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Towards reproducible neuroimaging - across different analysis pipelines

Camille Maumet

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Submitted on 27 Feb 2024

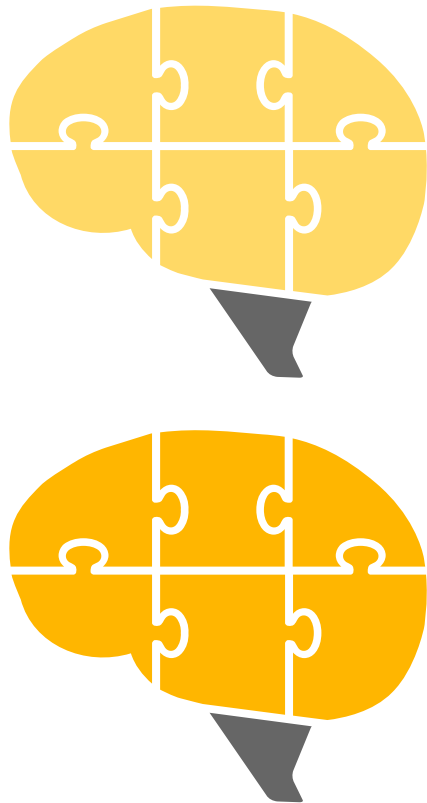
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Feb 20, 2024



Towards reproducible neuroimaging

across different analysis pipelines

McGill Seminar Series in Quantitative Life
Sciences and Medicine

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

**Wasted money
& effort** for
research



**Delayed
translation** into
clinical practice



Reduced trust
in science

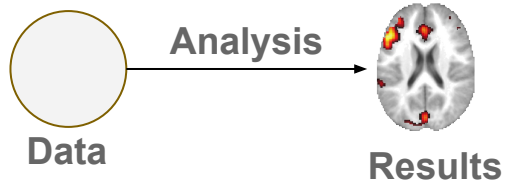


Reproducible research



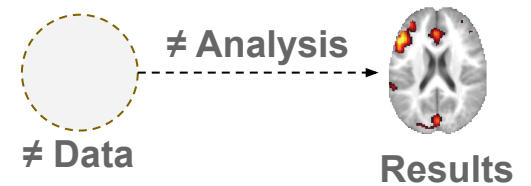
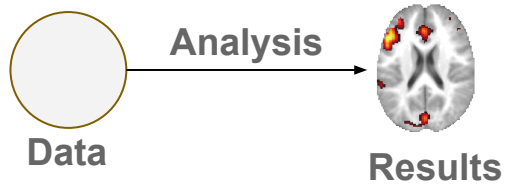
Reproducible research

Original study



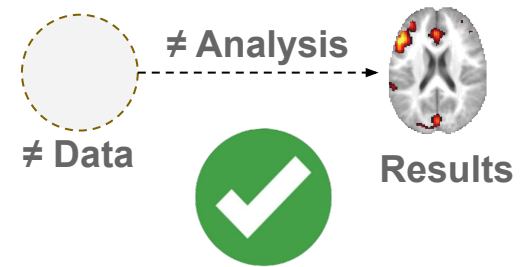
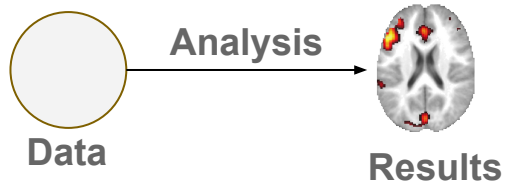
Reproducible research

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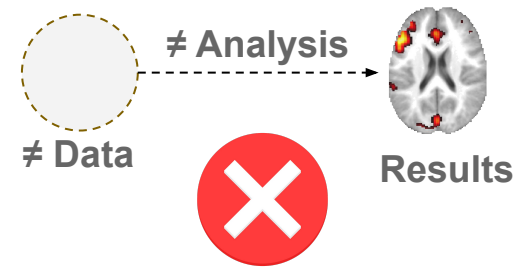
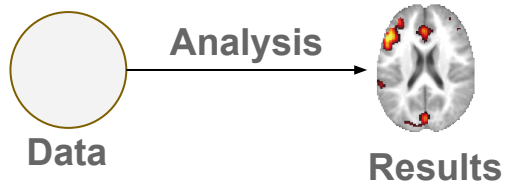
Reproducible research

Original study

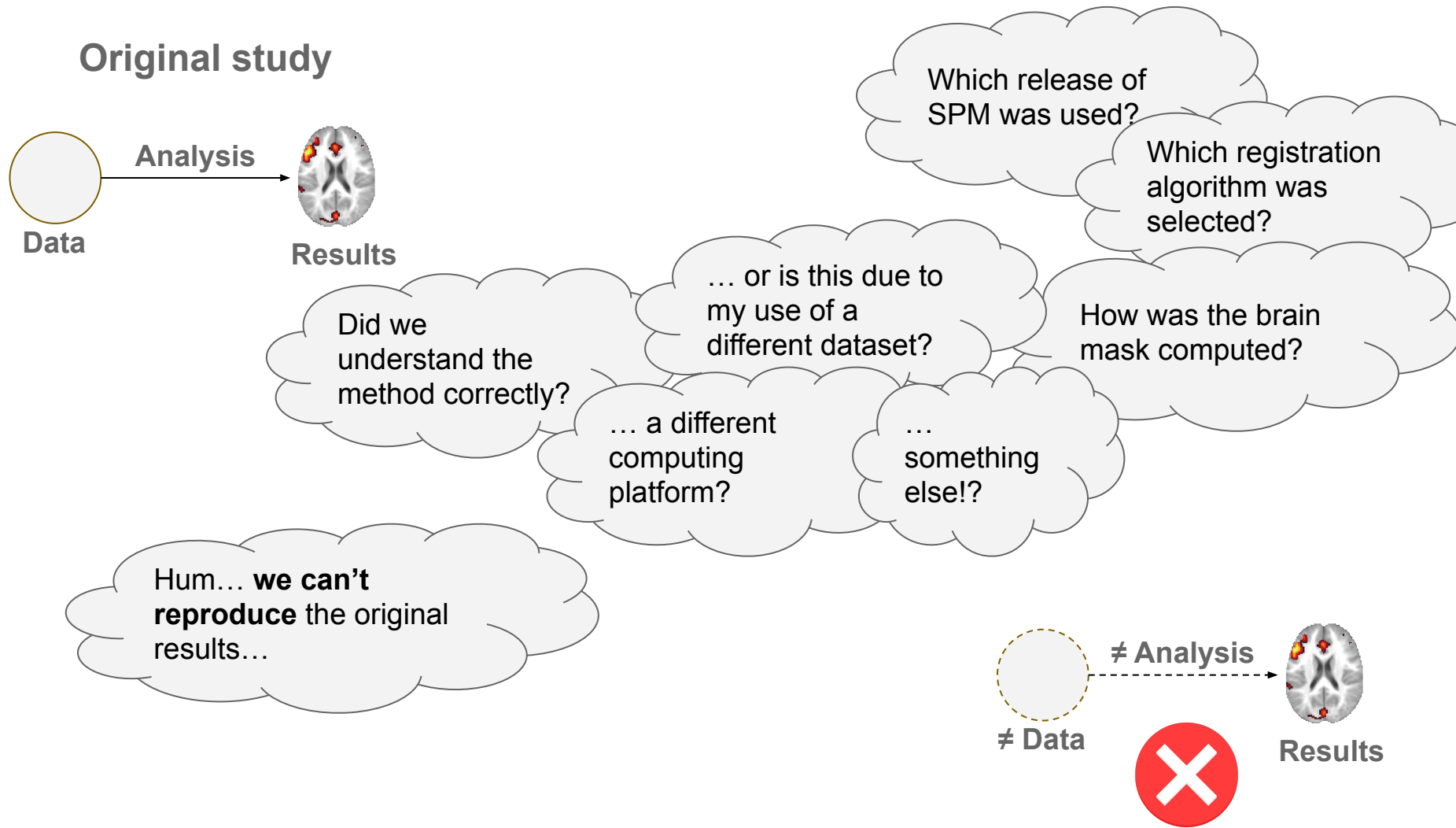


Reproducible research

Original study

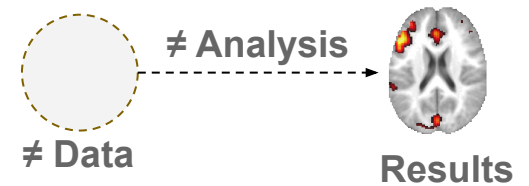
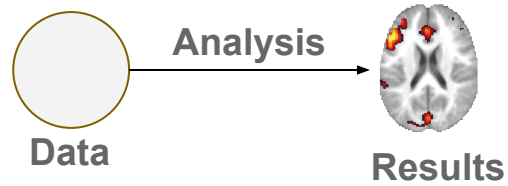
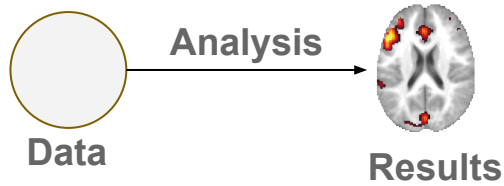


Reproducible research



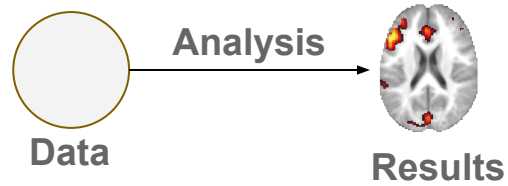
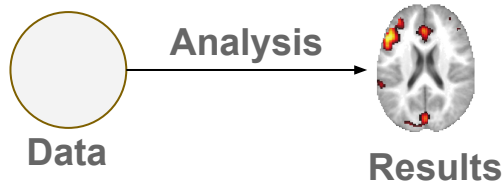
Reproducible research

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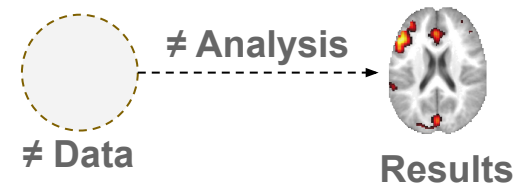


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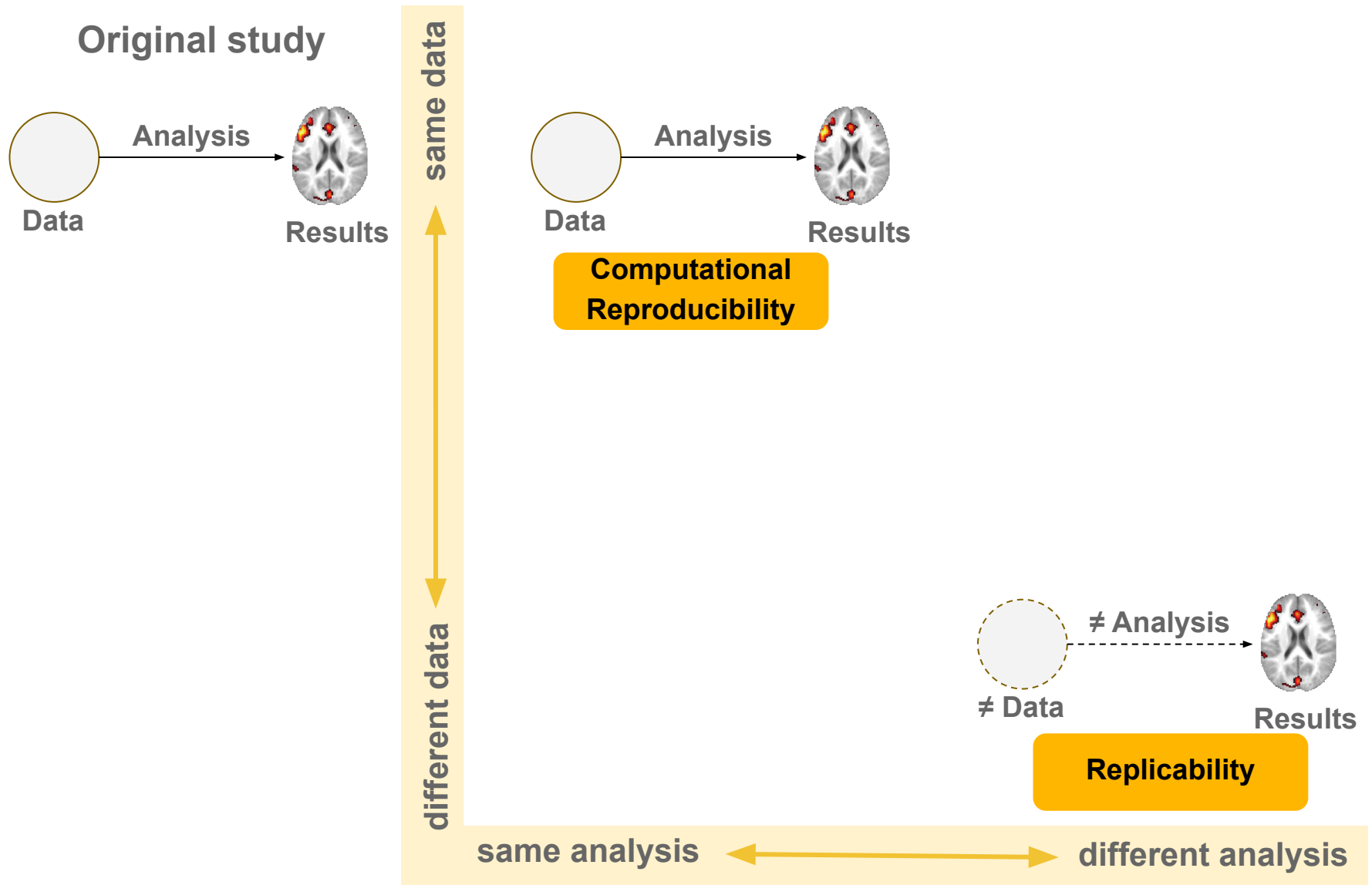


