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Towards reproducible neuroimaging across different analysis pipelines

Camille Maumet

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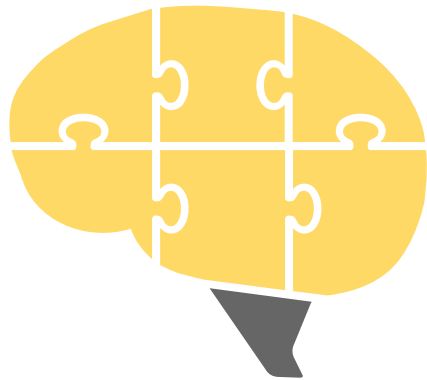
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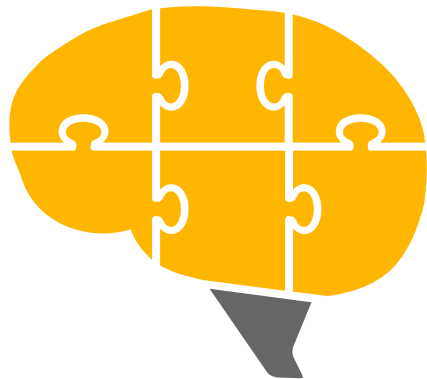
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Seminar at **Institut de Neurosciences
de la Timone: INT** (Marseille)

October 14, 2024



Towards reproducible neuroimaging across different analysis pipelines



Camille Maumet

Inria, Univ Rennes, Inserm, CNRS, IRISA



A crisis in experimental research

The **reproducibility crisis** has led to **reduced confidence in research findings**

Low reproduction rates in many fields

Cancer research: <11%

Psychology: 36%

Medicine: 44%

(Begley & Ellis 2012) (Open Science Collab 2016) (Ioannidis 2005)

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**Wasted money
& effort for
research**



**Delayed
translation into
clinical practice**



**Reduced trust
in science**

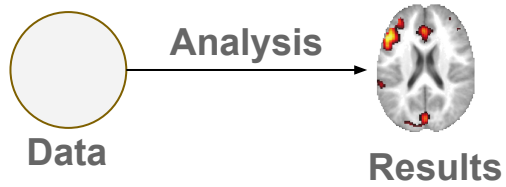


Reproducible research



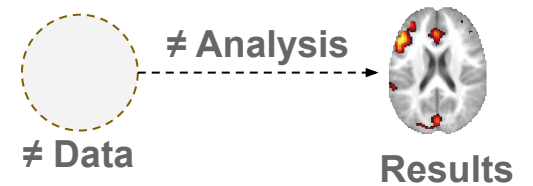
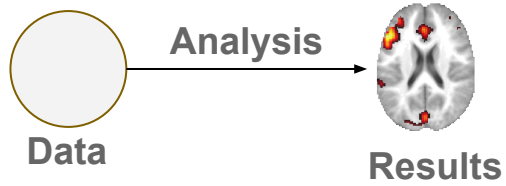
Reproducible research

Original study



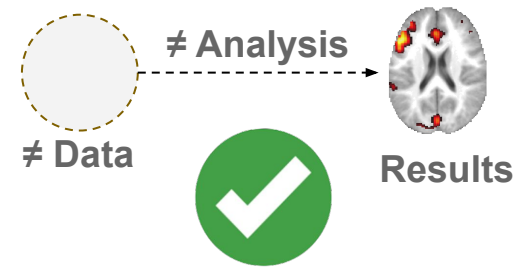
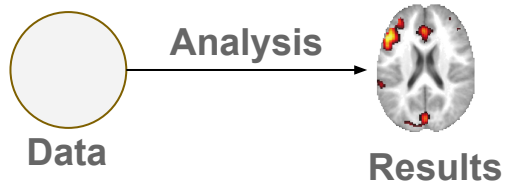
Reproducible research

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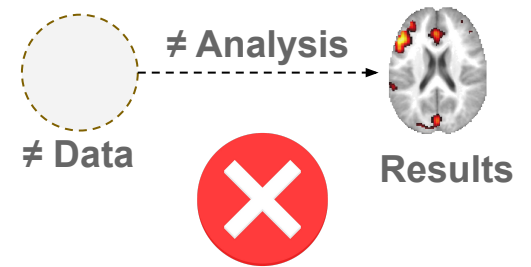
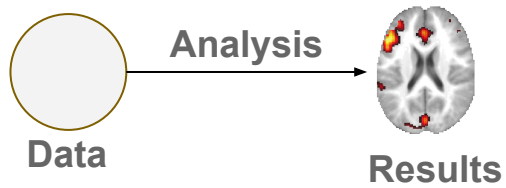
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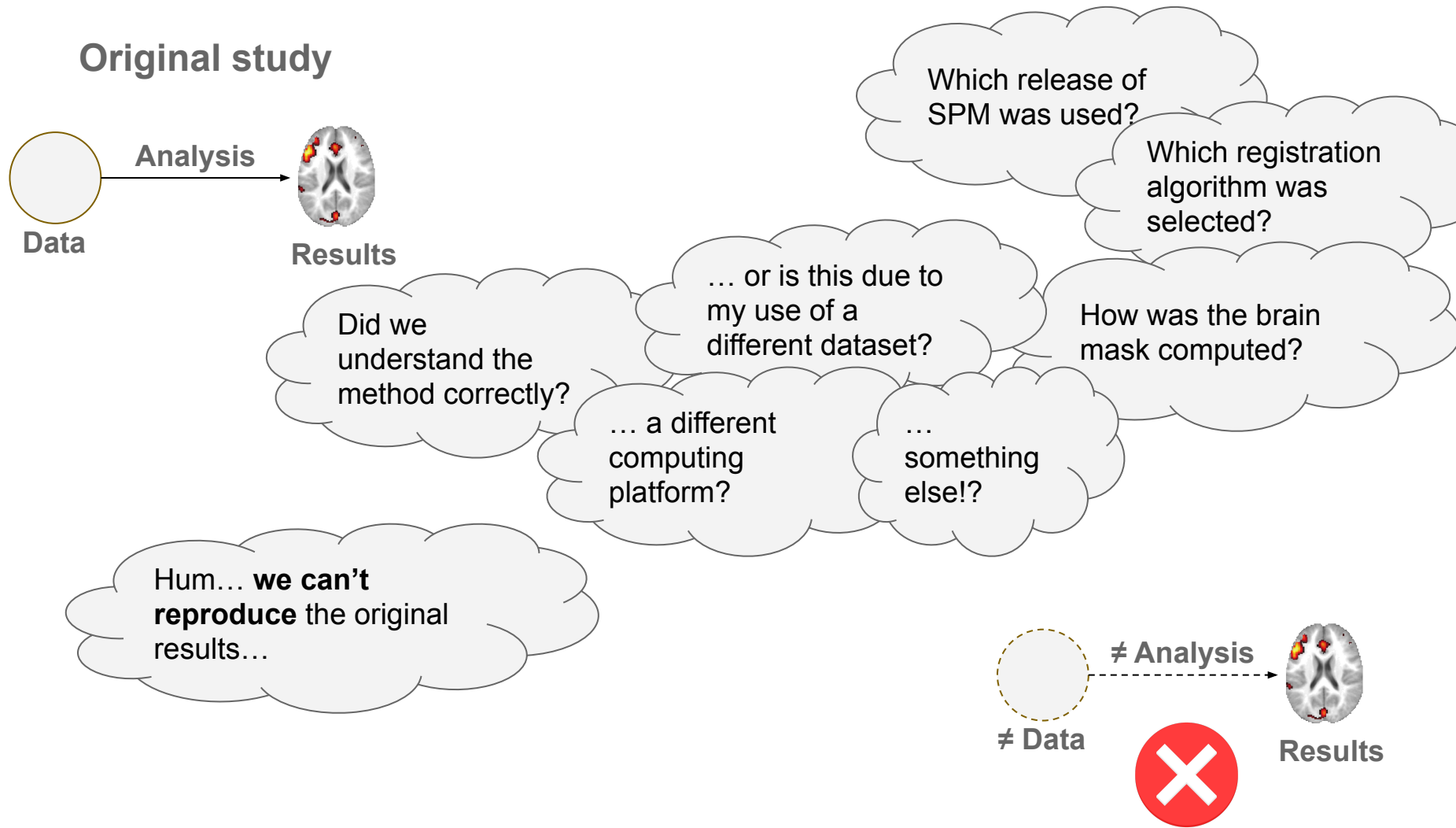


Reproducible research

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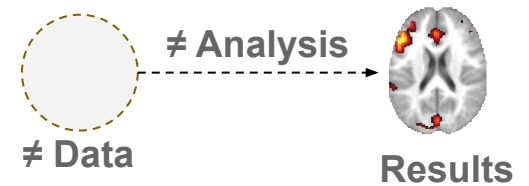
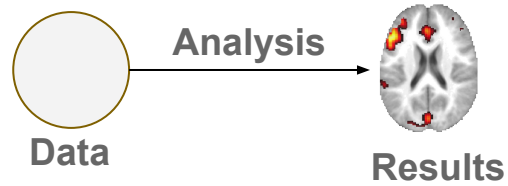
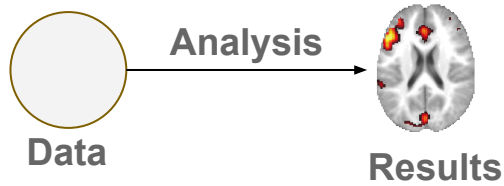


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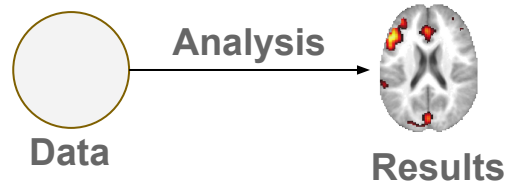
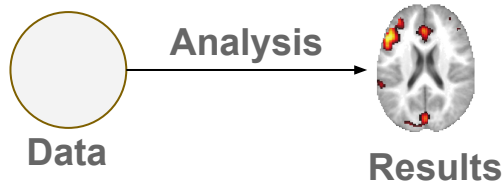
Reproducible research

Original study

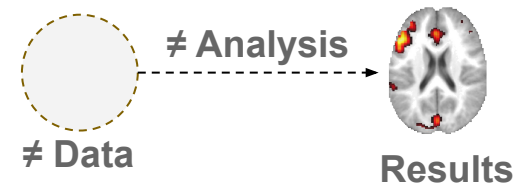


Reproducible research

Original study

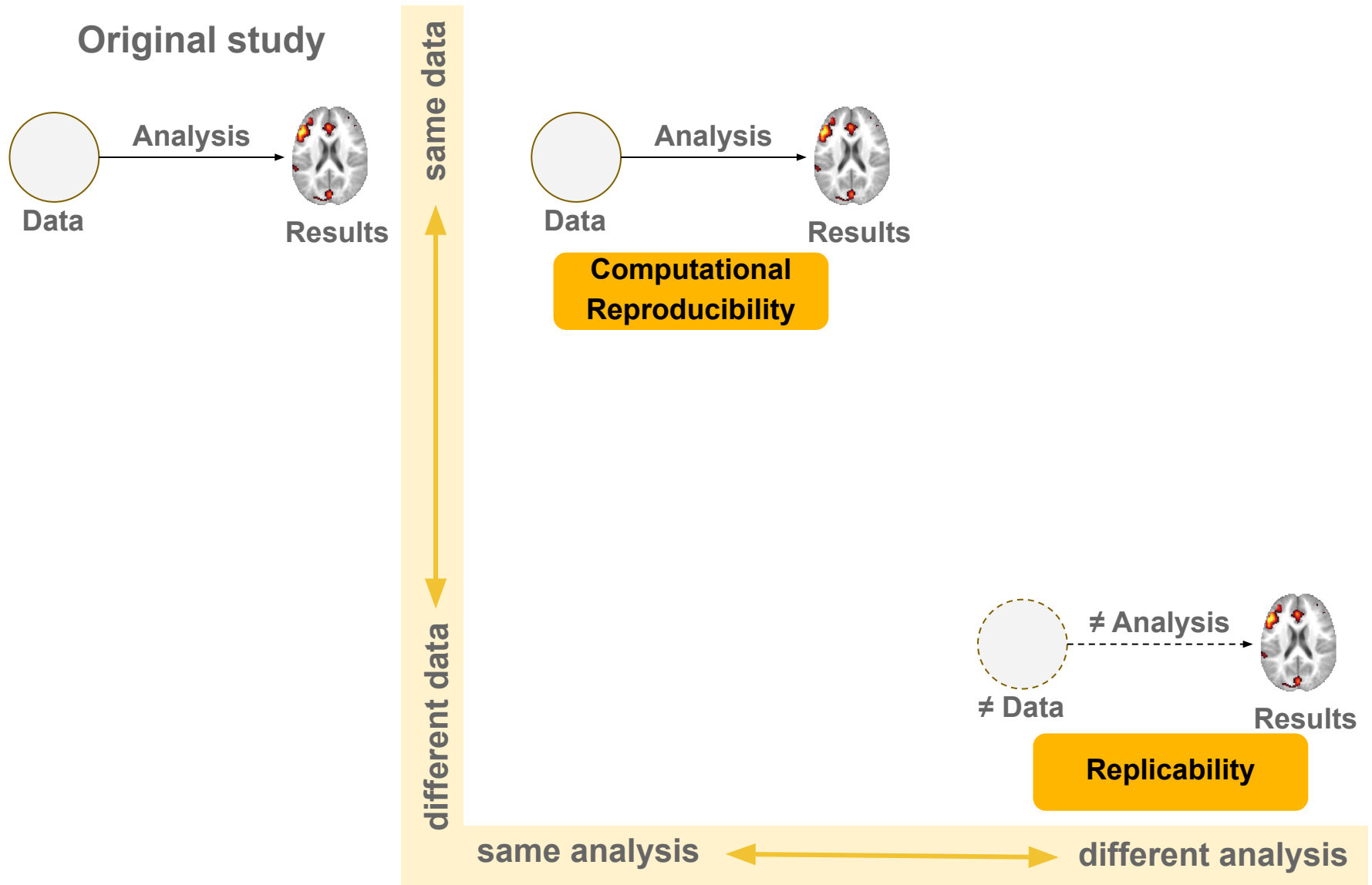


**Computational
Reproducibility**

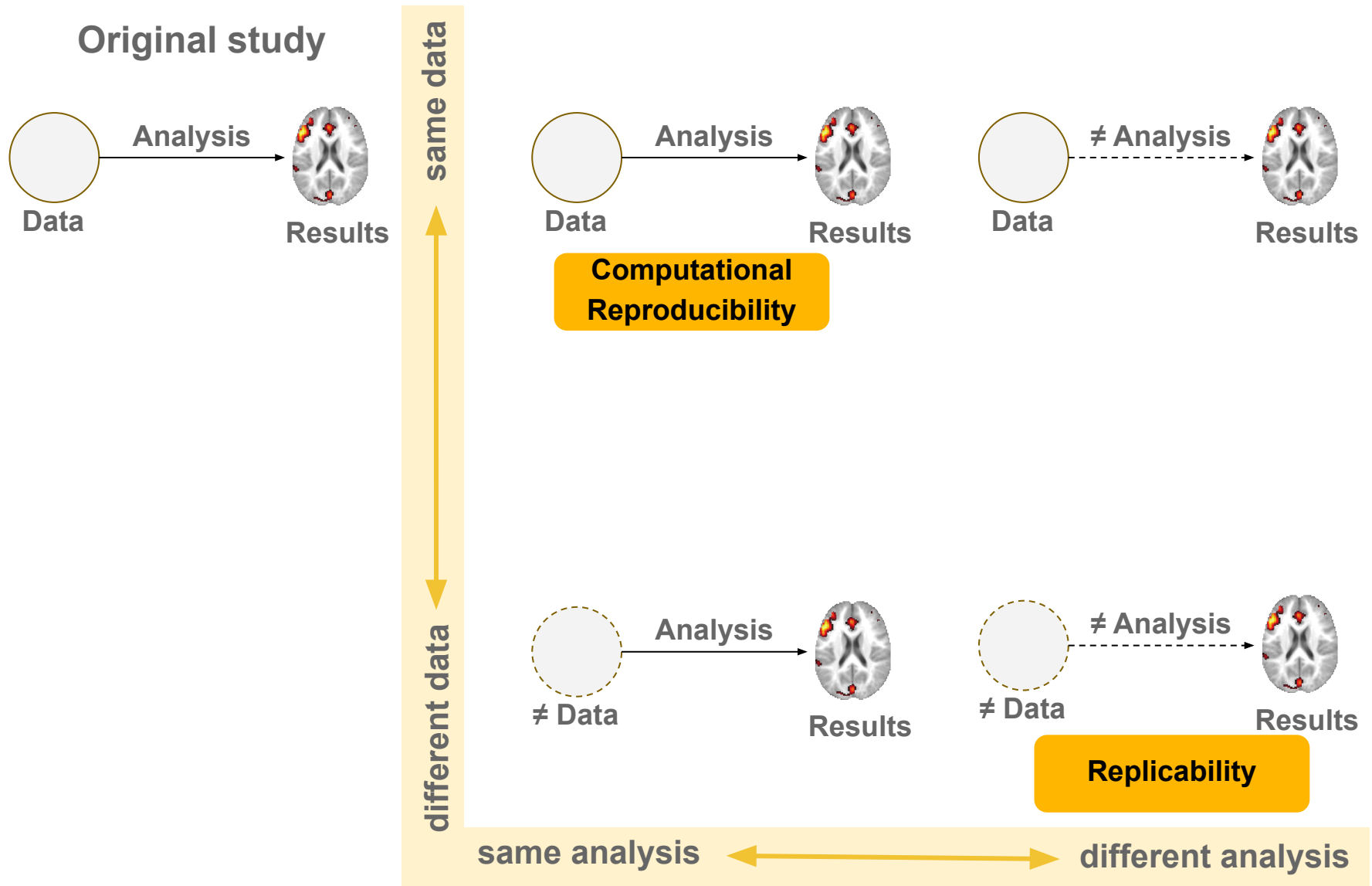


Replicability

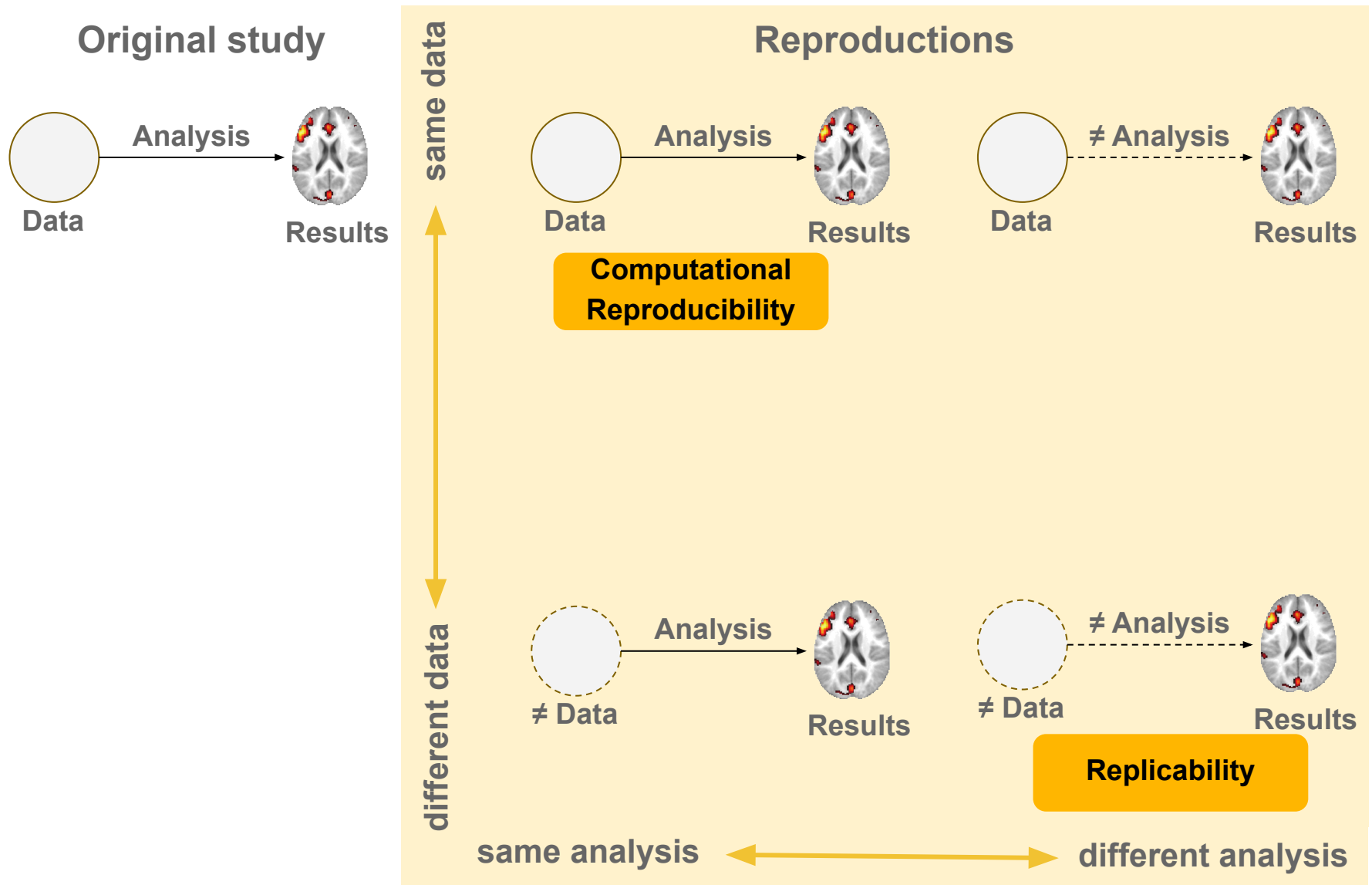
Reproducible research

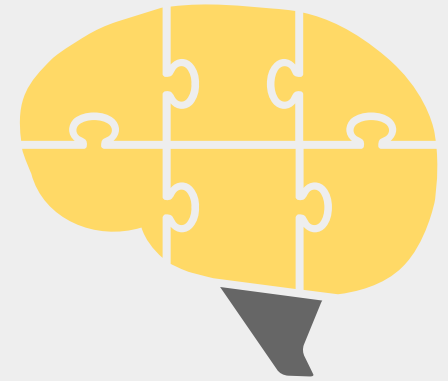
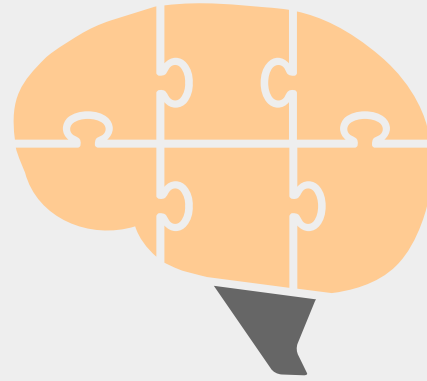


