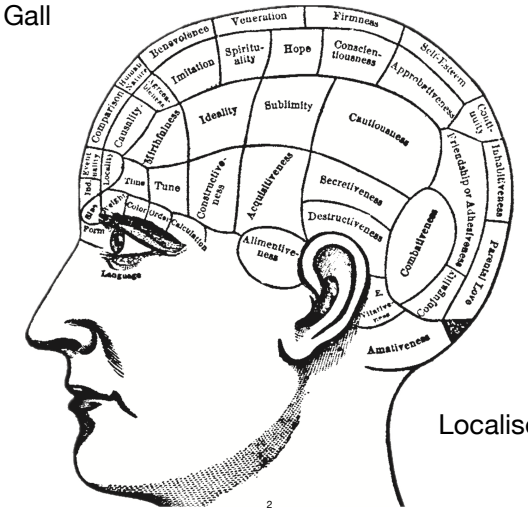
Three month in neuroscience

An personal account

Ludwig Hruza, Les Gustins, 22 July 2024

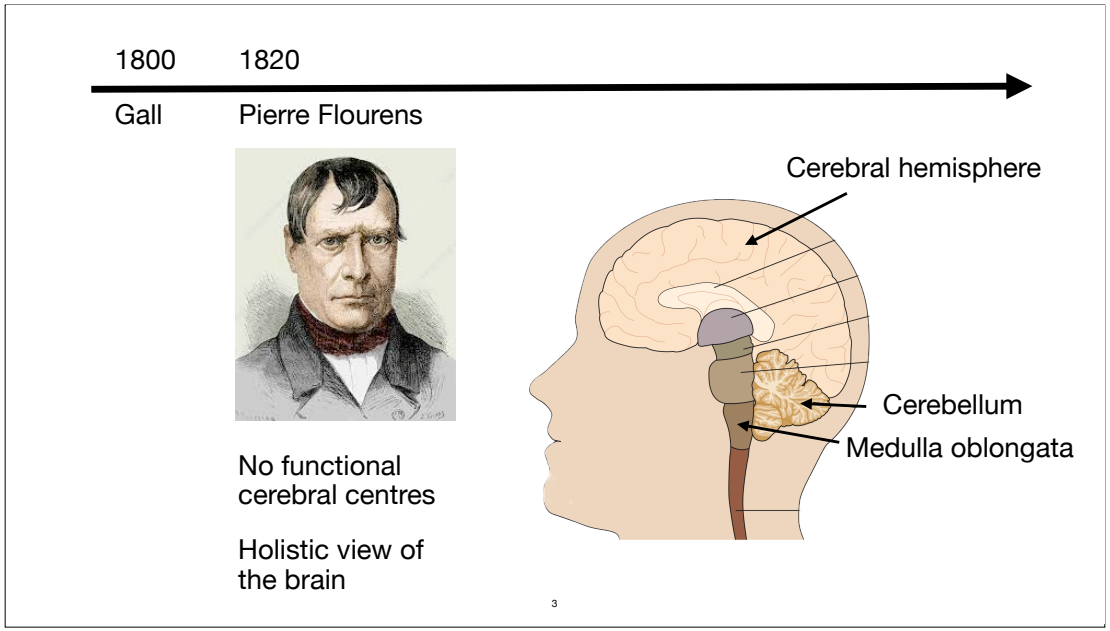
1800

Franz Joseph Gall

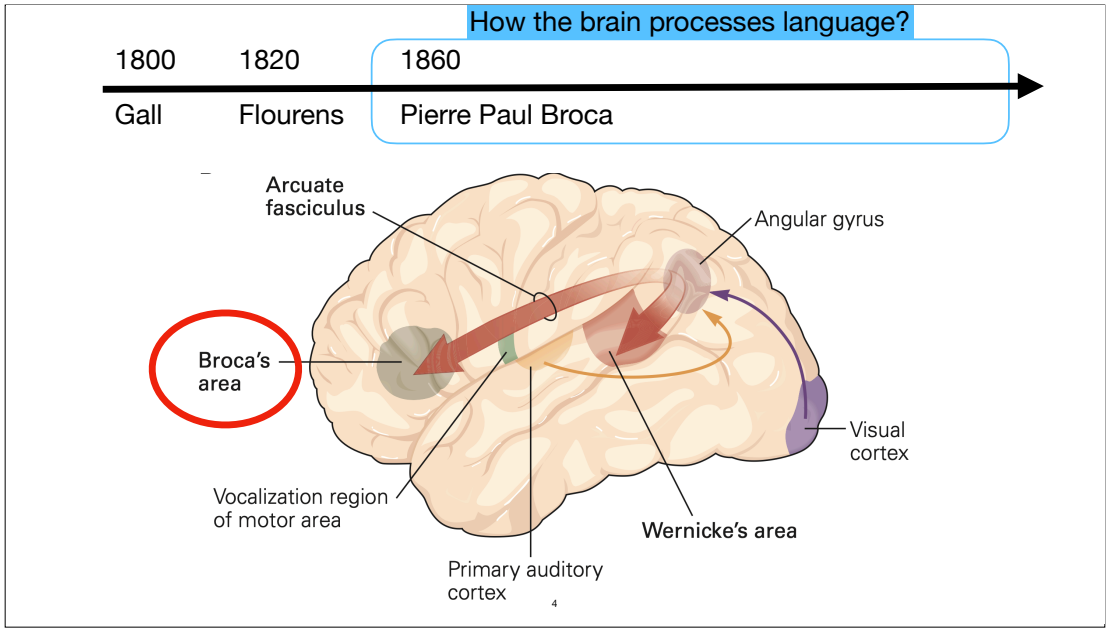


Localised brain functions

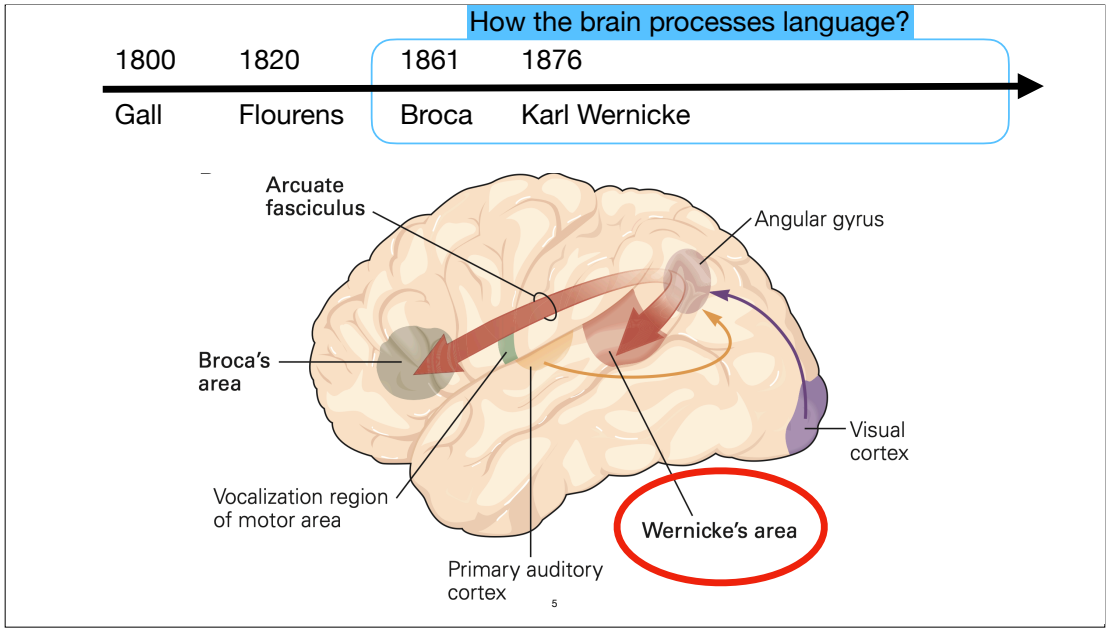
- Gall identifies 27 functionally distinct regions or “organs” of the cerebral cortex based on bumps and ridges on the skulls of people.
- Each region grows with use, such that shape of the head gives evidence about how developed each region is.
- Rejects the idea that mind and body are separate entities.



