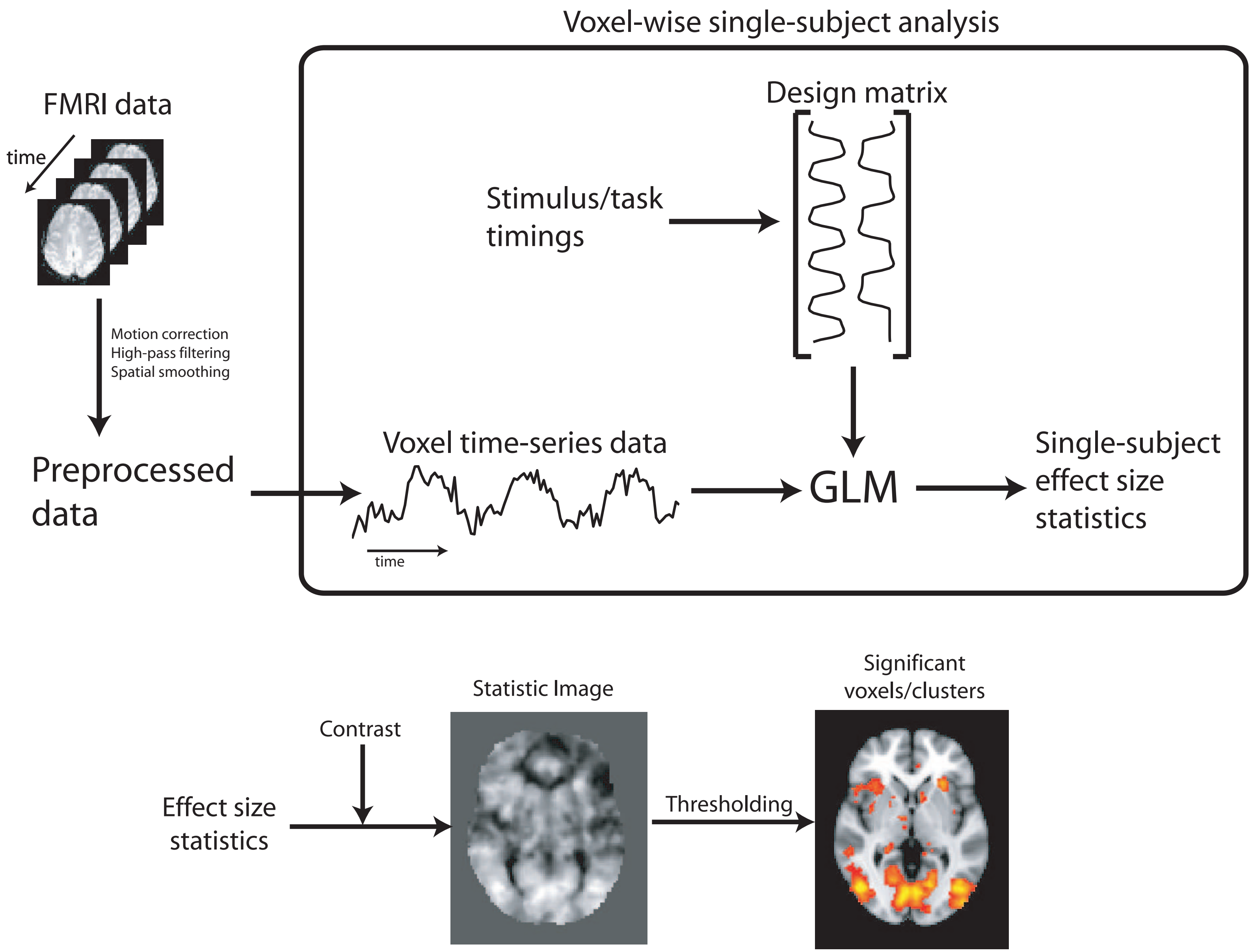
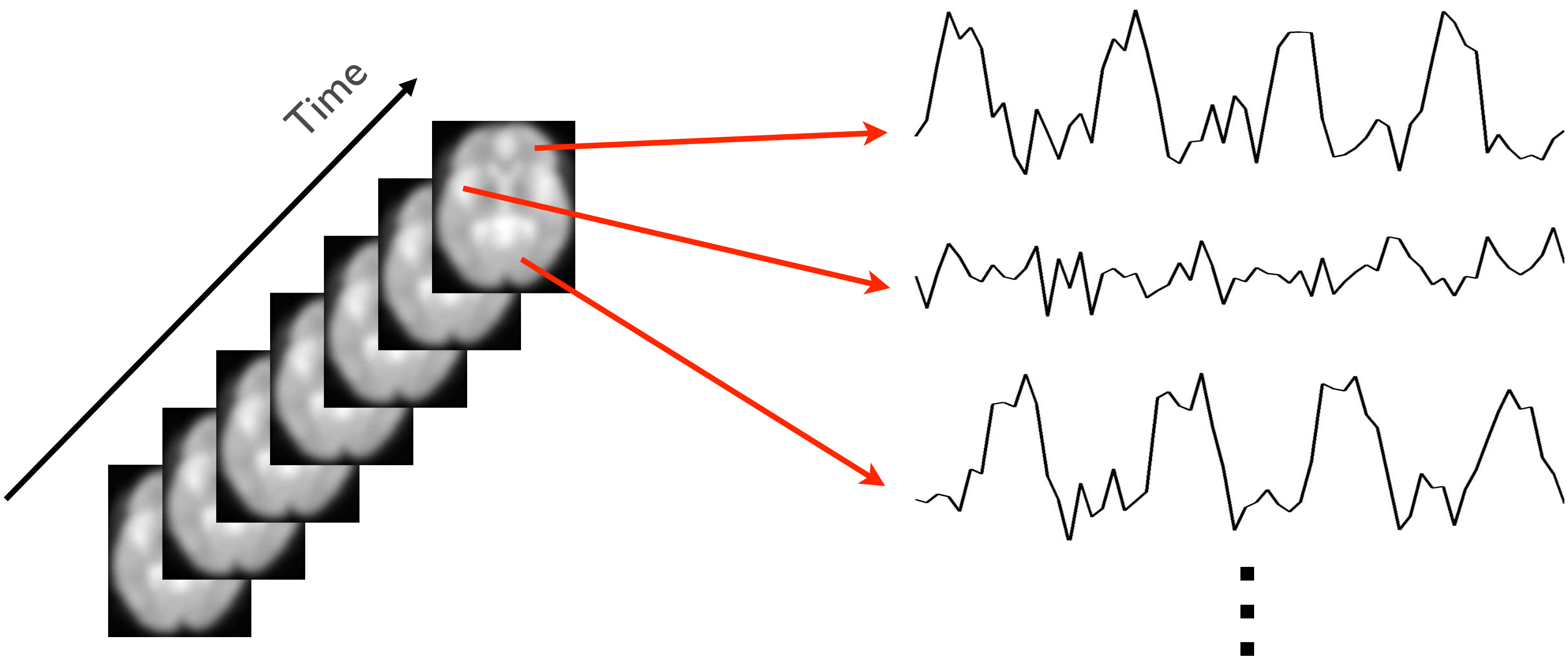
Single-Session Analysis



Two different views of the data

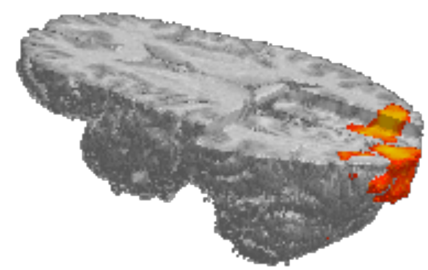


A "smallish" number of volumes

A **large** number of time series

FMRI Modelling and Statistics

- An example experiment
- Multiple regression (GLM)
- T and F Contrasts
- Null hypothesis testing
- The residuals
- Thresholding: multiple comparison correction



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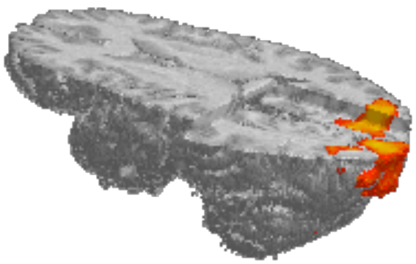
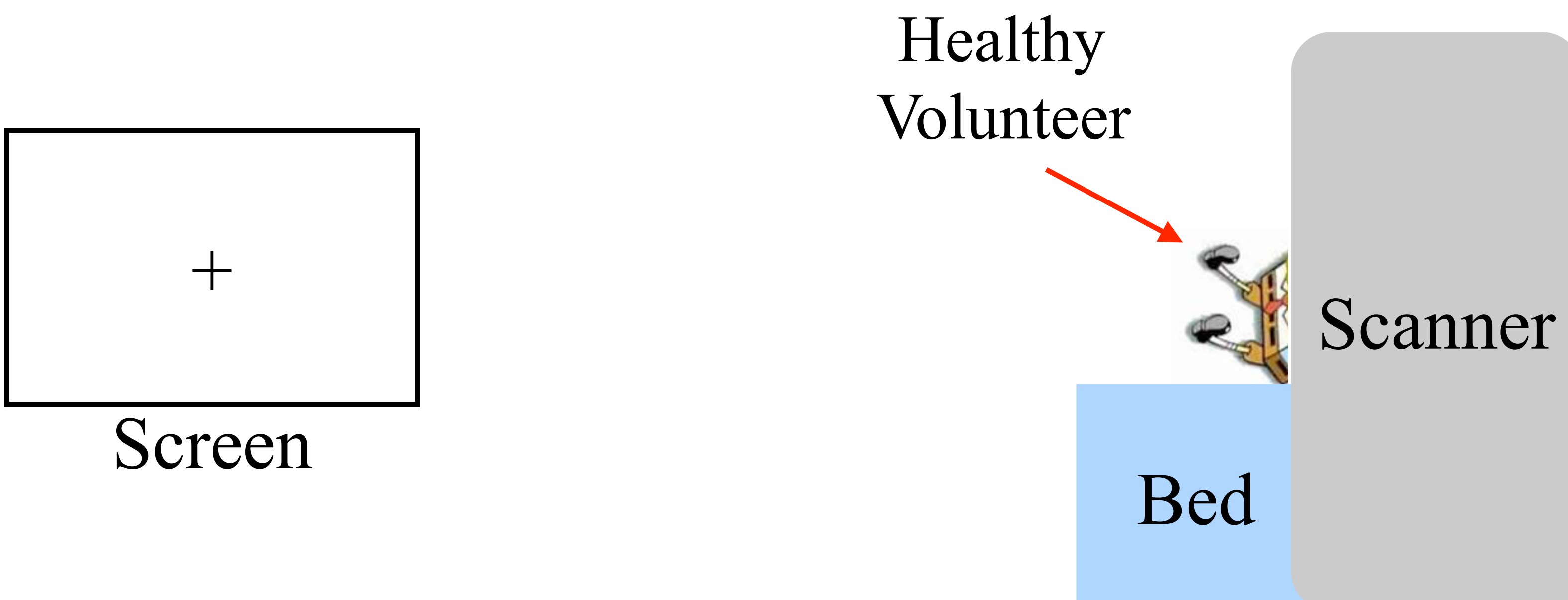


An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation



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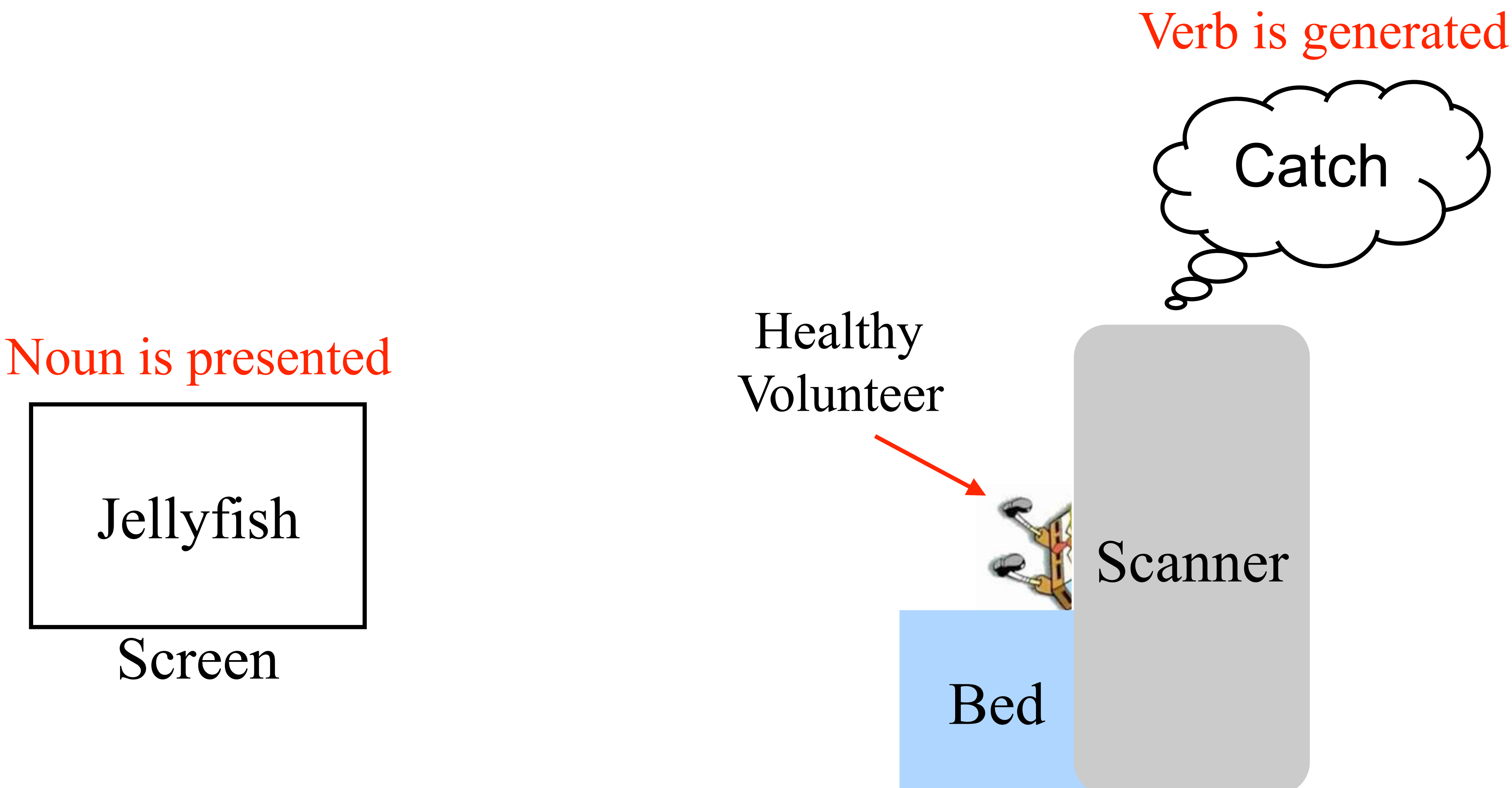

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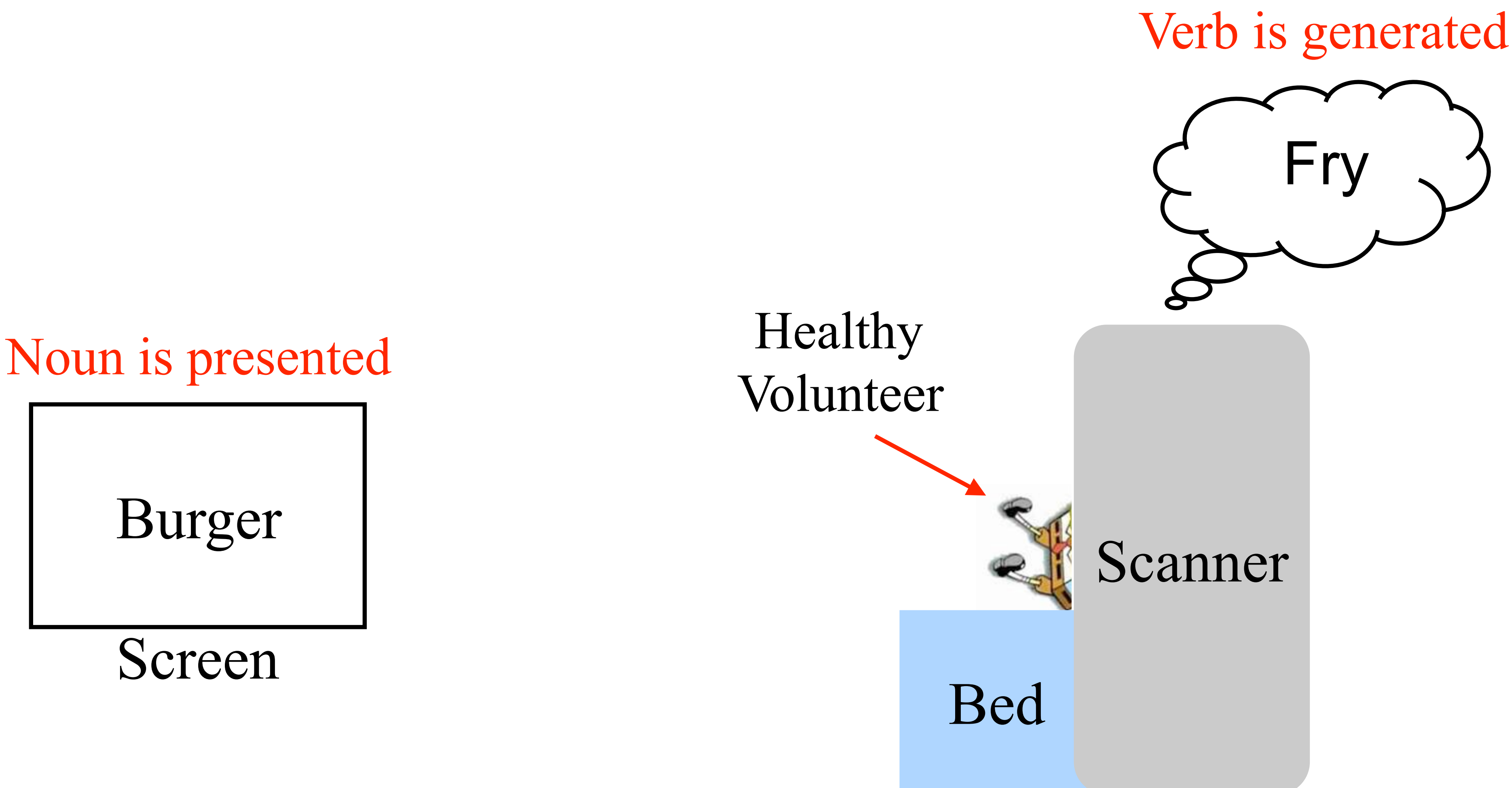
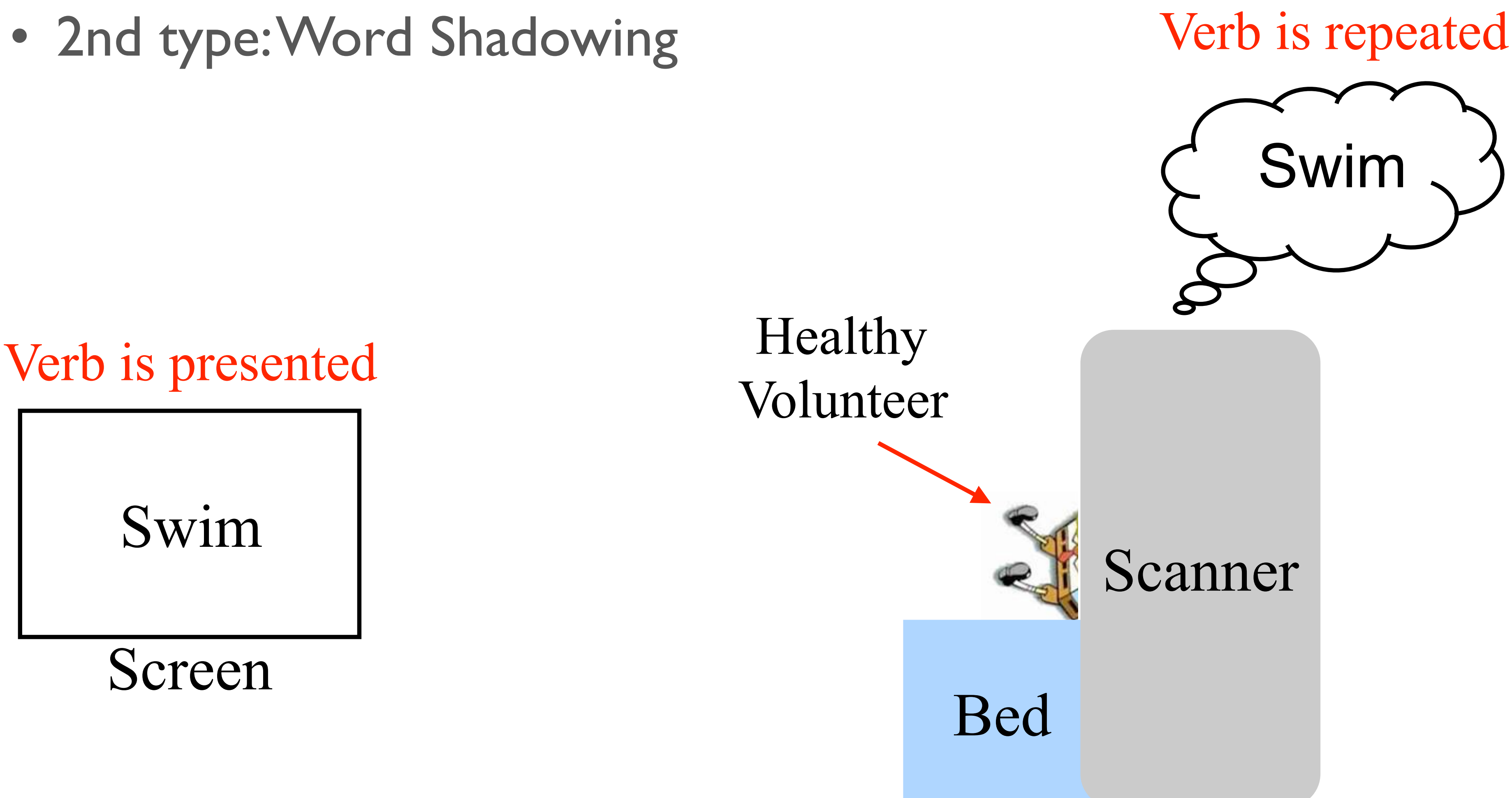


An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing



An example experiment

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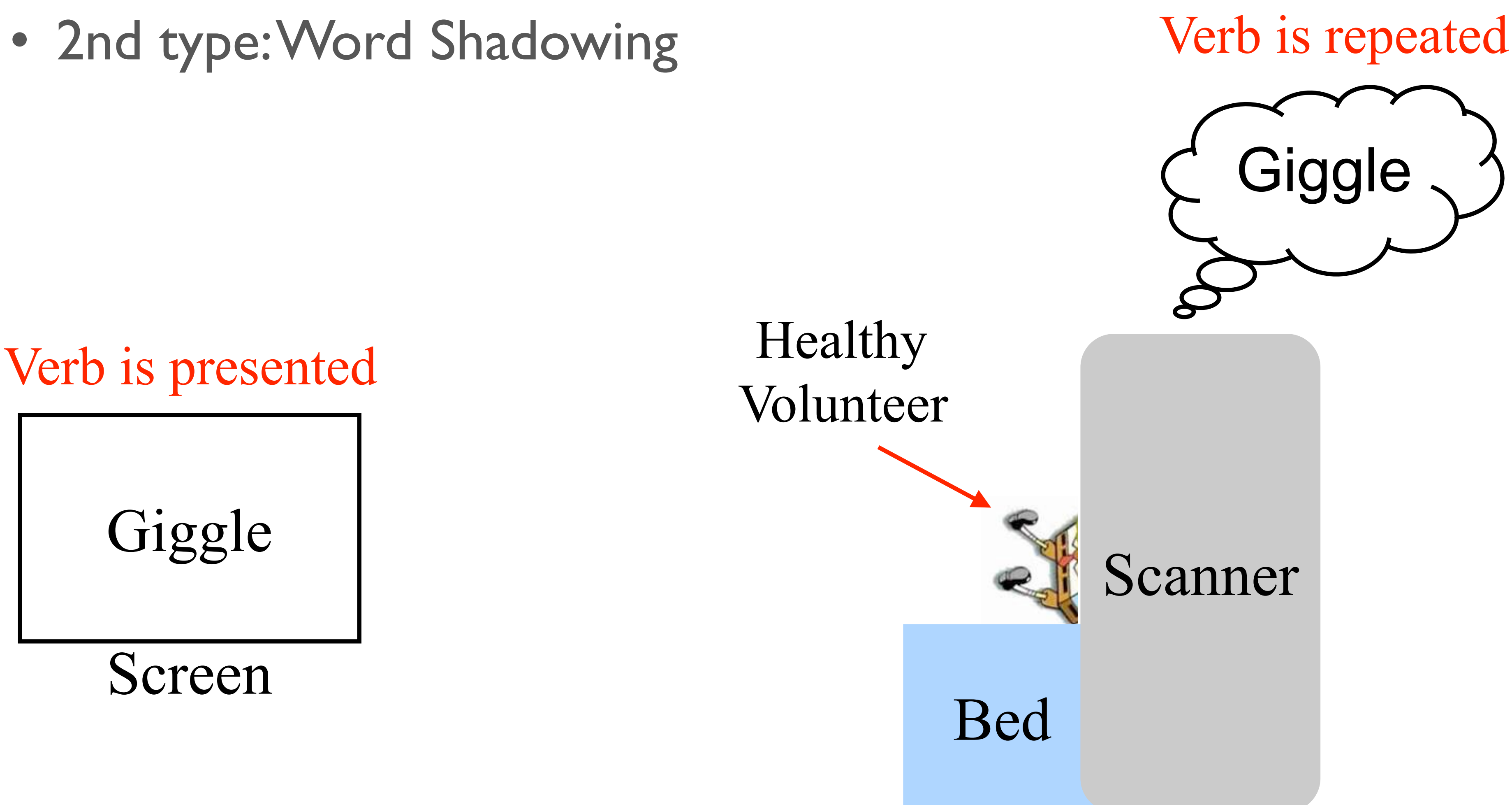
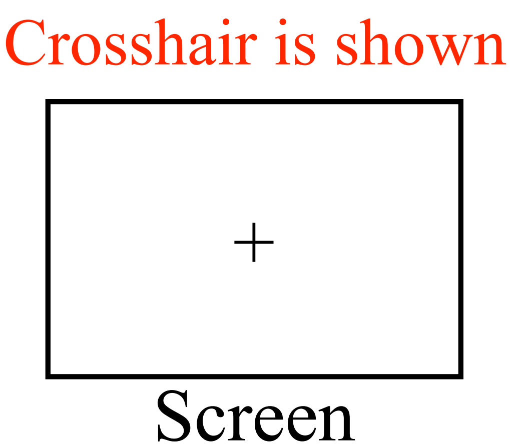
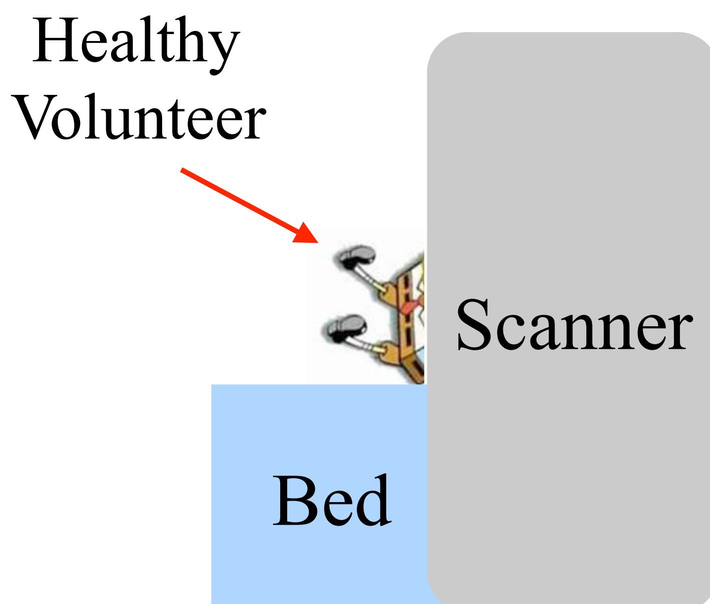


