Introduction to pattern analysis

Neuroimaging: Pattern Analysis 2017

Scope (1)

- Introducing the *concept* of pattern analyses
  - … & how it relates to other neuroimaging analyses
  - Conceptual rather than practical
  - Details will follow in week 2 (decoding) and 3 (RSA)

Scope (2)

- This lecture (and course in general) is mainly about pattern analyses of **task-based functional MRI** (fMRI), but it's (mostly) equally applicable to other neuroimaging data
  - Structural MRI, such as gray-matter based data (VBM) and white-matter based data (DTI/TBSS)
  - MEG/EEG data

Learning goals

- How are pattern analyses similar/different than 'traditional' fMRI analyses?
- What are the major 'flavors' of pattern analyses?
- How to estimate patterns?
- What factor(s) determine my choice of analysis?

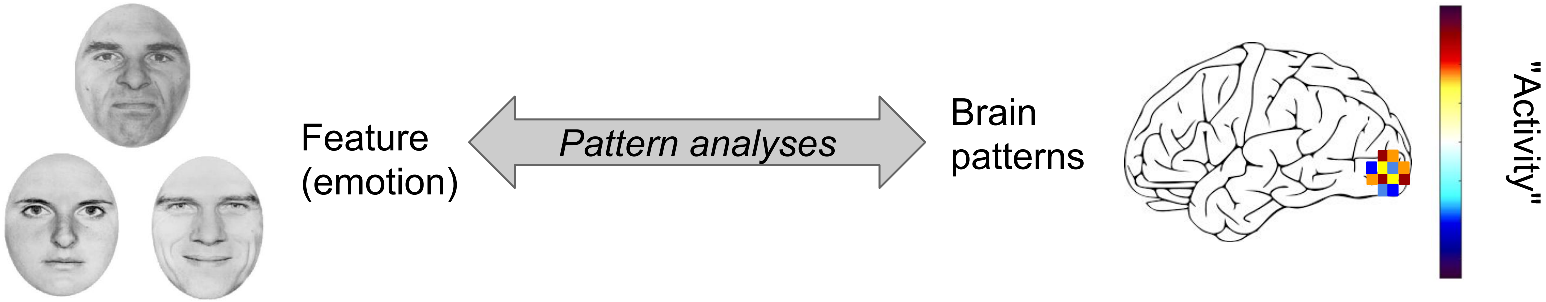
Contents

- PART 1: What is a pattern and how to analyze it?
  - Encoding vs. decoding
  - Machine learning vs. Representational Similarity Analysis
- PART 2: How to estimate patterns?
  - Within vs. between-subject designs
  - Different methods to 'extract' patterns

PART 1:
WHAT IS A PATTERN AND HOW TO ANALYZE IT?

What is pattern analysis?

... basically any analysis that relates ***patterns*** of voxels (or sensors in M/EEG) to features in the world (psychological processes, stimuli, traits, or behavior)



This is a very broad definition, but bear with me ...

What is pattern analysis?

- The most popular pattern analyses are **decoding** ('machine learning') **analyses** and **representational similarity analyses** (RSA)
- They both use *patterns* of brain activity in their models, but in a **different** way (we'll get to that)

Disclaimer

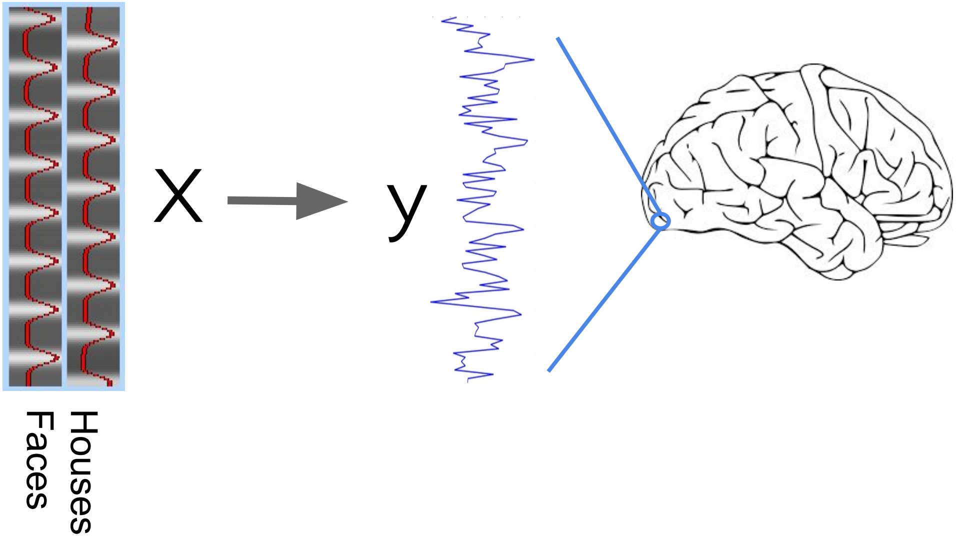
- In the literature, different names for 'pattern analysis' are used:
  - Multivoxel Pattern Analysis (MVPA)
  - Multivariate Pattern Analysis
  - Information-based analysis (versus 'activation-based analysis)
  - Representational analyses

Single voxels vs. patterns

- So how does pattern analysis **differ** from the standard 'activation-based' analyses you are familiar with?
    - Activation-based analyses "use" only *one voxel at the time*