Reproducible research



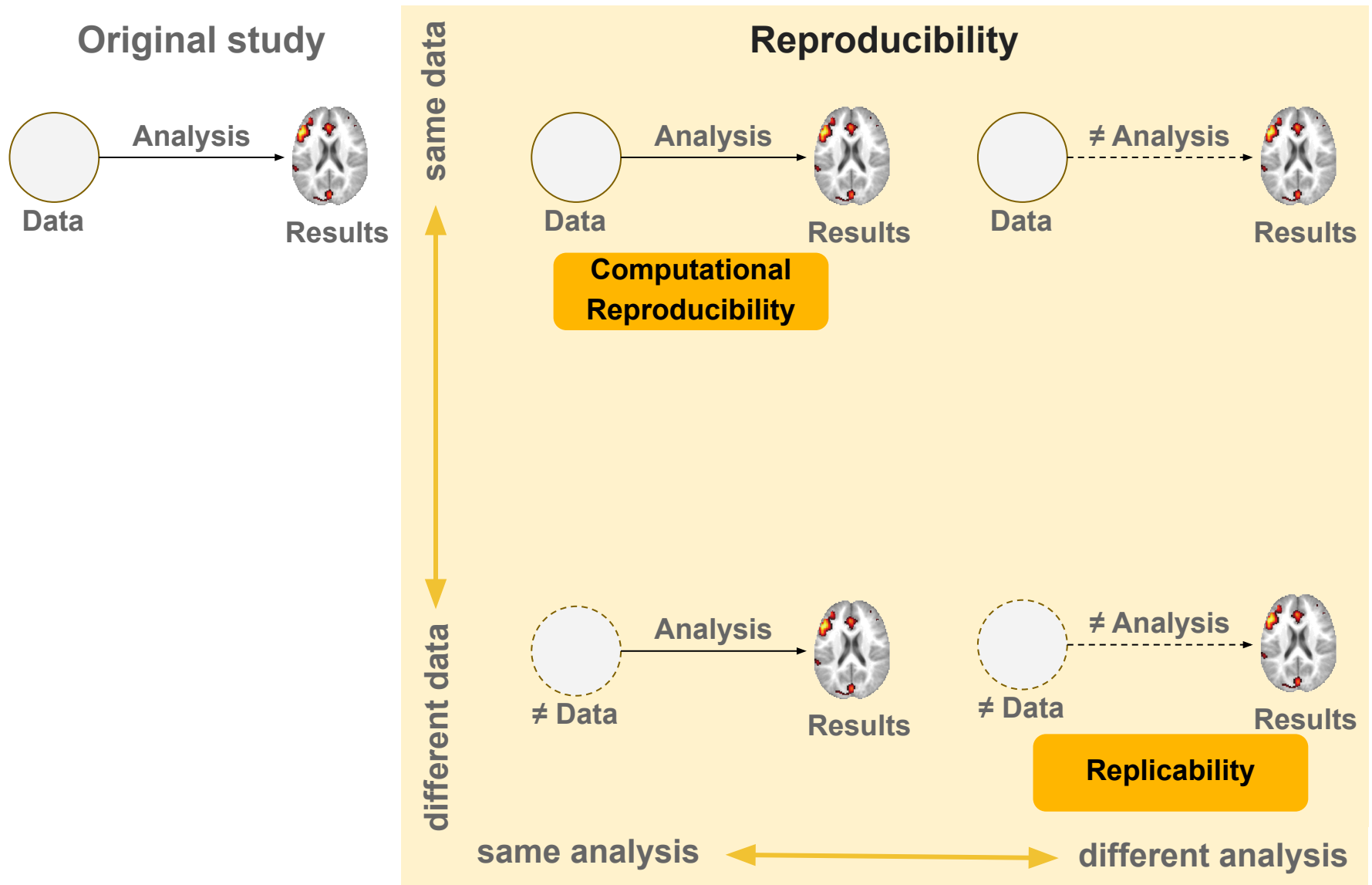
Reproducible research



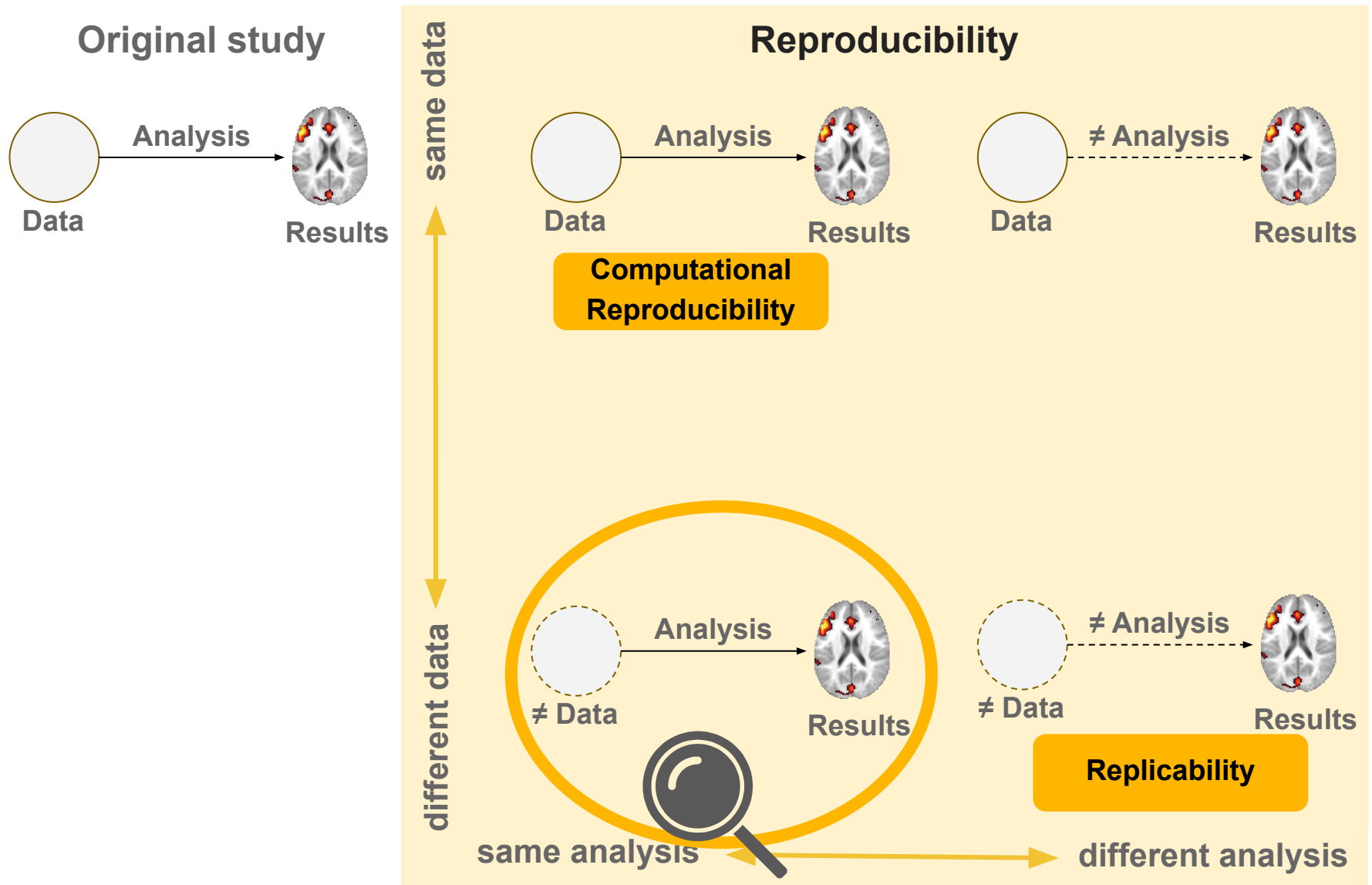


On our way to fix
irreproducibility...

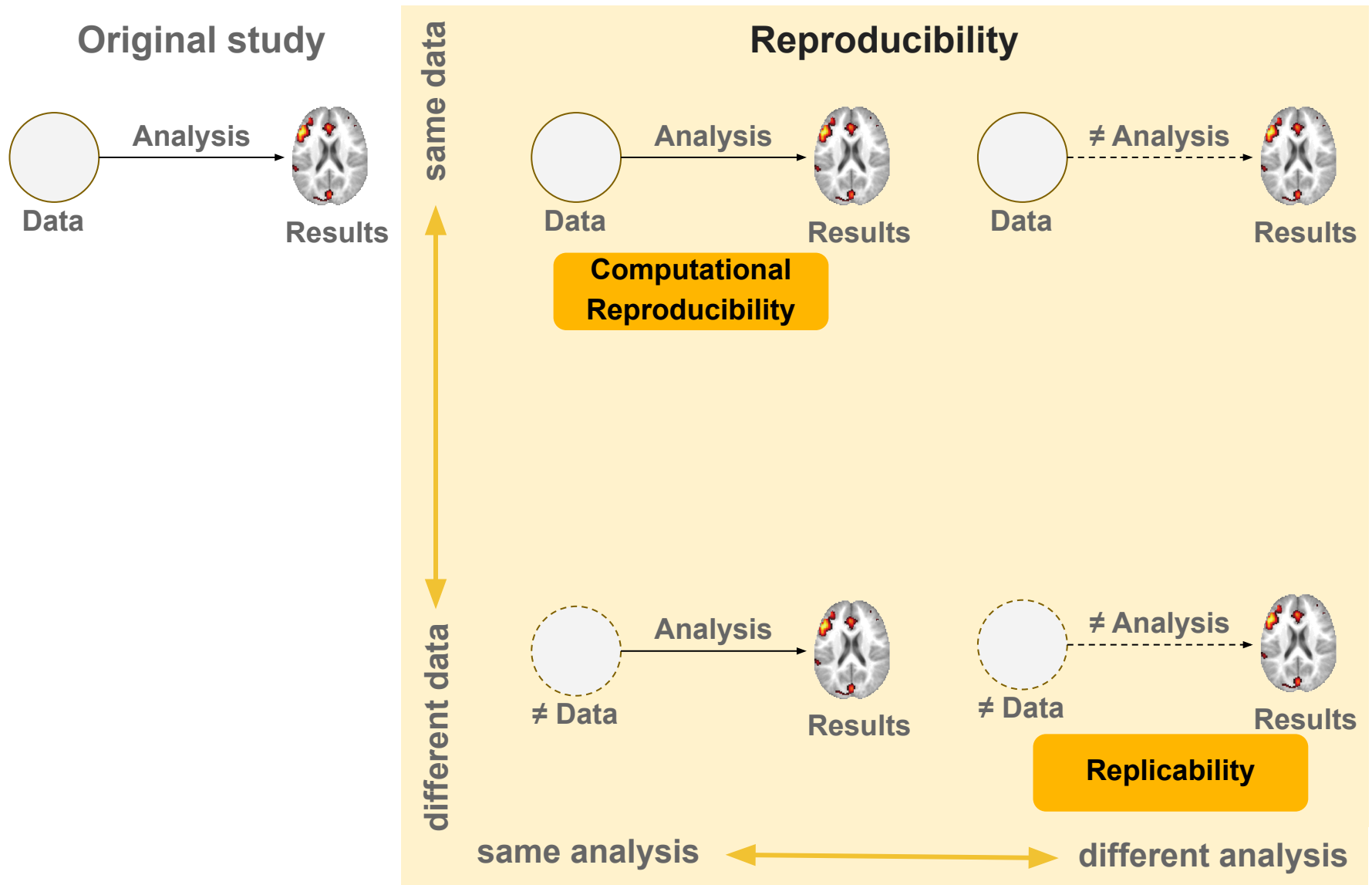
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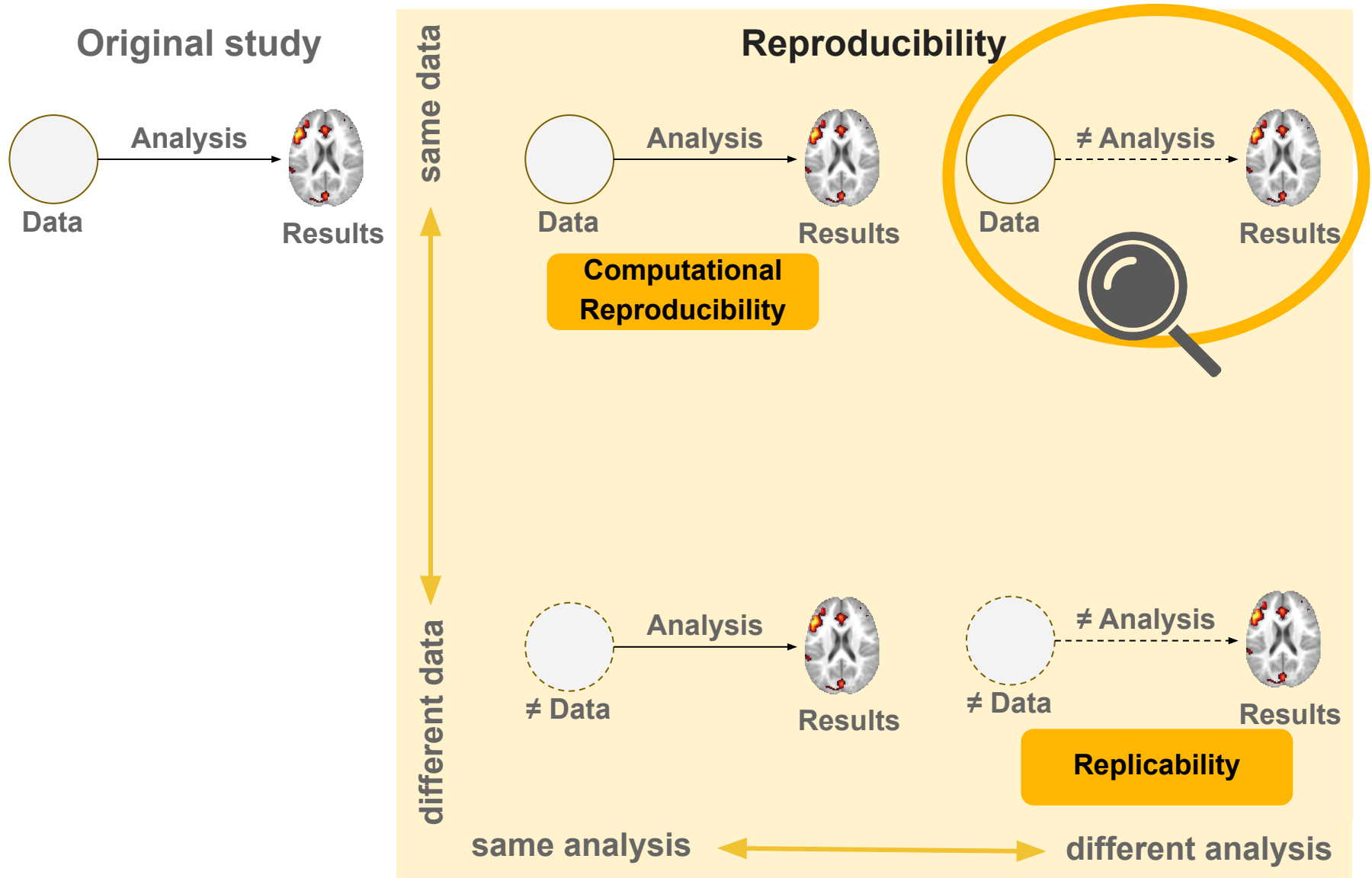
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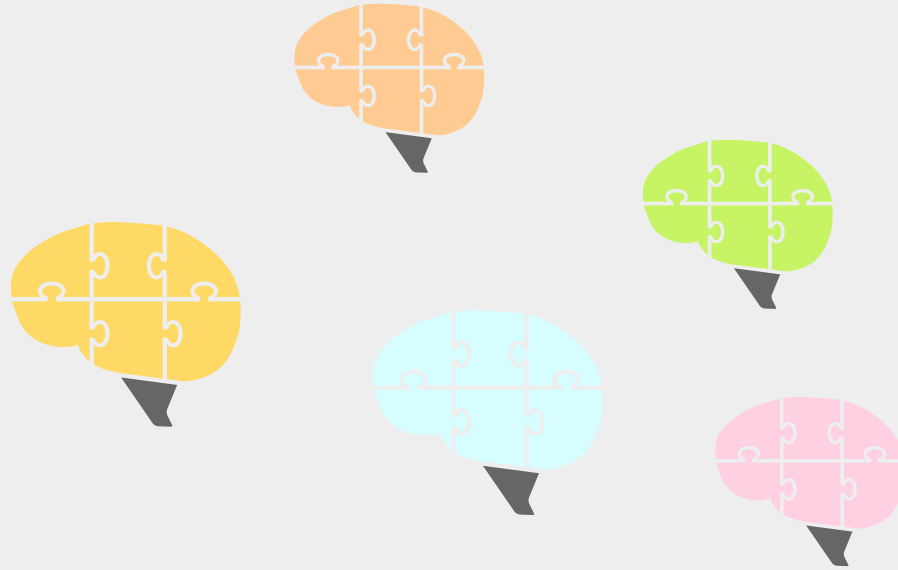


