The Hippocampus and the Olfactory System (Lecture 12)

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Roadmap

- Introduction to the hippocampus and olfactory systems
- Walter Freeman (Jr.) and Christine Skarda on chaos in the olfactory system
- HM, the hippocampus, and long-term memory
- My work on chaos in the olfactory system
- Large scale modelling of the central nervous system.

Resources

- The Book of Genesis, chapter 9
- Shepherd, GM, ed., 2004, *The Synaptic Organization of the Brain,* 5th edition, Oxford
  - Chapter 10, Neville and Haberly, "Olfactory Cortex," 415-454
  - Chapter 11, Johnston and Amaral, "Hippocampus," 455-498

Introduction

- These two 3-layered systems differ from the 6-layered *neocortex*, which is found in mammals. The *olfactory cortex* is also termed the *paleocortex*, while the *hippocampal formation* is also termed the *archicortex*.
- Their architectures are very similar
- The olfactory cortex handles the sense of smell and is important to emotions and sexual behaviour. It has no blood-brain barrier, so odorants can easily produce brain damage.
- The hippocampus plays a role in learning and long-term memory. It also contains *place cells,* so it is one place where a map of the environment may be maintained.

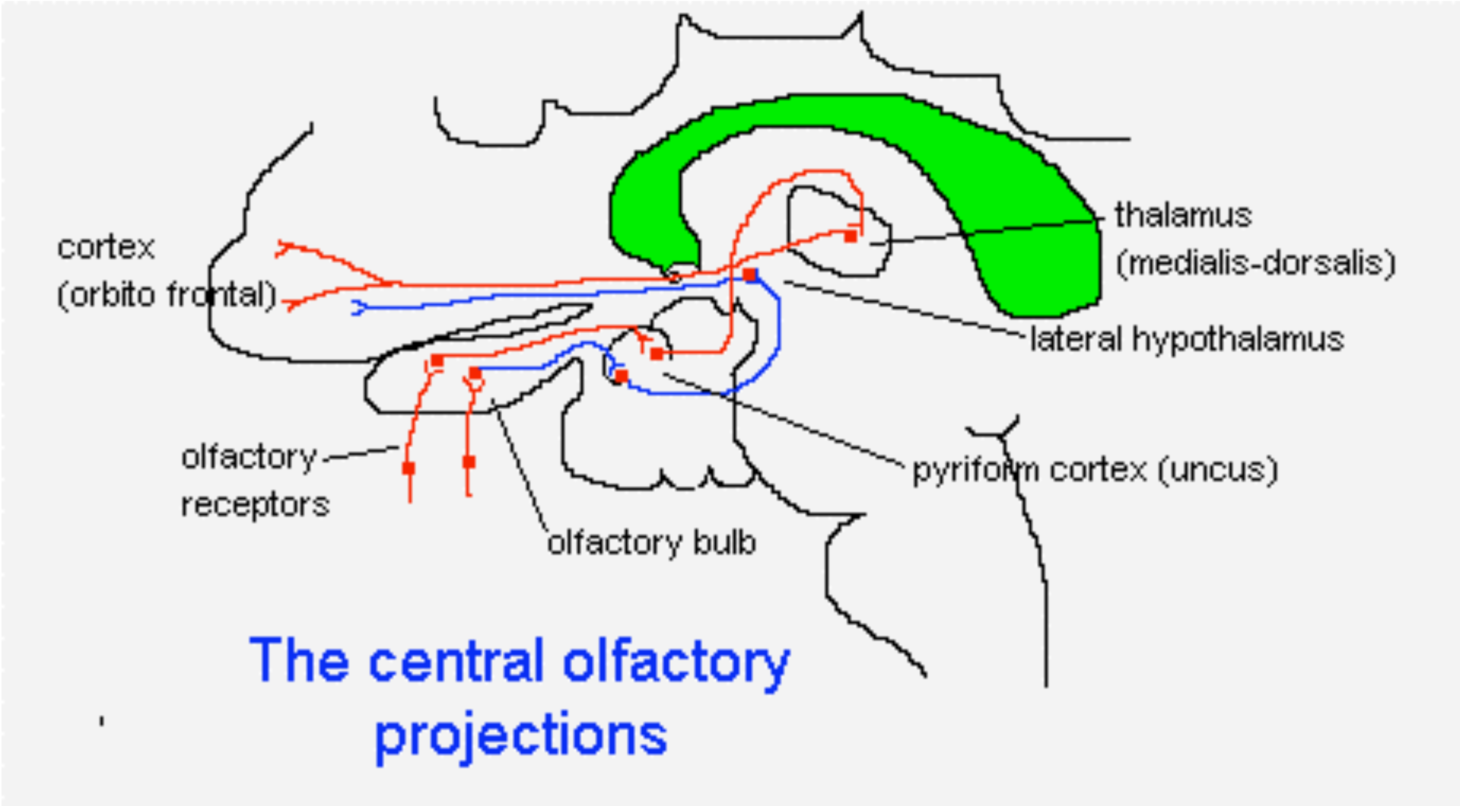
Olfactory Cortex

- Those areas receiving direct synaptic input from the olfactory bulb.
- The largest area is the *piriform cortex*.
- Two other areas are the *entorhinal cortex,* (which happens to provide input to the hippocampus) and the *agranular insula*. These areas provide input to the *amygdala*.

Hippocampus

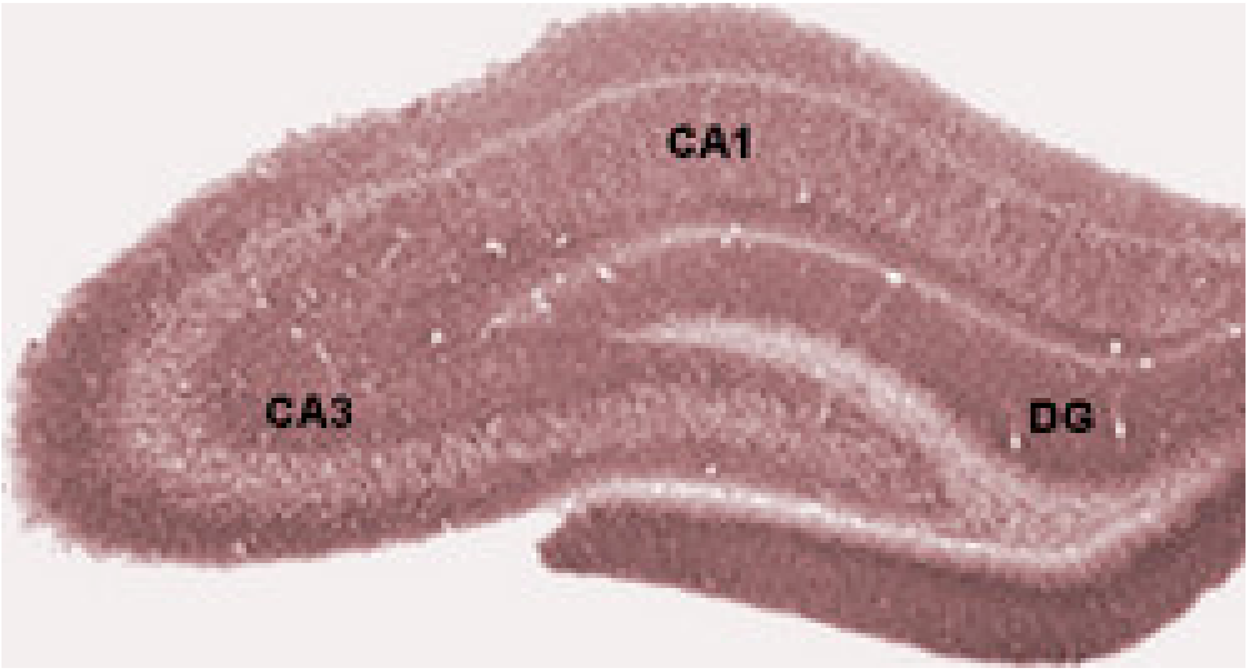
- Part of the limbic system within the *hippocampal formation*.
- Associated with the dentate gyrus, subiculum, and entorhinal cortex.
- Easily studied.
- Plays a role in learning and memory
- Very susceptible to epileptic seizures.
- Plays a role in Alzheimer's disease.
- Very susceptible to ischemia (stroke) and anoxia.

