9.13 The Human Brain Class 4

Outline for Today: Methods in Cog Neuro 1

I. Marr Computational Theory Level of Analysis

Case study: Color Vision

Rosa's Demo in Imaging Center Waiting Room

Discussion: What do we use color for?

Lecture: Computational challenges in color vision

II. Methods in Cognitive Neuroscience Methods, & the Questions they answer, applied to face perception (Part 1 of 2)

A. Computational theory.

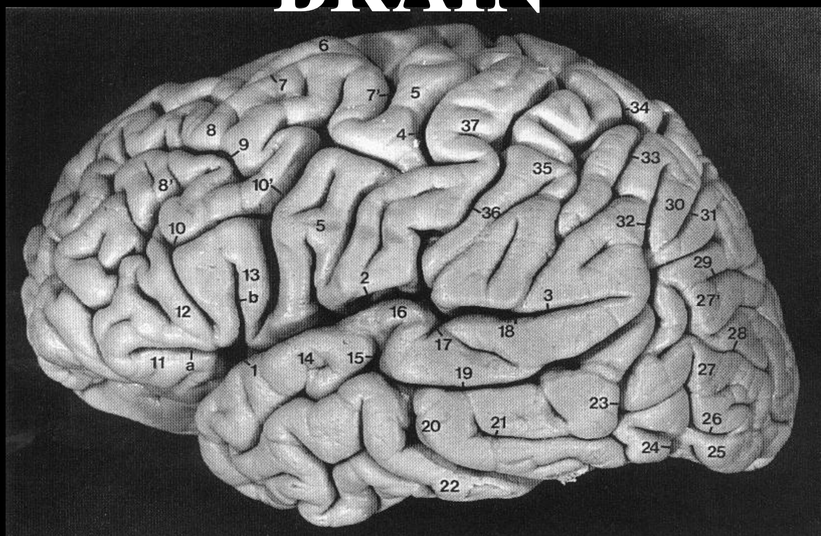
B. Behavior

C. fMRI

this part will be continue on Wednesday with other methods

The Main Question Considered in this Course:
How does the Brain give rise to the Mind?

BRAIN



?

MIND

Problem # 1. What is a mind anyway?

Standard working framework:

Mind = a set of *computations* that extract *representations (= percepts/thoughts)*.

So: Ideally, if we really understood the mind, we would be able to write code that carries out the same computations and extracts the same representations.

Mostly we cannot do this yet, but that is the goal.

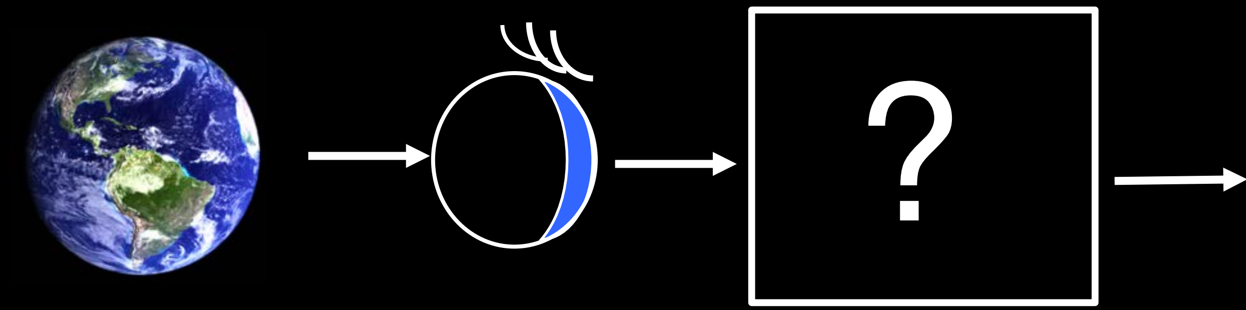
How do we get started even trying to think about this?

By first thinking about *what is computed and why*.

Marr's big insight is that this is the necessary first step, before empirical studies of minds or brains

How does the brain give rise to the mind?

Let's take vision for example: Let's get more specific: visual motion.



Knowledge of what you are looking at.

The mind is a set of *computations* that extract *representations*.
Ideally, if we really understood the mind, we would be able to write code that carries out the same computations and extracts the same representations.
Mostly we cannot do this yet, but that is the goal.
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How does the brain give rise to the mind?

Let's take vision for example:

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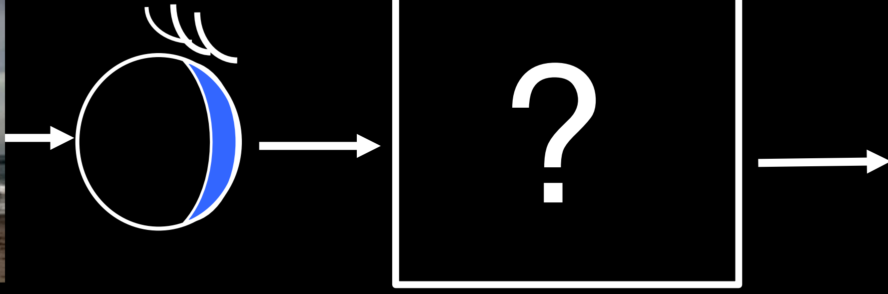


presence of motion?
presence of person?
motion from R to L?
jumping?
health?
mood?

To understand this, we need to know:

What is computed and why?
What are the inputs? What are the outputs?
What are the computational challenges in getting from inputs to outputs?
Marr: this is a prerequisite for understanding minds, and hence brains.

The mind is a set of *computations* that extract *representations*.
Ideally, if we really understood the mind, we would be able to write code that carries out the same computations and extracts the same representations.
Mostly we cannot do this yet, but that is the goal.
How do we get started even trying to think about this?
By first thinking about *what is computed and why*.

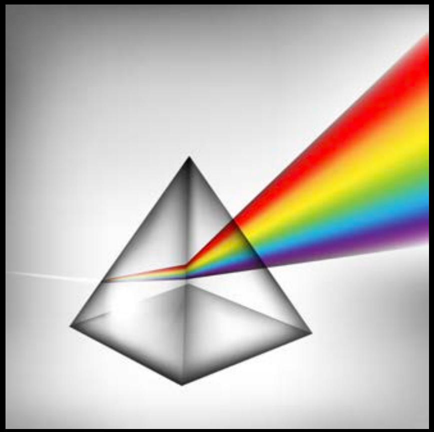
“Trying to understand perception by studying only neurons is like trying to understand bird flight by studying only feathers; it just cannot be done. To understand bird flight, you need to understand aerodynamics, only then can one make sense of the structure of feathers and the shape of wings. Similarly, you can't reach an understanding of why neurons in the visual system behave the way they do, just by studying their anatomy and physiology. “

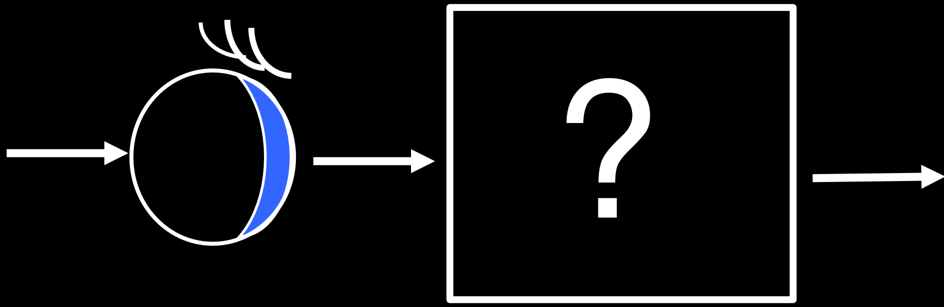
"The nature of the computations that underlie perception depends more upon the computational problems that have to be solved than upon the particular hardware in which their solutions are implemented. “

Marr, 1982

To better understand this, let’s apply this question to another case: Color vision.