**Computational
Reproducibility**

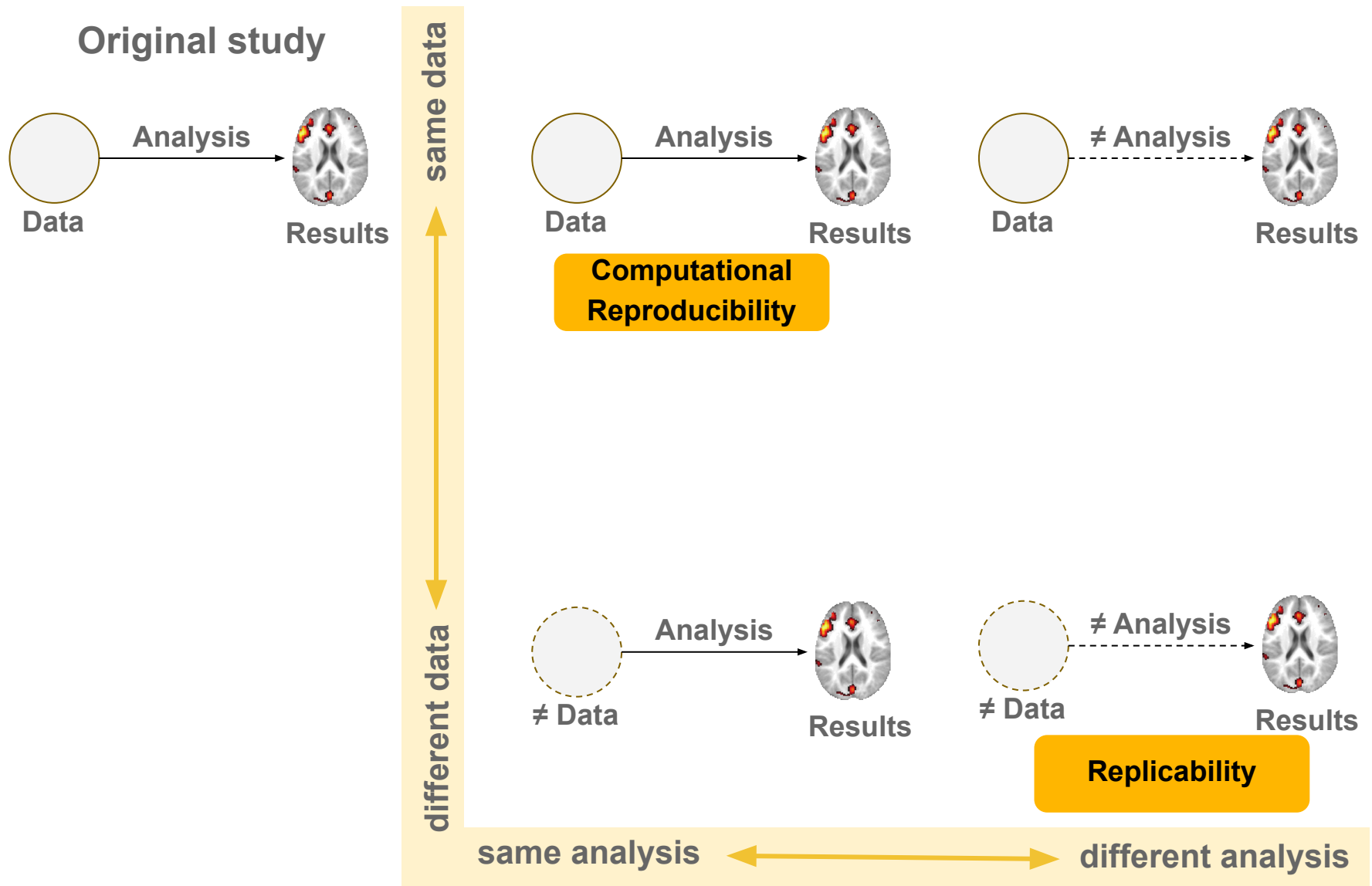


Replicability

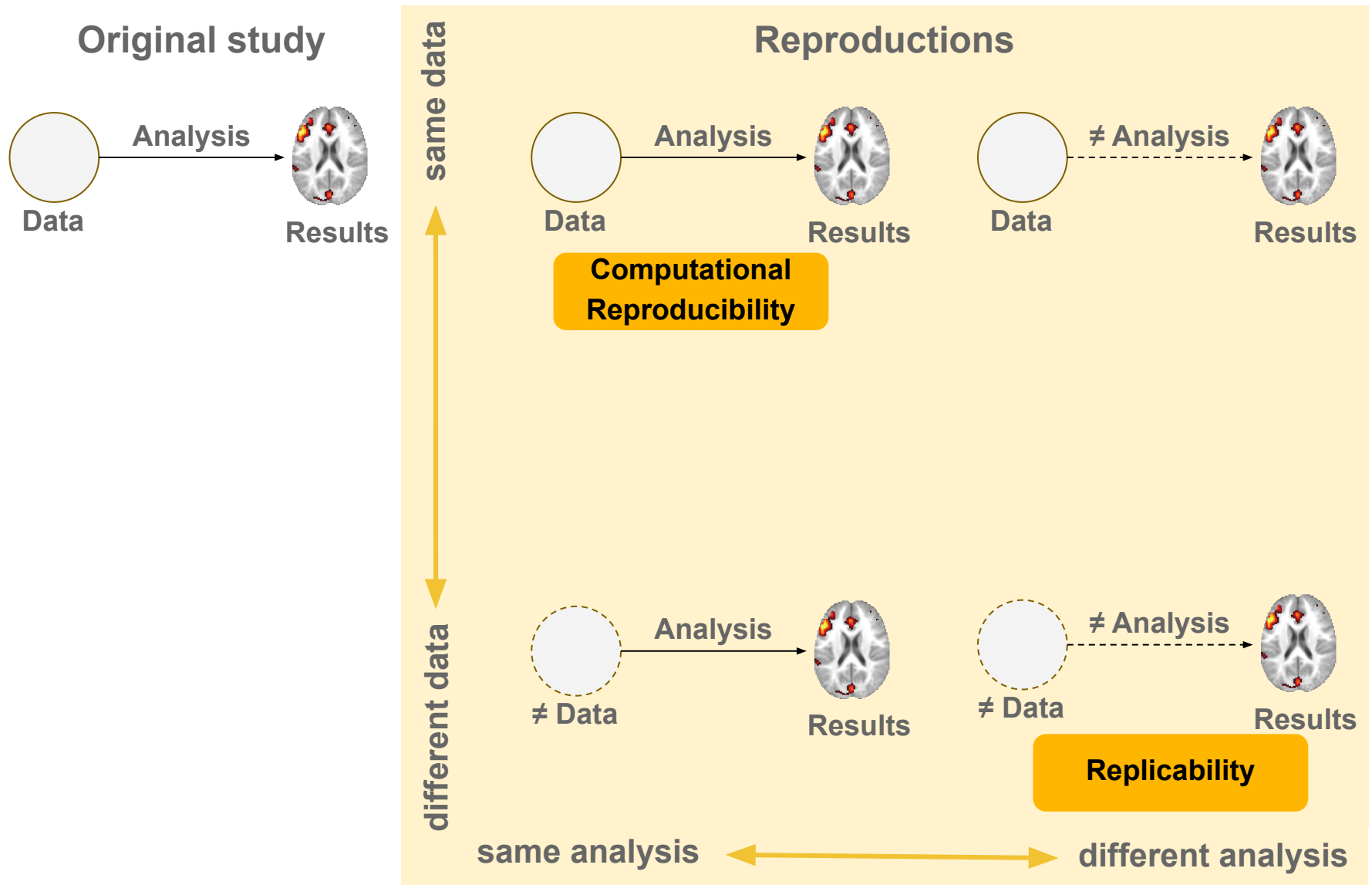
Reproducible research

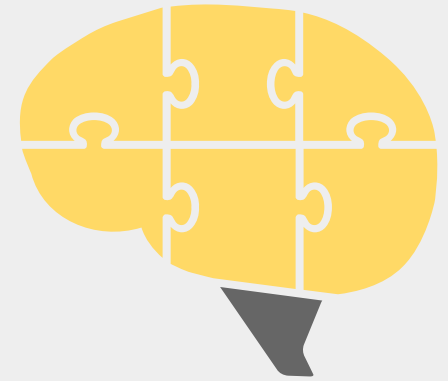
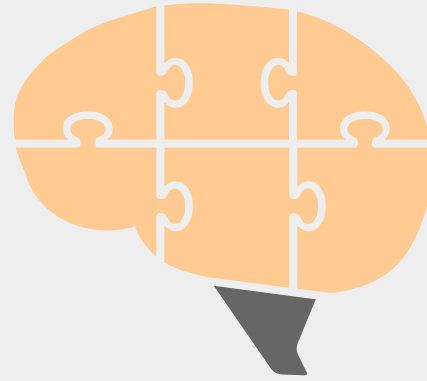


Reproducible research



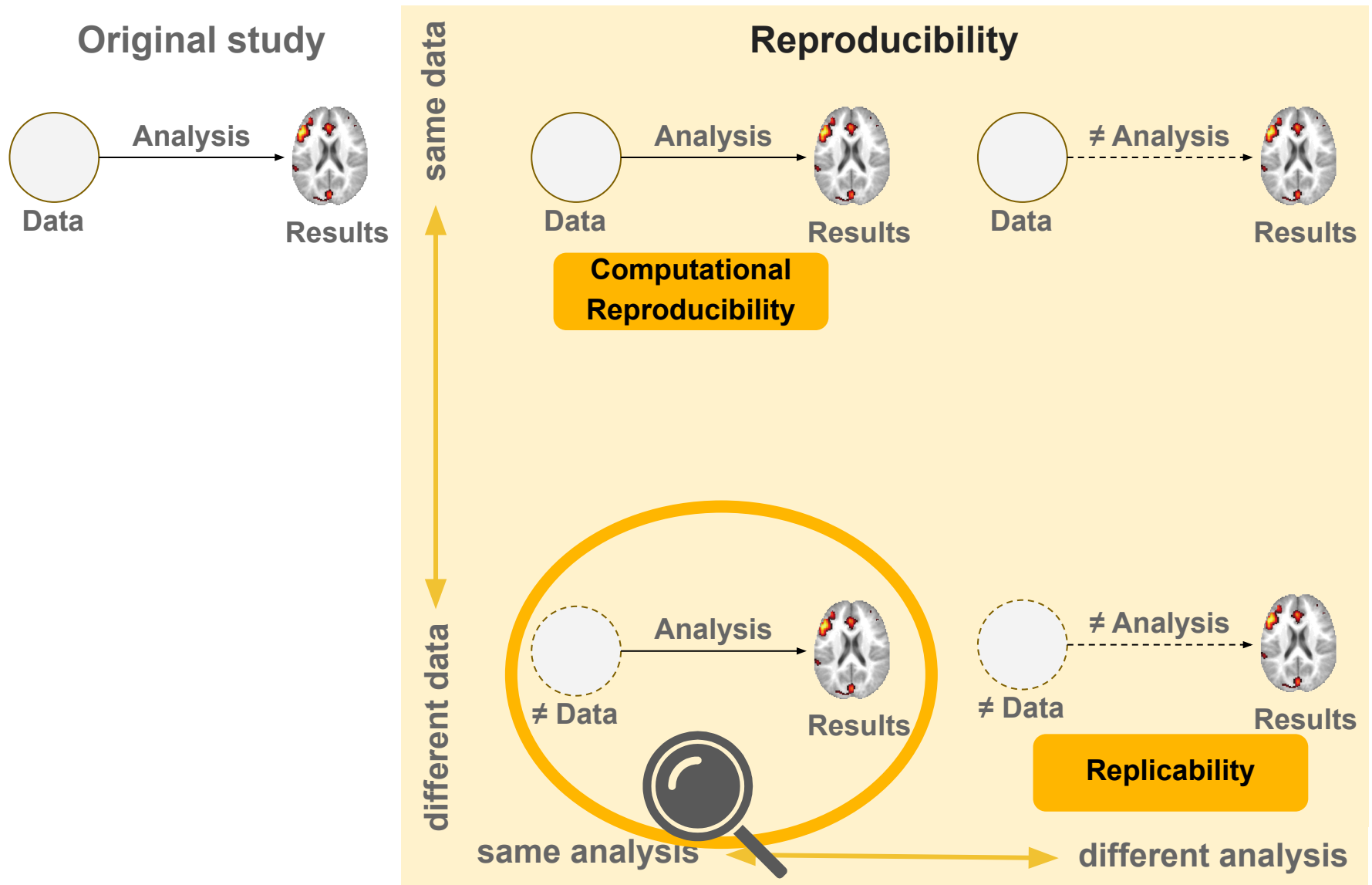
Reproducible research





On our way to fix
irreproducibility...

Reproducible research

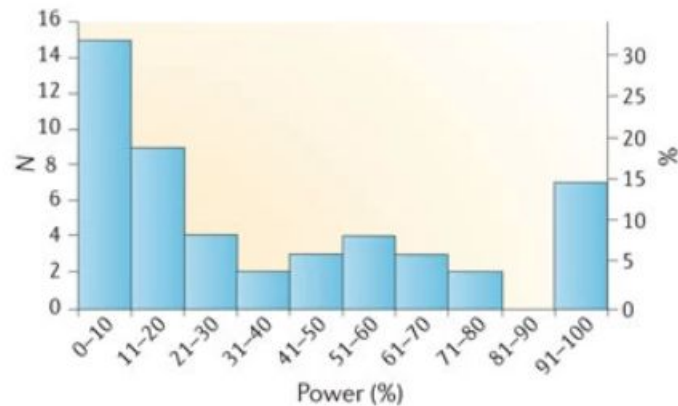


Fixing irreproducibility with different data

Small samples

Low statistical power

Power of neuroscience studies



(Button et. al, 2013)

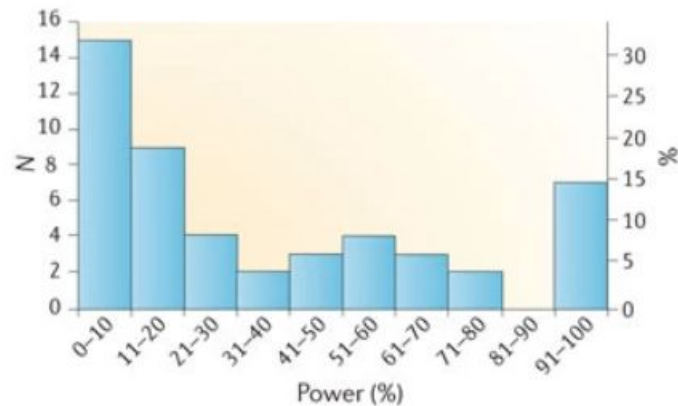
High rate of **false positives**
in the literature

Fixing irreproducibility with different data

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High rate of **false positives**
in the literature

Lack of representativity and diversity of the samples

X-ray: Lung opacity detection

Model trained on male images, tested on female images



(Larrazabal et. al, 2020)

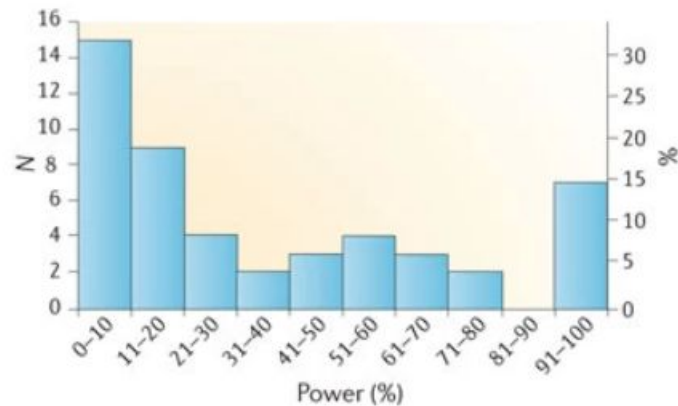
Lack of **generalisability**
and **fairness**

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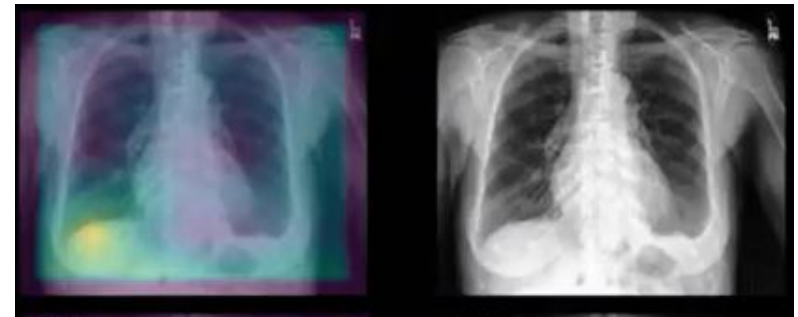


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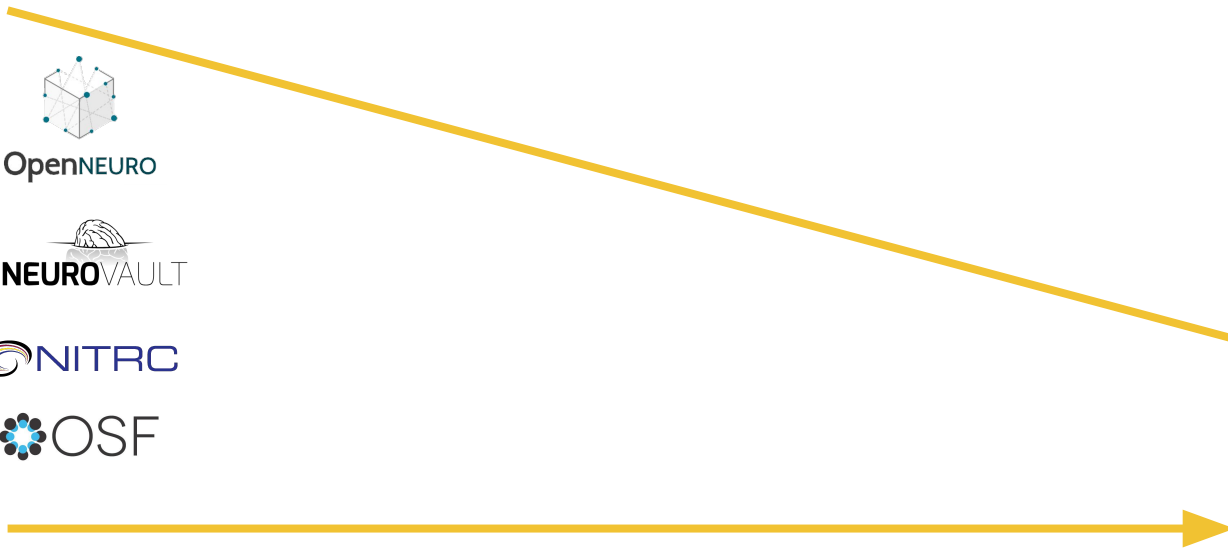
Lack of **generalisability**
and **fairness**

**Solution: Data
Sharing**

Neuroimaging data sharing

Single study

30 sub.



