is 'out there'. A wide range of indirect functions of the visual cortex converts these retinal depictions and patterns into higher level abstract mental descriptions, or mental models, which underlie the interaction between seeing and thinking known as '*mental imagery*'.

As all sighted people know from personal experience, the brain somehow analyses, in real time, these moving cortical 'pictures' produced on each retina and arrives at an impressively accurate sense of the objects being observed. The accuracy is impressive because the problems the brain is solving are, literally, unsolvable. David Marr was the first to describe vision as having evolved to convert these 'ill-posed problems' into solvable ones by adding *assumptions* about the world[12]. These inherent visual 'assumptions' are revealed by the many well known artificial and natural optical illusions used in party games (and psychology research, see figure 14). Hence, illusions unmask the assumptions that natural selection installed to allow our large visual cortex to solve unsolvable problems and know, much of the time, what is out there.

Figure 14: Optical illusions – chalice or face

Marr described vision as a process that produces from images of the external world a description, or mental model, that is useful to the viewer, but that is NOT a verbal one. It is an internal, abstract model (Pinker might say it is in 'mentalese'). If vision did not deliver such abstract mental models, every

[10]Hubel, DH.; 'Eye, Brain, and Vision'. New York, Scientific American, 1988.

[11]Cohen, D.; " The secret language of the mind". San Fransisco, Chronicle Books, pp 52-3, 1996.

[12]Marr, D. & Nishihara, HK.; 'Representation and recognition of the spatial organisation of three-dimensional shapes'. Proceedings of the Royal Society of London, B, 200, 269-294, 1978.

other mental faculty (e.g. language, walking, grasping, planning, imagining, etc.) would need its *own* procedure for creating one. For example, when vision deduces the shape of an object that gave rise to a pattern on the retina, *all* parts of the mind can (and do) exploit vision's abstract mental model. Some components of the visual system siphon off information to motor-control circuits that need to react quickly to moving targets. However, the visual system as a whole (almost 50% of the cerebral cortex) is not dedicated to any one kind of behaviour, but instead creates abstract representations of the world (mental images rather than retinal images), and inscribes them on a 'mental commons' for general use by *all* the mind's mental modules.

In other words, *mental imagery is the engine that drives our thinking (both real and abstract)* about objects in space. Visualising a shape feels like placing a picture for inspection in the mind's eye, which is a very different experience form silently vocalising a discussion of abstract issues. Creative people are famous for 'seeing' in their mind's eye solutions to both real and abstract problems, e.g.:

- Faraday and Maxwell visualised electromagnetic fields as tiny tubes filled with fluid.
- Kekule found the benzene ring structure, after a visual dream of snakes biting their tails.
- Einstein mentally saw what it would be like to ride on a beam of light or to drop a penny in a plummeting elevator. He explained that, 'My particular ability does not lie in mathematical calculation, but rather in visualising effects, possibilities, and consequences'.
- Painters and sculptors try out ideas in their minds, and even novelists visualise scenes and plots in their mind's eye before putting pen to paper.

The brain is capable of satisfying the demands of such a mental imagery system where information must flow freely from memory instead of up from the eyes, since the fibre pathways to the visual areas of the brain are two-way. They carry as much information down from the higher, conceptual levels as up from the lower, sensory levels, and therefore are equipped to download memory images into visual maps.

What is a *mental image?* The visual system uses a pseudo-three-dimensional (pseudo-3D) sketch which, in a very real sense, is a picture in the head. It is a mosaic of elements that stand for neurons in the visual field. This topographically organised cortical map is a patch of cortex in which each neuron responds to contours in one part of the visual field, and in which neighbouring neurons respond to neighbouring parts. Shapes are represented by filling in some of the elements in a pattern that matches the shape's projected contours. Innate shape-analysis mechanisms process information in the sketch by imposing reference frames, etc.

A mental image is simply a pseudo-3D sketch that is loaded from long-term memory rather than from the eyes.

2.7 Sound and Language

The process of hearing is itself a fascinating, multi-disciplinary subject, and the detailed workings of the ear and the neural pathways carrying sound inputs from each ear to the brain's hemispheres reveal much about evolution. For example, each hemisphere has evolved a distinct role in sound processing, so sounds are processed (and therefore experienced) differently depending on which ear they enter. However, in this section the intention is to focus not on how sounds are detected by humans, but on how and when the processing of a special range of sounds associated with man's uniquely complex language evolved, as well as on how man has developed this capability to express himself first in speech and very recently in text.

2.7.1 The evolution of complex language

Man's development of complex language changed the landscape of the brain radically because once language had taken hold it appears to have rapidly annexed large parts of the left hemisphere, previously given over to visuo-spatial functions. In doing so it created the asymmetry that distinguishes the human brain from that of any other animal. The reason for the emergence of complex language remains unknown, but the brain itself provides some clues[13].