Let’s Ask Computational Theory Questions about Color





what do we use color for?
what are the outputs?
let’s try to think about this by experiencing what we miss when we do not have color info.....

To understand this, we need to know:

What is computed and why?

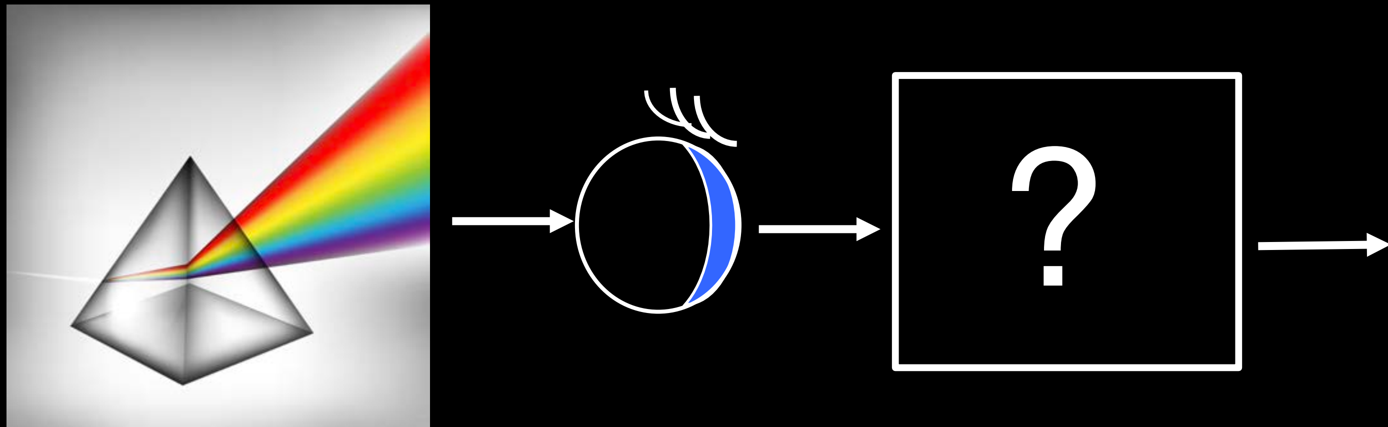
What are the inputs? What are the outputs?

What are the computational challenges in getting from inputs to outputs?

Marr: this is a prerequisite for understanding minds, and hence brains.

Off to Scanner waiting room
for Rosa Lafer-Sousa’s demo

Computational Theory Level Questions about Color



what do we use color for?

To understand this, we need to know:

- What is computed and why?
- What are the outputs?
- What are the inputs?
- What are the computational challenges in getting from inputs to outputs?

What do we use Color Vision for?

Standard story: to find fruit
How many berries?

And tell if it is ripe:

Indeed, macaques with 3 kinds of cone photoreceptors (like us) are faster at finding fruit than genetic variants with only two. (Melin, 2017)

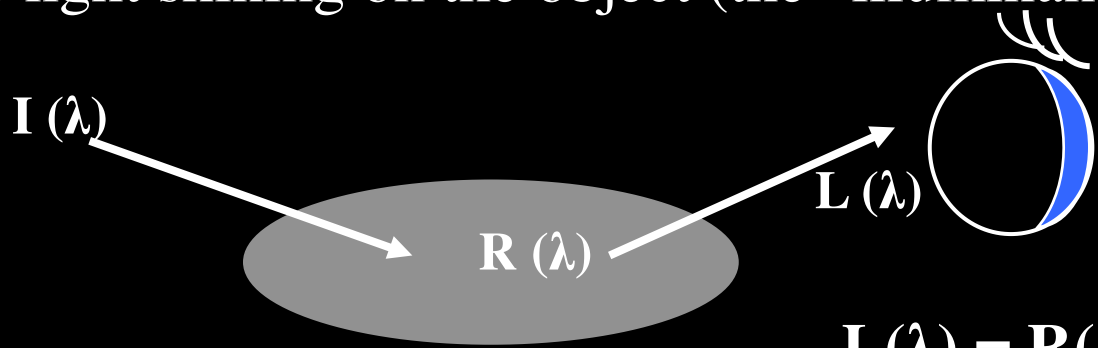
but there is a problem determining the color of an object…..

The problem:

We want to determining the color (or R, "reflectance") of an object.

But all we have is the light coming to us from the object (L).

And that light L is a function not only of the object, but also of the light shining on the object (the "illuminant" or I):



$$L(\lambda) = R(\lambda) \times I(\lambda)$$

Given L, what is R?

Uh-oh.

Like: A x B = 48, please solve for A and B.

This is an "ill-posed" or "underdetermined" problem.

Implications: Inferring R from L requires other info or assumptions about I.

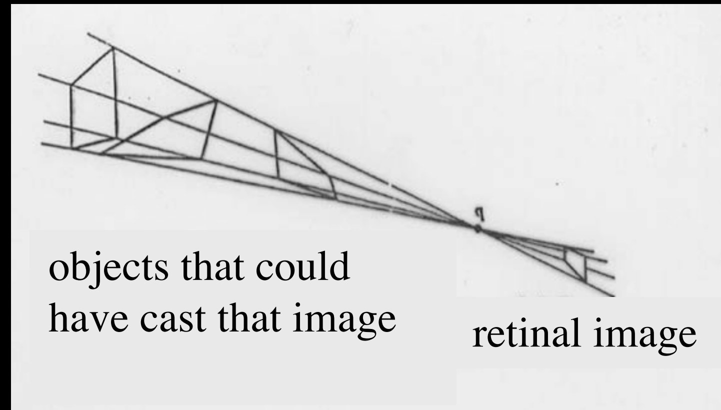
Big point: *Many inferences in perception and cognition are ill-posed*.

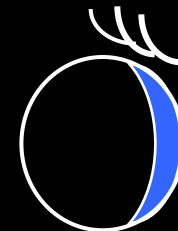
Two other examples…..

The Ill-Posed Nature of Much of Perception/Cognition

1. Shape Perception

World/
Visual field





Eye/
Retinal image

Vision as "inverse optics"

The Problem: Each retinal image could have been cast by many diff. objects. Inverse optics is "ill-posed", need other constraints to solve.

2. Word Learning

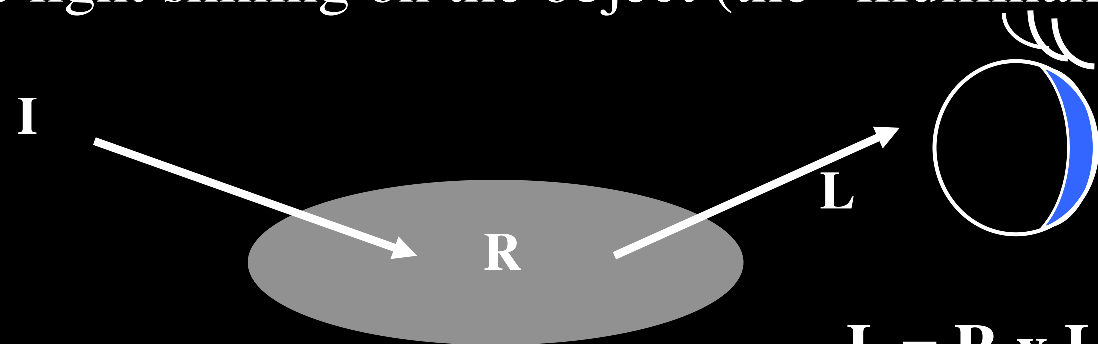
Many possible meanings
of a word;
which to learn?
Infants must add other
constraints to solve.