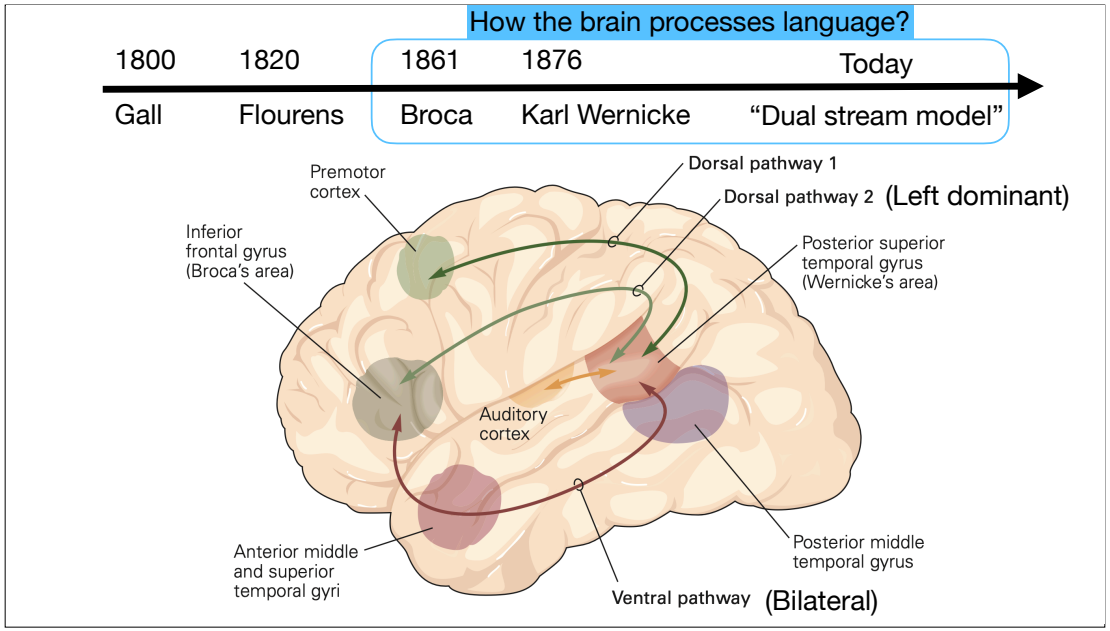
- Florence systematically removes, i.e. destroys, the functional brain centres described by Gall in rabbits and pigeons.
- Removal of cerebral hemispheres: all perceptions, motricity, and judgment were abolished. Removal of the cerebellum: the animal's equilibrium and motor coordination is affected. Removal of the brainstem (medulla oblongata): death
- However, in the cerebral hemisphere, every region participates in every mental operation, no functional centres as described by Gall



- Studies of patients with aphasia = language disorder
- Broca studied the Patient Leborgne, understood language but could not speak nor write complete sentences even though tongue and voice were not damaged. **Expressive malfunction.**
- Postmortem examination of the brain: lesion (damage) in a specific region of the **left** cerebral hemisphere, now called Broca's area: "Nous parlons avec l'hemisphère gauche".
- Broca studied 8 similar patients



- Wernicke's patient could form words but could not understand language. **Receptive malfunction**
- Model: Spoken or written words are initially processed in separate sensory areas of the cortex specialized for auditory or visual information. This information is then conveyed to a cortical association area, the angular gyrus where spoken or written words are transformed into a neural sensory code shared by both speech and writing. This representation is conveyed to Wernicke's area, where it is recognized as language and associated with meaning. It is also relayed to Broca's area, which contains the rules, or grammar, for transforming the sensory representation into a motor representation that can be realised as spoken or written language.
- Wernicke's model predicts this "conduction aphasia", characterized by an incorrect use of words (paraphasia). Patients with conduction aphasia understand words that they hear and read and have no motor difficulties when they speak. Yet they cannot speak coherently, they omit parts of words or substitute incorrect sounds and in particular they have difficulties repeating phrases. Although painfully aware of their own errors, they are unable to put them right.