OpenNEURO



NEUROVAULT



OSF

Neuroimaging data sharing

Single study

30 sub.



OpenNEURO



NEUROVAULT

NITRC

OSF

Consortium

1000 sub.



ABIDE
Autism Brain Imaging
Data Exchange



CORR
CONSORTIUM FOR
RELIABILITY AND
REPRODUCIBILITY



1000 Functional
Connectomes Project

Neuroimaging data sharing

Single study

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OpenNEURO



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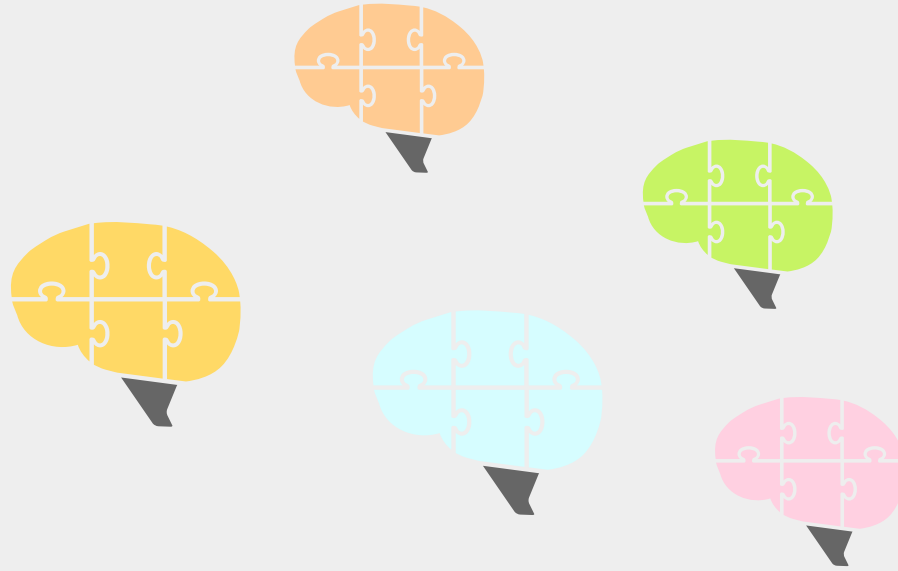


HUMAN
Connectome
PROJECT

Cohort

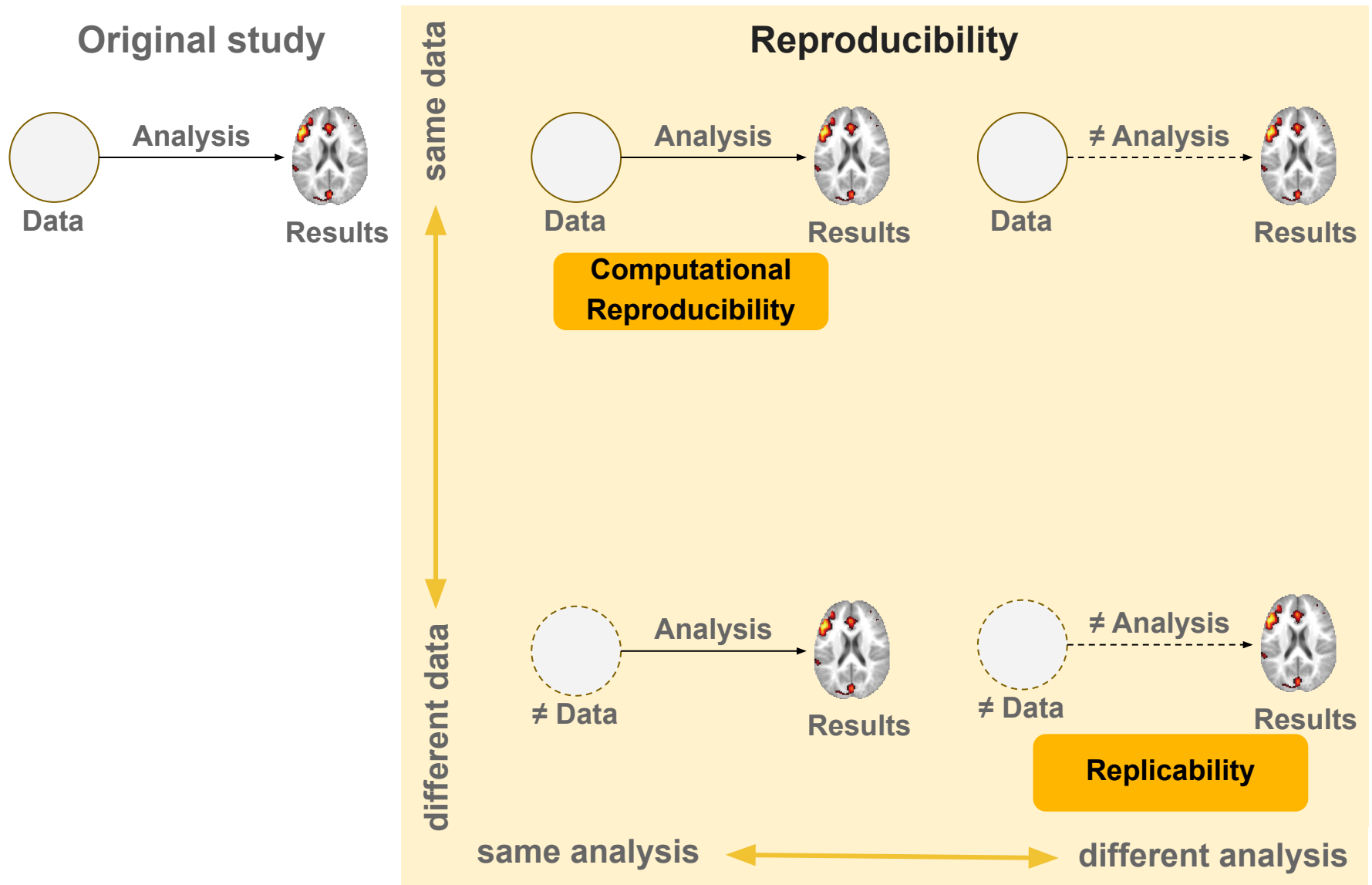
100 000 sub.

biobank
improving the health of future generations

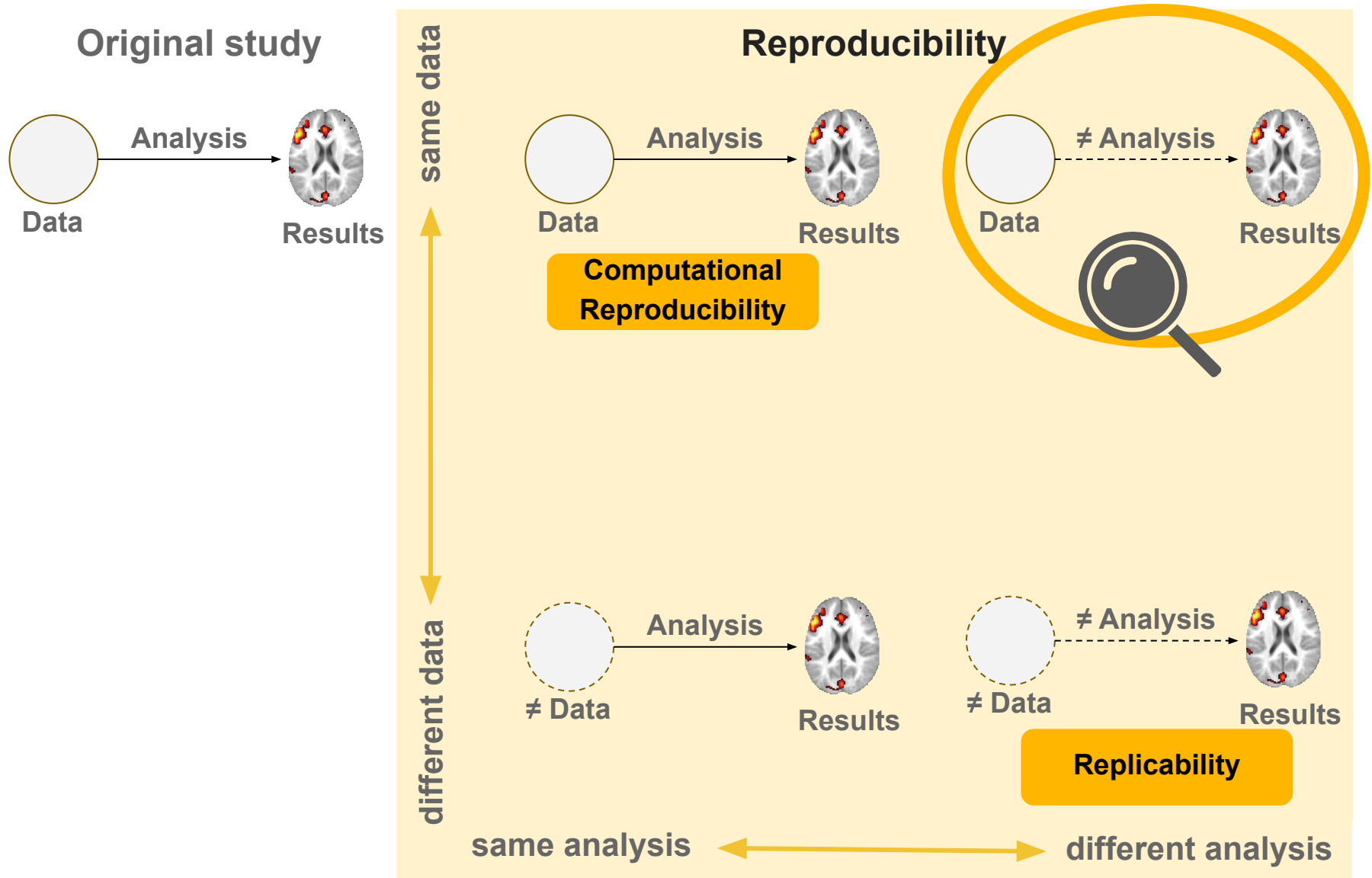


Different pipelines...
different results?

