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Reprogramming the cortex

The neocortex of the mammalian brain has been evolving at a tremendous rate. The complex task of trying to make sense of sensory information must have been an important source of the selective pressure behind this evolution. Distinct regions of the mammalian cortex are committed to specific sensory modalities; that is, they are involved in the interpretation of signals from a particular sensory pathway. The primary visual cortex (V1), for example, gets inputs mainly from the visual stream; the primary auditory cortex (A1) from the auditory stream etc. In short, the brain 'sees' with the help of the visual cortex, 'hears' with the help of the auditory cortex, and so on. Sensory data is collated by the thalamus, a system that lies towards the middle of the brain. The thalamus acts as a relay centre. It gathers sensory information from different sensory modalities at different ports (termed nuclei) and the nuclei redirect the information to the appropriate parts of the cortex. For example, the lateral geniculate nucleus (LGN) in the thalamus gets data from the retina and projects onto V1 (figure 1).

The cortex itself is organized in a way that reflects the organization of the sensory stimulus in the world outside. If one were to look at the response of cells in V1, for example, one would find a "map" of the visual space: neighbouring cells would be responsive to neighbouring areas in the visual field. Similarly the auditory cortex has a tonotopic organization (the neurons respond to different optimal frequencies) while the somatosensory cortex contains a map of the entire body surface.

Cells in V1, one of the best studied cortical areas, have further been shown to respond best to oriented bars of light in their portion of the visual space. Different cells respond best to bars of different (preferred) orientations. If one looks at the orientation selectivity of cells in a piece of V1 tissue in a plane horizontal to its surface, one sees beautifully ordered orientation 'maps' in which the preferred orientation changes in a semi-discontinuous manner.

How do the various cortical areas come by the maps that they contain? Clearly each map reflects some property of the signal sensed via that particular sensory modality. Is the pattern exhibited by a map genetically determined – hard-wired, so to speak –, or does it arise as a consequence of some facet of the patterning inherent in a specific sensory input? The group of Mriganka Sur and his colleagues at the Massachusetts Institute of Technology in the US has been developing a technique that allows them to address this question in a remarkably direct way by rewiring the brains of ferrets (Angelucci *et al* 1998; Sharma *et al* 2000; Merzenich 2000). By certain manipulations in ferret kits, they are able to route the retinal projections (via the LGN) to the auditory cortex (A1); while normal auditory inputs to this A1 are removed. Previously they had shown that the rewired A1 had a map of visual space (Roe *et al* 1990) and that the cells in it had other properties typical of cells in a normal V1.

In a recent paper, they have extended these observations and shown that the rewired A1 is similar to the normal V1 in a deeper way (Sharma *et al* 2000). They show the existence of the orientation maps (described above) in the rewired A1, complete with the so-called 'pinwheels' (the specific arrangements of the orientation columns in the normal V1). Besides, they also demonstrate the existence of horizontal connections that connect cells in neighbouring orientation columns. These horizontal connections are virtually never seen in this anatomical area of the normal brain. The orientation maps as well as the horizontal connections are of a higher order of complexity than the simple map of visual space, and these results show that even such higher order features can be driven by the sensory inputs.

Is the animal capable of making use of the redirected sensory inputs? In other words, does it realize that the information impinging on what ought to have been its auditory cortex is in fact visual in nature? von Melchner *et al* (2000) tested this by training rewired ferrets on behavioural tasks that involved the use of both the auditory and the visual modalities (Merzenich 2000). They found that the redirected inputs to the auditory cortex were correctly interpreted by the ferrets as being visual in nature.