Single voxels vs. patterns

- Activation-based analyses "use" only *one voxel at the time*

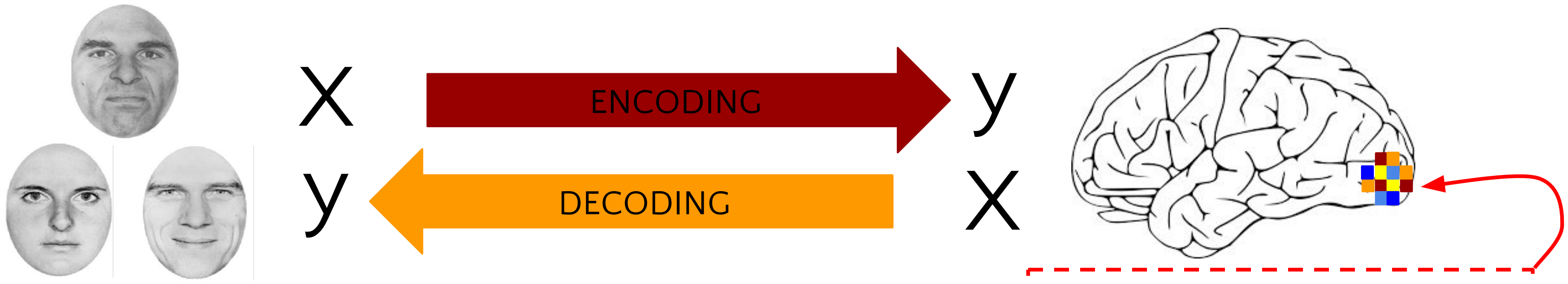


- Always map from stimulus (X) to brain (y)
- This makes it a (very simple) **encoding model**

"Uuuh ... what's an encoding model?"

Encoding vs. decoding

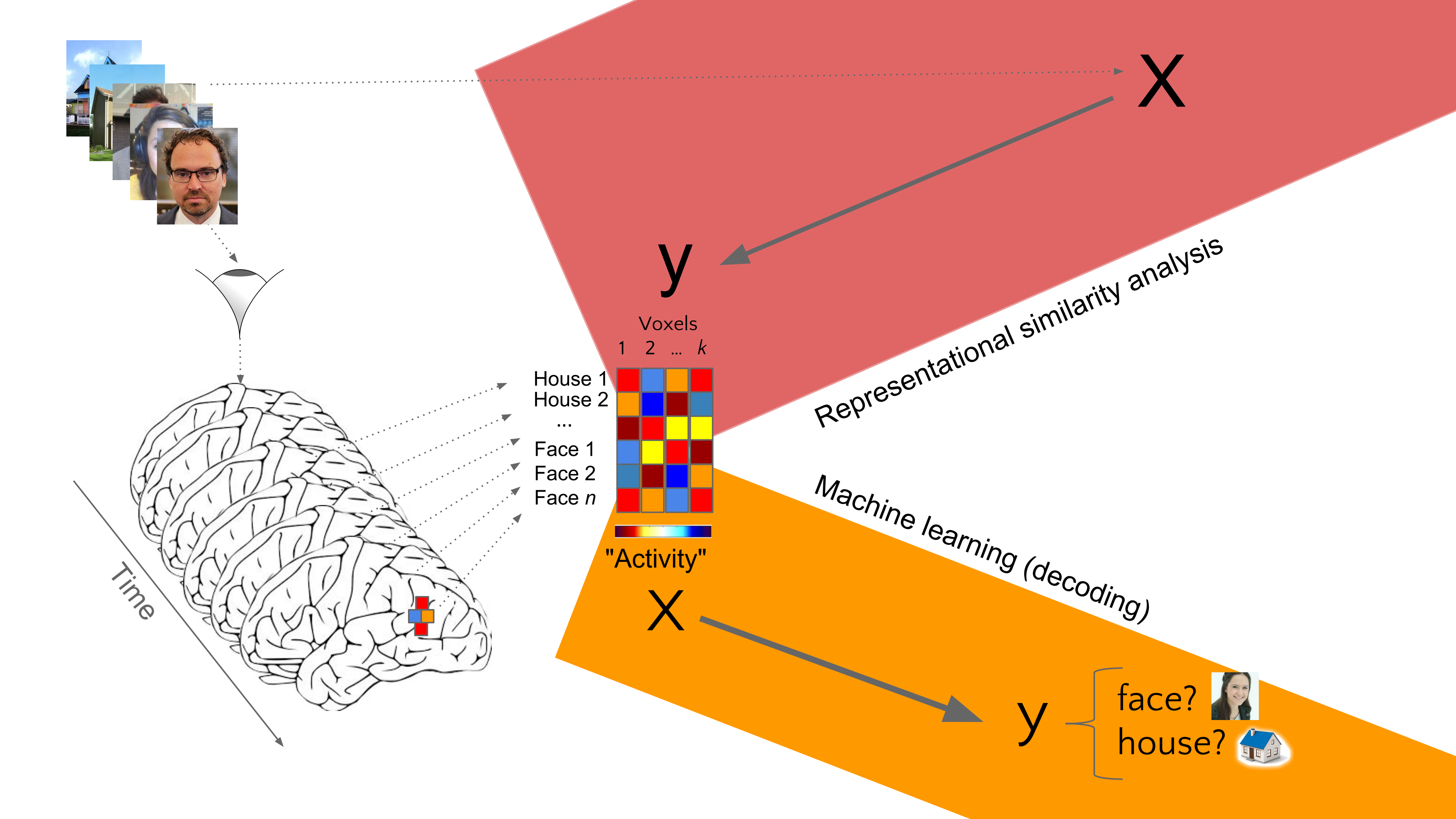
"Features in the world" "Features in the brain"



Whether you're explaining a single voxel (activation-based) or a pattern, it's both encoding!

Pattern analyses: encoding or decoding?