- Dronkers and colleagues in 2007 used modern MRI to characterize the brains of Leborgne and Lelong. Besides damage to the canonical Broca’s area, they revealed significant lesions to the inferior parietal lobe and insula as well as subcortical structures, including the basal ganglia and various white matter tracts
- Two separate auditory-motor interactions are believed to be engaged in dorsal stream processing: one that involves individual speech segments and is used to acquire and maintain basic articulatory phonetic skills, and a second involving sequences of speech segments that enable the learning of new vocabulary
- Hickok-Poeppel model argues that speech perception is bilaterally processed. Non- dominant hemisphere is crucial to the processing of prosodic features such as emotional tone, which are important facets of everyday communication.
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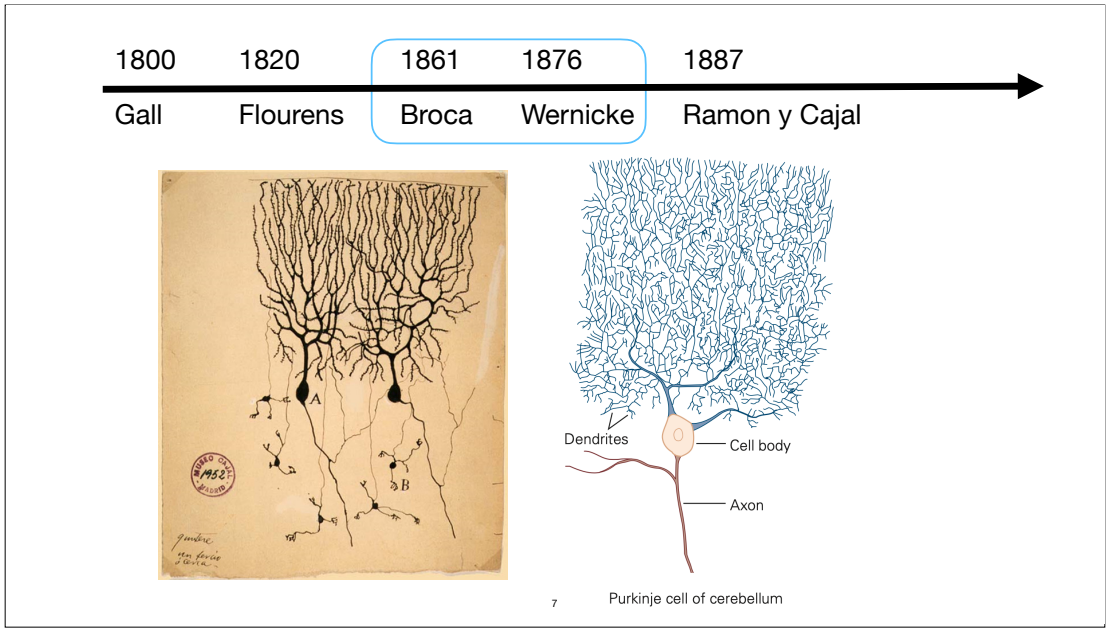
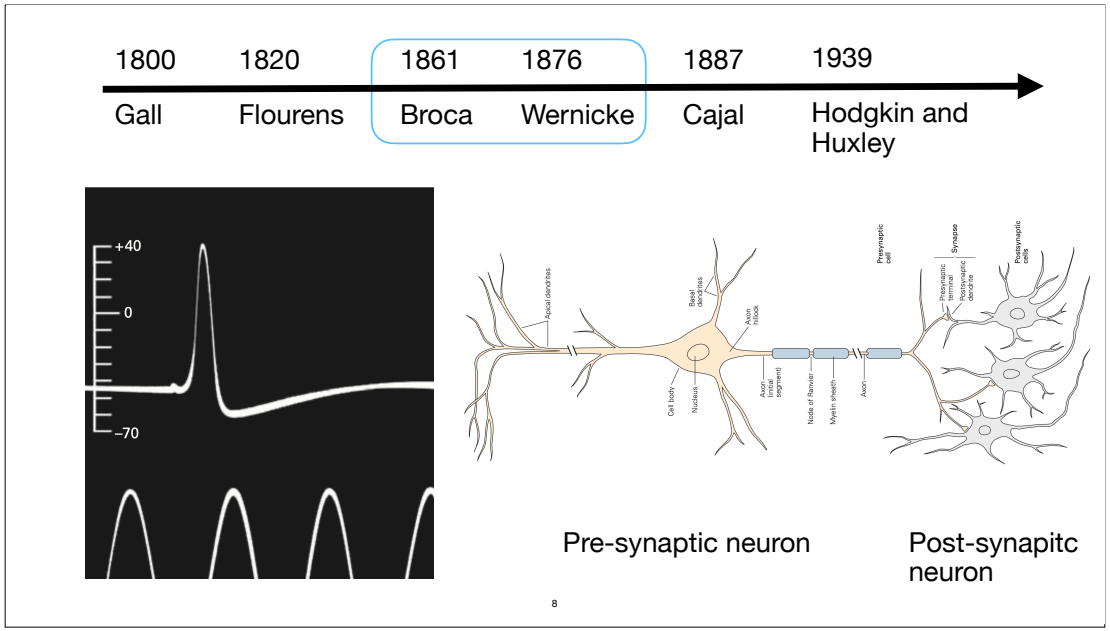


- Cajal stained (made visible) individual nerve cells in the brain for the first time in 1887.
- Drawing of Purkinje cells (A) and granule cells (B) from pigeon cerebellum by Santiago Ramón y Cajal, 1899.