Olfactory Cortex Anatomy



http://www.cf.ac.uk/biosi/staff/jacob/teaching/sensory/olfact1.html

Hippocampus Anatomy



http://en.wikipedia.org/wiki/Image:HippocampalRegions.jpg

Olfactory Connectivity

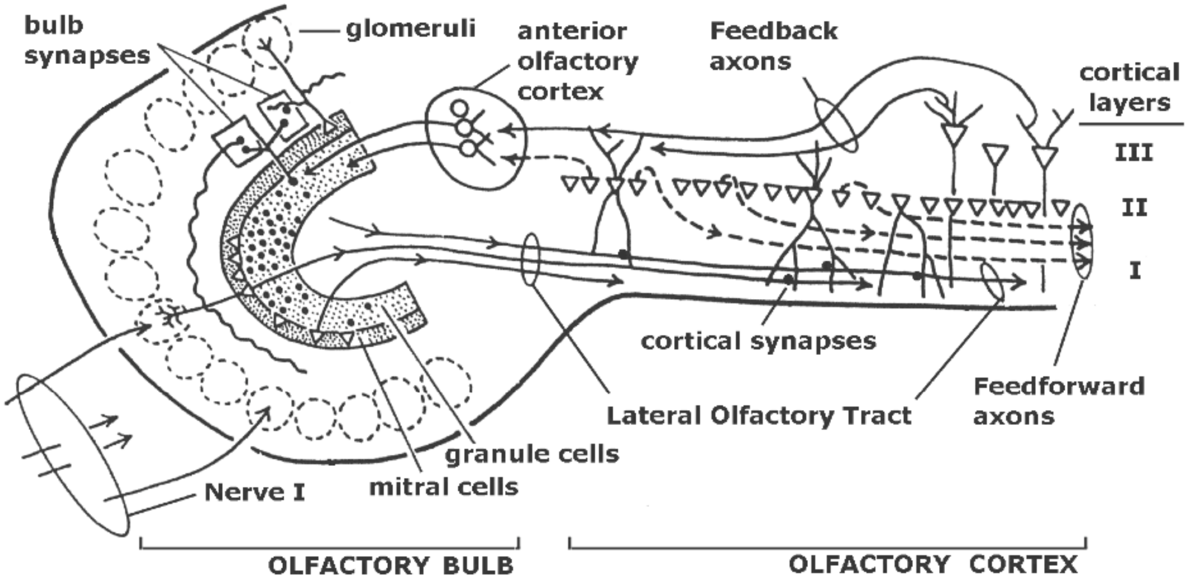
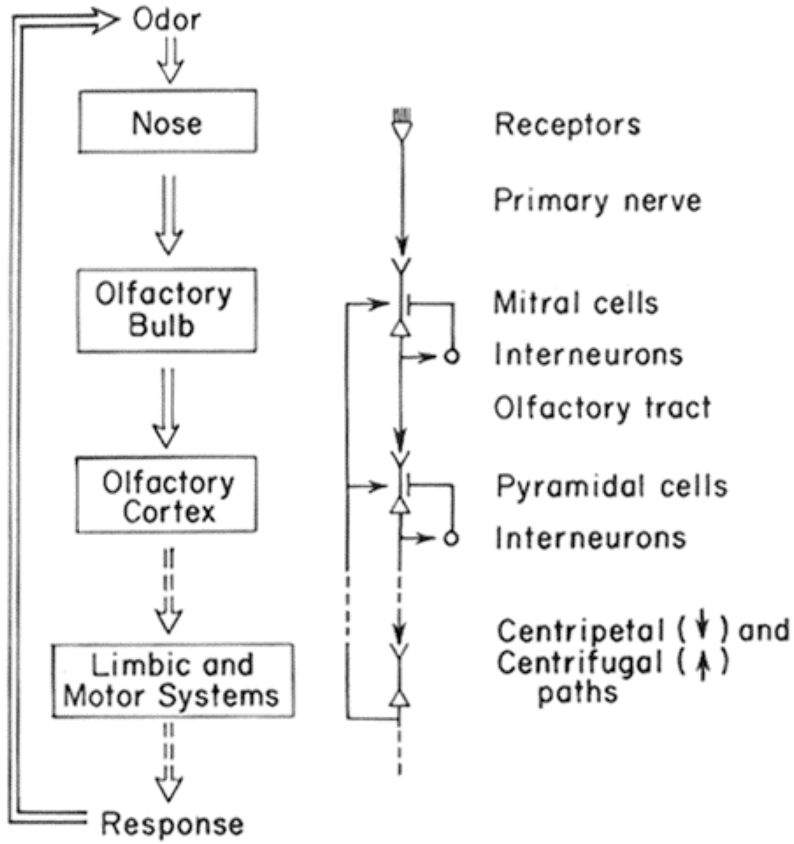