An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing
- 3rd type: Null event





An example experiment

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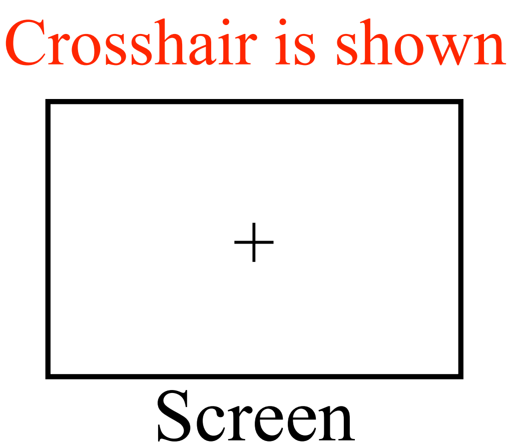
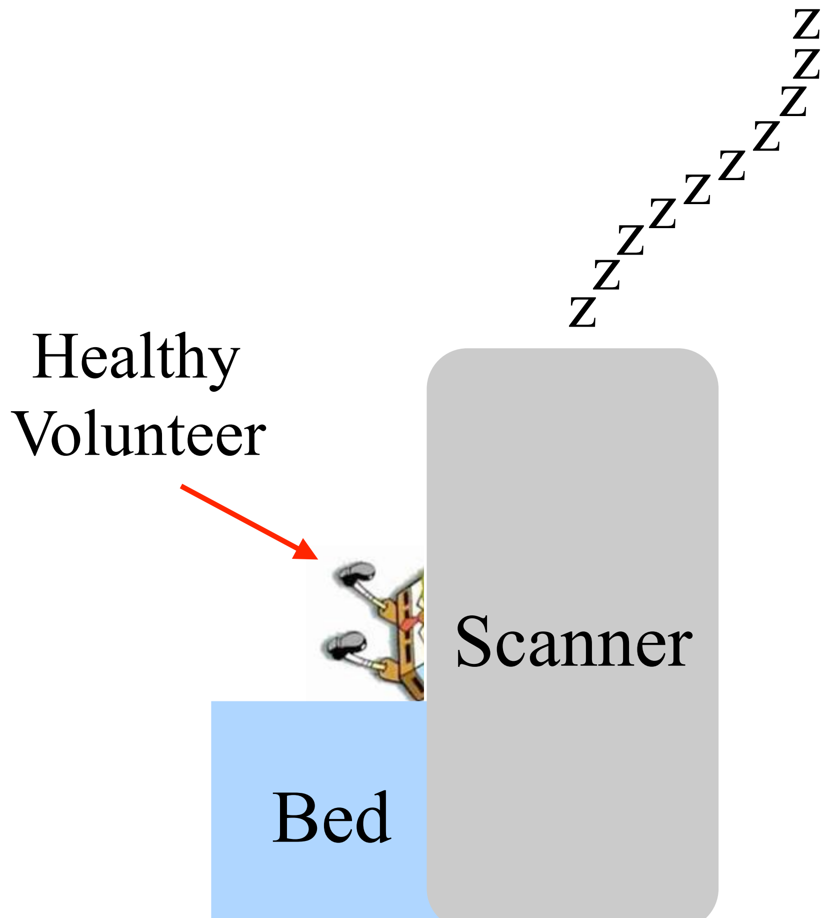




An example experiment

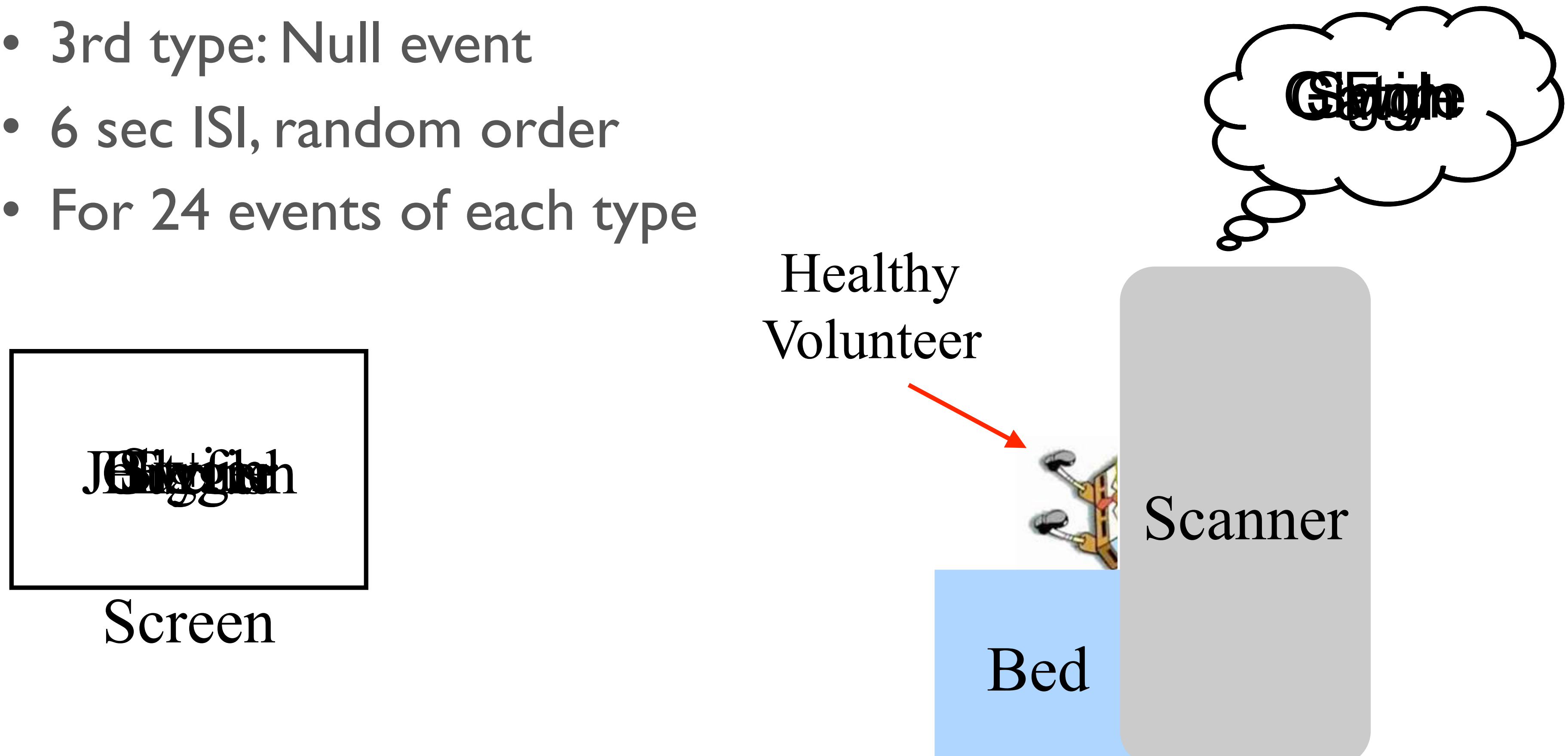
An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing
- 3rd type: Null event
- 6 sec ISI, random order

An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing
- 3rd type: Null event
- 6 sec ISI, random order
- For 24 events of each type



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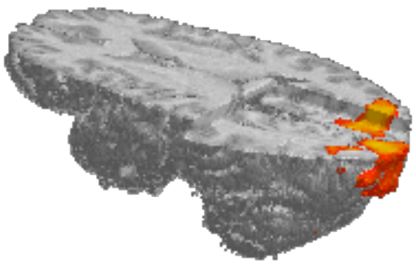

Building a model

Our task is now to build a model for that experiment

What is our predicted response to the word generation events?

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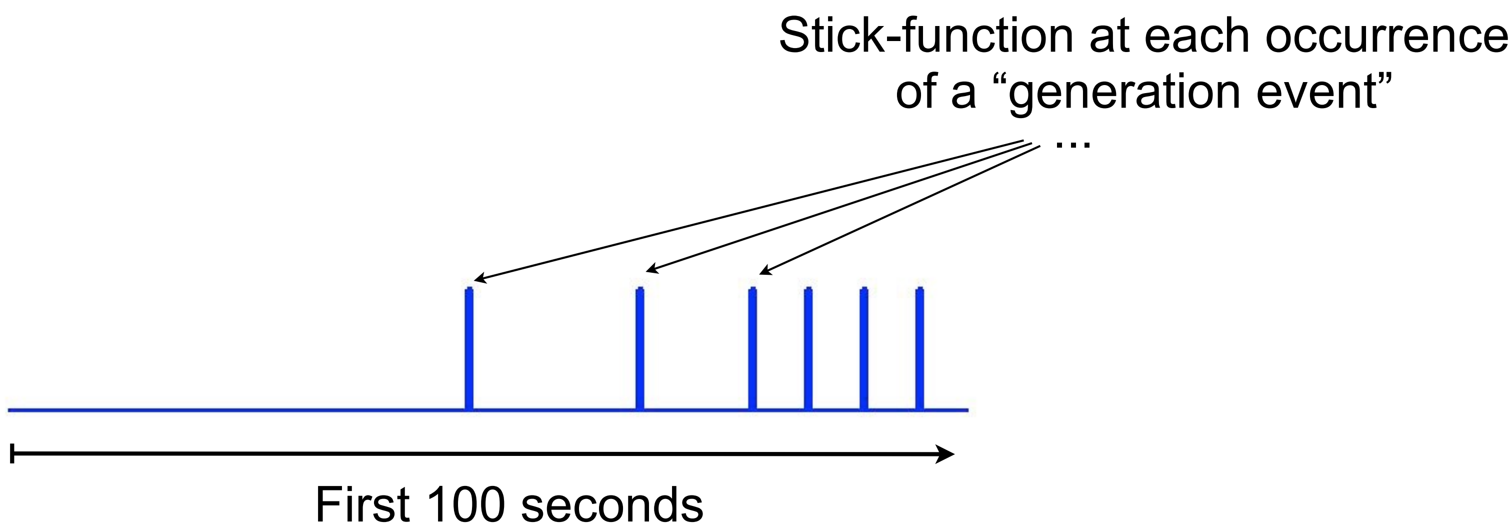
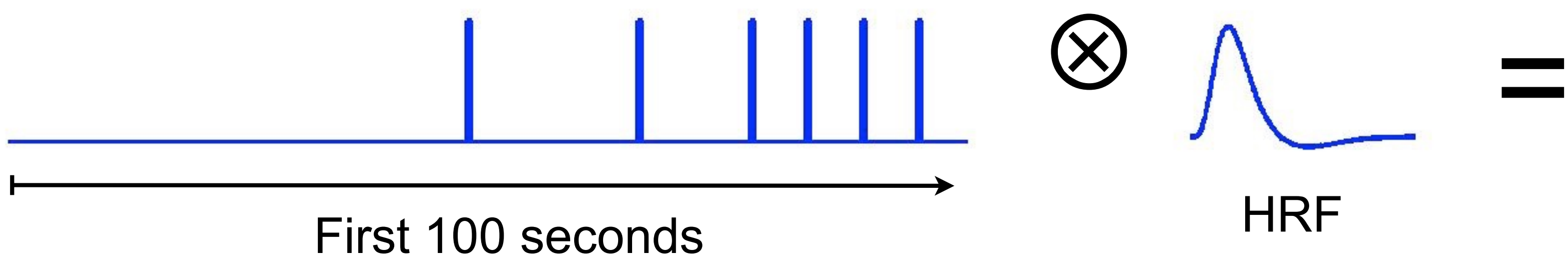


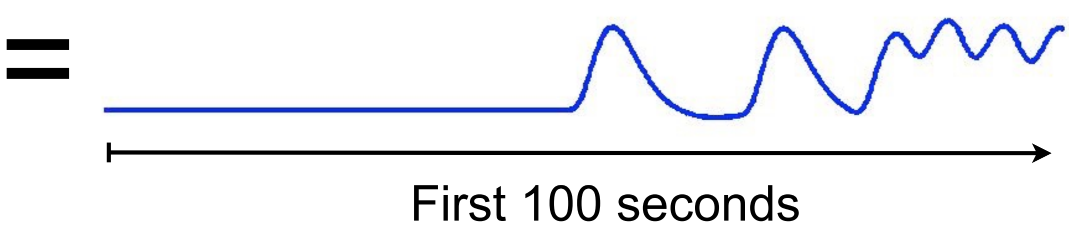
Well, hardly like this...

Building a model

Our task is now to build a model for that experiment

What is our predicted response to the word generation events?





predicted response

That looks better!

Building a model

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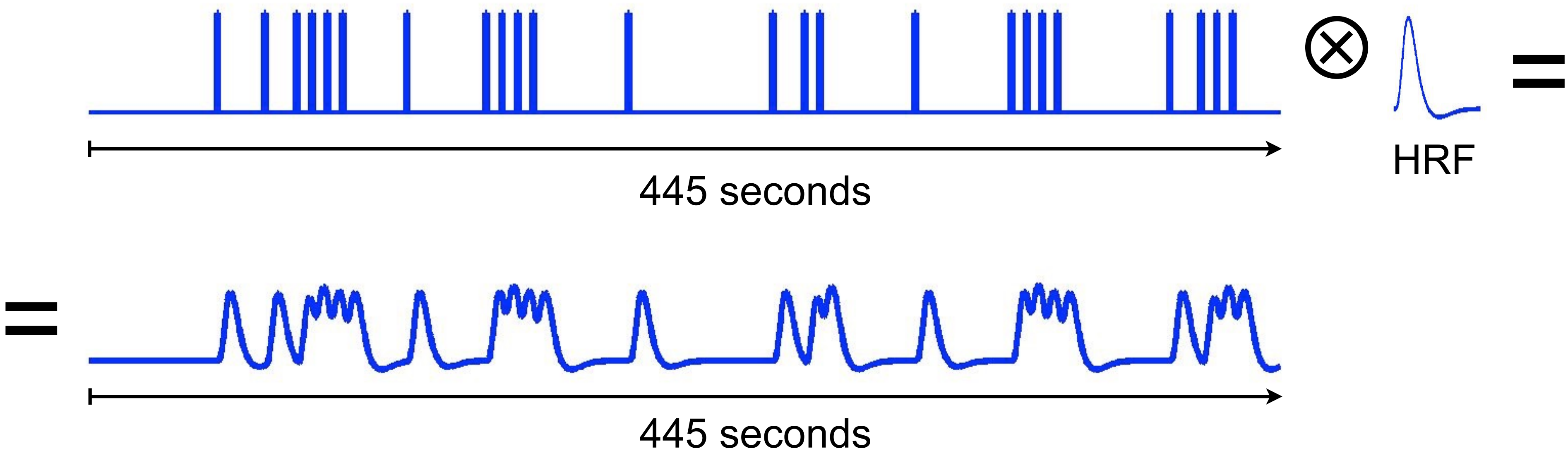
What is our predicted response to the word generation events?

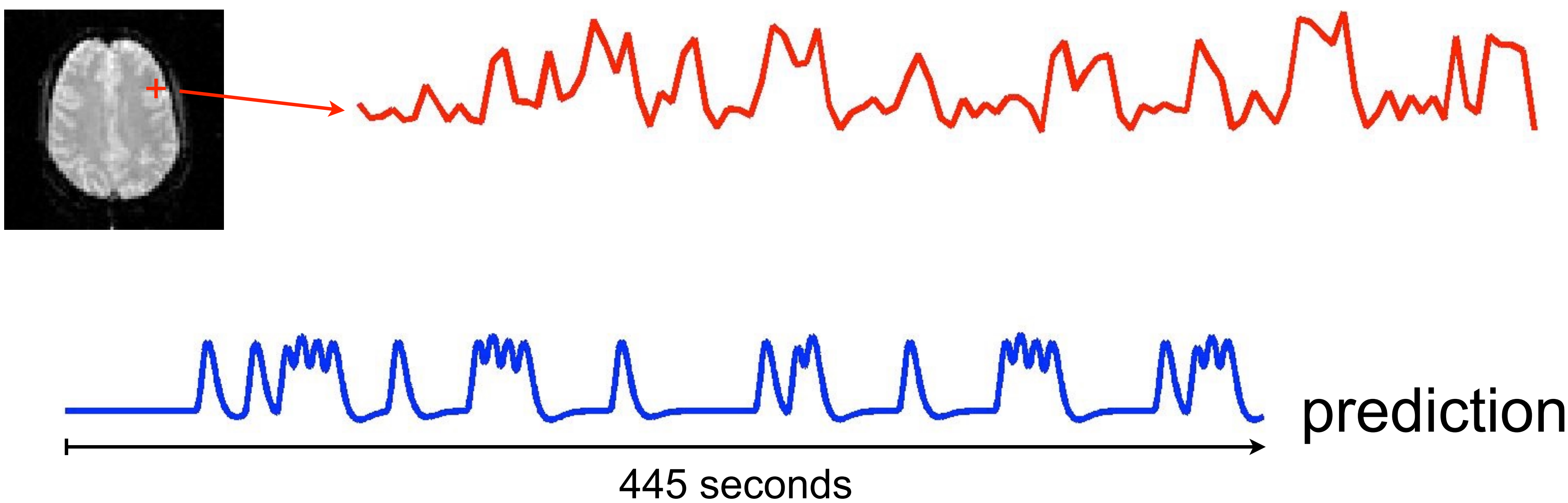


And this is the prediction for the whole time-series

Building a model

Our task is now to build a model for that experiment

What is our predicted response to the word generation events?

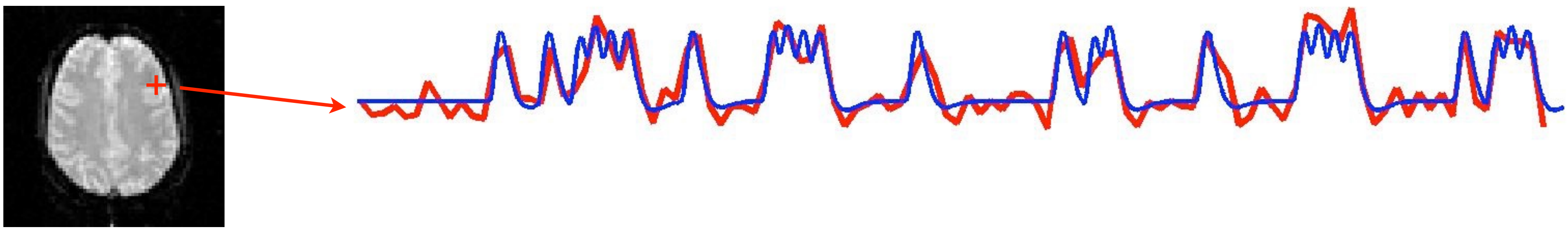


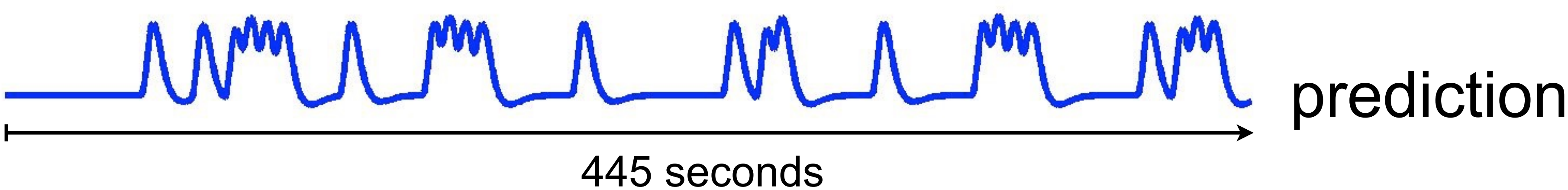
So, if we spot a time-series like this

Building a model

Our task is now to build a model for that experiment

What is our predicted response to the word generation events?



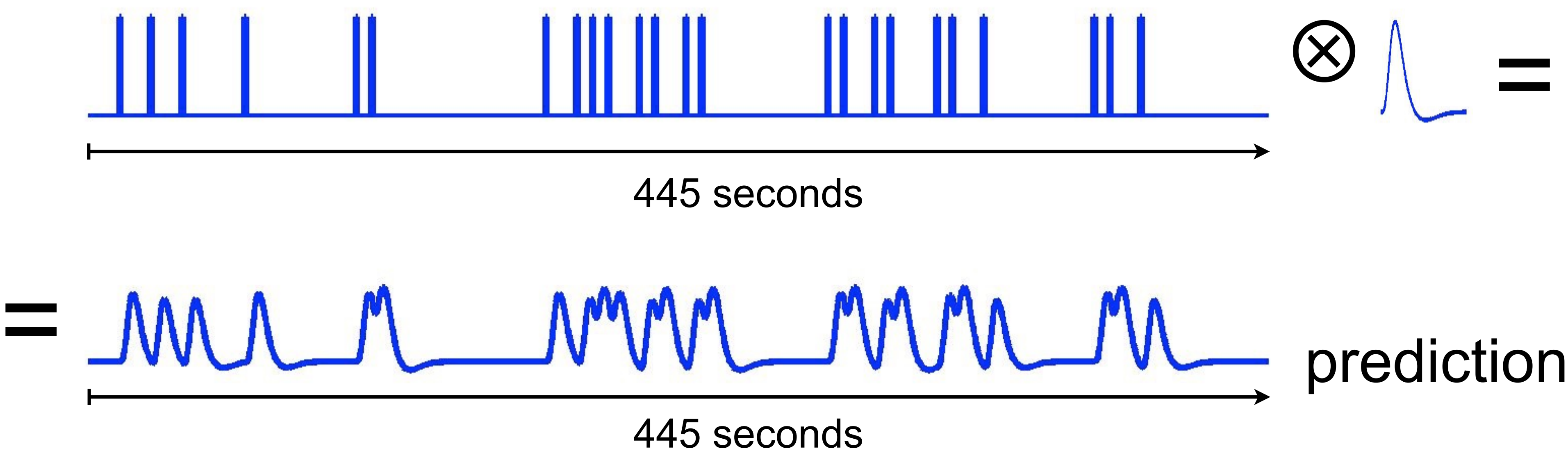


And then check it against our prediction
we can conclude that this pixel is into word generation

Building a model

Our task is now to build a model for that experiment

And we can do the same for the word shadowing events?