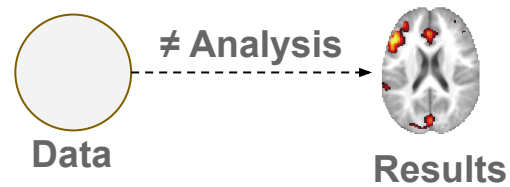
Reproducible research



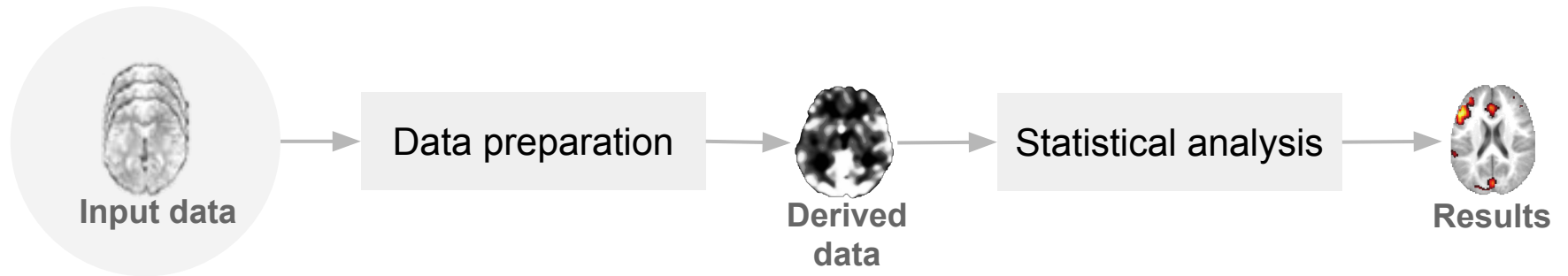
Reproducible research



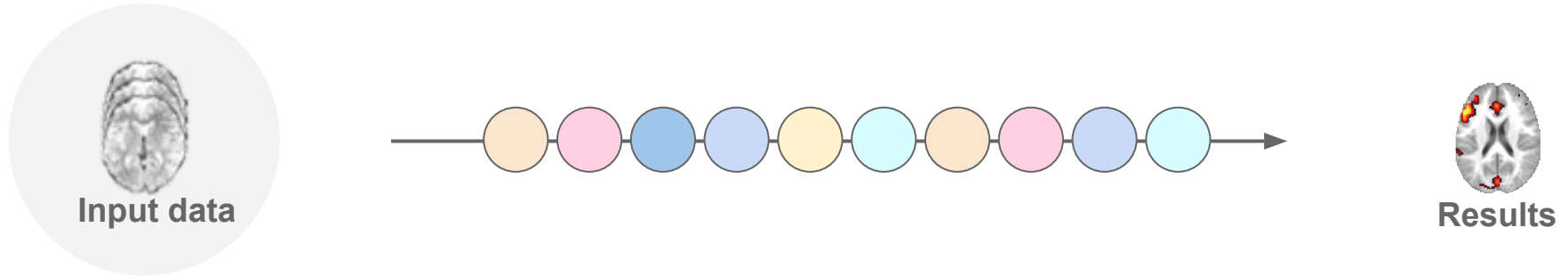
A multiplicity of analysis pipelines



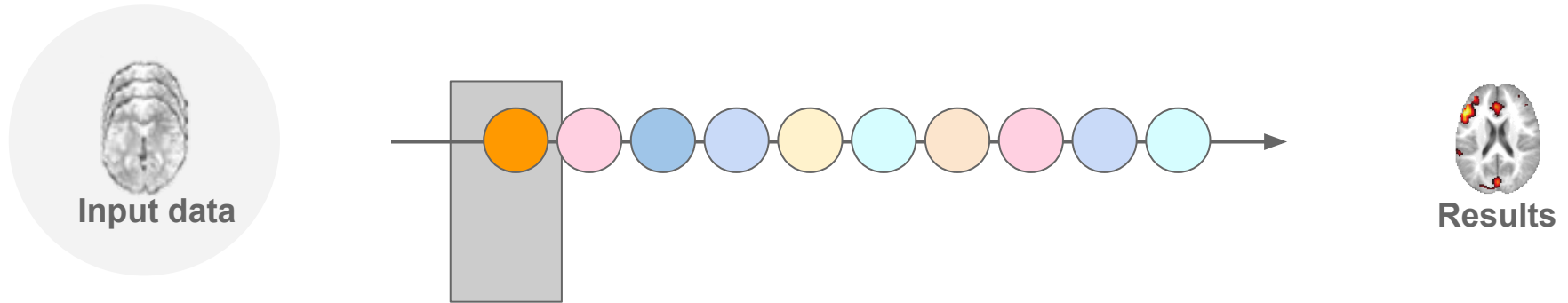
A multiplicity of analysis pipelines



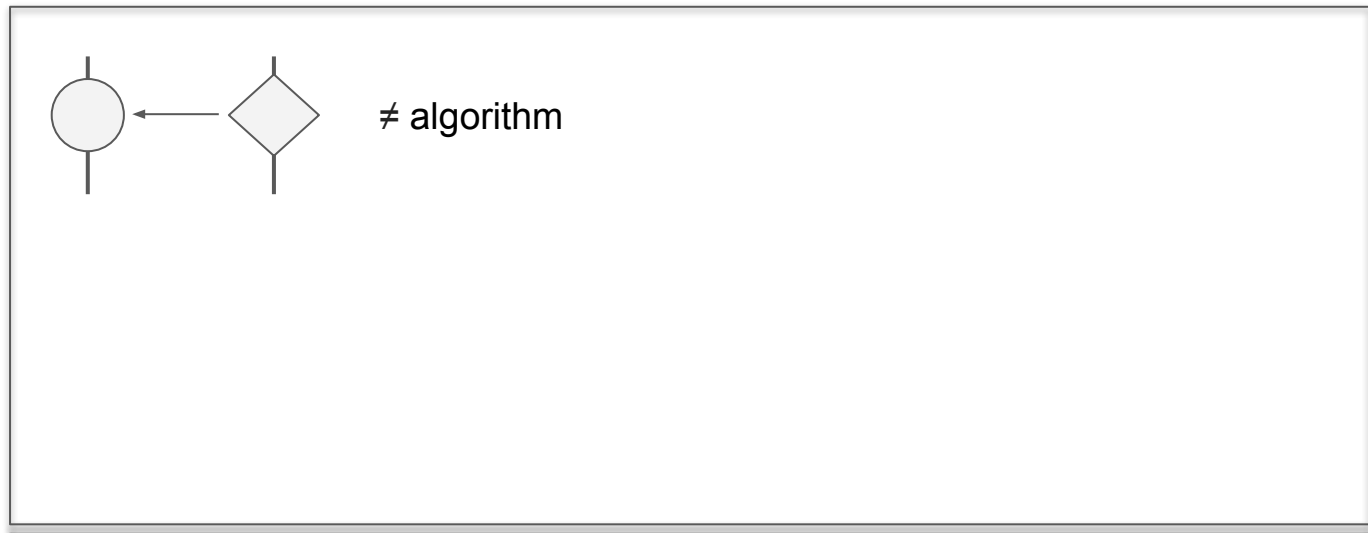
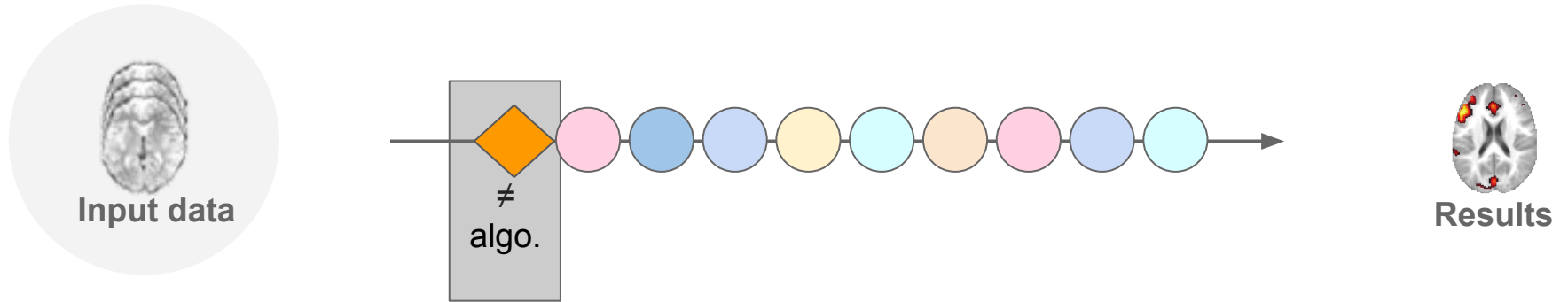
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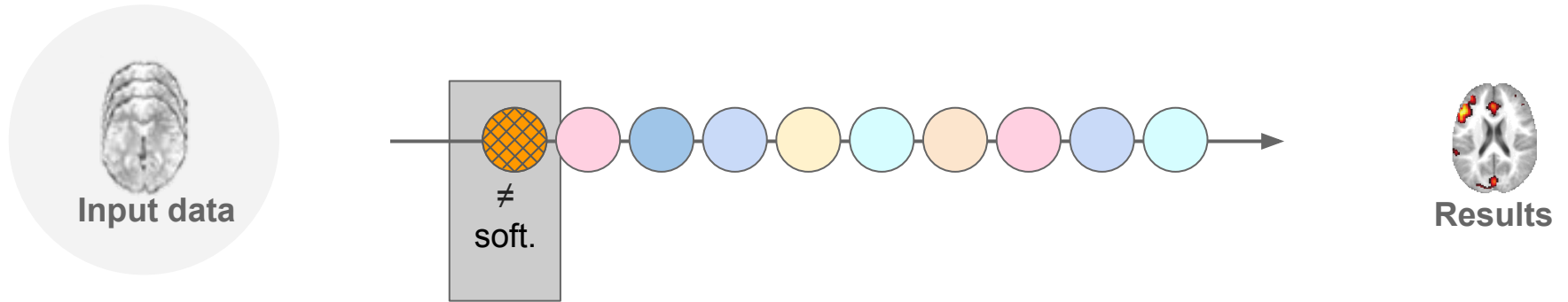
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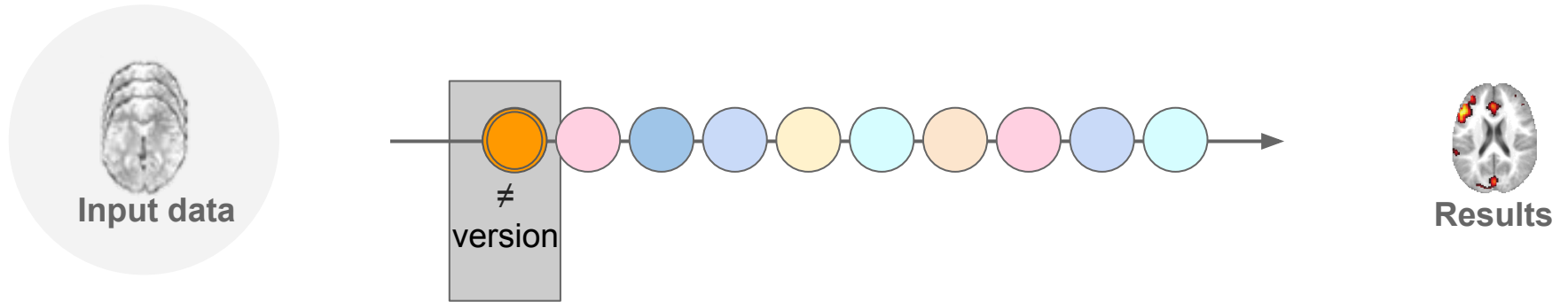
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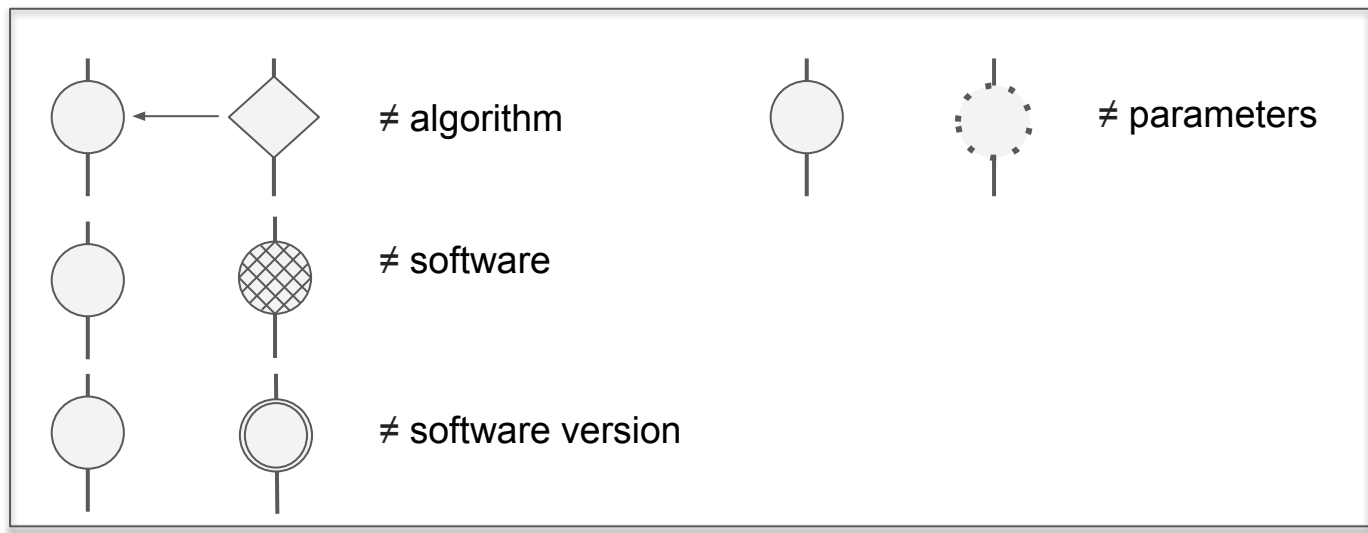
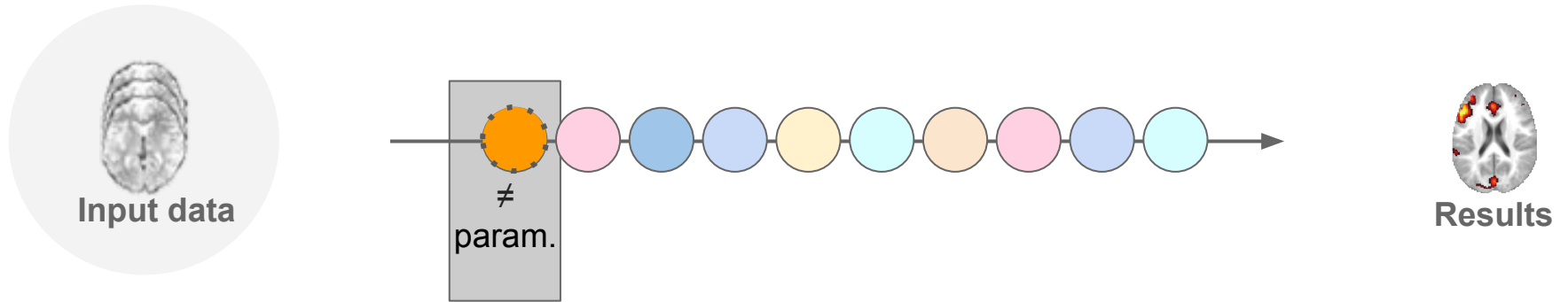
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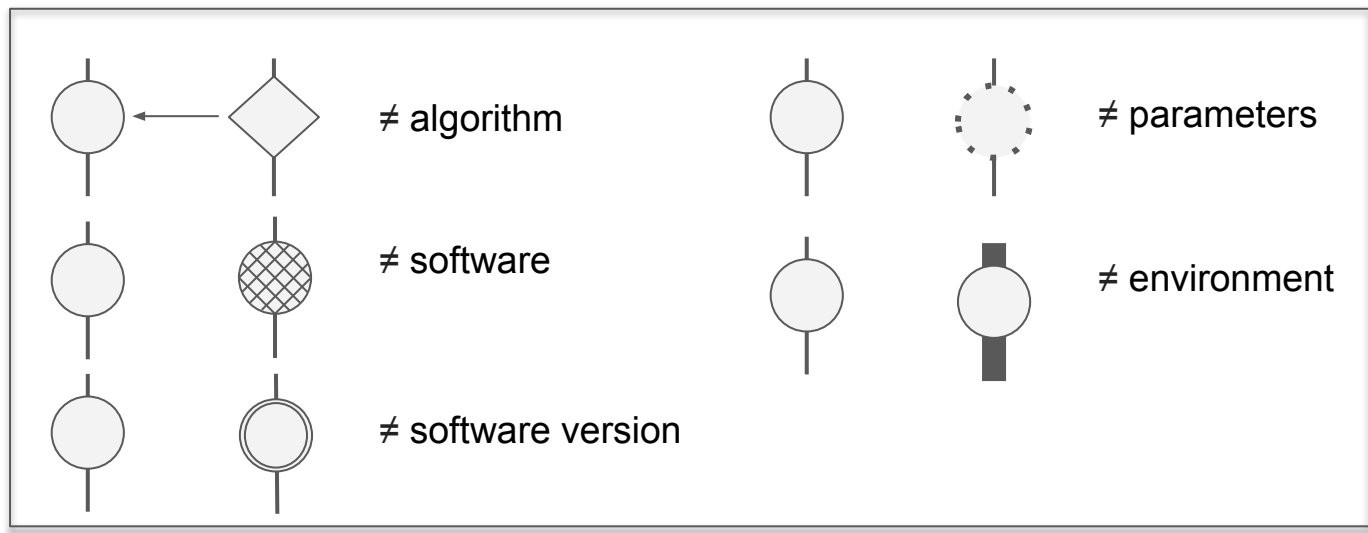
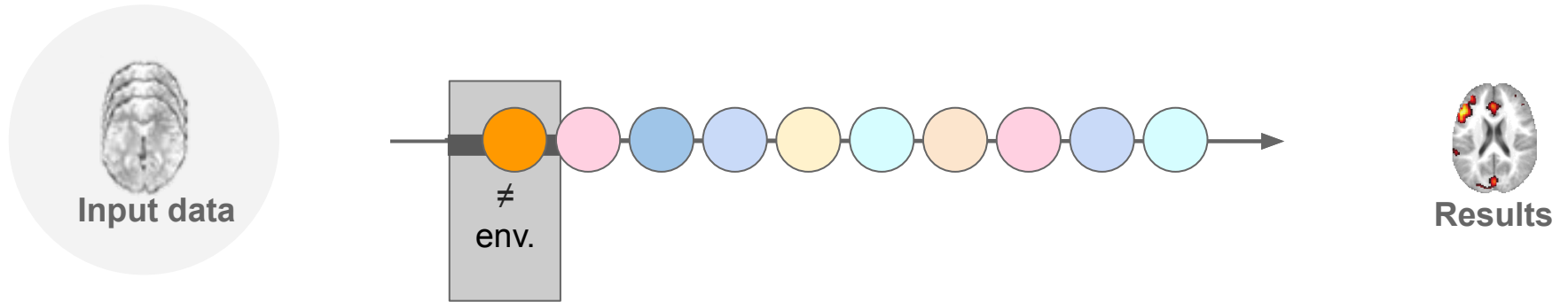
A multiplicity of analysis pipelines



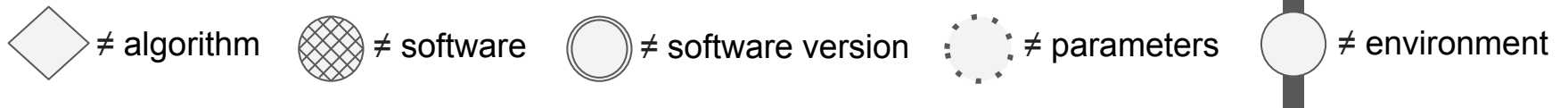
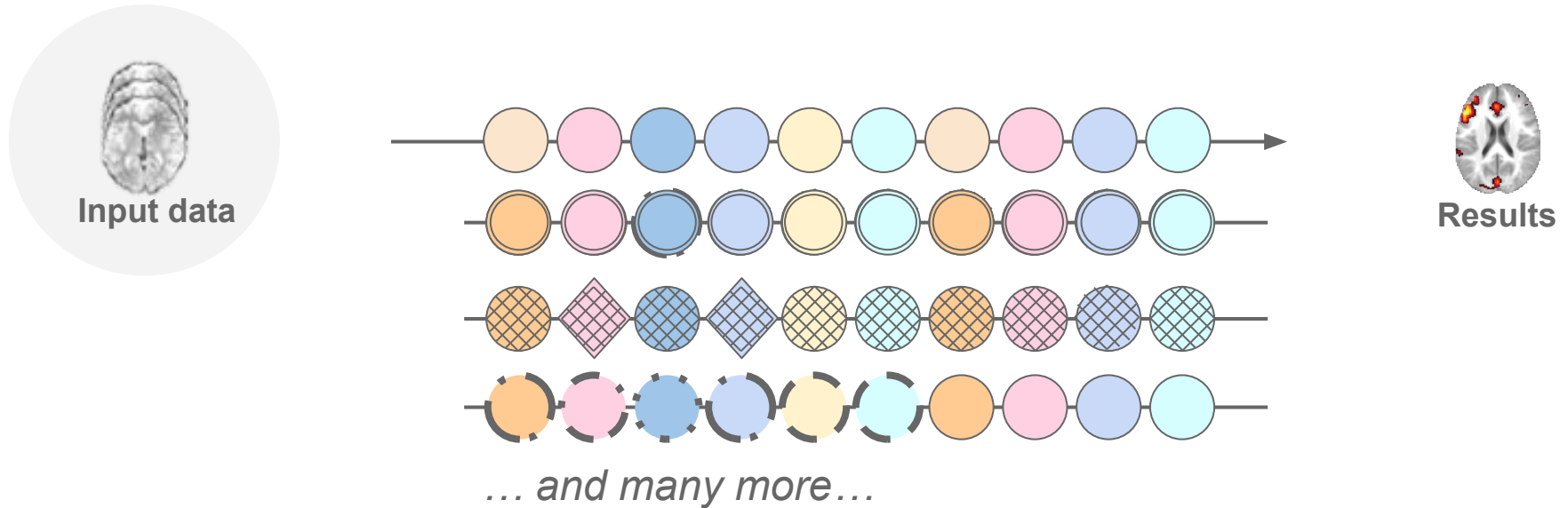
A multiplicity of analysis pipelines



