

The Functional Architecture of Human Intelligence

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lots of relevant short talks at:

<http://nancysbraintalks.mit.edu/>

The key question addressed in this course:

How does the brain produce intelligent behavior and how we may be able to replicate intelligence in machines?

Many possible approaches (computation, circuits, etc)

Today:

- I. Functional architecture of the human brain:
what are the basic components of the system?**
- II. Methods of Human Cognitive Neuroscience,
strengths and weaknesses of each
with examples from face recognition**

Is human intelligence the product of:

- special-purpose components, each optimized to solve a single specific problem?
- more general-purpose machinery that enables us to tackle a wide range of problems without being specialized for any of them in particular?



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Who cares?

Who Cares about Functional Components?

This question matters because:

- one of the most fundamental questions about the organization of mind and brain
- a classic way to make progress toward understanding any complicated system: “divide and conquer”
- the particular components have major implications for our understanding of the computations underlying cognition.
e.g., computational models of face processing will be very different if they must also be able to work for the recognition of objects, words, and scenes.

Many ways to investigate this question.....

1. Spearman (1904), General Intelligence

American Journal of Psychology

In an article sandwiched between a discussion of the soul and an account of “the psychology of the English sparrow”,.....

Spearman tested (in two schools)

**a variety of measures of academic ability (e.g. exam grades in various subjects)
sensory discrimination ability (tones, weights, brightness)**

What do you think? Should these things be correlated?

What he found:

most pairs of tasks were correlated with each other

those who do well at school are the same as those who do well at sensory discrimination.

non obvious and deep, did not have to come out this way!

What he inferred:

The general factor, common to all tasks: g

The specific factor, specific to each task: s

Some tasks (learning Greek) more g, others (music) more s

2. Franz Joseph Gall (1758-1828)

Distinct mental “faculties” reside in distinct regions of the brain.

1. The instinct of reproduction (located in the cerebellum).
2. The love of one's offspring.
3. Affection; friendship.
4. The instinct of self-defence; courage; the tendency to get into fights.
5. The carnivorous instinct; the tendency to murder.
6. Guile; acuteness; cleverness.
7. The feeling of property; the instinct of stocking up on food (in animals); covetousness; the tendency to steal.
8. Pride; arrogance; haughtiness; love of authority; loftiness.
9. Vanity; ambition; love of glory (a quality "beneficent for the individual and for society").
10. Circumspection; forethought.
11. The memory of things; the memory of facts; educability; perfectibility.
12. The sense of places; of space proportions.
13. The memory of people; the sense of people.
14. The memory of words.
15. The sense of language; of speech.
16. The sense of colours.
17. The sense of sounds; the gift of music.
18. The sense of connectedness between numbers.
19. The sense of mechanics, of construction; the talent for architecture.
20. Comparative sagacity.
21. The sense of metaphysics.
22. The sense of satire; the sense of witticism.
23. The poetical talent.
24. Kindness; benevolence; gentleness; compassion; sensitivity; moral sense.
25. The faculty to imitate; the mimic.
26. The organ of religion.
27. The firmness of purpose; constancy; perseverance; obstinacy.

The right idea,
The wrong method.

3. Lesion Method

- Flourens (1794 –1867):
 - lesioned pigeons and rabbits
 - “all sensory and volitional faculties exist in the cerebral hemispheres and must be regarded as occupying concurrently the same seat in these structures”*
- Broca announces at the Societe d’ Anthropologie in 1861 that left frontal lobe is the seat of speech.
- By 20th century, agreement on cortical specialization for primary sensory and motor functions;
debate continues on localization of higher-level functions
- an important method for answering this question....



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Source: C. Rorden, H. O. Karnath, "Using human brain lesions to infer function: a relic from a past era in the fMRI age?", *Nature Reviews Neuroscience* 5, 812-819, © 2004.

