As the liver secrets bile

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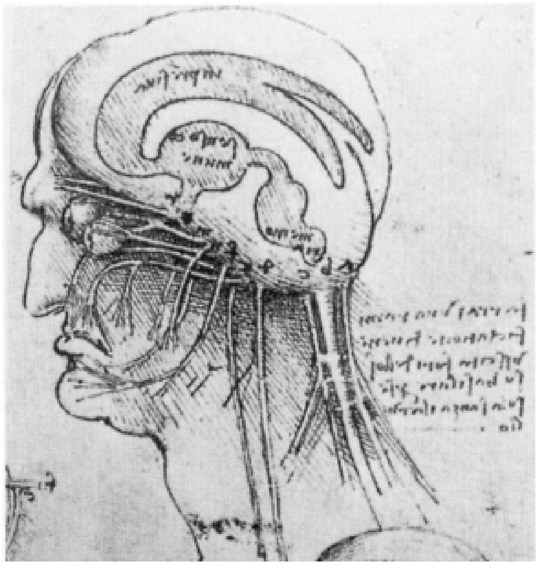
Hydraulic fluid theory of brain function

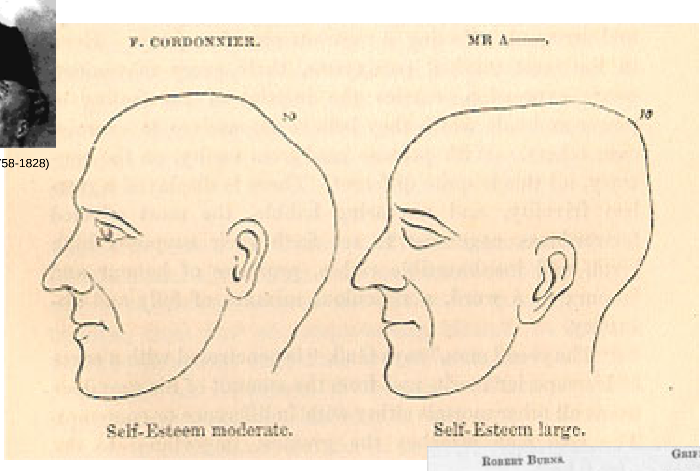
(Leonardo da Vinci XV century, Descartes XVI century)

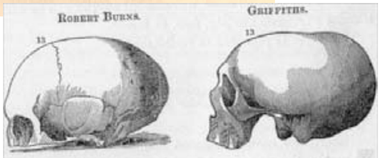


Leonardo da Vinci in the XVth century and Descartes in the XVIth century defended the hydraulic fluid theory of brain function, implying that the cerebrospinal fluid was pumped up through the ventricles into tubular structures producing limbs movement.

The Phrenology (1790-1880)

Franz Joseph Gall (1758-1828)





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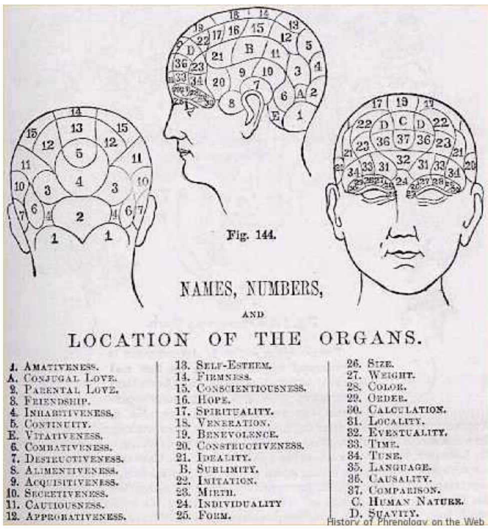
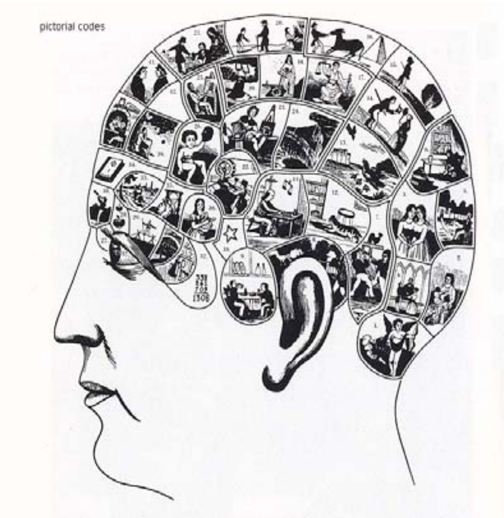
The phrenologists claimed there was a correlation between the structure of the head (bumps in the skull) with personality traits. Joseph Gall defended that the skull takes its shape from the brain, the surface of the skull can be read as an accurate index of psychological aptitudes and tendencies. They rightfully recognized that the brain is the organ of the mind and that there is a correlation between anatomy and function (which is, to some extent, widely accepted today).

The Phrenology (1790-1880)





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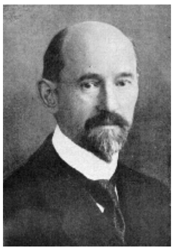
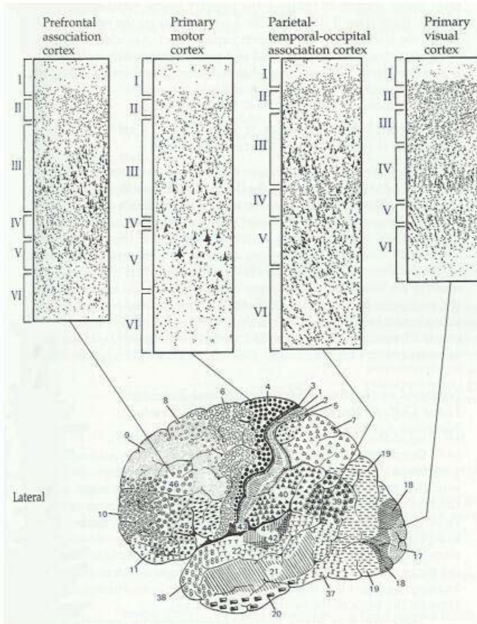
The phrenologist ‘atlas’ where traits such as self-esteem, human nature or eventuality can be quantified based on the anatomy of the skull.

Brodman's Cytoarchitectonic Map (1909)



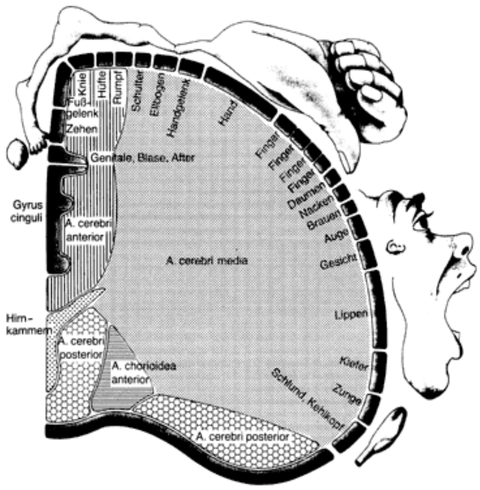
Korbinian Brodmann (1868-1918)

Silver staining technique



Korbinian Brodman used camilo Golgi's stainig technique to citoarchitectonicaly map the Lemur brain for the first time. Based on the specific layer structure, he created a map of the still used Broadman areas, which in most cases still nicely match functional brain units.

