

Symposium “What Neuroimaging Can Tell Us? From Correlation to Causation and Cognitive Ontologies”, OHBM 2016

June 27, 2016

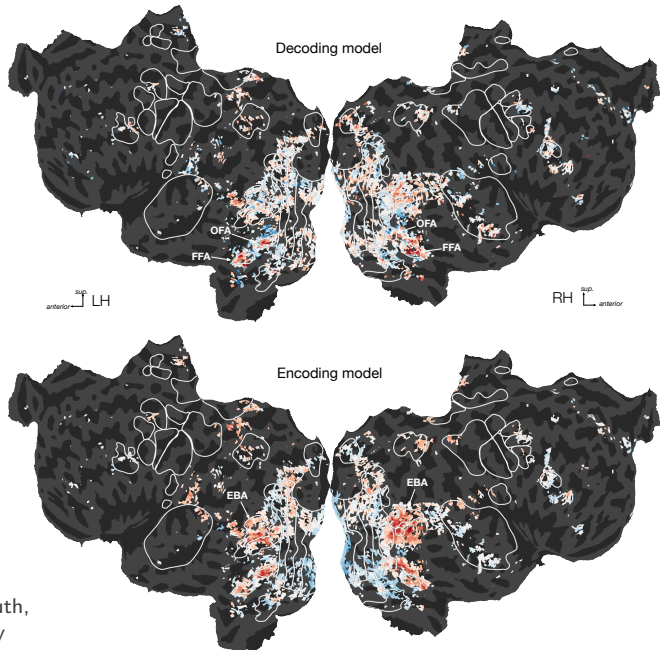
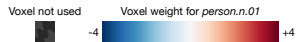


MAX-PLANCK-GESELLSCHAFT

HOW TO OBTAIN CAUSAL HYPOTHESES FROM NEUROIMAGING STUDIES?