Problem: What does "gavagai" mean?
rabbit?
fur?
ears?
motion?
"undetached rabbit-parts"
....

The problem:

We want to determining the color (or R, “reflectance”) of an object.

But all we have is the light coming to us from the object (L).
And that light L is a function not only of the object, but also of the light shining on the object (the ”illuminant” or I):



L = R x L

Given L, what is R?

Uh-oh.

Like: X x Y = 8, please solve for X and Y.

This is an “ill-posed” or “underdetermined” problem.

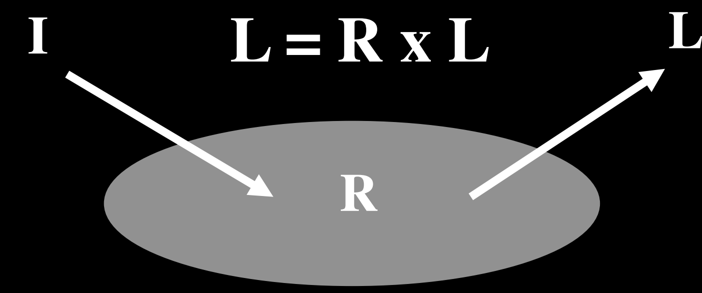
Implications: Inferring R from L requires other info or assumptions about I.

Big point: *Many inferences in perception and cognition are ill-posed.*

So require extra knowledge/assumptions about the physics/statistics of the world.

Marr's Levels of Analysis applied to Color Vision

<u>I. Computational theory</u>



what information is extracted and why?

R, useful for characterizing objects

what cues are available?

only L!

is the inference ill-posed?

Yes! because I is unknown

what regularities in the world constrain the inference?

what other sources of information might constrain I?

all of this with no data about mind or brain or machines!

just thinking, with a little optics, physics, ecology

one way: psychophysics! just asking people what they see for example….

<u>II. Algorithm/representation</u>

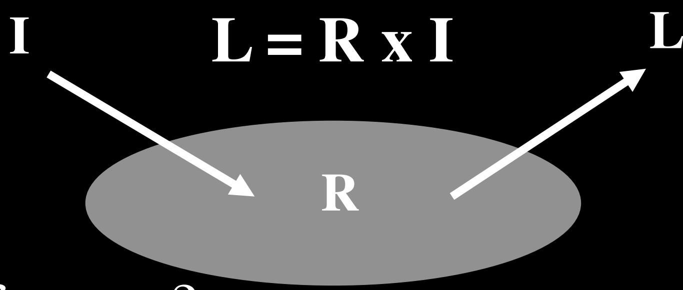
how does the system do what it does, i.e.

can we write the code to do this?

what assumptions, computations representations?

how would we find out?

Marr's Levels of Analysis



<u>I. Computational theory</u>

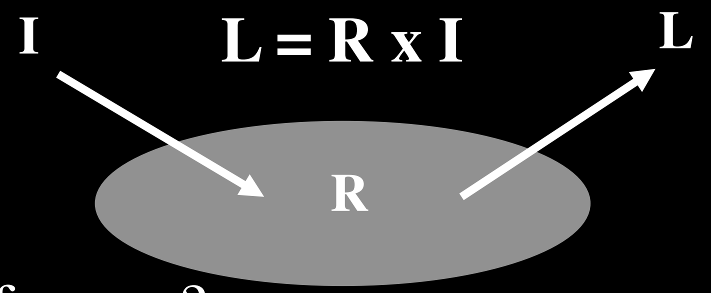
what information is extracted and why?
what cues are available?
is the inference ill-posed?
what regularities in the world constrain the inference?

<u>II. Algorithm/representation</u>

how does the system do what it does, i.e.
what assumptions, computations representations?
can we write the code to do this?

Behavior, or psychophysics, (including illusions) can reveal the assumptions the human perceptual system uses to constrain ill-posed problems.
In this case, assumptions we made about I to enable us to infer R from L.

Marr's Levels of Analysis



I. Computational theory

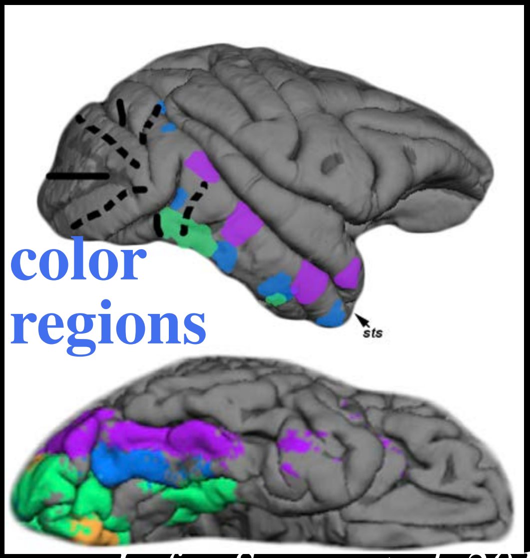
what information is extracted and why?
what cues are available?
is the inference ill-posed?
what regularities in the world constrain the inference?

II. Algorithm/representation

how does the system do what it does, i.e.
what assumptions, computations representations?
can we write the code to do this?

III. Hardware implementation

how is the system physically realized
in neurons & brains



Big Point:
Need many levels of analysis to understand minds & brains.
And many methods to answer these questions….

Lafer-Sousa et al, 2016

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Demo

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Lecture: Computational challenges in color vision

II. Methods in Cognitive Neuroscience & the questions they answer, applied to face perception (Part 1)

A. Computational theory

B. Behavior

C. fMRI

and lots of other methods (continued tomorrow)....

why face perception?

Face Perception: Who Cares?

What do we need face perception for?
I don't have a demo that enables you to experience life without face recognition.
But I can tell you about what it is like.
From the case of Jacob Hodes' freshman year at Swarthmore...

more technically...

See also:
https://www.cbsnews.com/news/60-minutes-face-blindness-when-everyone-is-a-stranger/

Face Perception is Important Because

Faces are enormously informative stimuli:

- they convey information about a person's:
  identity, age, sex, mood, race, direction of attention
  maybe aspects of personality (e.g., is this person trustworthy?)

Faces are among the stimuli we look at most frequently in daily life

Face perception abilities were probably important to our ancestors' survival

What questions do we want to answer about face recognition,
and what methods can we use to answer them?

Face Recognition: What we want to know

Some Key Questions about Face Recognition:

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level

2. How does face recognition work in humans?
   what computations, what representations?
   is this answer different for face versus object reocognition?

