Our Cartographic Brain

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"The brain is wider than the sky,
For, put them side by side,
The one the other will include
With ease, and you beside."

Emily Dickinson

We all live at the intersection of two worlds, the world of matter, existence, action and mortality, and the world of ideas, representations and appearances – which we might also call the world of information. For materialists like myself *information* is a wholly dependent effect of the world of matter: in fact it describes the locations of matter in space and time. The brains of living creatures are devices that evolved to collect and process information about the world of matter, to serve the vital interests of those creatures in moving, feeding, evading danger and reproducing themselves.

The human brain samples the world of real objects to collect packets of information that we call ideas, then assembles these samples to construct a more-or-less coherent movie which we experience as our lives. It performs this task using at least two separate bodily "hardware" systems. One of them, the older in evolutionary terms and shared with almost all other animals, is based on the broadcasting of chemical messages – hormones and neurotransmitters – throughout the whole body. The other, newer, system is based on circuits of neurons that can record, store and retrieve sampled images of all kinds.

Recent results in neuroscience from the likes of Chris Frith, Antonio Damasio and Jan Panksepp, put together with psychological and philosophical insights from Jonathan Haidt and Mark Johnson, are revealing that our behaviour is controlled as much by emotion as by reason, and that in consequence we grossly overestimate the power of our will and underestimate the extent to which our lives are ruled by unconscious processes [1]. We fail to spot unconscious motives in others; we mistake the names of things for the things themselves; and we tend to see an existing thing where there's nothing *but* a name.

Such insights may attract hostile criticism not only from religious believers, but also from humanists who hate "reductive" explanations of human mind and nature. I'm sympathetic to this hostility, but I nevertheless sincerely believe that neuroscience recently passed a crucial threshold beyond which it can produce explanations that are neither reductionist nor deterministic in any accepted sense. The mathematical discipline of Algorithmic Complexity Theory teaches that a system may become so complex that its future states can't be predicted *even in principle* from its starting conditions and the interactions between its material parts. Such a system is in effect free (in fact this might be the only properly materialist definition of freedom). Our brains are such systems. Even so, oversimplified comparisons between human minds and computers, currently prevalent in the Artificial Intelligence community, have lead believers to hope that we'll soon be able to emulate or even exceed the power of mind using silicon technologies, though the magnitudes of complexity involved are

vastly different.

That's not to say though that computers can't provide *analogies* useful in trying to understand the operation of subsystems within the human brain, and in particular our perceptual system. Like computers we store data about external events, sampled by our eyes, ears, tongues, noses and skin, in memory for future retrieval. A computer stores such data as long strings of digital bits that encode either events that succeed one another in time like sound waves, or arrangements of matter in space, like the colours that constitute a picture. Such representations are referred to by software engineers as "bitmaps", which suggests that some aspect of the physical input device is being mapped onto a region in the computer's memory one bit at a time. In practice most digitising devices employ more than a single bit to encode each datum: colour pictures typically employ 32 or 64 bits for each sampled pixel, but the generic name "bitmap" has nevertheless stuck.

Both human brains and computers store sampled data internally using a substance quite different from that of which the external object is made – neither you nor your camera store a picture of a banana using banana flesh. The precise form in which our brains store mental images is not yet known, and is certainly not like the bitmaps employed by digital cameras. For example the part of a rat's brain which processes signals from its whiskers turns out indeed to be a map, arranged in rows and columns corresponding to each hair on its snout, but unlike a digital bitmap in which each bit corresponds to one static pixel, the rat's brain processes these images dynamically – waves of neuronal activation periodically sweep across the map, and it's the phase and timing of these sweeps that encode the sense data. And the physical medium that supports this map is utterly different – neurons made of protein and filled with warm salty water as opposed to tiny transistors engraved on silicon. Even so, these physical details are less important than the similarities, namely that both involve the storage of two-dimensional arrays of samples that we can think of as maps.

All the different qualities of objects in the outside world that we experience, like colour, texture or sound pitch, are represented inside the brain using neurons that in no way physically resemble either the original object, nor the signals from it that were sampled. When I look at a red rose and experience "redness", the optical image on my retina would also look red but that's where the redness stops. Inside my brain red, yellow, hard, soft, G# and A minor are all represented by the same sort of stuff, some kind of electro-chemical state. The brain map representing that rose isn't red, and it differs from the map representing a yellow rose only by being stored in a different place.