Animals do not have specialised language areas - their brains are more or less symmetrical, and their own noises are produced and processed along with environmental noises on both sides. Similarly, language initially develops in infant humans, together with other sound processing, in both hemispheres of the brain. By the age of five, however, in 95% of cases language, but NOT any other sound processing, shifts to lodge only in the left hemisphere, in the temporal (side) and frontal lobes, areas which are marked by a distinct, one-sided bulge (not seen in any animals, even chimpanzees). After this migration, the abandoned early speech areas in the right hemisphere are given 'back' to the activities for which they were probably previously being used. These involve the processing of environmental noises and spatial skills, i.e.:

- the rhythm and melody of music;
- the 'where' of things in the outside world;
- fine hand movements - including gestures, but NOT formal sign language.

So human language appears to have behaved like a hermit crab, moving around the brain until it finds a location which, though alien, best fits its structure. What does this behaviour tell us? According to William Calvin, most brain regions are, to some extent, multifunctional. As a result, this often enables *new functions* to first appear by making spare-time use of some pre-existing part of the brain[14]. The implication is that, in evolutionary terms, human language is very young, is still 'under construction', and is far from being fully integrated into the brain. Rodney Cotterill comes to a similar conclusion:[15]

"There is a growing body of evidence which suggests that no new neural systems evolved to exclusively serve language[16], and that there was no discontinuity of language from other cognitive systems[17]. Instead, language appears to be a new mechanism that Nature constructed out of old parts,[18] these being cortical maps of sensorimotor origin."[19]

The previously visuo-spatial region where language has recently taken up tenancy is also rich in connections to deeper brain structures that process sensory stimuli. It is one of the places where stored

[13]Carter, R.; "Mapping the mind". Phoenix, Pp224-9, 1998.

[14]Calvin, WH.; "How brains think". Basic Books, p12, 1996.

[15]Cotterill, R.; "Enchanted Looms: Conscious Networks in Brains and Computers". Cambridge University Press, p 388, 1998.

[16]Deacon, T.; 'Brain-language coevolution'. In JA Hawkins & M Gell-Mann eds. 'The Evolution of Human Languages: Proceedings of the Santa Fe Institute Studies in the Sciences of Complexity'; San Franscisco: Addison Wesley, 1990.

[17]Deacon, T.; 'Rethinking mammalian brain evolution'. American Zoologist, 30, 629-705, 1990.

[18]Bates, E., Thal, D., & Marchman, V.; 'Symbols and syntax: a Darwinian approach to language development'. In N. Krasnegor, D. Rumbaugh, E. Schiefelbusch, & M. Studdert-Kennedy eds. 'Biological and Behavioural Determinants of Language Development'. Hillsdale, NJ: Erlbaum, 1991.

[19]Sereno, M.; 'Language and the Primate Brain'. San Diego: California University Centre for Research in Language, 1990.

impressions from different senses, particularly touch and hearing, are brought together and reassembled into coherent memories - i.e. it seems that language 'best fits' in a region where several different and important functions converged.

The language cortex completely surrounds the auditory, but with two main areas - *Wernicke's* and *Broca's* - having been recognised for more than a century. Recent brain imaging studies suggest that other areas are also involved, including part of the insula (see Figure 15). It is thought that the language cortex is probably split, like the sensory cortices, into many different processing regions and sub-regions, but brain imaging studies have yet to fully confirm this. However, damage to cortical areas adjacent to these two main ones can cause a wide range of very specific language problems, providing indirect evidence of the functional subdivision of the auditory cortex.

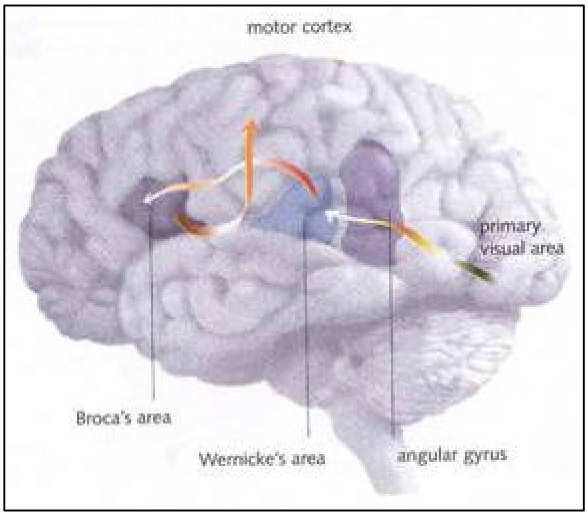

Figure 15: The language cortex

2.7.2 Speech processing

Analysing a stream of spoken words is highly complex. First, the brain has to recognise that what is coming in is, in fact, language. Speech is then shunted to the language areas to be processed, while environmental noises, music, and non-verbal messages (grunts, screams, laughs, sighs, etc.) go elsewhere. Once speech has been identified, as many words as possible are assigned some sort of meaning, whilst simultaneously the complex ribbon of sound is broken down into its elements - separate words or phrases. The two things are necessarily done together because without meaning it is almost impossible to make out language construction.