Reproducible research



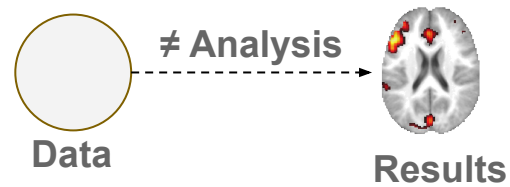
Reproducible research



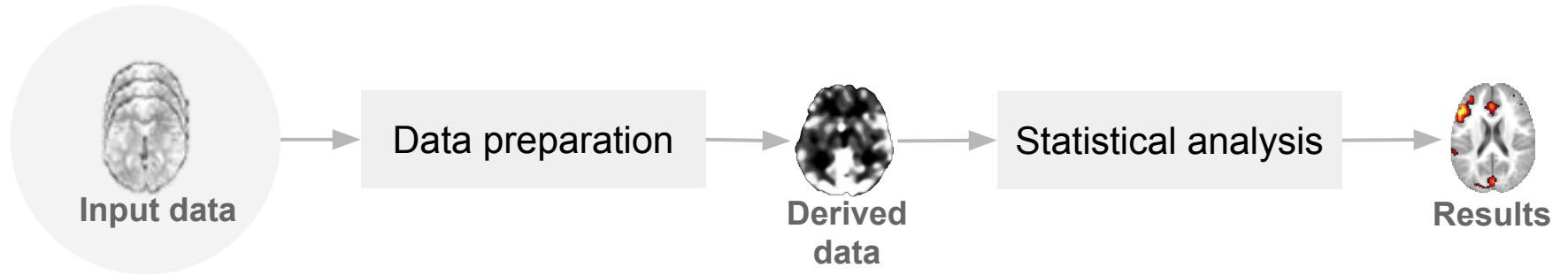


**Different
pipelines...** different
results?

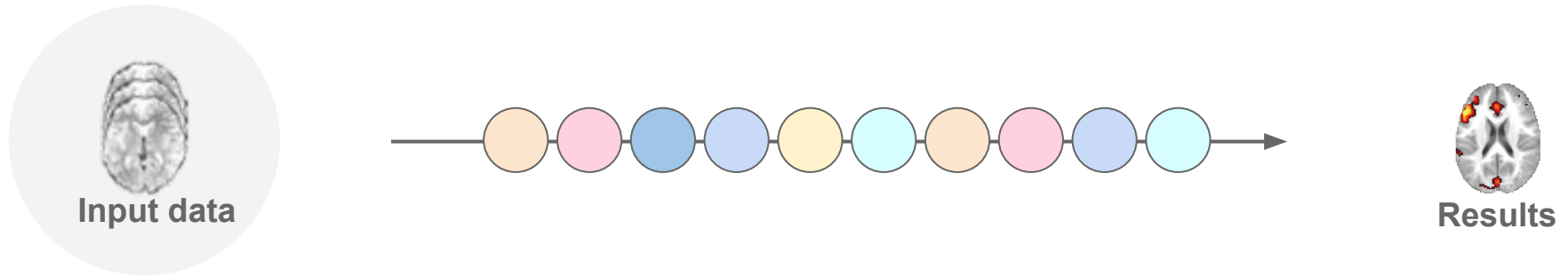
A multiplicity of analysis pipelines



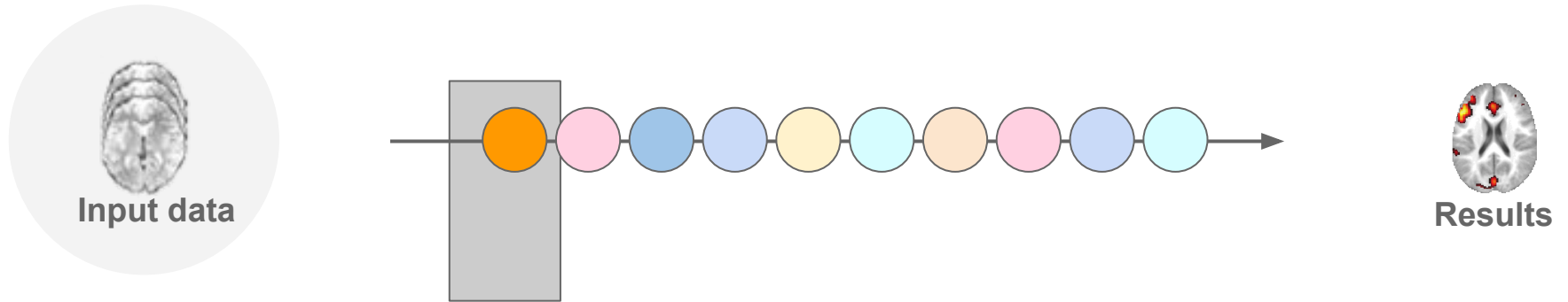
A multiplicity of analysis pipelines



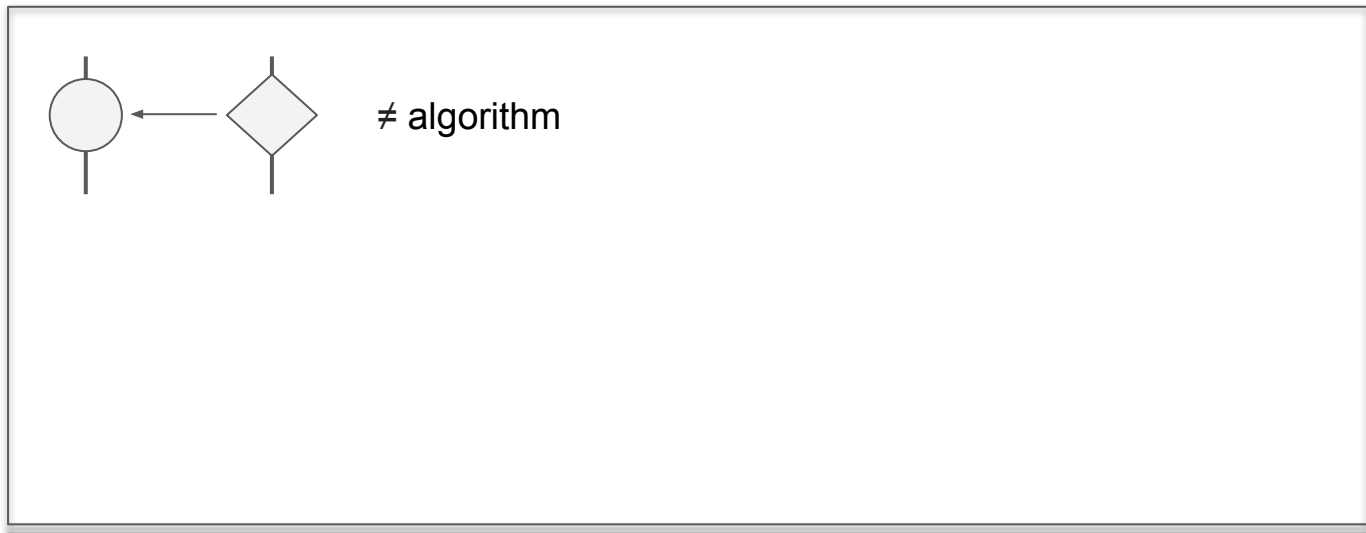
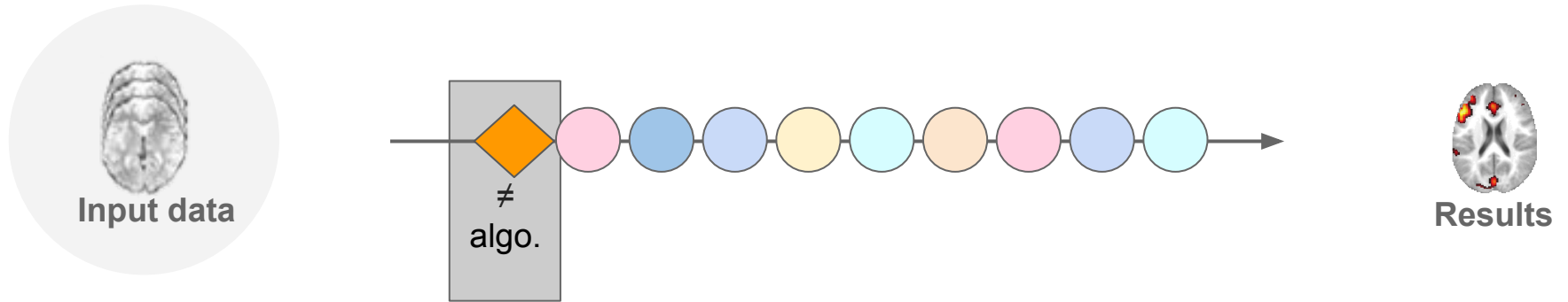
A multiplicity of analysis pipelines



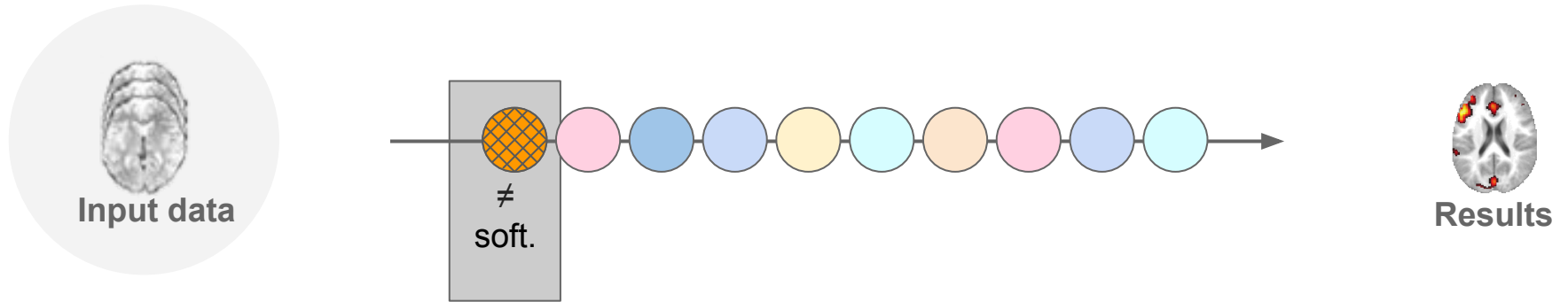
A multiplicity of analysis pipelines



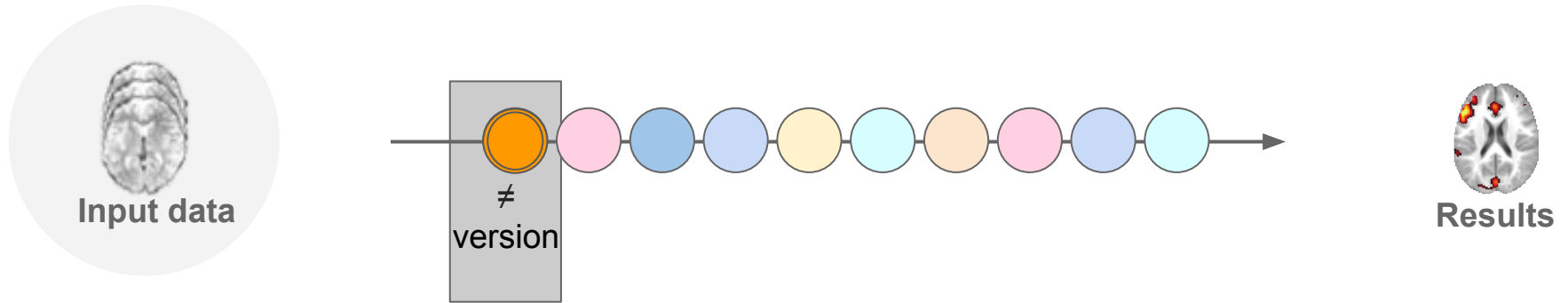
A multiplicity of analysis pipelines



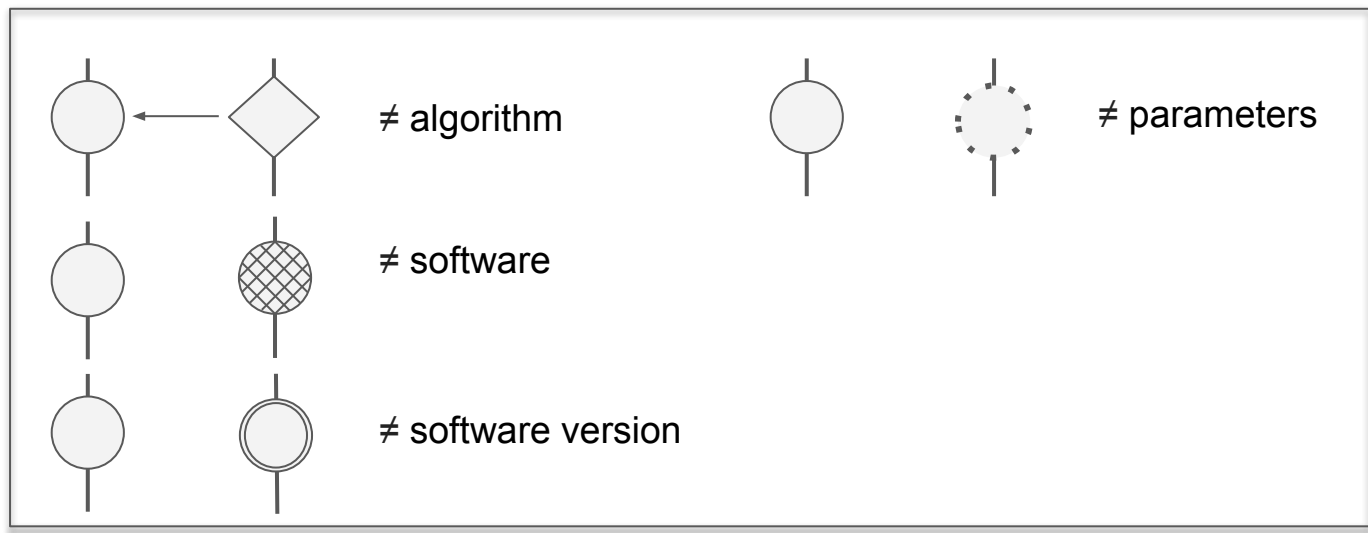
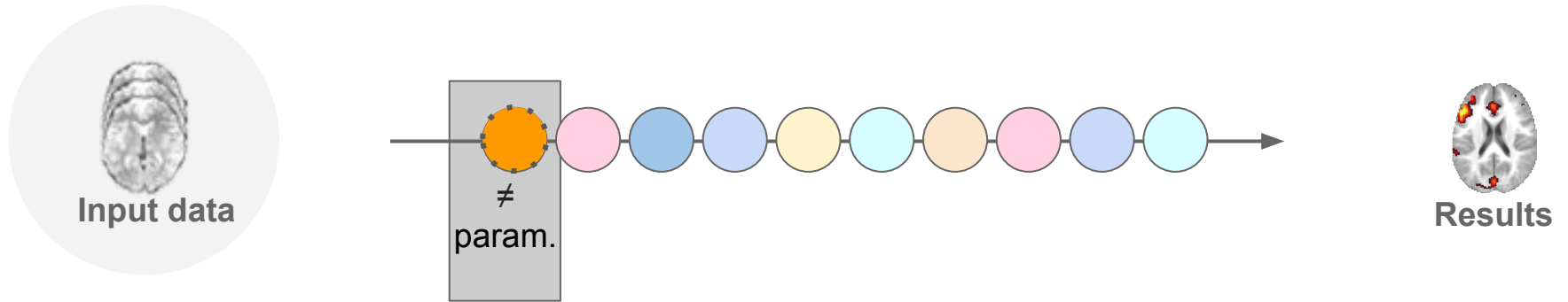
A multiplicity of analysis pipelines



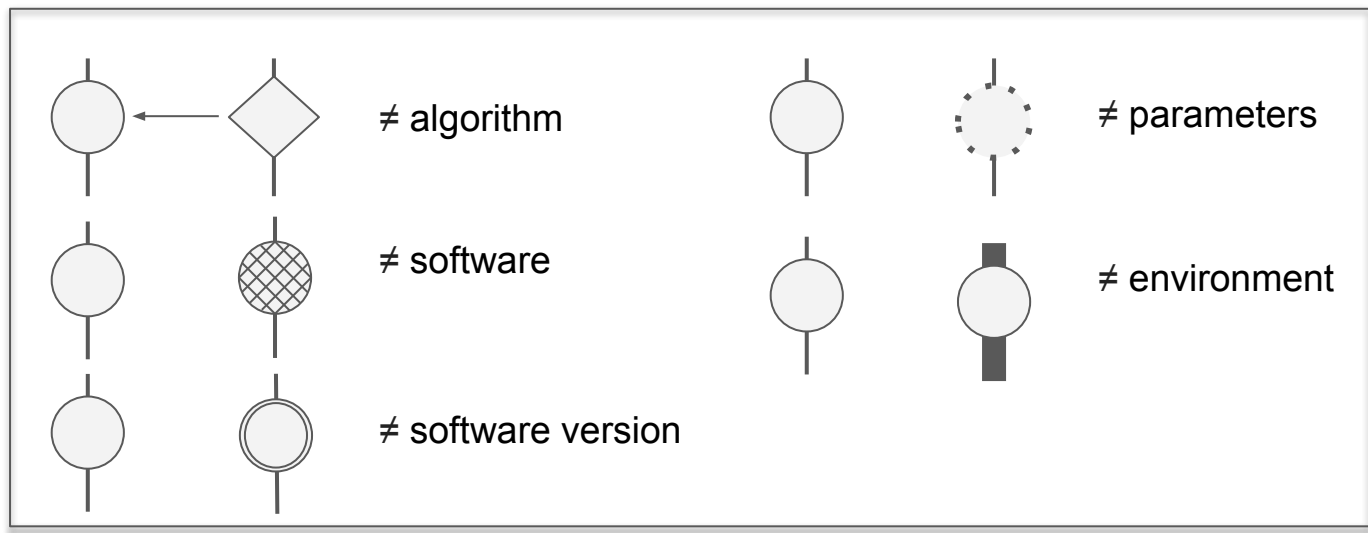
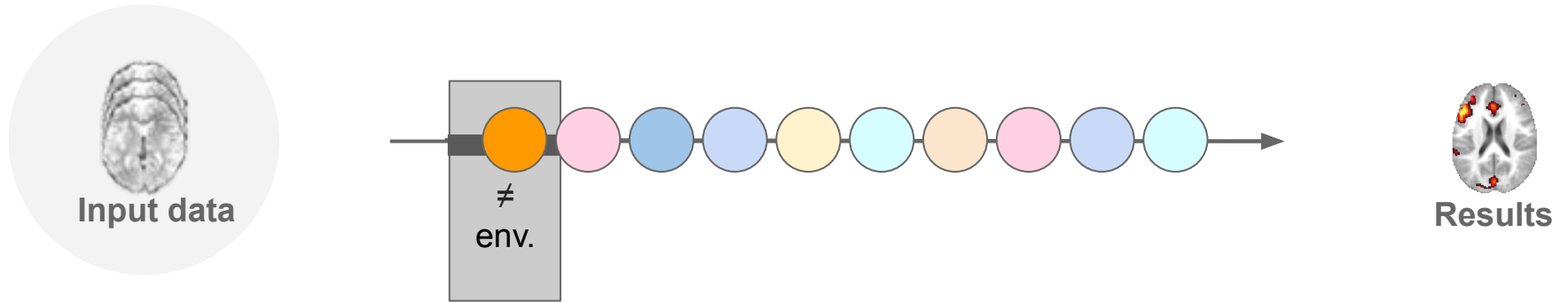
A multiplicity of analysis pipelines