- Pattern analyses can be decoding (machine learning analyses) **or** encoding (RSA)!
  - The next slide will illustrate this with a hypothetical experiment
  - Again, the *direction* of analysis is important here!


X
y
Representational similarity analysis
Voxels
1 2 ... k
House 1
House 2
...
Face 1
Face 2
Face n
"Activity"
Time
Machine learning (decoding)
X
y
face?
house?

Summary part 1

- Pattern analyses use **voxel patterns** instead of **single voxels** to relate to 'features in the world' (stimulus/response/behavior/process etc.)
- **Decoding** uses patterns (X) to predict the feature (y)
- **RSA** uses the stimulus (X) to explain patterns (y)
  - Think of RSA as a particular 'multivariate' equivalent of activation-based encoding analyses
- These are not the only pattern analyses!
  - cvMANOVA, pattern components modeling, etc.

Test your understanding!

Max measures the gray-matter density of a 100 subjects.

He then wants to investigate whether the gray-matter density in the hypothalamus is predictive of whether someone is male or female.

Encoding? ? Decoding?

Test your understanding!

Steven shows TV-commercials which are either boring, funny, or neutral.

He then wants to investigate which brain regions respond more to funny than to boring commercials.

Encoding?

?

Decoding?

Test your understanding!

Noor shows subjects images of different complexity ('visual clutter').

She then wants to analyze whether these complexity parameters can explain the voxel patterns in early visual cortex.

Encoding? ? Decoding?

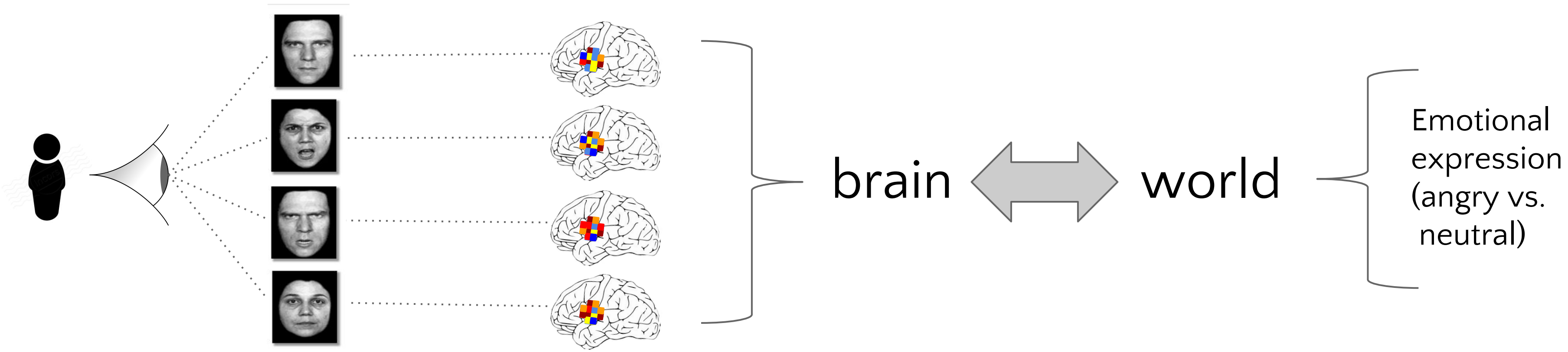
PART 2:
HOW TO ESTIMATE PATTERNS?

Within or between-subject?

- There are several considerations when estimating patterns for pattern analyses …
- One factor that influences the way you estimate patterns is whether you have a **within-subject** or a **between-subject** design

Within or between subject?

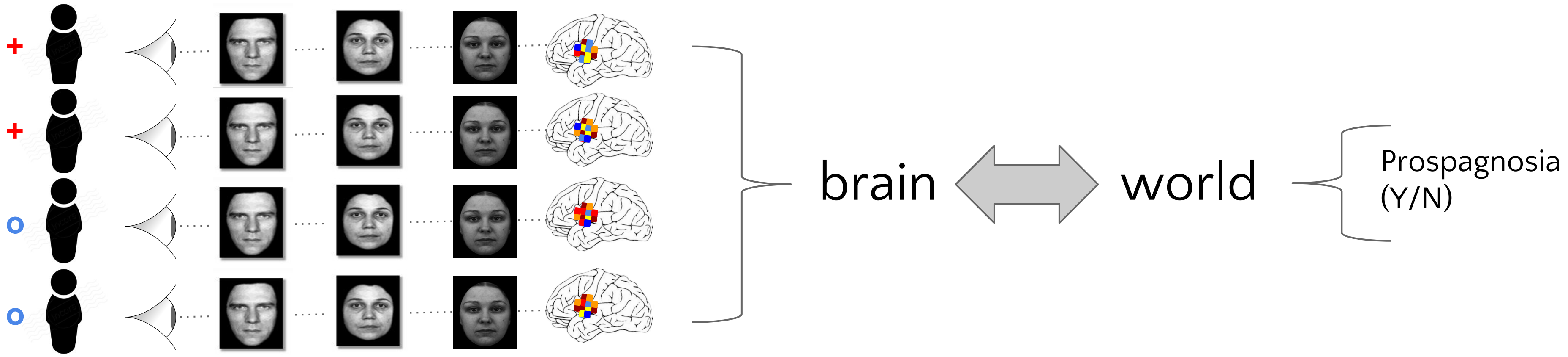
- In within-subject designs, your "feature in the world" varies within a subject



Within or between subject?