Penfield's homunculus (1930)



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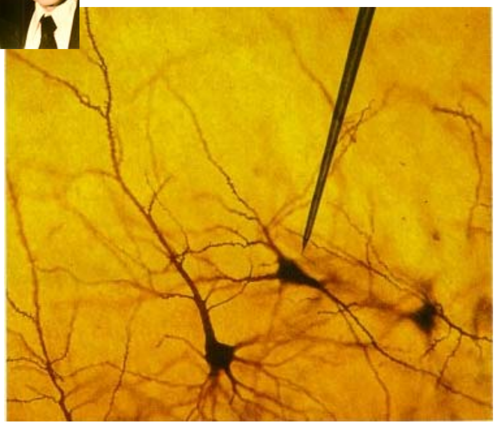
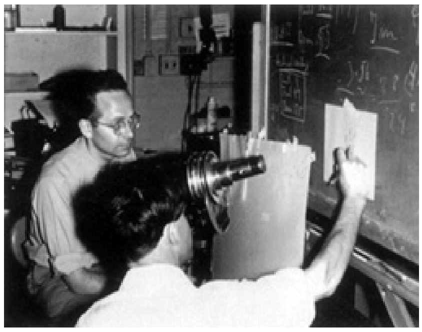
The sensory map in humans was originally charted by the Canadian neurosurgeon Wilder Penfield in the 1930s. Before operating epileptic patients, Penfield used electrodes to stimulate different parts of their brains and observed the elicited motor reactions or reported sensations. He could do this while the patients were awake, since the brain does not feel what is happening to it. In this way, Penfield soon learned exactly where each part of the body that was touched or moved was represented in the brain. He then showed it in his famous "homunculus" cartoon of the somatosensory and motor areas.

Hubel and Wiesel single cell recordings in cat striate cortex (1958)





David H. Hubel & Torsten N. Wiesel.

1981 Nobel Prize in Physiology for their discoveries concerning information processing in the visual system

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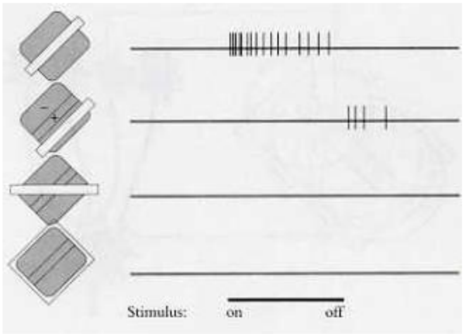
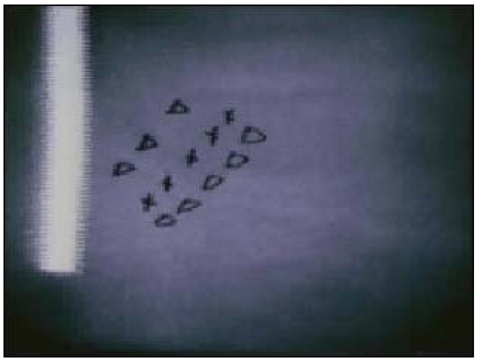
A mayor contribution to the moderns understanding of the brain was the work of David Hubel and Torsten Wiesel, who managed to record activity from single cells in the primary visual cortex of the cat while stimulating the retina with high contrast stimuli of different shapes.

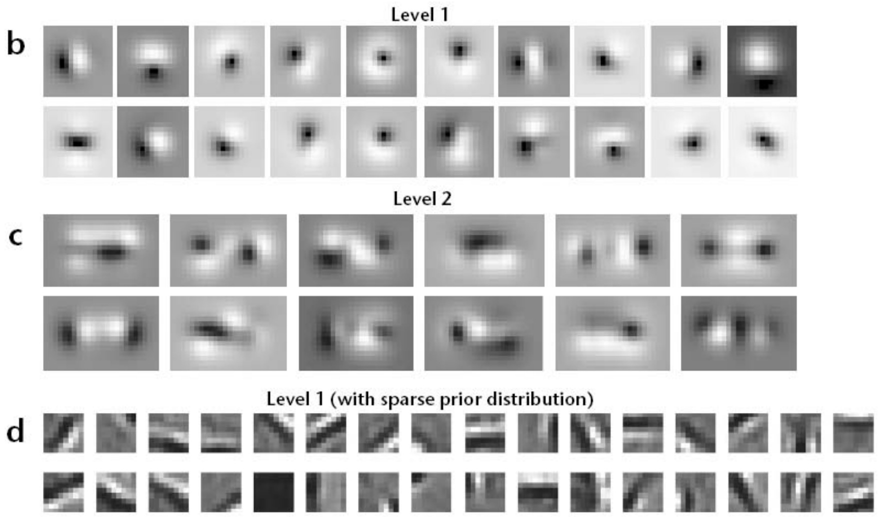
Hubel and Wiesel single cell recordings in cat striate cortex (1958)





Almost by accident, they discovered that neurons in the primary visual cortex posses fairly complex receptive fields that are specialized for certain spatial frequencies and event for certain orientations. In this original video recoding, for example, the neural firing can be heard as recorded from the electrode while it fire only to a right tilted bar presented in the center of the receptive field. Bars outside the center of the receptive field or with slightly different orientations fail to elicit any neural activity.

Different receptive fields in V1

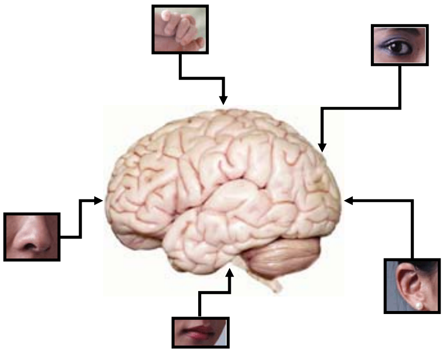


Rao and Ballard. Nature Neuroscience, 1999

Receptive field weighting profiles of modeled neurons in low a higher visual areas.

Neural activity leads to concious perception

The role of attention



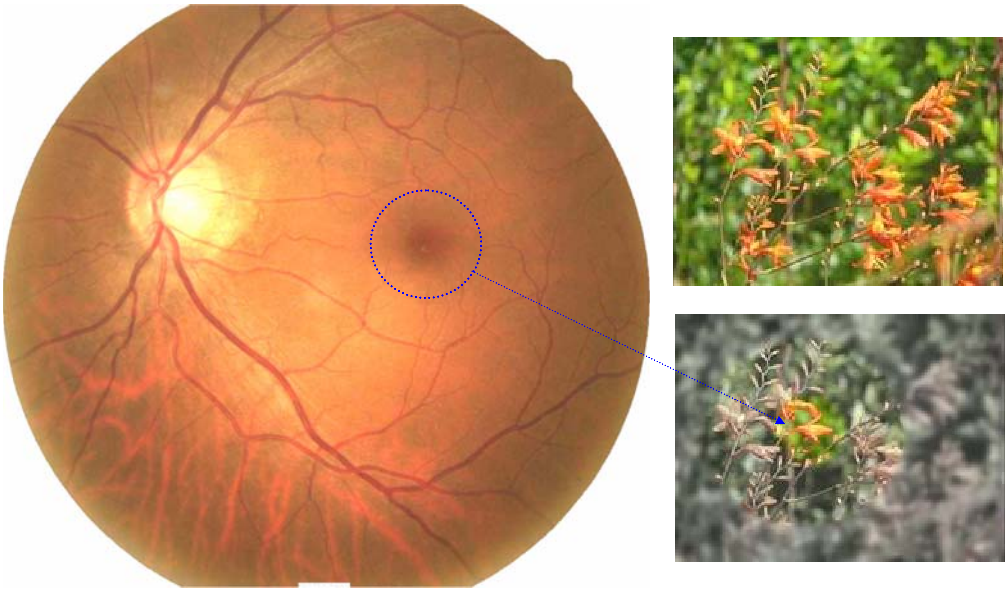
To allocate the limited processing resources to optimize performance

The vast amount of information coming form the sensory organs cannot be processed all at the same level. Attention filters sensory input according to rules and weights not only determined by the physical stimuli but also influence by adaptation and evolution, learning, memory etc. We only use discrete portions of the physical world to create our psychological world. What we use and what we don‘t is determined by the discrete portions of the physical world transduced by our sensors and by the attentional system.

Our psychological world is based on of the **incomplete** versions of the physical world delivered by our sensory organs…

…“**filtered**“ by attention!!!