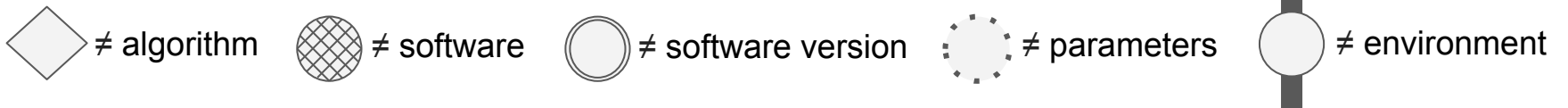
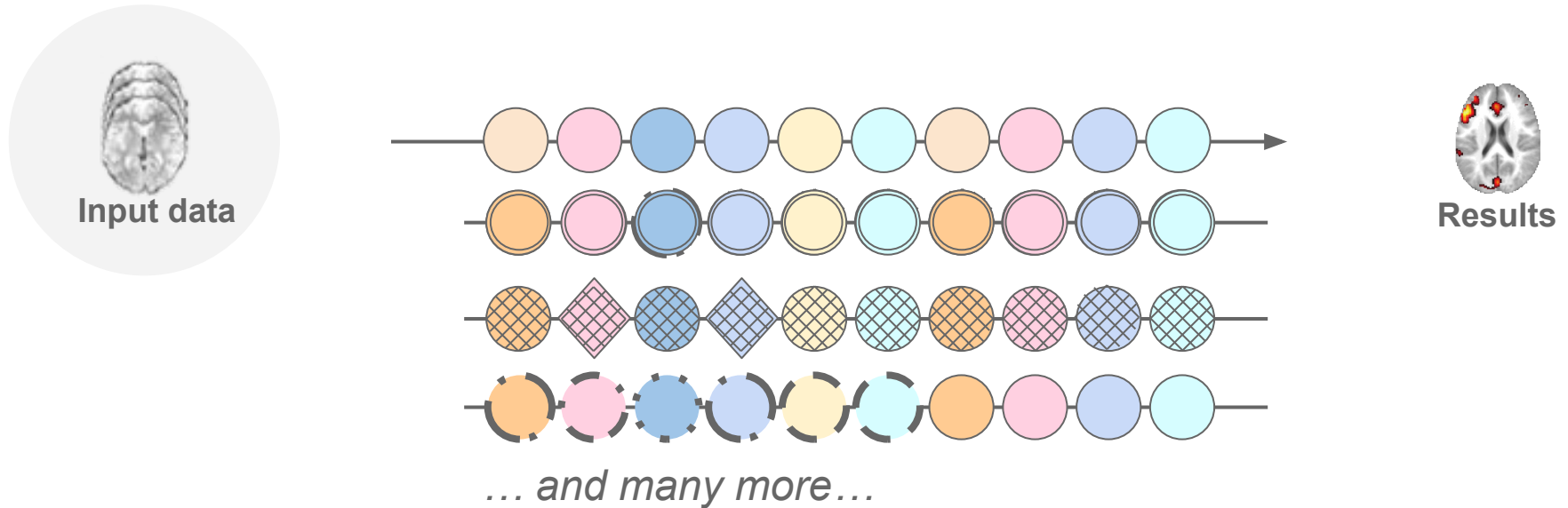
A multiplicity of analysis pipelines



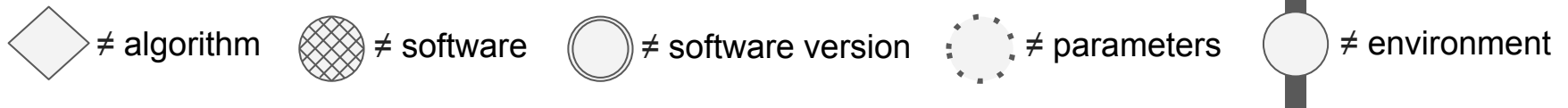
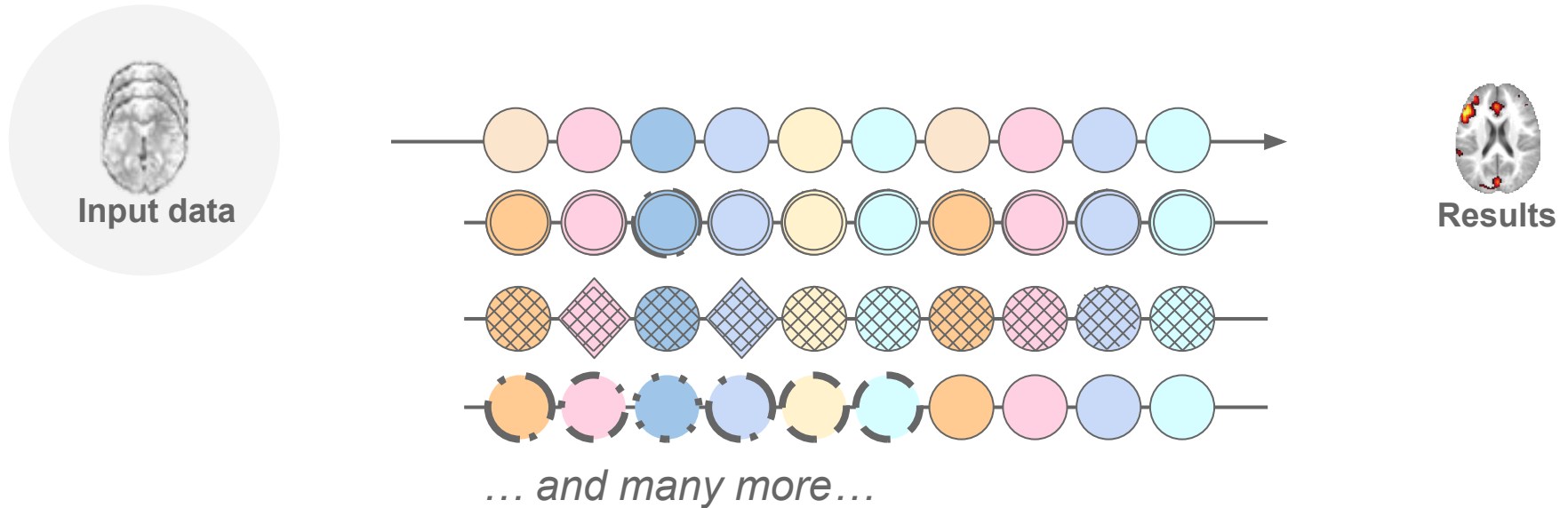
A multiplicity of analysis pipelines



A multiplicity of analysis pipelines



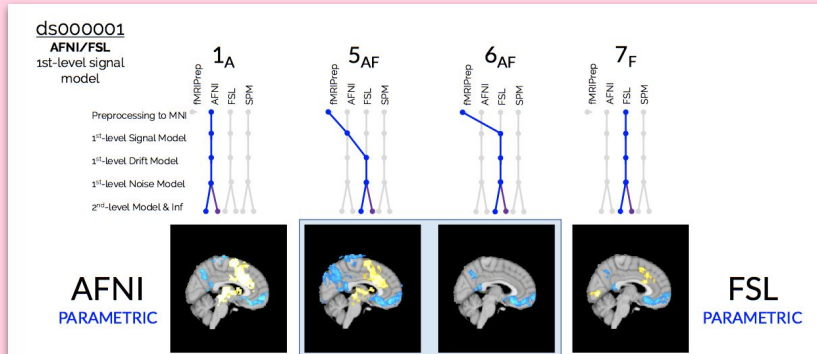
A multiplicity of analysis pipelines



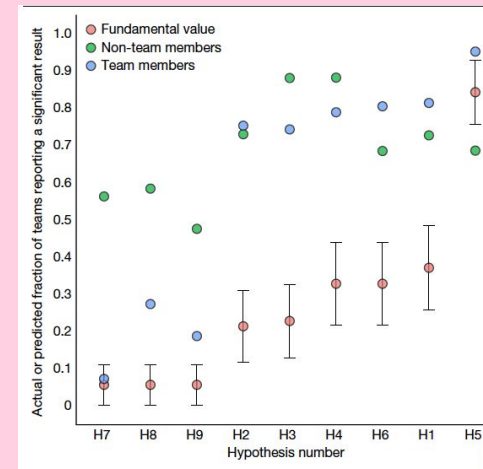
A family of acceptable pipelines
over 10^{30} combinations...

Different pipelines... different results?

Variability across neuroimaging software

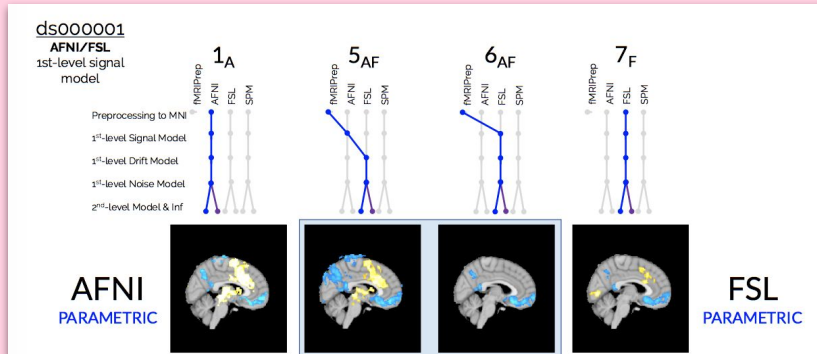


Variability across neuroimaging experts

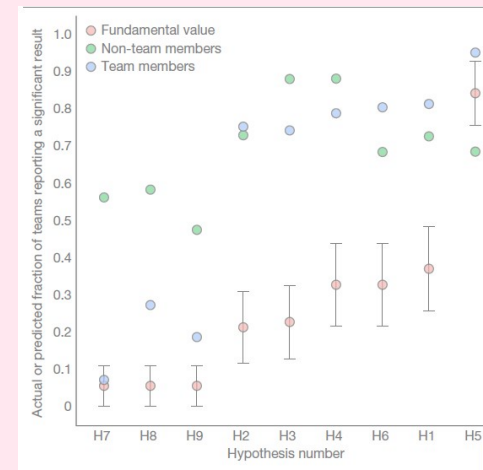


Different pipelines... different results?

Variability across neuroimaging software



Variability across neuroimaging experts



Variability across neuroimaging software



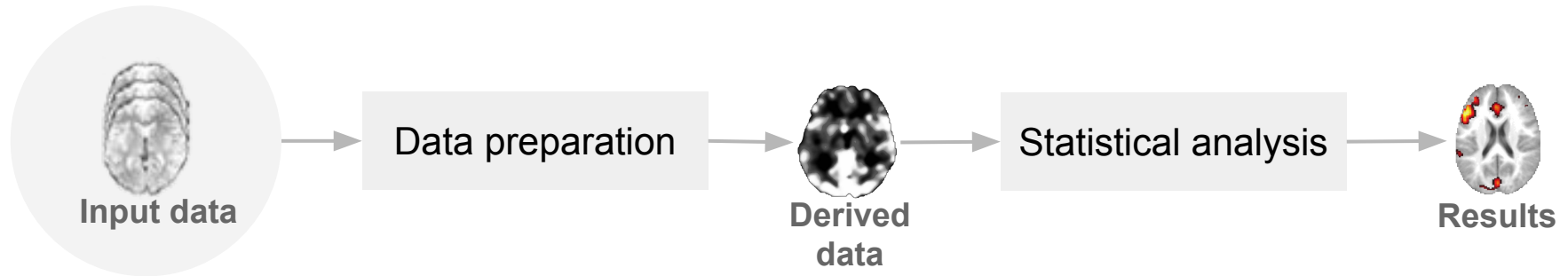
Alex Bowring



Tom Nichols

Oxford Uni. (UK)

Principles of functional MRI



Variability across neuroimaging software



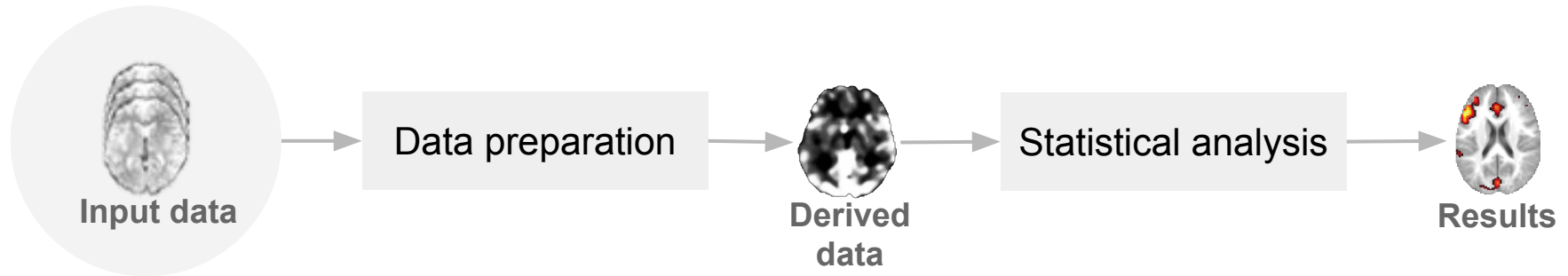
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Principles of functional MRI



Variability across neuroimaging software



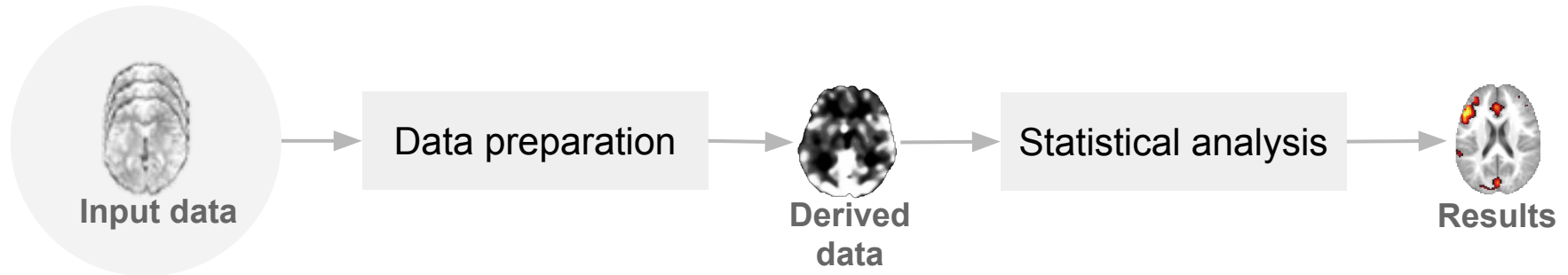
Alex Bowring



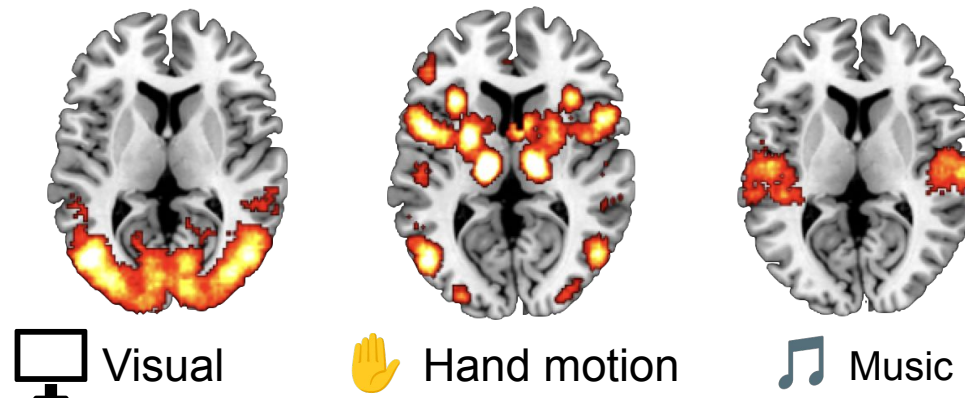
Tom Nichols

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Principles of functional MRI



fMRI results: Activations maps



Variability across neuroimaging software



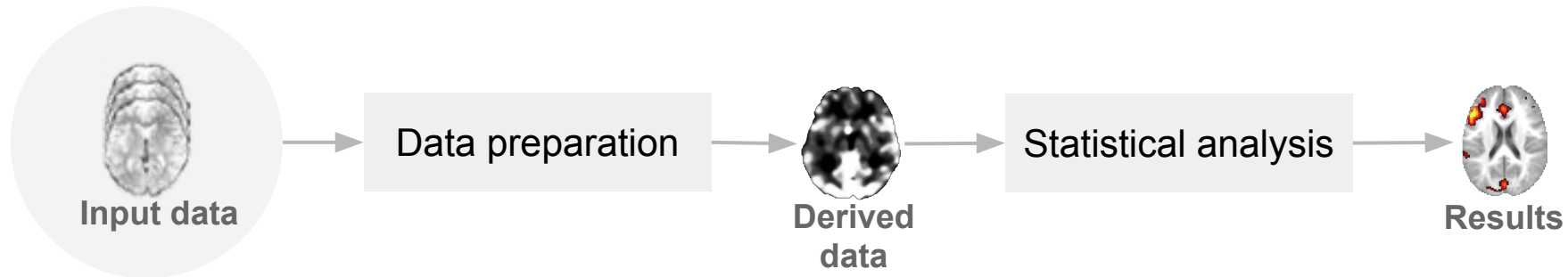
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Tom Nichols

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Principles of functional MRI



Goal 1: Investigate the **variability** observed in **fMRI results** when using **different software packages**

Variability across neuroimaging software



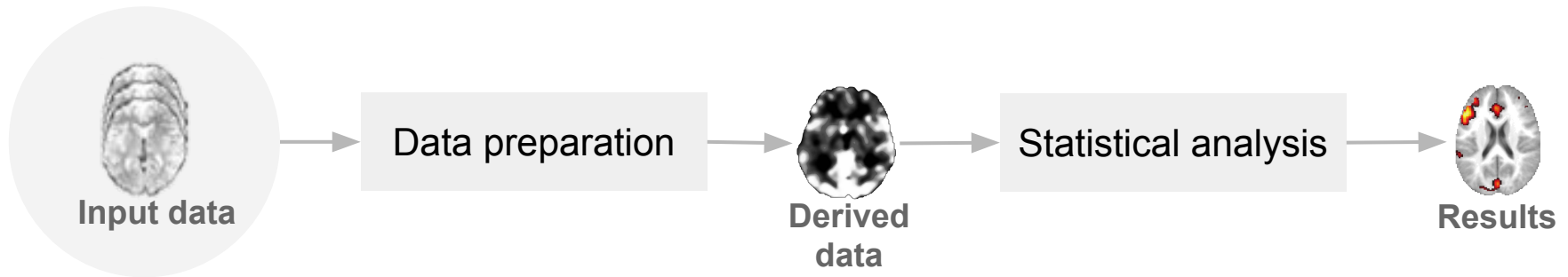
Alex Bowring



Tom Nichols

Oxford Uni. (UK)

Principles of functional MRI



Goal 1: Investigate the **variability** observed in **fMRI results** when using **different software packages**

- **Reproduced 3 studies** from the literature
- Using **3 fMRI software: AFNI, FSL, SPM**
(used in 80% literature ([Carp, 2012](#)))
- **Pipelines aligned** using available configurations.