Sebastian Weichwald
MPI for Intelligent Systems

Motivation



Thanks to Alexander Huth,
Gallant lab, UC Berkeley

Voxel weight for person.n.01

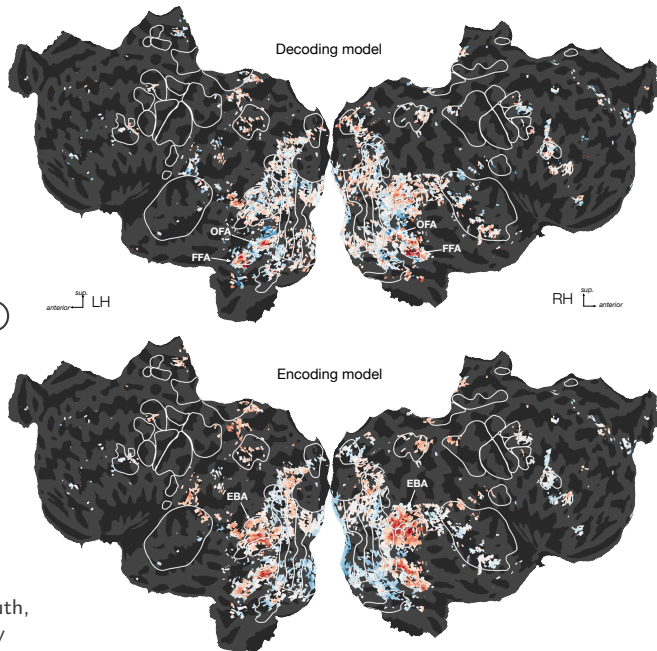
-4 +4

relevance

✓ ✓

✓ ✓

✓ ✓



Thanks to Alexander Huth,
Gallant lab, UC Berkeley

Voxel not used

Voxel weight for person.n.01

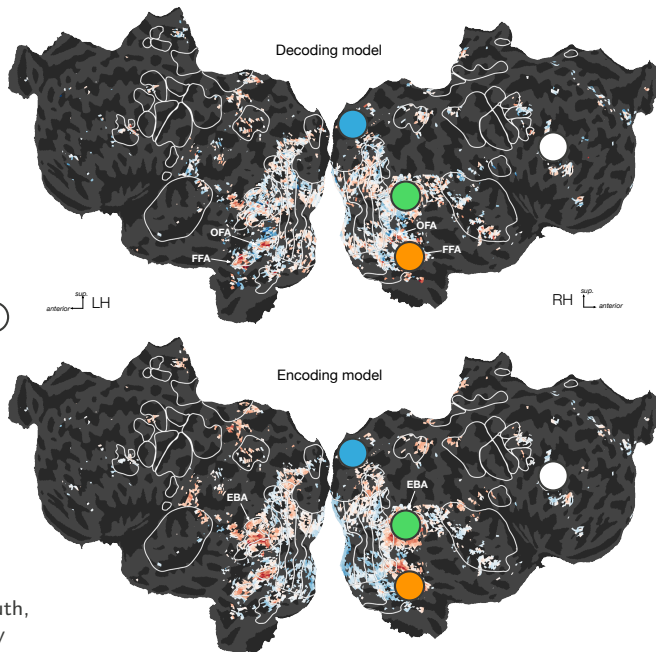
-4 +4

relevance

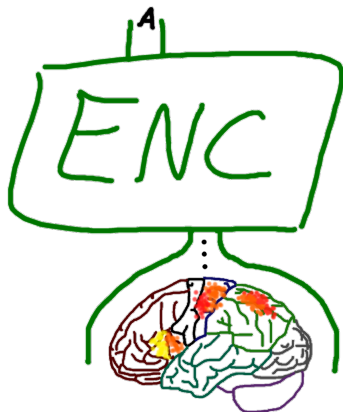
✓ ✓

✓ ✓

✓ ✓



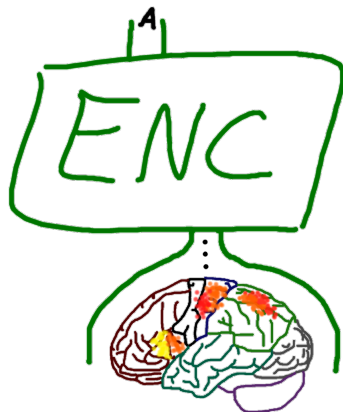
Thanks to Alexander Huth,
Gallant lab, UC Berkeley



GLM

difference in means

...



GLM

difference in means

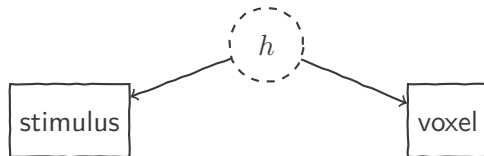
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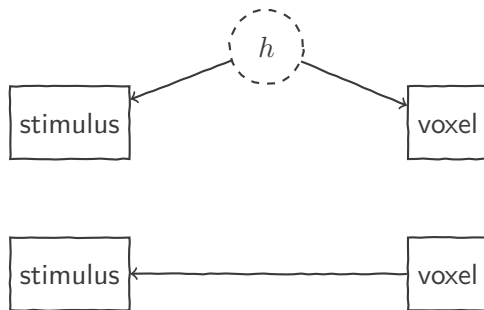
“Associated with experimental condition?”

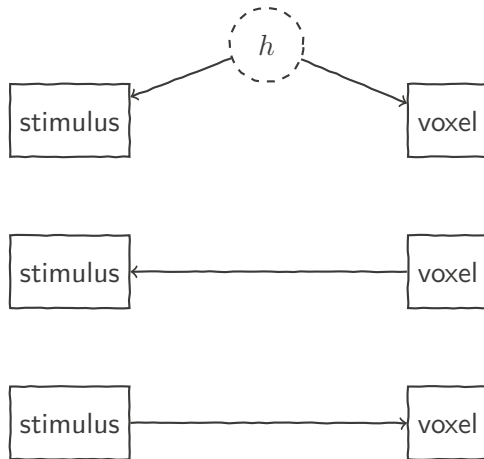


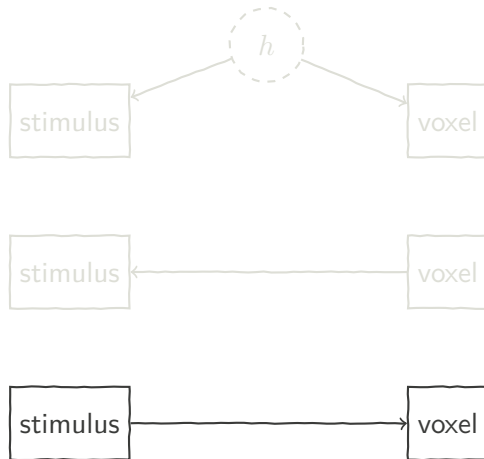
stimulus

voxel









	Voxel relevant?		Causal interpretation
	Encoding		
Stimulus-based	✓		
	×		

	Voxel relevant?		Causal interpretation
	Encoding		
Stimulus-based	✓		effect of S
	×		

	Voxel relevant?		Causal interpretation
	Encoding		
Stimulus-based	✓		effect of S
	×		no effect of S





“Does removal impair decoding performance?”