3. Is face perception a distinct system from the rest of vision/cognition?

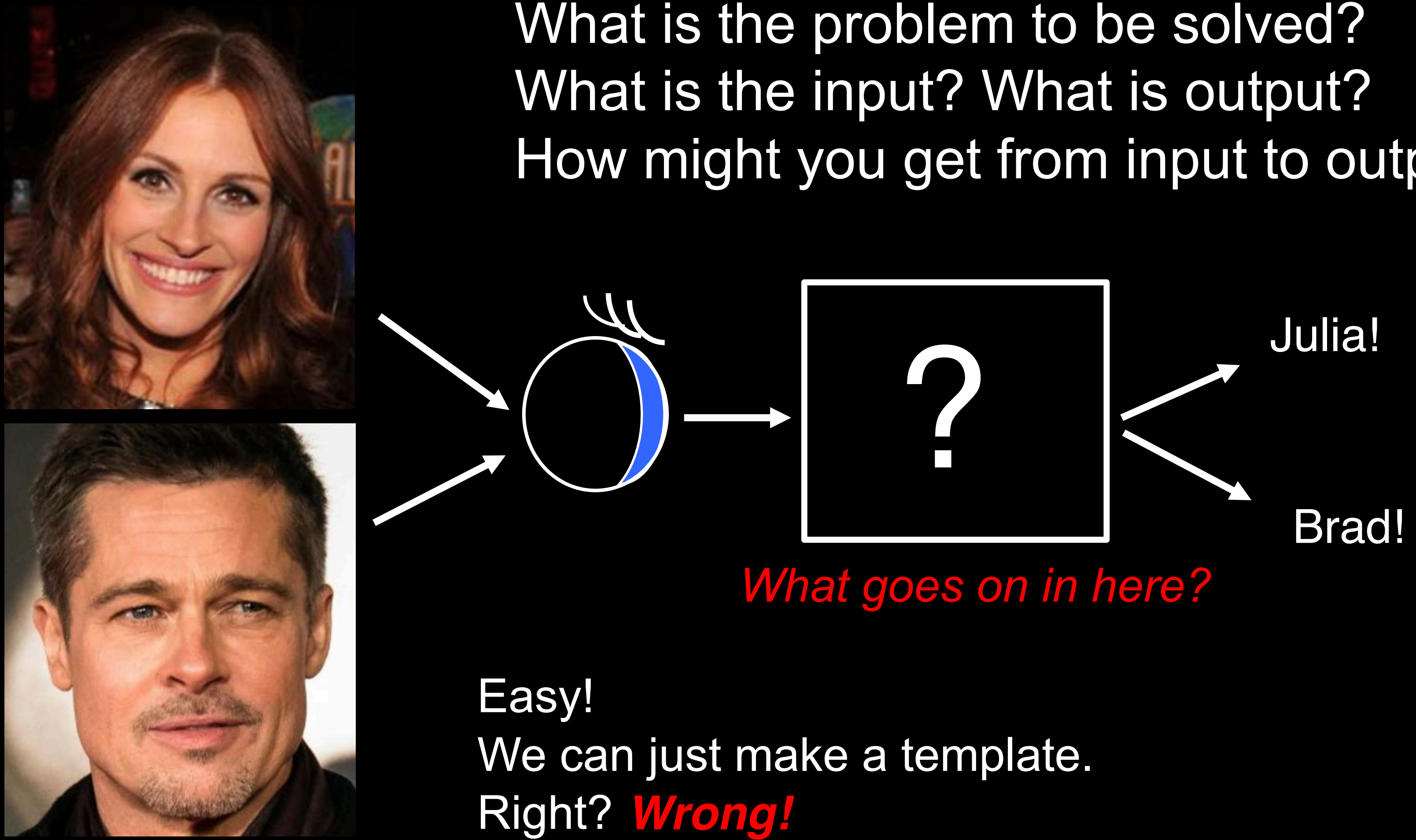
4. How fast are faces detected and recognized?

5. How is face recognition implement in individual neurons/circuits?

6. What is the causal role of each brain region in face recognition?

Face Recognition: Computational Theory

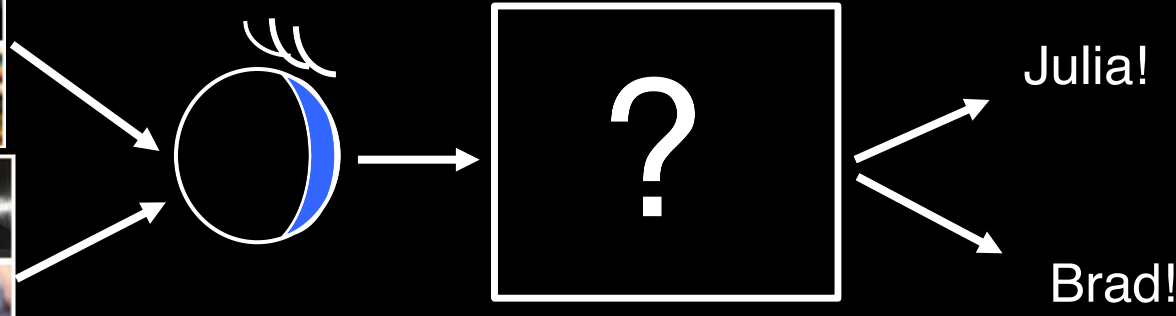
What is the problem to be solved?
What is the input? What is output?
How might you get from input to output?



What goes on in here?

Easy!
We can just make a template.
Right? ***Wrong!***

The Problem of Face Recognition



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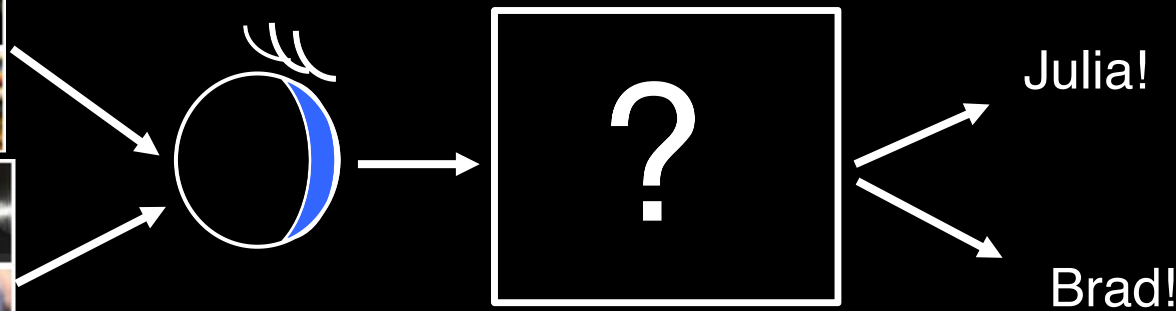
Right? ***Wrong!***

The same person (or thing) casts infinitely many different images as it changes in
position, distance/size, viewpoint, lighting, expression, hair….
Yet we still recognize individuals across these changes. How is this possible?
memorize lots of templates?
extract an “invariant” representation? (e.g. close eyes?)

The Problem of Face Recognition

Machine face recognition didn't work very well, until recently.
So we did not have working computational models for how face recognition *might* work until a few years ago...



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The Problem of Visual (Face) Recognition

Machine face recognition didn't work very well, until recently.
So we did not have working computational models for how face recognition *might* work until a few years ago...

[PDF] **Deep face recognition.**
OM **Parkhi**, A **Vedaldi**, A **Zisserman** - bmvc, **2015** - cis.csuohio.edu
The goal of this paper is face recognition–from either a single photograph or from a set of faces tracked in a video. Recent progress in this area has been due to two factors:(i) end to end learning for the task using a convolutional neural network (CNN), and (ii) the availability of very large scale training datasets. We make two contributions: first, we show how a very large scale dataset (2.6 M images, over 2.6 K people) can be assembled by a combination of automation and human in the loop, and discuss the trade off between data purity and time; …
☆ 99 Cited by 1754 Related articles All 8 versions »

'VGG-face' is very accurate at face recognition.
So, it is a possible model of how face recognition might work in humans.
That is progress.
But: It is not clear exactly how VGG-face itself works.
Or whether human face recognition works in a similar way.
So, what do we know about how face recognition works in humans?