- Analysis of word **meaning** is carried out either in or very close *to Wernicke's area*.
- The cortical area that finds **structure** in incoming speech has yet to be identified. The eminent linguist Noam Chomsky has produced an elegant hypothesis for some kind of 'language organ' in the brain, but what form it might take and where it might be located are not known. Steven Pinker has built on this theory, suggesting that the language organ may not be a neat module at all[20].

- *Broca's area* governs **speech production** - a different part of the brain which is further forward in the side of the left frontal lobe. It abuts the motor cortex that controls the jaw, larynx, tongue and lips, and appears to instruct these neighbouring parts of the motor cortex to articulate speech. People with damage to Broca's area can understand what is said to them perfectly well, and they know what they want to say. They just cannot say it!

2.7.3 Reading[21]

Babies are tuned to hearing speech from birth, or even perhaps in *utero*. Speaking also comes naturally to infants - provided they are exposed to *spoken* language during infancy. Therefore, even though language seems to be such a comparatively recent acquisition, the basics of hearing and speech

[20]Pinker, S.; 'The Language Instinct'. New York: Harper Collins, 1994.

[21]Carter, R.; "Mapping the mind". Phoenix, Pp251-4, 1998.

previously must have been ‘hard wired’ into the brain to carry out procedurally similar cognitive functions, and as an essential precursor to the emergence of complex language[22][23].

Whilst infants do not need to be taught the basics of hearing and speaking language, by contrast, reading and writing are far from being natural acquisitions and can only be learned by children after speech has been established. Printed text has only been widely available for a few hundred years, and therefore, on the evolutionary time scale, reading has had no time at all to even begin to become an innate ability. The only reasonable explanation is that we learn to read and produce written language by pressing into use the language system as evolved for speech, together with relevant parts of the visual and touch systems, e.g. object identification and gesturing systems (to use fine hand movements to manipulate a writing instrument).[24]

It is not surprising, then, that the areas dedicated to processing the written word are situated around the junctions between the areas given over to these different skills. Just behind Wernicke’s area lies a bulge called the angular gyrus, which seems to act as a bridge between the visual word recognition system and the rest of the language process. It is a region of the brain where vision, spatial skills and language appear to overlap on the margins of the occipital, parietal and temporal lobes[25] (see Figure 16).

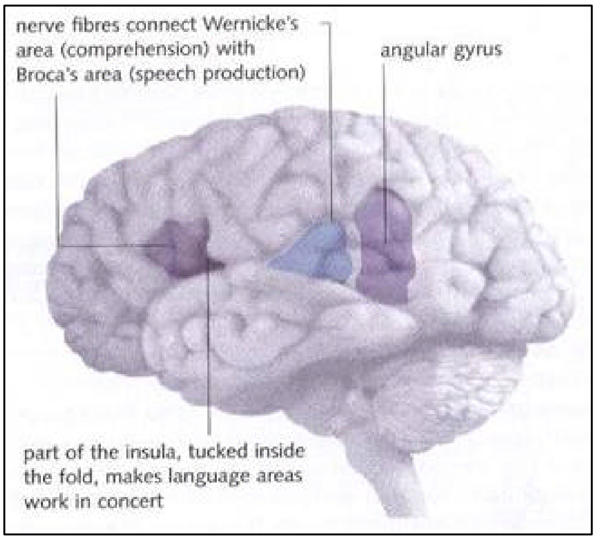

Figure16: Processing the written word

It is important to emphasise that the unnatural nature of reading and writing have serious implications in their use both to receive information (reading) and to express ourselves (writing). We do not write as we speak (especially in text books and academic journals). Therefore, how accurately does what we have (unnaturally) written represent what we would (naturally) have said? And what about the reader? Assuming the text being read *does* accurately represent what the writer intended, the reader has to, via a learned process (likely to be slow and inaccurate) convert that text into abstract mental models (either directly, if a speed reader, or using an additional sub-vocalisation step), and hope that those models accurately represent the writers intentions. Text has advantages, especially representing abstract concepts and details. But the cognitive scientific reasons why it is prone to slow information transfer, serious inaccuracies and poor retrieval need to be fully appreciated. Even for the literate people on this planet, in cognitive terms, text is the least efficient and effective of all the available communications media.

[22]Cotterill, R.; “Enchanted Looms: Conscious Networks in Brains and Computers”. Cambridge University Press, p 388, 1998.

[23]Pinker, S.; ‘The Language Instinct’. New York: Harper Collins, 1994.

[24]Kosslyn, SM, & Koenig, O; “Wet Mind: the new cognitive neuroscience” (New York, Free Press, 1992)

[25]Carter, R.; “Mapping the mind”. Phoenix, Pp254-8, 1998.