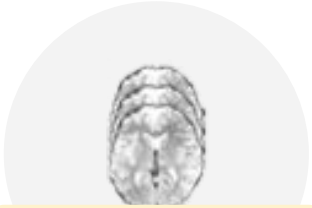
A multiplicity of analysis pipelines



A multiplicity of analysis pipelines



Many-analyst project : NARPS

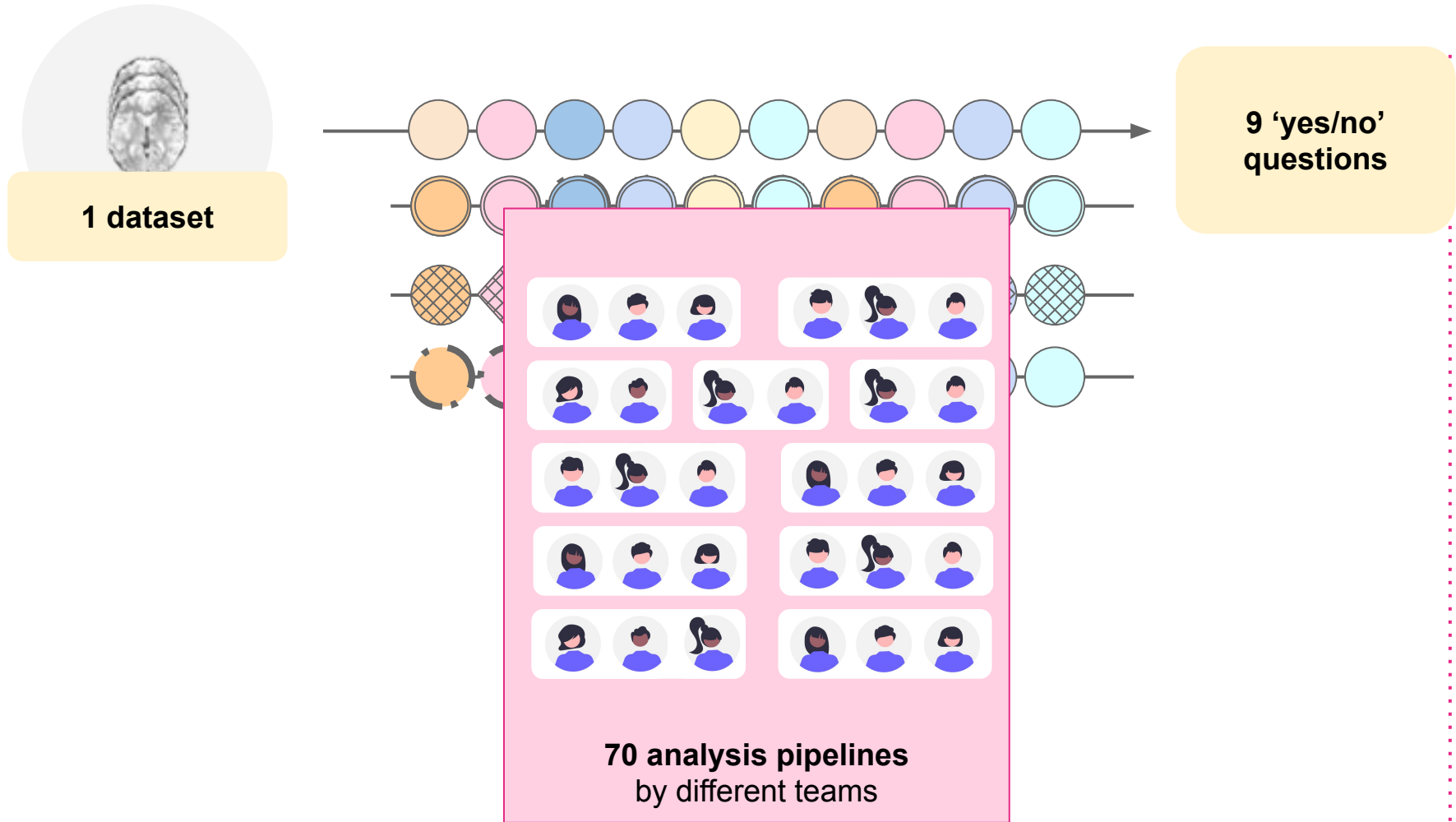


1 dataset

**9 'yes/no'
questions**

[Botvinik-Nezer et. al, Nature 2020]

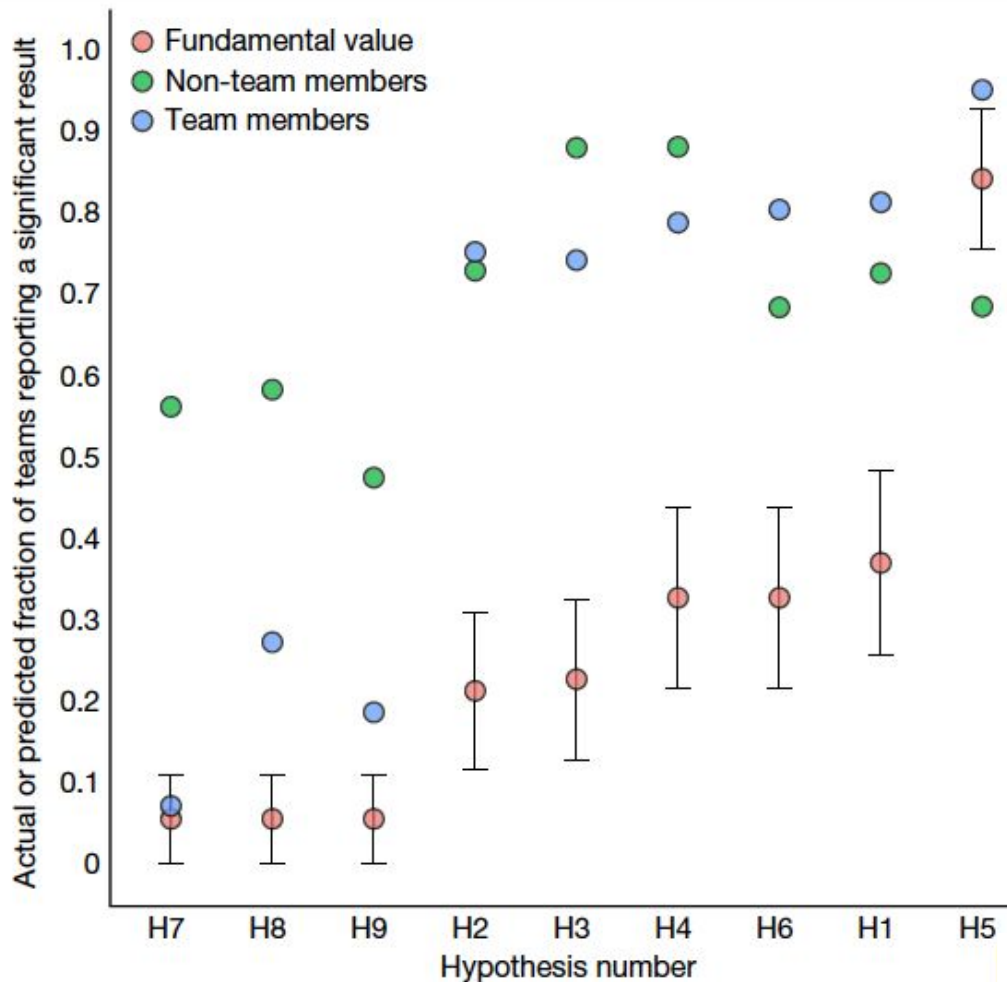
Many-analyst project : NARPS



[Botvinik-Nezer et. al, Nature 2020]

Many-analyst project : NARPS

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

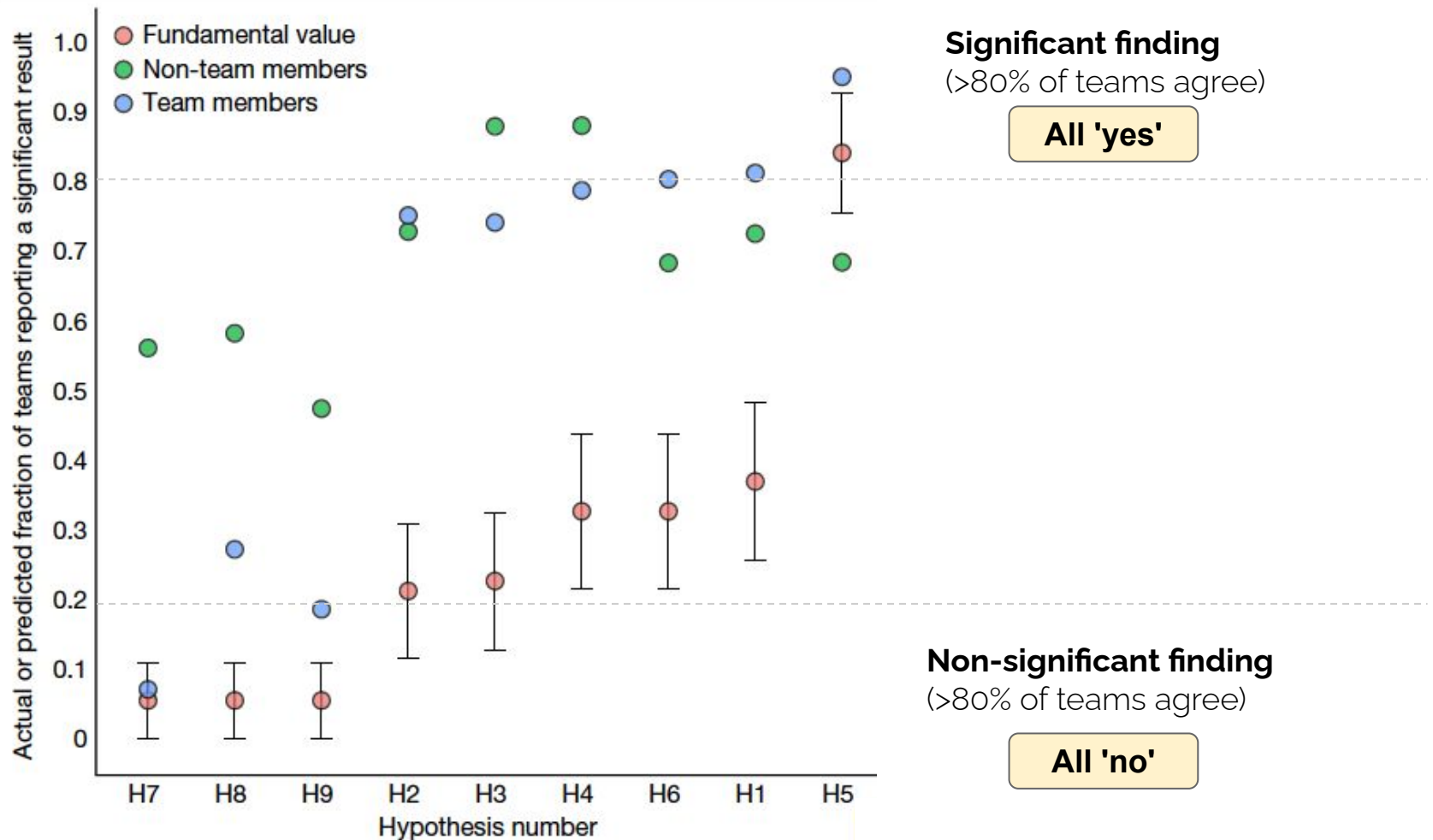


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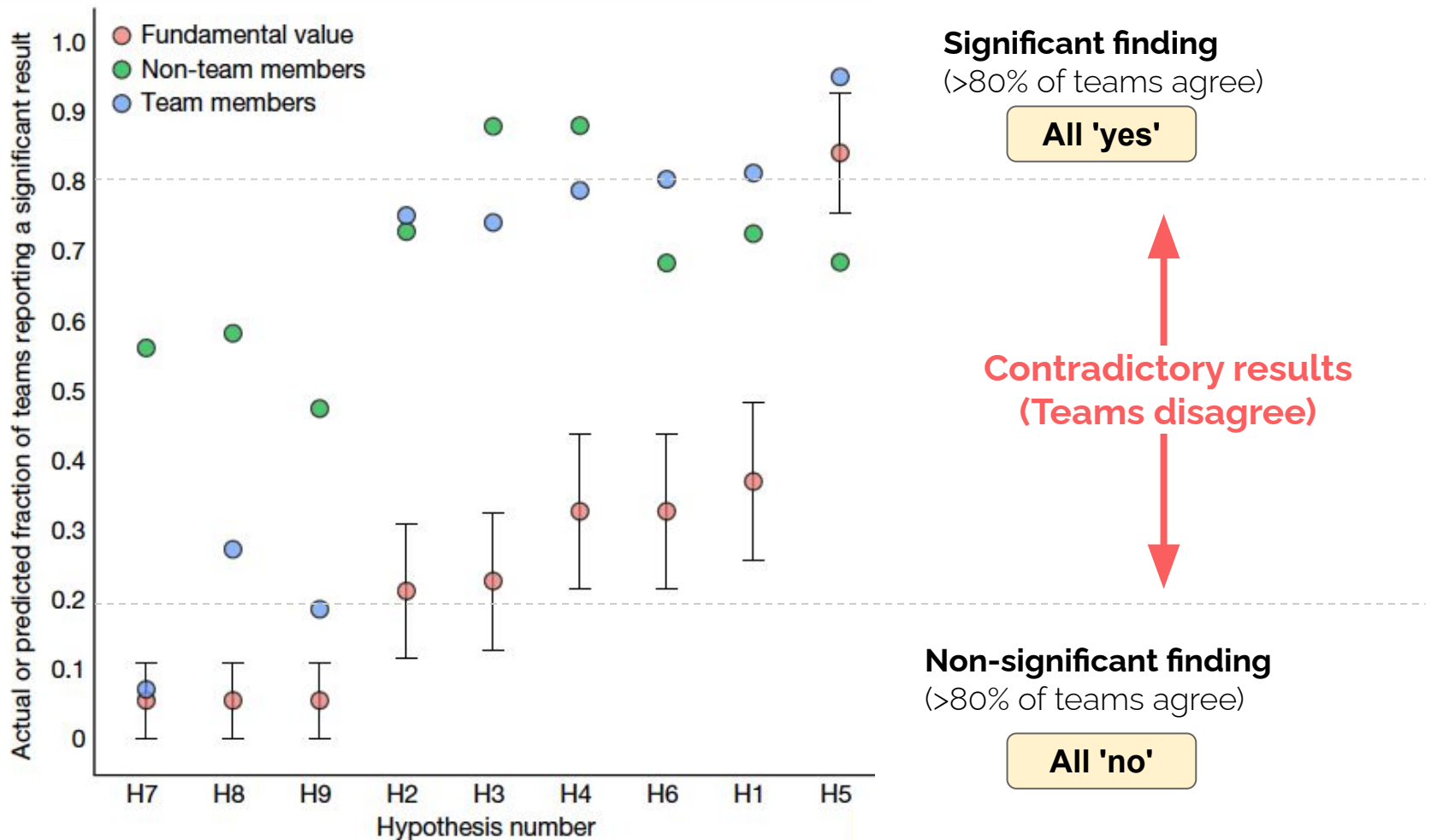


9 'yes/no' questions

[Botvinik-Nezer et. al, Nature 2020]

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



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[Botvinik-Nezer et. al, Nature 2020]

