Figure 1 Two proposed courses for evolution of the mammalian neocortex and the forebrain of reptiles, from forebrain structures of a hypothesized stem amniote (from which both evolved). The main question is whether the temporal neocortex and the dorsal ventricular ridge (DVR) evolved from the same primordial structure in early amniotes (as depicted on the right of each panel) or not (depicted on the left). D, diencephalon; DP, dorsal pallidum; IC, internal capsule. (Modified from ref. 7.)

ic connections of the neocortex.

Modern developmental neurobiology is also helping us to work out how the neocortex is subdivided into its various areas. The neocortex varies greatly, not only in size — from a surface area of 1.5 cm² in small-brained shrews to 800 cm² per hemisphere in humans — but also in the number of subdivisions. Small-brained mammals typically have about 15 well-differentiated neocortical areas, whereas monkeys and humans have well over 50. We do not know how such subdivisions are formed, nor how their numbers increased during evolution. One possibility is that cortical areas develop owing to differences in gene expression, which, in turn, depend on position in the brain. For example, the main subdivisions of the forebrain are characterized by differences in the expression of homeobox genes. Such differences in expression can, in fact, be used to identify homologous portions of the forebrain across vertebrates⁴. So, regional differences in the expression of genes may differentiate the neocortex into areas, and gene duplication followed by gene divergence may increase the number of these areas during evolution.

Of course, neurons within the different areas need to form proper connections with other structures, and these connection patterns need to be modified as new cortical areas evolve. Perhaps growing outputs from the cortex interact with growing inputs from the thalamus as they approach each other, and appropriate matches are recognized

chemically. In this way, subsequent growth could be guided to the proper targets⁵ — an idea known as the 'handshake hypothesis'. Connection patterns could be altered by modifying these chemical-recognition signals. Another characteristic of developing nervous systems is that they initially generate patterns of neural activity that then further shape structural development of the nervous system⁶. To the extent that this occurs in the neocortex, this region could develop in structurally different ways depending on the factors that influence neural activity. And genetically mediated changes in the sensitivity of neurons, and the time course of that sensitivity to activity-dependent mechanisms in development, could be among the potent forces that shaped evolution of the neocortex. □

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Daedalus

Play it again, Sam

Last week Daedalus proposed taping a sequence of electrodes on the skin above a nerve trunk (the spinal cord, say). A voltage spike stepped upwards along the array at a specific velocity would, on travelling-wave-tube principles, fire the one fibre in the trunk with that exact transmission velocity. The array could thus address individual fibres, and induce controllable 'virtual sensations'.

He now muses that a voltage spike stepped down the spinal cord at a specific velocity would induce a pulse in the matching downgoing motor nerve. It would drive some muscle somewhere in the body. Detailed experiments would be needed to discover what nerve-fibres with what transmission velocities served which muscles; but then a controlled pattern of downgoing voltage spikes could drive just the right muscles in the correct sequence to induce a specific 'synthetic action'.

The obvious beneficiaries are dedicated joggers and exercisers. Once equipped with electrode arrays taped over the relevant nerves and driven from a portable computer pack, they would need no will-power. They could simply relax and let themselves be jogged along automatically by their own muscles. Assembly-line workers and others engaged on dreary repetitive tasks would also welcome nerve automation. They would find themselves repeatedly 'going through the motions' without thought or effort. Their automatic routines, optimized and pre-recorded, would be repeated with wonderful fidelity. Users could, of course, still exercise judgement, and vary their actions by added conscious intention.

Synthetic action would also be a splendid form of practical training. Skills such as typing or playing the piano could be programmed into an electrode array driving the subject's muscles, and replayed repeatedly. He would learn the 'feel' of the skill, and would soon be able to carry it out by himself.

The only snag is that a downgoing voltage spike, intended to activate a specific muscle, might also induce a downgoing impulse in some sensory nerve whose traffic goes the other way. This would cancel its upcoming signals and induce a selective anaesthesia. Nerve-automated personnel may be plagued with strange repetitive patterns of numbness. On the other hand, surgeons would welcome a tightly targeted local anaesthesia that could be instantly switched on and off.

David Jones