High chromatic and spatial resolution vision is only provided at the fovea



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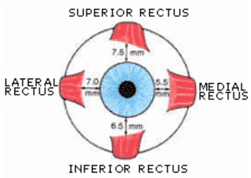
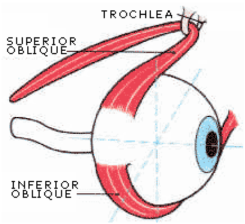
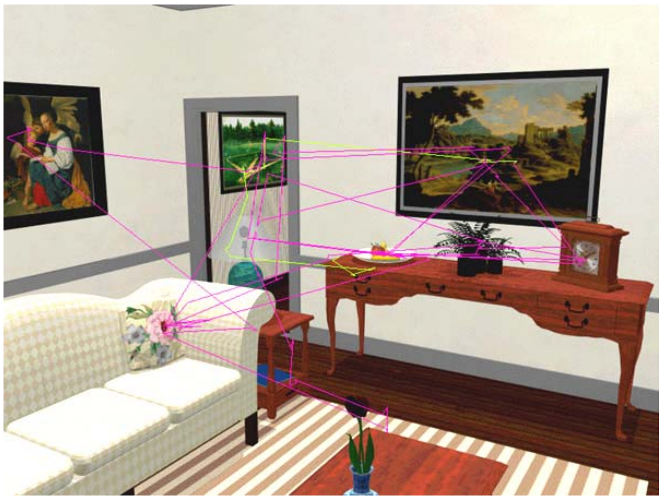
A good example of these selective processing comes from the visual system: Because of the irregular distribution of cone receptors across the retina, only the portion of the visual field that is projected onto the fovea, can be resolved at high chromatic and spatial resolution. Only objects falling within this small area will be processed in detail by the visual system.

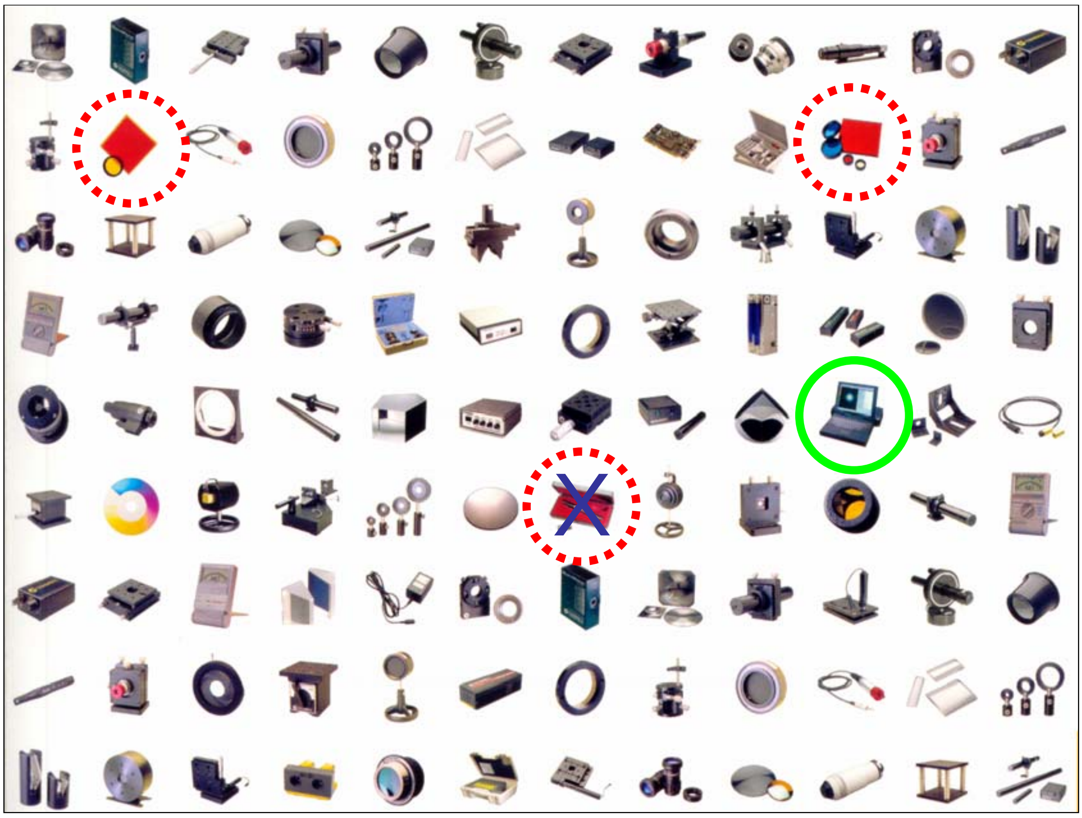
Saccades move our eyes to 'foveate' objects of interest





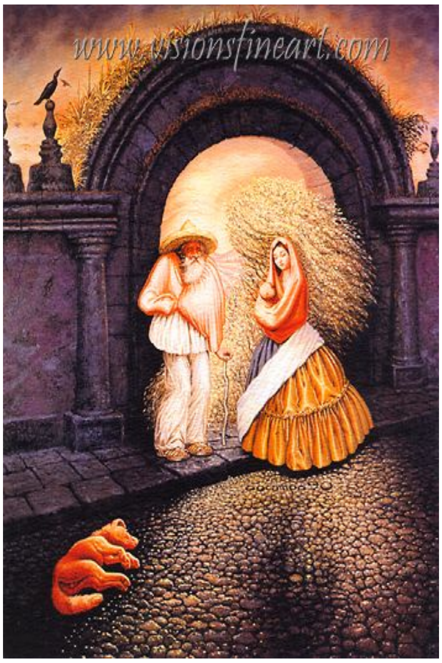


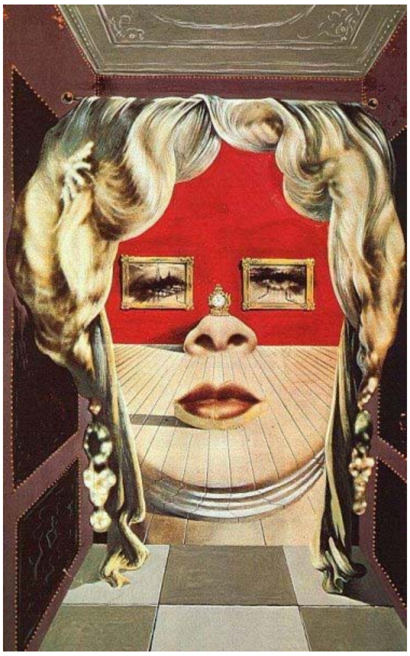
In order to compensate for this limitation, three pairs of muscles generate very fast eye movements (also called saccades) that maximize the efficiency of the retina by sequentially bringing the relevant parts of the visual scene onto foveal vision



Most theories of attention propose that information is processed in two sequential stages: the first in which all the available information is processed in parallel upon some simple features, and a second serial processing stage during which the integration of features and the matching with our cognitive representations takes place.

In this visual search demonstration, observers working on a computer (green circle) are asked to find 'the red filters'. During the first stage, observers process in parallel all objects and segment only those that share the basic color feature 'red' (red dotted circles) and eye movements are performed to those few pre-selected objects in order to bring them to the fovea for detail analysis. It is only during this second stage, where observers integrate other dimensions and match them against higher cognitive representations of the searched object (such as the shape and other physical characteristics, and the function of a 'filter'). Despite this image containing more than 100 complex objects, observers manage to find the 'red filters' in few seconds and with little effort, while being unable to name or describe other objects in the scene.

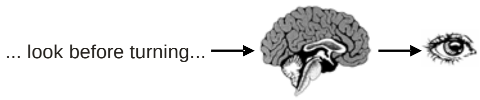




Salvador Dali, 1934-35 ‘*El rostro de Mae West que puede ser usado como un apartamento’*

Saccadic eye movements are the result of bottom-up and top-down processes

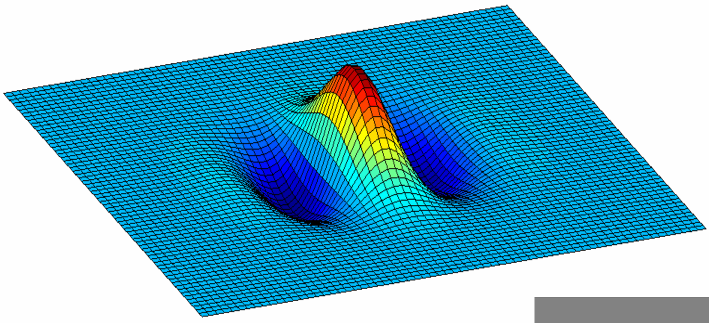
Stimulus-driven

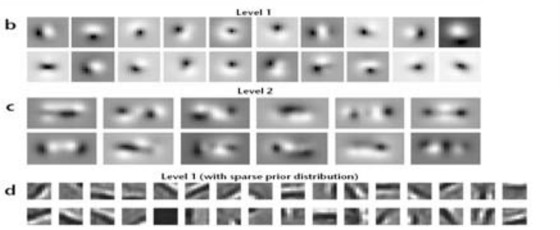


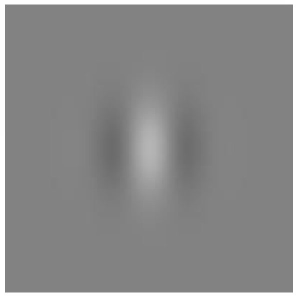
Goal-directed

Saccadic eye movements (such as those performed during visual search) are the behavioural result of a complex system that integrates both, bottom-up and top-down processes. In a typical bottom-up/stimulus driven saccade, a very salient stimulus triggers a reflexive movement towards its location (such as looking to a salient sign announcing construction work). A top-down/goal directed eye movement is characterized by a high degree of intention, such as when making a saccade to the rear mirror of our car before entering the highway lane to see if other cars are coming.

