The Entropic Miracle

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0.1. The entropic miracle

One of the greatest differences, if not the greatest, between human beings and the rest of the animal world is the semiotic ability, i.e. the faculty of transforming the magmatic reality revealing itself in front of our eyes into compact, well defined concepts. From the chaotic and incredibly dense state of the primordial singularity, or the 'Big Bang', to the expected heat death, or 'Big Rip', the human species made its appearance in an entropic miracle where the ontologically identical components of reality assembled themselves in a meaningful and manyfold reality where complex systems could generate emergent properties and behaviour, adding new dimensions to the phase space of this reality. What strikes me the most is how the most complex of these systems, the brain, evolved the ability to extrapolate patterns from an otherwise undistinguished and undefined reality, and can navigate to higher or lower dimensions of this reality, establishing boundaries and assigning definitions (from latin 'definitionem' - a boundary). One hundred miles from the tip of a mountain we can be certain of not being on that mountain anymore, but how about one mile? And what is the resolution of the mountain's boundary? Moreover, boundaries can be time dependent. If a coffee cup's handle breaks off, is what remains the same coffee cup? Is it still a coffee cup? These are questions that keep philosophers awake at night, and nevertheless the human brain constantly recognises patterns arising from the world with little or no effort, careless of the fact that these boundaries may not be 'real', in a reductionist interpretation of this word. Both the ontogenesis of emergent properties from complex interactions of fields and networks (e.g. the consciousness from the neurons' network) and the brain's ability of transforming an undefined reality into a world of meaning made of concepts and communicated, with others or with oneself, through the use of symbols, mental or physical, is what amazes me the most.

The first and most accurate analysis of the problem of knowledge formation, generalisation and concept creation can be found in the wide body of Plato's work. Three, I believe, are the main topics that have greatly influenced the western view of the world and that still powerfully resonate in the modern science of knowledge and information, either in the form of psychology, epistemology, neuroscience or machine learning (ML). These three topics are: ἀνάμνησις ('recollection'), or knowledge as recollection; μετέχειν ('participation'), or participation of the many instances to the archetypical, generalised concept [1]; νομίζειν/καθορᾶν ('naming/discerning'), or naming and discerning as the problem of pattern recognition and separation of reality into distinct classes [2] [3].

0.2. ἀνάμνησις, or knowledge as recollection

The concept of ἀνάμνησις, or knowledge as recollection, resonates, for example, in the work of Gerald M. Edelman. With the concept of 'remembered present' [4] Edelman highlights the role of memory as the mean through which the brain modifies his dynamics in order to reproduce a behaviour. In the framework of Neural Darwinism [5], memory represents the ability of a dynamical system, shaped by selection and which shows degeneracy, to repeat or eliminate a mental or physical act. Knowledge as recollection means memory as constructive recategorization, as opposed to memory as punctual representation of past events. This not only falls in place with Hebbian theory of synaptic plasticity [6], but Neural Darwinism in general is strongly influencing the promising field of evolutionary robotics, which is producing both novel approaches and interesting insights into the possible evolutionary causes of biological complexity [7].

0.3. μετέχειν, or participation of the many instances to the archetypical

The concept of μετέχειν, or participation of the many instances to the archetypical, generalised concept, is also a fundamental topic in both neuroscience and ML. In one of the greatest films of all time, '2001: A Space Odyssey' by Stanley Kubrick, in the section named 'The Dawn of Man', we see a perfect rendition of the first spark of human consciousness enlightening a hominid which looking and playing with a bone manages to abstract from from the physical reality of the inert stick and creates and keeps in mind a mental representation of its possible uses in different, imaginary but plausible, realities and finally creates a completely new entity:

