EC 490

Lecture 3: The brain: basic information processing

1. Do computers help us understand biological information processing? Yes, in one crucial way. The theory and practice of designing computing machines shows us how complex functions can be implemented from the interactions of many simple binary switches. Why is this so important? Intelligent behavior is highly complex. We could not claim we were even beginning to understand if we could find no level at which the complexity were *discharged*. The simple essence of brain signaling is the existence of networked units that can tell one another whether they are off or on, and in which this news influences the probabilities with which the units receiving the information will be off or on.

2. Nothing else about the brain's information processing is simple. It is typical of systems built by evolution. Since evolution has no foresight, it can't design *elegant* systems, in which each part or aspect efficient contributes one function and the functions are parceled out logically. Internal communication in the brain uses five different channels:

    a. Individual neurons communicate point to point across *synapses*. A synapse is a sophisticated machine that receives chemical information on the pre-synaptic side, and transmits this across a boundary (a *cleft*). When it receives just the kind of chemical signal to which it is adapted – either by gene action or by learning – its post-synaptic machinery converts this into an electrical signal that pulses down the post-synaptic neuron. There are more than 100 trillion synapses in the human brain. That is on a similar order of magnitude as the number of stars in the universe. The chemical bearers of the basic signals are called *neurotrasmitters*. Different functional pathways (‘circuits’) rely mainly on different neurotransmitters. There are ten neurotransmitters we understand: Acetylcholine (ACh), norepinephrine (NE), dopamine (DA), serotonin (5-HT), melatonin, histamine, glutamate, gamma aminobutyric acid (GABA), aspartate, glycine, Adenosine, ATP and GTP.

b. Neurons broadcast messages through whole areas of the brain by releasing messenger molecules (such as nitrous oxide). These signals change the firing dispositions of whole groups of neurons.

c. Hormones in the blood carry information about the state of the body. Release of new hormones from glands in the brain alters global states of the organism, which potentially feeds back on all aspects of nervous communication.

d. Glial cells – as many as 100 per neuron – are sensitive to the chemical states of neurons. On this basis they appear to provide a range of information-processing support services. Certainly they do repair work. But it also seems that they may be involved in *routing* information from one brain area to another. They may even implement a parallel information-spreading network of their own. In general, their role is still poorly understood. I predict we’ll be hearing a lot about them over the next decade or so, as the full extent of their functionality is slowly revealed.

e. Brains pass *internal* information by way of the *external* environment. One part of the brain can change the state of other parts of the brain by causing images to be placed before the eyes, objects to be put in the mouth, and by changing the body's geography or orientation. In humans, and probably some others, the brain can loop internal communications through the auditory system by talking to itself using culturally evolved public language (e.g. English). Imagine you see an indistinct figure coming towards you. Contrast two possible states: (a) there is something familiar about that figure; his gestures are friendly, not menacing; he is approaching me with a relaxed gait; (b) saying to myself: "That's Mbanga!". In (a) various parts of the brain have probably recognized Mbanga *implicitly*. But these states are not the same, and have different consequences.

3. When thinking about the brain, it is useful to remember the following fact: there is far more information being processed in your hundred billion neurons at a given time than is being processed on the entire Internet at that same time. Now ask yourself: could any physically possible system reactively monitor everything now flowing through the Internet? Clearly not. This shows that the idea that a person could possibly be conscious of anything but a miniscule fraction of what is going on in their brains is *ludicrous*.

4. Because the brain needs lots of connections, but is space constrained, the cables that link neurons and carry the electrical pulses – *axons* – must be miniature. This requires extra apparatus, myelin sheathing, to boost speed. In addition, the physical substrate of the brain, salty water, is a poor medium for electrical conductivity. Thus axonal systems need relay boosters, just like undersea telephone cables. The brain in fact uses a double-battery system, combining a +50 megavolt sodium battery and a -70 mv potassium battery. Sodium and potassium ions are transferred

across the gates of these batteries, amplifying small initial changes in synaptic excitation into nerve pulses that carry all the way down axons.

5. Putting all of this together, what are the main determinants of ‘what gets said’ within the brain as external and internal states change? We may list them (knowing that our list is incomplete, perhaps hilariously so):
    a. the brain’s ‘wiring diagram’ – which neurons synapse on which others?;
    b. levels of neurotransmitter availability / scarcity within specific circuits;
    c. the distribution and balance of hormones in the bloodstream;
    d. the state of the supporting infrastructure: myelin, ion channels, blood vessels etc..
    e. properties of glial cells and networks - ??
    f. information about the external environment being delivered by perceptual systems;
    g. the organism’s capacity for culturally mediated self-stimulation.

6. Various kinds of *neuroimaging* are used to study the working brain. The types are Positron Emission Tomography (PET), Transcranial Magnetic Stimulation (TMS), electroencephalography (EEG), magnetoencephalography (MEG), and functional Magnetic Resonance Imaging (fMRI). Of these, the most important for neuroeconomics has been fMRI. See O’Shea’s description on pp. 24-27, and follow this up with a Google investigation. fMRI relies on generation of a strong magnetic field around a subject’s head. This enables bloodflow around and within the brain to be estimated. Working neurons require extra blood hemoglobin, so bloodflow in the brain is a lagged indicator of areas of neural activation. *Note that this is a highly indirect form of*

observation. It relies on statistical inferences across all of the following relationships: (i) from magnetic signals to bloodflow (highly reliable); (ii) from bloodflow patterns to neural activation patterns (much less reliable); (iii) from neural activation patterns to associations between behavioral / cognitive tasks and activity of particular groups of neurons (very tricky and statistically adventurous). When you look at fMRI ‘images’ (e.g., the photographs in Zweig’s book) you should remember that these are *not* pictures of ‘lit up’ brain activity. They’re diagrams of statistical properties: brighter regions indicate higher confidence in rejecting the null hypothesis that no neurons in the area in question were more active than their baseline level across the full set of observations.

7. In non-human animals and surgical patients, much more invasive – and much more reliable – single cell recording can be used to test fMRI data, and to generate hypotheses for design of fMRI probes. We would still know very little about the brain without the conscripted help of monkeys, rats, cats and squid.