Gabor Functions and receptive fields







Simple on/off receptive field

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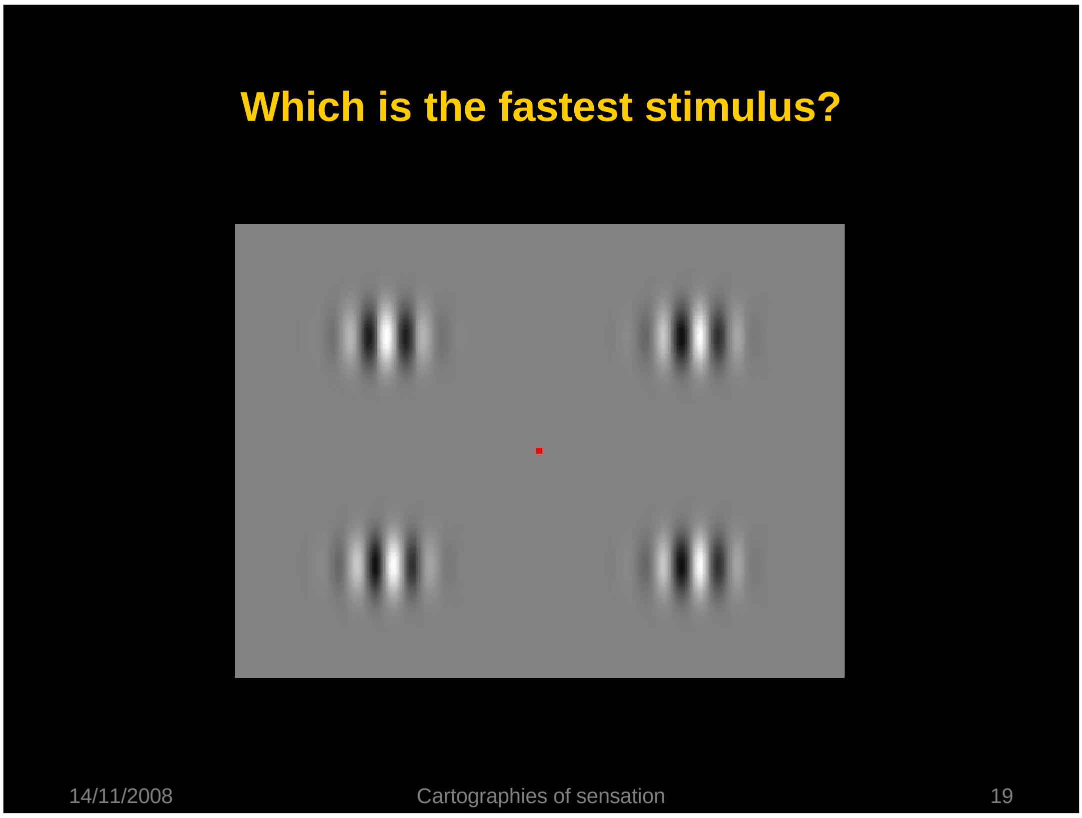
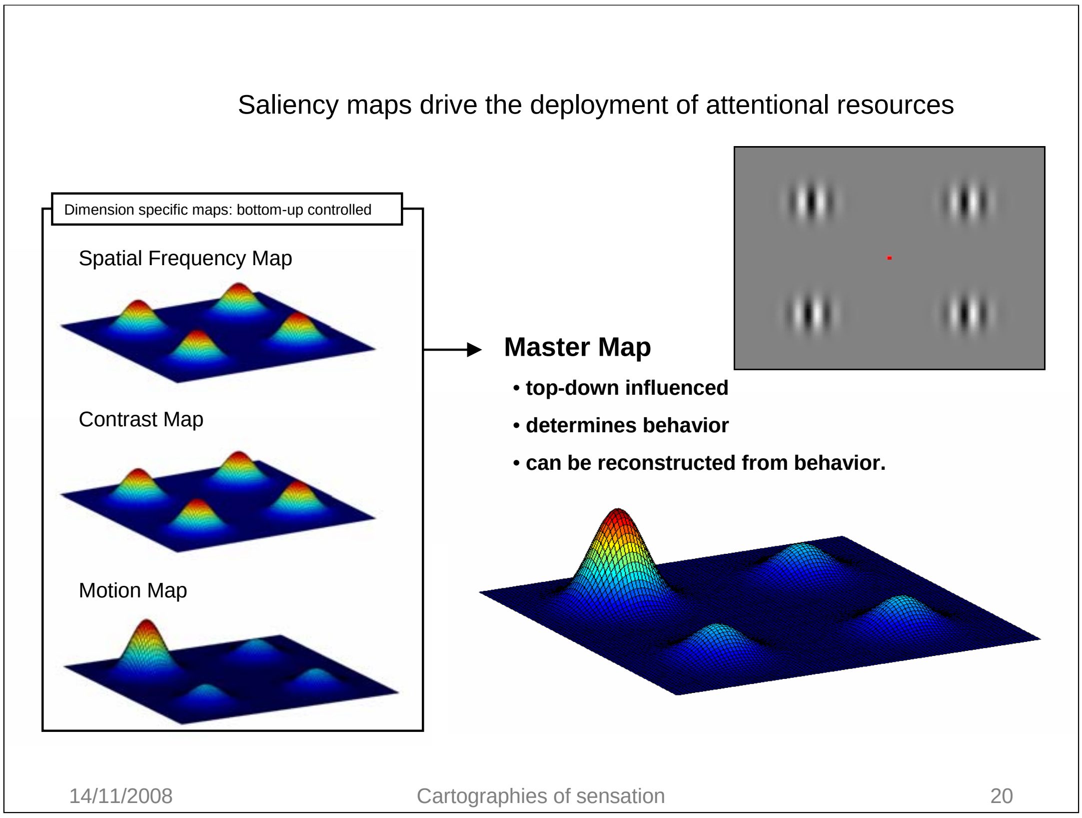
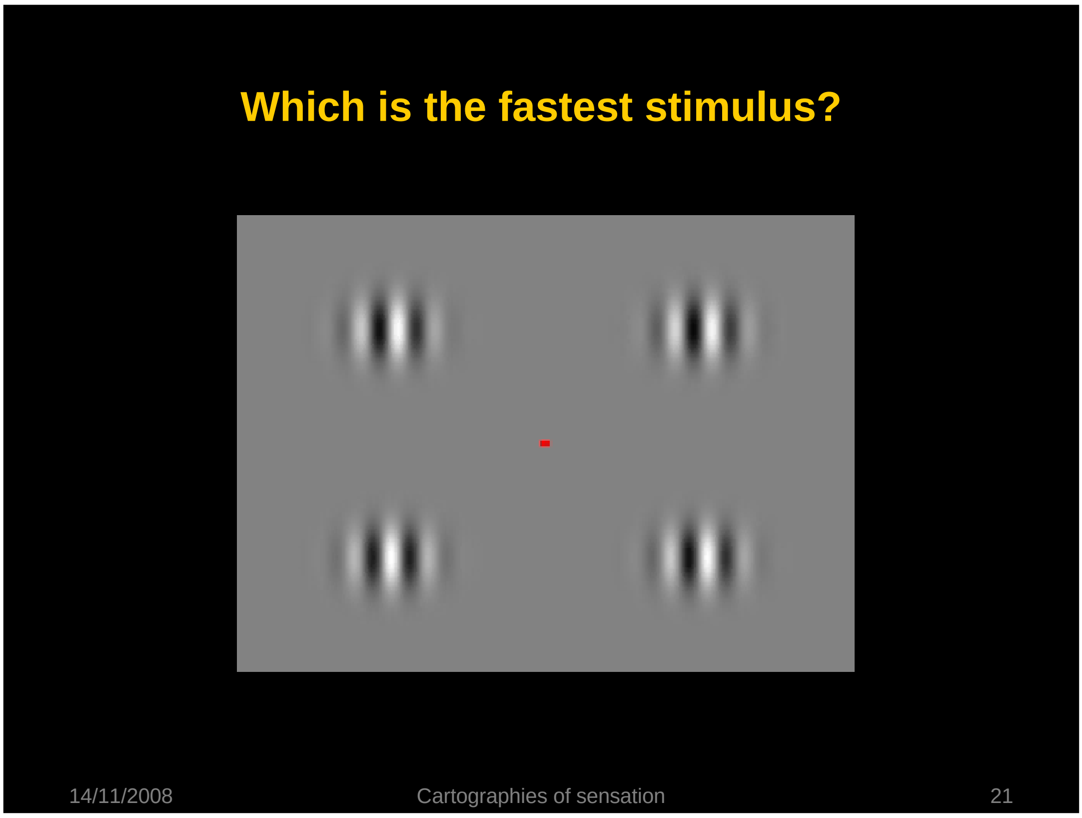
Gabor functions nicely represent the receptive fields of some basic neurons in the visual system. They are defined by a large number of dimensions that can be experimentally manipulated (such as spatial frequency, contrast, orientation, phase drift velocity and direction, etc.) and have a very low emotional load (i.e. very useful to study low level vision).