- In between-subject designs, your "feature in the world" varies between-subjects

+ = prosopagnosia
O = control



Within-subject designs

To-be-analyzed 'feature' is a **within-subject factor** in the experiment, for example:

- Showing negative, positive, or neutral images (WS-factor: valence)
- Example analysis: decoding stimulus valence from brain patterns in the amygdala

Between-subject design

To-be-analyzed 'feature' is a **between-subject factor** in the experiment:

- Measuring white-matter tract strength of both schizophrenic patients and healthy controls (BS-factor: disease Y/N)
- Example analysis: Predicting whether someone is schizophrenic (or not) based on their white-matter

Test your knowledge!

Subjects perform a memory task in which they have to give responses. Their responses can be either correct or incorrect.

I want to analyze whether the patterns in parietal cortex are predictive of whether someone is going to respond (in)correctly.

Within-subject ? Between-subject

Test your knowledge!

Subjects are scanned while viewing emotional images. One random group of subjects are given the drug 'Propanolol' (a beta blocker) before the experiment. The other group is given a placebo.

I want to investigate whether the patterns in the insula are different when subjects are given Propanolol.

Within-subject ? Between-subject

Test your knowledge!

Subjects are shown two types of images: images of animate (living) objects and images of inanimate (non-living) objects.

I want to train a model that distinguishes animate from inanimate images based on patterns in the fusiform gyrus.

Within-subject ? Between-subject

ToThink!

What should be the most important factor in choosing a between or within-subject pattern analysis strategy?

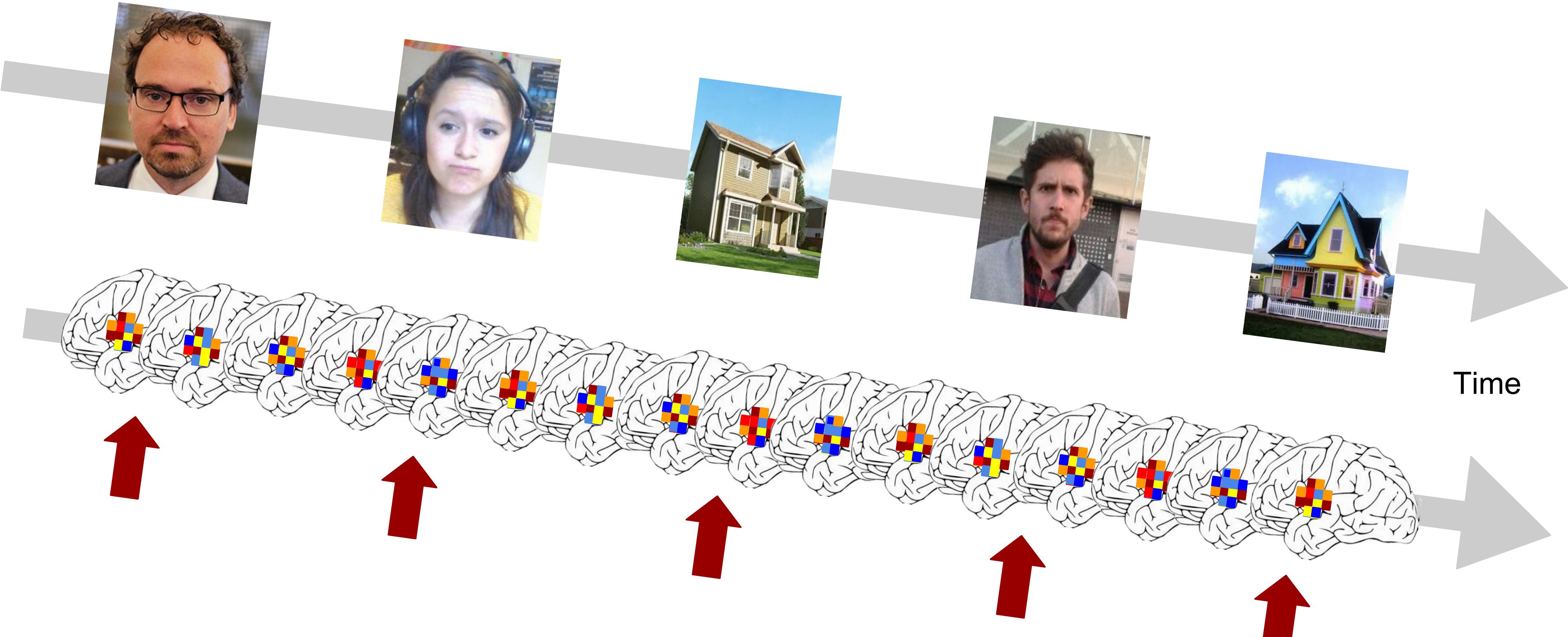
Estimating patterns

- When you want to estimate a pattern, you should ask yourself three things:
  - **WHEN** do I estimate my patterns?
  - **WHERE** do I estimate my patterns?
  - **WHAT** contrast do I use to for estimation of my patterns? (between-subject only)

WHEN?