Variability across neuroimaging software

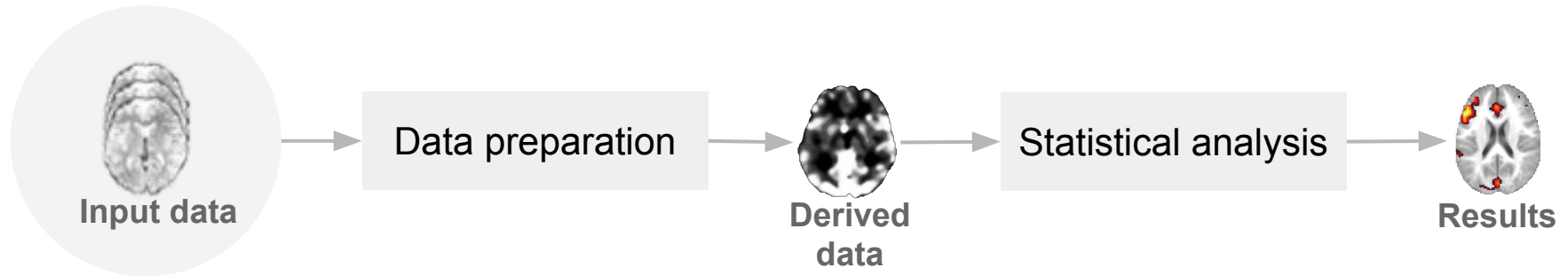


Alex Bowring



Tom Nichols
Oxford Uni. (UK)

Principles of functional MRI



Variability across neuroimaging software



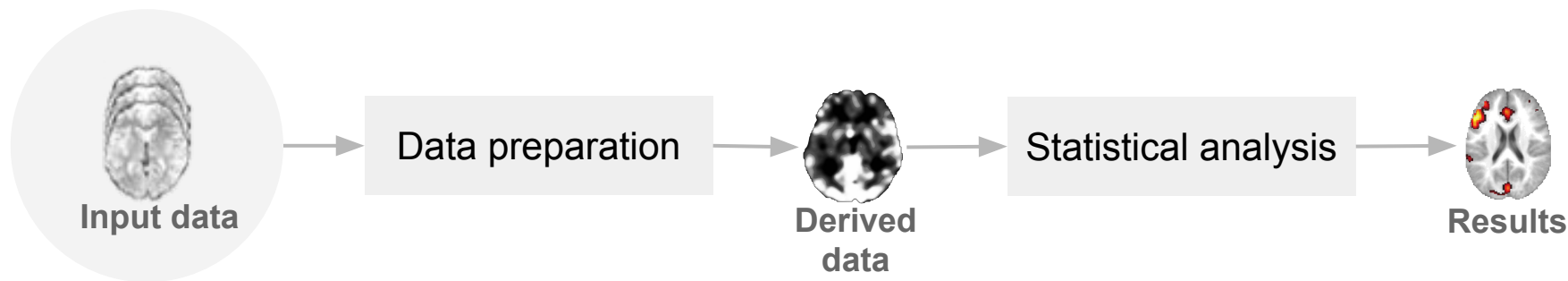
Alex Bowring



Tom Nichols

Oxford Uni. (UK)

Principles of functional MRI



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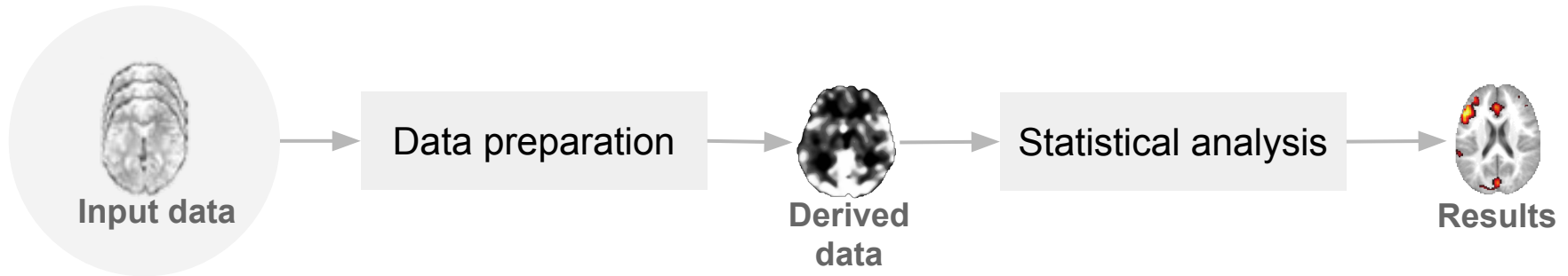
Alex Bowring



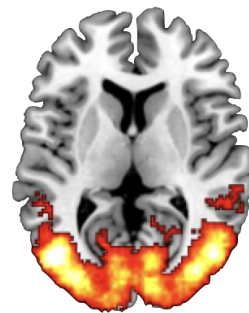
Tom Nichols

Oxford Uni. (UK)

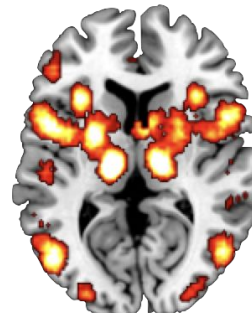
Principles of functional MRI



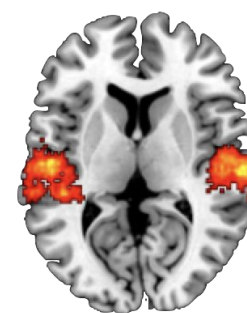
fMRI results: Activations maps



 Visual



 Hand motion



 Music

Variability across neuroimaging software

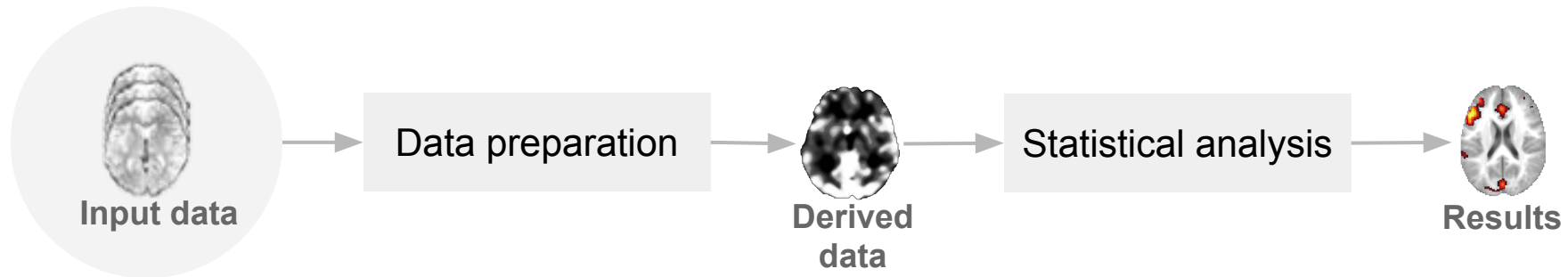


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Tom Nichols
Oxford Uni. (UK)

Principles of functional MRI



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

Variability across neuroimaging software



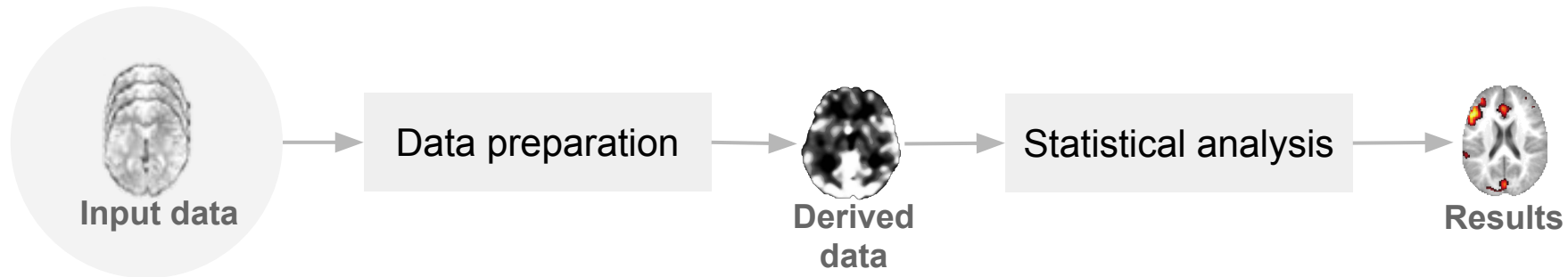
Alex Bowring



Tom Nichols

Oxford Uni. (UK)

Principles of functional MRI



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

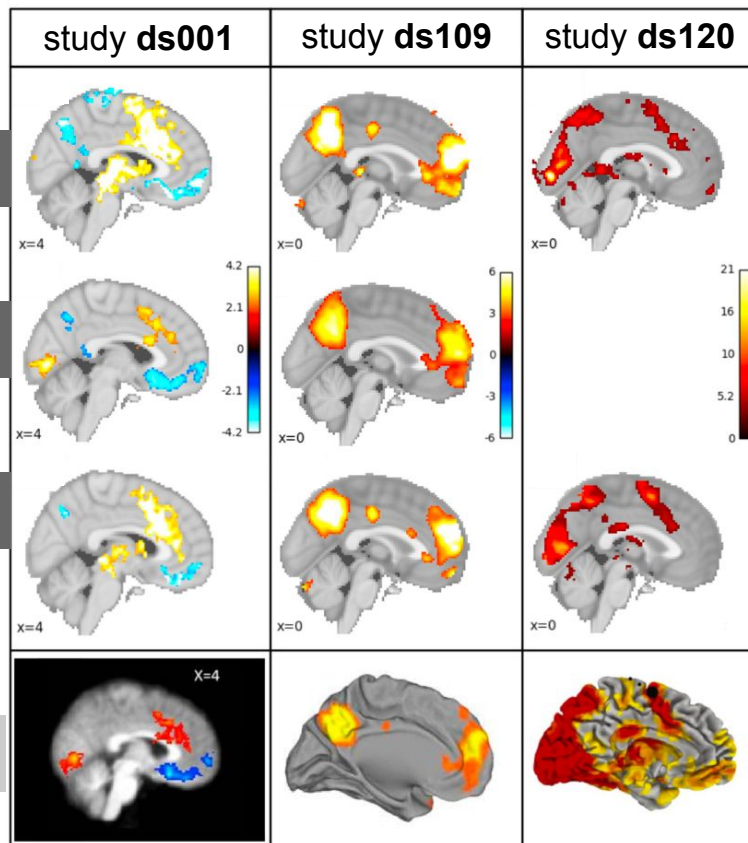
- **Reproduced 3 studies** from the literature
- Using **3 fMRI software: AFNI, FSL, SPM**
(used in 80% literature ([Carp, 2012](#)))
- **Pipelines aligned** using available configurations.

Variability across neuroimaging software



Alex Bowring Tom Nichols
Oxford Uni. (UK)

- Variability in the activation maps



[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software

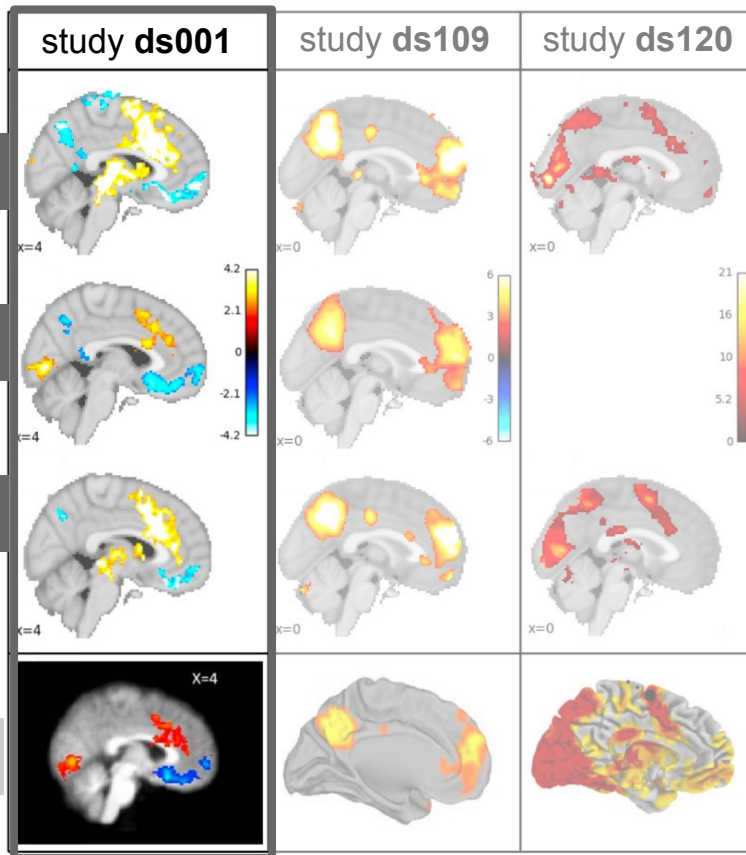


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Tom Nichols
Oxford Uni. (UK)

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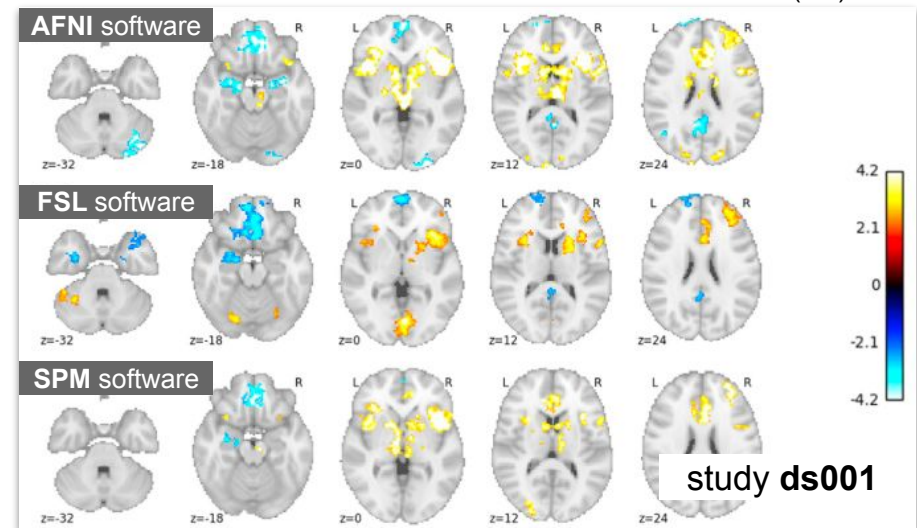
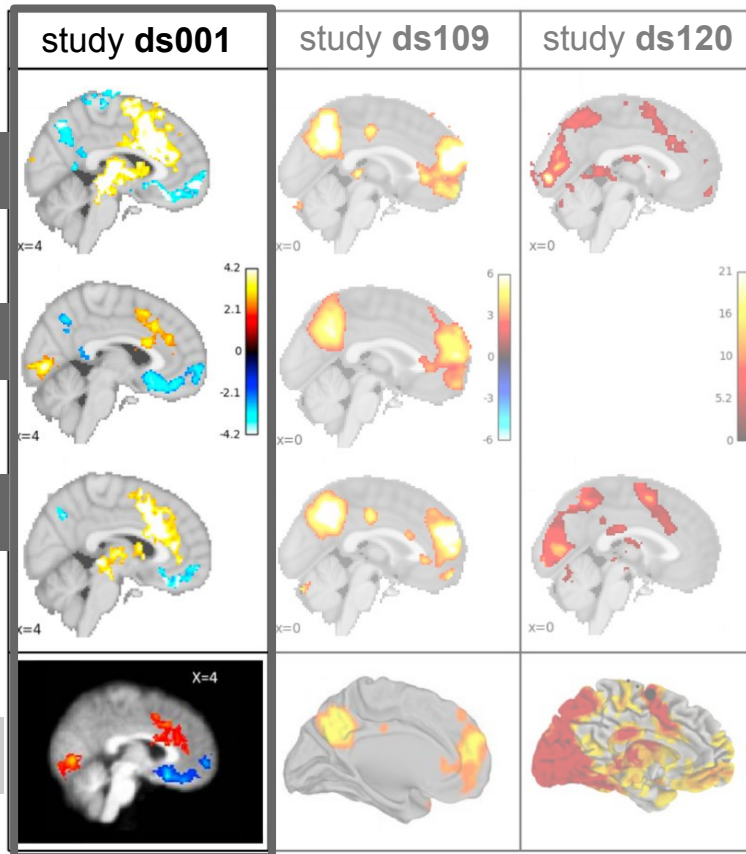
[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software



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Oxford Uni. (UK)