There does appear to be some "common currency" inside the brain that encodes all the different modalities of sense data – images, sounds, textures, pressures – as brain maps. The precise formats and locations of these maps aren't yet understood and needn't concern us here, but the phenomenon of *synaesthesia* – where a person experiences sounds as colours or vice versa – suggests there is indeed such a common currency. Such evidence is barely needed though because we know the brain is composed of only a few kinds of neurons, fundamentally similar in structure, and that patterns of activation of those neurons are all that's available to store anything.

When I look at that red rose, the only absolutely certain knowledge I have is that I'm seeing *this* red, right *here,* right *now.* I can't say whether or not you see the same shade of red, nor whether it's the same red it was an hour ago (in physical wavelength it most certainly isn't, because the quality of sunlight changes throughout the day, though my brain silently compensates for this). Light reflected from the rose hits the retina of my eye, triggers neural signals to my visual cortex where a variety of filters separate out different features like edges, convexity, colour and texture. This processing is quite invisible to me and I feel no need to prove that a red rose actually exists out there. (Since the invention of photography a reasonable proof is available – take a picture and compare it to what I'm seeing: the chance that my eye and the camera lens share the same defect is pretty remote). Political and economic pundits love to remind us that we're living in'the information age', but in the most profound sense we always have done. Everything we see, hear, taste, feel, think, hope, wish

and remember is information, stored as maps for longer or shorter times within sheets of neurons in our brains.

These sheets of neurons connect to one another in unimaginably complex ways, which permits the brain to compare, extract differences between, identify features within, and a myriad other operations on the sensory inputs temporarily stored there. Some neurophysiologists believe that this massive interconnection, when extended to sufficiently deep levels of recursion, is capable of generating and ultimately responsible for the phenomenon of consciousness. If proved this would finally settle the mind/matter dispute, since mind would then be unquestionably a function of brain.

New tools like Functional Magnetic Resonance Imaging (fMRI), anatomically-constrained Magnetoencephalography (aMEG) and Transcranial Magnetic Stimulation (TMS) enable neuroscientists to watch in real time which parts of the brain become active as actions, movements and thoughts are being performed. The mysteries that remain are in what precise formats the brain stores data, and the "hard problem" of consciousness itself – the fact that we each face the world separately, peering out through two holes in our skull and experiencing the information stream as the qualities of external objects. For dualist theories of mind, the last refuge is that perhaps some other substance might inhabit the connections between neurons, but frankly that seems very, very unlikely.

Feats of Imagination

The raw maps captured by the retina of your eye, the cochlea of your ear and other sense organs are sent to dedicated areas of the cerebral cortex that strip them down, searching for features that provide evidence of structure in the outside world. For example when you look at a house, your retinal bitmap gets sent through successive layers of visual cortex at the back of your brain which analyse it for certain geometric, textural and tonal features. They identify horizontal, vertical and diagonal edges and extract these as separate maps; contours are deduced from the way that shadows fall, identifying convexities and concavities. Once these features have been separated out, the brain then puts them back together again, but now instead of a flat bitmap it has a model of a solid object with squarish corners, vertical walls, sloping roofs, and lit from above by sunlight.

In all likelihood your memory doesn't store all of this scene data but rather some highly-compressed string of references to it, so that remembering the house involves an act of imagination, a reconstruction of something like the original house from a library of such features. And this imaginative remembering of scenes isn't just an occasional event, during moments of reverie. It's happening continuously throughout every second of your life. The image currently on your retina represents only the world at the single instant now, but to maintain an illusion of a continuously-existing self who moves through a persistent world, your brain must be constantly referring to the succession of images collected and analysed over the last few seconds, without you being aware of this massive feat of reconstruction.

This is merely the first of the stupendous feats of information processing your brain performs in order that you shall be conscious. Maps representing sense data get dispatched to various different areas of your brain simultaneously where they are compared against equivalent maps that your brain maintains of your own internal body state. Muscles get adjusted accordingly, so that you can perform actions on the external objects you perceive, or perhaps dodge threats that they might pose. Maps representing vocal sounds get analysed as language utterances and call up the ideas corresponding to the words uttered or heard. Your brain integrates all these various information streams in such a way as to make you believe in a persistent, solid world that contains other agents besides yourself, who have minds of their own similar to yours. And the function that performs all these feats of analysis and reassembly is imagination, that same imagination with which you can conjure up a blue cow or fairies at the bottom of your garden.