2.8 Memory

The only way that the brain can take in the data it needs to construct knowledge and behaviours is through the sensory perceptions that enter through the windows of the body's five senses. Anything that a person does, perceives, thinks, or feels while acting in the world gets processed through complex systems of storage pathways[26] and creates memory.

The brain has 100 trillion connections joining billions of neurons and each junction has the potential to be part of a memory. So the memory capacity of a human brain is effectively infinite, providing it is stored in the right way[27]. The human memory is different from a computer's in that it is selective. Items of interest - those that ultimately have some bearing on survival - are retained better than those that are not. So personal and meaningful memories can be held in their billions while learnt 'dry facts' (usually text-based) often quickly fade.

2.8.1 What is memory?

Although researchers are still not 100% sure how memory works, neuroscientists are making important discoveries in this area. Several models of memory exist, including the popular concept that our brains somehow record or 'videotape' life. This theory has its origins in reports that during surgery, electrical stimulation of the temporal lobe produced episodes of recall, almost like 'seeing movie clips'. It persists even though such findings could not be replicated and have been dismissed by most experts!

Researchers generally agree that memory is not a fixed thing or singular skill, but rather is a process where a transient stimulus creates a persistent change in the brain. Our memories are not stored in a single location. Instead many distinct locations are implicated with certain memories (e.g. sound in the auditory cortex, learned skills in the basal ganglia, associative memory formulation in the cerebellum, etc.). Hence, a complex set of multiple memory locations and systems are responsible for our best learning and recall[28] (see Figure 17).

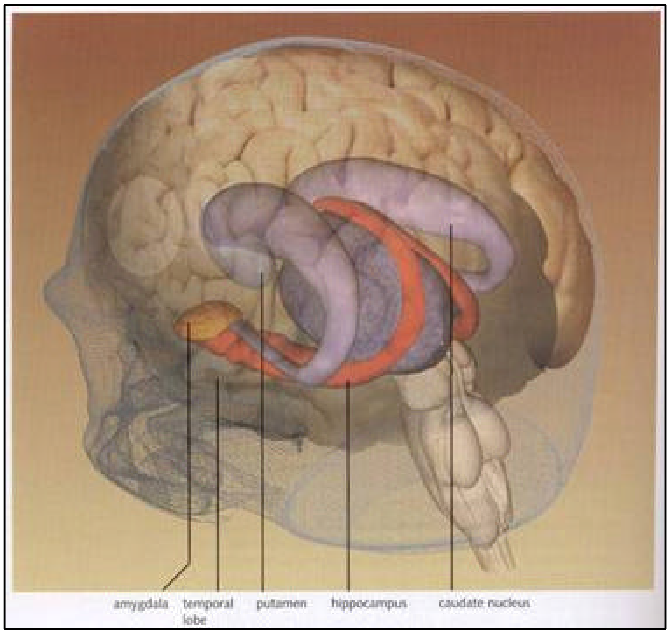

Figure 17: Memory involves many locations in the brain

The process for *retrieval* is proving to be much more consistent than is the location the memory was elicited from, and hence this is providing a much better platform for understanding memory.

2.8.2 Retrieval

There is no firm distinction between how well a person thinks and how well he or she remembers.[29] We can retrieve most of what we have paid attention to originally, but the success of that retrieval is highly

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[26]Restak, RM.; 'The brain: The last frontier'. New York: Warner, 1980.

[27]Carter, R.; "Mapping the mind". Phoenix, pp288-9, 1998.

[28]Schacter, DL.; 'Understanding Implicit Memory'. American Psychologist 47, 4: 559-569, 1992.

[29]Turkington, C.; 'The Brain Encyclopedia'. New York: Facts on File, 1996.

dependant upon multiple factors, including state, time and content. For example, remarkable levels of recall have been demonstrated for Spanish,[30] mathematics,[31] city streets, locations, names, and faces when careful attention was paid to context and state. The variety of ways in which information is stored and retrieved indicates that our focus should move on from simple 'memory' to 'which kind of memory and how it can be retrieved'[32].