Figure 2. Schematic diagram of mammalian olfactory system anatomy. Input from receptor cells in the nose arrive via the axons comprising the first cranial nerve, making synaptic contact with the dendrites of mitral cells in the olfactory bulb. Mitral cell axons in turn make synaptic contact with the apical dendrites (projecting downward, towards the cortical surface) of primary cells in the olfactory cortex. Cortical cell axons project forward to become input to successive anatomical structures (entorhinal cortex, hippocampus) as well as projecting backwards to become feedback input to the inhibitory cells of the olfactory bulb.

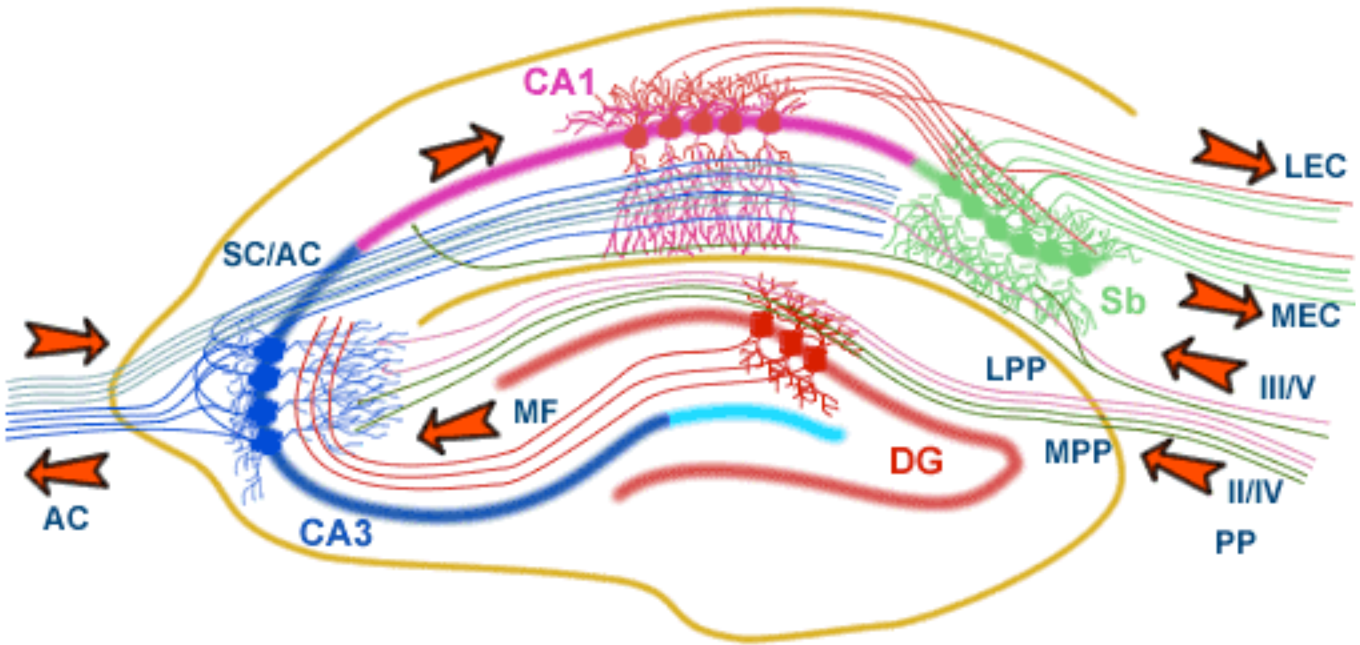
Granger, 2002, "Olfactory Cortex as a model for telencephalic processing," *Learning and Memory*