The very term imagination has become a source of great confusion nowadays. Because imagination takes place within individual minds, thinkers of a scientistic or objectivist persuasion may distrust it as irredeemably subjective, the source of error and delusion. On the other hand people of a more romantic bent may see it as the source of creativity and poetry, superior to dull reason. In the sense I'm using the term here, imagination is just a name for the brain's ability to organise its mental representations into the unified objects and ideas of our experience. It's that process via which the brain takes apart and reassembles sensory inputs, manipulates its stores of information and sequences them in time so as to give us a coherent experience of the world.

The everyday meanings of imagination – delusion, as in "you're just imagining it", or the creative force behind fiction and poetry – are both contained within this broader notion of imagination, but as only two of its aspects. Imagination certainly can lead us astray just as the objectivists fear, because some of the things we see "out there" indeed aren't real, as every lawyer and every policeman knows.

The brain continually draws on recent memories to fill-in those parts of our visible world that it lacks the bandwidth to monitor fully in real time: for example the things you see in your peripheral vision are mostly reconstructed from memories of what was there when you last looked in that direction, so artfully integrated with what you're seeing now in your central vision that they appear real. And then there are dreams, daydreams, imaginary companions and outright hallucinations. Not every brain map corresponds to an external lump of matter. The brain often dips into its database to create the appearance of some object internally, then superimposes this appearance onto an object it perceives from the outside. We call that wishful thinking, seeing what you want to see, and we very often see what we expect to see, or remember seeing, rather than what's actually there now.

Imagination also plays an important role in our social interactions via the phenomenon called theory of mind, that recognition that other people have minds similar to our own and our ability to put ourselves into their mind and hence predict their reactions. We're beginning to understand the neurophysiological basis for this ability, thanks to the discovery of brain subsystems like the mirror neurons, which assess other peoples' intentions by mimicking their actions and expressions in imagination rather than in practice. This central role of imagination means that *all* our knowledge of an outside world must be wholly symbolic. Since brain maps aren't at all the same kind of thing as the external objects they were sampled from, they can only stand as *symbols* for those objects, the same way the glyph A stands as a symbol for a puff of air emitted from someone's larynx.

Immanuel Kant understood imagination in precisely this sense in his *Critique of Judgement* back in 1790, as the mental faculty that mediates between the contents of sense perception and our abstract ideas, and hence underpins our language ability. In modern times, the American philosopher Mark Johnson has taken Kant's theory of imagination a step further by extending it to encompass mental structures that he calls image schemas, which encode much of our innate knowledge about the physical world and its relation to our own bodies – facts like gravity, up-ness and down-ness, containment, directions and paths, succession in time, scale, distance and size, and much, much more. Johnson proposes that in order for us to have meaningful connected experiences that we can comprehend and reason about, there must be a pattern and order to our actions, perceptions and conceptions. A schema is a recurrent pattern, shape, and regularity in, or of, these ongoing ordering activities.

One example of a very fundamental image schema is Johnson's IN-OUT orientation schema, which applies to all situations where one thing or idea is contained within another. It's a topological property concerned with crossing of boundaries. It need not refer solely to physical containment, though that certainly comes into it (this sentence itself contains an instance of the schema, by employing the word "into"). You go *in* and *out* of your house, you look *into* a mirror and see yourself looking *out,* you pour out a cup of tea and put a

a slice of bread *into* the toaster, but you also talk someone *into* a better frame of mind, because they were going *out* of their mind. The IN-OUT schema gets invoked during mental processing whenever there's a need to describe an instance of such containment, encoding what all in-out scenarios have in common, and it projects into our language ability, both governing our choice of words, and organising unconscious processes internal to the brain – for example a muscular action concerned with removing some object from inside something else.

Such schemas must have physical representation within the brain, whether in hardware or software – that is, as separate, connected neural circuits or merely electrical impulses that traverse such circuits. We don't know in what format they're stored nor which are hard-wired by evolution and which get learned through life experiences. Think of them for the time being as yet another sort of brain map, operating at the very highest level to structure our perceptions into thoughts and utterances. Neurophysiology is approaching the point where it may soon be able to illuminate the age-old philosophical dispute about how much (if any) of our knowledge is innate and how much is learned, by identifying the filters and pattern-recognizers that manipulate the brain maps generated by our senses, when Kant's categories and Johnson's schemas may well be found to correspond to actual neuronal circuitry.