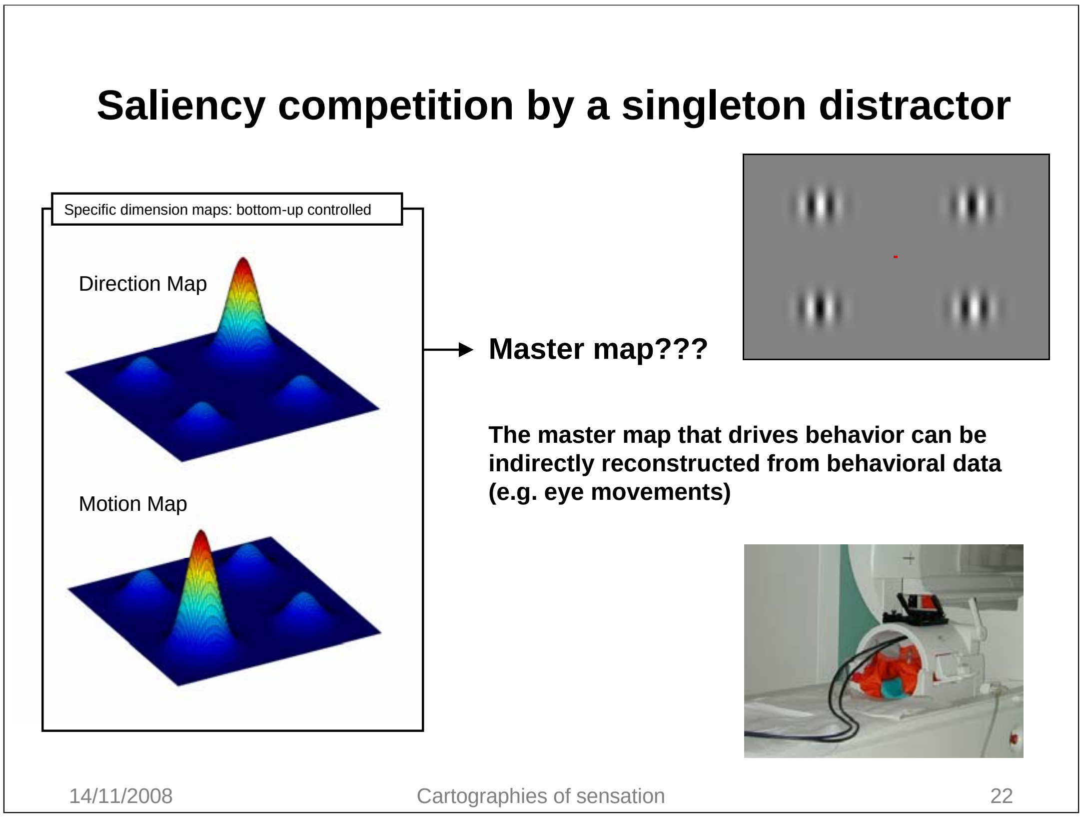
In this video, four drifting Gabors are shown during some half a second. They all have identical values in all dimensions except in the drift velocity. One of the Gabor stimulus has a higher drift velocity and produces a pop-out effect that captures our attention, which in turn, relocates our visual resources to that one item.



In our visual brain, the combination of single dimension maps results in a master map that contains an item which is ‘salient’ (i.e. according to information theory, has a higher information content and therefore is worth processing it in detail)



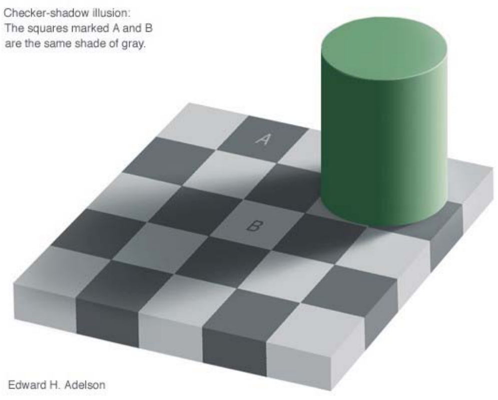
In this second video, observers task is again search for the fastest drifting Gabors stimulus. Again in this case, all stimuli have the same drift speed except one. In theory, it would be easy to find the ‘salient’ fastest Gabor, if not because the drift direction of one other Gabor has been reversed.   This ‘odd’ stimulus also potentially contains a high load of information and distracts our attention to its location in an automatic way (triggering a saccade to that direction in most cases). This is what happens while driving when we stop looking at the road to look at a spectacular accident on the side road and crash against the car in front of us. A ‘singleton’ ‘odd’ distracter can reflexively capture our attention. Realizing this and extrapolating it to the real visual world this means that external stimuli drive our behavior even against our intention. These techniques are greatly exploited by the film industry to engage viewers into the filmic experience that triggers all sorts of emotional responses in our brains.



When these competing salient stimuli are integrated into a master behavioral map, the outcome is difficult to predict and we need to use behavioral measures to infer what our cognitive responses are. In the lower right you can se a photograph of the eye tracking device we use in our brain imaging experiments (fMRI). Because foveating an object is necessary for detail analysis (i.e. saccadic eye movements are ‘slaves’ of attention), we assume that those objects we look at are those objects we process in greater detail.