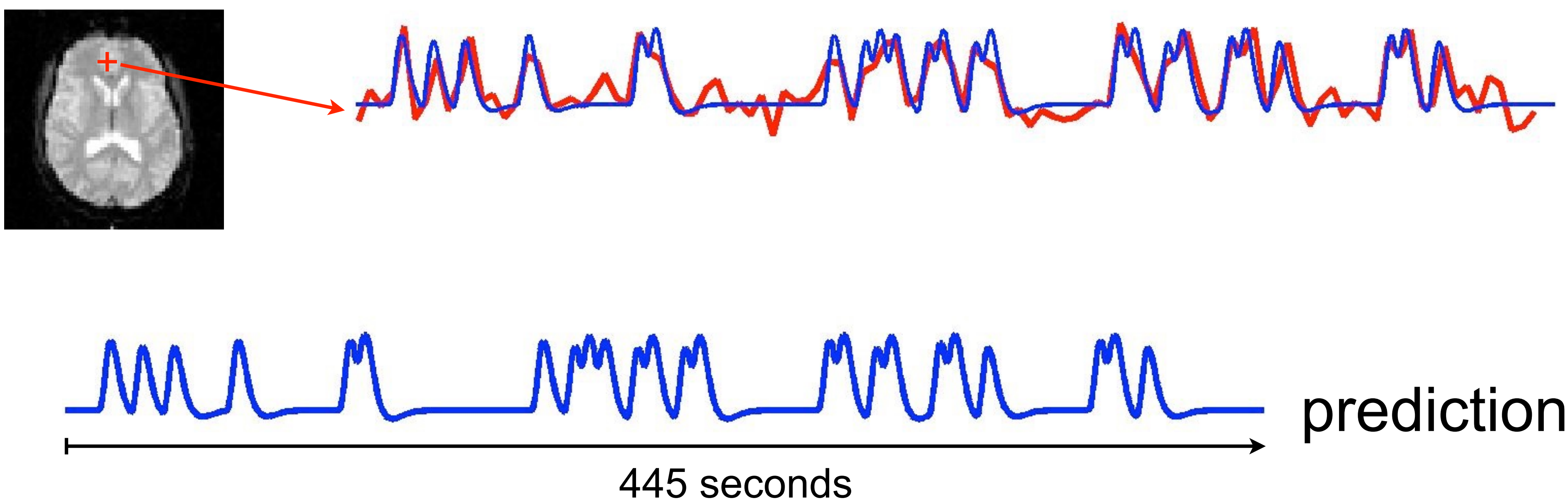


This time we used the onset times for the shadowing events to get the predicted brain response for those

Building a model

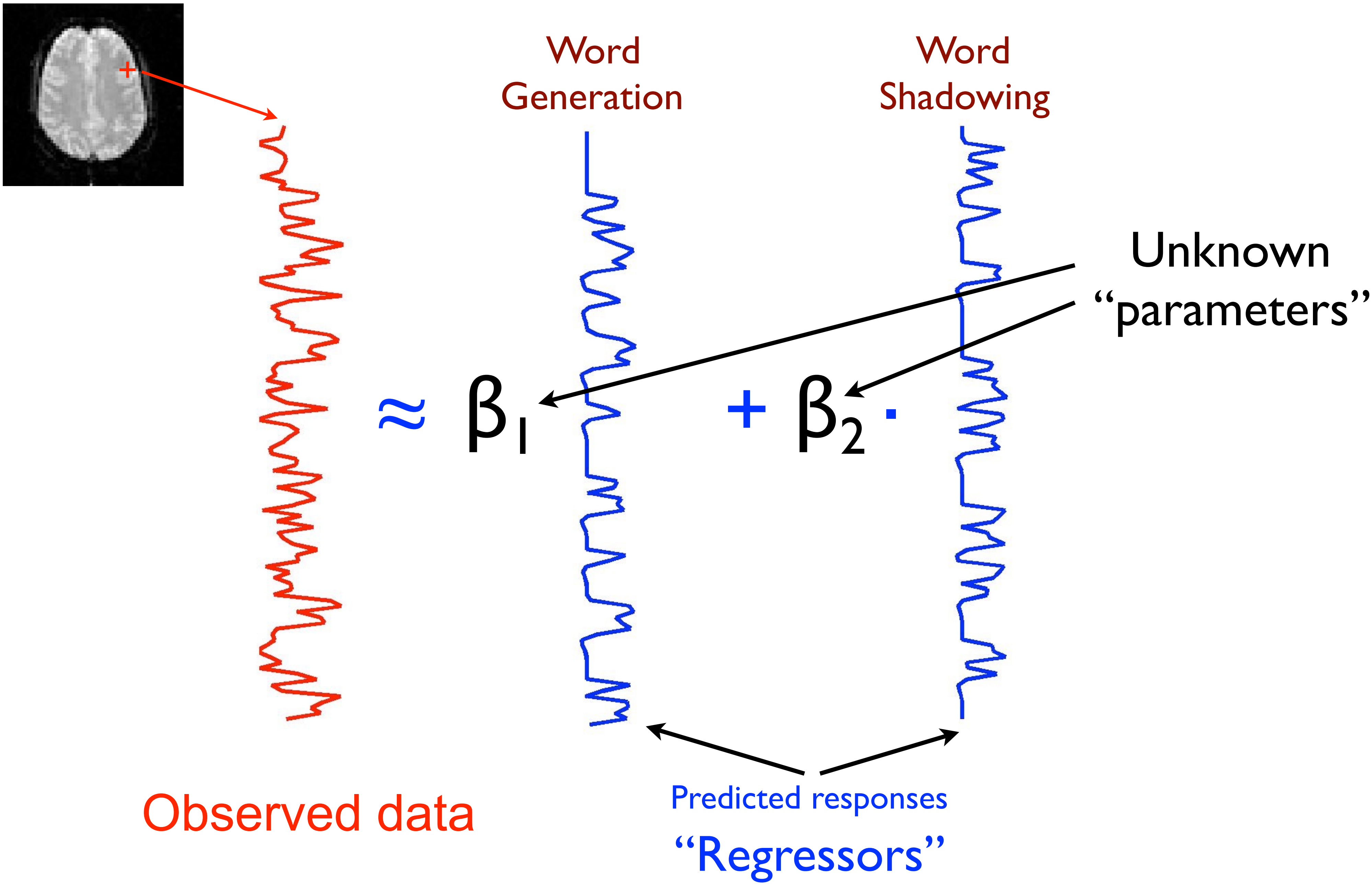
Our task is now to build a model for that experiment

And we can do the same for the word shadowing events?

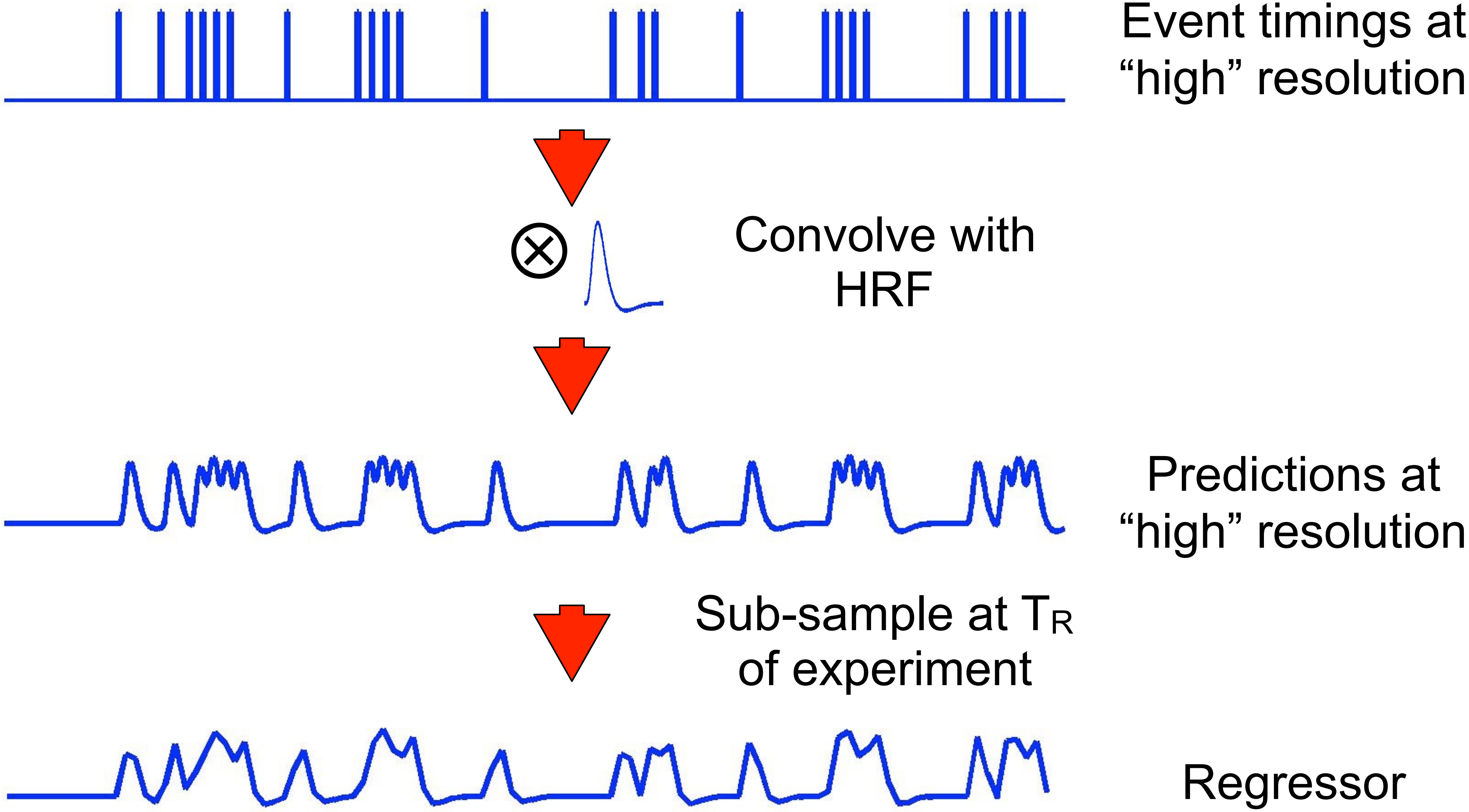


And we can look for voxels that match that

Formalising it: Multiple regression

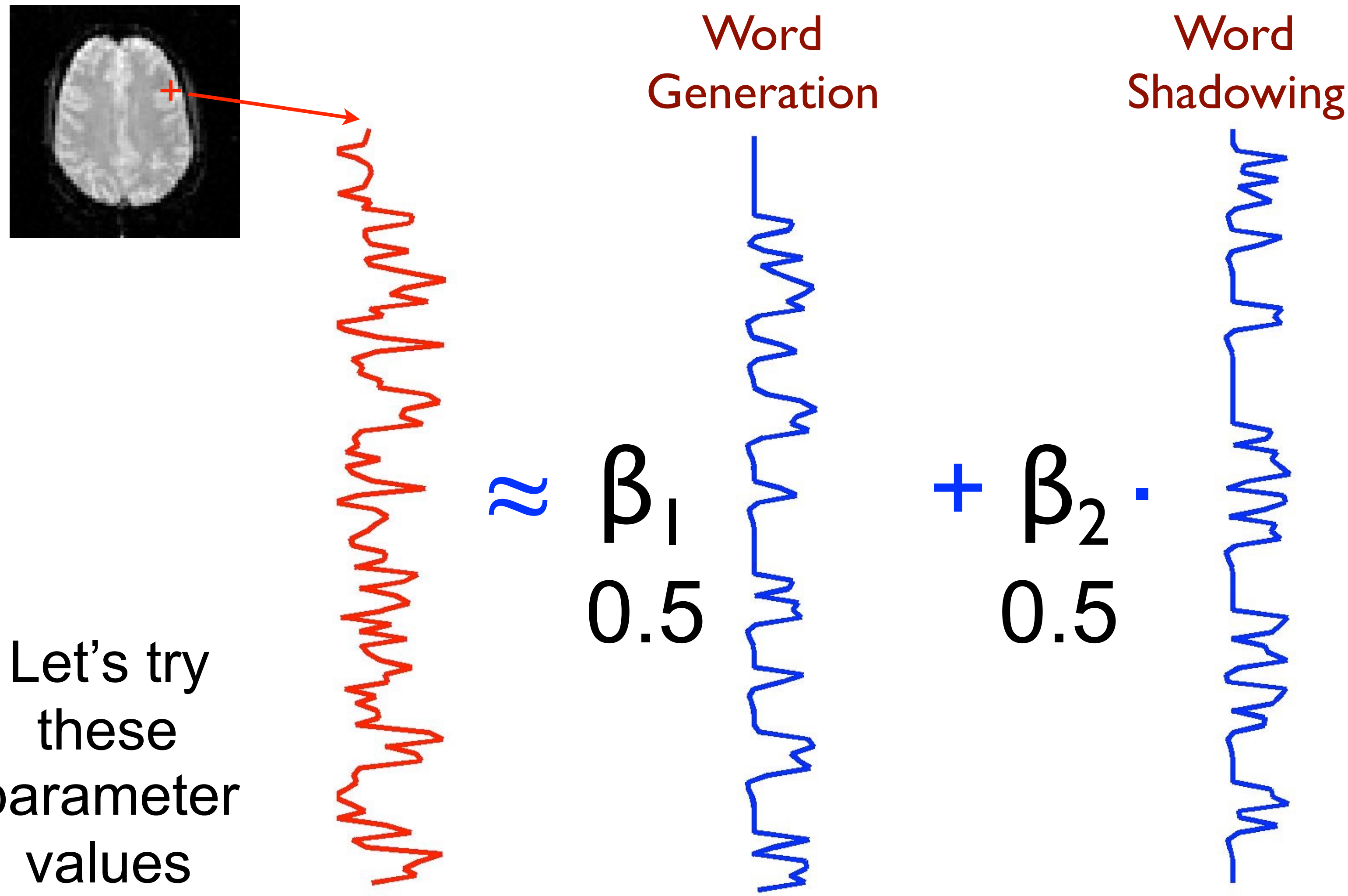


Slight detour: Making regressors



Estimation: Finding the "best" parameter values

- The estimation entails finding the parameter values such that the linear combination "best" fits the data.



Let's try these parameter values

Estimation:
Finding the "best" parameter values

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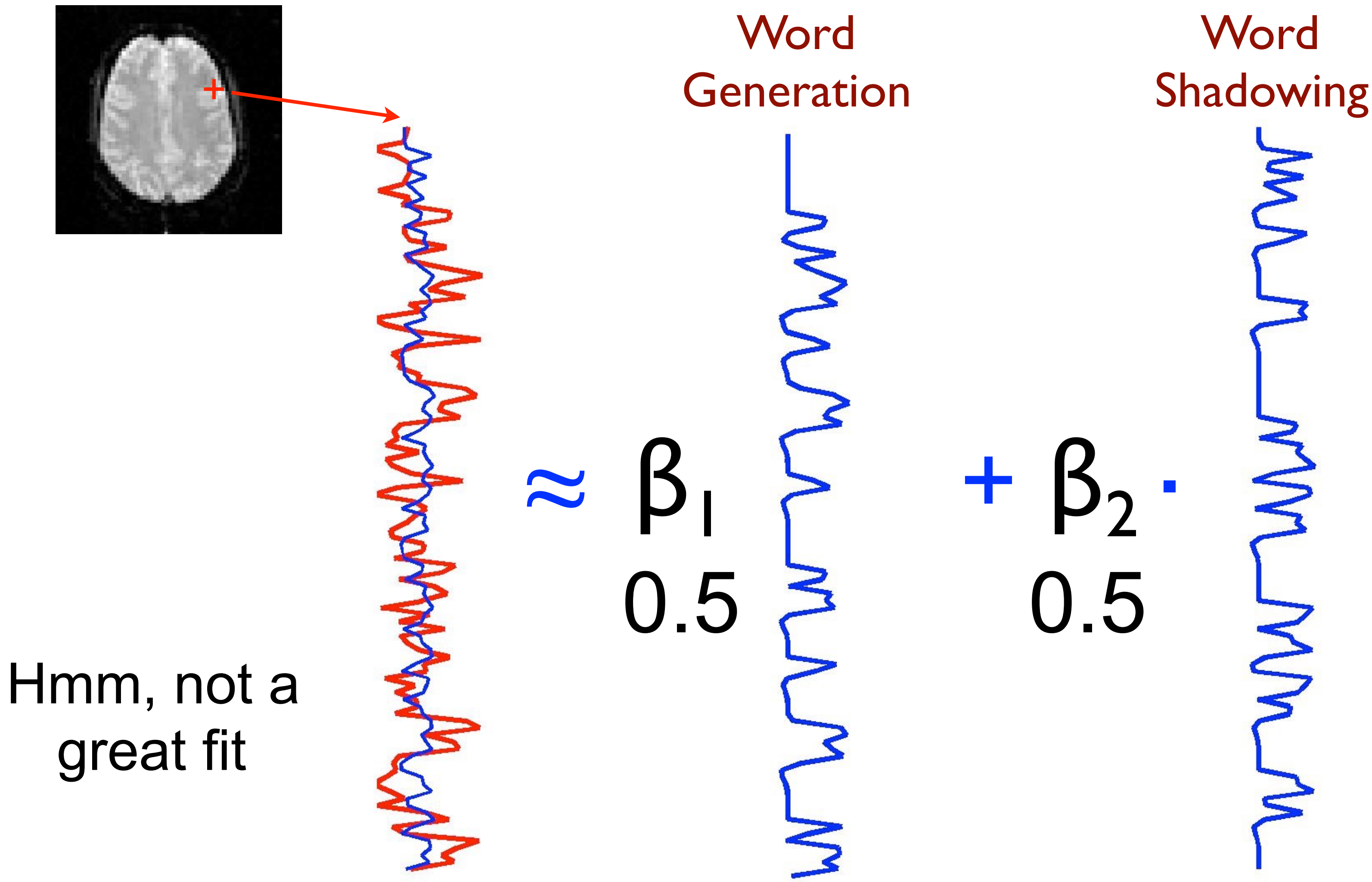

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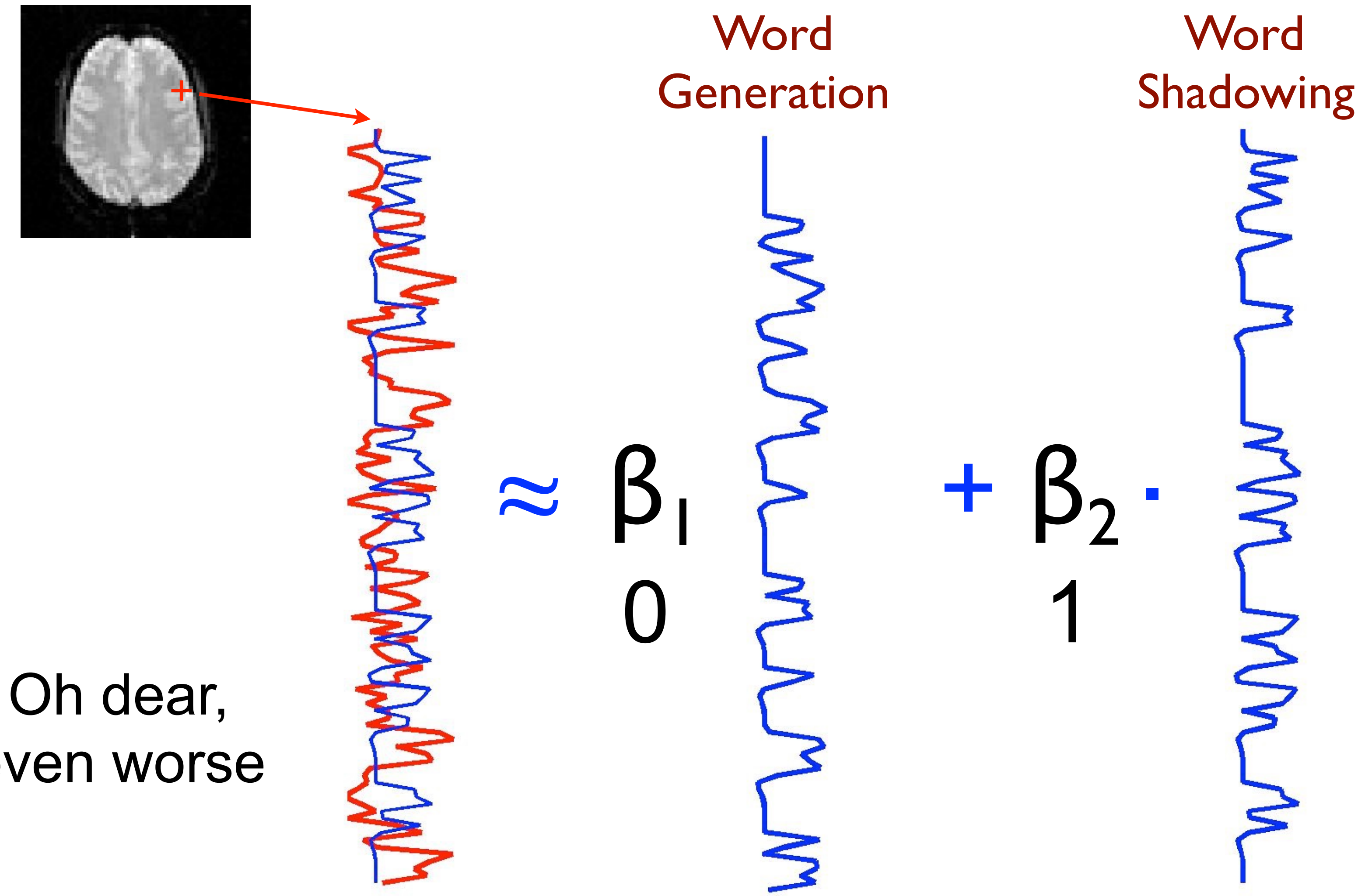

Oh dear, even worse

Estimation:
Finding the "best" parameter values

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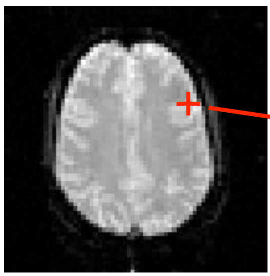

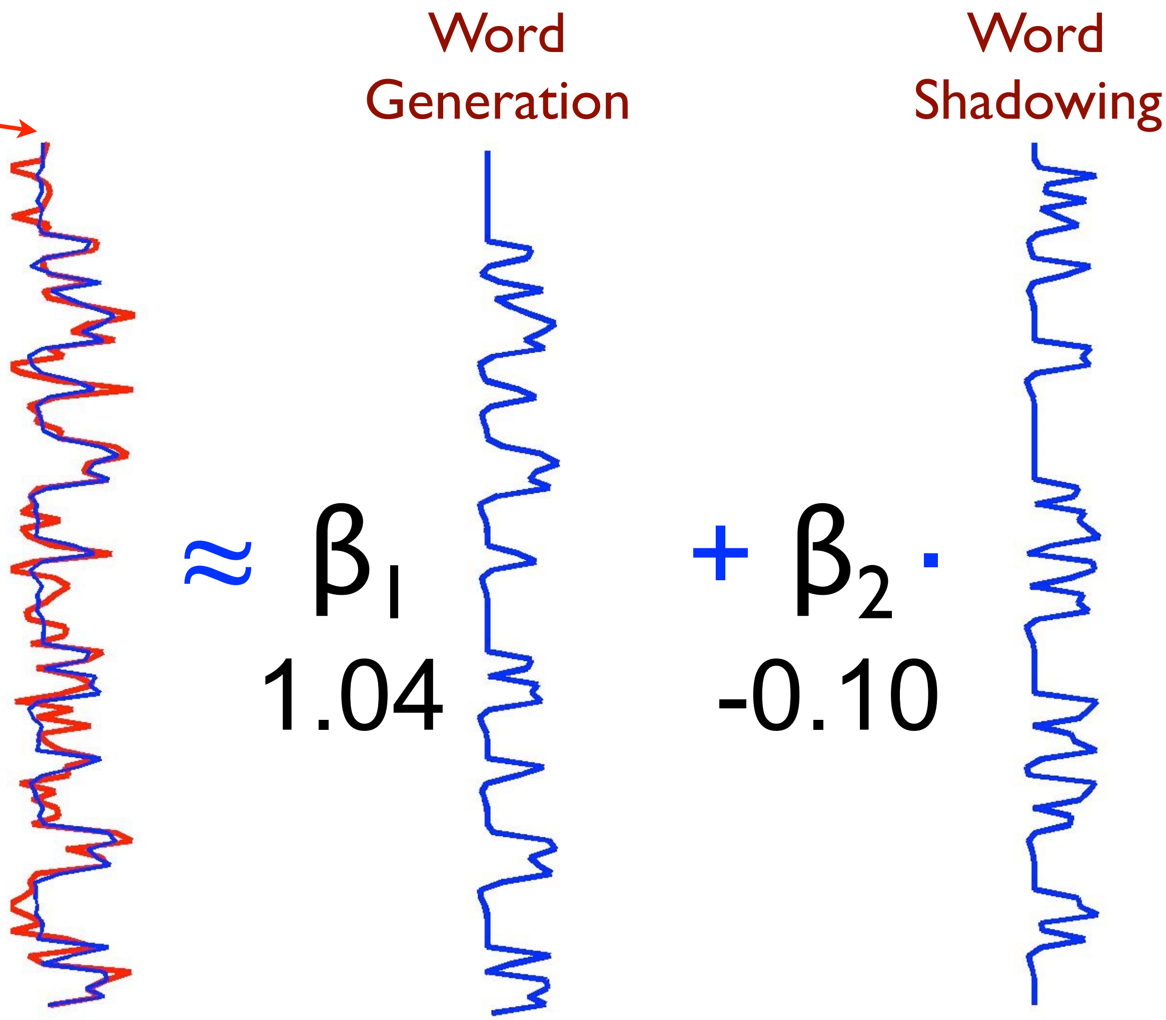

But that looks good

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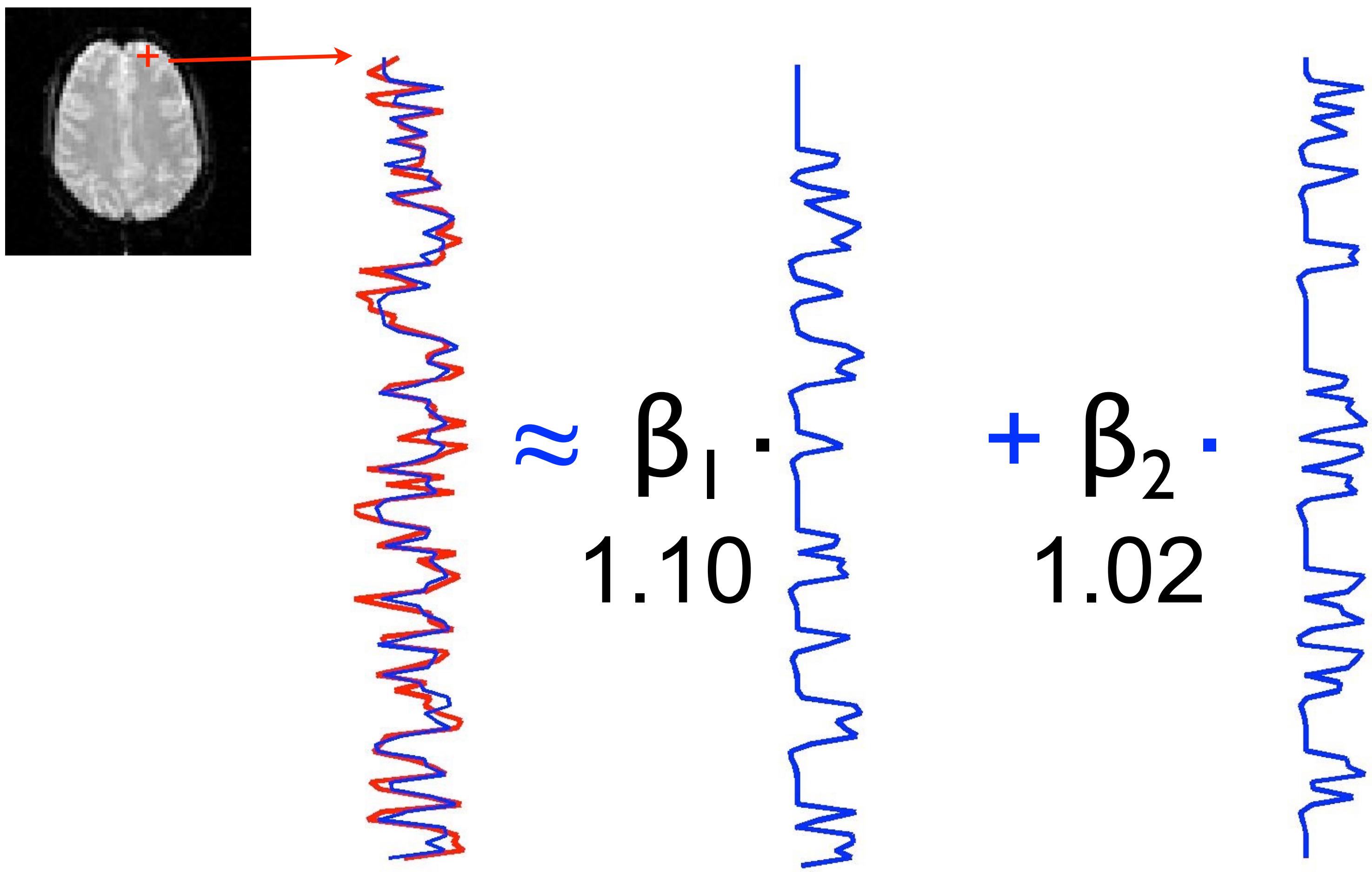