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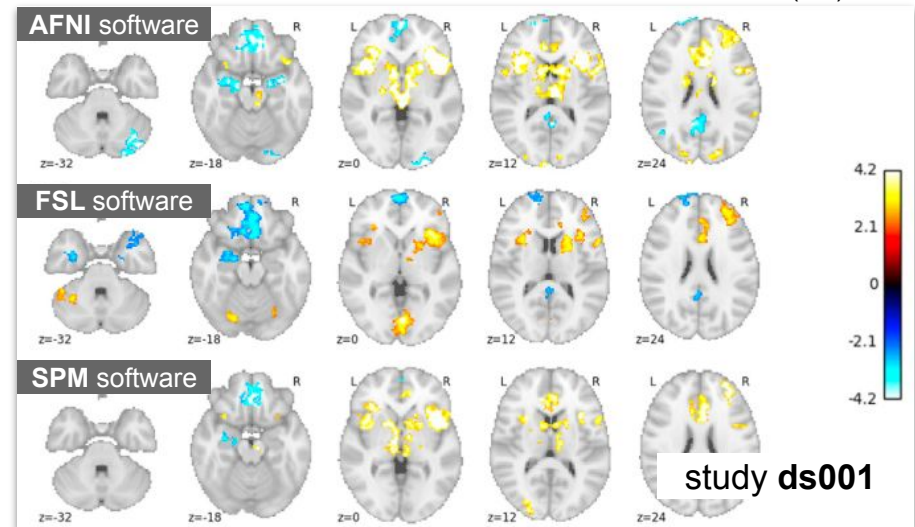
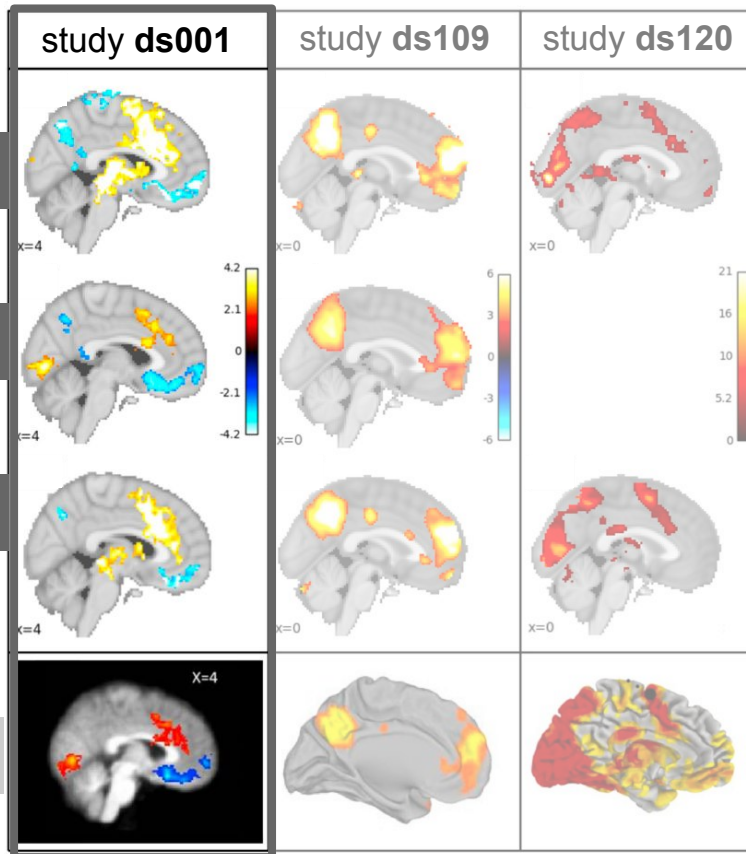
[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software

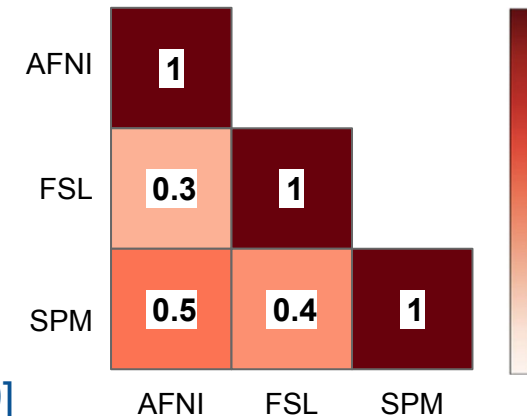


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- Variability in the activation maps



Dice coefficient



[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software

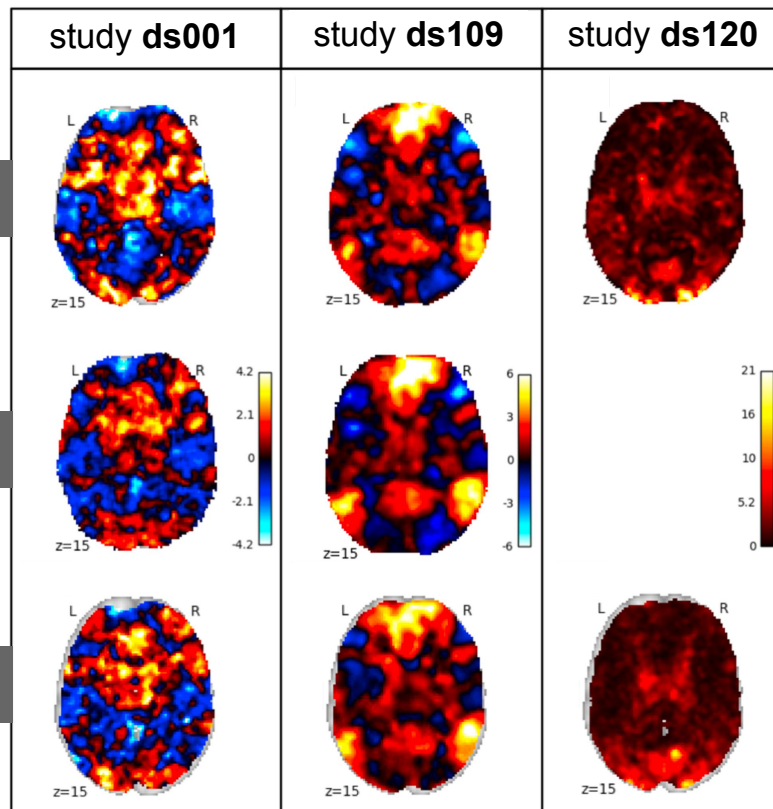


Alex Bowring



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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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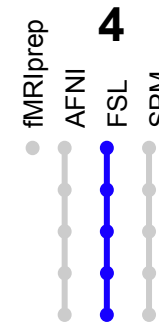
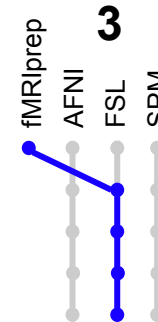
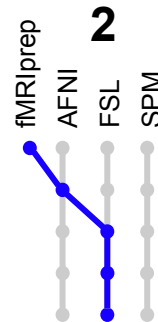
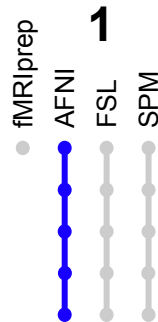


Tom Nichols
Oxford Uni. (UK)

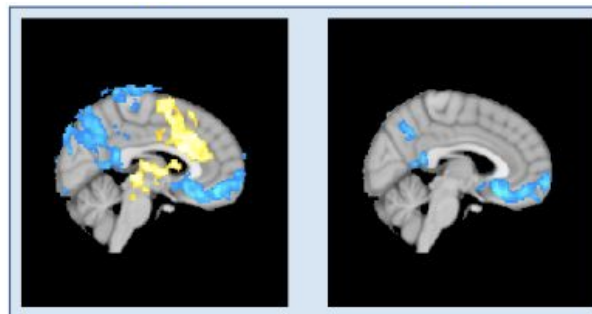
Goal 2: Investigate how remaining differences in software implementations can explain the observed differences

study ds001

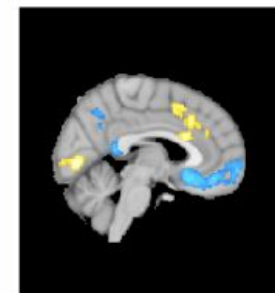
1. Preprocessing
2. Subject-level Signal
3. Subject-level Drift
4. Subject-level Noise
5. Group-level Stat



AFNI
software



FSL
software



[Bowring Nichols* Maumet*, HBM 2021]

Variability across neuroimaging software



Alex Bowring

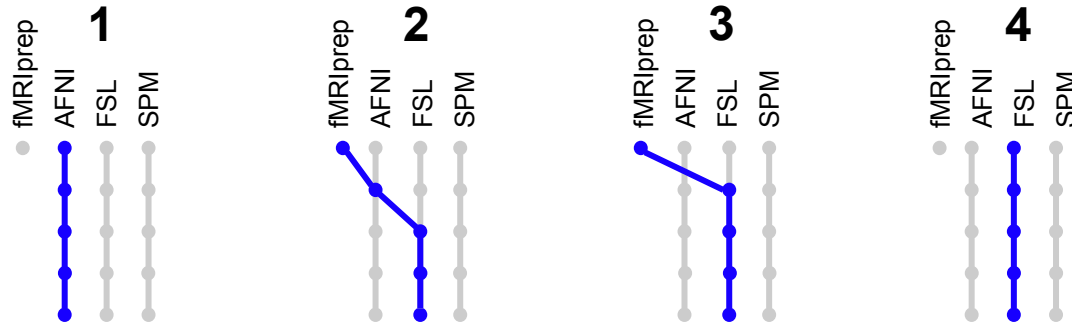


Tom Nichols
Oxford Uni. (UK)

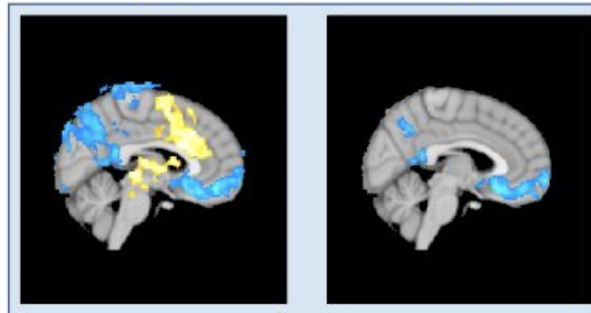
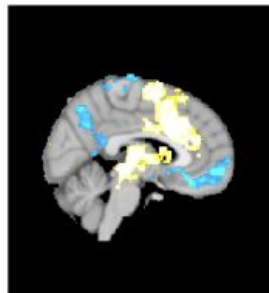
Goal 2: Investigate how remaining differences in software implementations can explain the observed differences

study ds001

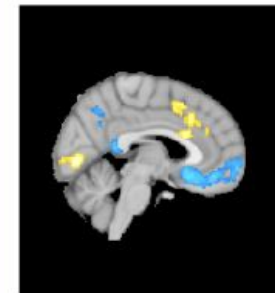
1. Preprocessing
2. Subject-level Signal
3. Subject-level Drift
4. Subject-level Noise
5. Group-level Stat



AFNI
software

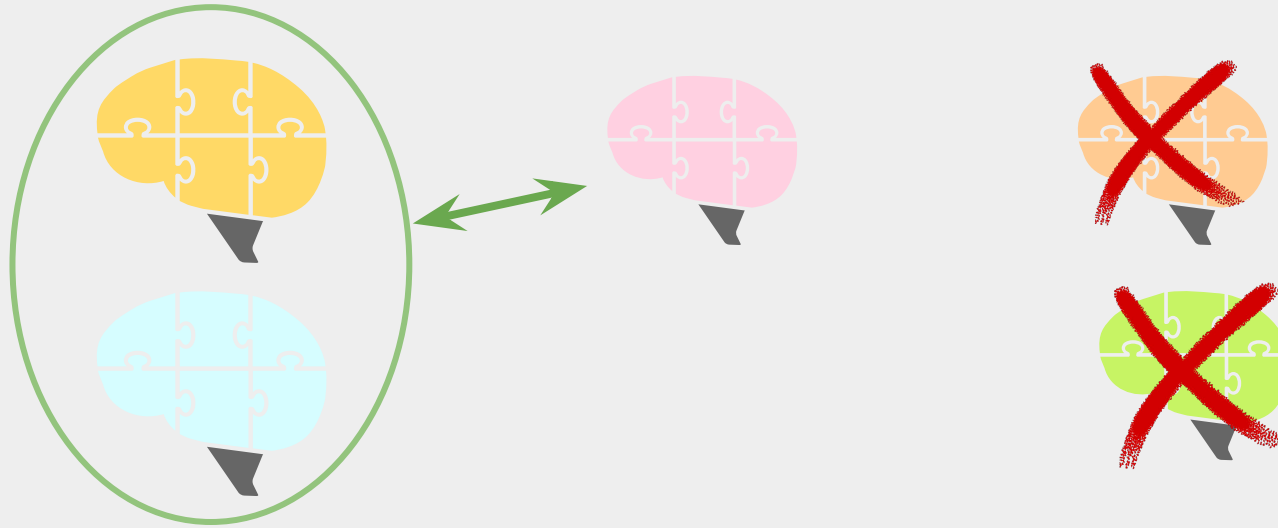


FSL
software



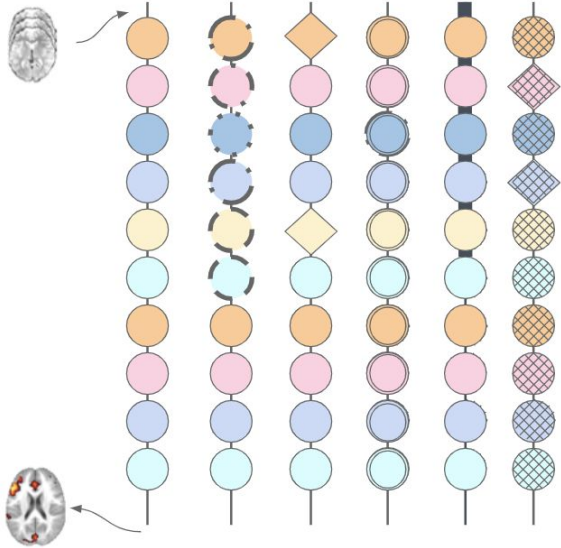
Conclusion: 1 main contributing factor was found but different for each study

[Bowring Nichols* Maumet*, HBM 2021]



Understanding
analytical variability

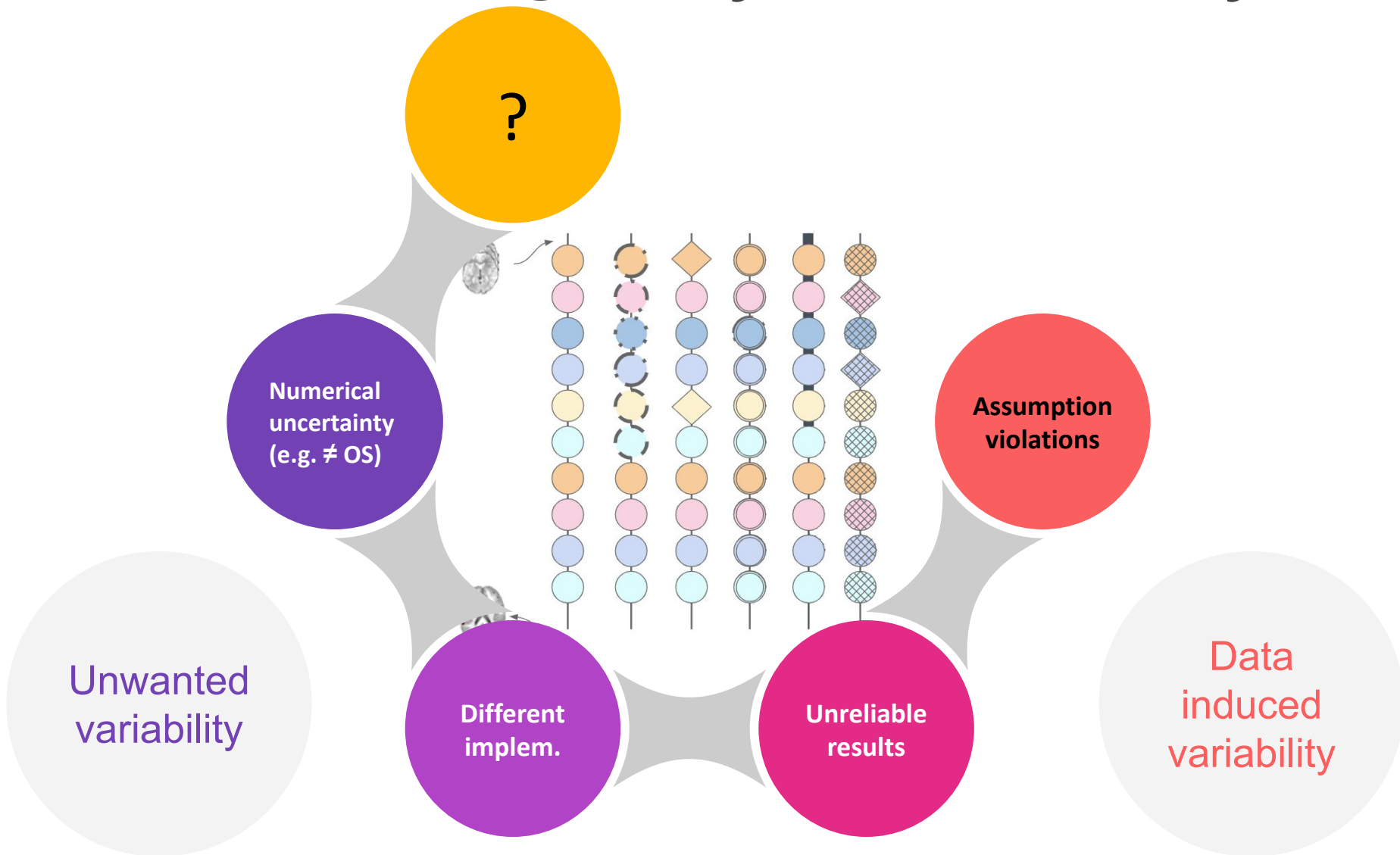
Understanding analytical variability...