Explicit/Declarative Memory. This is formed in the hippocampus and stored in the medial temporal lobes. It comes in several forms, including the more word-based semantic memory and the event-type episodic memory:

- *Semantic Pathways:* Semantic memory is also known as explicit, factual, taxon, or linguistic memory, and includes names, facts, figures, and textbook information. It is word-based and is activated by association, similarities, or contrasts. The capacity limitations are more strongly influenced by the strength of associations made than the sheer quantity of items. We remember best in 'chunks', which are single thoughts, ideas, or groups of related ideas. A 3-year-old can handle 1 chunk, which increases to 7 (+ or - 2) in people of 15 years and older. The brain does not appear to be well equipped to routinely retrieve this type of information, since humans have had little need for semantic recall until recent history when books and literacy became common. *Given the newness of this need, it is not surprising that this is by far the weakest of our retrieval systems.*

- *Episodic Pathways:* This system is also known as the loci, spatial, event, or contextual recall process - a thematic map of daily experiences. The visual system has both 'what' (content) and 'where' (location) pathways[33] (see Vision section), and it *is believed that this information is processed visually by the hippocampus.* Learning and memory are prompted by contextual cues, such as location and circumstances. The formation of this natural memory is motivated by curiosity, novelty, and expectations, and is enhanced by intensified sensory input, such as sights, sounds, smells, taste, touch and emotions. Episodic memory has *unlimited capacity*, forms quickly, is easily updated, requires no practice, is effortless, and is used naturally by everyone.

Implicit memory: Our minds are full of information, but our ability to recall it depends on which pathway we use to access it, and whether we realise that we know that information in the first place. Two distinct pathways are discussed here: procedural and reflexive.

- *Procedural Pathway:* This is often known as motor memory, body learning, or habit memory and involves both the basal ganglia and the cerebellum. Body and brain are not separate but are parts of the same contiguous organism, and what happens to the body happens to the brain. This dual stimulus creates a more detailed 'map' for the brain to use for storage and retrieval[34]. Such 'hands-on learning' creates a wider, more complex, and over-all greater source of sensory input to the brain than mere cognitive activity. It appears to have unlimited storage, requires minimal review,

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[30]Bahrick, HP.; 'Semantic memory Content in Permastore: Fifty Years of memory for Spanish Learned in School'. Journal of Experimental Psychology, 113: 1-29, 1984.

[31]Bahrick, HP, & Hall, LK.; 'Lifetime Maintenance of High School Mathematics Content'. Journal of Experimental Psychology, 120: 20-33, 1991.

[32]Jensen, E.; "Teaching with the brain in mind". Association for Supervision and Curriculum Development (ASCD) Publications, pp99-109, 1998.

[33]Kosslyn, S. 'Wet Mind'. New York: Simon and Shuster, 1992.

[34]Squire, L.; 'Memory and the Hippocampus: A Synthesis from Findings with rats, Monkeys, and Humans'. Psychological Review 99, 2: 195-231, 1992.

and needs little intrinsic motivation. At school, this type of learning diminishes each year until it is virtually absent (as in most tertiary courses). Yet a summary of the research tells us that this learning is easier to master, is fairly well remembered, and creates lasting positive memories.

- *Reflexive Pathway:* Our reflexive retrieval system is automatic, almost permanently in use, and full of instant associations. Emotionally laden experiences receive privileged treatment and are more easily recalled than neural experiences. Auditory memories are potent emotional triggers - e.g. a favourite song. Researchers speculate that this stimulation takes separate pathways from the more mundane content-laden ones.

2.8.3 Working memory

A new term has recently emerged to describe how we juggle perceptions, memories and concepts: *working memory*.

Memory used to be regarded as a simple library with a long-term store (childhood memories and so on) and a short-term store (a temporary holder in which information is retained for as long as it is needed, then discarded). As experimental techniques became refined, however, it has become clear that there is no rigid dividing line between a memory and a thought[35]. A range of related findings has led to the abandonment of the idea that a single short-term memory serves as the working memory. It has been replaced by a tripartite scheme which, according to the model of working memory developed by Alan Baddeley and his colleagues[36], comprises a *central executive* and two subsidiary *slave systems*, as indicated in their highly schematic diagram (see fig 19 overleaf):

The Central Executive: is an attention-controlling system, probably located in the prefrontal cortex. It co-ordinates information from a number of sources, directs the ability to focus and switch attention, organises incoming material and the retrieval of old memories. It marshals cyclic processes in the two slave temporary storage systems, namely the visuo-spatial sketchpad, and the phonological loop. These might each be a series of successively linked cortical clusters, their interactions being mediated by the forward and reverse projections that are common features of the cortex. Recent brain imaging studies at the Wellcome Department of Cognitive Neurology have found that the three parts are echoed precisely in the activity seen when people carry out cognitive tasks, and have confirmed the separate nature of visuo-spatial imagery and verbal repetition:[37]

[35]Baddeley, AD. & Hitch, GJ.; ‘Working Memory.’ In GH Bower ed. ‘The Psychology of Learning and Motivation’, Vol. 8, New York, Academic Press, 1974.

[36]Baddeley, AD.; ‘Working Memory’. Science, 255, 556-9, 1992.

[37]Cotterill, R.; “Enchanted Looms: Conscious Networks in Brains and Computers”. Cambridge University Press, pp283-5, 1998.