- First intra cellular recording from an action potential. It was recorded in 1939 by Hodgkin and Huxley from a squid giant axon, using glass capillary electrodes filled with sea water. The timing pulses are separated by 2 ms
- Presynaptic neurone fires (i.e. sends an action potential along its axion), if it receives enough input from other neurones through its dendrites such that the membrane potential crosses a threshold.
- Input from other neuron's can be exhibitory (increasing the membrane potential) or inhibitory (decreasing the membrane potential)

1939 1959

Hodgkin and Huxley

Hubel and Wiesel

1939 1959 From 90s onwards

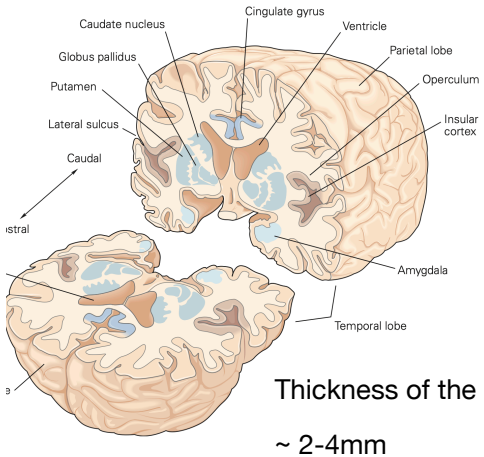
Hodgkin and Huxley

Hubel and Wiesel

Recognition of the importance of the collective neural dynamics of many neuron's in "neural state space"

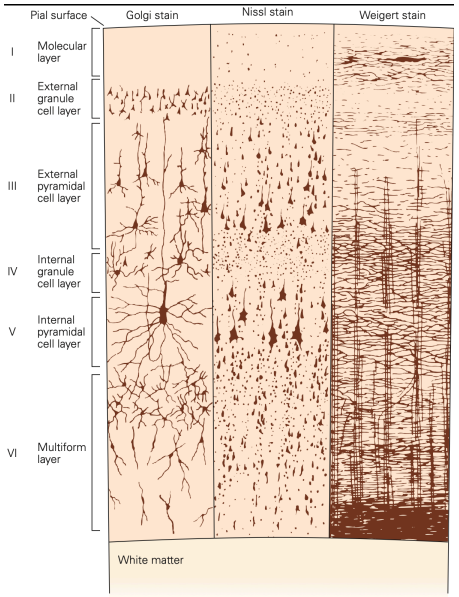
Appearance of dimensional "manifolds"