Visual attention is partially driven by saliency maps that can be also modulated by top-down processes

Interpreting sensory information



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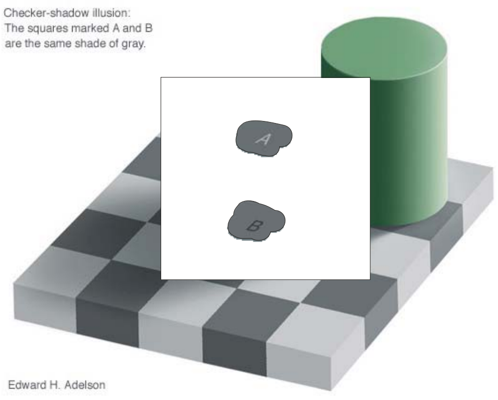
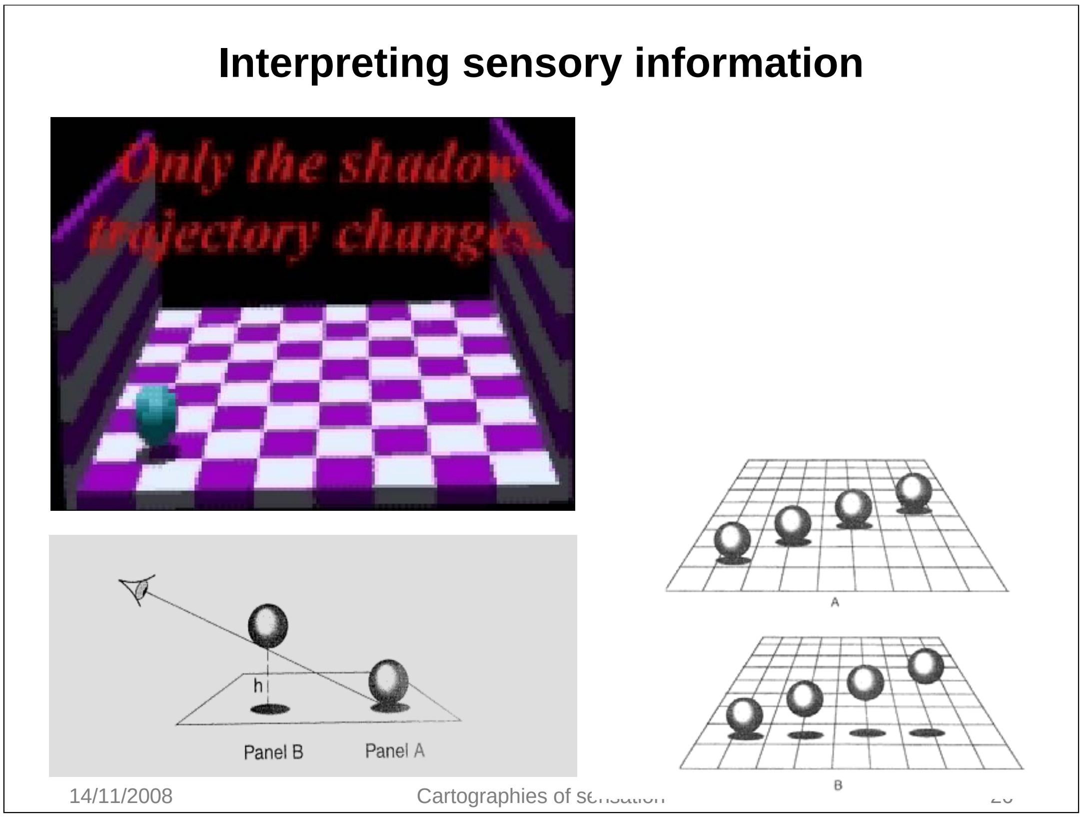
This is a beautiful example of how our stored knowledge of the physical world (i.e. all we know about casting shadows and checkerboards) sometimes hinders us to properly recreate the physical world. In this image, squares A and B have physically identical luminance/gray levels, even though most observers would think that A is in fact darker that B.

Interpreting sensory information



The identical luminance level of squares A and B becomes apparent when we mask out the contextual information (i.e. the shade)



Another similar example: In this video, only the shadow changes its trajectory, creating a totally different perception of movement.

Sensory information is not the only source of information used to construct our psychological world…

…also available *stored* information contributes to this construction process.

Same but different

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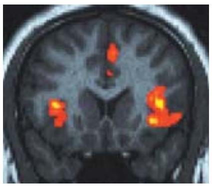
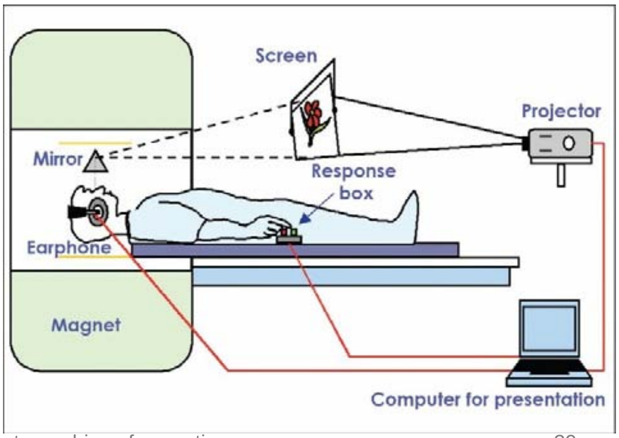
Our emotional responses to external stimuli are also influenced by complex stored information such as memories and past experiences: Why these two messages are so different if the are the same? They posses qualitatively different emotional loads: there is no real reason for a yellow bird to be pleasant and cute and a hand to be something aggressive and defying. To most observers though, there is something unpleasant about <u>that</u> hand that has nothing to do with a neutral representation of a hand.

Functional brain imaging (fMRI)



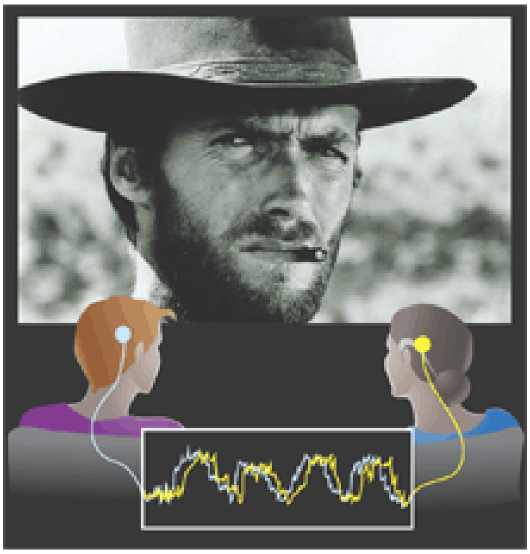


In a similar device to the ‘dream oven’ from the middle ages, today we can measure brain activity while subjects are presented with complex stimuli such as movies. While we are very far away from being able to read dreams and thoughts, based on our knowledge about the different processing ‘modules’ of the brain we can attempt to identify activity patterns that match certain behaviors or even emotional states.

Films expose viewers to a carefully constructed sequences of visual and auditory stimulation where saliency is manipulated to channel the viewer‘s gaze and attention.

This, in turn, can elicit similar emotions and affetcs in viewers with similar cultural and socio-ethical backgrounds.

