# Neural Information Processing: Introduction

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# Course Introduction

- Welcome and administration
- Course outline and context
- A short neuroscience summary

# Administration

- All course materials will be posted on Learn.
- A Piazza forum will be used, access this via Learn.
- Complete (not assessed) homework before classes.
- Assessment is an exam (75%) and coursework (25%)
- Assignments:
  - Assignment 1: 26 February 2019, 4pm
  - Assignment 2: 5 April 2019, 4pm
  - A1 will be an exercise, A2 will be on class papers.

# Notes

- You need a good grounding in maths, specifically in
  - probability and statistics
  - vectors and matrices
- You do not need any background in neurobiology.
- I will work on the board/doc cam occasionally, make sure to take notes.
- Interrupt and ask questions in class if something is unclear, or you feel more explanation is useful.
- Treat everything shown as 'examinable', except where explicitly said otherwise.
- Any questions/issues - please email m.hennig@ed.ac.uk.

# Course aims

This course will explore

- how the brain computes,
- how neuroscience can inspire technology,
- how computer science can help address questions in neuroscience.

# Relationships to other courses

NC
: Wider introduction, more biological, but less abstract than NIP

CCN
: Cognition and coding, high level understanding (Peggy Series)

PMR
: Pure ML perspective (Michael Gutmann)

# Reading materials

Course topics:

- Theoretical Neuroscience by Peter Dayan and Larry Abbott (MIT Press 2001)
- Natural Image Statistics by Aapo Hyvarinen, Jarmo Hurri, and Patrik O. Hoyer (http:/)/naturalimagestatistics.net/
- Information Theory, Inference and Learning Algorithms by David MacKay (http://www.inference.phy.cam.ac.uk/itila/book.html)

More in depth:

- Neuronal Dynamics by Wulfram Gerstner, Werner M. Kistler, Richard Naud and Liam Paninski (http://neuronaldynamics.epfl.ch/)
- Introduction to the Theory of Neural Computation, by John Hertz et al.
- Literature cited on the lecture slides

# Course outline

1. Computational methods to get better insight in neural coding and computation:
   - Neural code is complex: distributed and high dimensional
   - Data collection is improving
2. Biologically inspired algorithms and hardware.

Topics covered:

- Neural coding: encoding and decoding
- Information theory
- Statistical models: modelling neural activity and neuro-inspired machine learning
- Unconventional computing: dynamics and attractors

# Linsker (1988)

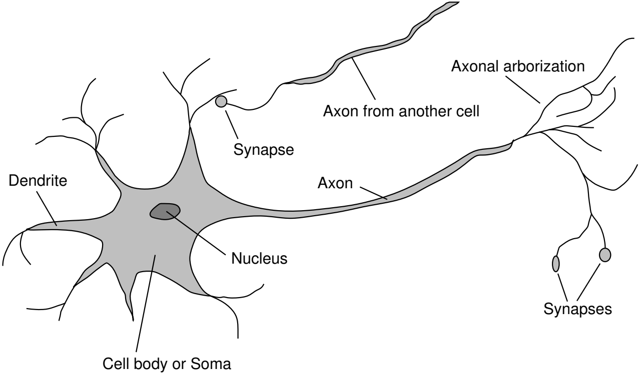
R. Linsker, IEEE Computer Magazine, March 1988

Might there be organizing principles

1. that explain some essential aspects of how a perceptual system develops and functions,
2. that we can attempt to infer without waiting for far more detailed experimental information,
3. that can lead to profitable experimental programs, testable predictions, and applications to synthetic perception as well as to neuroscientific understanding.

# Neurons

The fundamental unit of all nervous system tissue is the *neuron*




[Figure: Russell and Norvig, 1995]

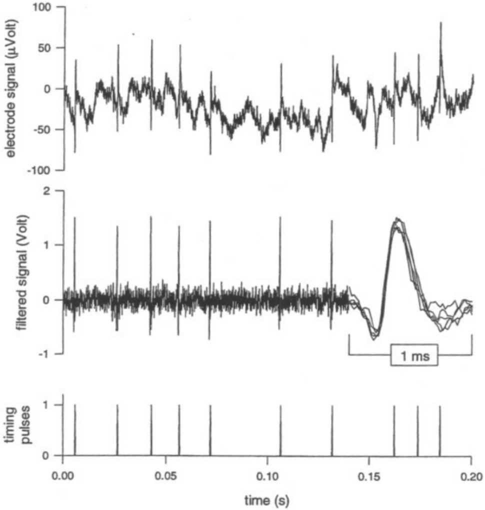
# Neurons

A neuron consists of

- a **soma**, the cell body, which contains the cell nucleus
- **dendrites**: input fibres which branch out from the cell body
- an **axon**: a single long (output) fibre which branches out over a distance that can be up to 1m long
- **synapse**: a connecting junction between the axon and other cells

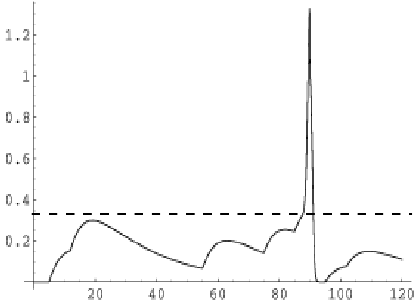
# Action potentials (Spikes)

Information is transmitted between neurons by all-or-none events.