Olfactory System Schematic



http://sulcus.berkeley.edu/FreemanWWW/manuscripts/IC3/83.html

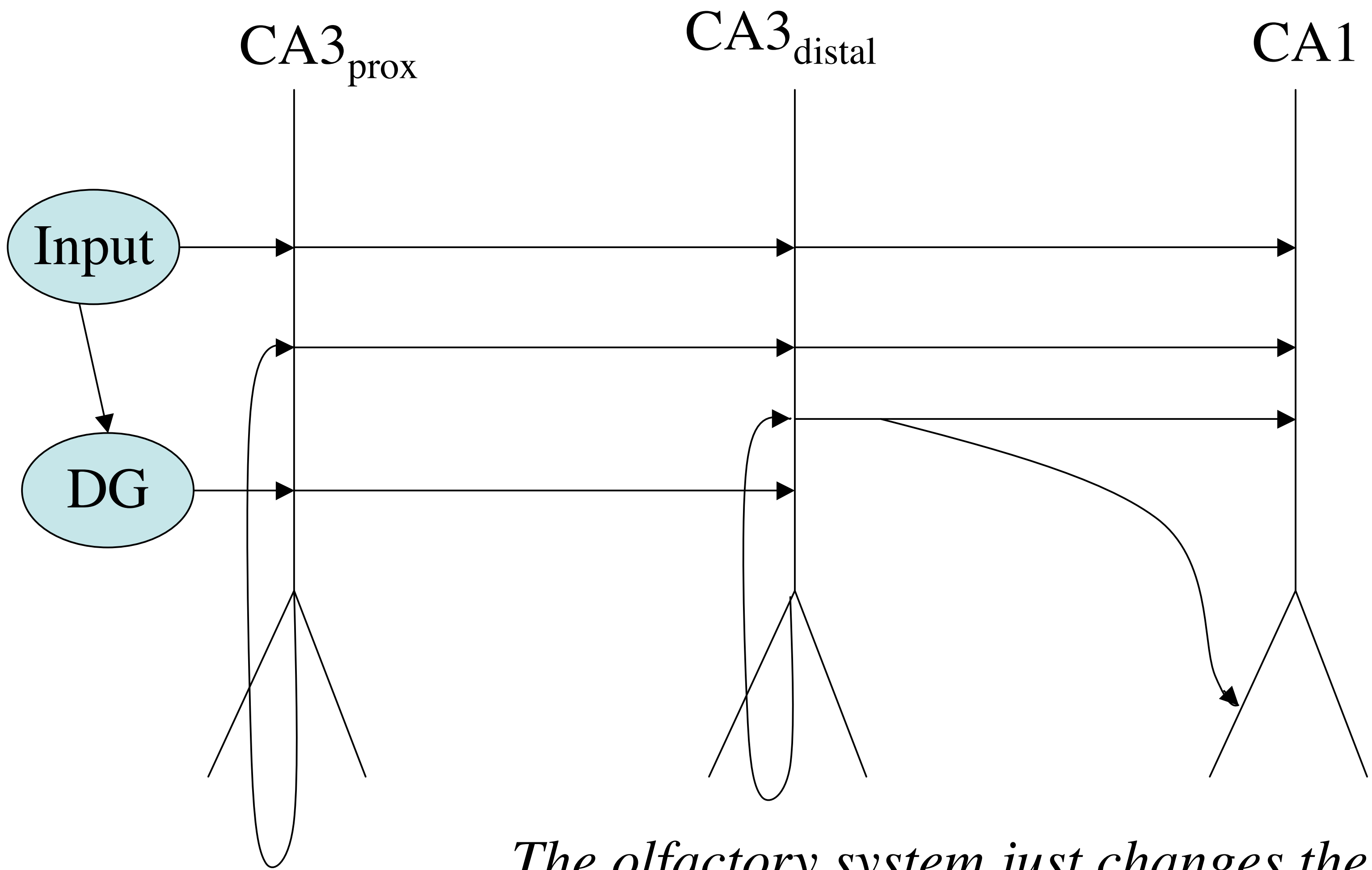
Hippocampal Connectivity



The Hippocampal Network: The hippocampus forms a principally uni-directional network, with input from the Entorhinal Cortex (EC) that forms connections with the Dentate Gyrus (DG) and CA3 pyramidal neurons via the Perforant Path (PP - split into lateral and medial). CA3 neurons also receive input from the DG via the mossy fibres (MF). They send axons to CA1 pyramidal cells via the Schaffer Collateral Pathway (SC), as well as to CA1 cells in the contralateral hippocampus via the Associational Commissural pathway (AC). CA1 neurons also receive input directly from