Intersubject Synchronization of Cortical Activity During Natural Vision



Uri Hasson et al. Science, 2004

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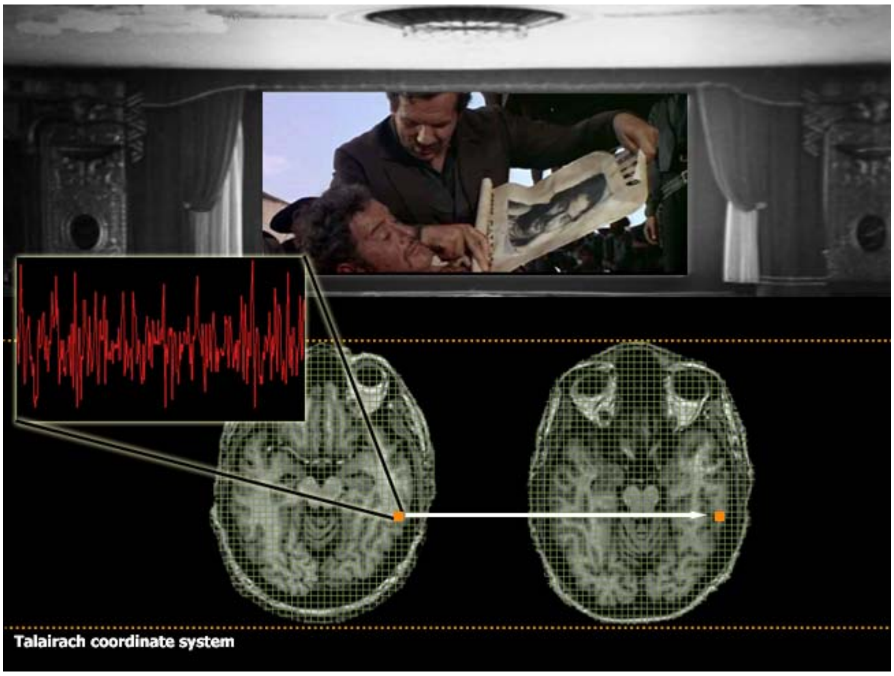
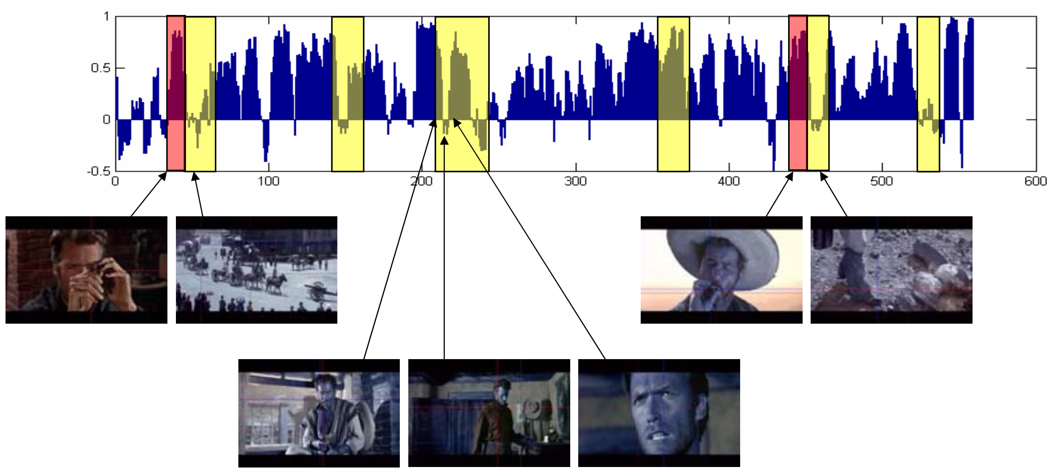
Some few years ago a fascinating line of research was started with this incredible Science article written by Uri Hasson et al. They found empirical evidence of intersubject synchronization of neural activity in the brain while observers watched commercial movies.

Inter-subject brain activity correlation



The technique is based on continuously measuring the BOLD (Blood Oxigen-Level Dependent) signal, which indirectly measures neural activity, in several observes while presented with popular commercial movies. After anatomically normalizing their brains to an standard atlas, the signal time-series were extracted from each part of the brain for all subjects and a correlation index was calculated. This way, the authors could estimate how similar were brains responses to different moments and scenes of the movie.

Inter-subject eye movement correlation



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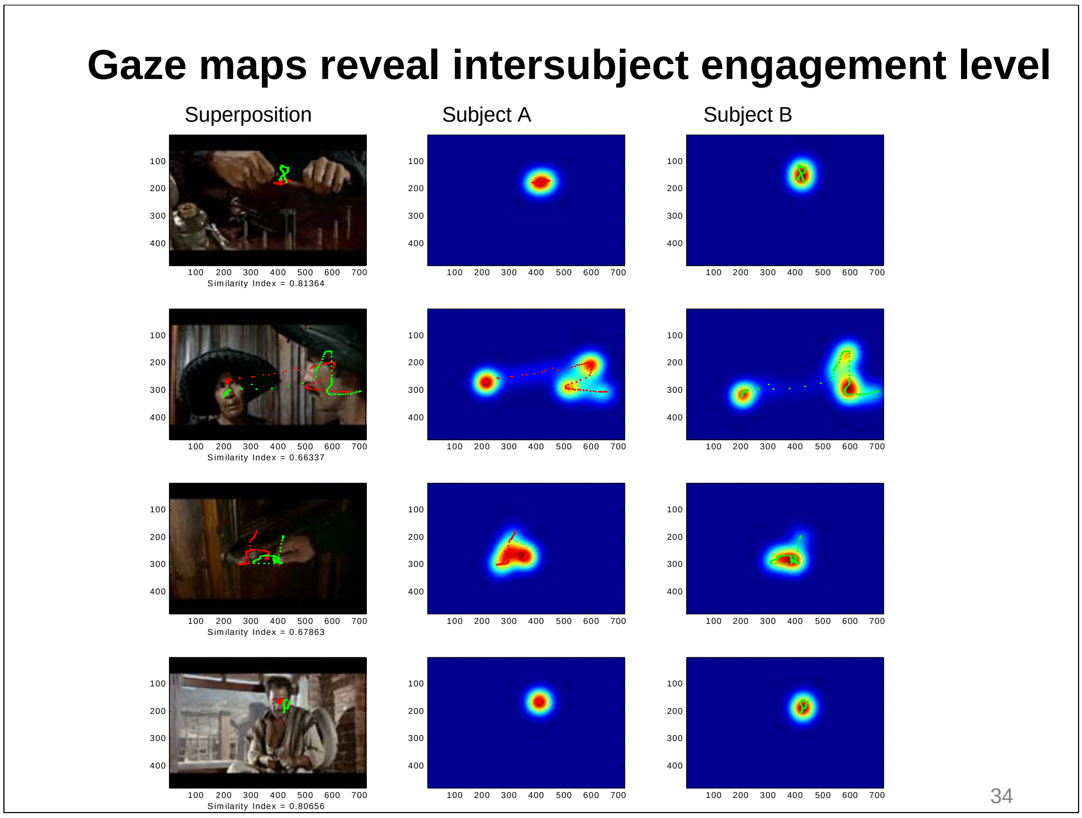
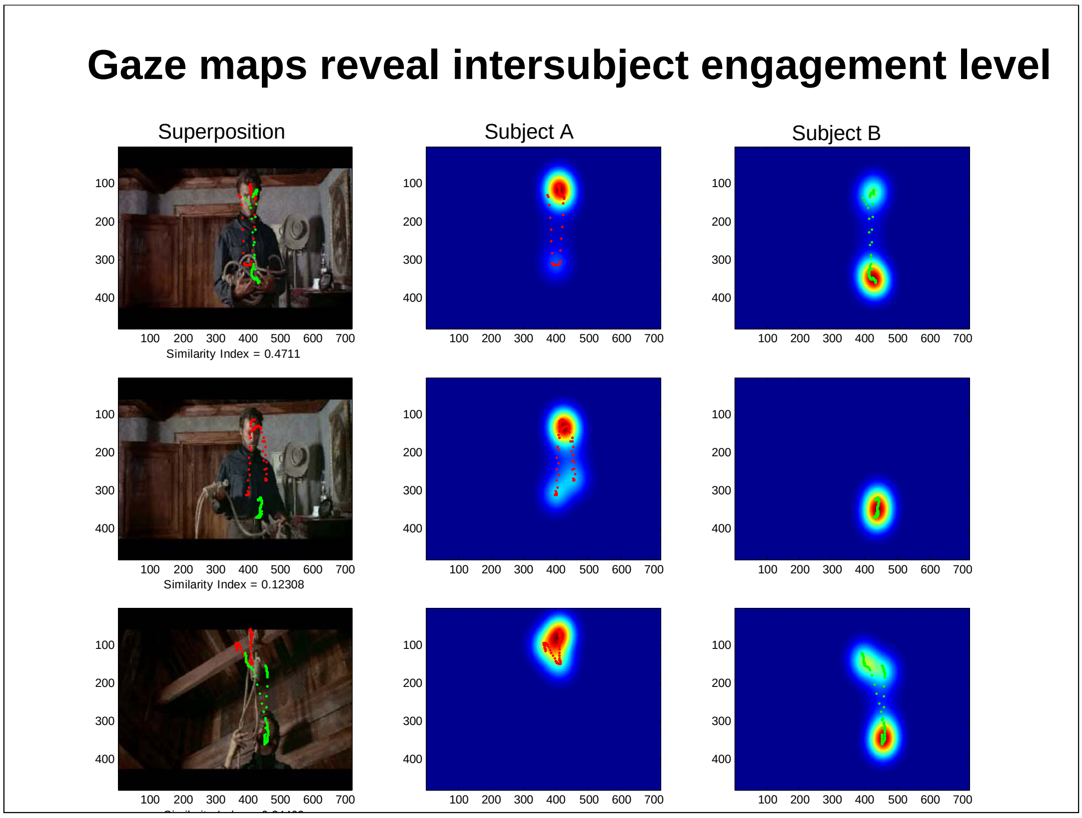
We also found a high degree of intersubject eye movement correlation, specially in some highly engaging scenes. The bar plot shows the eye-movement correlation index across subjects during the different scenes of the movie. Gaze (red and blue crosses) was tracked during the fMRI measurements together with brain activity.