- You want to extract voxel patterns **when** you think the brain contains information about your to-be-analyzed feature
- In other words, extract patterns when you think they 'correlate' with your feature-of-interest

Within-subject design

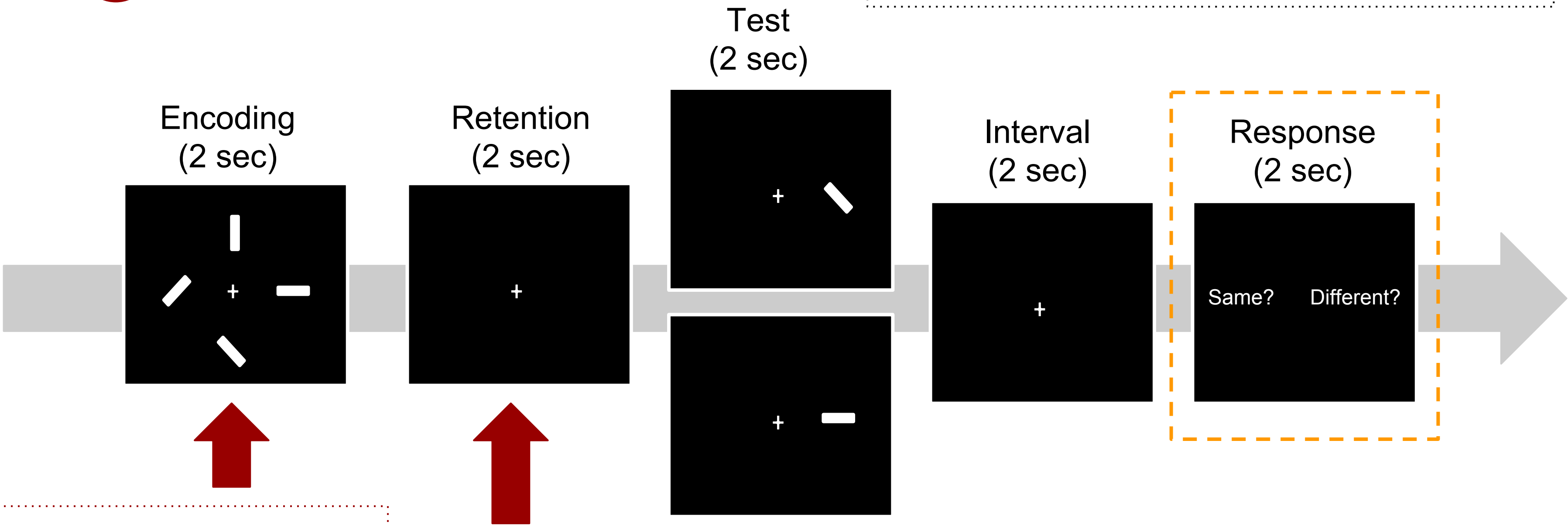


Within-subject design

- Experiments where the feature-of-interest is something about the **stimulus**, you should extract patterns reflecting the stimulus itself …
- … but you can also be more creative!
- Consider this working memory experiment:

Suppose I want to investigate what brain patterns are predictive of a correct vs. incorrect response?

Within-subject design



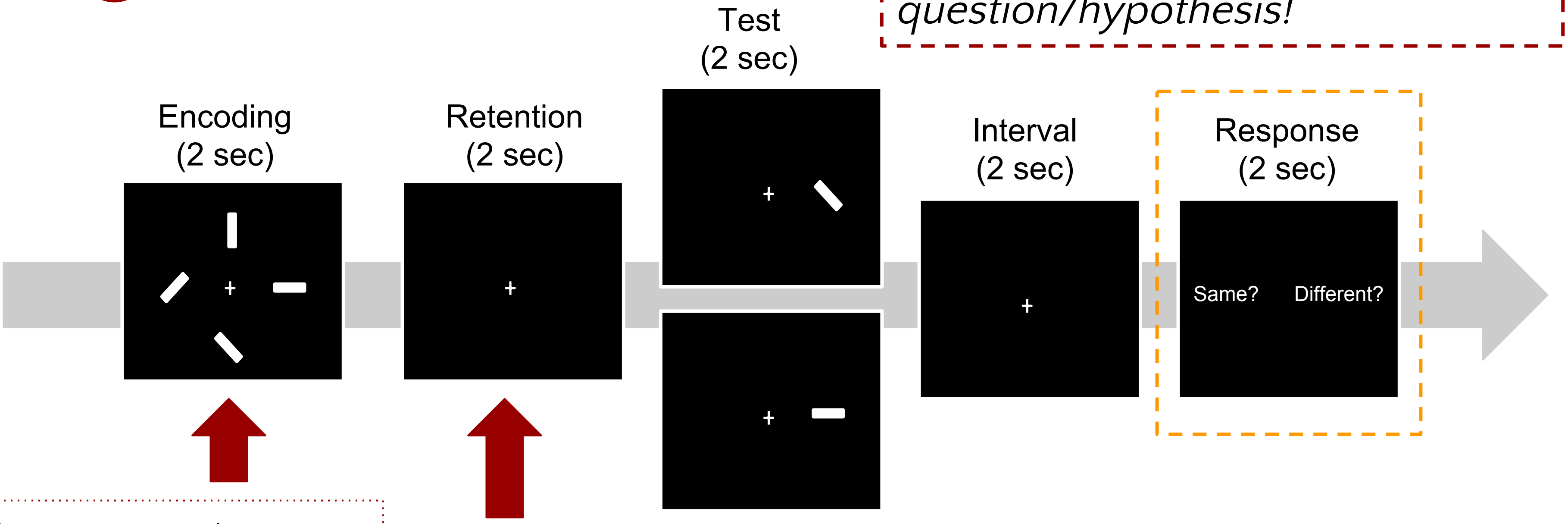
"Are patterns in brain region x ***during stimulus encoding*** predictive of later task performance?

"Are patterns in brain region y ***during WM retention*** predictive of later task performance?

Pattern en/decoding can be applied '***across time***' (more about 'cross-decoding' in week 2)

Within-subject design

The specific moment you extract the patterns thus depends on your specific research question/hypothesis!



"Are patterns in brain region x ***during stimulus encoding*** predictive of later task performance?