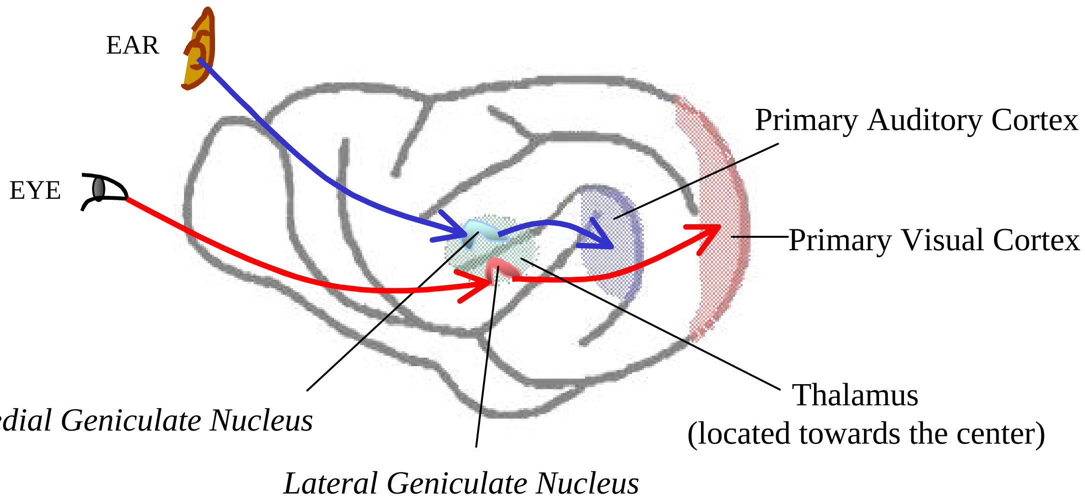

Figure 1. A sketch of a ferret brain showing relevant neuronal connections in the auditory and visual pathways. Nerve fibers from the ear carry auditory information to the *medial geniculate nucleus* (MGN) in the thalamus. The MGN projects to the primary auditory cortex (A1). Projections from the eye carry visual information to the *lateral geniculate nucleus* (LGN) in the thalamus. The LGN in turn projects to the primary visual cortex (V1).

These experiments demonstrate the role of the incoming inputs, guided by the thalamus, to programme the cortex. Besides, they point to some underlying similarities in different sub-areas of the cortex with respect to their computational capabilities. After all, if the so-called auditory cortical tissue can process visual information, it could mean that the different cortical areas are carrying out similar kinds of computations; and in that sense are not inherently very different. However, this is not strictly true. The orientation map in the rewired A1, though it shares several features of the normal V1, also has differences, which appear to derive from some inherent feature of the anatomical area that would have been the normal A1. Thus, a complete understanding of cortical development would need to balance the roles of both the extrinsic as well as the intrinsic cues in the cortex.

A further implication seems to be that it is the thalamus that plays the crucial role in assigning different roles to different areas of the sensory cortex. Metaphorically speaking, one might say that the thalamus is a smart input/output port that treats the cortex as a programmable chip. And, during the course of development, it makes use of various (differently structured) sensory inputs to ‘write in’ the appropriate algorithms that aid the brain as a whole in interpreting the precise information contained in the inputs.

References

Angelucci A, Clasca F and Sur M 1998 Brainstem inputs to the ferret medial geniculate nucleus and the effect of early deafferentation on novel retinal projections to the auditory thalamus; *J. Comp. Neurol.* **400** 417–439

Merzenich M 2000 Seeing in the sound zone; *Nature* (*London*) **404** 820–821

Roe A W, Pallas S L, Hahm J O and Sur M 1990 A map of visual space induced in primary auditory cortex; *Science* **250** 818–820

Sharma J, Angelucci A and Sur M 2000 Induction of Visual Orientation Modules in Auditory Cortex; *Nature* (*London*) **404** 841–847

von Melchner L, Pallas S L and Sur M 2000 Visual Behaviour Mediated by Retinal Projections Directed to the Auditory Pathway; *Nature* (*London*) **404** 871–876

MOHINISH SHUKLA
Cognitive Neuroscience Sector,
International School for Advanced Studies (SISSA),
Via Beirut 9,
34014 Trieste, Italy
(Email, shukla@sissa.it)