Variability across neuroimaging software

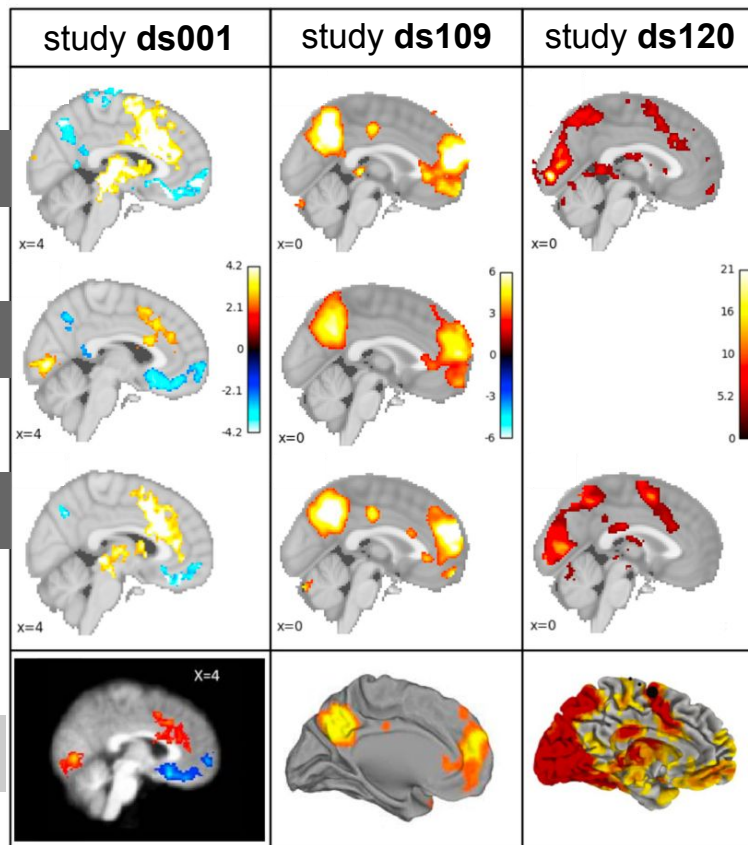


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- Variability in the activation maps



[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software

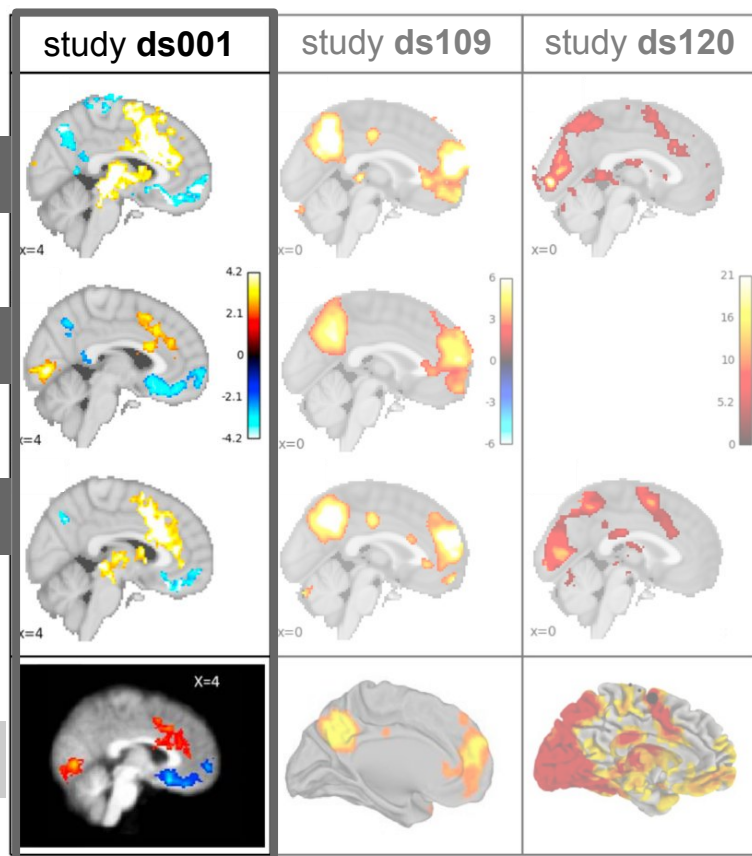


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- Variability in the activation maps



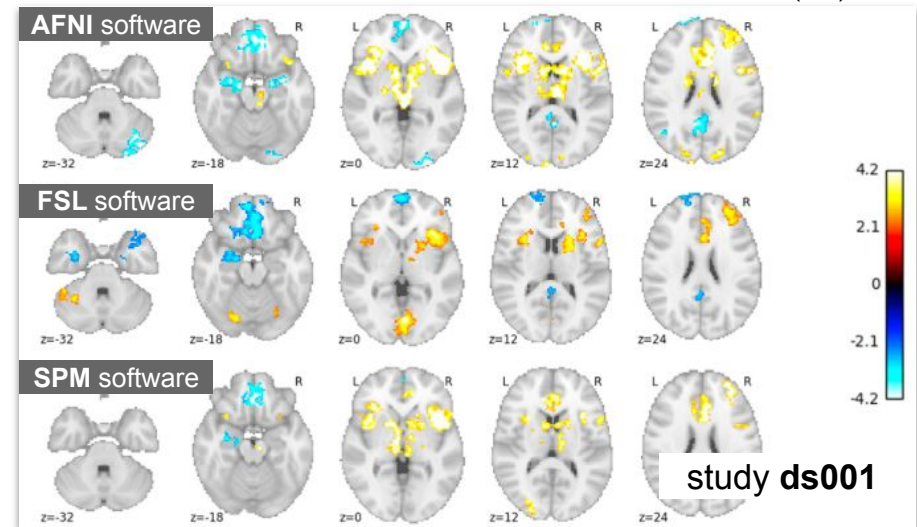
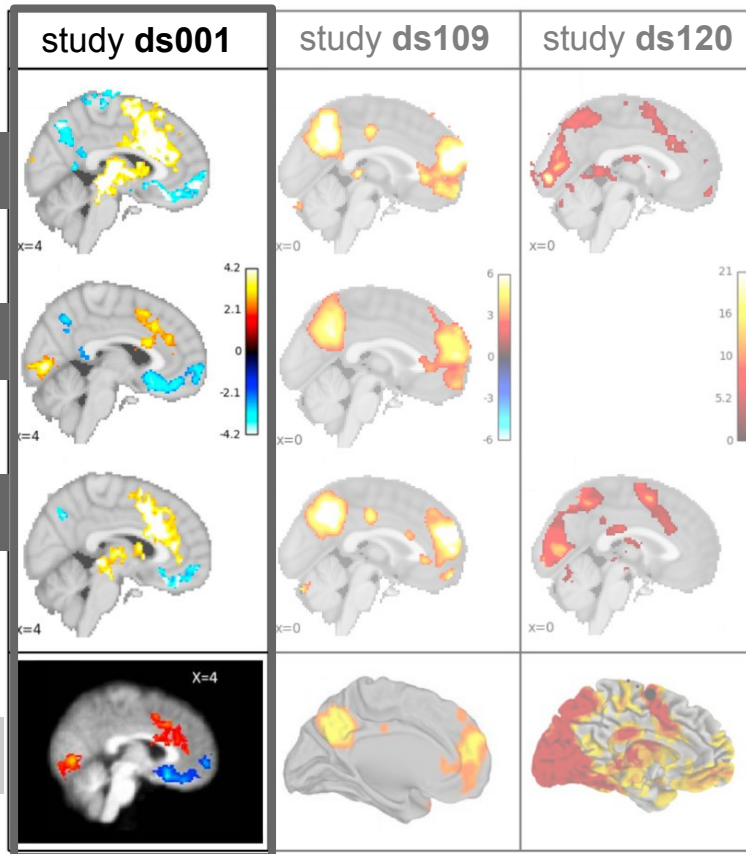
[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software



Alex Bowring Tom Nichols
Oxford Uni. (UK)

- Variability in the activation maps



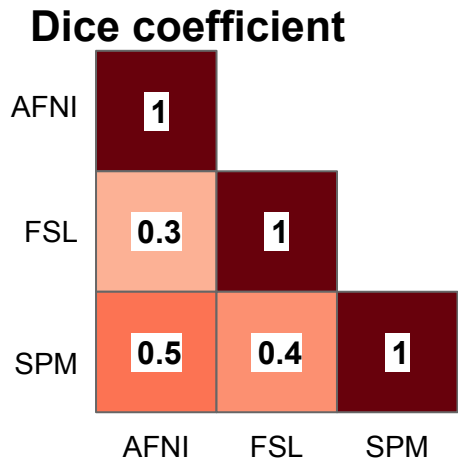
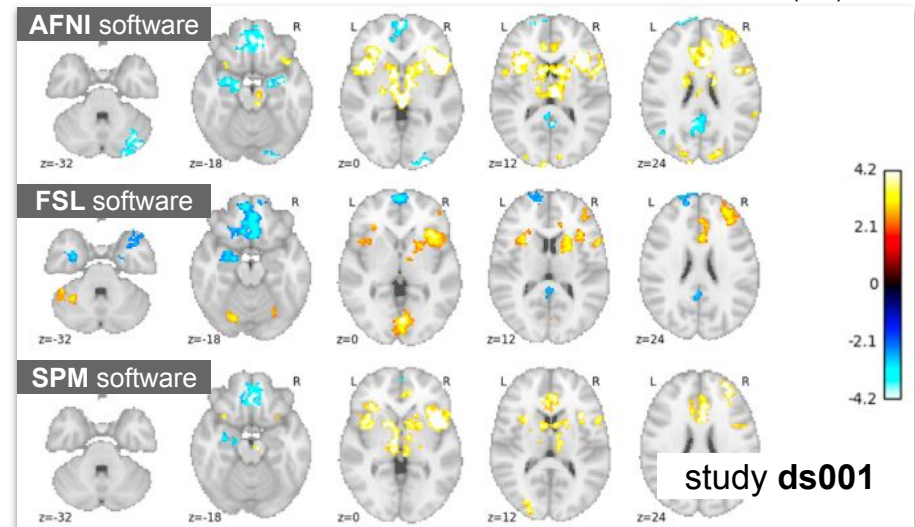
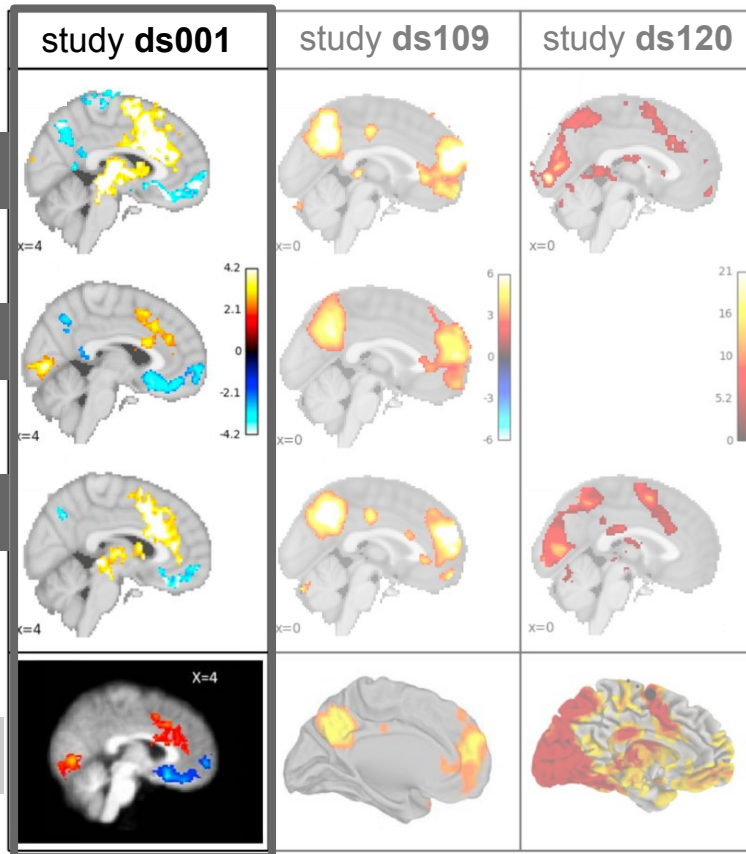
[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software



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Oxford Uni. (UK)

- Variability in the activation maps



[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software



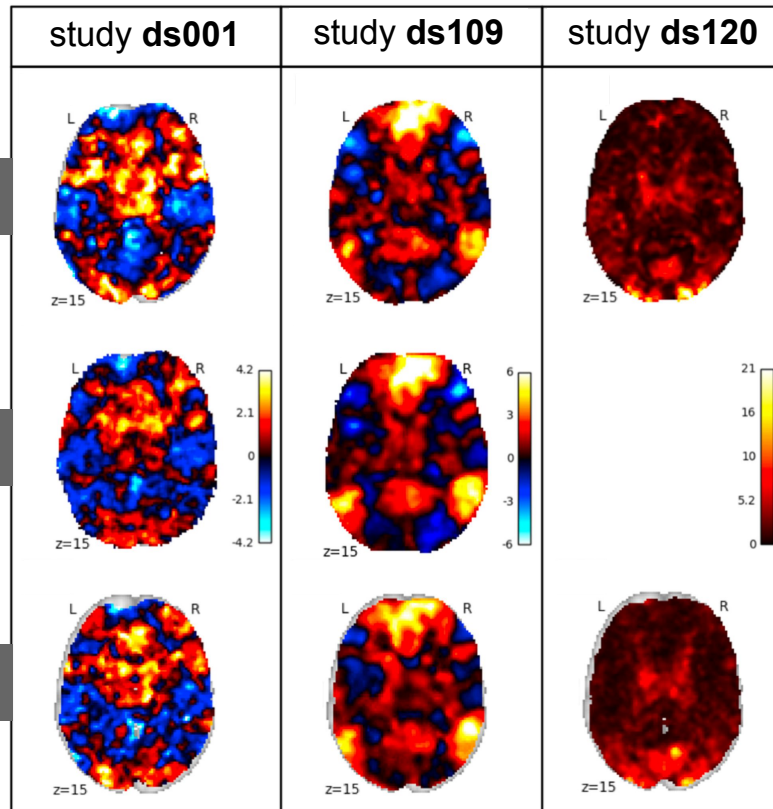
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Tom Nichols

Oxford Uni. (UK)

- Variability in the unthresholded statistic maps



Correlations

AFNI vs. FSL	0.62
AFNI vs. SPM	0.61
FSL vs. SPM	0.68

Conclusion: The choice of software impacted both the final activation and statistic maps.

[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software



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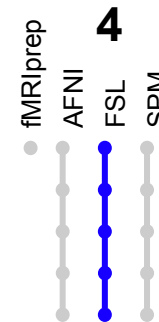
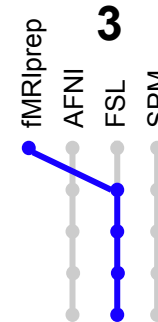
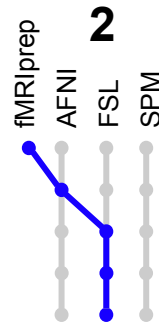
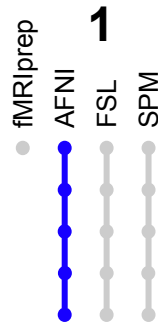


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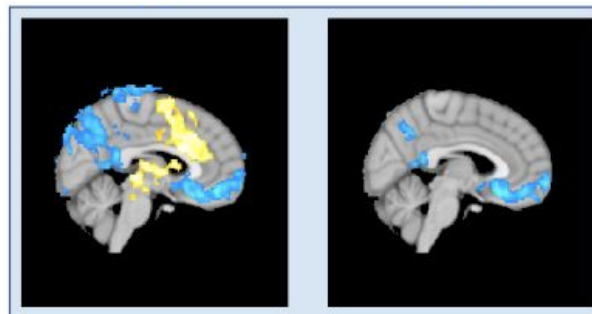
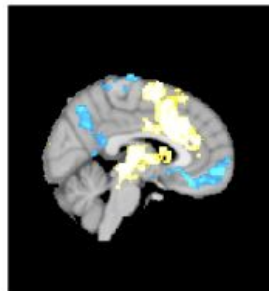
Goal 2: Investigate how remaining differences in software implementations can explain the observed differences

study ds001

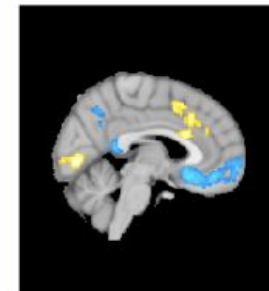
1. Preprocessing
2. Subject-level Signal
3. Subject-level Drift
4. Subject-level Noise
5. Group-level Stat



AFNI
software



FSL
software



[Bowring Nichols* Maumet*, HBM 2021]

Variability across neuroimaging software



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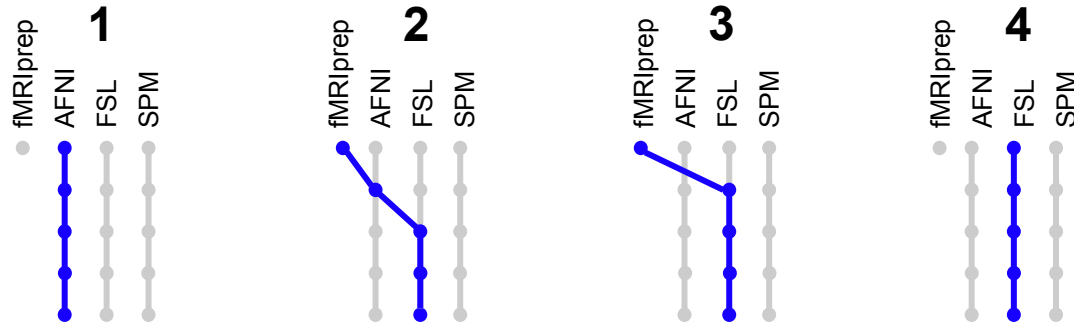


Tom Nichols
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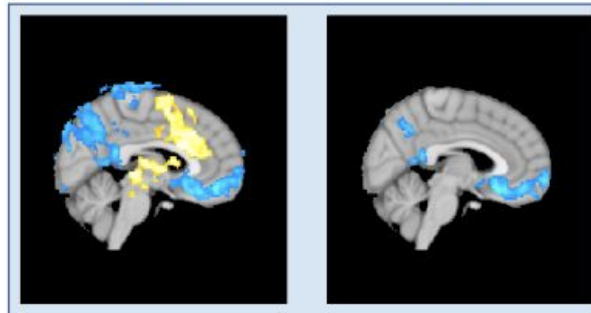
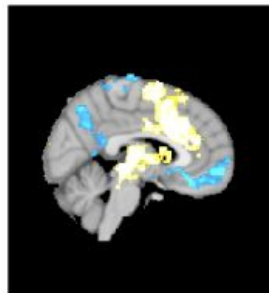
Goal 2: Investigate how remaining differences in software implementations can explain the observed differences

study ds001

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3. Subject-level Drift
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5. Group-level Stat



AFNI
software



FSL
software

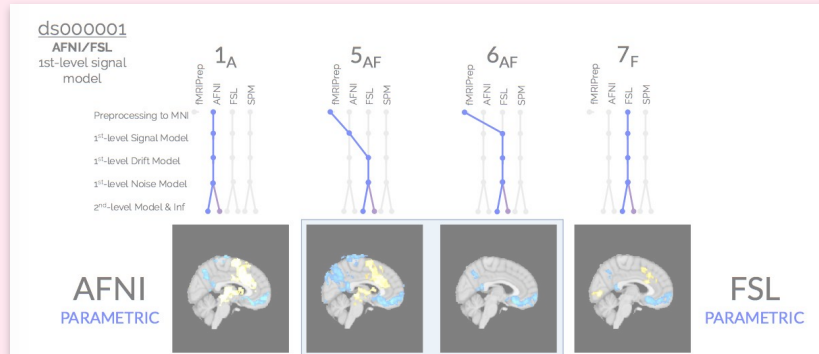


Conclusion: 1 main contributing factor was found but different for each study

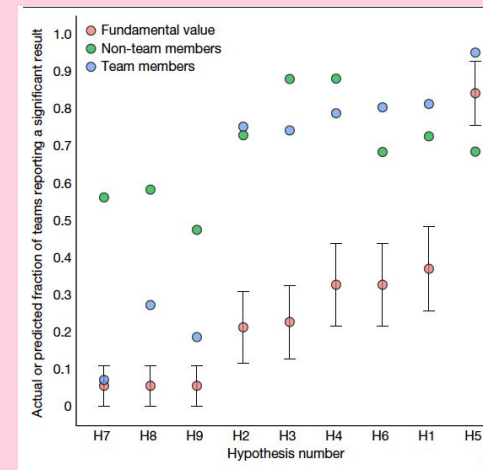
[Bowring Nichols* Maumet*, HBM 2021]

Different pipelines... different results?