the Perforant Path and send axons to the Subiculum (Sb). These neuron in turn send the main hippocampal output back to the EC, forming a loop.

http://www.bris.ac.uk/synaptic/info/pathway/hippocampal.htm

Similarity of the OC and HC



The olfactory system just changes the names.

Chaos in the Olfactory System

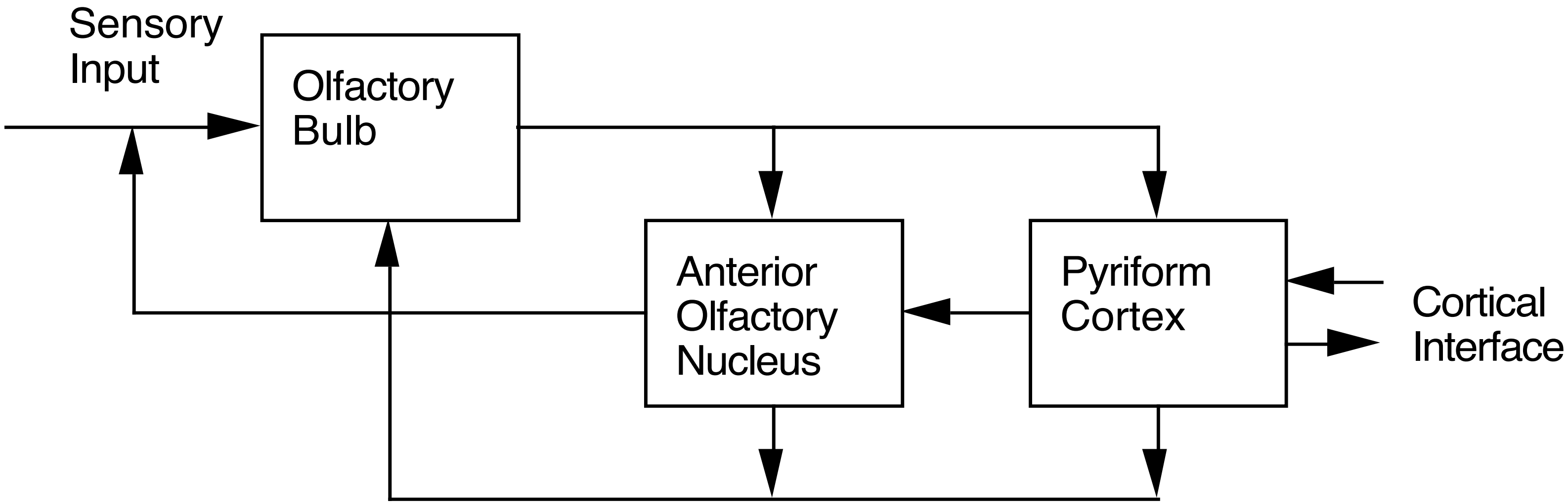
- First proposed by Christine Skarda and Walter Freeman in 1987
- See http://sulcus.berkeley.edu/FLM/MS/WJF_man2.html
- Role of these dynamics is not clearly understood.
- Changes in the *dimensionality* of the dynamics are associated with orientation to novel stimuli.
- It does hint that consciousness cannot be digitised, as any discrete model will converge to a limit cycle.