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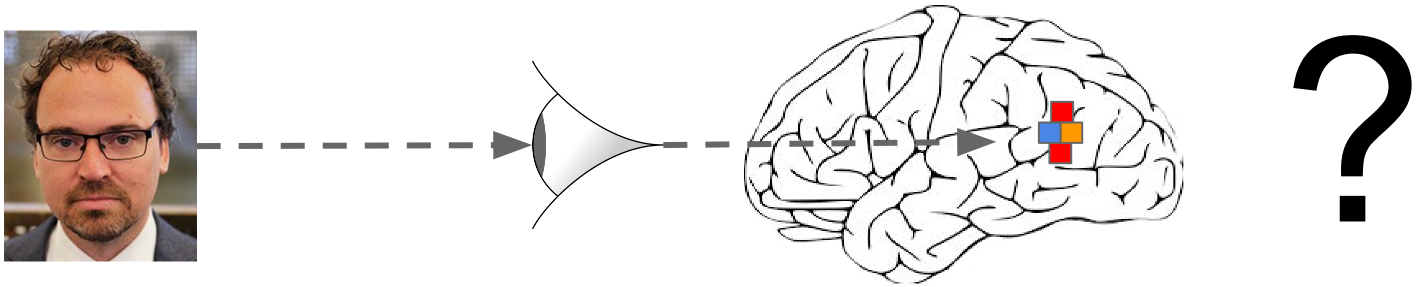
Pattern en/decoding can be applied '***across time***' (more about 'cross-decoding' in week 2)

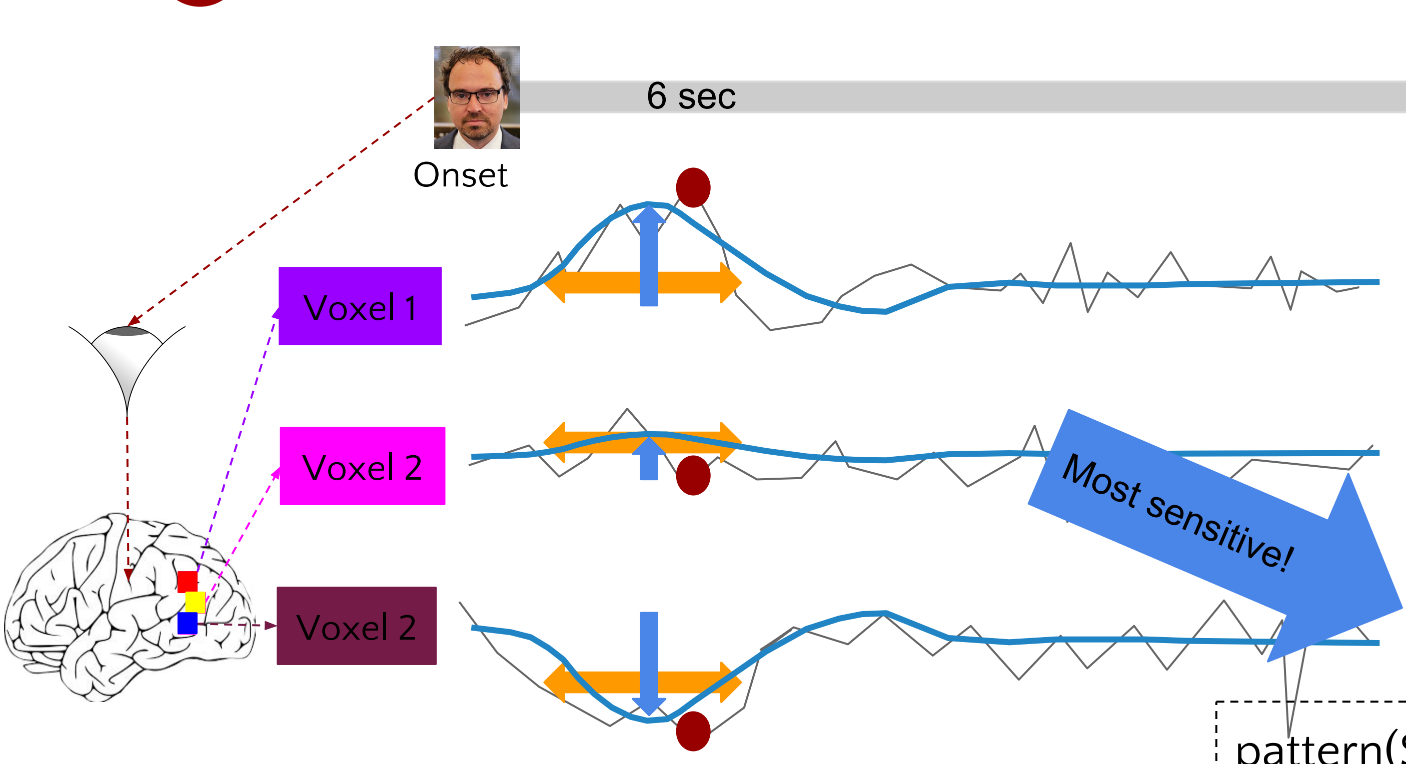
WHERE?

- Similarly, you also have different options **where** in the brain you extract patterns …
  - In a specific region-of-interest (e.g. the amygdala);
  - From the entire brain ('whole-brain pattern analysis')
  - … this will be a separate lecture by Steven about 'spatial scales in neuroimaging' in week 4.

How do we get here?