fMRI: functional Magnetic Resonance Imaging



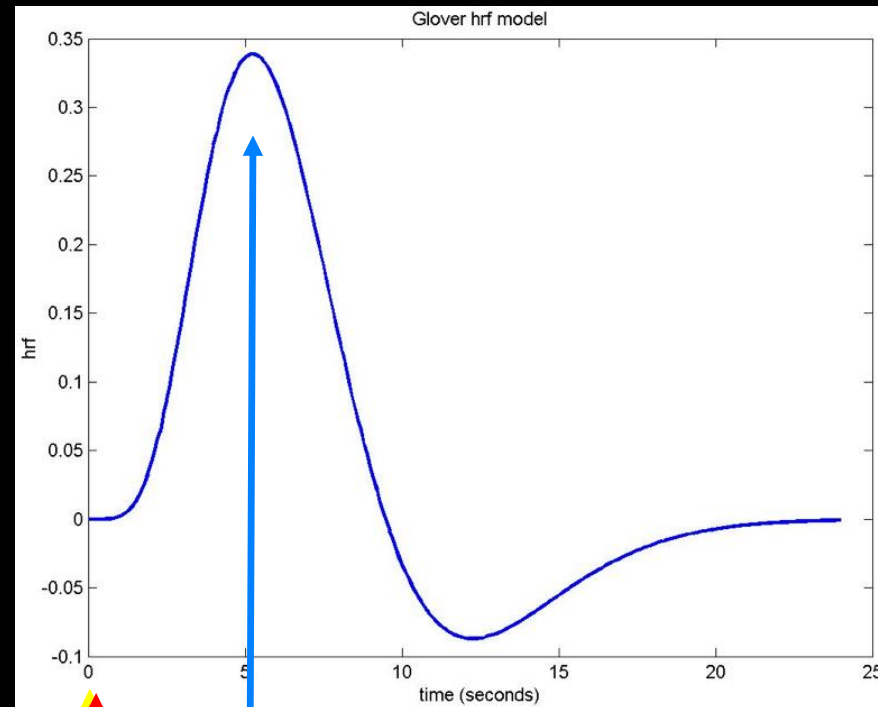
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Increased neural activity >
Increased local blood flow >
Change in oxygenation of hemoglobin
increase in MRI signal

The best spatial resolution available for measuring neural activity noninvasively in the whole human brain.

Format of Raw Data:
~30,000 3D pixels (“voxels”) covering the whole brain sample once every ~2 secs

Temporal Properties of fMRI (BOLD) Response: The hemodynamic response function (HRF)



Visual stimulus on
Neurons fire
BOLD resp

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>>>> BOLD response is *SLOW*, usually peaking around 5-6 seconds after stimulus onset. Several implications.....