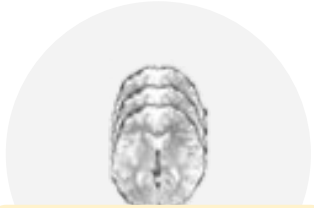
Variability across neuroimaging software



Variability across neuroimaging experts



Many-analyst project : NARPS

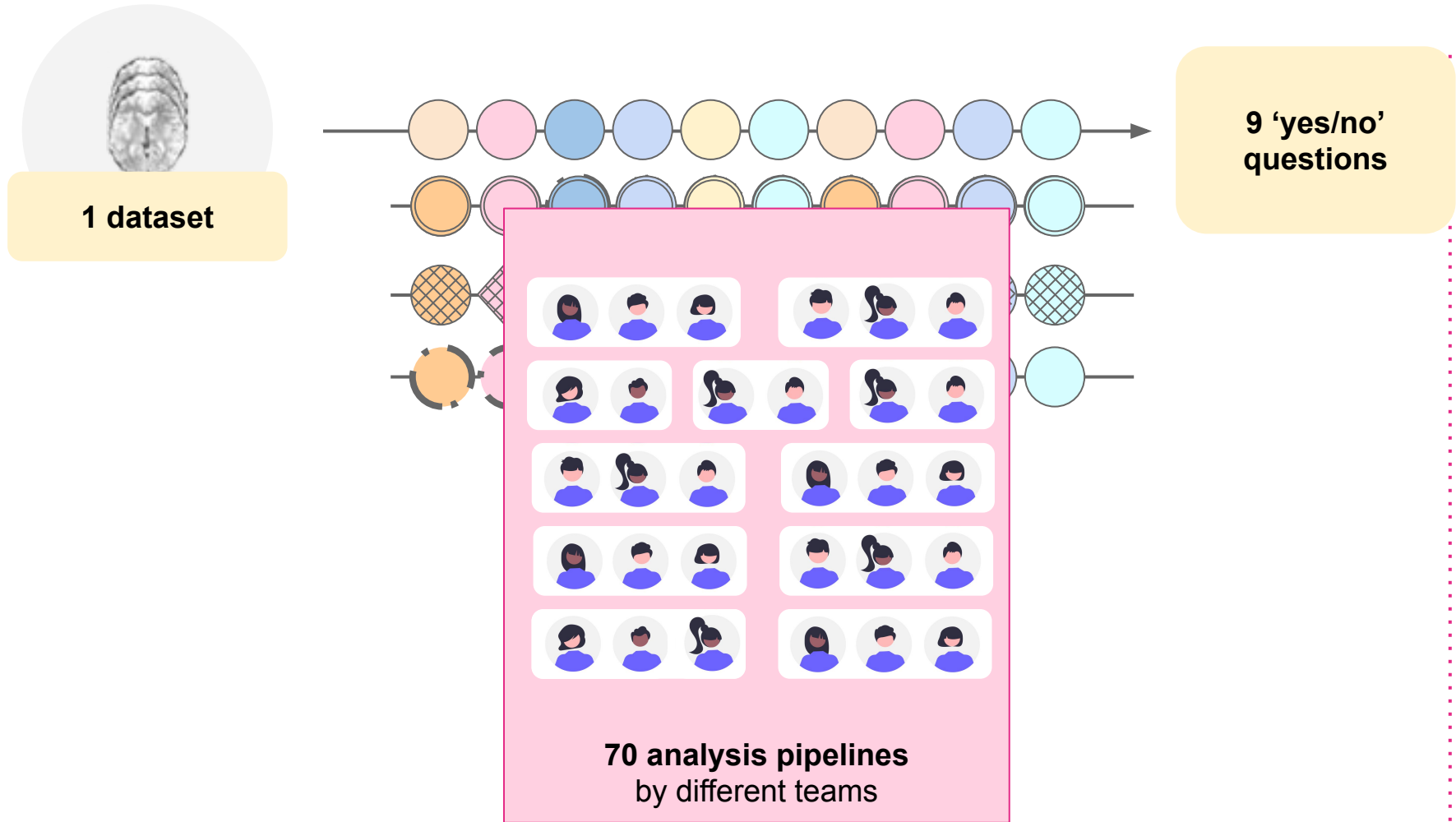


1 dataset

**9 'yes/no'
questions**

[Botvinik-Nezer et. al, Nature 2020]

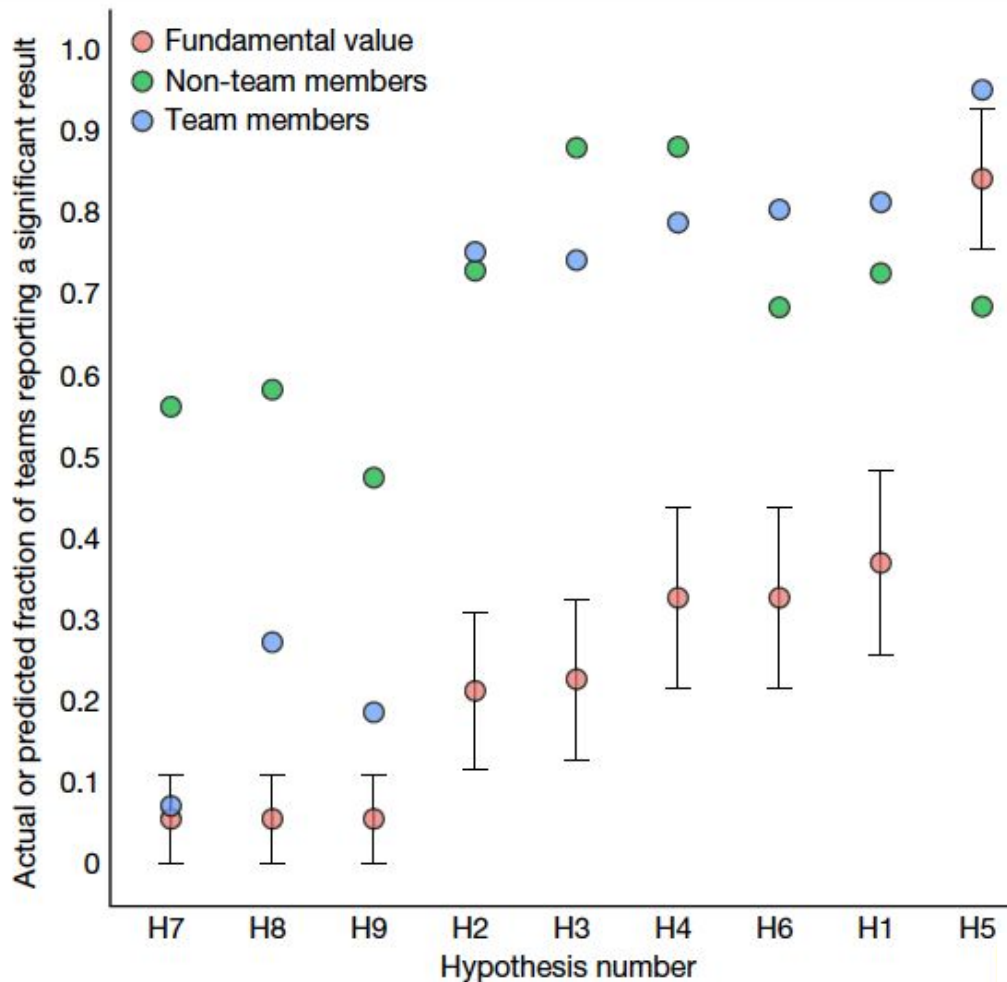
Many-analyst project : NARPS



[Botvinik-Nezer et. al, Nature 2020]

Many-analyst project : NARPS

Results over the **70 post-processing pipelines**:

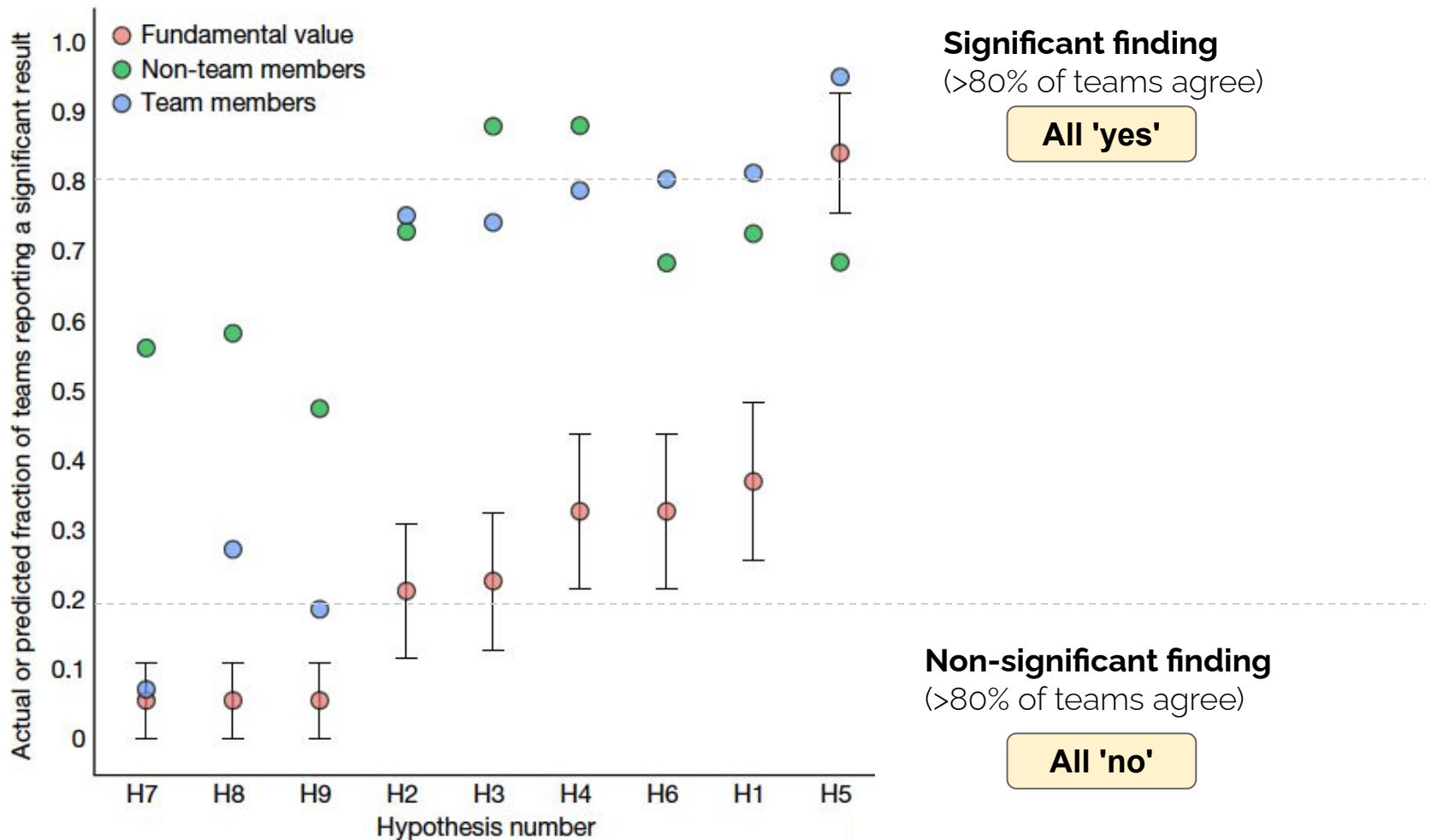


9 'yes/no' questions

[Botvinik-Nezer et. al, Nature 2020]

Many-analyst project : NARPS

Results over the **70 post-processing pipelines**:

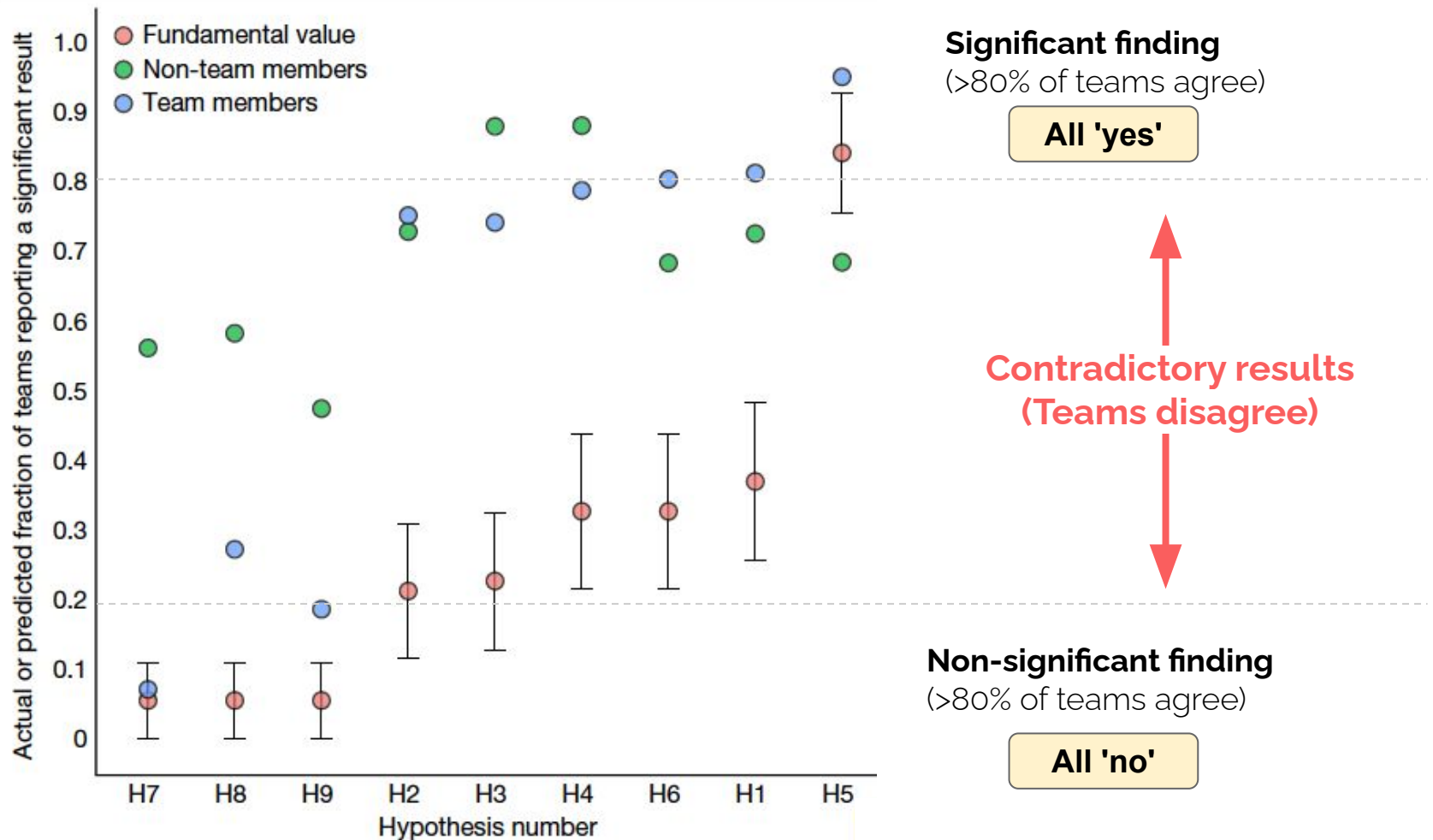


9 'yes/no' questions

[Botvinik-Nezer et. al, Nature 2020]

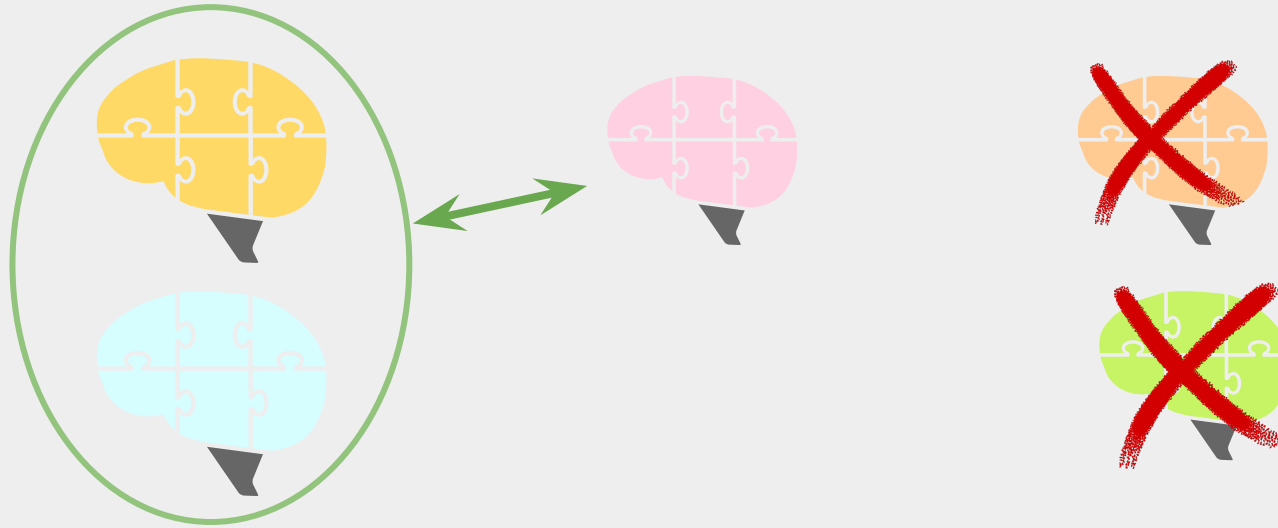
Many-analyst project : NARPS

Results over the **70 post-processing pipelines**:



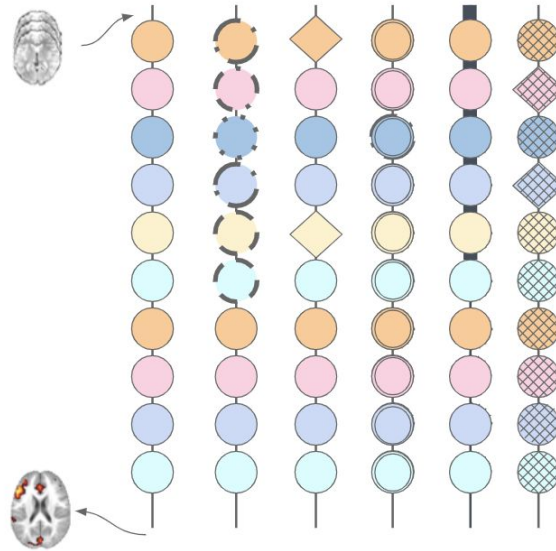
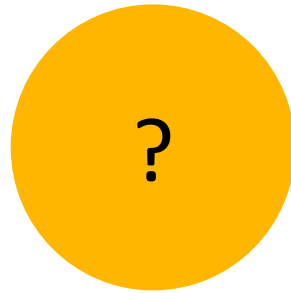
9 'yes/no' questions

[Botvinik-Nezer et. al, Nature 2020]



Understanding
analytical variability

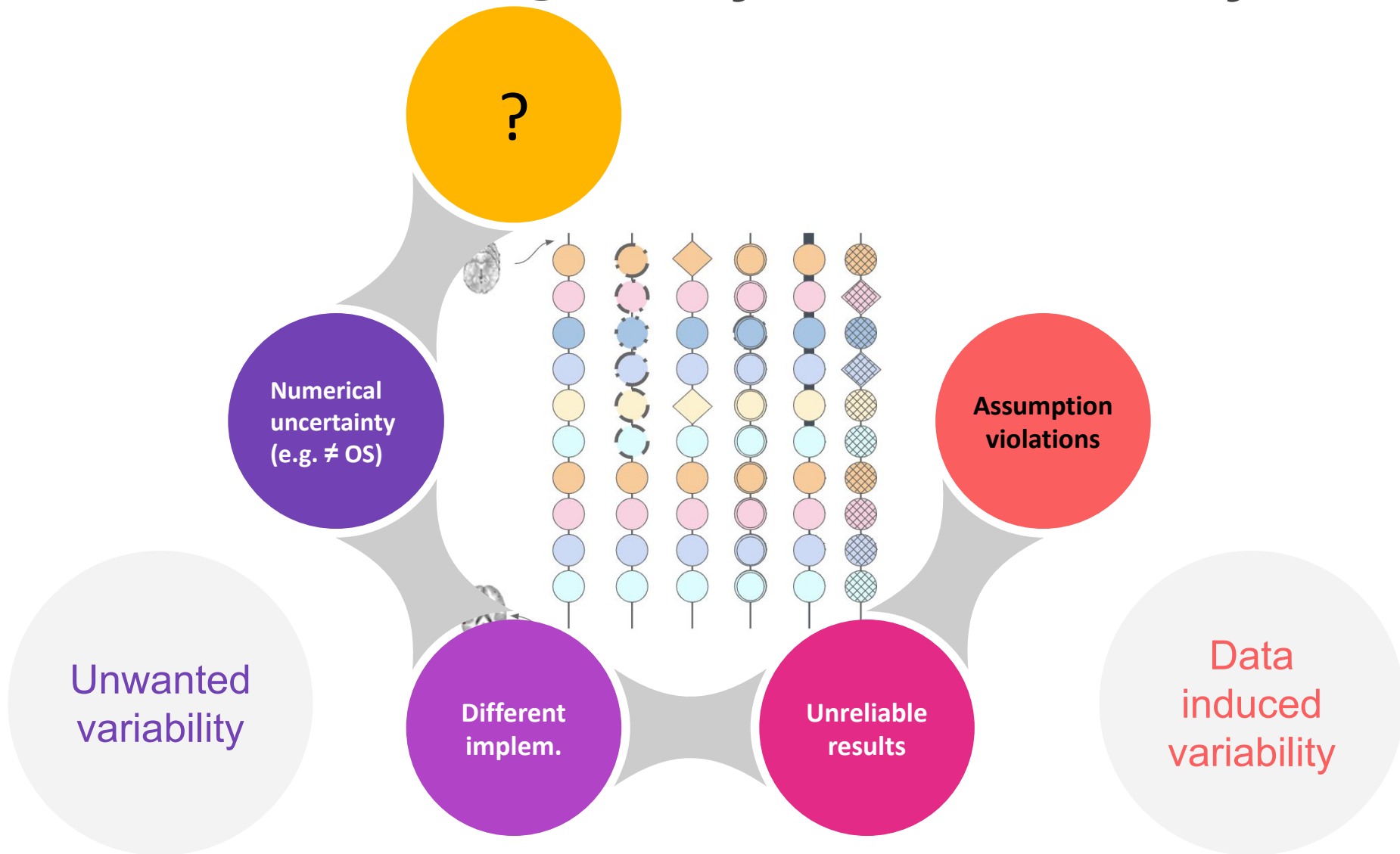
Understanding analytical variability...