Face Recognition: What we want to know

Key Questions about Face Recognition:

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level
   major challenge: huge variation across images of a single face

2. How does face recognition work in humans?
   what computations, what representations?
   is this answer different for face versus object reocognition?
   if it is after 12:10, skip to #3 for now

3. Is face perception a distinct system from the rest of vision/cognition?

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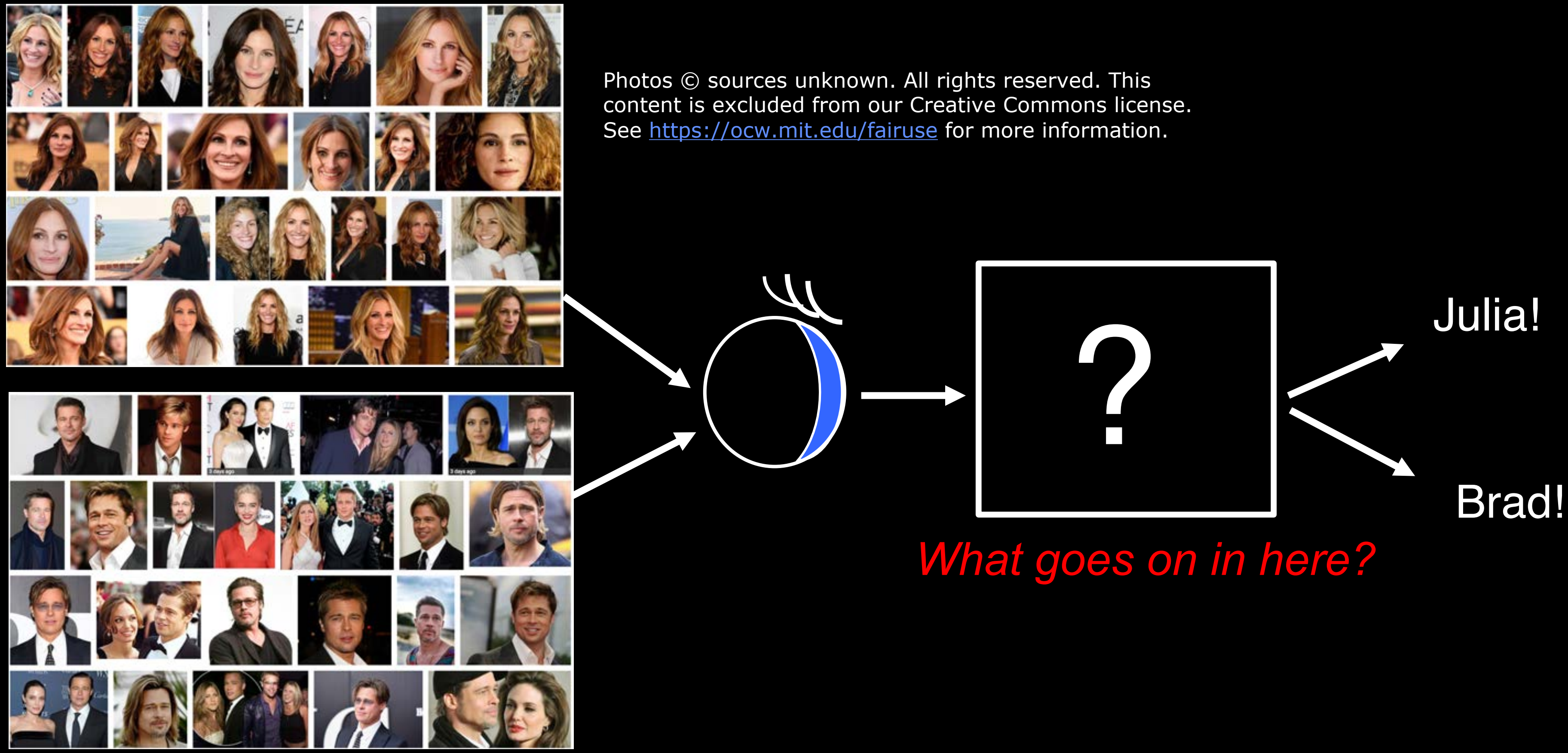
How does Face Recognition Work in Humans?



What goes on in here?

We recognize individuals across these changes. How is this possible?

memorize lots of templates? << This should *not work for unfamiliar faces.*

extract an "invariant" representation? << This should work for unfamiliar faces.

Which story is right for humans?

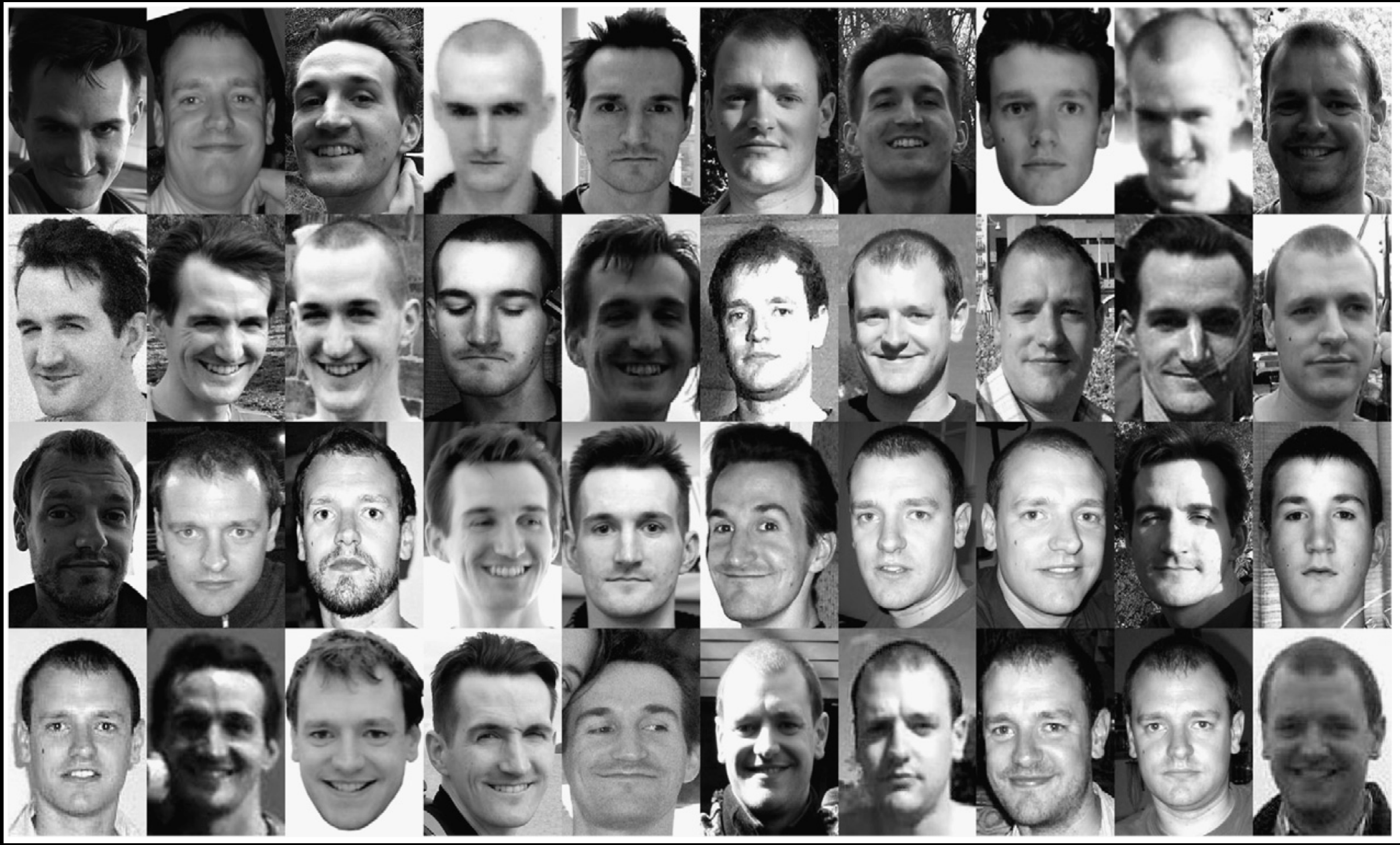
Key test: can we tell if two different photos are of the same person *if we do not know that person?*

Can we Match Different Photos of the Same Unfamiliar Person?