And different voxels yield different parameters

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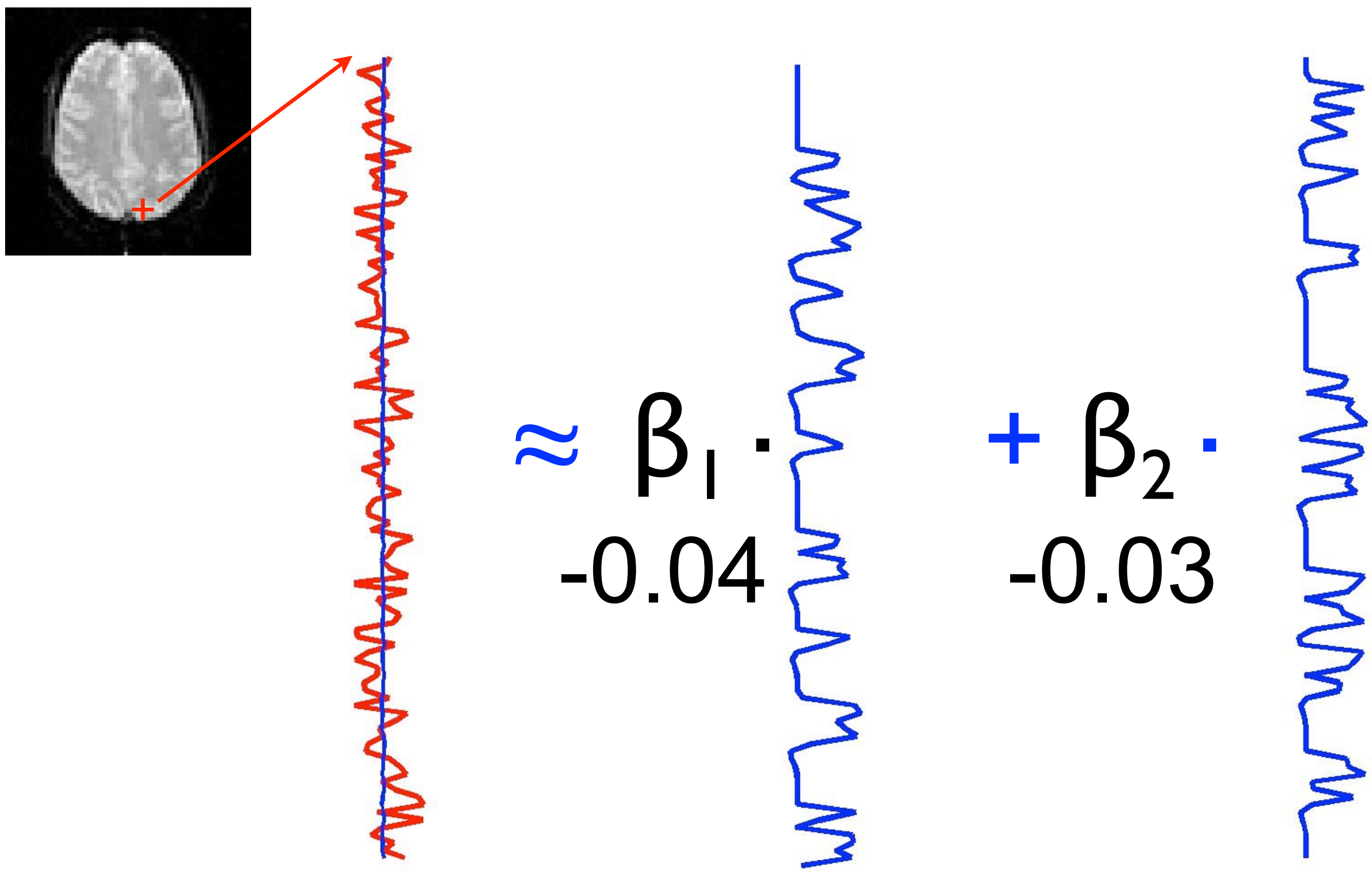
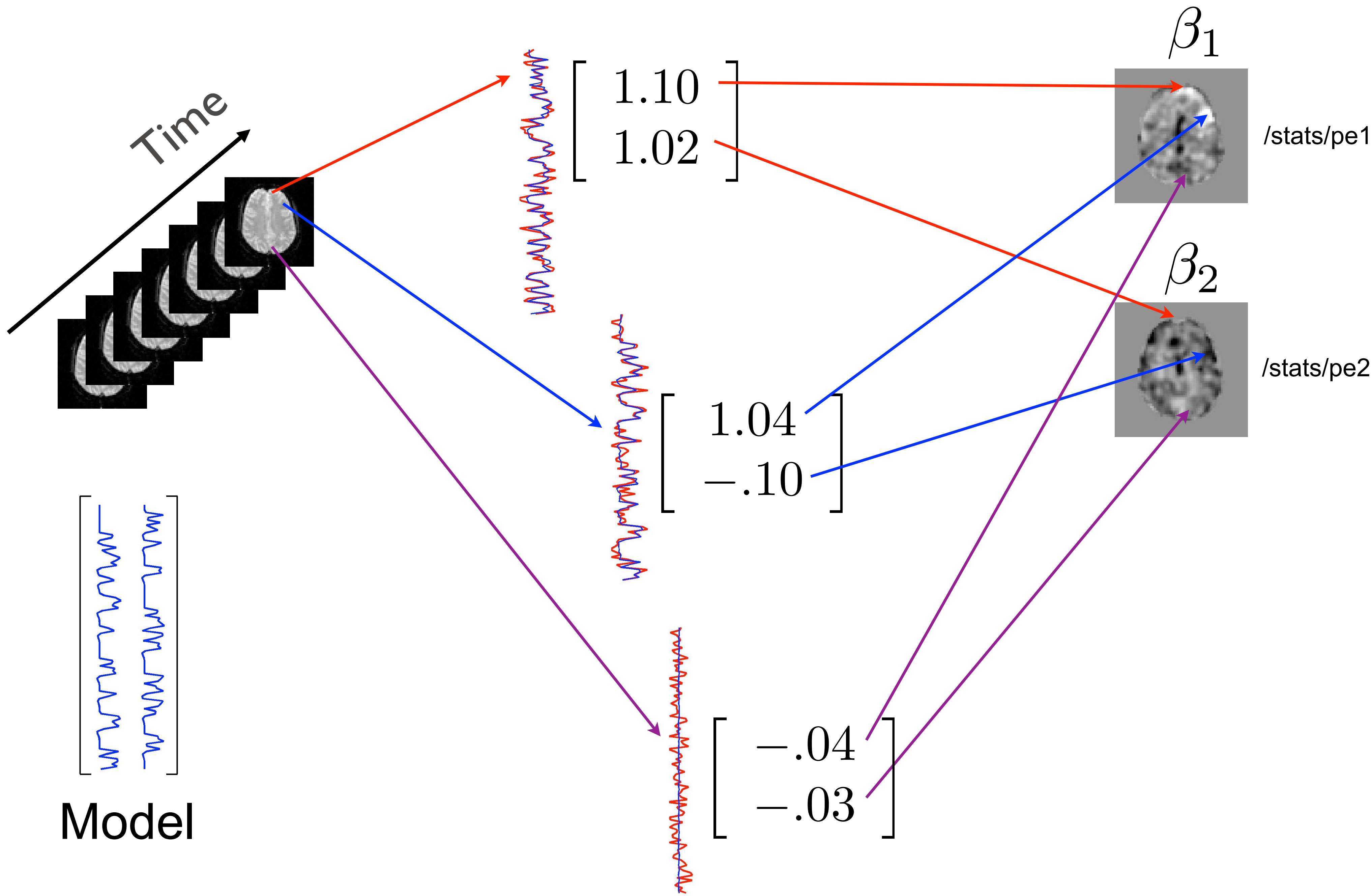
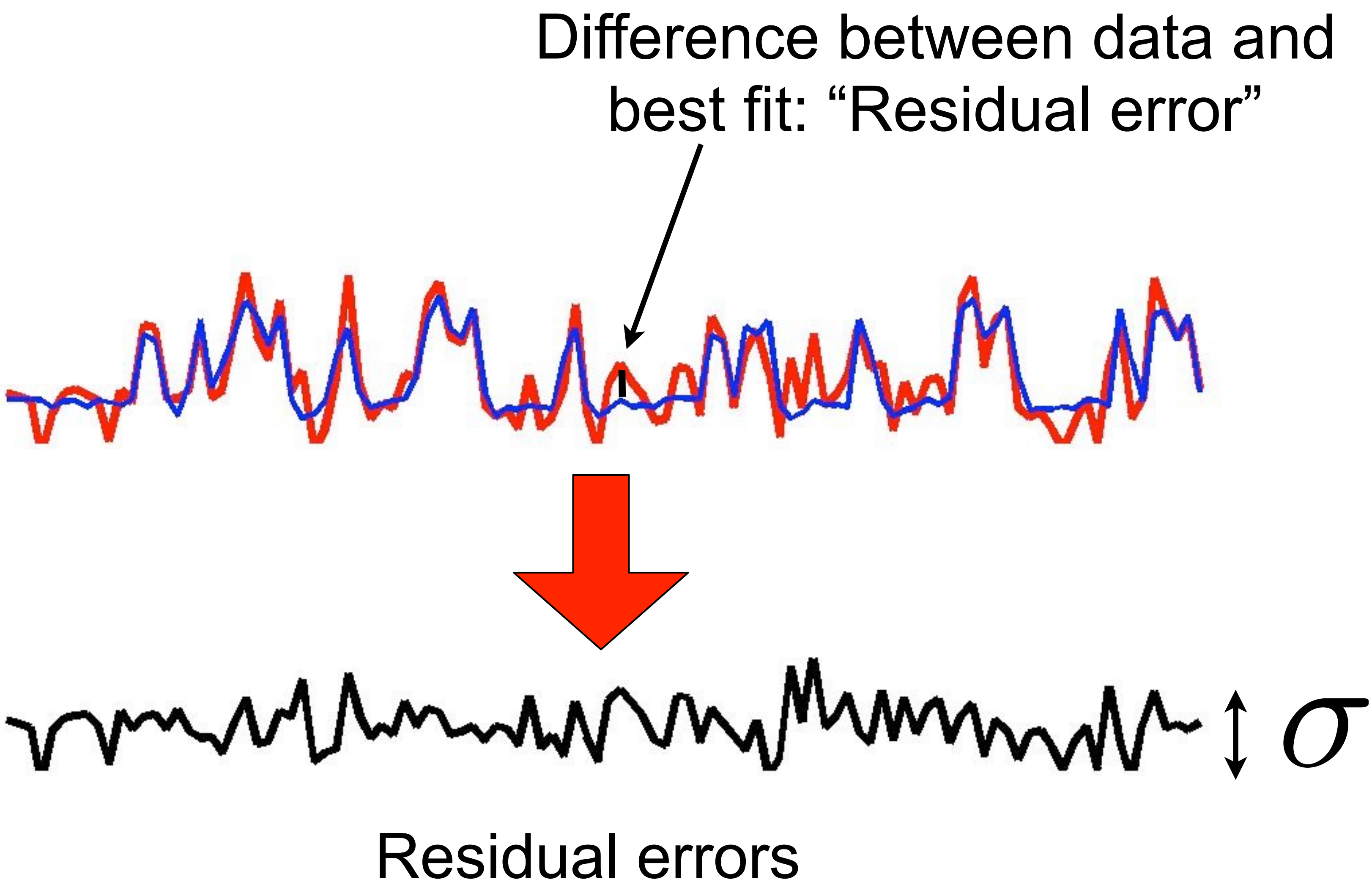


And different voxels yield different parameters

One model to fit them all



And we can also estimate the residual error



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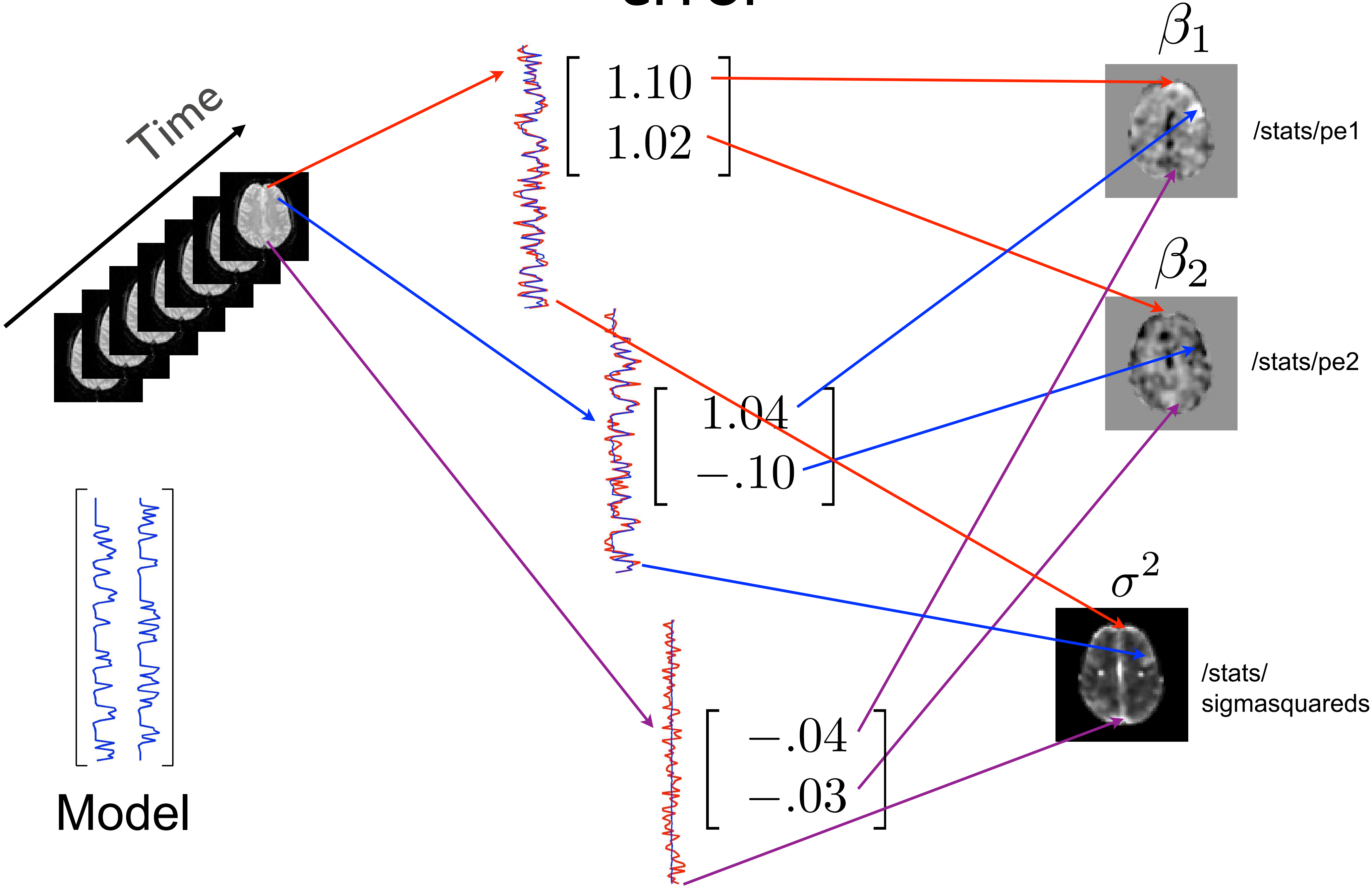
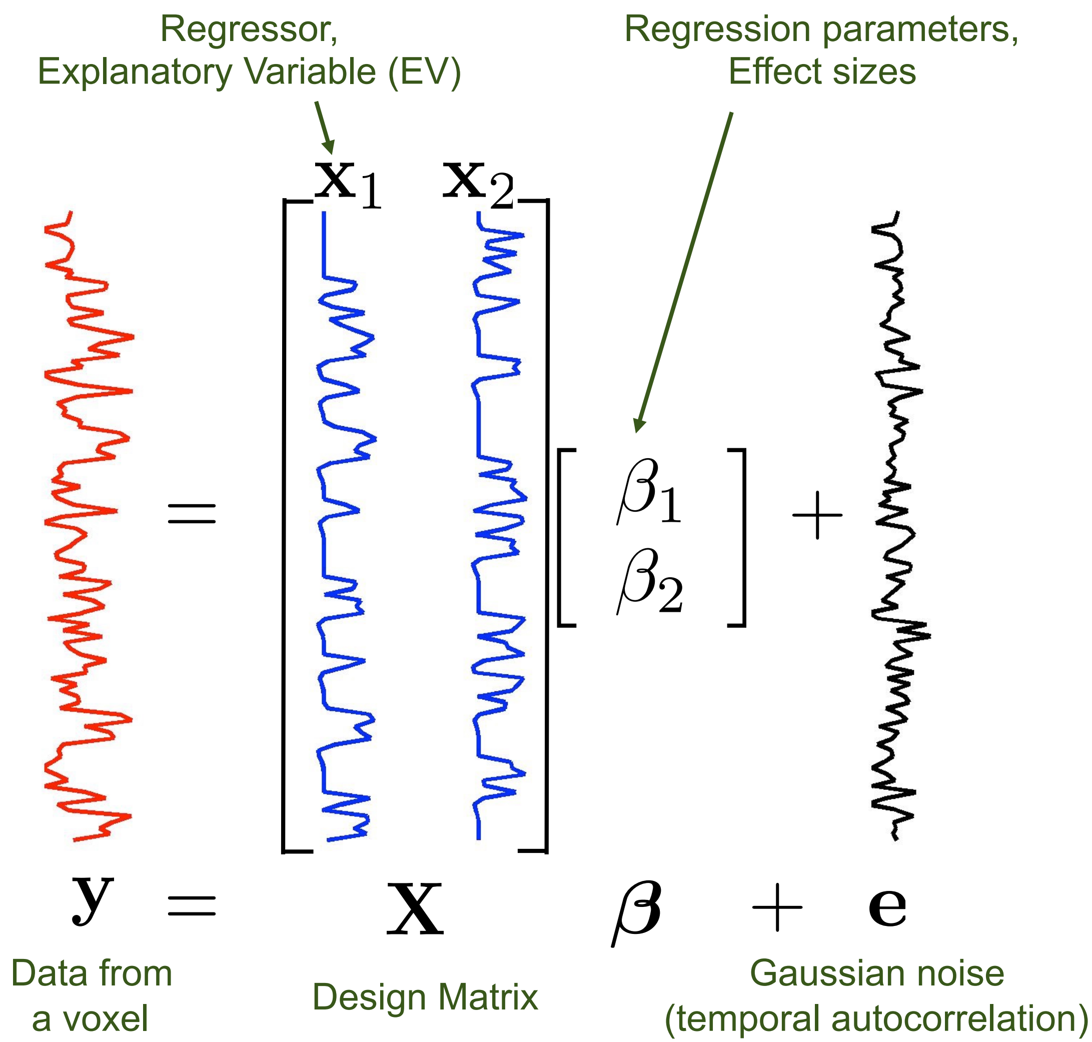


Summary of what we learned so far

- The "Model" consists of a set of "regressors" i.e. tentative time series that we expect to see as a response to our stimulus
- The model typically consists of our stimulus functions convolved by the HRF
- The estimation entails finding the parameter values such that the linear combination of regressors ”best” fits the data
- Every voxel has its own unique parameter values, that is how a single model can fit so many different time series
- We can also get an estimate of the error through the "residuals"

General Linear Model (GLM)

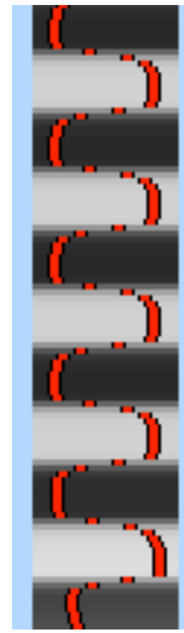
- This is placed into the General Linear Model (GLM) framework



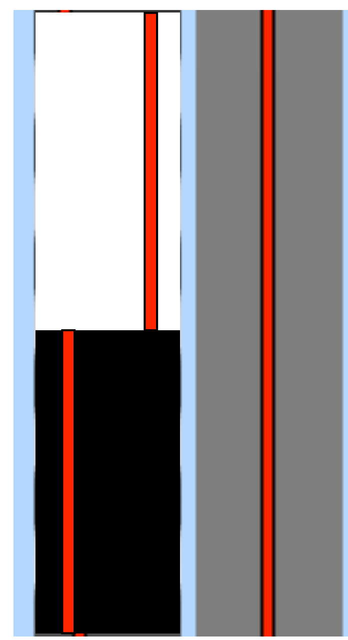
"Demeaning" and the GLM

- The mean value is uninteresting in an FMRI session
- There are two equivalent options:
    1. remove the mean from the data and don't model it
    2. put a term into the model to account for the mean

option #1



option #2



In FSL we use option #1 for first-level analyses and #2 for higher-level analyses

A consequence is that the baseline condition in first-level analysis is ***NOT*** explicitly modelled (in FSL)

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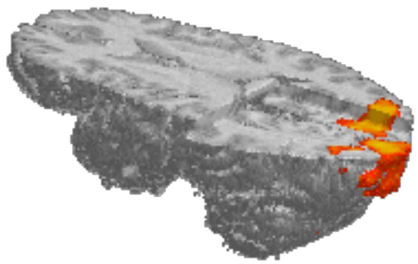


t-contrasts

- A contrast of parameter estimates (COPE) is a linear combination of PEs:

[1 0]: COPE = $1 \times \widehat{\beta}_1 + 0 \times \widehat{\beta}_2 = \widehat{\beta}_1$

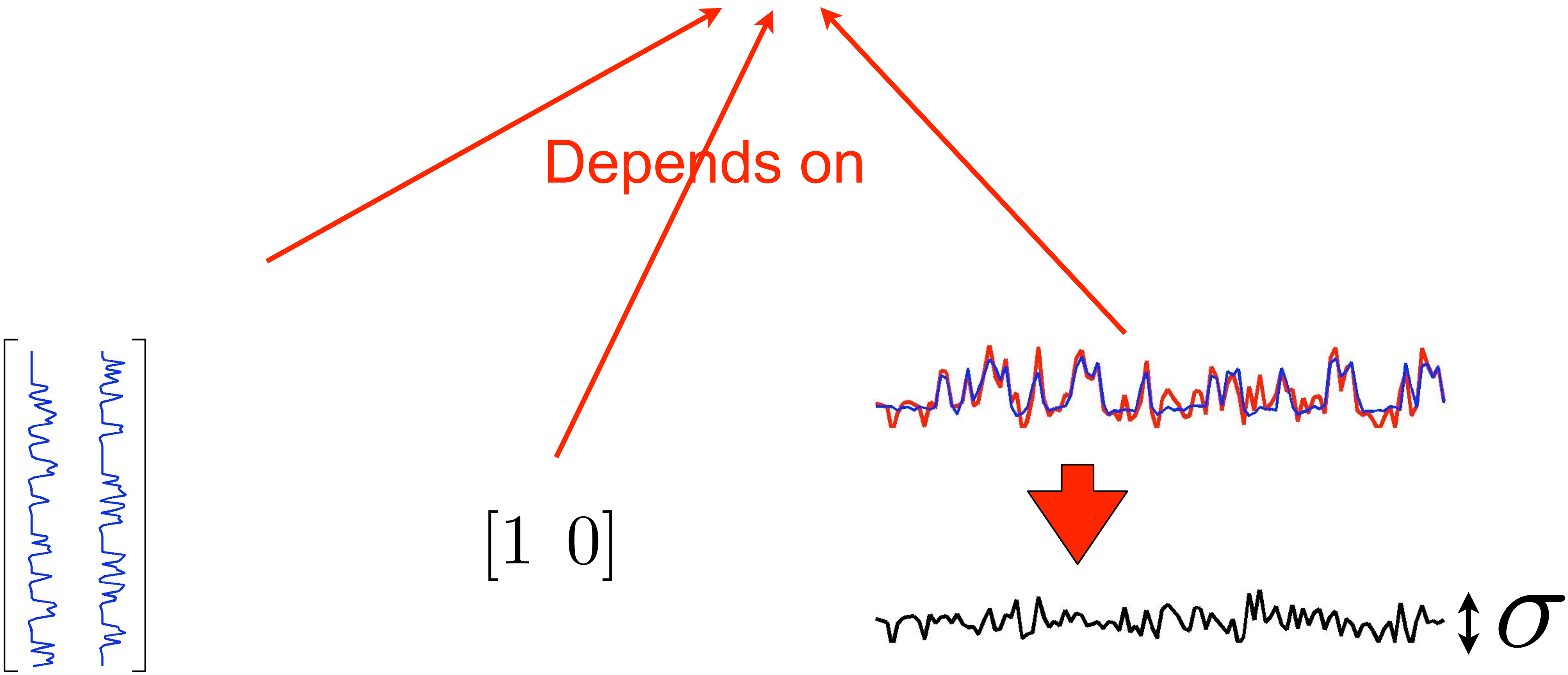
[1 -1]: COPE = $1 \times \widehat{\beta}_1 + -1 \times \widehat{\beta}_2 = \widehat{\beta}_1 - \widehat{\beta}_2$