Estimating patterns: within



Three ways to extract patterns:

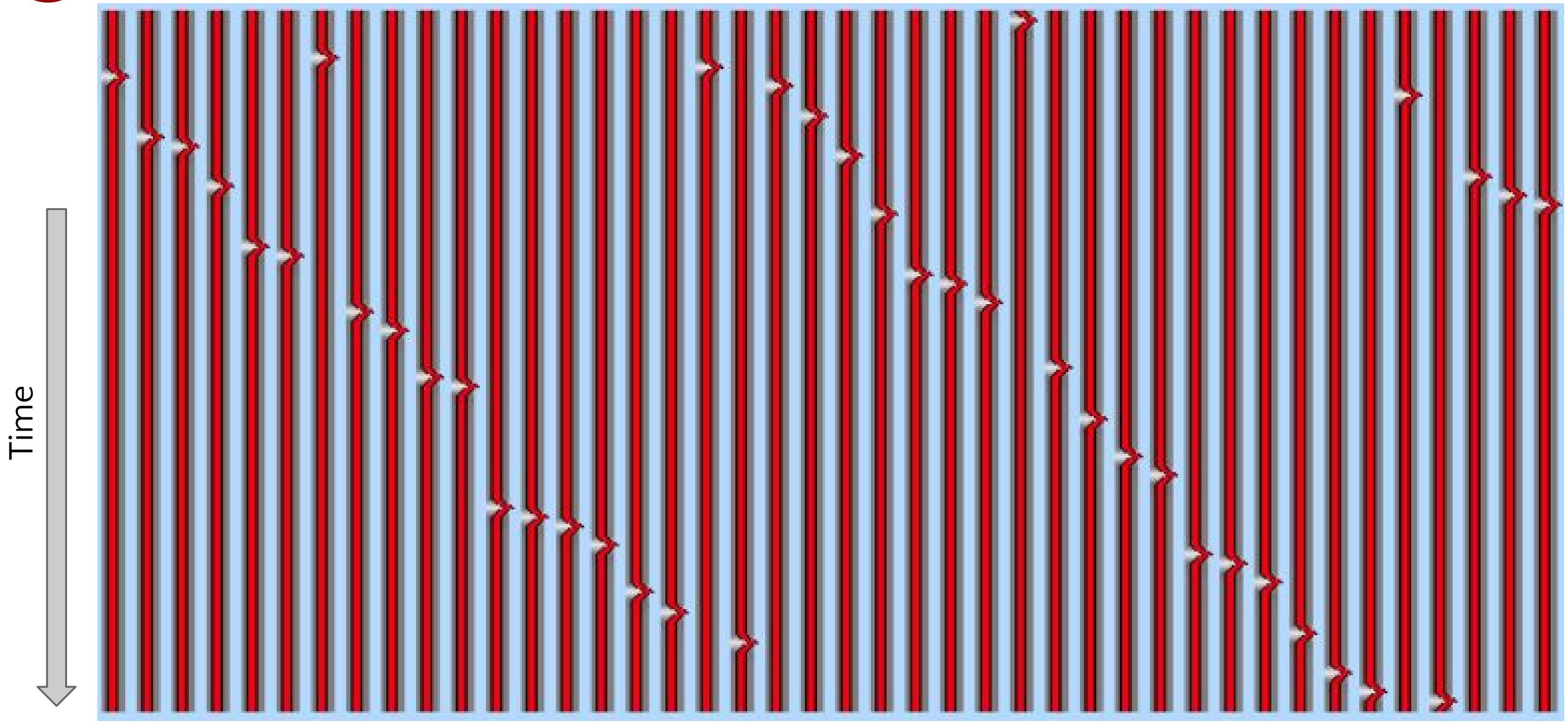
1. **Extract datapoint at a prespecified timepoint;**
2. **Extract mean of range of timepoints;**
3. **Fit HRF and extract ß or t-value;**

pattern(Steven) = [3.1, 0.4, -4.2]

Estimating patterns: within

- The design(-matrix) used in within-subject pattern analyses is often called a **single-trial design**
- Thus, you estimate a pattern **for each instance of your feature-of-interest** ("trial")

Estimating patterns: within



ToThink!

The design-matrix in single-trial designs often have more **features** (here: trials) than **samples** (here: time-points)

- "N<P problem"
- Problem with calculating X^{-1}, in $y = (X'X)^{-1}X'y$
- Renders potentially inflated β-values

This is, in terms of statistics, a problem in 'activation-based analyses'.

Why is that **not** a problem in pattern-based analyses?

Estimating patterns: between

- In between-subject pattern analysis, **each subject represents represents one pattern**
  - … instead of each instance of a feature represents one pattern in within-subject analyses
- In addition to **when** and **where** you extract patterns, you now also have flexibility in **what** type of pattern you choose …

Estimating patterns: between

- An example: you want to investigate whether you can predict whether someone has depression or not based on the brain patterns during passive viewing of images of neutral and negative facial expressions:

Neutral *Negative*

Estimating patterns: between

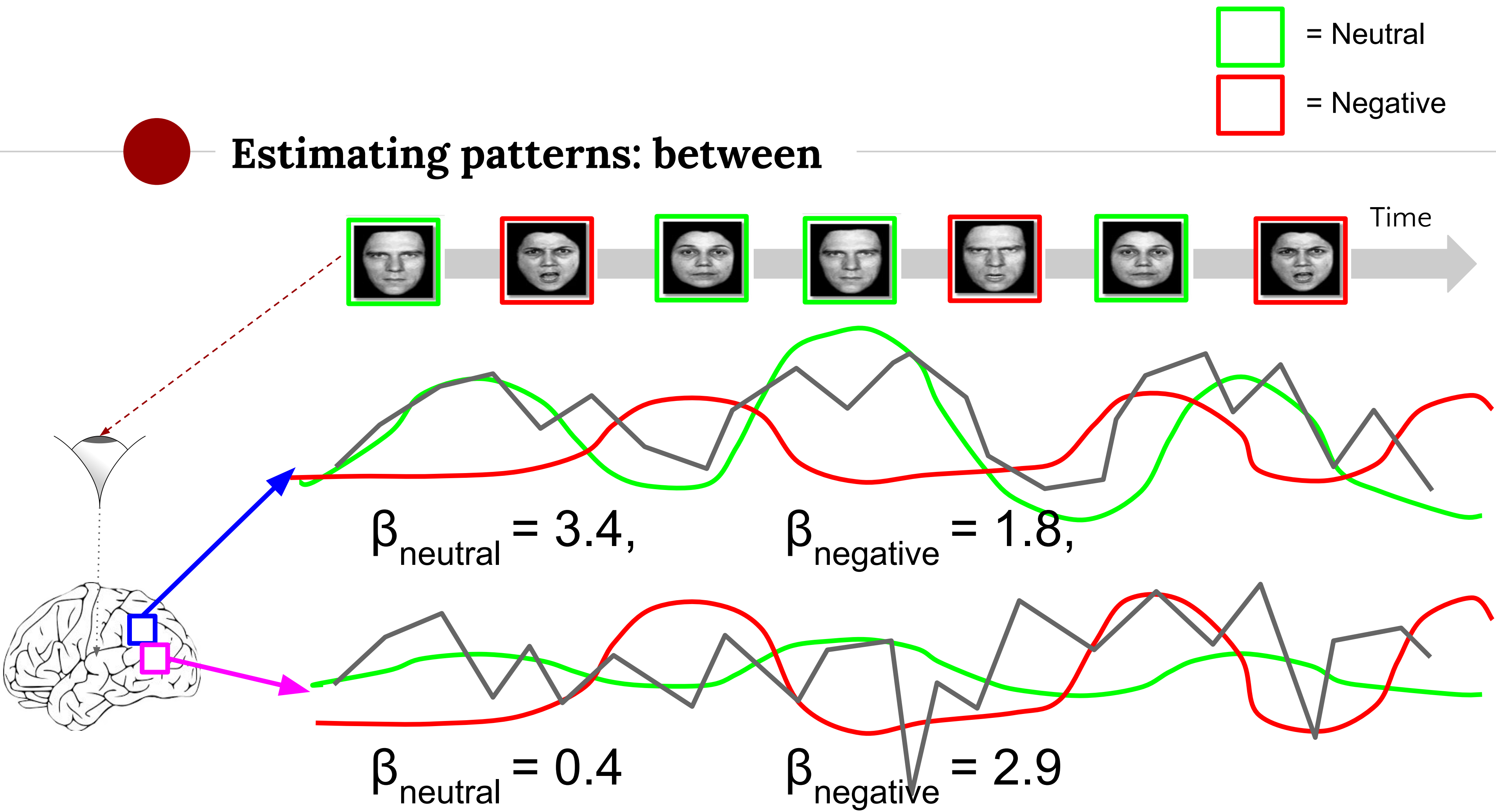
- Goal: predict y (depression Y/N) from patterns in the brain (X)

Neutral *Negative*

Estimating patterns: between

- Again, you can estimate (between-subject) patterns by extracting specific TRs (method 1), averaged windows of TRs (method 2), or fitting HRFs (method 3)
- Fitting HRFs is recommended (but is slightly more complicated)

Estimating patterns: between



$\beta_{neutral} = 3.4, \quad \beta_{negative} = 1.8,$

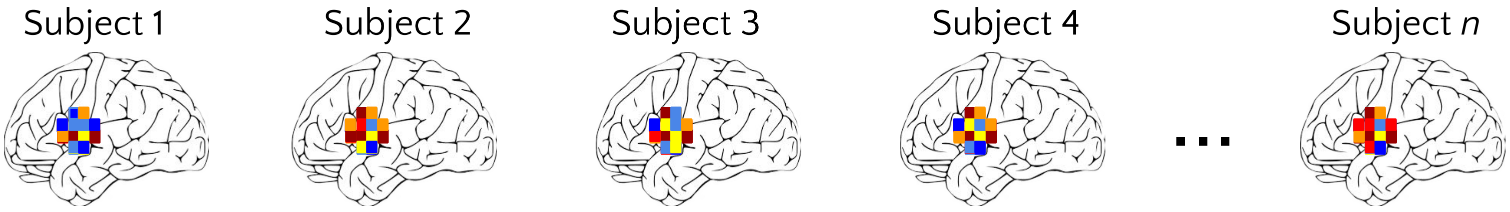
$\beta_{neutral} = 0.4 \quad \beta_{negative} = 2.9$

The contrast on which you base your pattern should be – again- based on your research question/hypotheses!

WHAT?

- Now we have a pattern per subject – but which pattern should we choose?

β(negative) – β(neutral)



Brain patterns represent ***the difference between* negative** and **neutral** facial expressions

Summary part 2

- Your research question/hypotheses largely determine your analysis:
  - Whether you have a within or between subject design;
  - When (and where) you extract patterns;
  - What contrast you use in estimating your patterns;
- *How* you extract patterns does not matter *that* much, but HRF-fitting is probably most sensitive;

Articles and lab this week

- Articles:
  - Davis & Poldrack (2013). Good overview of activation-based vs. pattern analyses. You may skip the section on 'adaptation analyses';
  - Naselaris et al. (2011). Good explanation of encoding/decoding. You may skip from "Experimental designs that exploit the major advantage of encoding models" onwards.
- This week's lab is about extracting, loading, and transforming pattern estimates and some new programming concepts (object-oriented programming)

Questions?