Jenkins et al, Cognition, 2011

1. Collected photos off the web of Dutch politicians, will multiple images of each.
   Asked subjects to sort them into different piles of the same identity.
   Let's try it……..

How many different people are here?



Courtesy Elsevier, Inc., https://www.sciencedirect.com. Used with permission.

Can we Match Different Photos of the Same Unfamiliar Person?

Jenkins et al, Cognition, 2011

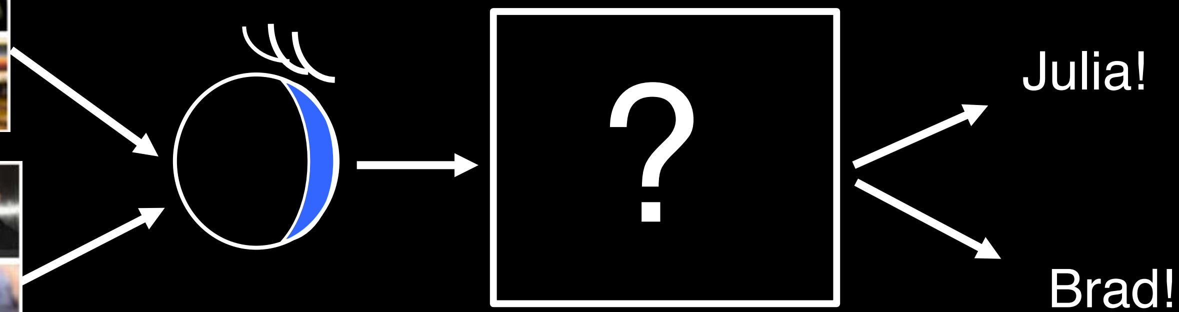
1. Collected photos off the web of Dutch politicians, will multiple images of each. Asked subjects to sort them into different piles of the same identity.
   How many think there are over ten different people? under 10? over 5? under 5?
   Actually, there are only TWO!

2. The mean number of piles made by Jenkins' subjects…..
   7.5!
   None of Jenkins' subjects got it right (range: 3-16)
   maybe these were just low-quality photos?
   to find out…..

3. They tested Dutch subjects *who know these two politicians*, and….
   almost everyone performed perfectly.

So...

What Representations do we Extract from Faces?



What goes on in here?

We recognize individuals across these changes. How is this possible?

memorize lots of templates? << This should work *only for familiar faces.*

extract an "invariant" representation? << This should work for unfamiliar faces.

Which story is right for humans?

You tell me!

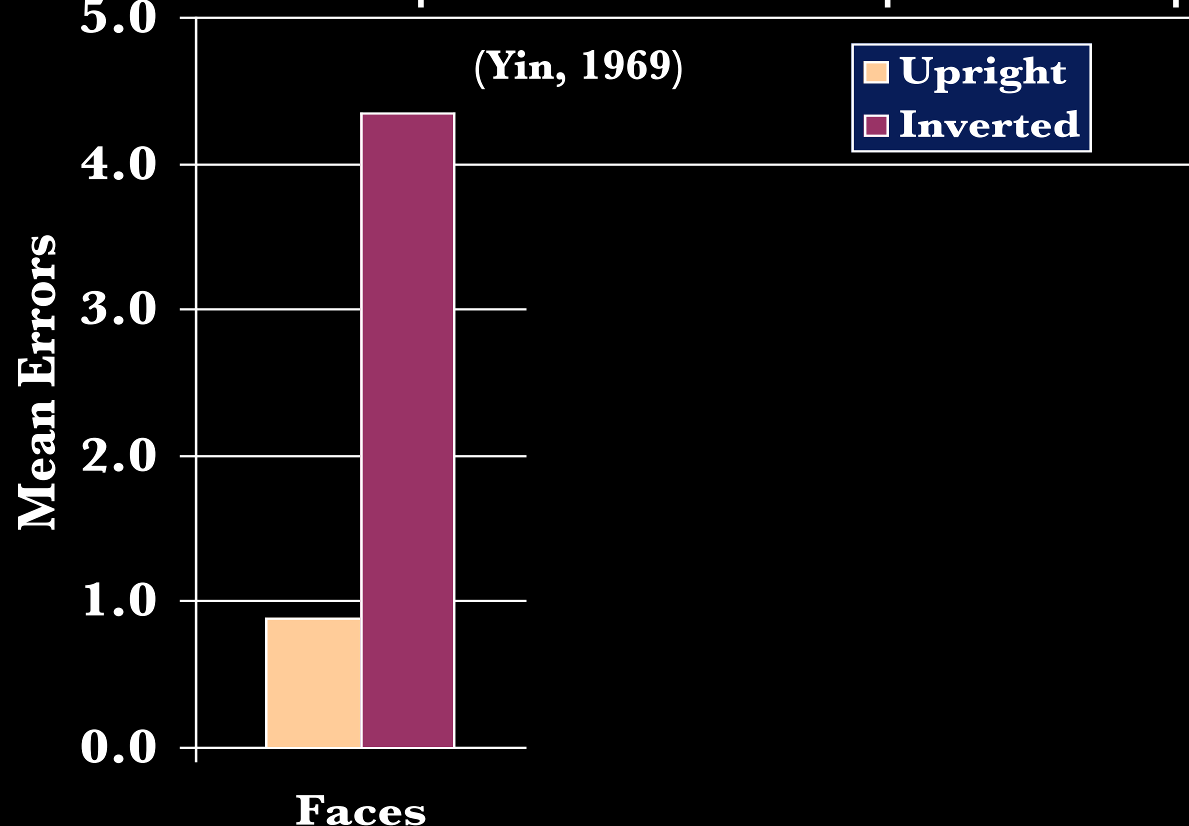
What are these templates like? probably not literal pixel arrays in the head...

Lots of cool behavioral studies that have told us a great deal about this. E.g.,

A Low-Tech but Profound Discovery Made in this Department in 1969

The "face inversion effect":

An increase in errors for upside-down compared to upright stimuli



The Inversion effect is *greater for faces than other stimuli.*

Suggests face recognition may work differently from object rec.

Many different versions of the face inversion effect....

Face Recognition: What we want to know

Key Questions about Face Recognition:

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level

   major challenge: huge variation across images of a single face
2. What is the nature of the representations we humans extract form faces?
   not image invariant
   orientation specific

   insights from simple behavioral data
3. Is face perception a distinct system from the rest of vision/cognition?