a weapon. The anthropological importance of the development in the early hominids mind of the ability to abstract from reality is highlighted in several studies on the evolution of stone tools manufacturing as connected to the evolution of human intelligence [8]. What is interesting, in particular, is the gradual development of the ability of creating a mental image which is composed of different and distinct features of the imaginary mental representation of the stone, which will then guide the manufacturer action to physically transform the uniform stone into a faceted tool or weapon [9]. One of the most prominent theories for explaining consciousness is the Integrated Information Theory (IIT) [10], developed by neuroscientists Giulio Tononi and Christoph Koch, which is a perfect mathematical translation of the concept of μετέχειν through an adaptation of Shannon information theory. IIT represents a powerful attempt to quantify the phenomenon of consciousness by the level of integration of the underlying components (biological or not) from which consciousness emerges. What generates emergent and complex phenomena is the collective participation of elementary and simple components. Using the words of Aristotle's doctrine of 'hylomorphism': is the form (shape) that matters, not the substance (material) [11]. Moreover, a connected fascinating topic in ML is the problem of 'generalisation', or at least one aspect of it. The IIT proposes that, on many levels, elementary blocks participate to the integration of a congruent scene: single neurons, reacting to radically different stimuli (e.g. sound, light, etc.), integrate to form neural maps and these maps then integrate in forming the conscious (unitary) experience [12]. This relates to the still open problem in ML of how single artificial neurons can integrate in generating a meaningful generalisation. What is it that distinguishes neural networks that generalise well from those that don't [13]?

0.4. νομίζειν/καθορᾶν, or naming and discerning as the problem of pattern recognition and separation of reality into distinct classes

A different aspect of the generalisation problem can be connected to the concept of νομίζειν/καθορᾶν, or naming and discerning as the problem of pattern recognition and separation of reality into distinct classes. Reality is composed of elementary, perfectly identical and indistinguishable elements (e.g. electrons). However, us humans perceive a multiform reality composed of many different 'things'. Moreover, different cultures, different languages and even different people perceive, recognise and name (three strictly correlated activities) in very different ways. An example of this is given by the popular example, first introduced by anthropologist Franz Boas [14], of the many names corresponding to different types of snow in the Eskimo languages which then implicates a richer perception of reality, as having more names for types of snow (in comparison to other languages) implies being actually able to perceive more of these types. Even though this example has nowadays become a cliché, it still introduces very clearly the issue of breaking down reality into distinct categories. The ability of the brain to perceive different objects and classes of objects is the consequence of a peculiar collaboration between 'nature and nurture' [15].

As Kant first proposed, our perception of reality emerges as a consequence of both innate, a priori structures, as the perception of space and time, and empirical, a posteriori experience [16]. The perception of space in particular, which represents (together with the principle of locality [17]) one of the most fundamental features of reality, plays a fundamental role in the organisation of conceptual knowledge. The fascinating field of research of 'path integration' and the neural correlates of the 'cognitive map' [18] is opening a series of connections between memory, knowledge and space navigation. In fact a directional six-fold rotational signal, found in a network of entorhinal/subicular, posterior and medial parietal, lateral temporal and medial prefrontal areas using fMRI, was correlated with spatial memory performance, opening the possibility of understanding behaviour at the systems level [19]. The concept of grid cells and the discovery of a gridline code in humans for organising conceptual knowledge can represent a first step in understanding how the brain organises and 'navigates' concepts in a mental map. Moreover this is a further example of how nature and biological evolution readapts, as a tinkerer [20], preexisting structures to create novel features and connecting the understanding of higher order features, e.g. knowledge, to primordial structures, e.g. grid-cell navigation system, can provide a better understanding of the former.

0.5. The brain circuitry as a complex network

Working on the robustness and stability of patterns on complex networks I had the opportunity to understand the role of geometry and topology on emergent behaviour, as confirmed by the effort of the Blue Brain project of connecting brain structures and functions to the underlying geometry and understanding the basic principles at the basis of the neural circuitry [21]. Moreover, I had the occasion of appreciating the power of network theory even at the clinical level, as applying stability analysis is opening the way to seizure control strategies which are significantly less invasive than the traditional surgical techniques, whose current approach consists in resecting the epileptogenic regions [22]. In an amazingly complex network as the brain's neural network, it can be extremely arduous to recognise, extrapolate and interpret significant and possibly function-related patterns of neural activity. For this reason, still burning in my mind remains the question of wether smilingly random networks can be transformed into spatial ones, e.g. one-dimensional rings, whose relevant activity-related properties, e.g. the pattern's wavelength, can be easily recognised [23].

I wonder if in my lifetime I will be able to understand how matter thought itself [24].

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