- Test null hypothesis that COPE=0

t-statistic: $$t = \frac{COPE}{std(COPE)}$$

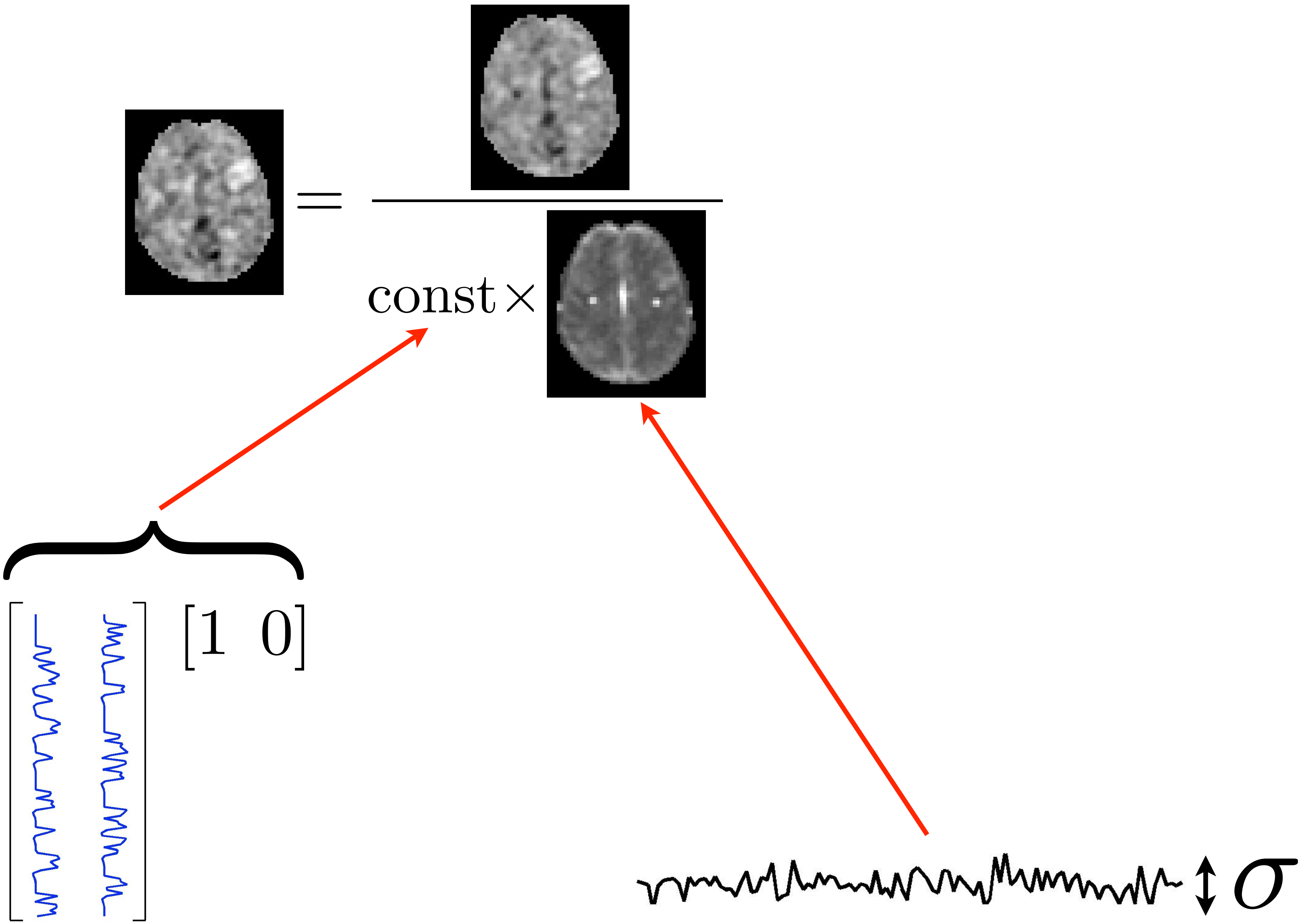
t-contrasts

$$t = \frac{COPE}{std(COPE)}$$



The Model ,the Contrast and the Residual Error

t-contrasts



The Model & the Contrast and the Residual Error

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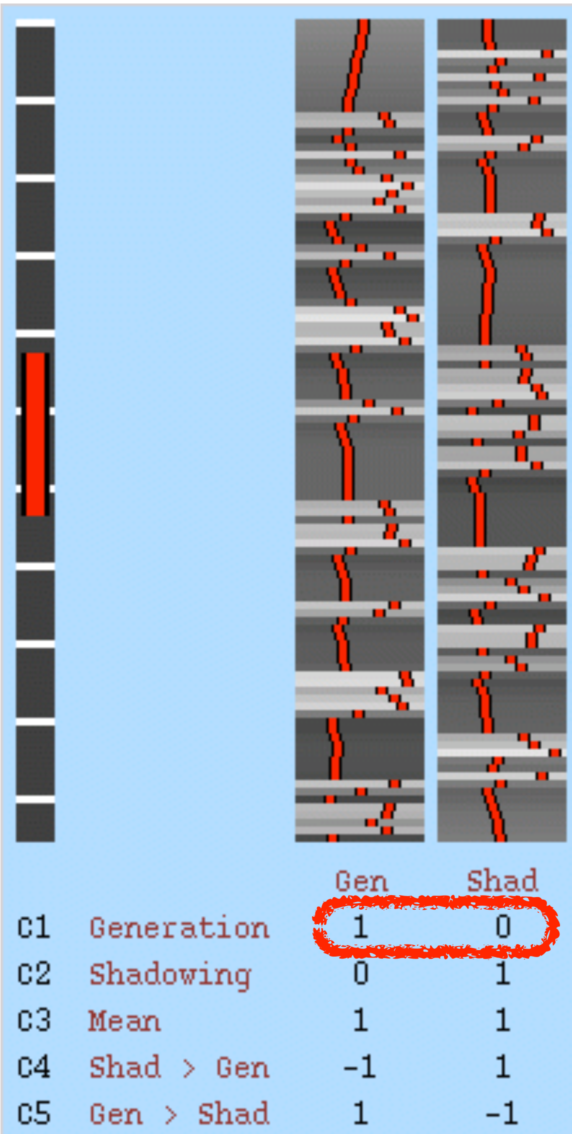
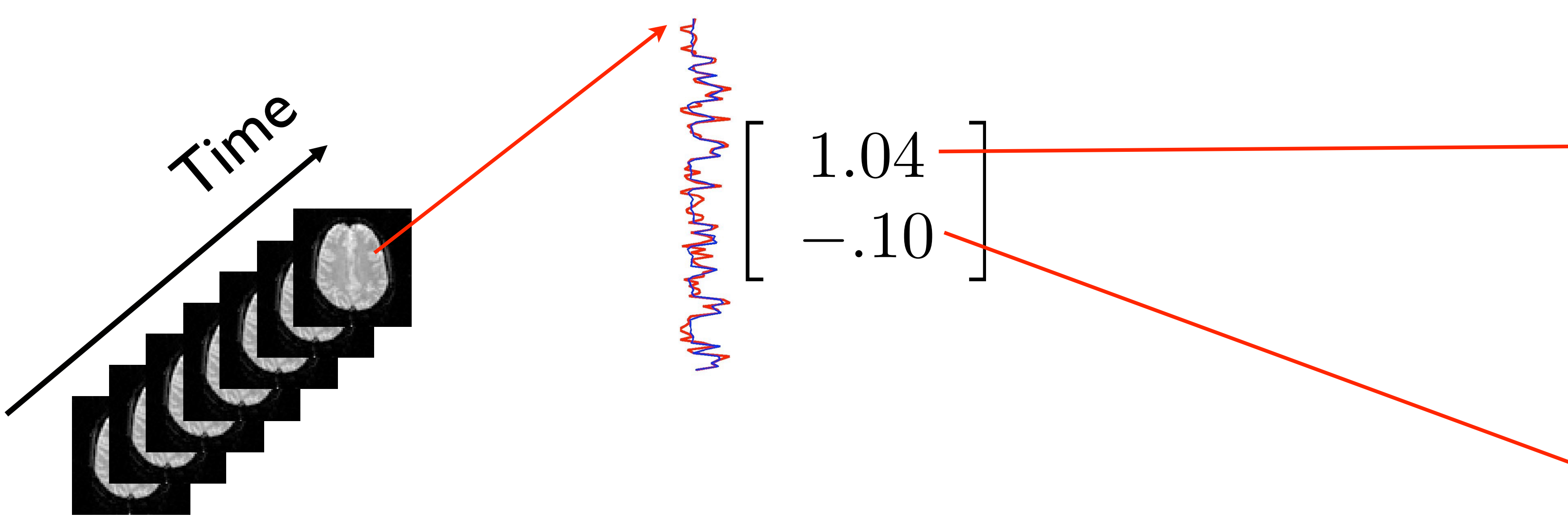
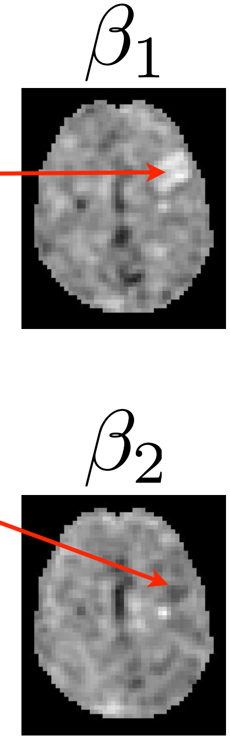


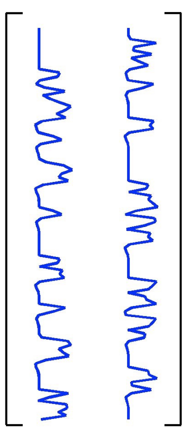
- [1 0] : EV1 only (i.e. Generation vs rest)
- [0 1] : EV2 only (i.e. Shadowing vs rest)

t-contrasts





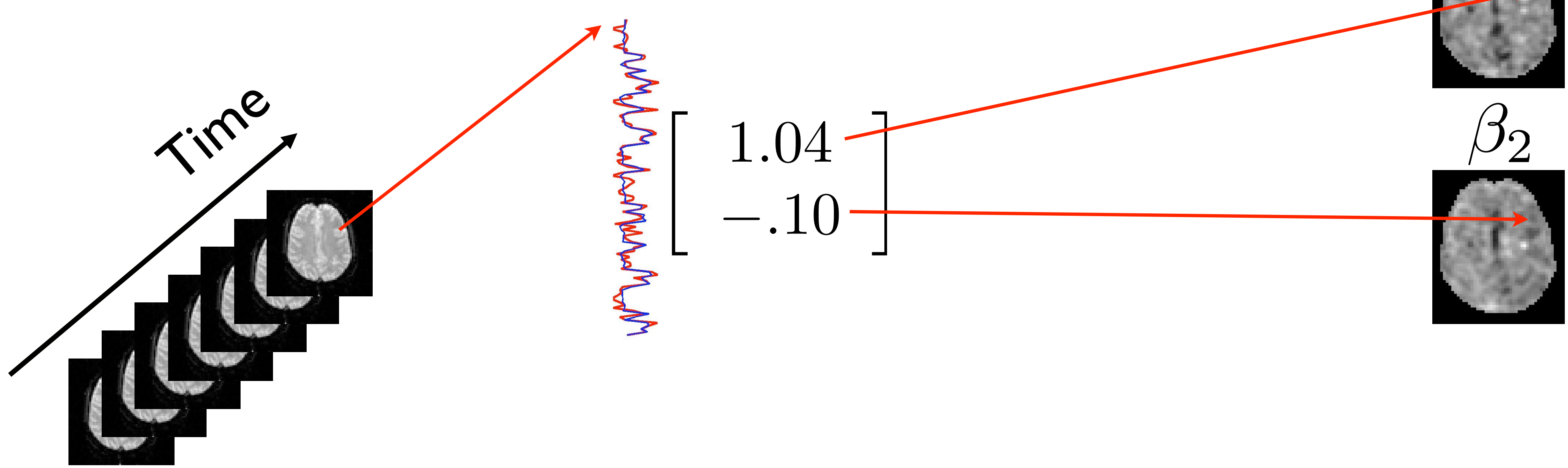
Contrast weight vector: $[1 \;\; 0]$



Model

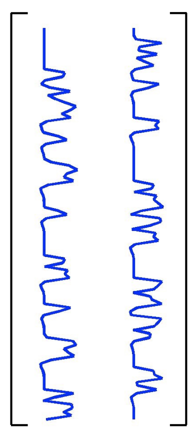
Asks the question: Where do we need this regressor to model the data, i.e. what parts of the brain are used when seeing nouns and generating related verbs?

t-contrasts



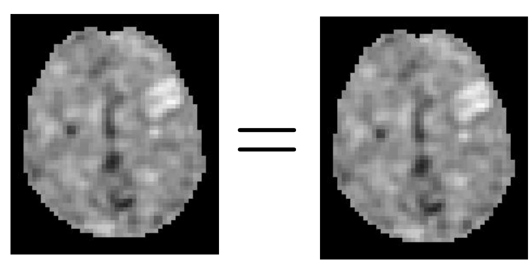
Contrast weight vector: $[1 \;\; 0]$

$$\text{COPE} = 1 \times 1.04 + 0 \times -0.10 = 1.04$$



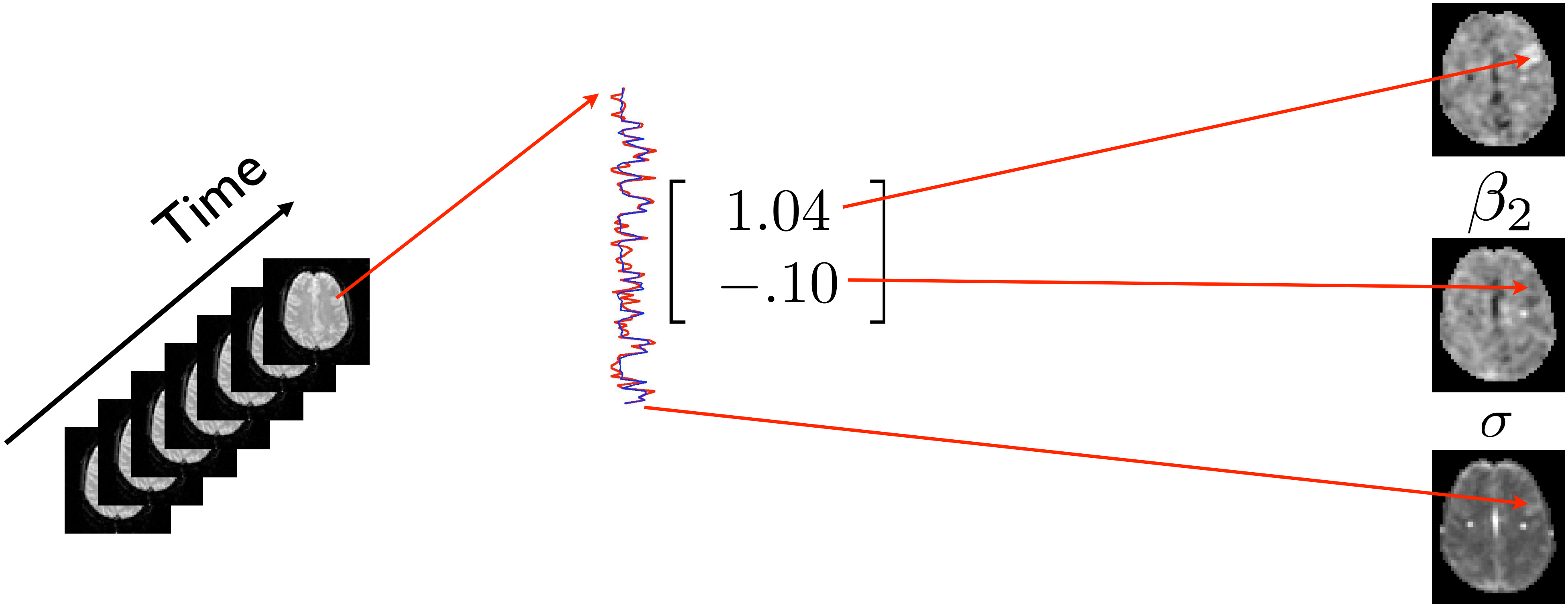
Model

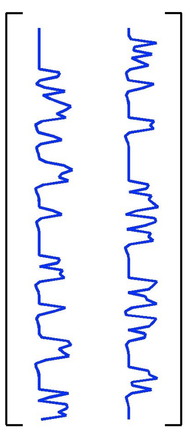
$\text{COPE} =$



β_1

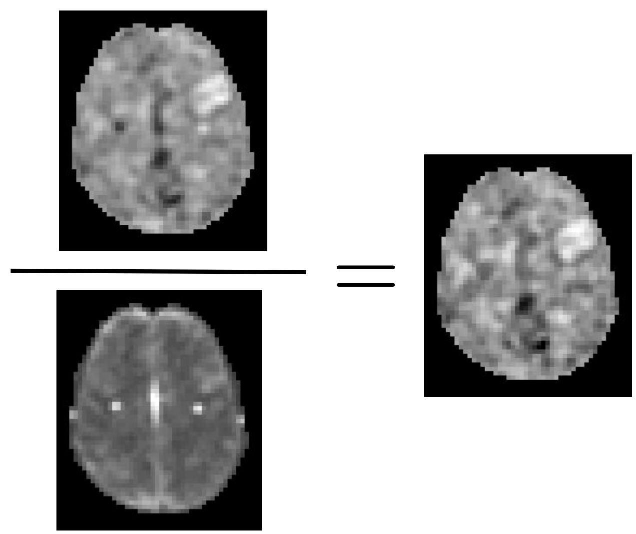
t-contrasts



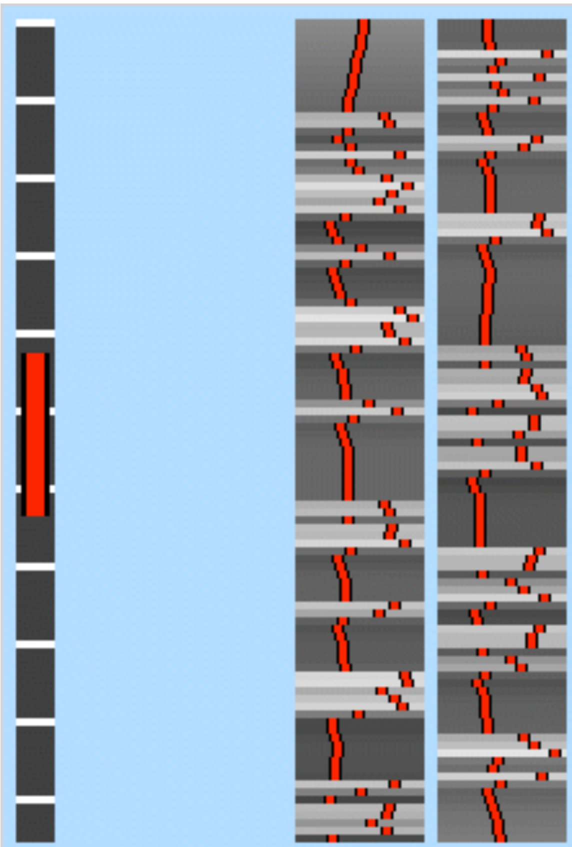


Model

$$t = \frac{\text{COPE}}{\text{std(COPE)}} =$$



t-contrasts

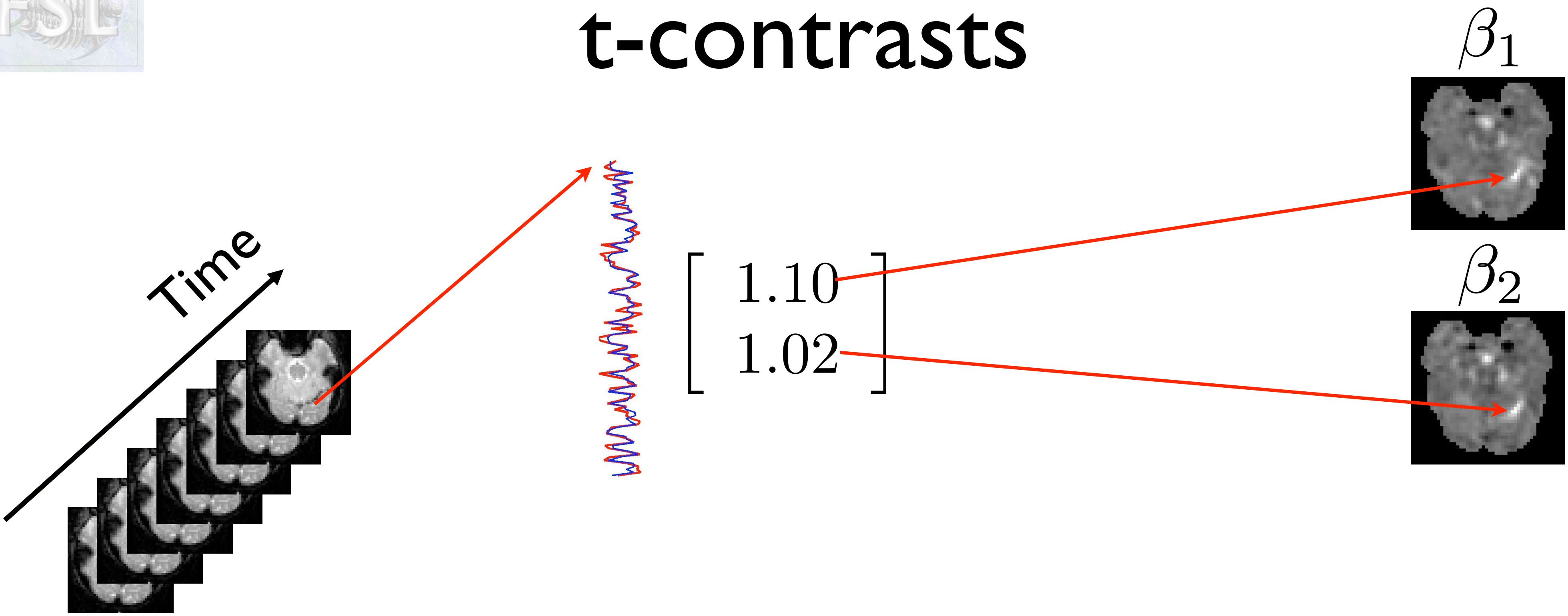


		Gen	Shad
C1	Generation	1	0
C2	Shadowing	0	1
C3	Mean	1	1
C4	Shad > Gen	-1	1
C5	Gen > Shad	1	-1

- [1 0] : EV1 only (i.e. Generation vs rest)
- [0 1] : EV2 only (i.e. Shadowing vs rest)