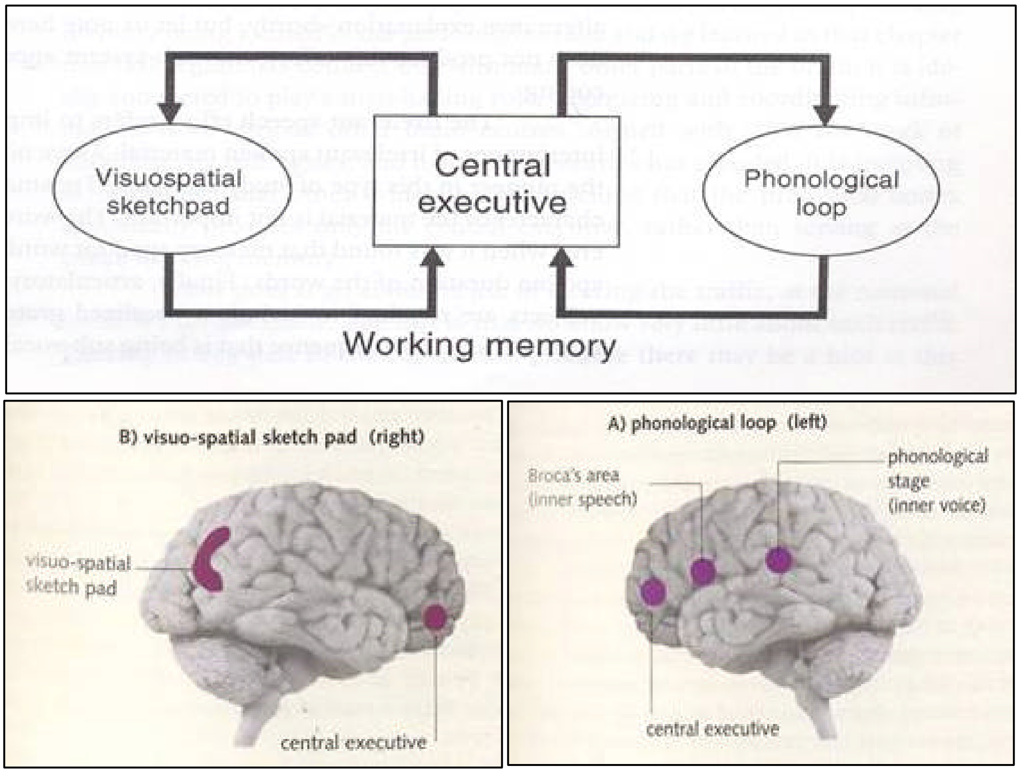
- 

Figure 18: Components of working memory

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patial sketch pad is responsible for setting up and manipulating visuo-spatial imagery, with further separation between *positional* (occipital lobe) and *pattern* (parietal lobe) processing in the visual domain. It is complex and remains poorly understood, although the four active regions so far identified by functional imaging are thought to represent 'what', where', executive control, and possibly image rehearsal.

- *The Phonological loop* maintains acoustic and speech-based information, and can be split into two components: a *phonological store* that holds a fast decaying (1 - 2 seconds) speech-based trace, and an *articulatory control mechanism* which plays a mediatory role, and which permits us to register visual information in the phonological store via sub-vocalisation. This store is thought to serve as a backup system for speech comprehension.

Working memory is best regarded as a mechanism that permits performance of complex cognitive tasks through its ability to temporarily store information related to the various sensory modalities, particularly those of vision and audition. It enables us to use our memory systems flexibly; to hold onto information by rehearsing it in our minds; to relate that information to older knowledge; and to plan our future actions. In Alan Baddeley's view, working memory stands at the crossroads between memory, attention and perception, and as such, its role in human cognition and learning could hardly be more important.

2.9 Natural Learning

2.9.1 Brain development and early learning

For the first year or two of life outside the womb, our brains are in the most pliable, impressionable, and receptive state they will ever be in'[38]. We begin to be shaped as our immensely receptive brain/mind interacts with our early environment and interpersonal relationships. In part, there are predetermined sequences of development in childhood, including windows of opportunity for laying down the basic hardware necessary for later learning. Such opportunities are why new languages, as well as the arts, ought to be introduced to children very early in life.

Babies are tuned to speech from birth (perhaps even before). "Proper" language starts in the second year with the activation of Wernicke's area and Broca's area[39] (see Sound section). Language comes naturally to children - provided they are exposed to it during infancy. But if they are deprived of the sound of speech, their brains may be physically disordered. All babies are born with the potential to speak any language and many languages, but if they are only exposed to a single tongue their options soon narrow because the neurological wiring needed to distinguish sounds atrophies if it is not stimulated in the first two years of life. Therefore, people who learn foreign languages as adults rarely speak them without an accent.[40] Indeed, second languages (learned later in life with much greater difficulty and poorer results) are processed in a different section of the language area than the mother tongue[41].