“Does removal impair decoding performance?”

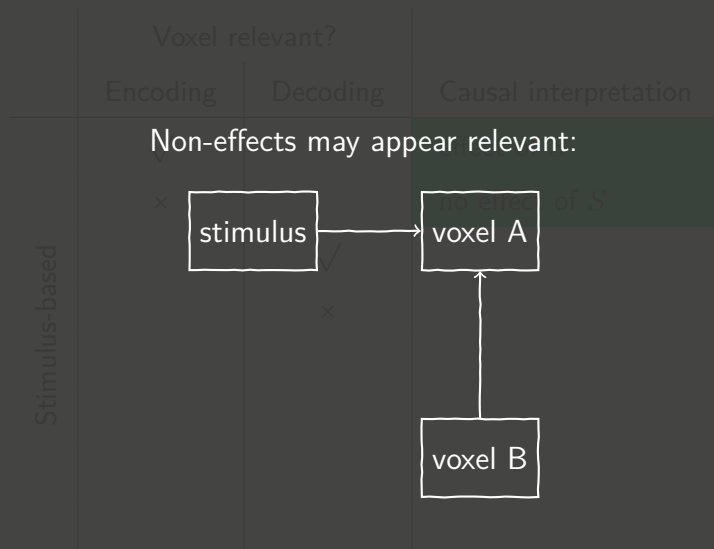
“Associated after taking all other variables into account?”

Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding		
Stimulus-based	✓		effect of S
	×		no effect of S

Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	
		×	



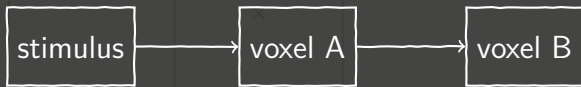
Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	
		×	

Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	inconclusive
		×	

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
Effects may be missed: inclusive			
	stimulus	voxel A	voxel B



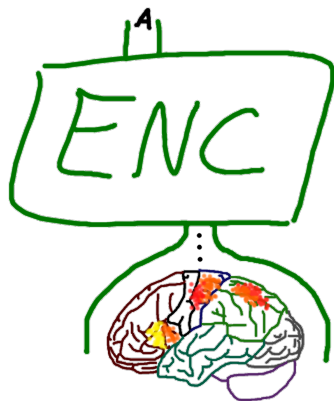
Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	inconclusive
		×	

Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓	✓ ×	effect of S
	×		no effect of S
			inconclusive
			inconclusive

Are decoding models useful?



&



Causal interpretation chart

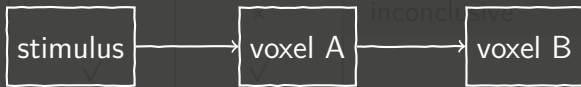
	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓	✓ ×	effect of S
	×		no effect of S
			inconclusive
			inconclusive

Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	inconclusive
		×	inconclusive
	✓	✓	
	✓	×	
	×	✓	
	×	×	

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
	✓	×	inconclusive
	×	✓	inconclusive
	×	×	

Encoding plus decoding allows to identify indirect effects:



Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	inconclusive
		×	inconclusive
	✓	✓	
	✓	×	
	×	✓	
	×	×	

Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	inconclusive
		×	inconclusive
	✓	✓	
	✓	×	indirect effect of S
	×	✓	
	×	×	

	Voxel relevant?		
	Encoding	Decoding	Causal interpretation
Encoding clarifies role of voxels relevant in decoding:			
Stimulus-based	x		no effect of S
		✓	inconclusive
		x	inconclusive
	✓	✓	
	✓	x	
	x	✓	effect of S
	x	x	

```
graph LR; stimulus[stimulus] --> voxelA[voxel A]; voxelB[voxel B] --> voxelA;
```