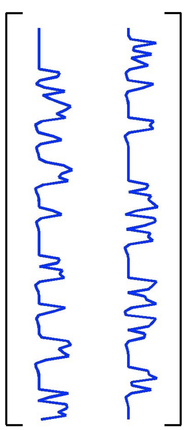
- [1 1] : EV1 + EV2 (Mean activation)

t-contrasts



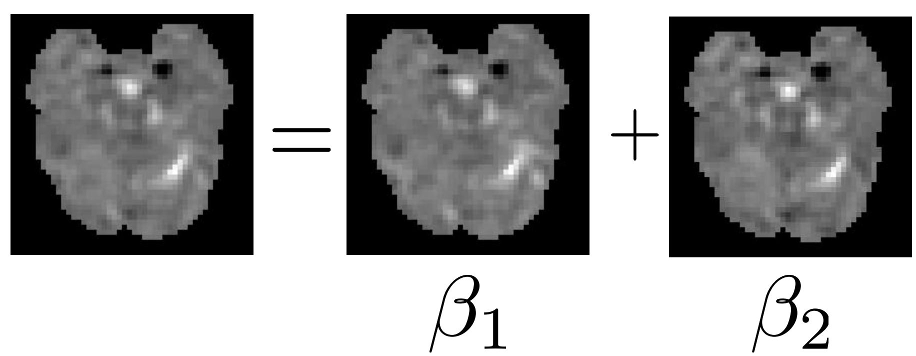
Contrast weight vector: $[1 \ \ 1]$

$$\text{COPE} = 1 \times 1.10 + 1 \times 1.02 = 2.12$$

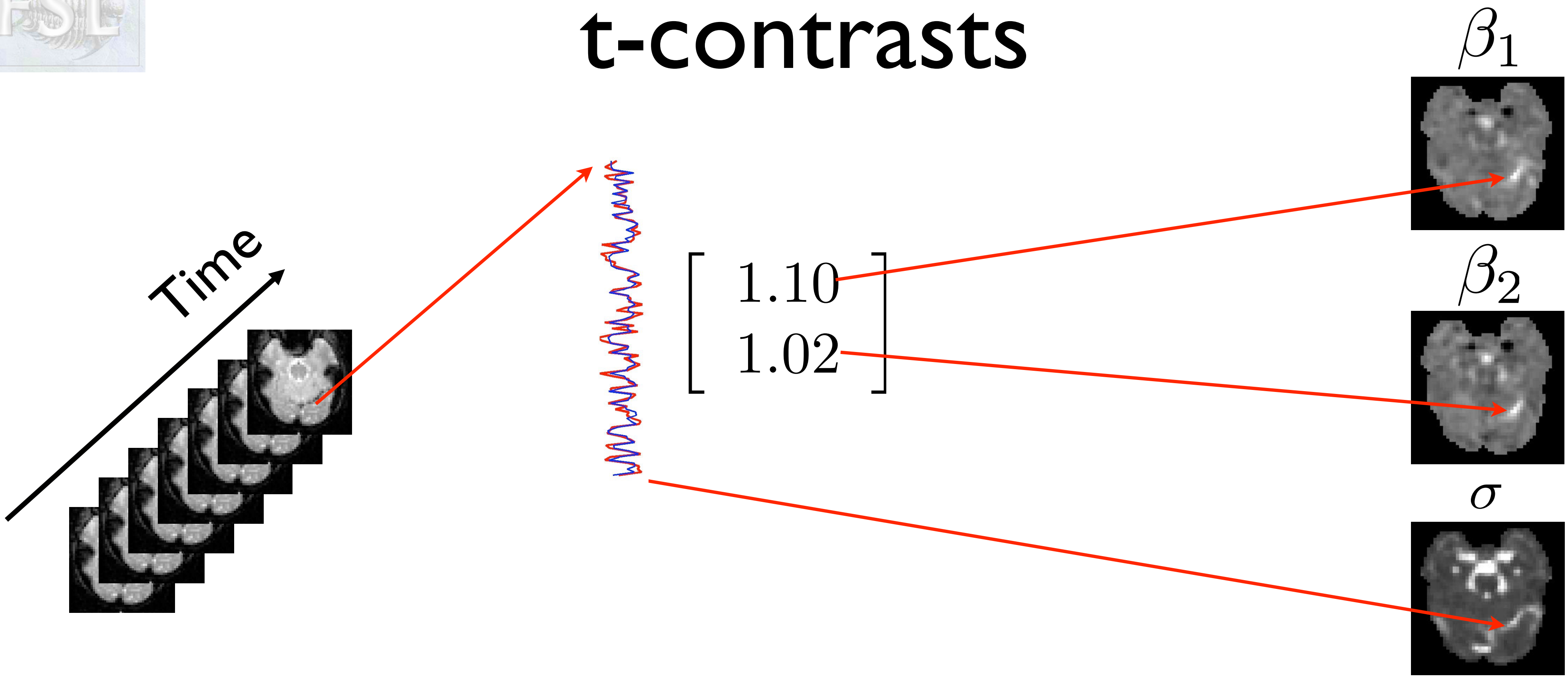


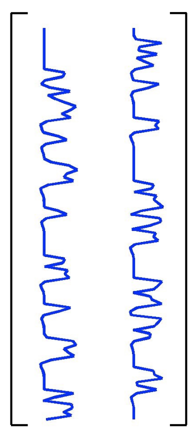
Model

$\text{COPE} =$

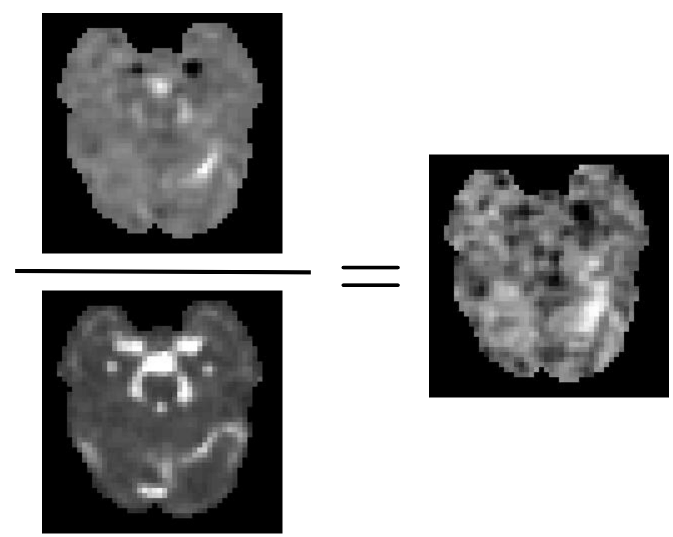


t-contrasts

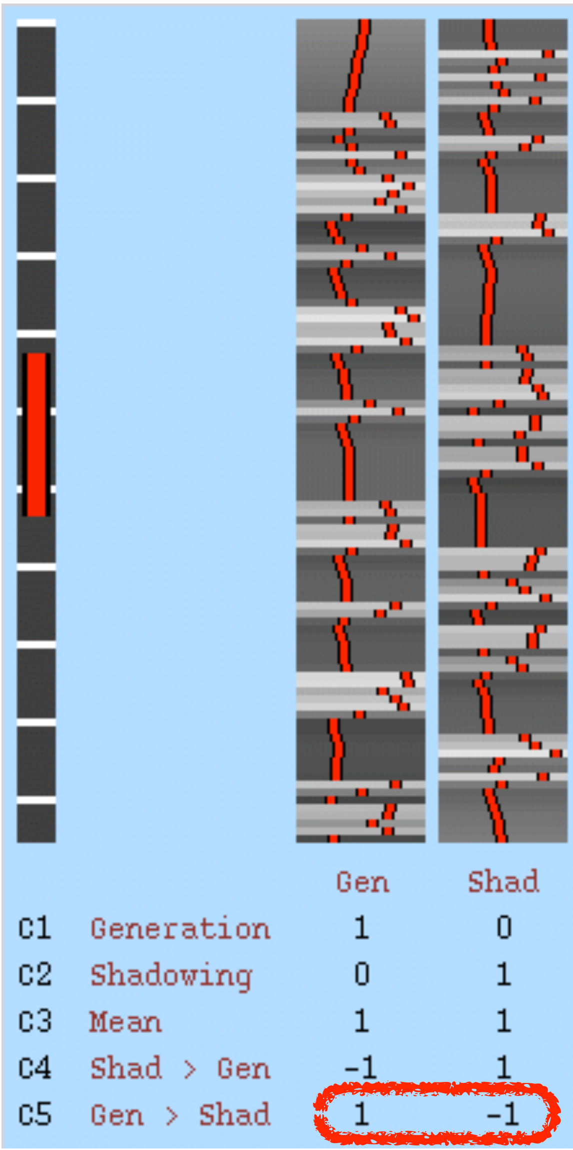




$$t = \frac{\mathrm{COPE}}{\mathrm{std}(\mathrm{COPE})} =$$

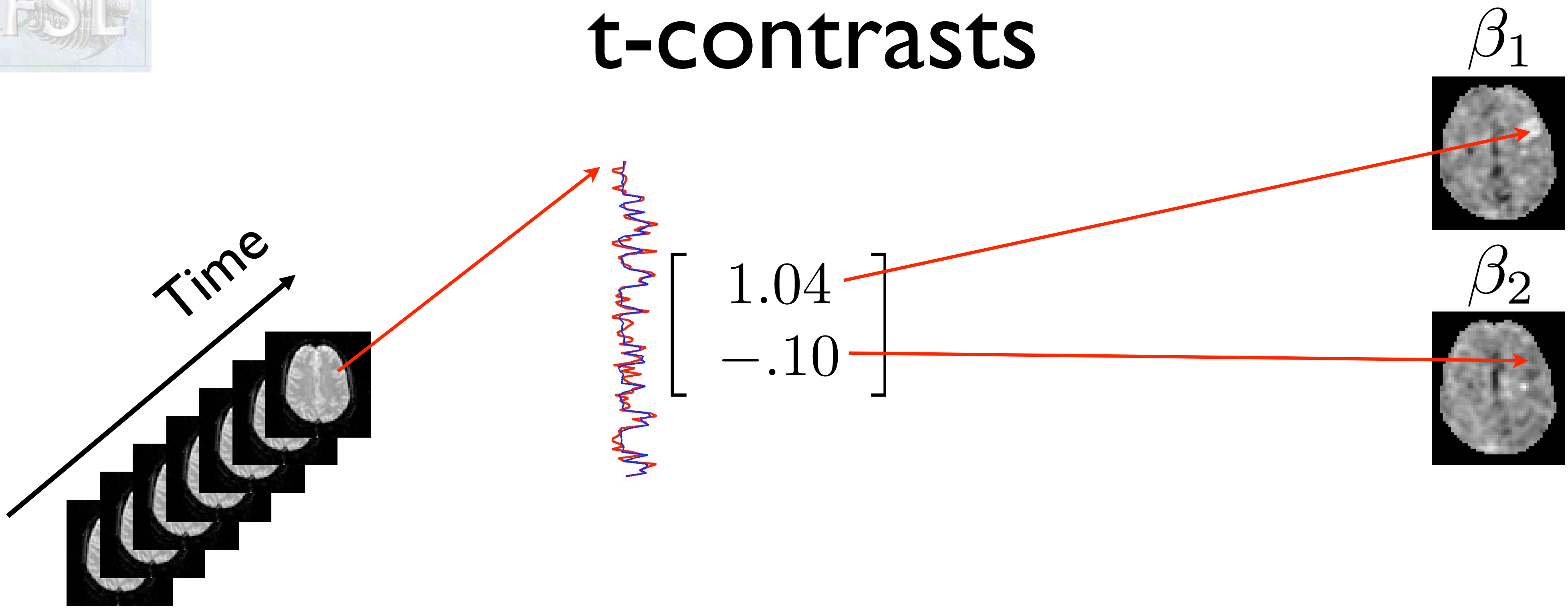


t-contrasts



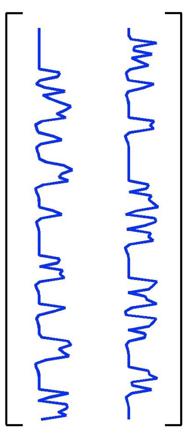
- [1 0] : EV1 only (i.e. Generation vs rest)
- [0 1] : EV2 only (i.e. Shadowing vs rest)
- [1 1] : EV1 + EV2 (Mean activation)
- [-1 1]: EV2 - EV1 (More activated by Shadowing than Generation)
- [1 -1]: EV1 - EV2 (More activated by Generation than Shadowing (*t*-tests are directional))

t-contrasts



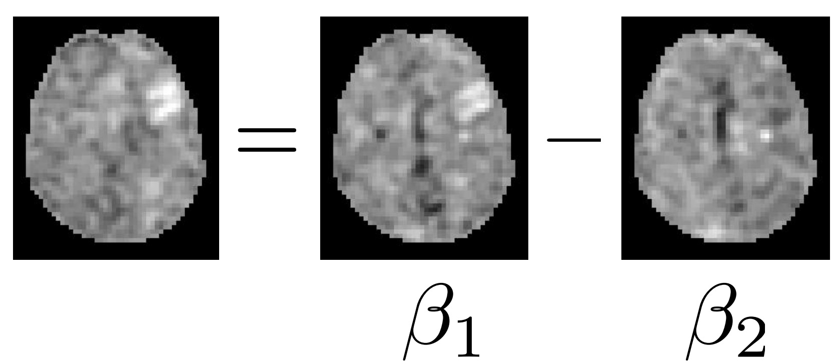
Contrast weight vector: $[1 \quad -1]$

$$\mathrm{COPE} = 1 \times 1.04 - 1 \times -0.10 = 1.14$$

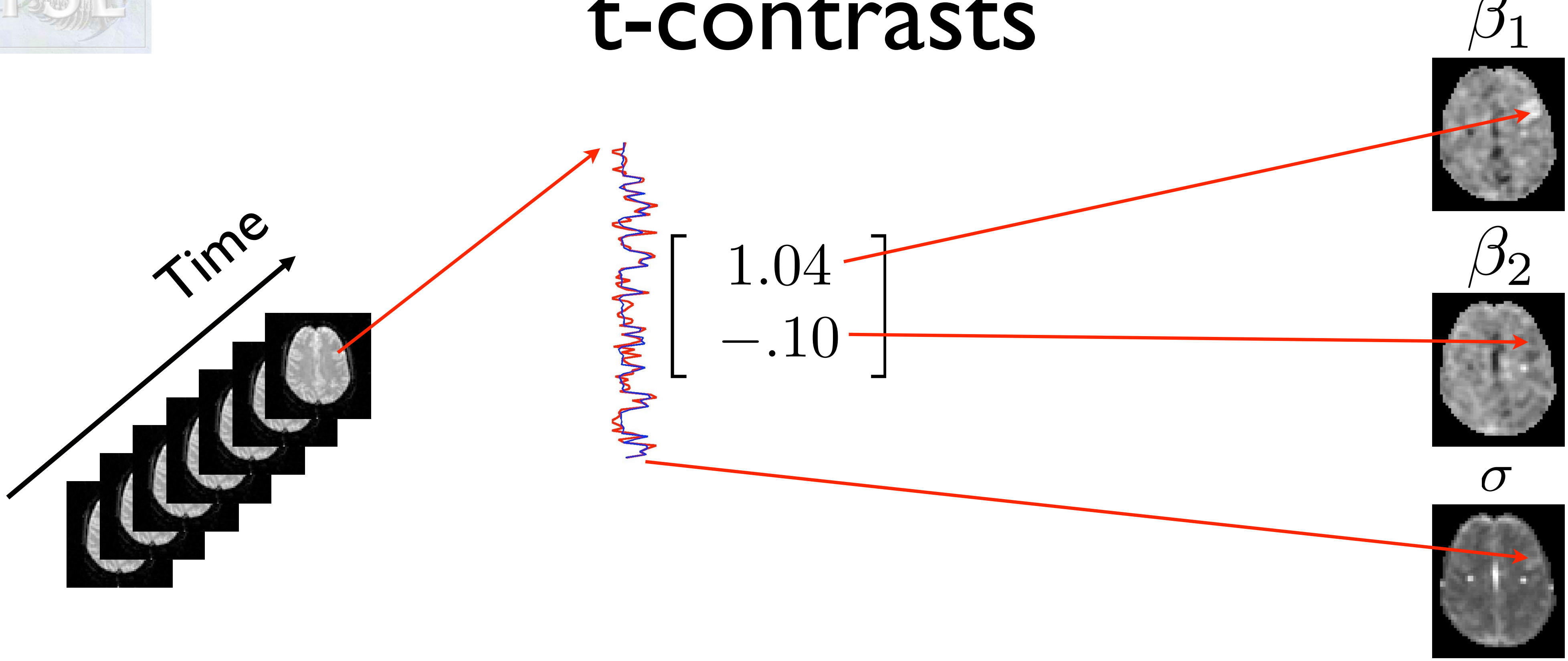


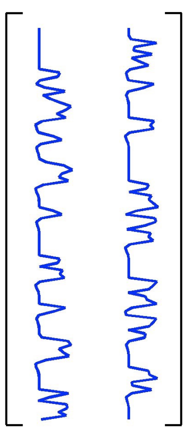
Model

$\mathrm{COPE} =$

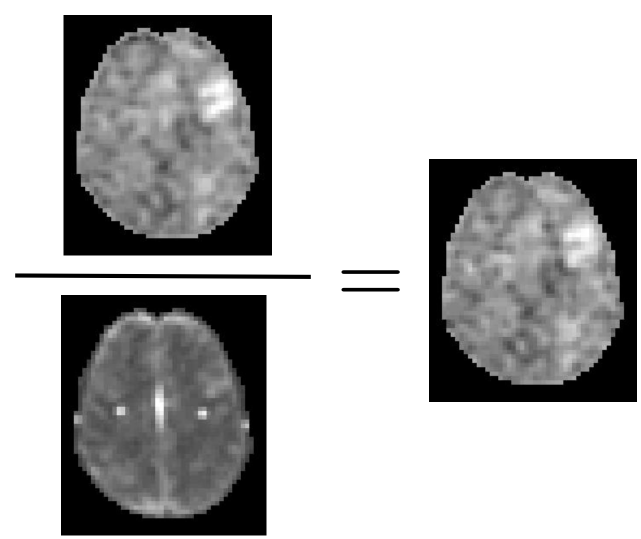


t-contrasts

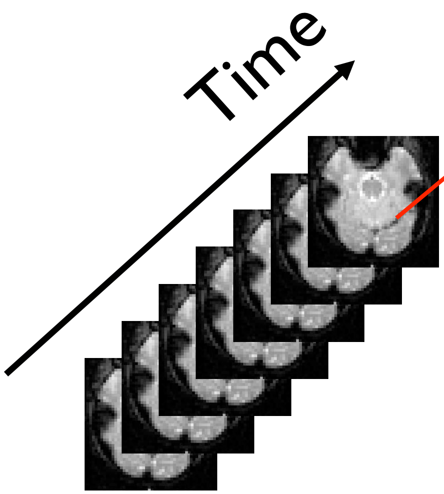


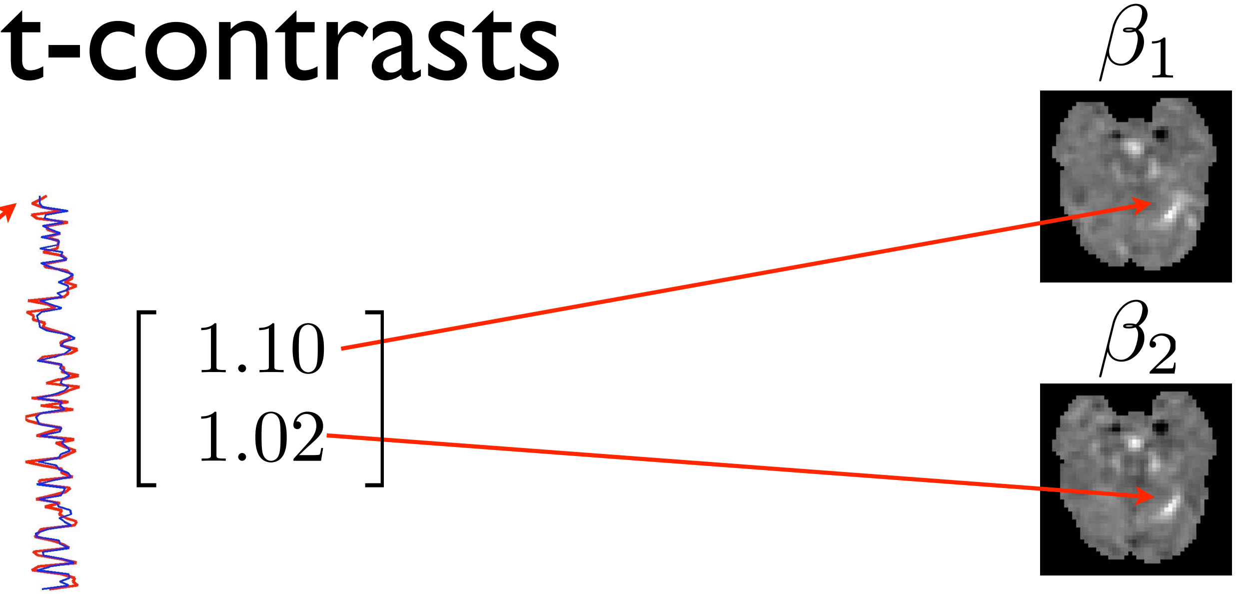


$$t = \frac{\text{COPE}}{\text{std(COPE)}} =$$



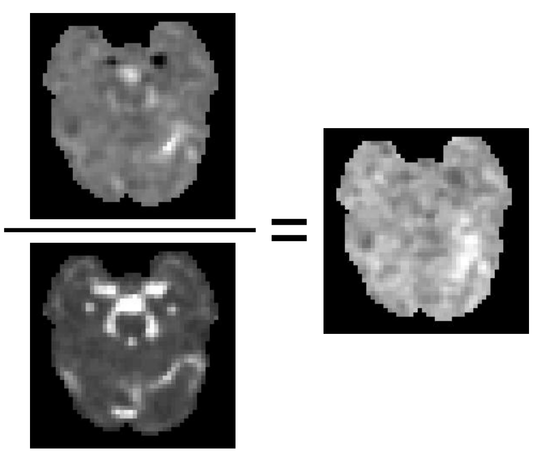
t-contrasts



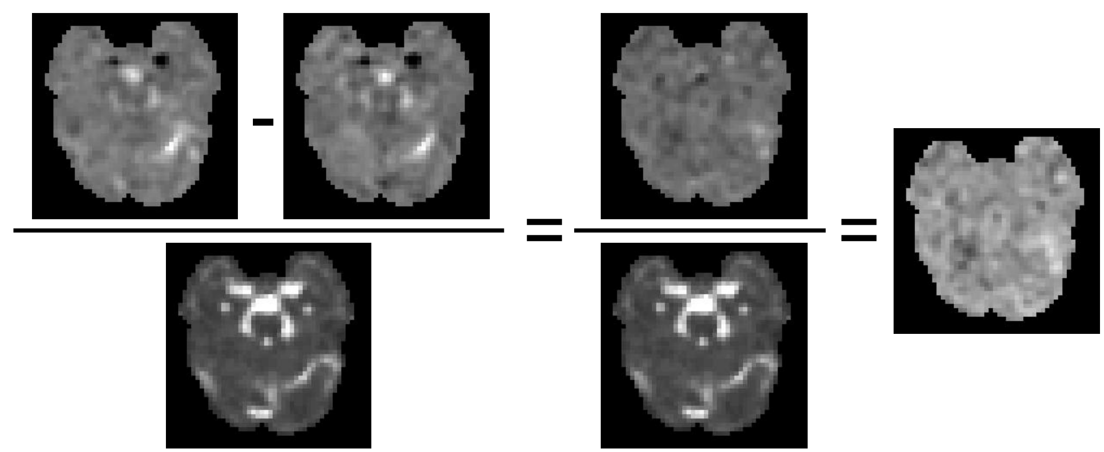


Why $[1 \;\; -1]$ instead of $[1 \;\; 0]$?

$[1 \;\; 0]$



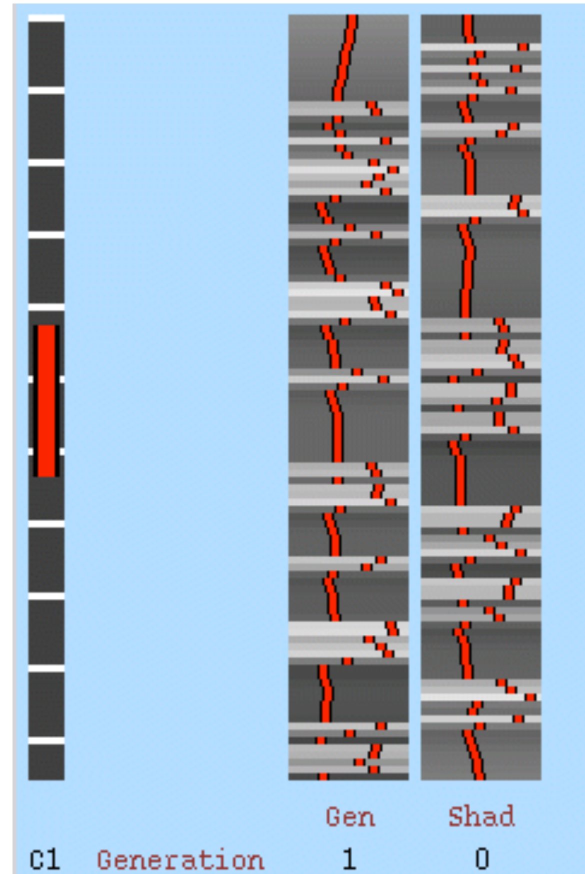
$[1 \;\; -1]$



F-contrasts

We have two conditions:
Word Generation and Shadowing

We want to know:
Is there an activation to any condition?



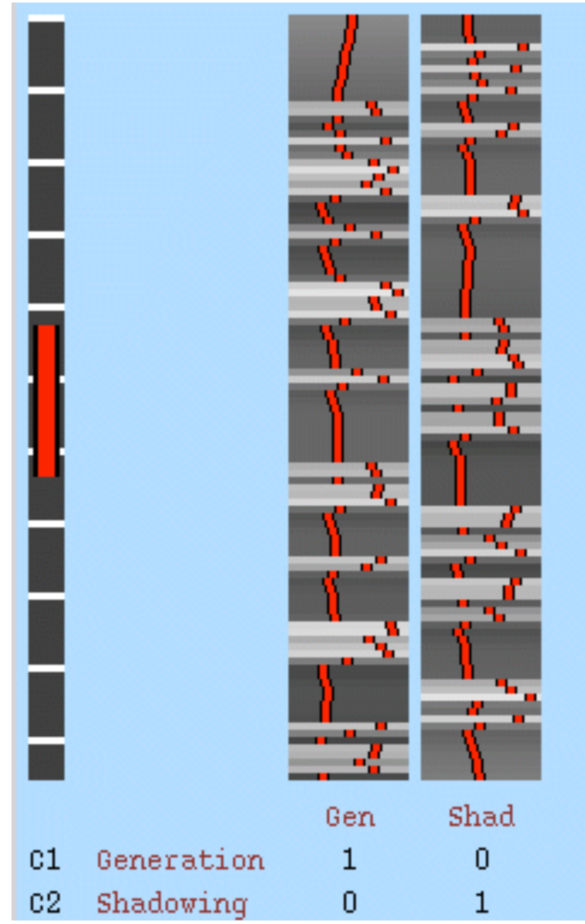
FIrst we ask: Is there activation to Generation?

$$\begin{bmatrix} 1 & 0 \end{bmatrix}$$

F-contrasts

We have two conditions:
Word Generation and Shadowing

We want to know:
Is there an activation to any condition?



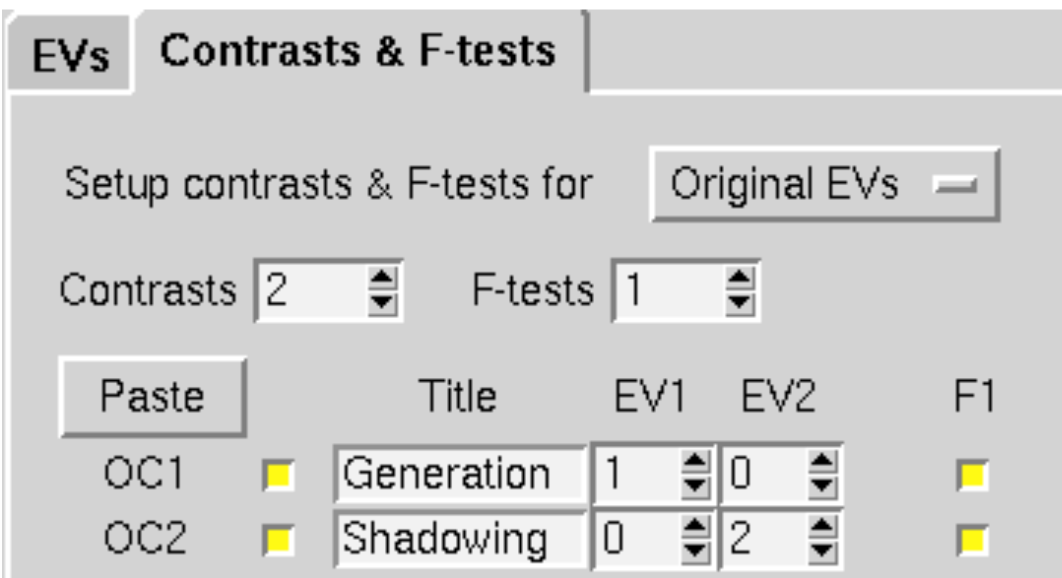
Then we ask: Is there activation to Shadowing?