4. How fast are faces detected and recognized?

5. How is face recognition implement in individual neurons/circuits?

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Strengths and Weakness of Behavioral Methods

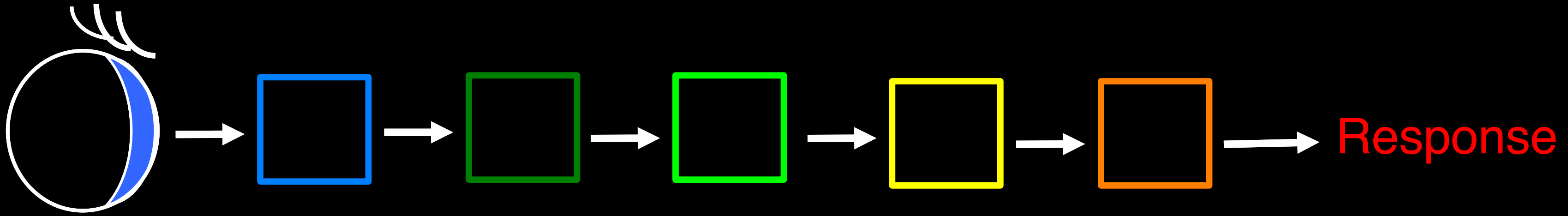
Strengths:

1. Good for characterizing internal representations.
   at least qualitatively
2. Good for dissociating distinct mental phenomena.
   e.g. face versus object processing
3. Cheap!

Weaknesses:

1. No relationship to the brain, at least not without further information

2. Data are sparse: all we have is the output of the final stage,
   but we would like to characterize each stage in the whole sequence of processing.
   Many ways to do this, but a particularly powerful one is fMRI….



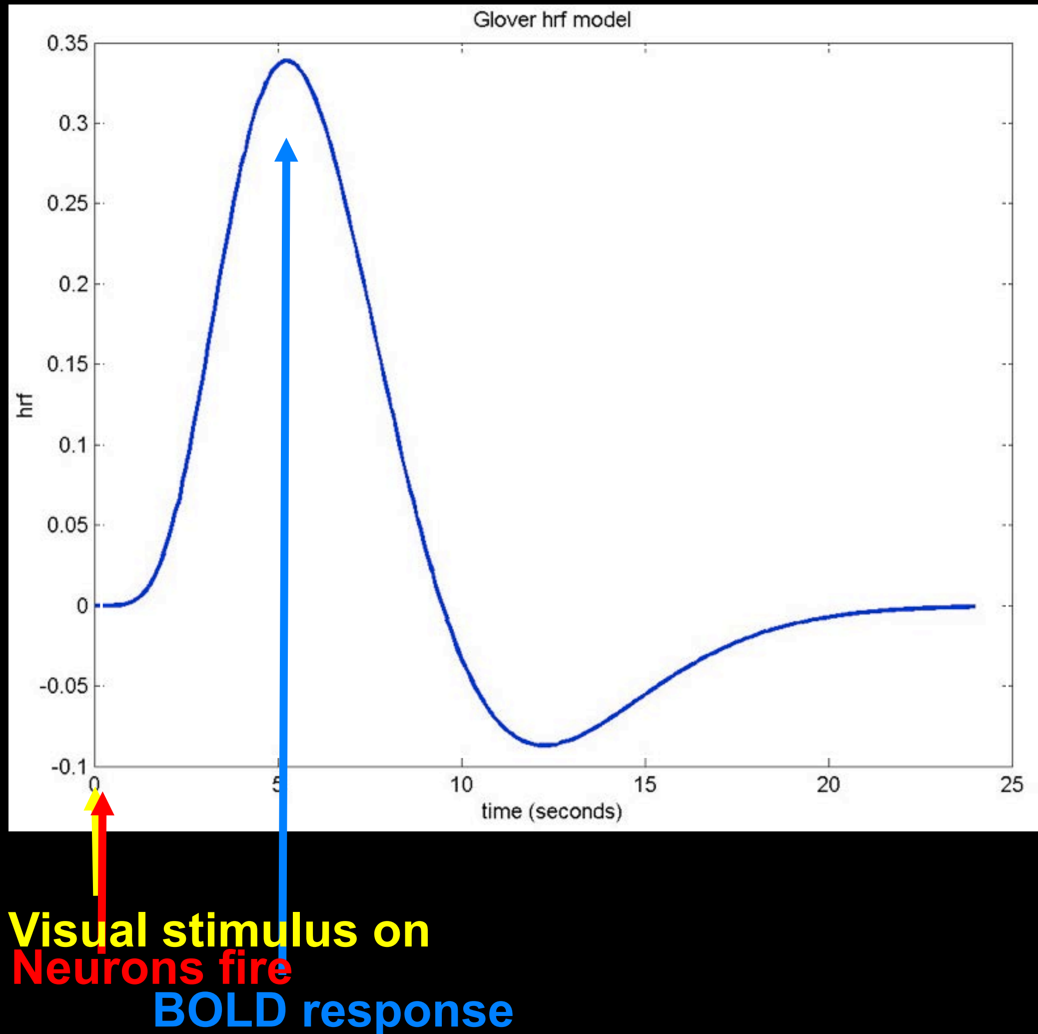
Functional Magnetic Resonance Imaging (fMRI)

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

Because this is a blood-flow based signal….

“BOLD” (blood oxygenation level dependent) signal:
Increased neural activity >
Increased local blood flow more than compensates for O_2 use >
decrease in deO_2Hb concentration>
increase in MR signal intensity (deO_2Hb is paramagnetic)

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



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

Important caveats about the BOLD fMRI signal:

- Because the BOLD signal is based on blood flow, the spatial & temporal resolution is limited: ~ 1 mm; > a few 100 milliseconds

- Physiological basis of the BOLD signal is unknown (Action potentials? Synaptic activity? Inhibition?)

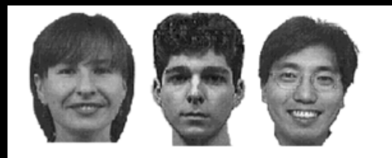
- Cannot measure absolute amounts of activity/metabolism, only *differences* between two conditions.

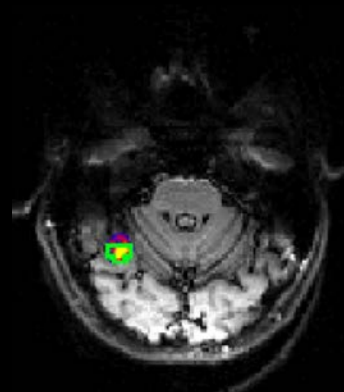
- Nonetheless we can use it to find cool stuff……

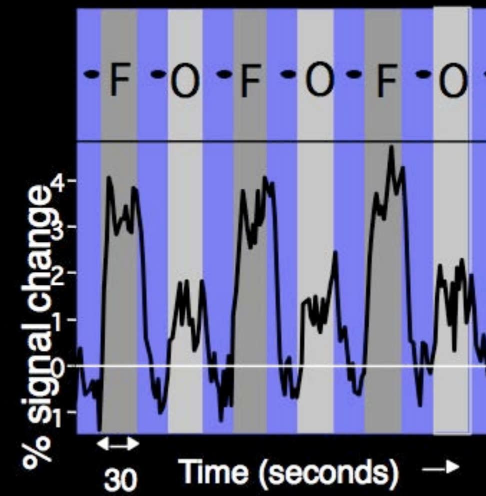
Is there a region in the brain specialized for face recognition?

Maybe!