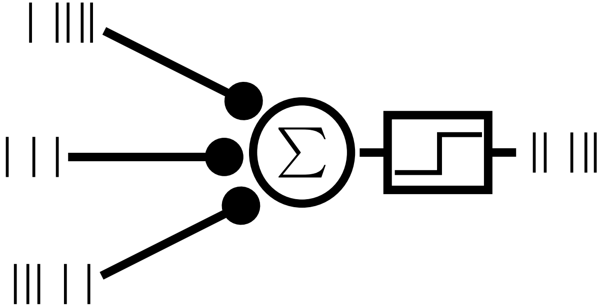

Spikes are easily seen in extracellular recordings.

Spikes are generated when the intracellular membrane potential passes a threshold.



# Synapses

Simplified neuron as summation and threshold device.



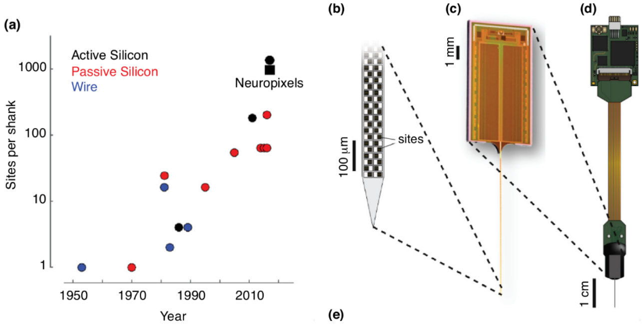
Synapses can be **inhibitory** (lower the post-synaptic potential) or **excitatory** (raise the post-synaptic potential).

- Each neuron can form synapses with anywhere between 10 and $10^5$ other neurons
- Signals are propagated at the synapse through the release of chemical transmitters which raise or lower the electrical potential of the cell
- When the potential reaches a **threshold value**, an **action potential** is sent down the axon
- This eventually reaches the synapses and they release transmitters that affect subsequent neurons
- Synapses can also exhibit long term changes of strength (plasticity) in response to the pattern of stimulation (the basis of learning and memory)

# Assumptions

- Spikes are assumed to be the fundamental information carrier
- We will ignore non-linear interactions between inputs
- Spikes can be modelled as rate-modulated random processes
- We will ignore biophysical details

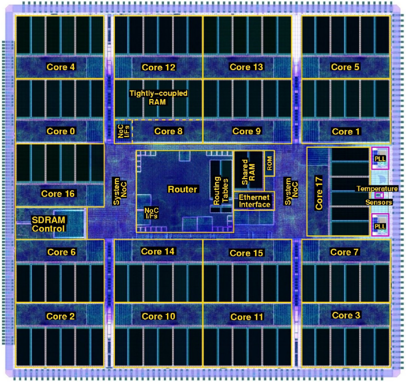
# Recent developments: Neurobiology technique




[Steinmetz et al., 2018]

- Recordings from many neurons at once (Moore's law)

# Recent developments: Computing Hardware




[Furber et al., 2014]

- Single CPU speed limit reached
- Novel brain-inspired parallel hardware and algorithms: slow, noisy, energy-efficient
- SpiNNaker engine: massively-parallel asynchronous 1,036,800 ARM9 system

# Recent developments: Machine Learning

Figure 3. Top: Top 48 stimuli of the best neuron from the test set. Bottom: The optimal stimulus according to numerical constraint optimization.

[Le et al., 2012]

- Neural network algorithms, developed 30 years ago, were considered superseeded.
- But now, using GPUs and big data, they are top performers in vision, audition and natural language.

# References I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*Proc IEEE*, 102(5):652–665.

Le, Q. V., Ranzato, M., Monga, R., Devin, M., Chen, K., Corrado, G. S., Dean, J., and Ng, A. Y. (2012).
Building high-level features using large scale unsupervised learning.
In *ICM*.
ICML 2012: 29th International Conference on Machine Learning, Edinburgh, Scotland, June, 2012.

Steinmetz, N. A., Koch, C., Harris, K. D., and Carandini, M. (2018).
Challenges and opportunities for large-scale electrophysiology with neuropixels probes.
*Current opinion in neurobiology*, 50:92–100.