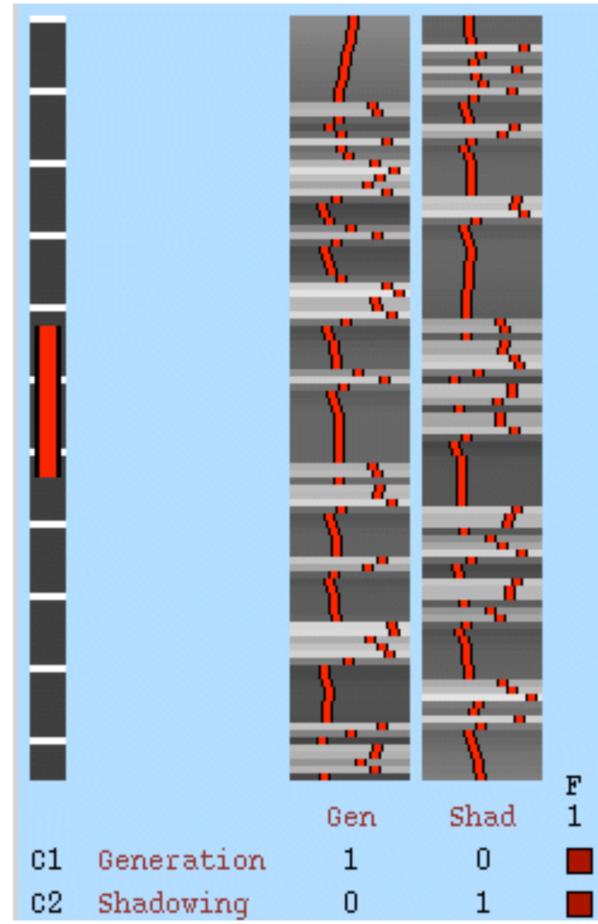
$$\begin{bmatrix} 1 & 0 \end{bmatrix}$$
$$\begin{bmatrix} 0 & 1 \end{bmatrix}$$

F-contrasts

We have two conditions:
Word Generation and Shadowing

We want to know:
Is there an activation to any condition?





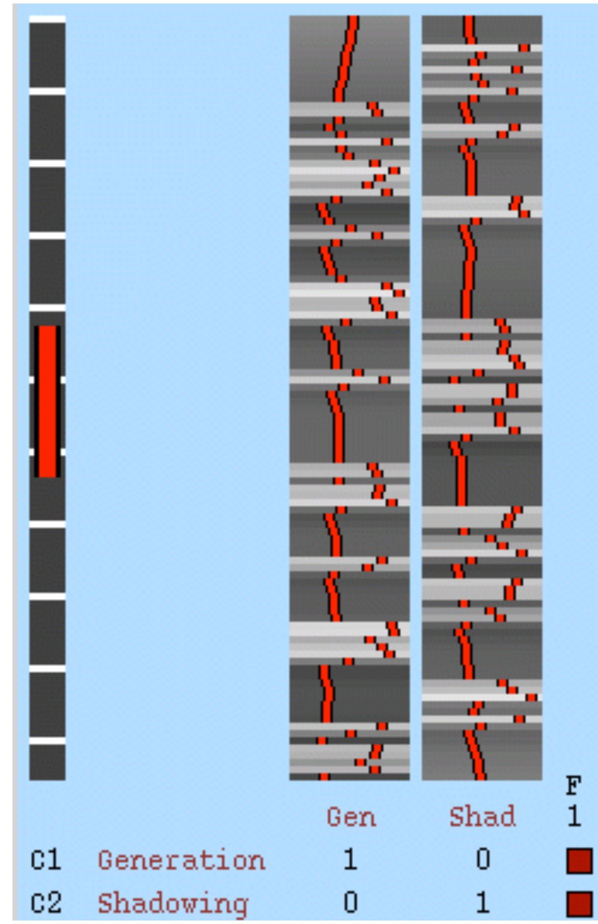
Then we add the OR

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

F-contrasts

We have two conditions:
Word Generation and Shadowing

We want to know:
Is there an activation to any condition?



Is there an activation to any condition?

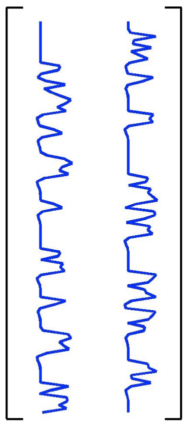
Is equivalent to:

Does any regressor explain the variance in the data?

Then we add the OR

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

F-contrasts

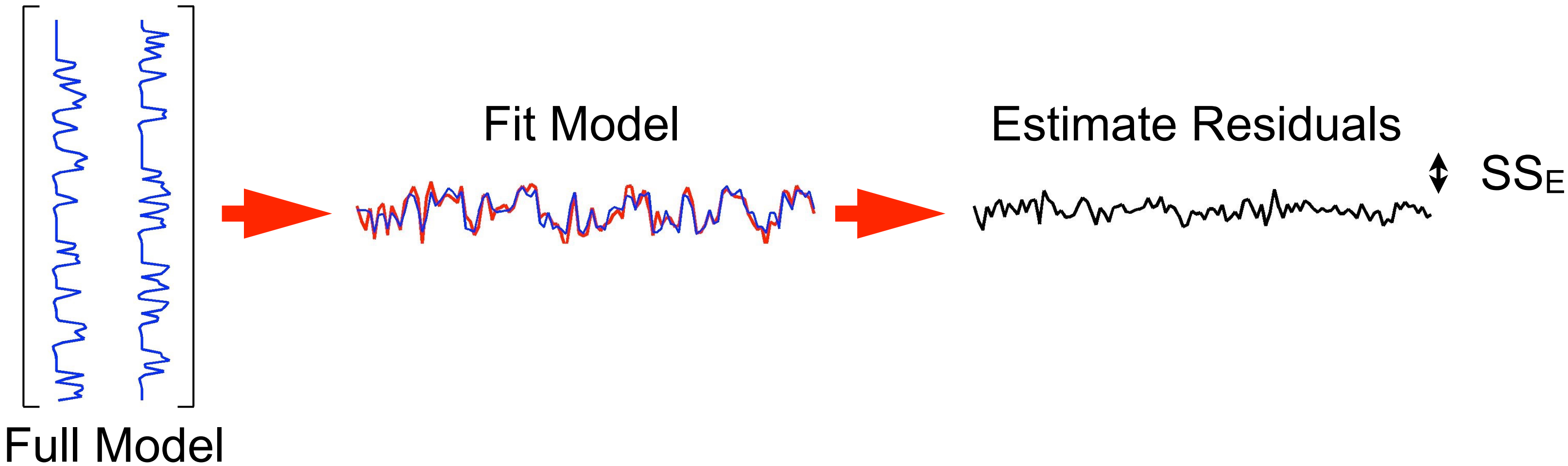


Full Model

&

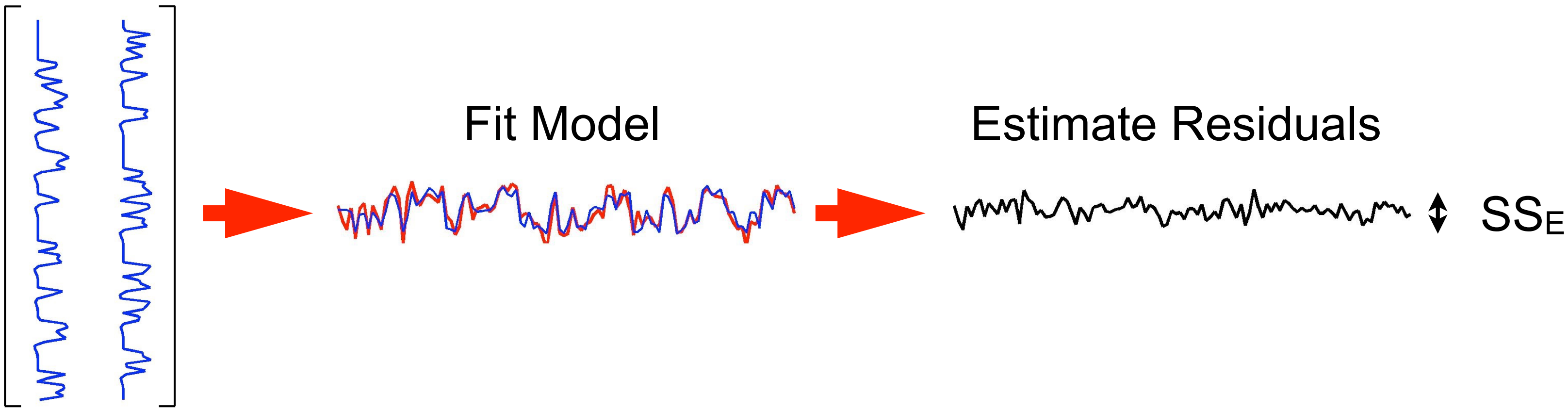
Data

F-contrasts



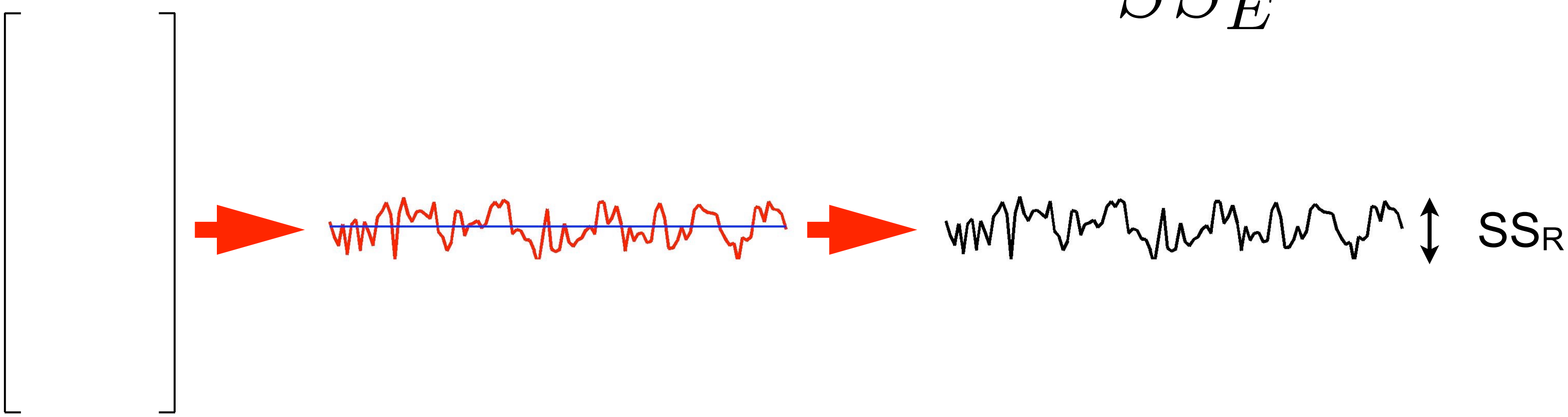
F-contrasts

$$\begin{bmatrix}1 & 0\end{bmatrix}$$
$$\begin{bmatrix}0 & 1\end{bmatrix}$$



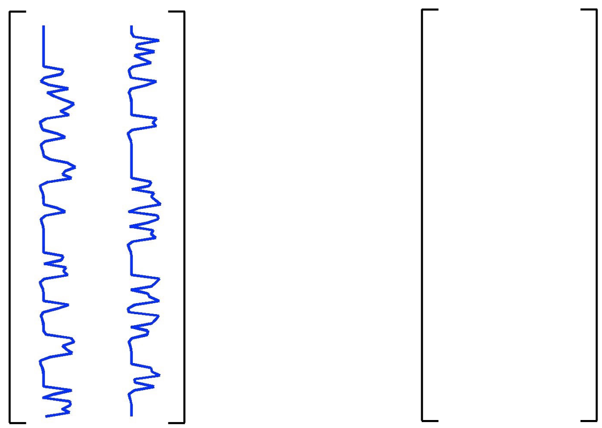
Full Model

$$F = \frac{SS_R - SS_E}{SS_E}$$



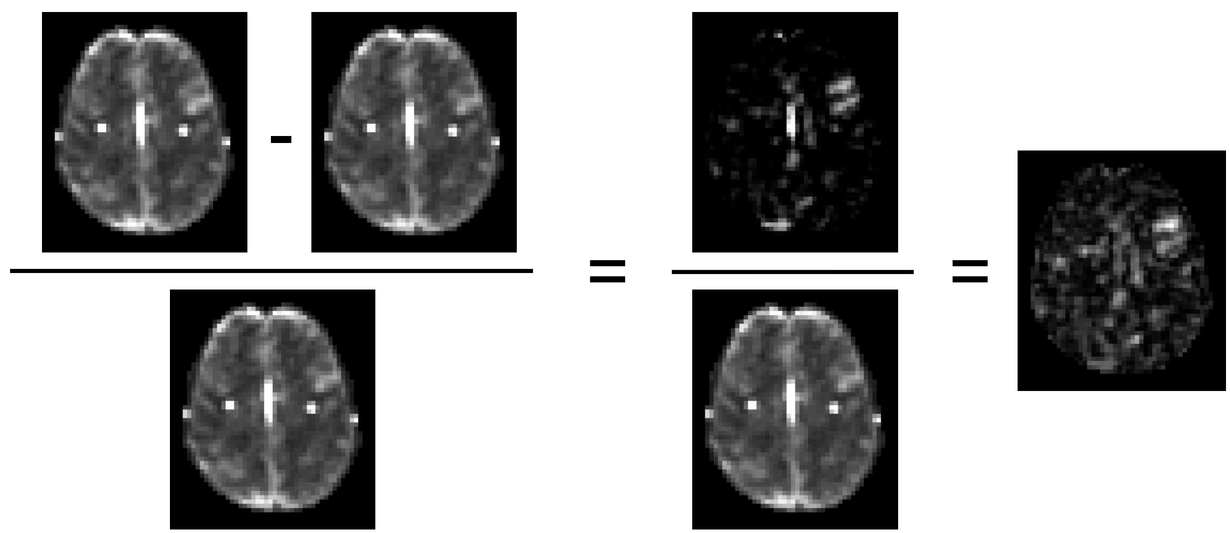
Reduced Model

F-contrasts



Full Model Reduced Model

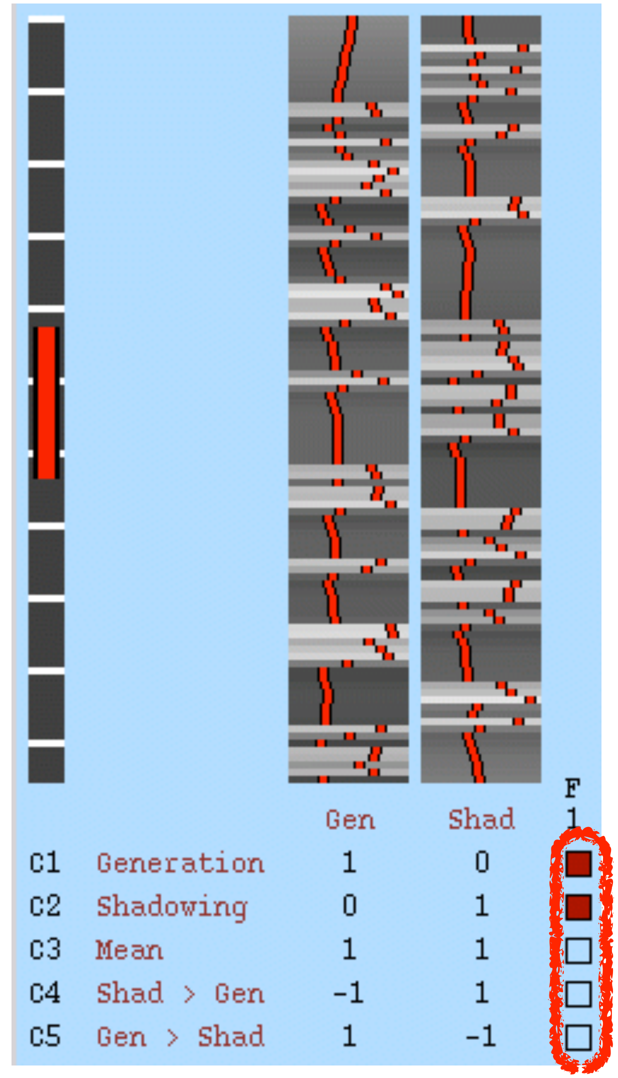
$$F = \frac{SS_R - SS_E}{SS_E} =$$



F-contrasts

- Two conditions: A,B

- Is any condition significant?



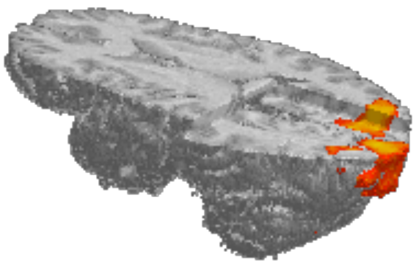
- Set of COPEs form an F-contrast

- Or: "Is there a significant amount of power in the data explained by the combination of the COPEs in the F-contrast?"

- F-contrast is F-distributed

FMRI Modelling and Statistics

- An example experiment
- Multiple regression (GLM)
- T and F Contrasts
- Null hypothesis testing
- The residuals
- Thresholding: multiple comparison correction

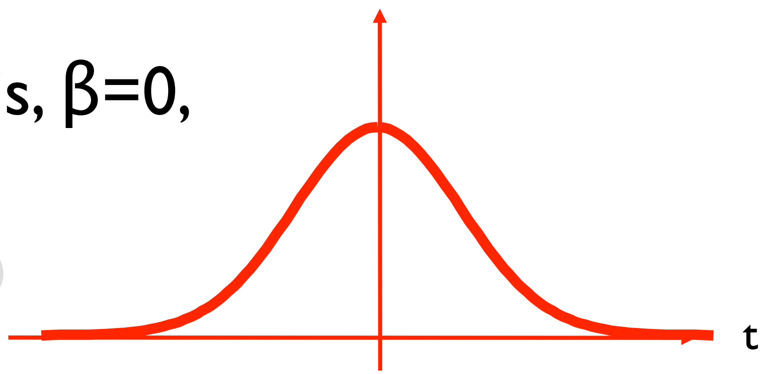


Null Hypothesis Testing

t-statistic: $$t = \frac{\widehat{\beta}}{\widehat{std(\beta)}}$$

Under null hypothesis, β=0,
t is t-distributed

(what are the chances of that?)



Null Hypothesis Testing

t-statistic: $$t = \frac{\widehat{\beta}}{\widehat{std(\beta)}}$$

Under null hypothesis, β=0,
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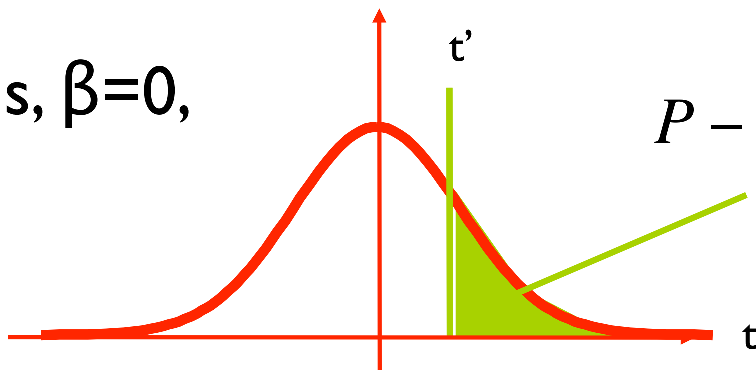
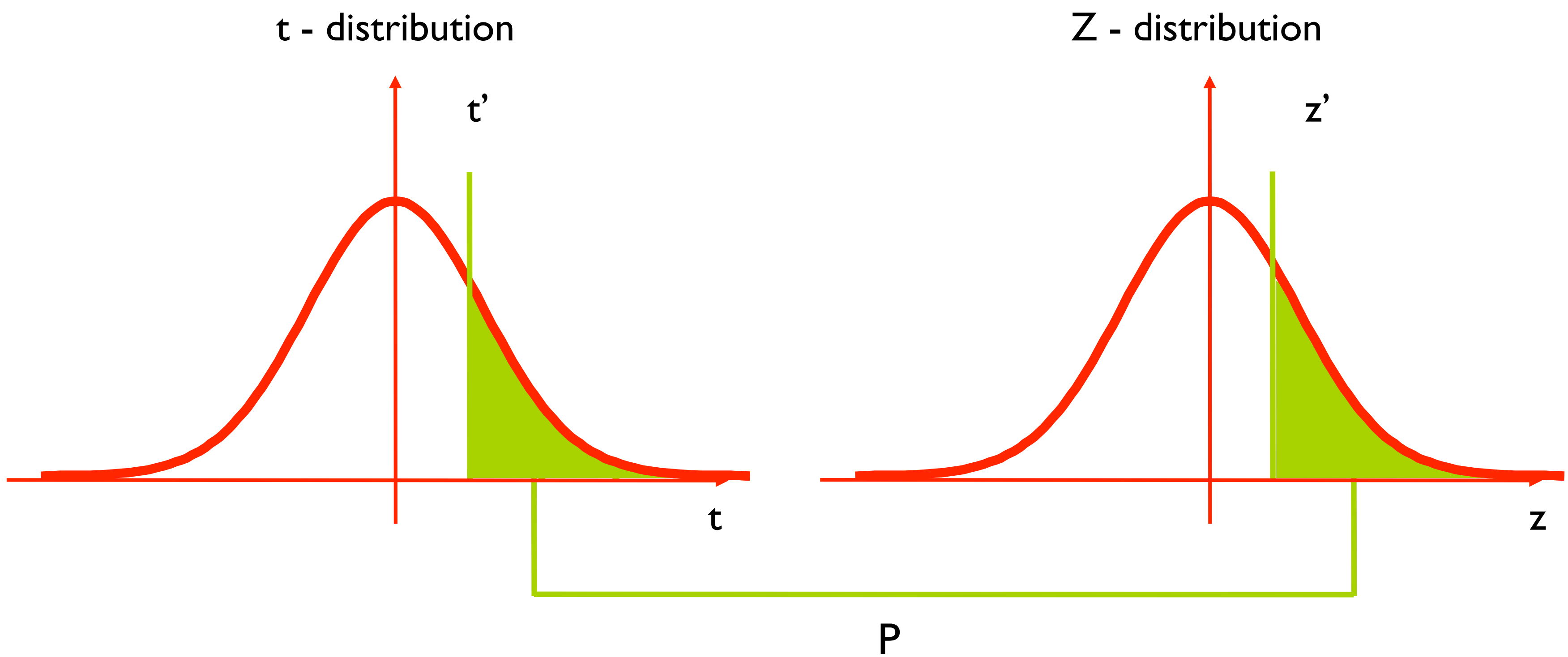


$$P - Value = p(t > t' | \beta = 0)$$

Small P-Value = null hypothesis unlikely
If P-Value < P-threshold then voxel is "active"
P-threshold corresponds to False Positive Rate (FPR)

T to P to Z

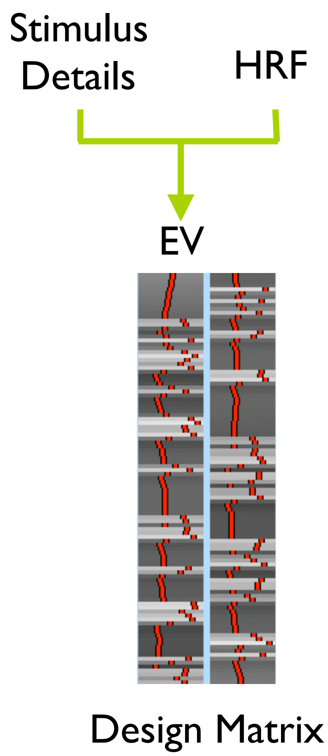


- FEAT performs spatial inference on z statistic maps
- Therefore, we convert t statistics to z statistics by equating probabilities under the tails of the distributions (t'-> p->z')

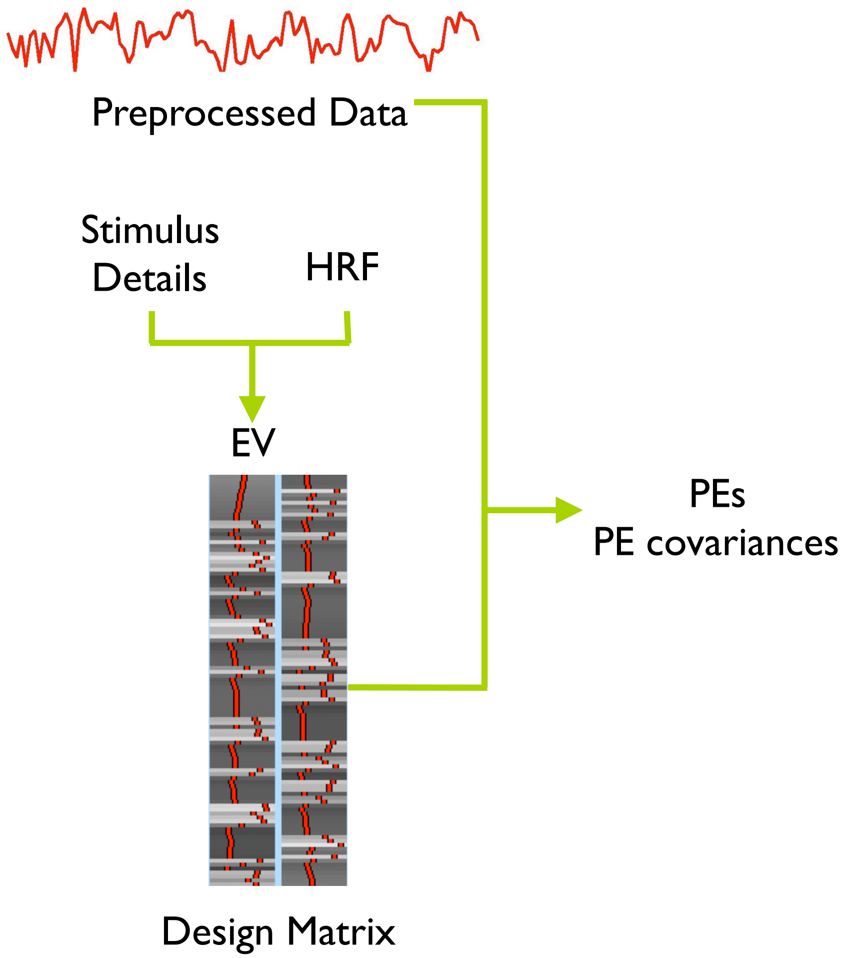
Summary of what we learned so far

- Once you have fitted your model and estimated your parameters you can ask directed questions of your data using contrasts.
- A contrast can be a *t*-contrast, which asks relatively specific question, or an F-contrast, which can ask more general questions.
- A *t*- or F-value specifies the "degree of surprise" of the data (given that the null-hypothesis is true).
- A *t*- or F-value can be transformed to a z-score with the same p-value (degree of surprise).