An Imagined Reality

Behavioural and cognitive psychology experiments reveal that perception is more than just this one-way process in which external information enters the brain. All evidence points to a more complicated process that begins on the brain side. That doesn't mean that light literally shines from our eyes like a movie projector, nor that sounds emanate from our ears: it means that our perceptual system proceeds from what it's *expecting* to see or hear, then compares this with what is in *fact* being seen or heard. It's an iterative process, repeated unconsciously over a few tens of milliseconds to reconcile our brain's internal model of the world with what's actually there.

Why would evolution have fashioned such an indirect method of perception? For several very good, and by no means obvious, reasons:

> 1) The raw inputs to our senses may be ambiguous. That rose may be red because its petals reflect light of a particular wavelength, say 700 nanometres, but the wavelength of light actually reaching our eye varies enormously with the ambient lighting. Our brains continually compare the colour of surrounding objects held in short-term memory to cancel distortion due to changing illumination – the so-called colour constancy effect – so we experience a similar red under almost any lighting conditions.
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> 2) Analysing a bitmap into meaningful components is a major computational task. Our iterative, two-way perceptual process reduces this computational load considerably because the brain rarely needs to analyse a scene from scratch – it starts with already computed features from an earlier time. Even for novel scenes the brain retrieves knowledge of the *sorts* of things you've seen before to reduce the amount of new analysis – a great source of unreliability in witness reports, when people saw what they expected to see.
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> 3) Most importantly, indirect perception prevents us from becoming enslaved by the torrent of sense data we receive during every waking moment. So long as we're conscious we cannot switch off our eyes, ears and other senses, yet we experience and respond to only a tiny but vital fraction of that input. Directing *attention* onto what matters is crucial for our survival, and it's possible only because what we actually experience is our constantly-updated internal

model of the world, rather than the voluminous direct sensory stream. (The loss of this ability by certain unfortunate stroke victims leads to a gross disability where every new stimulus precipitates a change of activity. Sufferers feel impelled to drink from every cup they see, open every door, put on every coat even when already wearing one).

Several decades of experiments by Chris Frith's team at University College London suggest that our brains don't integrate fresh sensory data into our world model by simply tossing it onto the pile of previous data, but rather blend it in proportion to the new input's *likelihood,* using a Bayesian statistical logic. When I pick up a book, what I see, feel with my fingers and weigh against my arm muscles will all be simultaneously incorporated into my perception of what I'm holding. If that book turns out to weigh 100lbs, or is scalding hot, that will be very surprising indeed and will radically alter my beliefs about the object. Bayesian logic mathematically describes that iterative, two-way information flow: my internal model *predicts* what I expect to encounter, and whenever this prediction is at odds with sense data, my belief about the world gets changed in an appropriate direction. This new belief gets re-tested, over and again, until the discrepancy has been reduced to some acceptably low level – automatically, unconsciously and so fast that I remain convinced that my perceptions are direct and transparent.

We in effect live in our internal model world, constantly updating and adjusting it to better correspond with the evidence of our senses, but that model is more than just a picture of the world. It's value-laden, it knows which parts of the world are nastier and which nicer. Recent findings in affective neuroscience show us how the older, chemical part of our brain's messaging system – the part that works through hormones and controls emotions – intersects with the more modern, neuronal part. All of our memories, which include the perceptual data used to update the model, get labelled with a signifier of the emotional state that prevailed when they were laid down. When we recall past information to help solve a current problem, or predict its future outcome, these labels get processed and weighed in our frontal cortex. This is the process we call judgement or wisdom. It's the process the Situationists sought to invoke with their practice of psychogeography and the Confucians with *feng shui,* and which may be impaired in psychopaths. T. S. Eliot famously claimed that 'Humankind cannot bear very much reality' but we can now quantify that *apercu.* Our brains are exquisitely adapted to extract precisely the amount of reality that's consistent with feeling happy and secure. Too much or too little knowledge about the future can lead to fear and anxiety, although pursuing an excess of knowledge has become a peculiarly modern kind of extreme sport, the intellectual equivalent of bungee jumping.

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