Brain Anatomy



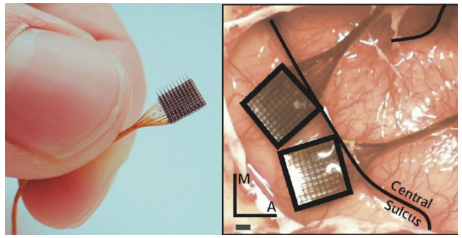
Thickness of the cortex

~ 2-4mm

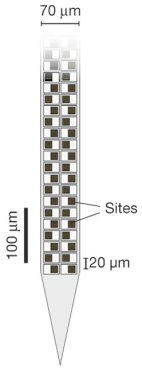


Recording Techniques

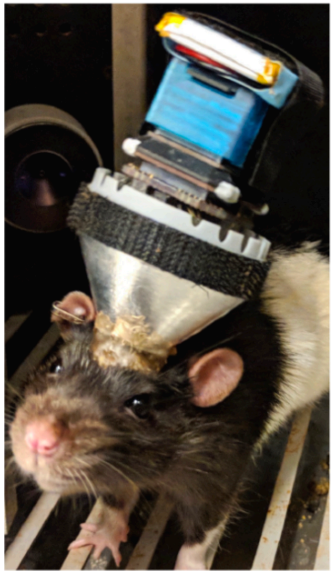
Electrophysiology



Utah arrays, ~100 electrodes

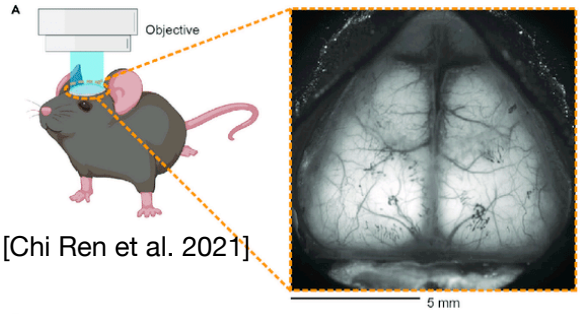


NeuroPixels ~
1000 electrodes

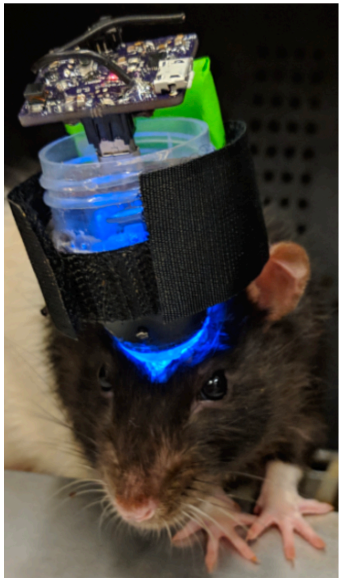


Recording Techniques

Optical imaging

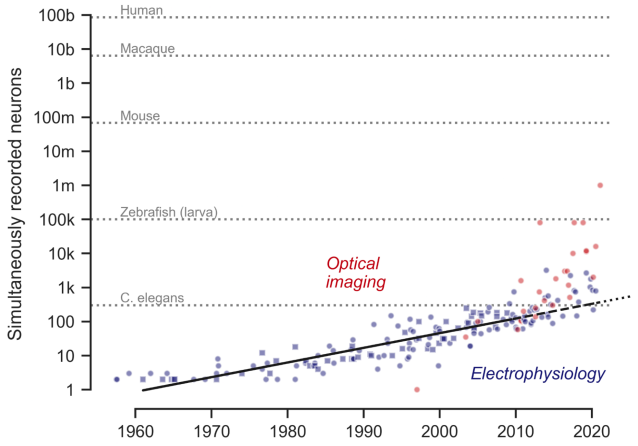


[Chi Ren et al. 2021]



Genetically encoded Calcium fluorescent indicator is injected into the brain. Under a 2-photon or 3-photon microscope, this allows to visualise up to 1000 neutrons on a patch of 0.5mm x 0.5 mm.

Recording Techniques

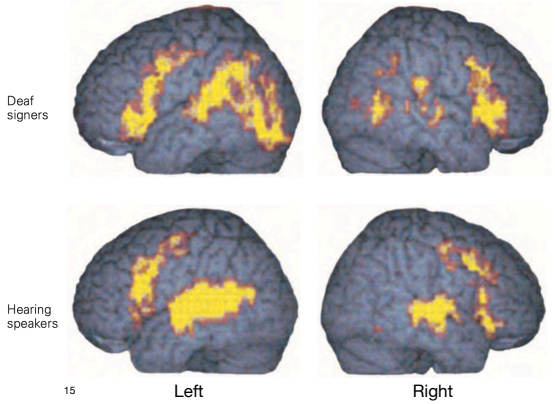


[Urai et al, 2021]

Recording Techniques

FMRI (Functional magnetic resonance imaging)

- Measures brain activity by detecting changes associated with blood flow due to energy use of brain cells.
- Since the 1990s
- Non-invasive
- Δx ~ 1mm, Δt ~ 1s



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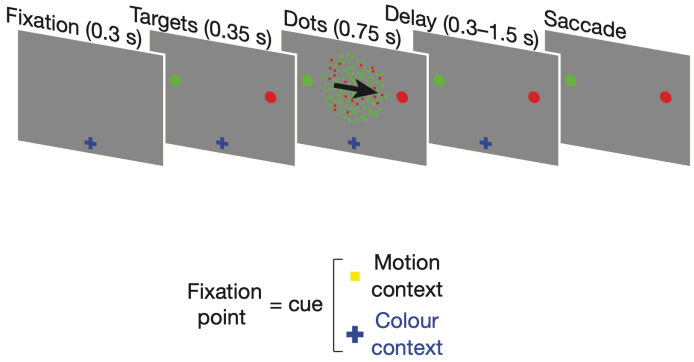
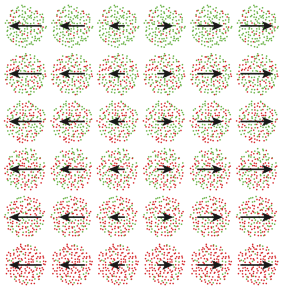
MRI brain scans use a strong, permanent, static magnetic field to align nuclei in the brain region being studied. Another magnetic field, the gradient field, is then applied to spatially locate different nuclei. Finally, a radiofrequency (RF) pulse is played to kick the nuclei to higher magnetization levels, with the effect now depending on where they are located. When the RF field is removed, the nuclei go back to their original states, and the energy they emit is measured with a coil to recreate the positions of the nuclei. MRI thus provides a static structural view of brain matter. The central thrust behind fMRI was to extend MRI to capture functional changes in the brain caused by neuronal activity. Differences in magnetic properties between arterial (oxygen-rich) and venous (oxygen-poor) blood provided this link