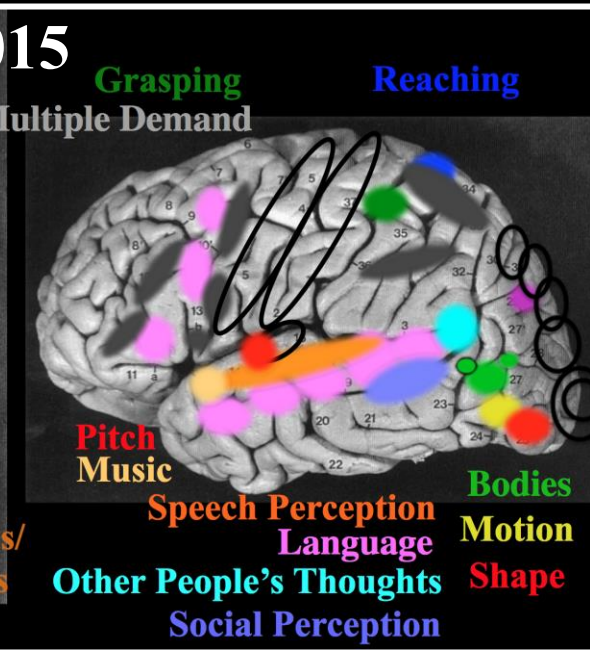
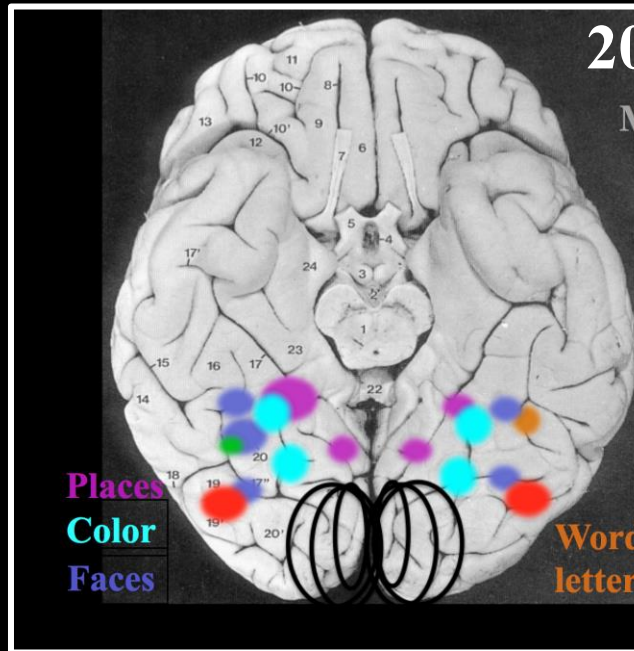
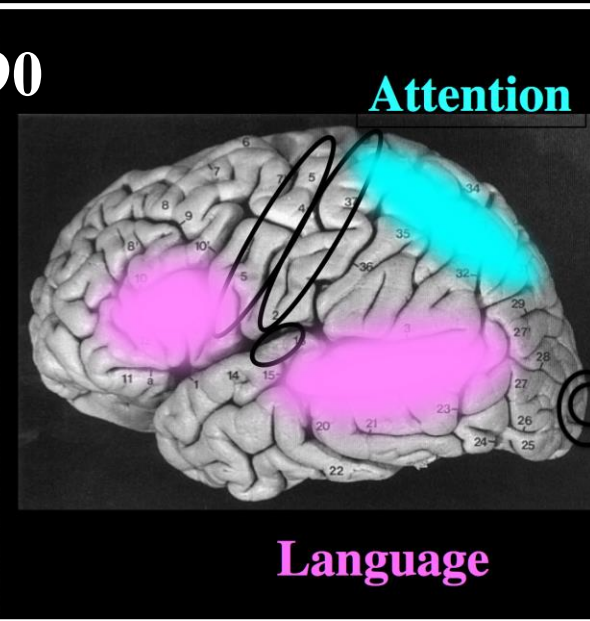
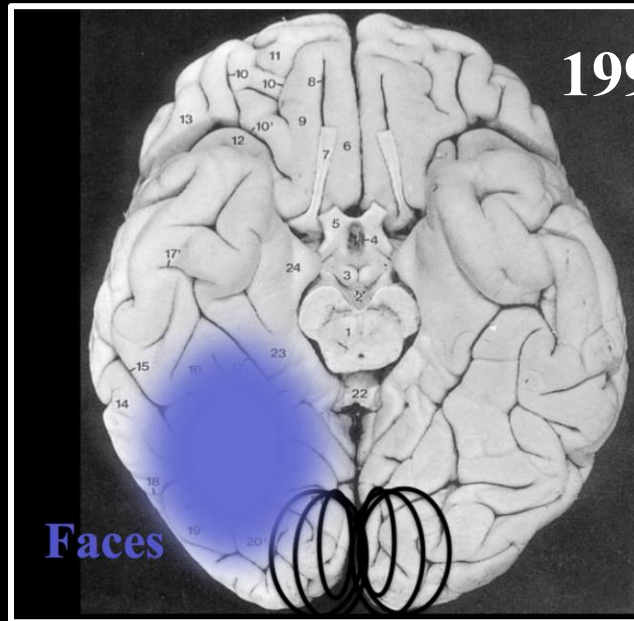
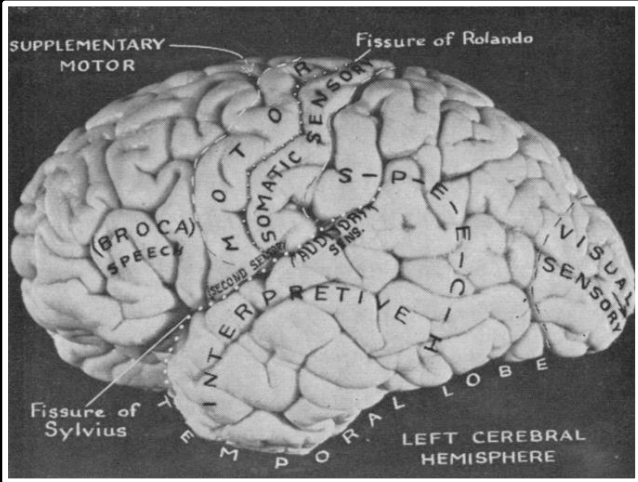
Important aspects of BOLD signal:

- Because the BOLD signal is based on blood flow, the temporal resolution is limited by the precision of blood flow regulation:
a few 100 milliseconds
- Spatial resolution is largely limited by the strength of the signal.
max about 1 mm at 3 T, a little better at 7T
100s of thousands of neurons in each voxel!
- Cannot measure absolute amounts of activity/metabolism,
only *differences* between two conditions.
- Physiological basis of the BOLD signal is unknown
(Action potentials? Synaptic activity? Inhibition?)
- Like other recording methods, cannot test causal role of activity

but even so it has had a major impact...

Functional Organization of the Human Brain

1957



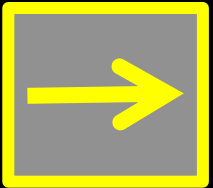
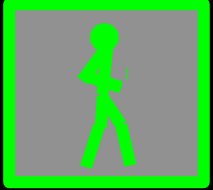
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Source: Penfield, Wilder. "Some mechanisms of consciousness discovered during electrical stimulation of the brain." Proceedings of the National Academy of Sciences 44, no. 2 (1958): 51-66.