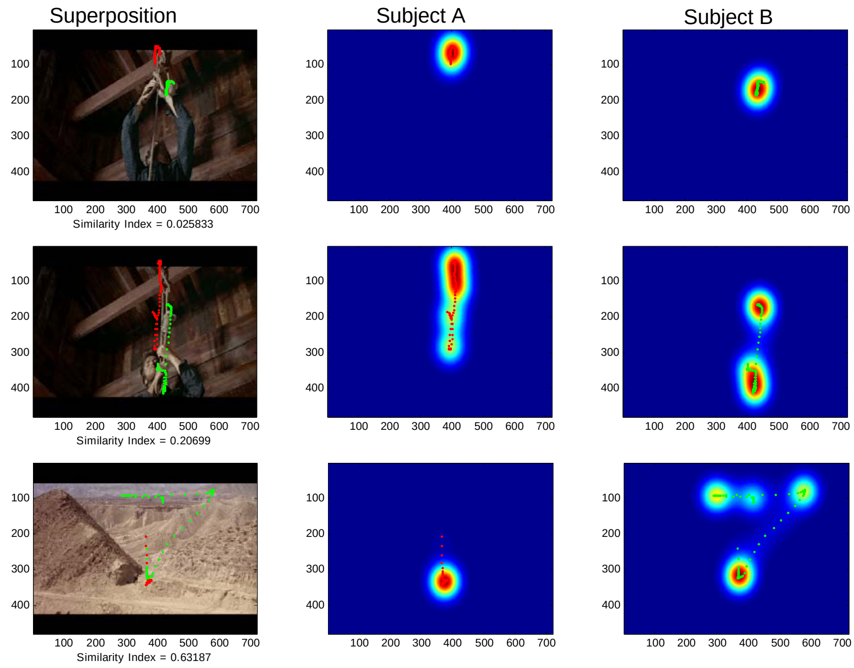


By creating 500ms gaze maps (additively convolving gaze with a a 3D gaussian bell), we could estimate the intersubject correlation during the different scenes in the movie. Based on these maps, we found that most observers do look at the movie ins a similar way (both based on bottom-up factors such as framing and focus, and top-down factors such as the plot itself).



The director allows for some freedom in this case where two ‘salient’ objects (the face and the rope) compete, such in the example with the Gabor stimuli, for attentional resources and thus reflect in different gaze maps.

Gaze maps reveal intersubject engagement level



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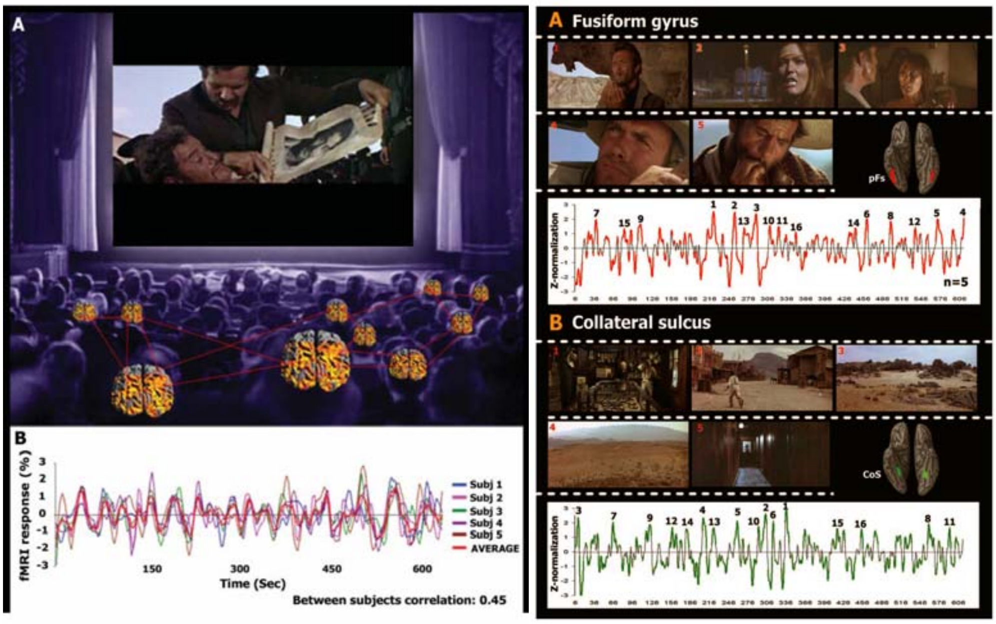
In the top frames, the manipulation of the rope has both a high level of bottom-up saliency (high spatial frequency, motion etc.) and also top-down semantic relevance (for the story), engaging gaze equally in most subjects.

Engaging movies elicit large brain-activity intersubject correlation



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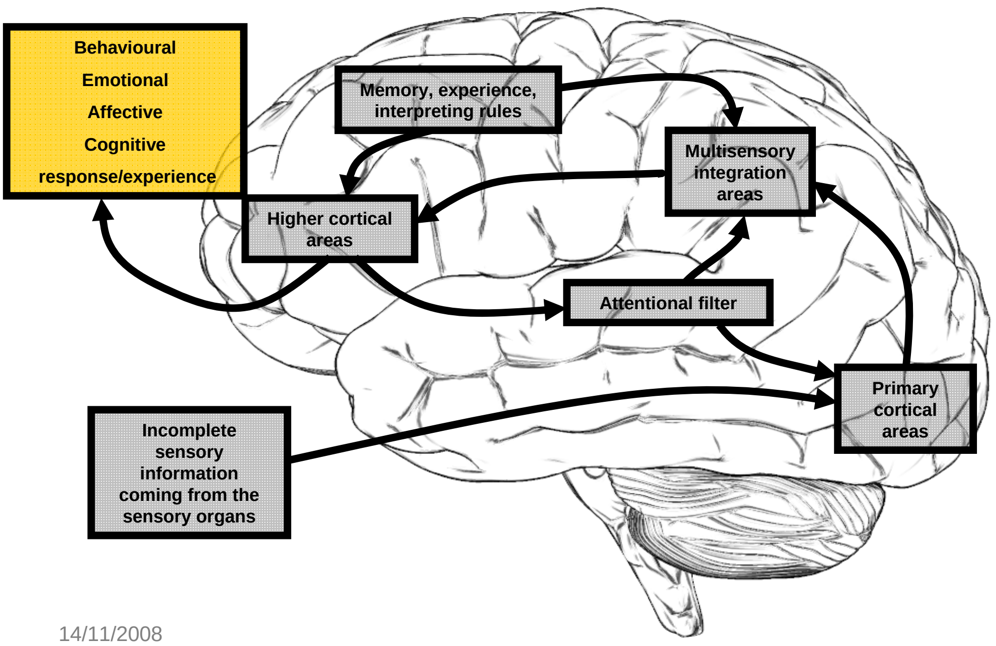
Uri et al. found great level of intersubject synchronization in several areas of the brain which selectively process distinct aspects of the scene. They found for example high degrees of correlation in the fusiform gyrus when face close-ups were shown, and high degree of correlation in the collateral sulcus when open spaces were presented.

Filmic language is able to recreate reality in a way that similar brain and oculo-motor responses are elicited in ‘similar’ observers. The principles discussed with the low level vision examples presented before (e.g. gabor saliency or checkerboard illusion) can be extrapolated to much more complex stimuli combined in a commercial movie to conclude that our psychological reality is a mixture of the available physical stimulation (in real life or during a movie projection), a large asset of information stored in our brain, and a complex system of instinctive and intentional processes.

The construction of the psychological world



It is all our brain‘s fault!

… which „secrets though as the liver secrets bile“.

Pierre Jean George Cabanis, French physiologist, 1757 - 1808

Thank You!