Context dependent decision making

(Mante et al. 2013, Nature)



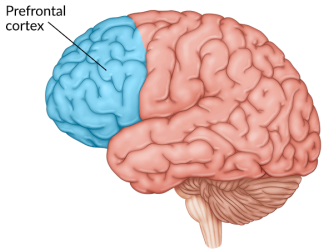


Context dependent decision making

(Mante et al. 2013, Nature)

Experiment in monkeys

~1500 neurones recorded with electrodes in the prefrontal cortex

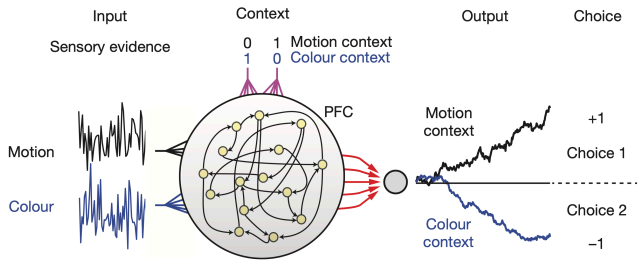


Context dependent decision making

(Mante et al. 2013, Nature)

Train a recurrent neural network (RNN) to solve the task

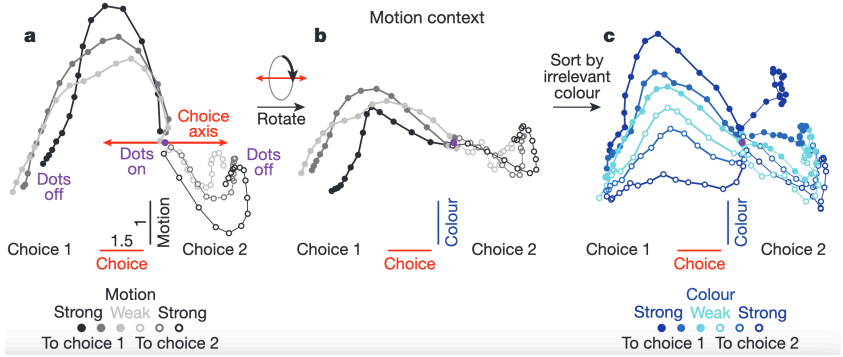
$$\tau \dot{x} = -x + W \tanh(x) + I_{color} + I_{motion} + I_{context} \qquad z = w \cdot \tanh(x) \in \{+1, -1\}$$



Context dependent decision making

(Mante et al. 2013, Nature)

Result of neural recordings (after dimensional reduction and linear regression)



Context dependent decision making

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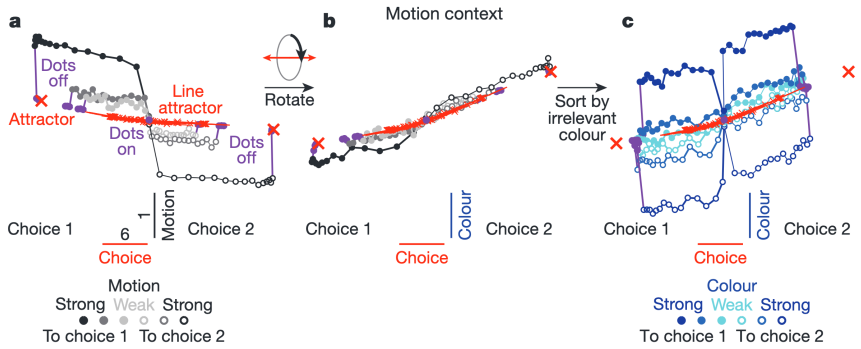
Result of RNN simulation (after dimensional reduction and linear regression)



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