Whether you want to call it a bioprogramme or a Universal Grammar, learning the hardest aspects of language seems to be made easier by a childhood acquisitiveness that has a biological basis (like learning to walk upright). Perhaps this acquisitiveness looks for intricate patterns in sound and sight and learns to mimic them. In many ways, this pattern-seeking bioprogramme looks like an important underpinning for human levels of intelligence[42].

This is supported by the fact that all people, from birth, also engage in a kind of scientific thinking. Natural selection shaped man to be intuitive physicists, biologists, engineers, psychologists, and mathematicians so that he could master his local environment[43]. However, it is important to distinguish these intuitive abilities from the modern, academic disciplines that most people find so hard to understand and learn.

For example, formal mathematics is an extension of the mathematical intuitions expresses by one week-old babies, who are aware when a scene changes from two to three items, or vice versa. Arithmetic grew out of our sense of number, and geometry out of our sense of shape and space. But, to assert that academic mathematics follows from our intuitive mathematics does not say that it follows easily.

According to psychologist George Miller, 'The crowning intellectual accomplishment of the brain is the real world.... All the fundamental aspects of the real world of our experience are adaptive interpretations of the really real world of physics'. Many cognitive scientists agree that the mind is

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[38]Darling, DJ.; 'Zen Physics: The Sense of Death, the Logic of Reincarnation'. New York: Harper Collins, p 18, 1996.

[39]Carter, R.; "Mapping the mind". Phoenix, Pp254-8, 1998.

[40]Oliver Sacks; 'Seeing Voices'

[41]Kim, KHS, et al; "Distinct cortical areas associated with native and second languages", letter to nature, 388: 6538 (1997), 171.

[42]Calvin, WH.; "How brains think". Basic Books, p74, 1996.

[43]Pinker, S.; "How the Mind Works". Penguin, p299-360, 1997.

equipped with innate intuitive modules which represent major ways of understanding the world. There are modules for objects and forces, for animate beings, for artefacts, for minds, and for natural kinds like animals, plants, and minerals. Although these different ways of knowing are innate, this does NOT mean that knowledge is innate. The concepts of innate modules help explain learning, they cannot minimise it. Beyond simply capturing experiences, learning requires a system for recording our experiences so that they generalise in useful ways.

2.9.2 How do we learn

Learning is what the human brain does best. Scientists are unsure precisely *how* this happens, but they have some ideas of *what* happens[44].

To our brain, we are either doing something we already know how to do or we are doing something new (i.e. learning). Doing what we already know how to do is merely exercise, whilst doing something new is *stimulation*. As long as it is coherent, this novel mental or motor stimulation produces greater beneficial electrical energy than repetitive exercise. This input is converted to nervous impulses which travel to extraction and sorting stations like the thalamus, located in the middle of the brain. In intentional behaviour, a multisensory convergence takes place and a 'map' is quickly formed in the hippocampus[45]. From there, signals are distributed to specific areas of the brain (see Memory section).

Once this input is received, each neuron transmits an electro-chemical impulse (powered by the difference in concentration of sodium and potassium ions across the cell membrane), and resultant voltage changes stimulate the demand for dendritic growth. The process is repeated, via the synapse, to the next neuron, and so on. Eventually, the repeated electrical stimulation fosters neuron growth by way of dendritic branching. These branches lead to even more connections until, in some cases, whole, dedicated 'neural forests' help us understand better and, maybe someday, make us an expert in that topic. Hence, new dendrites and synapses usually appear in the effected parts of the cortex after quality learning.

Learning and memory are two sides of a coin to neuroscientists - i.e. the only evidence of learning is memory. Lasting learning, or long-term potentiation (LTP), has long been accepted as essential to the actual physical process of learning. Since its discovery in 1973 by Bliss and Lomo, countless experiments have defined its intricacies. Neurons change their receptivity to messages based on previous stimulation, i.e. the neurons have 'learned' and changed their behaviour. In short, our learning is achieved through the development of new dendrites and synapses, and the alteration of synaptic efficacy.

The daily chemistry of our brain adds great complexity to the question, 'how does our brain learn?'. Neurotransmitters (e.g. glutamate, GABA,..) act as 'cellular phones' offering specific communications between synapses, whereas the other chemicals (e.g. serotonin, dopamine, noradrenaline, ..) act more like 'loud speakers' that can broadcast to wide areas of the brain. The latter produce observable behaviours such as attention, stress, or drowsiness. In short, learning happens on many complex levels simultaneously.

2.9.3 Improving learning and intelligence

The end result of learning for humans is intelligence. The key to getting smarter is not having a bigger brain or more brain cells per cc., but is growing more dendrites and synaptic connections between

[44]Jensen, E.; "Teaching with the brain in mind". Association for Supervision and Curriculum Development (ASCD) Publications, pp13-16, 1998.