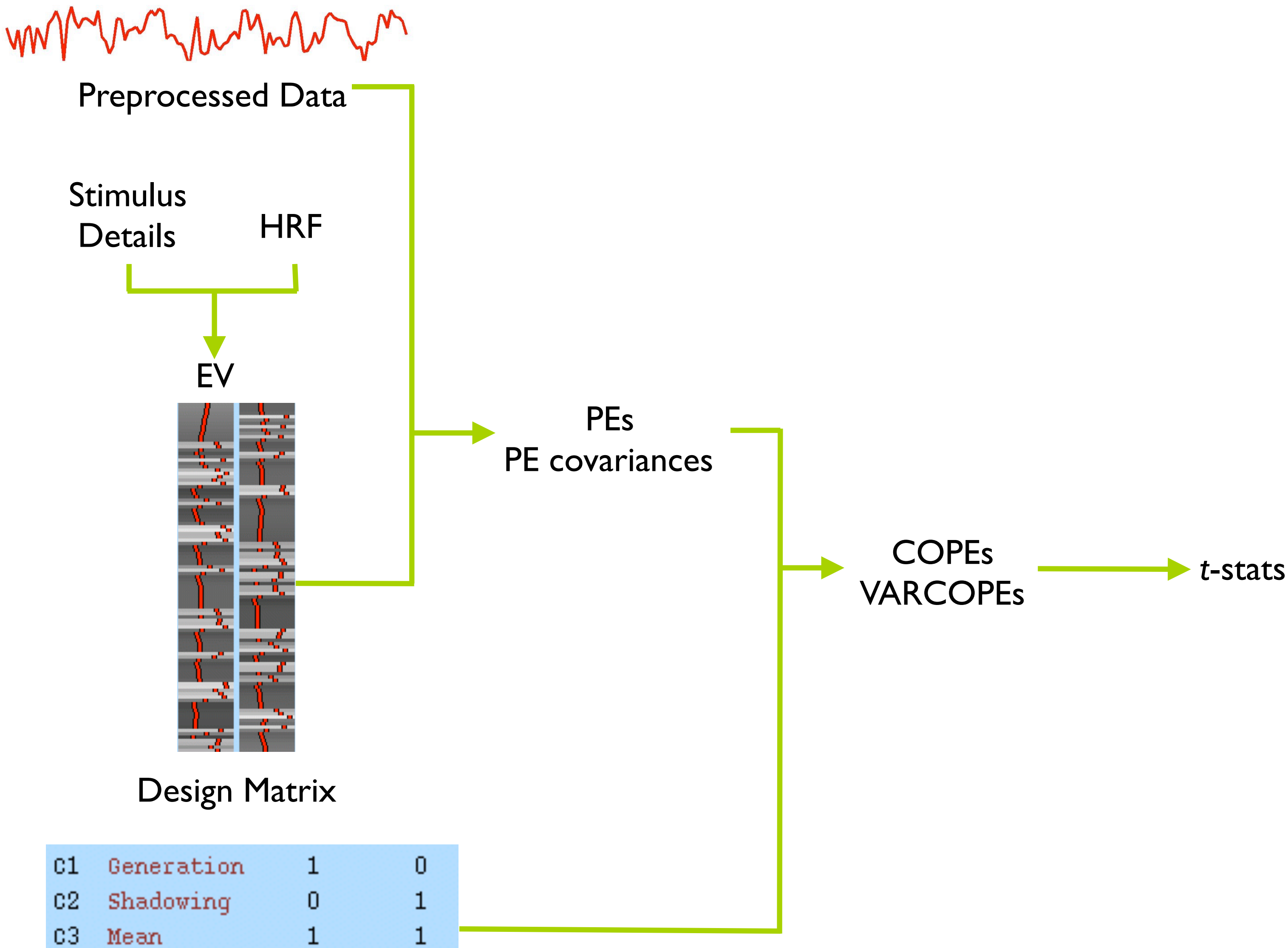
FEAT Schematic



FEAT Schematic

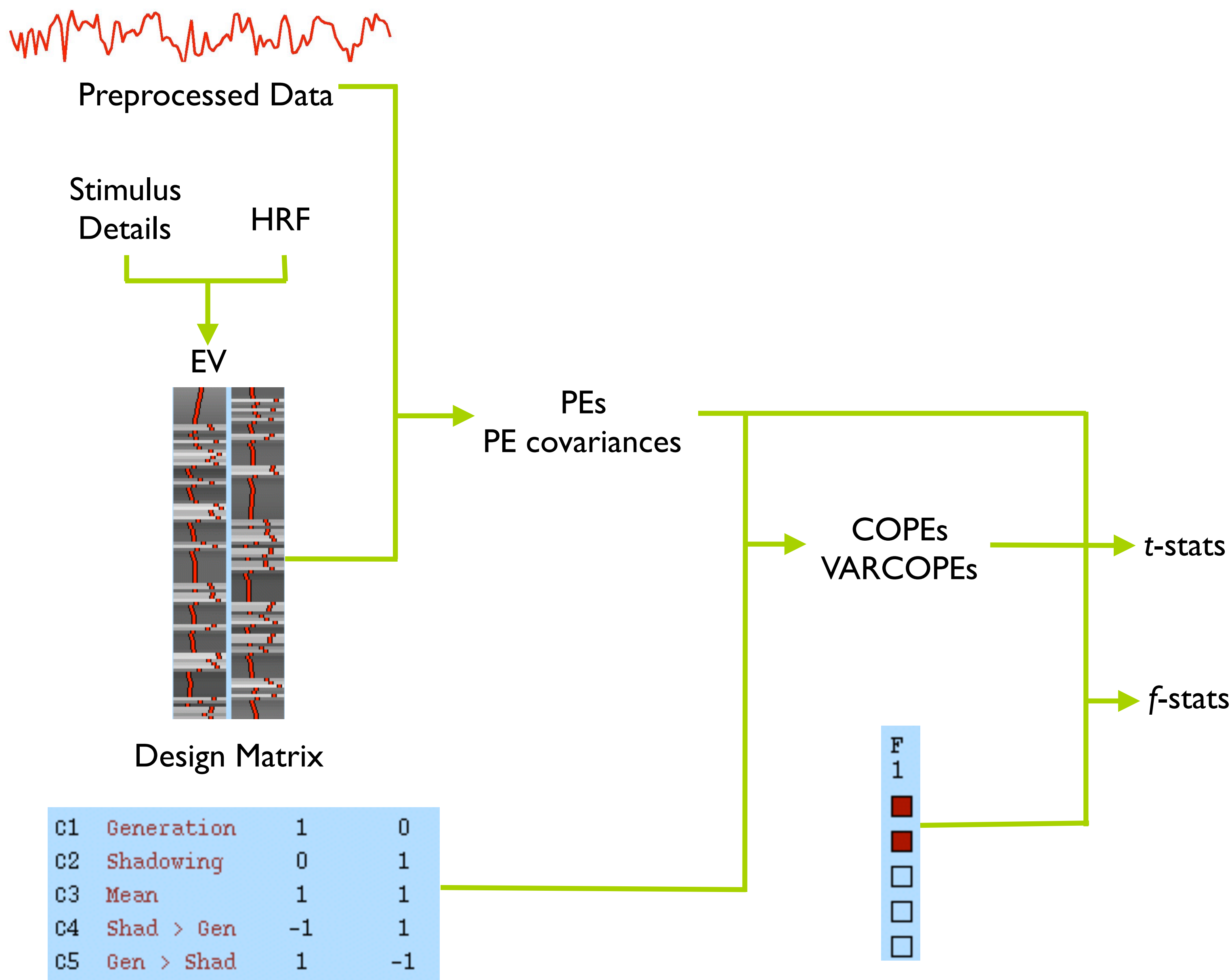


FEAT Schematic

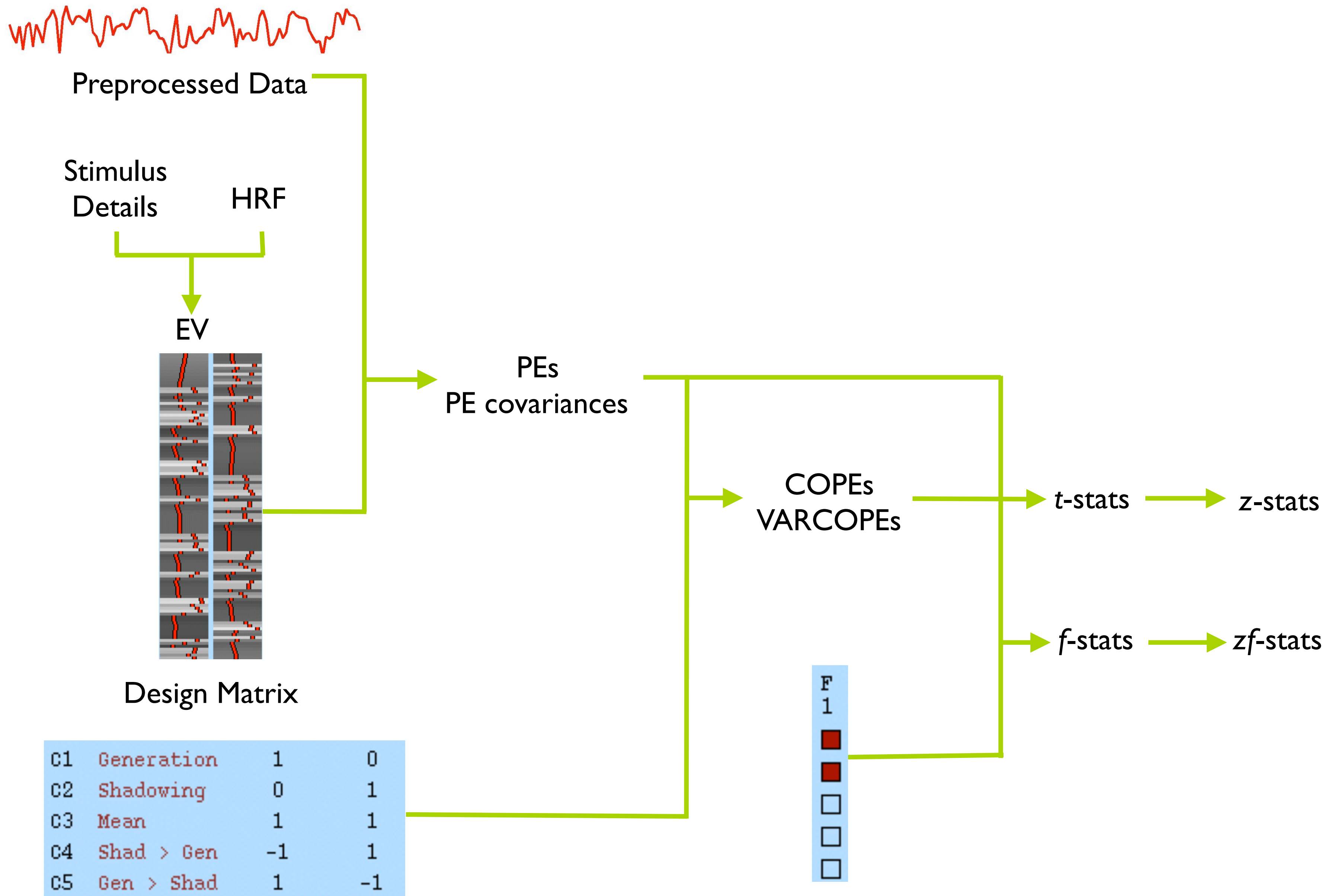


C1	Generation	1	0
C2	Shadowing	0	1
C3	Mean	1	1
C4	Shad > Gen	-1	1
C5	Gen > Shad	1	-1

FEAT Schematic



FEAT Schematic



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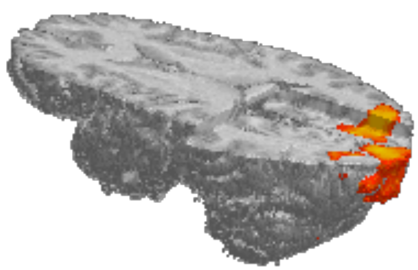
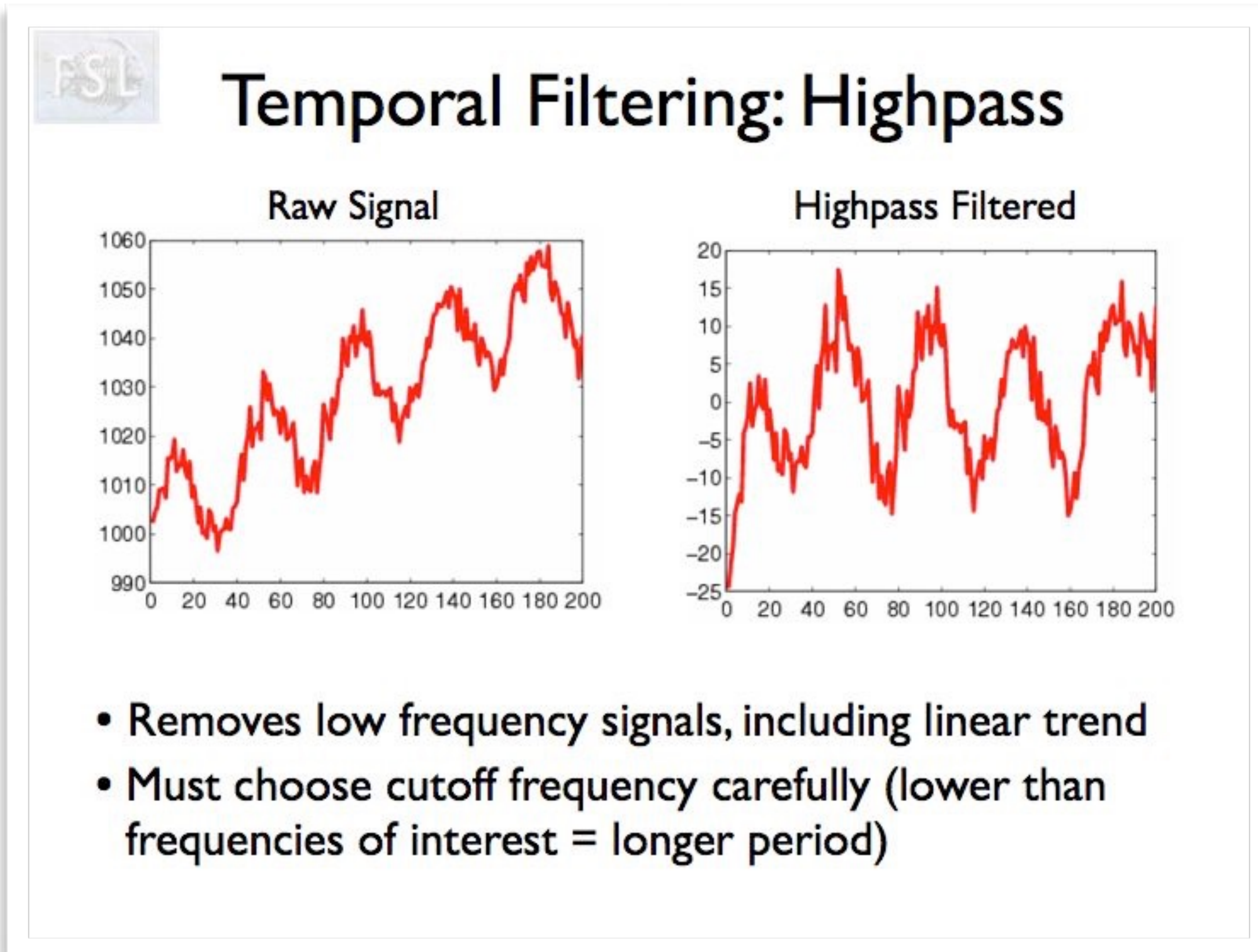


Choosing High-Pass Filter Cut-off

- Can use the tool *cutoffcalc* to determine a good cut-off value

Remember that MJ mentioned highpass filtering?



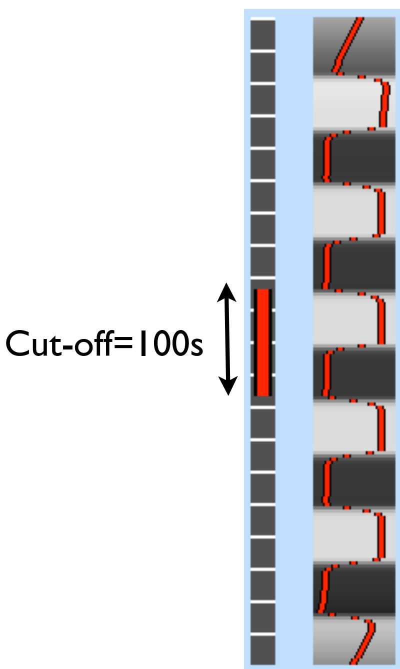
Choosing High-Pass Filter Cut-off

- Can use the tool *cutoffcalc* to determine a good cut-off value

OR

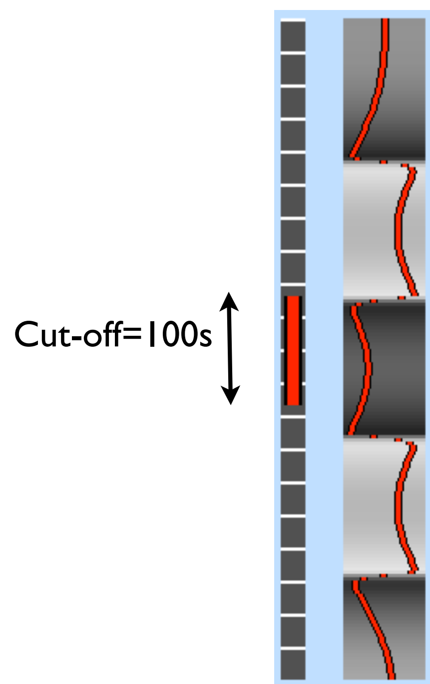
- Set by hand, but make sure model is not badly affected

Example: Boxcar EV with period 100s

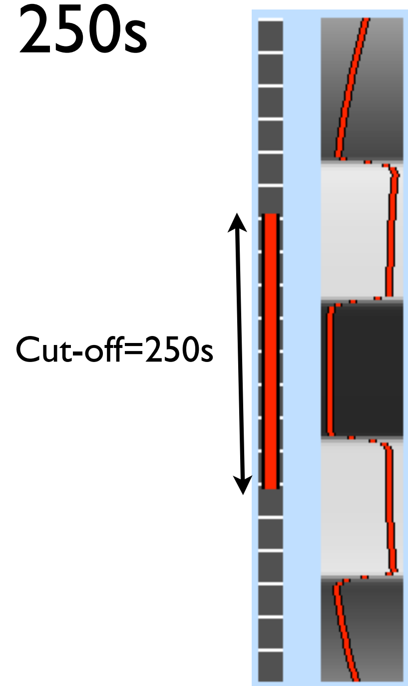


Negligible effect on EV, so use cut-off of 100s

Example: Boxcar with period 250s

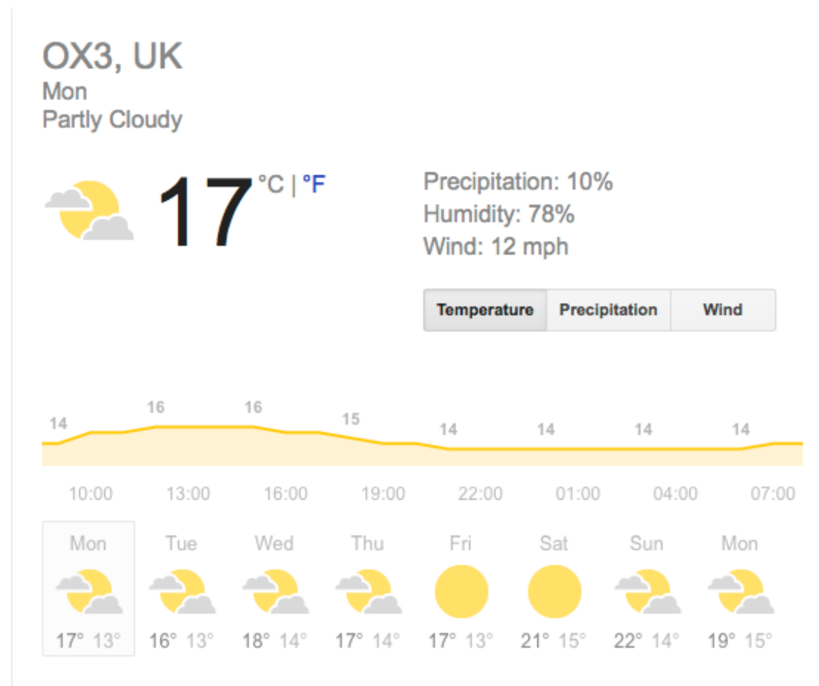


Substantial effect on EV, so need longer cut-off



Negligible effect on EV, so use cut-off of 250s

Non-independent/Autocorrelation/ Coloured FMRI noise



Uncorrected, this causes:

- biased stats (increased false positives)
- decreased sensitivity

FSL fixes it for you in FEAT!

Cannot use randomise (see later) because of autocorrelation

FMRI Modelling and Statistics

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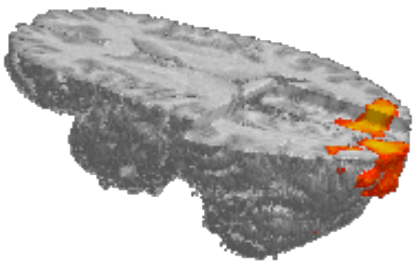
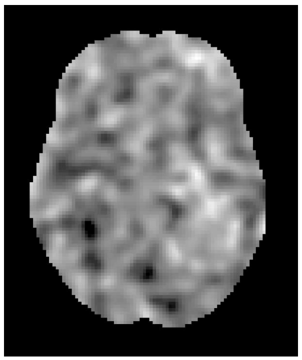
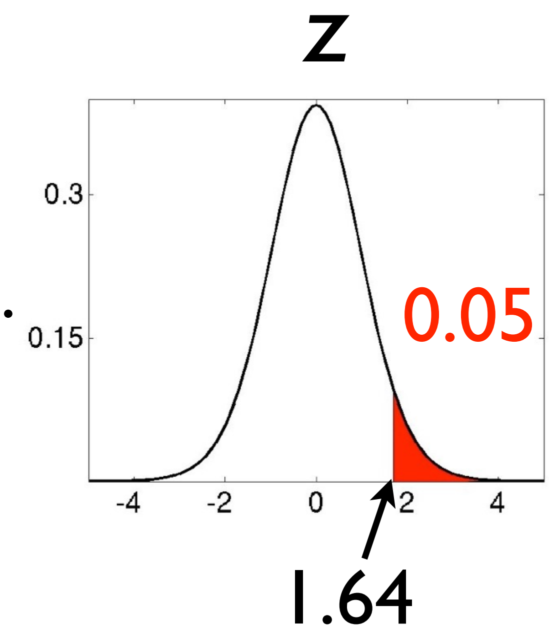


What happens when we apply "standard" statistical testing to imaging data?



z-map where each voxel ~*N*.
Null-hypothesis true everywhere, i.e.
NO ACTIVATIONS



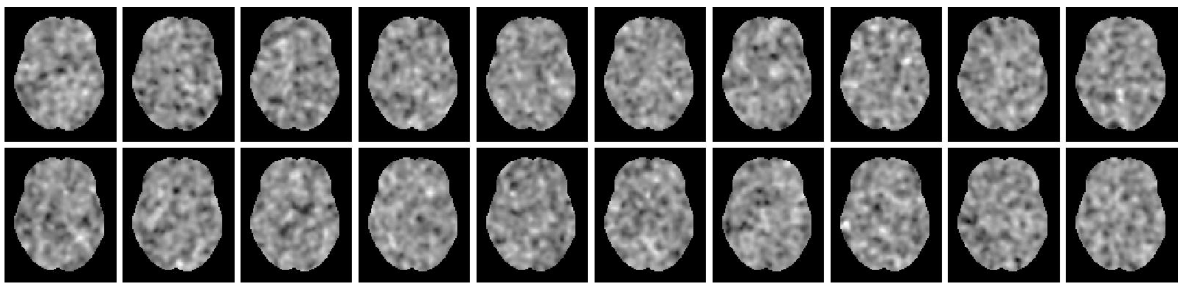
z-map
thresholded at
1.64

16 clusters
288 voxels
~5.5% of the voxels

That's a LOT of false positives

What we really want

Let's say we perform a series of identical studies



Each z-map is the end result of a study

Let us further say that the null-hypothesis is true

We want to threshold the data so that only once in 20 studies do we find a voxel above this threshold

There will be a whole talk on how to find such a threshold

Summary

- The GLM is used to summarise data in a few parameters that are pertinent to the experiment.
- GLM predicts how BOLD activity might change as a result of the experiment.
- We can test for significant effects by using t or f contrasts on the GLM parameters
- When thresholding the number of false positives needs to be controlled across the entire brain

That's all folks