& then fMRI came along...
 >>A (blurry!) picture of the architecture of human intelligence

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The Functional Architecture of Intelligence



- The human mind and brain contains a set of highly specialized components, each solving a different, specific problem.
- Each of these regions is present in ~every normal person.
- These regions are basic components of the human mind/ brain.
- This view is often confused with different ideas
 - let's consider them to get precise about what we mean...

Important to distinguish these different ideas:

1. Functional specificity

Is this brain region only/primarily engaged in specific mental process X?

2. Anatomical Specificity

Is this the *only* brain region that conducts this mental function?

existence of several regions selectively involved in X is not evidence against #1

3. Necessity

Is this region *necessary* for mental function X?

This is what we most want to know: causal role.

4. Sufficiency

Is this region *sufficient* for the mental function? (never)

5. Interaction/connectivity.

Is this region “part of a network” and does it interact with other regions?

Answer is always yes.

In no way does this argue against #1.

6. Innateness.

Is this region innately specified or is its specificity determined by experience?

A key question, rarely answerable, *completely orthogonal to #1*.

Functional specificity of a brain region need not imply innateness!

Selectivity of visual word/letter region must be crafted by that individual’s experience

For more info, see NBT video: What is the Role of Experience in the Development of Face Recognition

Neuroimage. 2008 Apr 1;40(2):415-9. Epub 2007 Nov 7.

Let's face it: it's a cortical network.

Ishai A¹.

This Idea of Functional Specificity is Unpopular

Huettel et al (2004): *"unlike the phrenologists, who believed that very complex traits were associated with discrete brain regions, modern researchers recognize that a single brain region may participate in more than one function"*.

Lisa Feldman Barrett (NYT July 31 2015): *"In general, the workings of the brain are not one-to-one, whereby a given region has a distinct psychological purpose"*.

Uttal (2011): *"Any studies using brain images that report single areas of activation exclusively associated with any particular cognitive process should a priori be considered to be artifacts of the arbitrary thresholds set by investigators and seriously questioned."*

Please engage with the **data!**
Here is some of mine.....

Evidence for Functional Specificity

fROI Method:

1. Functionally identify the region in each individual
2. Then measure its response in new conditions

strong selectivity, tested against lots of alternatives

present in virtually every normal subject

part of the basic architecture of the brain

Legitimate

Counterarguments exist

pattern analysis

causal role

etc.

will return to this

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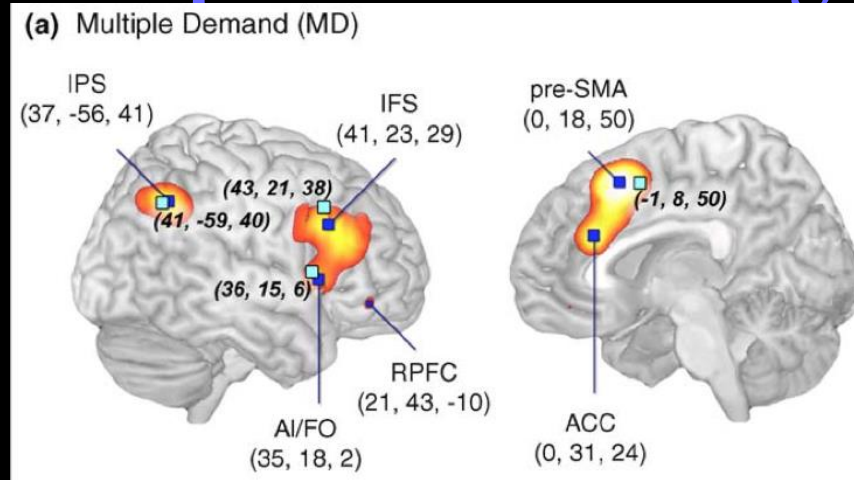
Evidence for Functional Specificity

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What I Mean by Functional Specificity

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“Multiple Demand” Regions



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Source: Duncan, John. "The multiple-demand (MD) system of the primate brain: mental programs for intelligent behaviour." Trends in cognitive sciences 14, no. 4 (2010): 172-179.

- **engaged in a wide variety of difficult cognitive tasks**
hence “multiple demand”
- **related to fluid intelligence:**
activated during fluid intelligence tasks
causal role in fluid intelligence
6.5 IQ pts/ 10 cm³ of MD cortex
- **critical for solving novel problems**

A stronger test of this idea....

MIT OpenCourseWare
<https://ocw.mit.edu>

Resource: Brains, Minds and Machines Summer Course
Tomaso Poggio and Gabriel Kreiman

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