1. Scan subjects while they view faces and objects



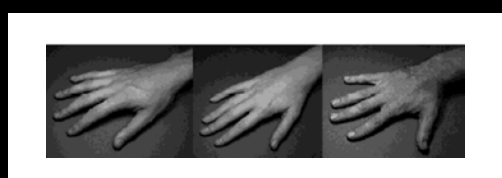




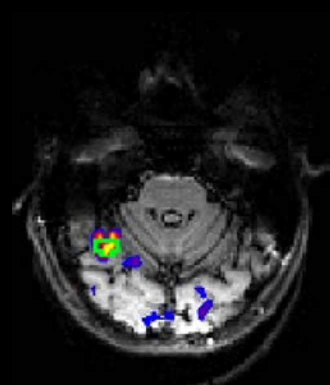
Alternative hypothesis: Is there a simpler account of this response?

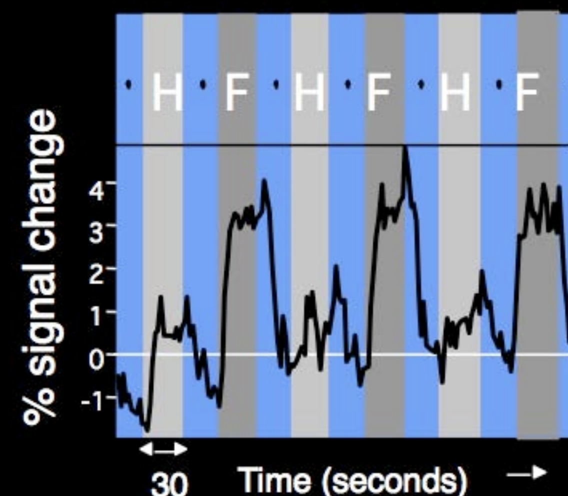
2. Does it respond to

~~anything human?~~ ~~any body part?~~ ~~anything attended?~~ ~~anything curvy?~~



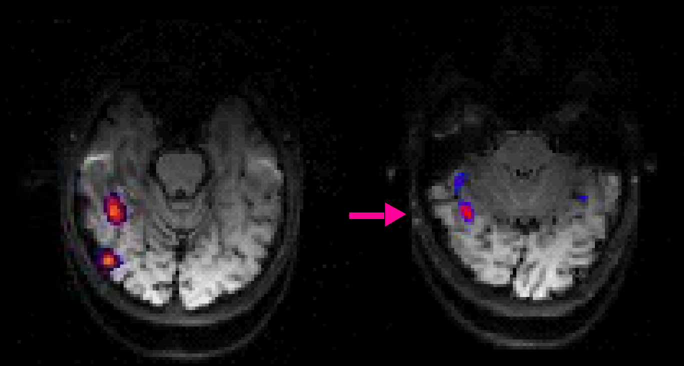
(1-back)

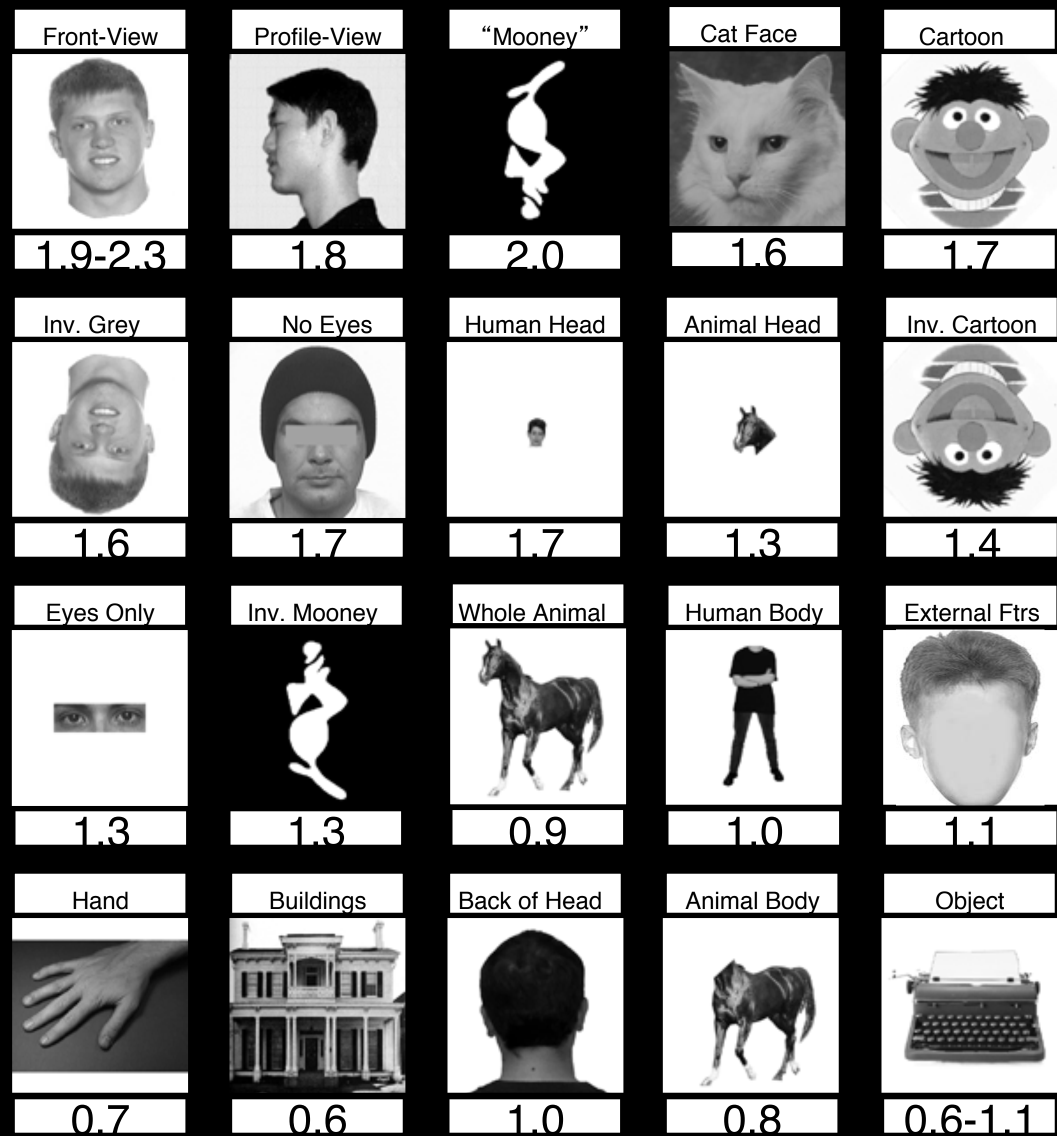




Can you think of a stimulus that looks a lot like a face but is not processed like a face?

Fusiform Face Area





Clearly prefers faces.
Some response to nonfaces, but much less.
Present in ~every normal person.
So, where are we now?

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2. What is the nature of the representations we humans extract form faces?
   not image invariant
   orientation specific
3. Is face perception a distinct system from the rest of vision/cognition?

   Looks like it, from both behavior and fMRI, but we have not yet nailed the case.
   Think about why.

4. How fast are faces detected and recognized?

5. How is face recognition implement in individual neurons/circuits?

6. What is the causal role of each brain region in face recognition?

Important Points from Today

1. Marr computational theory: to understand a perceptual or cognitive process need to
   Think about the nature of the computation being solved
   What inputs? what outputs?
   What makes each inference computationally challenging?
   Examples: color perception, face recognition
2. Even low-tech behavioral experiments can provide insights
   about the computations entailed in a mental process
   e.g. lack of "invariance" for unfamiliar faces
   and disproportionate inversion effect fof faces
3. fMRI suggests that distinct neural tissue is engaged in face vs object recognition.

And we'll learn more about face recognition,
and the methods we can use to study it
tomorrow!