The Story of HM

My Research Interest

- Erwin, 1995, “The Application of Katchalsky Network Models to Radar Pattern Classification,” in *Origins: Brain and Self-Organization,* K. Pribram, ed., INNS Press and Lawrence Erlbaum Associates, Inc., 1994.
- Chaotic dynamics in neural networks were first predicted in 1983 by Bernardo Huberman (*Physical Review* A28, 1204).
- More recently, Walter Freeman identified chaotic processing dynamics in the olfactory bulb of rabbits (see his 1991 paper in *Scientific American*).
- Those results are intriguing since a chaotic process can be efficient at exploring a search space and can converge exponentially fast to a terminal state once a pattern is identified.

The Architecture Modelled



- The three components with their feedback loops produce an architecture that can evolve chaotically in the absence of expectation.
- If there are alternative cortical expectations, this architecture can choose among them exponentially fast.
- If the sensory input fails to match *any* expectation, this architecture continues to hunt chaotically.

Olfactory Bulb Function

- The OB appears to function as a content addressable memory (CoAM) array, with groups of mitral/tufted cells competing to respond to the patterns of sensory data input.
- The fundamental dynamics of the OB are nonlinear and periodic, with the mitral/tufted cells outputting to pyramidal cells in the AON and PC.
- The OB output to the AON appears to preserve neighborhoods, while the output to the PC is thoroughly mixed (spatially integrated).
- The AON and PC are structured similarly to the OB, with densely interconnected networks of excitatory and inhibitory cells interacting nonlinearly to produce periodic outputs.
- The AON feeds back to the glomeruli and inhibitory granule cells in the OB, and forward to the PC.
- The deepest layer of the PC is the primary interface to the rest of the brain.

The OB and Semantics

- Freeman has found that the activation patterns in the nucleus of the olfactory bulb are not invariant functions of the sensory stimuli, but instead appear to reflect the *meaning* of the stimuli.
- There is also a similar lack of invariance in the storage of mental images of past experience, with changes in stimulus or expectation changing the spatial pattern of activation.
- This suggests (in engineering terms) that the cortex loads the olfactory system (in real time) with a meaningful (semantic) representation of the environment, which is then the basis for reports back to the cortex classifying external events.
- This biological system provides a conceptual design for an intelligent system for stimulus identification and classification based on limited sensor data.

Heterogeneous Pattern Classifiers

- Although automatic pattern-classification algorithms have been effective in a number of well-defined applications, the heterogeneous pattern-classification problem remains extremely difficult.
- Pattern-classification using a chaotic process is a possible solution to this problem.
- There are a number of reasons for this, including:
  - Exponential speed of search.
  - Better search coverage.
  - Optimal search in a complex landscape.

Modelling Large Systems

- Chapter 9 provides a tutorial on modelling large systems.
- You might also investigate whether it generates chaotic dynamics. My research used coupled oscillators rather than neural models, but it did generate chaos.

Potential Projects

- I will be happy to work with you if you do a GENESIS-based MSc project. It need not be in neuroscience, although I would like it to be inspired by neuroscience in some way.

Take Home Exam