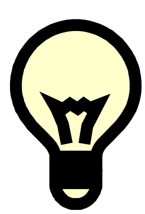
Human Neocortex and Origins of Language

Perhaps the 2 most distinctive features of humans are their possession of a very large neocortex and language. These 2 features seem to be interrelated: language requires extra cortex, but the only way to "program" all that extra cortex is to possess language. This is because the Hebbian mechanism that extracts environmental regularities (possibly supplemented by genetic "learning" over the lifetime of the species) cannot extract "deep" but "weak" regularities (we can learn that apples fall from our own personal experience but only Newton could figure out the underlying law, and even he needed help from friends like Galileo and Kepler). However, if we can learn new ideas not only by observing the (inevitably confusing) world directly, but also by learning from the hard-won insights of others, via language, the neocortex could transcend learning error limits, and expand. Of course this is a chicken and egg situation, like the emergence of the RNA world and later the DNA/protein world. The extra cortex cannot be programmed without language, and language cannot emerge without extra cortex. However, we have seen that in the case of RNA at least a solution to the dilemma is possible : a "chegg" – a spontaneously assembling ribozyme that can catalyse RNA replication.

So even though the mammalian neocortex is a particularly powerful Hebbian learning machine, it is not infinitely powerful. But its power can be further enhanced by acquisition of language. From an abstract point of view, the real issue in human origins is not the exact sequence of obscure neural changes that accompanied and drove hominid evolution, but the nature and extent of the limits to neocortical learning.

Let us consider the origin of language, from an abstract point of view. Monkeys can emit specific sounds that communicate information to others about the nature of events around them : "snake" and "tiger" sounds for example. This capacity is obviously very useful, so why has it developed only in humans? Let us consider a monkey-like "protolanguage". For simplicity we define an individual's protolanguage by the set of sounds she can make together with the set of objects these sounds might describe. Consider the probability $p_{i,j}$ that an individual uses a sound j to represent an object i. A primitive protolanguage could therefore be defined as a matrix ($\mathbf{L}^1$) of $p_{i,j}$ s

LOCK BULB FROG ……



Notice very carefully that the protolanguage does not correspond to FROG – “frog”, LOCK – “lock” and BULB – “bulb”. It does not even correspond to FROG –“bulb”, LOCK – “frog” etc. Instead it corresponds to a person’s tendency to say certain sounds to mean a certain object. The point is that WE know what a language is but the early hominid did not: he was just more likely to utter certain sounds at the sight of a tiger than other sounds, but in a rather capricious way.

For simplicity we will assume that an individual hominid did not learn his protolanguage (how could he? – there is as yet no common language). Instead, we will assume he inherited it, and therefore he has a gene (or set of genes) for his **L**. Now another individual has another protolanguage, $\mathbf{L}^2$ defined by a different matrix of probabilities (possibly for different sounds and objects). If 2 individuals have similar protolanguages, they can communicate. We will assume that successful communication offers a fitness advantage to the individuals that can communicate. Therefore genes that encode the same (or similar) protolanguages will be selected, and eventually the whole population will end up speaking the same protolanguage. This can be followed by watching computer simulations of the evolution of <**L**>, which is L averaged over the whole population. It starts out quite uniform (since initially everyone has a different protolanguage) but converges to a sparse matrix which represents a common or shared protolanguage. The convergence process is basically similar to the way a neural network converges to the first PC of the input distribution. (This shared protolanguage is not necessarily optimal – for example, it may represent 2 different objects using the same sounds (homonymy) or 2 sounds for the same object). Genetically isolated populations would end up speaking different protolanguages – Tower of Babel.

Consider the size m of the matrix of this common protolanguage. We might expect that the larger m the greater the fitness advantage conferred, so that protolanguages would grow indefinitely. However, as speakers use a greater range of sounds the possibility of confusion increases. Did he say “run!” or “come”? It can be shown that if the probability of misinterpretation is e, then the fitness advantage conferred by protolanguage maximizes at a richness $m/[(1+(m-1)e]$, which approaches $1/e$ for large m. This “linguistic error limit” is reminiscent of Eigen’s replication error limit. Indeed it stems from the same phenomenon – large complex objects such as genes, brains and languages can only be as complex as the rule generating them is accurate. In the case of language the basic rule is coupling sounds to objects, events and actions.

This is why monkeys have very small vocabularies and merely protolanguage. It is basically the same reason why the RNA world was not really alive.

What is required to transcend the linguistic error threshold? Martin Nowak has argued this requires adopting “universal” phonological and semantic rules. Phonological rules (including the anatomical specification of the vocal tract) mean that sounds become words. If sounds are not continuous, but sharply subdivided into digital categories, this enormously helps recognition. Likewise the adoption of syntax, by sharply delineating the universe of possible word combinations, also enormously lowers *e* and makes true language possible. It is not yet clear to what extent phonology and grammar are learned or genetically predetermined, though obviously there is an enormous learned component.

In conclusion, from an abstract perspective, language can be viewed as a device for minimizing communications errors, and ultimately as a device to overcome Hebbian limits. In other words, the special adaptations of the human neocortex (Broca's motor speech area, Wernicke's auditory speech area etc etc) are what allows the human neocortex to transcend its own limitations as a merely neocortical learning machine. There is an element of circularity here, but it is the same tautology we noted in connection with Darwinian evolution: life is a device for producing more life! Human understanding is a device for understanding things. We do not yet know what are the limits, if any, to human understanding.

There is an interesting analogy between the emergence of human levels of intelligence via language and the emergence of eukaryotic organisms from prokaryotic organisms via the adoption of sex. Although prokaryotes can exchange genetic material, they do not reproduce sexually, with meiosis, fertilisation etc. In other words they have not developed a protocol that allows essentially arbitrary exchange of information. As a result, prokaryotes are largely obliged to adapt using mutation alone, and not Mendelian genetics. Though in principle mutation alone can find any genetic solution to an environmental "problem", it is in practice limited by several obstacles. First, because the total number of organisms is finite, a "quasispecies" does not contain all possible potential solutions. Second, the Eigen error threshold limits the "spread" of the quasispecies. Third, the environment may have changed before a combination of favorable mutations shows up (by chance) in the population. Sexual reproduction greatly speeds up adaptation, because 2 separately neutral mutations that together are advantageous can come together (by chance) in a progeny genome. As we have seen, language is essentially a protocol for exchanging information between brains. While in principle a single individual brain might eventually be able to discover hidden regularities merely by using correlation-based experience, the language protocol allows combinations of partial solutions to be tested against reality. It is interesting that in both cases adoption of the information-exchange protocol incurs initial heavy overhead. In the case of sex, elaborate machinery for meiosis, fertilization etc must be invented; furthermore, sexual reproduction is half as efficient as asexual reproduction. Evolution of language required elaborate brain development that does not in itself (in the absence of successful communication) provide any individual advantage.

In this course we have studied how magnets, genomes and brains emerge, in an almost miraculous way, from the laws of physics and chemistry. In particular we have seen that DNA-based-life and human levels of intelligence represent dramatic increases in the level of complexity of selforganisation without requiring divine intervention, as a result of elaboration of simpler precursors.