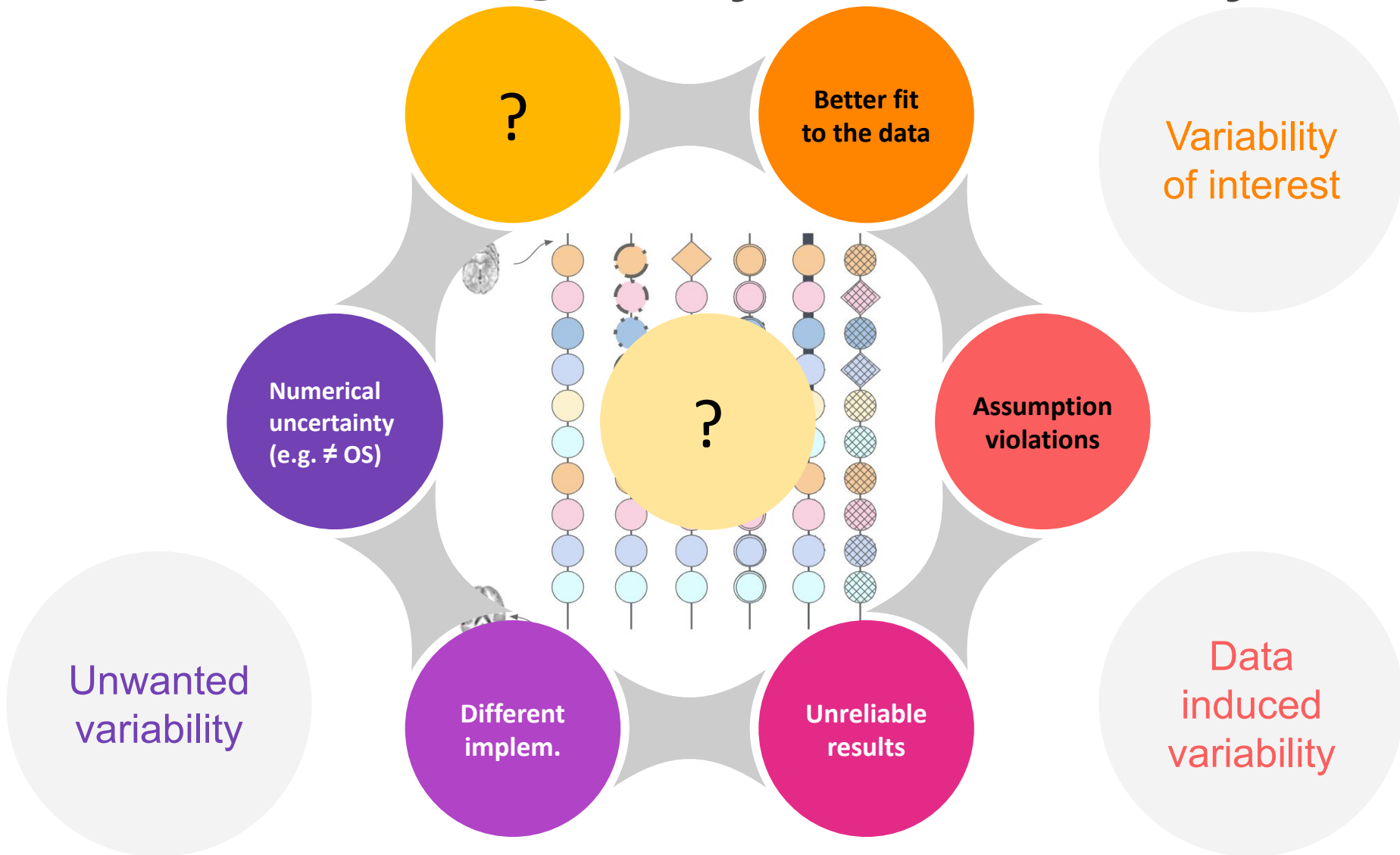
Understanding analytical variability...

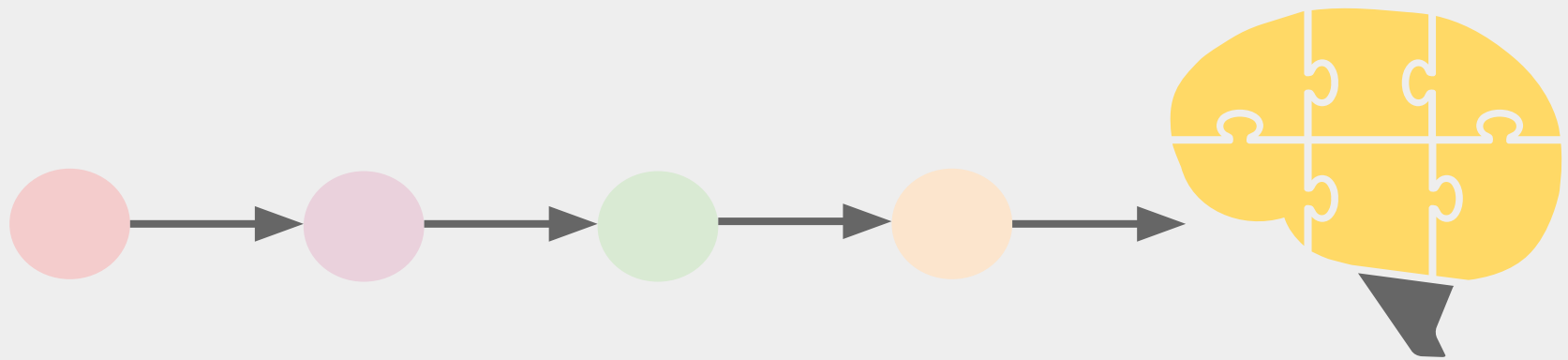


Understanding analytical variability...



Understanding analytical variability...

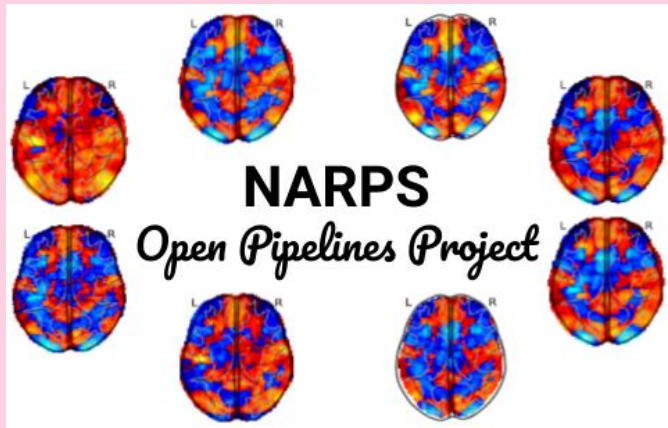




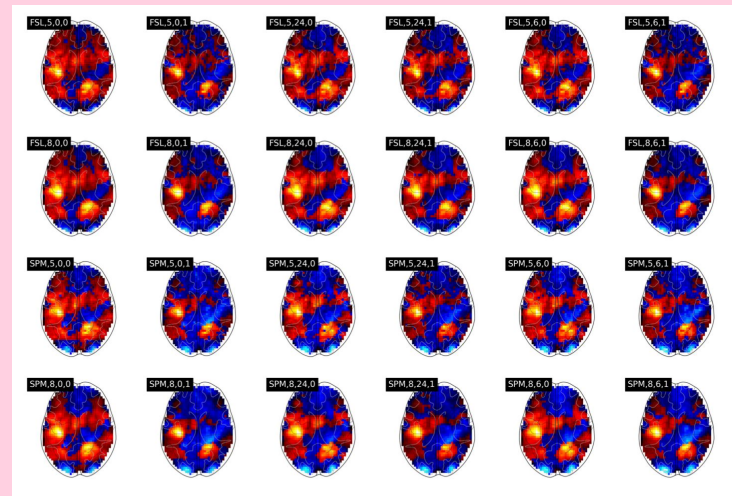
Describing the
neuroimaging
pipeline space

Open code and data to investigate analytical variability

NARPS open pipelines

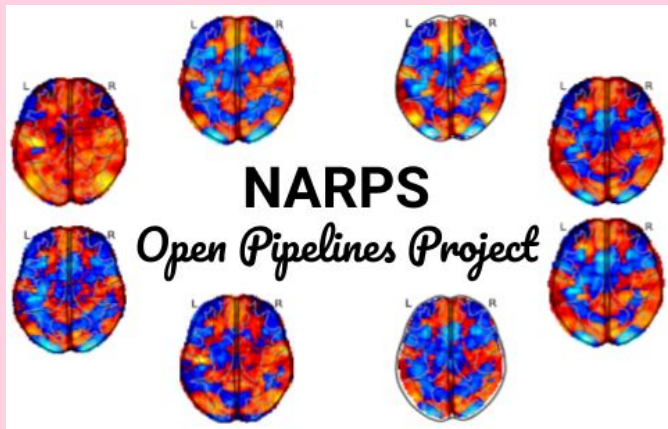


HCP many pipeline

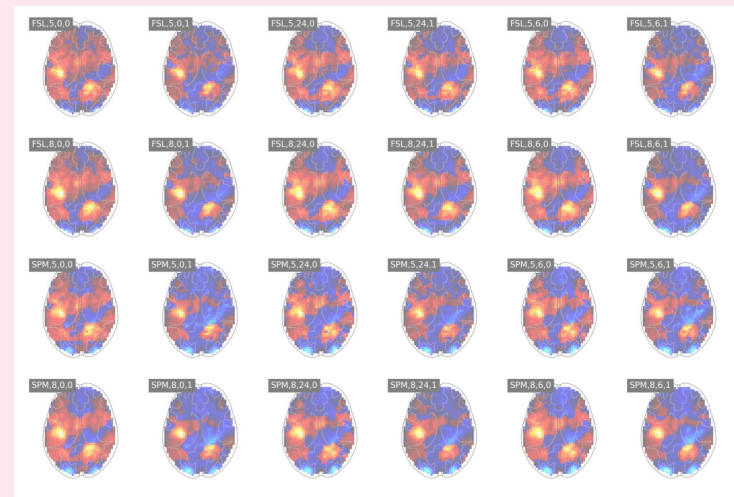


Open code and data to investigate analytical variability

NARPS open pipelines



HCP many pipeline



NARPS open pipelines



Boris Clenet



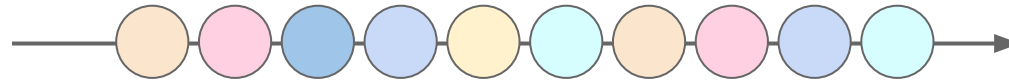
Elodie Germani



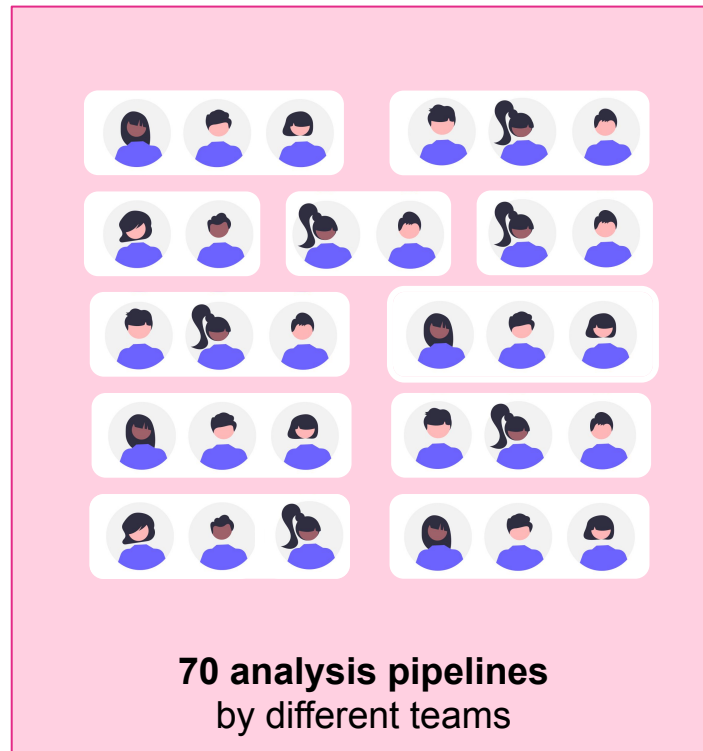
Jérémy Lefort-Besnard



1 dataset



9 'yes/no' questions



NARPS open pipelines



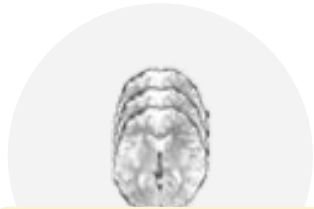
Boris Clenet



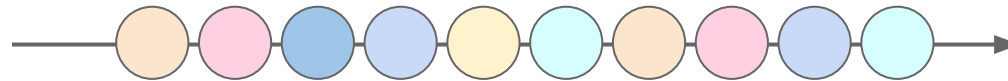
Elodie Germani



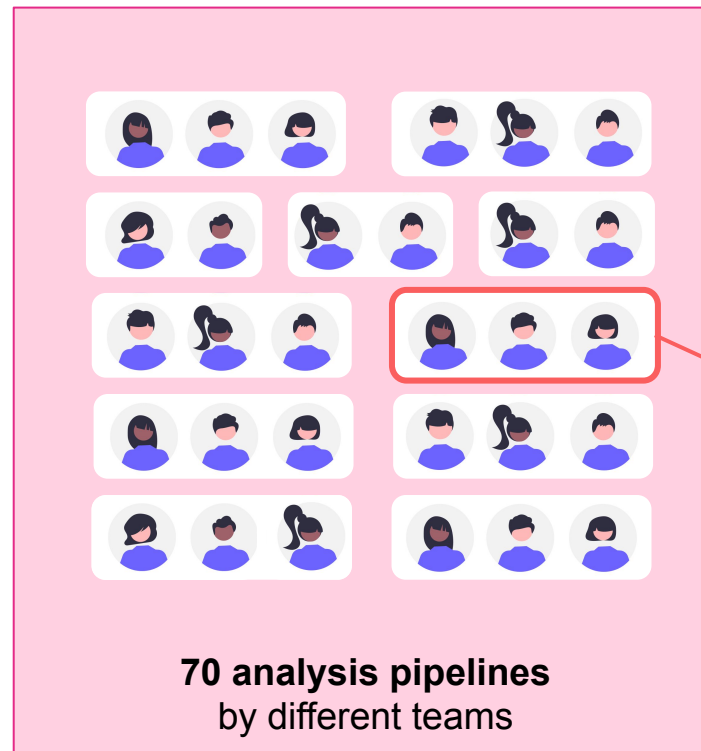
Jérémy Lefort-Besnard

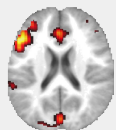


1 dataset



9 'yes/no' questions



1- Q1: "yes" 

2- Activation +
Statistic brain maps

3- Textual
COBIDAS-compliant
description of the
methods

NARPS open pipelines



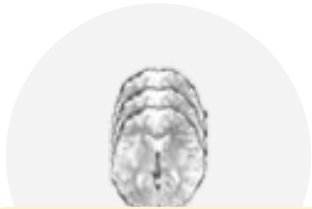
Boris Clenet



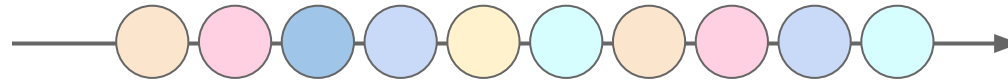
Elodie Germani



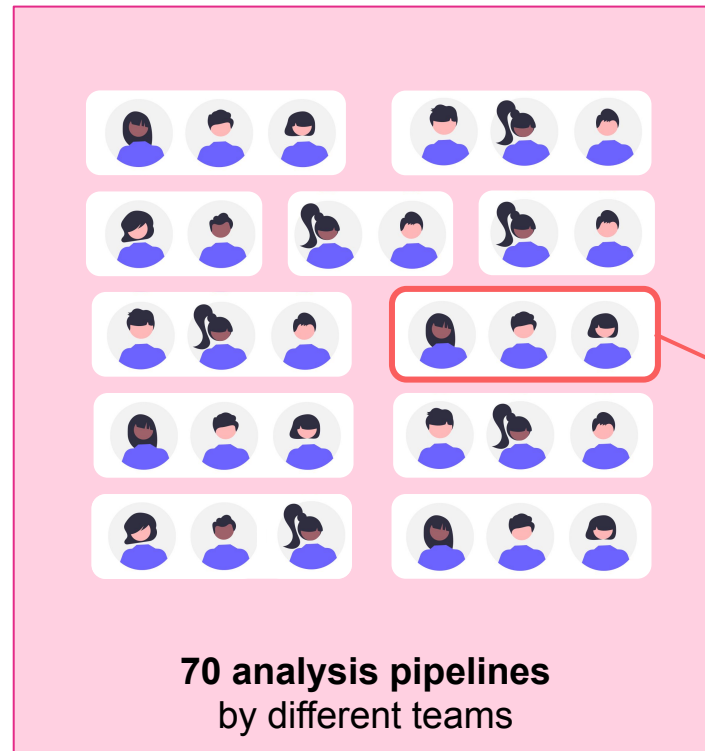
Jérémy Lefort-Besnard

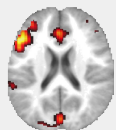


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COBIDAS-compliant
description of the
methods

+ Code



https://github.com/Inria-Empenn/narps_open_pipelines/

NARPS open pipelines



**Boris
Clenet**



**Elodie
Germani**



**Jérémy
Lefort-Besnard**

brainhack.org

Credits - This project was presented and received contributions during the following events:

- Empenn hackathon (February 2024)
- [Brainhack Marseille 2023](#) (December 2023)
- [ORIGAMI lab](#) hackathon (September 2023)
- [OHBM Brainhack 2023](#) (July 2023): Arshitha Basavaraj, Boris Clenet, Rémi Gau, Élodie Germani, Yaroslav Halchenko, Camille Maumet, Paul Taylor.
- [e-ReproNim FENS NENS Cluster Brainhack](#) (June 2023) : Liz Bushby, Boris Clenet, Michael Dayan, Aimee Westbrook.
- [OHBM Brainhack 2022](#) (June 2022): Elodie Germani, Arshitha Basavaraj, Trang Cao, Rémi Gau, Anna Menacher, Camille Maumet.