[45]Freeman, W; 'Societies of Brains'. Hillsdale, NJ.: Lawrence Erlbaum and Associates, 1995.

neurons as well as not losing existing connections. It is these connections that enable us to solve problems and figure things out (i.e. act intelligently and learn).

The brain is 'plastic', which means that much of its hard wiring can be changed by an individual's experiences. Research shows that complex learning is enhanced by challenge and inhibited by threat. The mind learns optimally when it is appropriately challenged in an environment that encourages taking risks. Under these circumstances, rat brains make maximum connections in the areas where learning is taking place by their neurons growing large numbers of new dendrites and synapses within a few hours (see Figure 19). Conversely, the mind appears to 'down-shifts' under perceived threat. Under threat, rat brains reduce connections by their neurons losing significant numbers of dendrites and synapses within a few days. The mind then becomes less flexible and reverts to primitive attitudes and procedures. Low threat, however, is NOT synonymous with simply 'feeling good'. The essential element of perceived threat is a feeling of helplessness or fatigue.

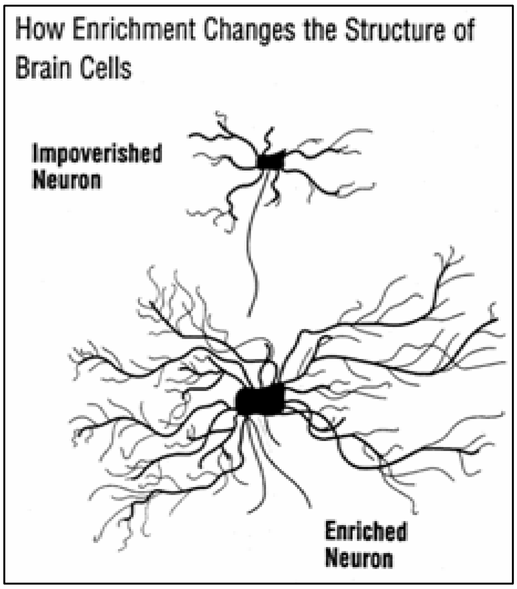

Figure 19: Enrichment grows dendrites and increases connections

Occasional stress and anxiety are inevitable and are to be expected in genuine learning. The reason is that genuine learning involves changes that lead to a reorganisation of the self. Such learning can be intrinsically stressful, irrespective of the skill of, and support offered by, a teacher.

Although each of our 100 billion neurons ordinarily connects with between 1,000 and 10,000 other neurons, theoretically, they could connect with far more. Hobson has calculated that a normal brain could be capable of processing as much as 10^{27} bits of data per second[46]. Some estimate that we use much less than 1% of our brain's projected processing capacity. Whatever the case, the brain's architecture has the inherent capacity for every individual to significantly increase their intelligence!

2.9.4 Individuals, society and the learning process

Learning is significantly influenced by the nature of the society within which people are existing. Vygotsky emphasised the social construction of knowledge[47], and it is now generally accepted that throughout our lives, our minds change in response to engagement with others. Hence, individuals, their identities and their learning, should be seen to be integral parts of larger social systems.

But every individual's mind inherits the lifelong drive to 'search for meaning' (i.e. the passion to learn). This search for meaning tries to make sense of our experiences, is survival oriented, and at its core, is driven by the individual's purposes and values. The range of human purposes and values, and their strong relationship to differing social systems was discussed by Maslow[48]. Thus, the search for meaning ranges from the need to eat and find safety, through the development of relationships and a sense of identity, to an exploration of our potential and the quest for transcendence[49].

[46]Hobson, JA.; 'Chemistry of Conscious States'. Boston, Mass.: Little, Brown and Co.. 1994.

[47]Vygotsky, LS.; 'Mind in Society'. Cambridge, Mass: Harvard University Press, 1978.

[48]Maslow, AH.; 'Toward a Psychology of Being'. 2nd ed. New York: D Van Nostrand Company, 1968.

[49]Caine, RN. & Caine, G.; "Education on the Edge of possibility". ASCD Publications, pp104-8, 1997.

Most societies place a high value on learning. Yet their emphasis is on ‘measurable’ results, whilst the crucial, but more complex processes of learning tend to be down-played. What ensures our survival is using our highly effective and adaptive minds to adapt and create options. Humans have survived for thousands of years by trying out new things, usually in small groups, NOT by always getting the ‘right’, tried-and-true answer - that’s not healthy for growing a smart, adaptive mind.

This raises important questions regarding the appropriateness of a variety of combinations of individual or group learning in independent or interactive modes:

- When is independent learning most effective (just the learner and the learning material)?
- When is individual tutoring most effective (just the learner, the tutor, and the learning material)?
- When is group learning most effective (small groups (2 - 5) of learners actively interacting with each other, the learning material, and perhaps a tutor/facilitator)?
- When is classroom/lecture theatre instruction most effective (large groups (15 - 400) of learners passively being instructed by a single teacher/lecturer)?

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