Causal interpretation chart

	Voxel relevant?		Causal interpretation
	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	inconclusive
		×	inconclusive
	✓	✓	
	✓	×	indirect effect of S
	×	✓	
	×	×	

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	Encoding	Decoding	
Stimulus-based	✓		effect of S
	×		no effect of S
		✓	inconclusive
		×	inconclusive
	✓	✓	effect of S
	✓	×	indirect effect of S
	×	✓	provides context
	×	×	

	Voxel relevant?		Causal interpretation
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	×		no effect of S
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	✓	×	indirect effect of S
	×	✓	provides context
	×	×	no effect of S

Wrap-up

- Simple causal interpretation chart

- Simple causal interpretation chart (also response-based paradigms)

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Relevant in encoding/correlated? \times/\checkmark (e. g. GLM)

- ▶ Simple causal interpretation chart (also response-based paradigms)

Relevant in encoding/correlated? \times/\checkmark (e. g. GLM)

Relevant in decoding/partially correlated? \times/\checkmark (e. g. classifier)

- ▶ Simple causal interpretation chart (also response-based paradigms)

Relevant in encoding/correlated? \times/\checkmark (e. g. GLM)

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\leadsto Read off causal interpretation

- ▶ Simple causal interpretation chart (also response-based paradigms)

Relevant in encoding/correlated? \times/\checkmark (e. g. GLM)

Relevant in decoding/partially correlated? \times/\checkmark (e. g. classifier)

\leadsto Read off causal interpretation

(Weichwald et al., *NeuroImage*, 2015)

- ▶ Simple causal interpretation chart (also response-based paradigms)

Relevant in encoding/correlated? \times/\checkmark (e. g. GLM)

Relevant in decoding/partially correlated? \times/\checkmark (e. g. classifier)

\leadsto Read off causal interpretation

(Weichwald et al., *NeuroImage*, 2015)

Extensions

- ▶ Simple causal interpretation chart (also response-based paradigms)

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Relevant in decoding/partially correlated? \times/\checkmark (e. g. classifier)

\leadsto Read off causal interpretation

(Weichwald et al., *NeuroImage*, 2015)

Extensions

- ▶ Stimulus-based causal inference

- ▶ Simple causal interpretation chart (also response-based paradigms)

Relevant in encoding/correlated? \times/\checkmark (e. g. GLM)

Relevant in decoding/partially correlated? \times/\checkmark (e. g. classifier)

\leadsto Read off causal interpretation

(Weichwald et al., *NeuroImage*, 2015)

Extensions

- ▶ Stimulus-based causal inference

\leadsto Cause-effect relationships between neural processes

- ▶ Simple causal interpretation chart (also response-based paradigms)

Relevant in encoding/correlated? \times/\checkmark (e. g. GLM)

Relevant in decoding/partially correlated? \times/\checkmark (e. g. classifier)

\leadsto Read off causal interpretation

(Weichwald et al., *NeuroImage*, 2015)

Extensions

- ▶ Stimulus-based causal inference

\leadsto Cause-effect relationships between neural processes

(Grosse-Wentrup et al., *NeuroImage*, 2016)

- Technical assumption of faithfulness

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 - ↪ “Nature does not hide dependencies.”

- Technical assumption of faithfulness
 - ↪ “Nature does not hide dependencies.”
- Readiness to interpret negative results, i. e., uncorrelatedness

- ▶ Causal and anti-causal learning in pattern recognition for neuroimaging. *PRNI*, 2014. 🌐 e-print arxiv.org/pdf/1512.04808.
- ▶ Causal interpretation rules for encoding and decoding models in neuroimaging. *NeuroImage*, 2015. 🌐 sweichwald.de/neuroimage2015.
- ▶ Identification of causal relations in neuroimaging data with latent confounders: An instrumental variable approach. *NeuroImage*, 2016. 🌐 e-print mlin.kyb.tuebingen.mpg.de/Grosse-WentrupNI2015.pdf.
- ▶ Recovery of non-linear cause-effect relationships from linearly mixed neuroimaging data. *PRNI*, 2016. 🌐 e-print arxiv.org/pdf/1512.04808.
- ▶ MERLiN: Mixture Effect Recovery in Linear Networks. Under review. 🌐 e-print arxiv.org/pdf/1512.01255.