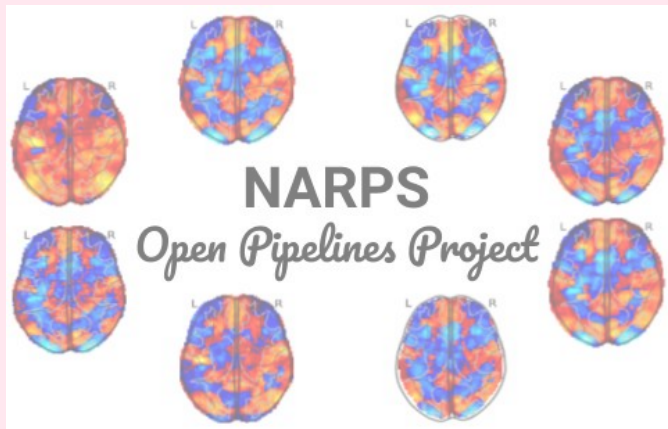
Open code



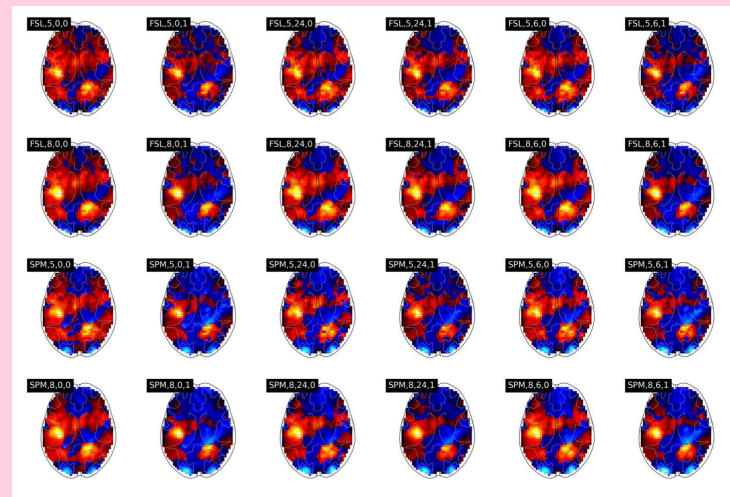
https://github.com/Inria-Empenn/narps_open_pipelines/

Open code and data to investigate analytical variability

NARPS open pipelines



HCP many pipeline



HCP many pipeline



Elodie Germani

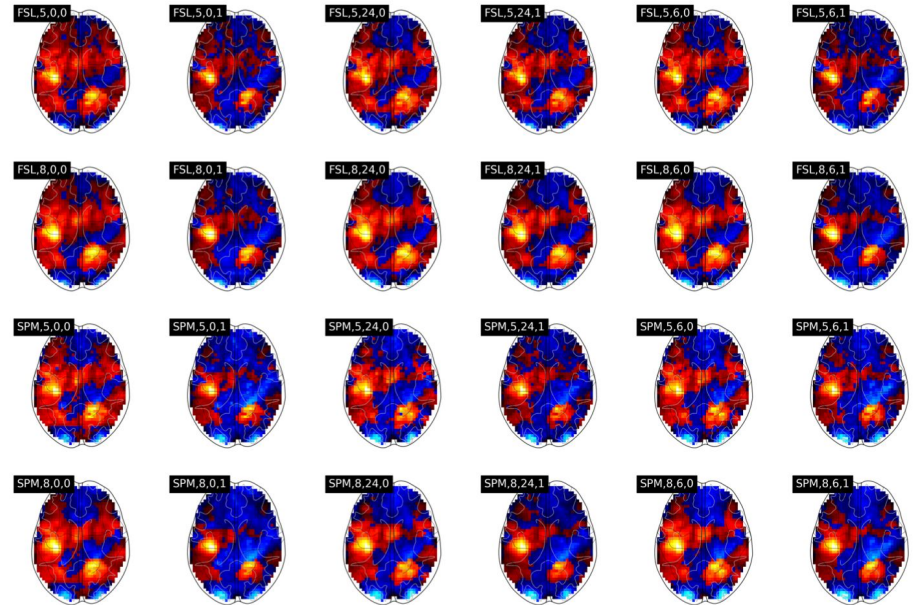


Pierre Maurel



Elisa Fromont

- **1 dataset**
 - HCP Young Adult
- **24 pipelines**
 - FSL, SPM / 2 HRF / 2 smoothing / 3 motion regressors
- **1080 participants and 1000 groups (50 subjects)**

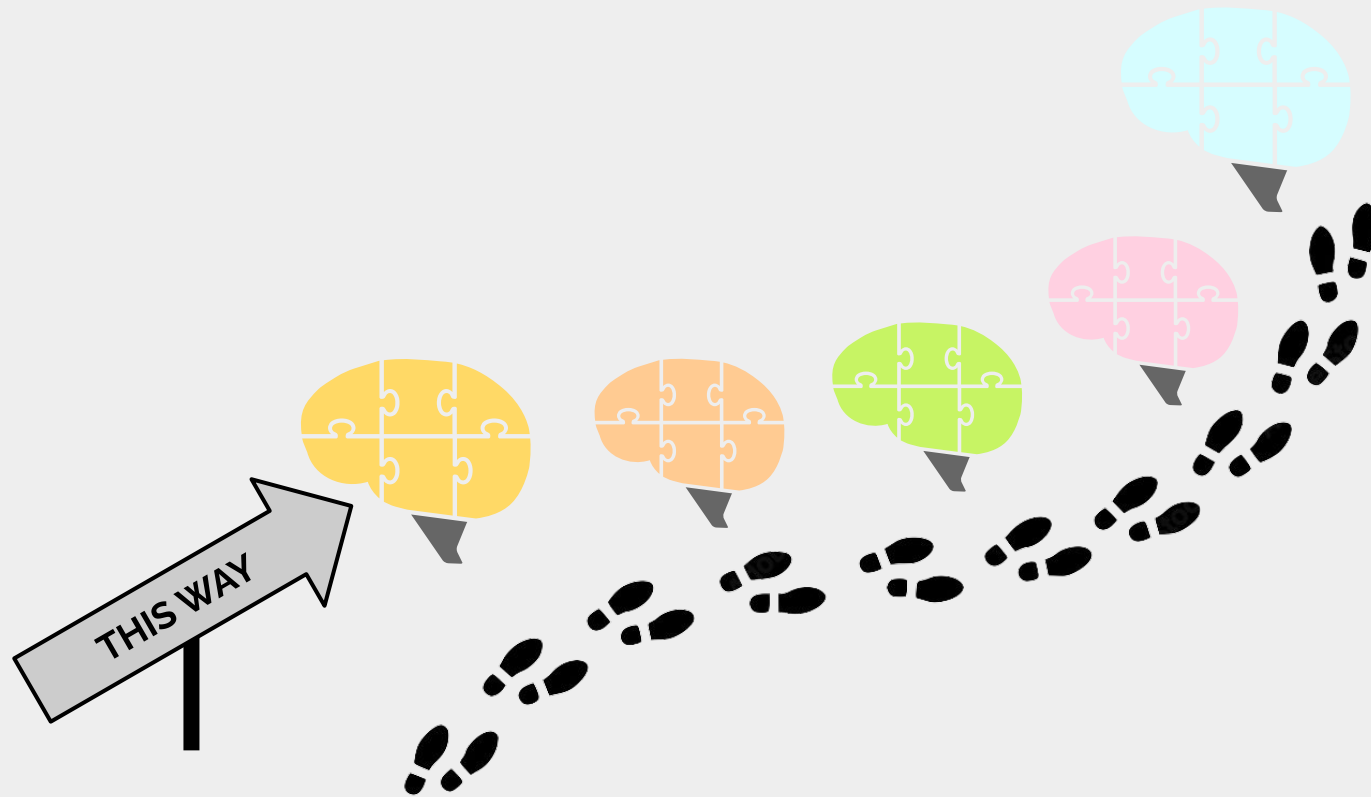


Shared data (in compliance with GDPR)



<https://publicneuro-catalogue.netlify.app>

[Germani et al, preprint [hal:inserm-04356768](https://hal.inserm-04356768)]



Which solutions **for**
practitioners ?

Same data meta-analysis

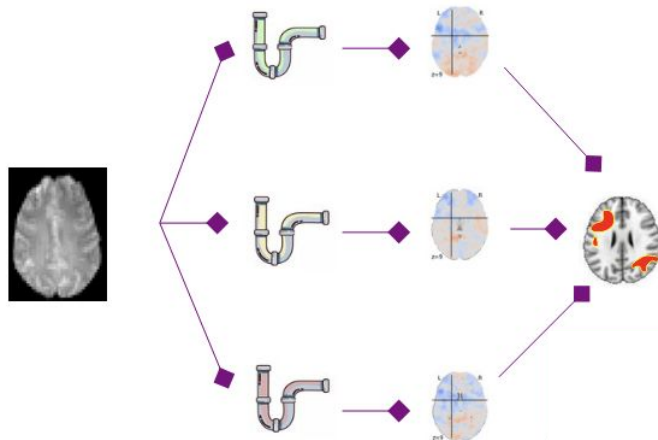


Jérémy
Lefort-Besnard



Tom Nichols
Oxford Uni. (UK)

Multiverse



[Lefort-Besnard Nichols* Maumet*, OHBM 2024]

Same data meta-analysis

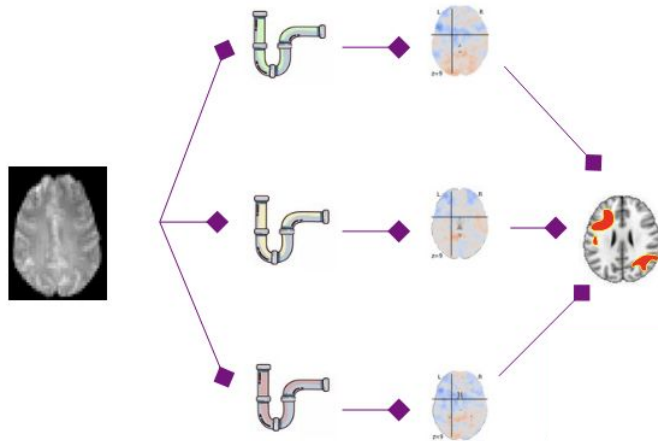


Jérémy
Lefort-Besnard

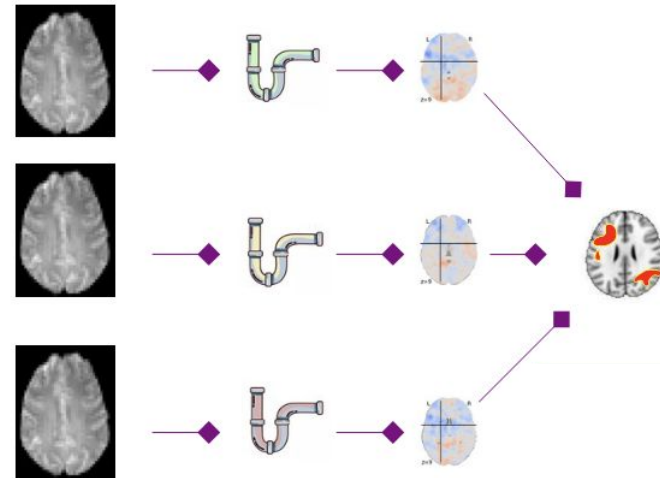


Tom Nichols
Oxford Uni. (UK)

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Traditional analysis setting



[Lefort-Besnard Nichols* Maumet*, OHBM 2024]

Same data meta-analysis

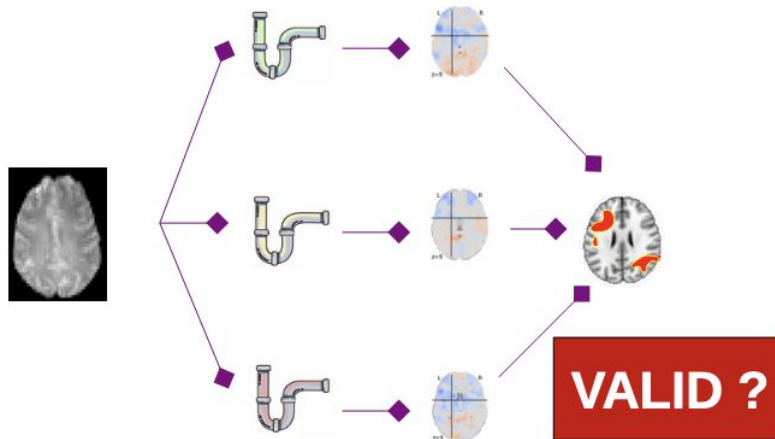


Jérémy
Lefort-Besnard

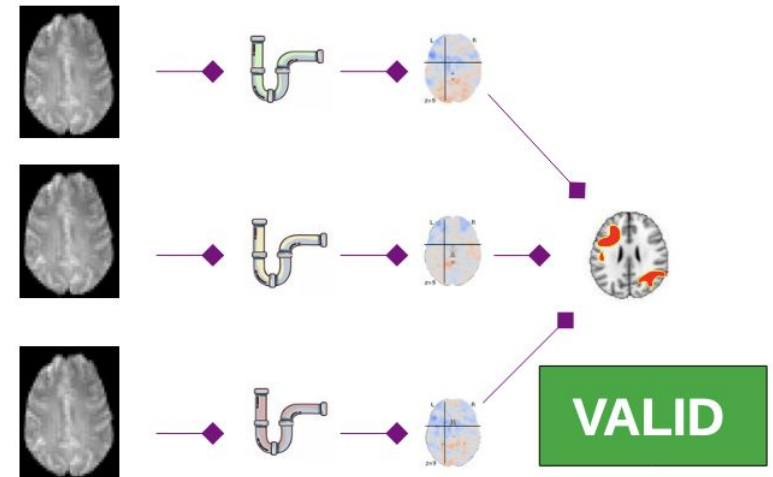


Tom Nichols
Oxford Uni. (UK)

Multiverse



Traditional analysis setting



Goal: Investigate the **validity** of **same-data meta-analysis** methods

[Lefort-Besnard Nichols* Maumet*, OHBM 2024]

Same data meta-analysis

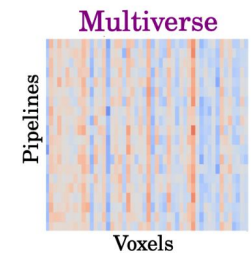
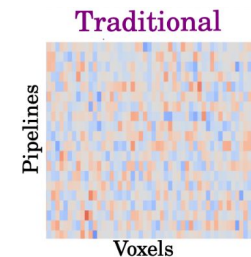


Jérémie Lefort-Besnard



Tom Nichols
Oxford Uni. (UK)

Meta-Analysis	Same-Data Meta-Analysis				
Stouffer $Z_j^S = \frac{\bar{Y}_j}{\sqrt{1/K}}$ <p>Average standardized</p>	SDMA Stouffer $Z_j^{SS} = \frac{\bar{Y}_j}{\sqrt{\mathbf{1}_k^T \mathbf{Q} \mathbf{1}_k / K^2}}$ <p>Average standardized accounting for dependence</p>	Consensus SDMA Stouffer $Z_j^{CSS} = Z_j^{SS} - \langle Z^{SS} \rangle + \mu_C$ <p>Average standardized accounting for dependence, and shifted empirically</p>	Consensus Average $Z_j^{CA} = \frac{\bar{Y}_j - \langle \bar{Y} \rangle}{\sqrt{\langle \bar{Y} \rangle}} \sigma_C + \mu_C$ <p>Average, scaled and shifted empirically</p>	SDMA GLS $Z_j^{SG} = \frac{\mathbf{1}^T \mathbf{Q}^{-1} \mathbf{Y}_j}{\sqrt{\mathbf{1}^T \mathbf{Q}^{-1} \mathbf{1}}}$ <p>Optimal average, standardized</p>	
Valid 4.7%	Valid 4.7%	Valid 4.8%	Valid 4.8%	Valid 4.4%	
Invalid 30%	Valid 4.9%	Valid 5.0%	Valid 5.0%	Valid 4.9%	



P<0.05 (uncorrected)

[Lefort-Besnard Nichols* Maumet*, OHBM 2024]

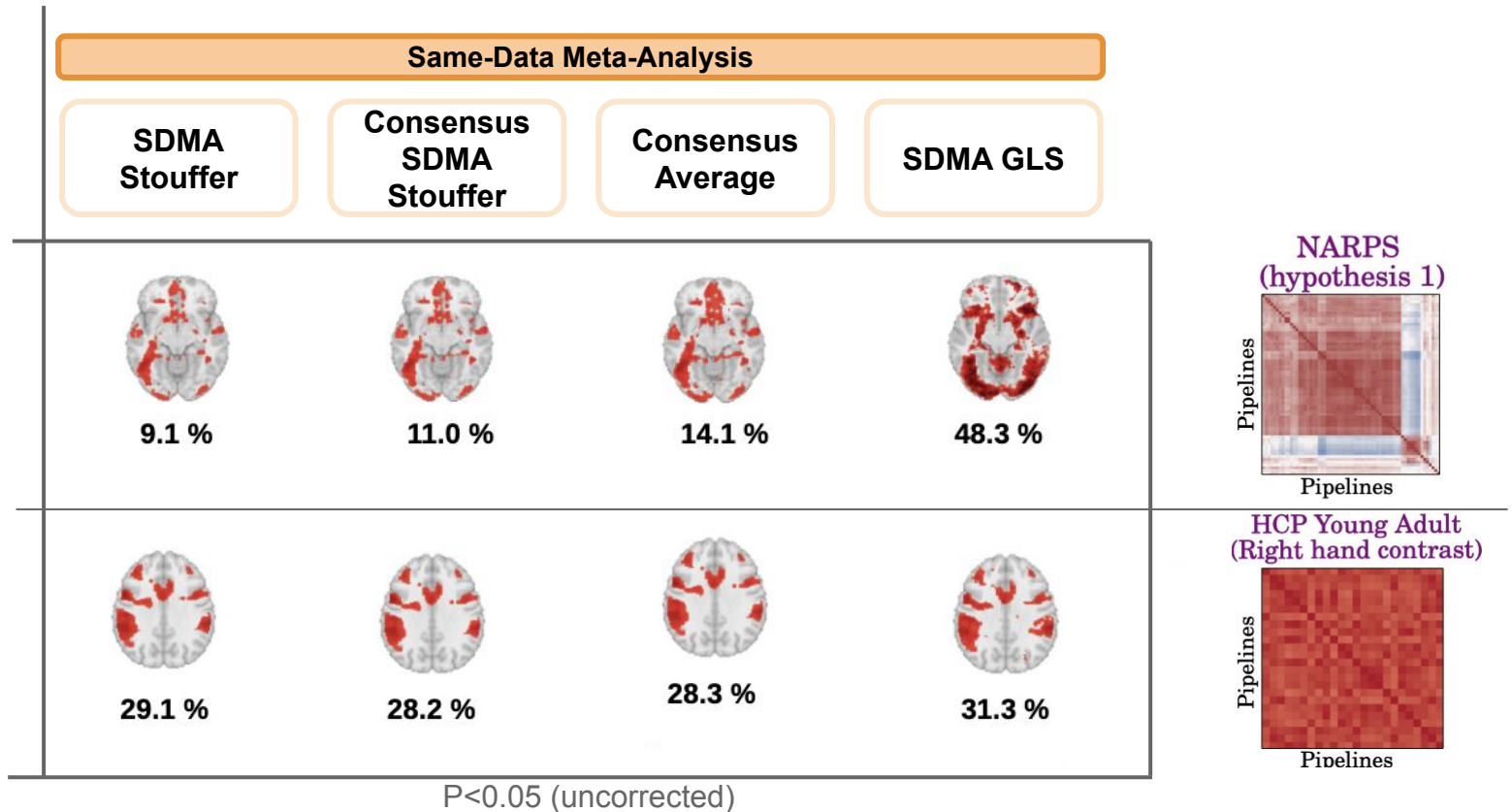
Same data meta-analysis



Jérémie
Lefort-Besnard

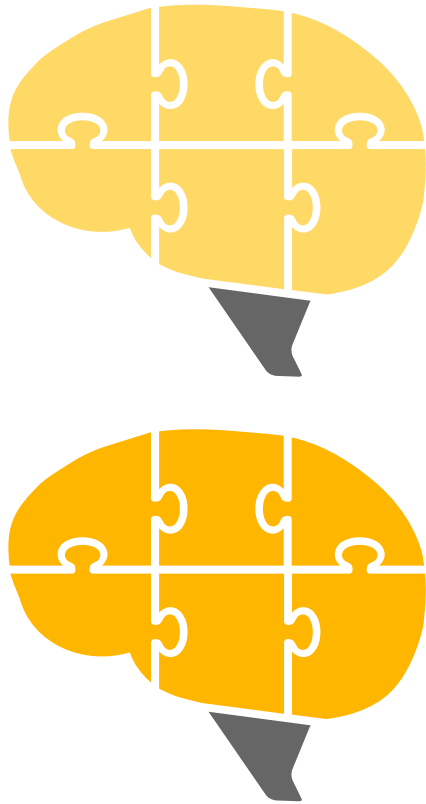


Tom Nichols
Oxford Uni. (UK)



[Lefort-Besnard Nichols* Maumet*, OHBM 2024]

Seminar at INT
October 14, 2024



Towards reproducible neuroimaging across different analysis pipelines

Camille Maumet

Thank you!

Credit: Presentation template and icons by
[SlidesCarnival](#), adapted



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