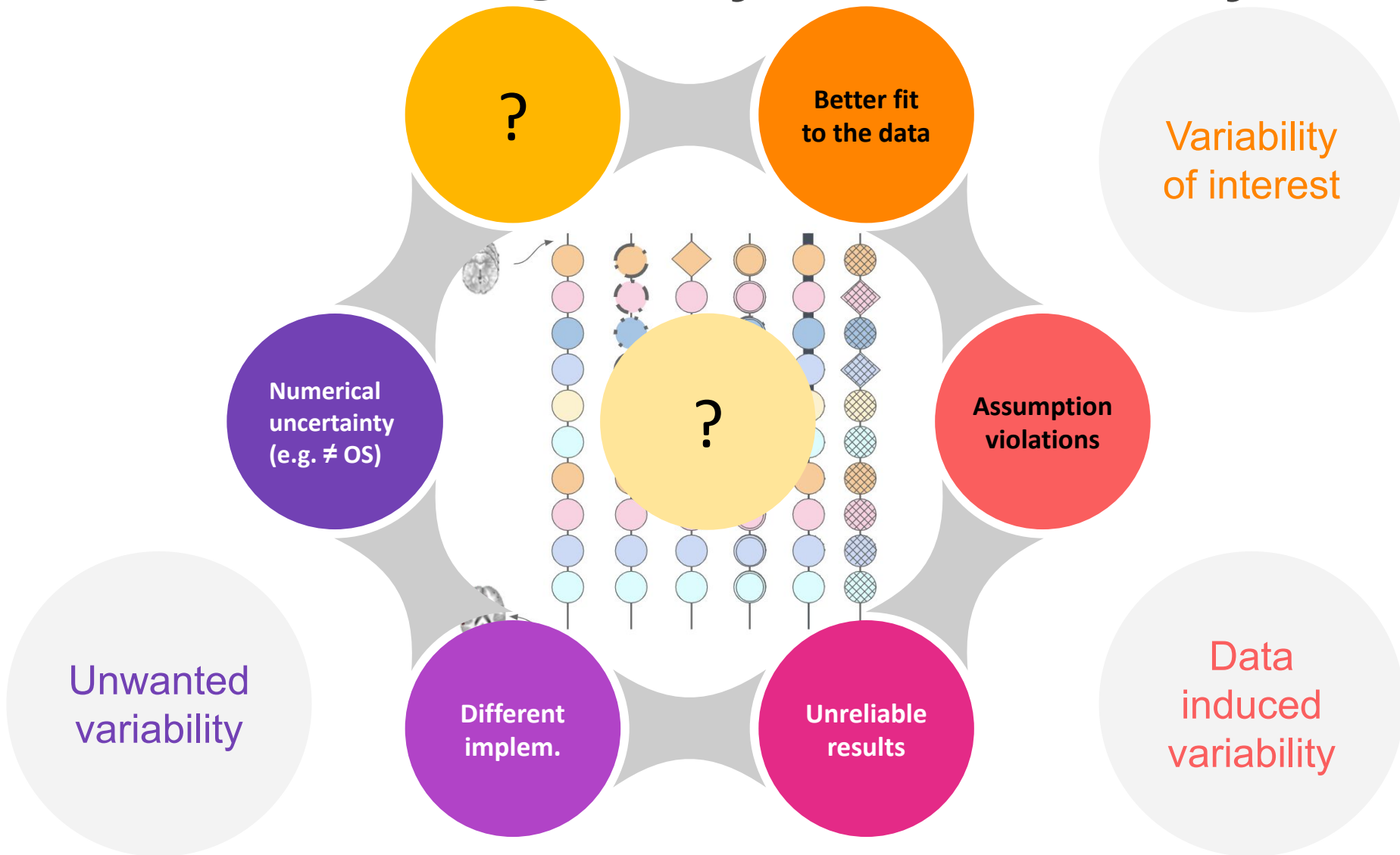
Understanding analytical variability...

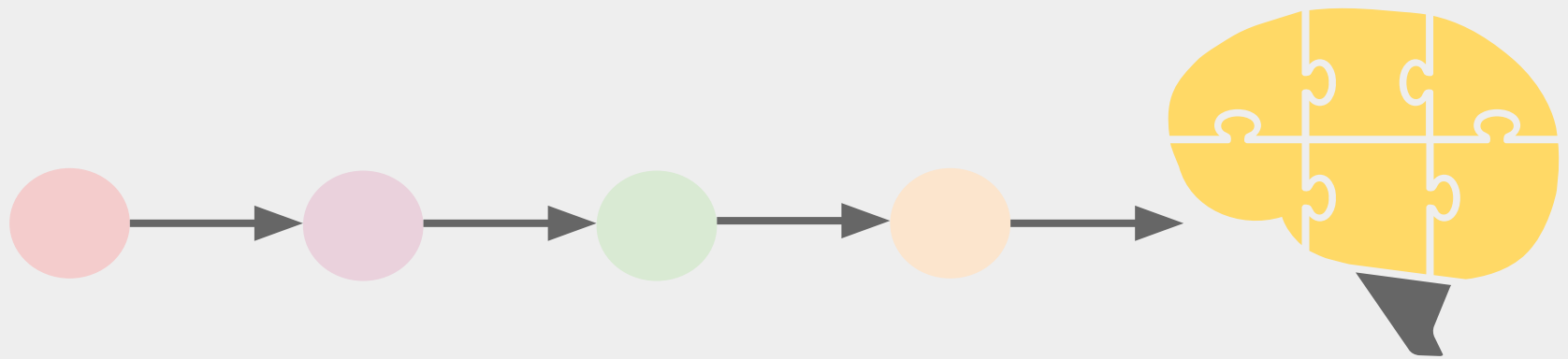


Understanding analytical variability...



Understanding analytical variability...





Describing the
neuroimaging
pipeline space

NARPS open pipelines



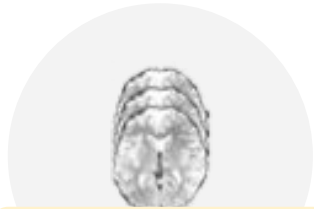
Boris Clenet



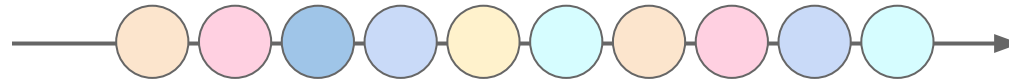
Elodie Germani



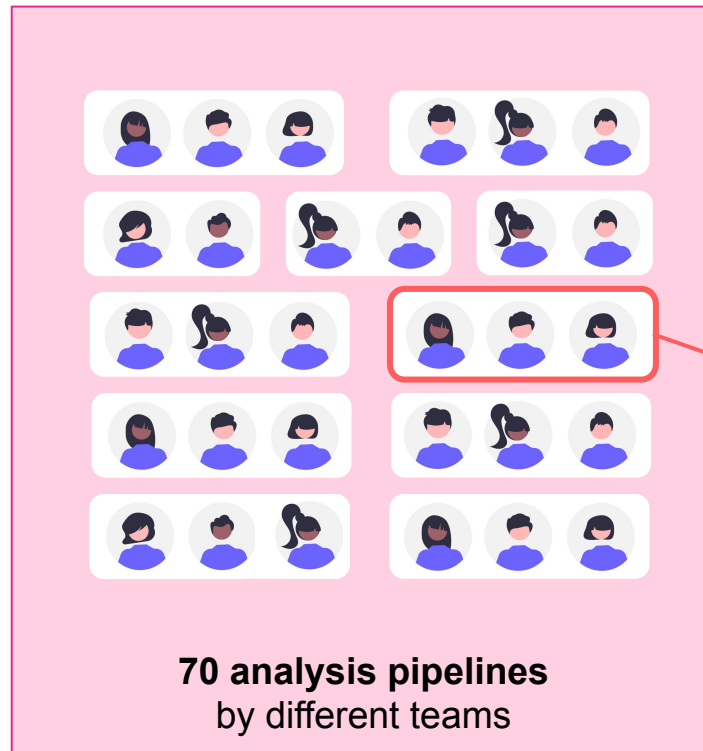
Jérémy Lefort-Besnard



1 dataset

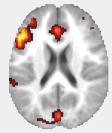


9 'yes/no' questions



1- H1: "yes"

2- Activation +
Statistic brain
maps



3- Textual
description of the
methods

NARPS open pipelines



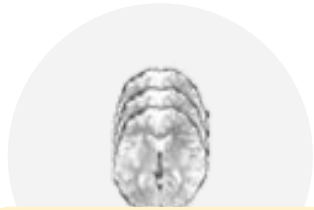
Boris Clenet



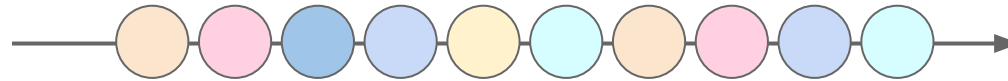
Elodie Germani



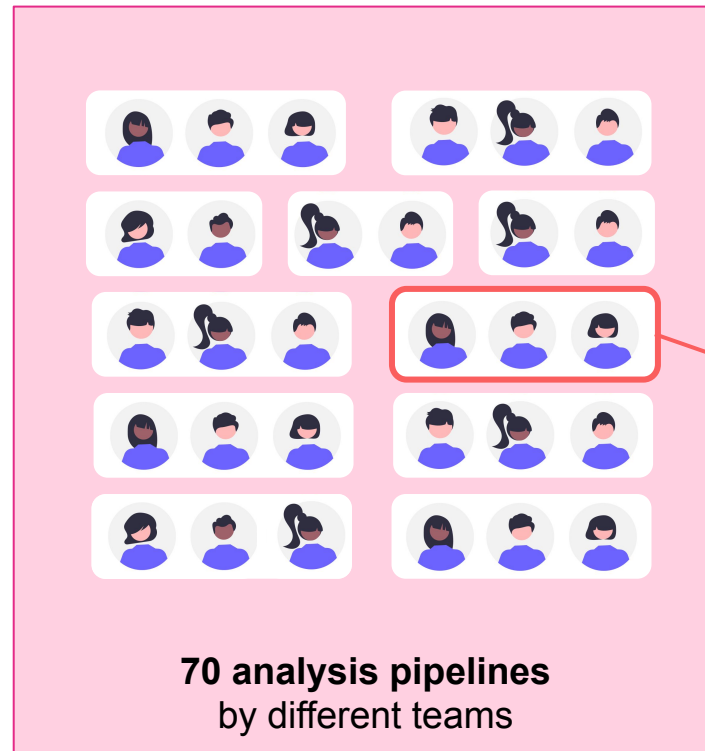
Jérémy Lefort-Besnard



1 dataset

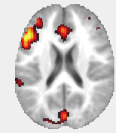


9 'yes/no' questions



1- H1: "yes"

2- Activation +
Statistic brain
maps



3- Textual
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.



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

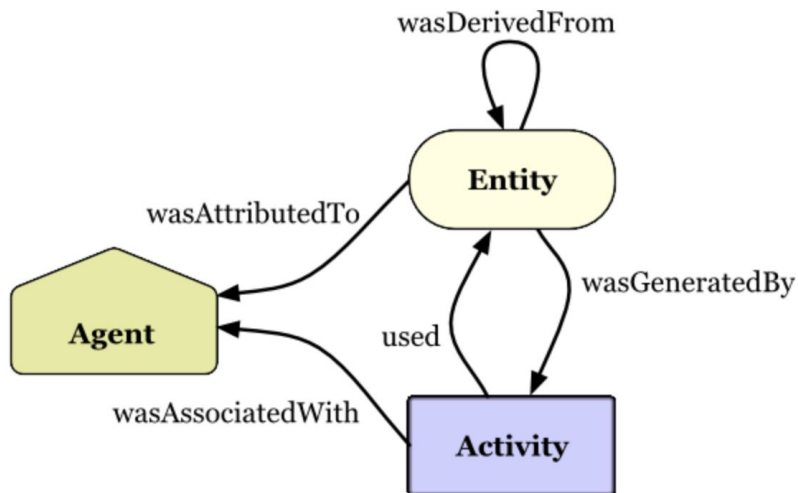
Tracing provenance in neuroimaging



Satra Ghosh

“Provenance describe how an artifact or set of artifacts was produced” [Wikipedia](#)

- Based on W3C PROV



- As part of neuroimaging standardization efforts



<https://www.w3.org/TR/2013/NOTE-prov-primer-20130430/>

Provenance Use Case 1 **An unambiguous description of the methods**



Provenance Use Case 1 **An unambiguous description of the methods**



Which release of SPM was used?

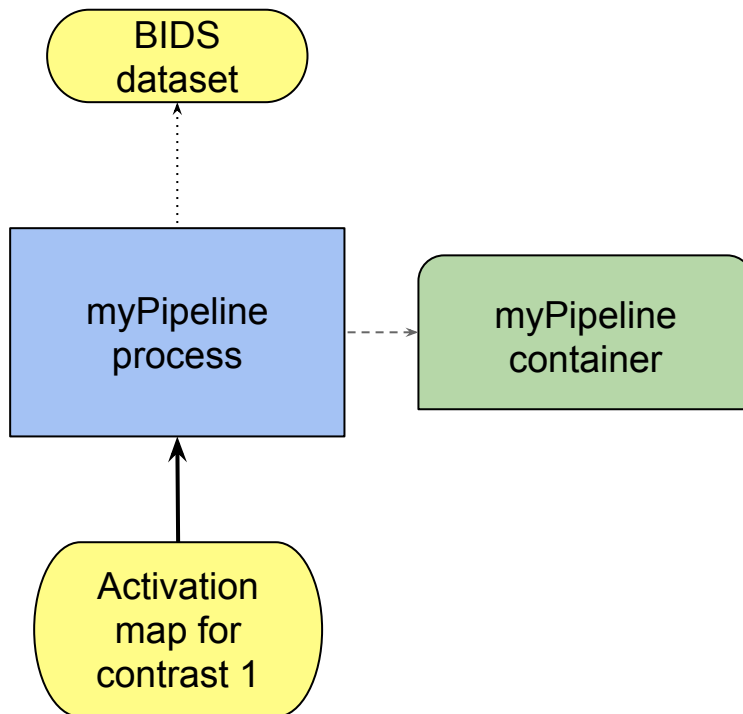
Which registration algorithm was selected?

How was the brain mask computed?

Provenance Use Case 1 **An unambiguous description of the methods**

Can we
reproduce
exactly the same
results
(same data, same
methods)?

Provenance Use Case 1 **An unambiguous description of the methods**



Can we
**reproduce
exactly the same
results**
(same data, same
methods)?

Provenance Use Case 2 **Dealing with unwanted variability**

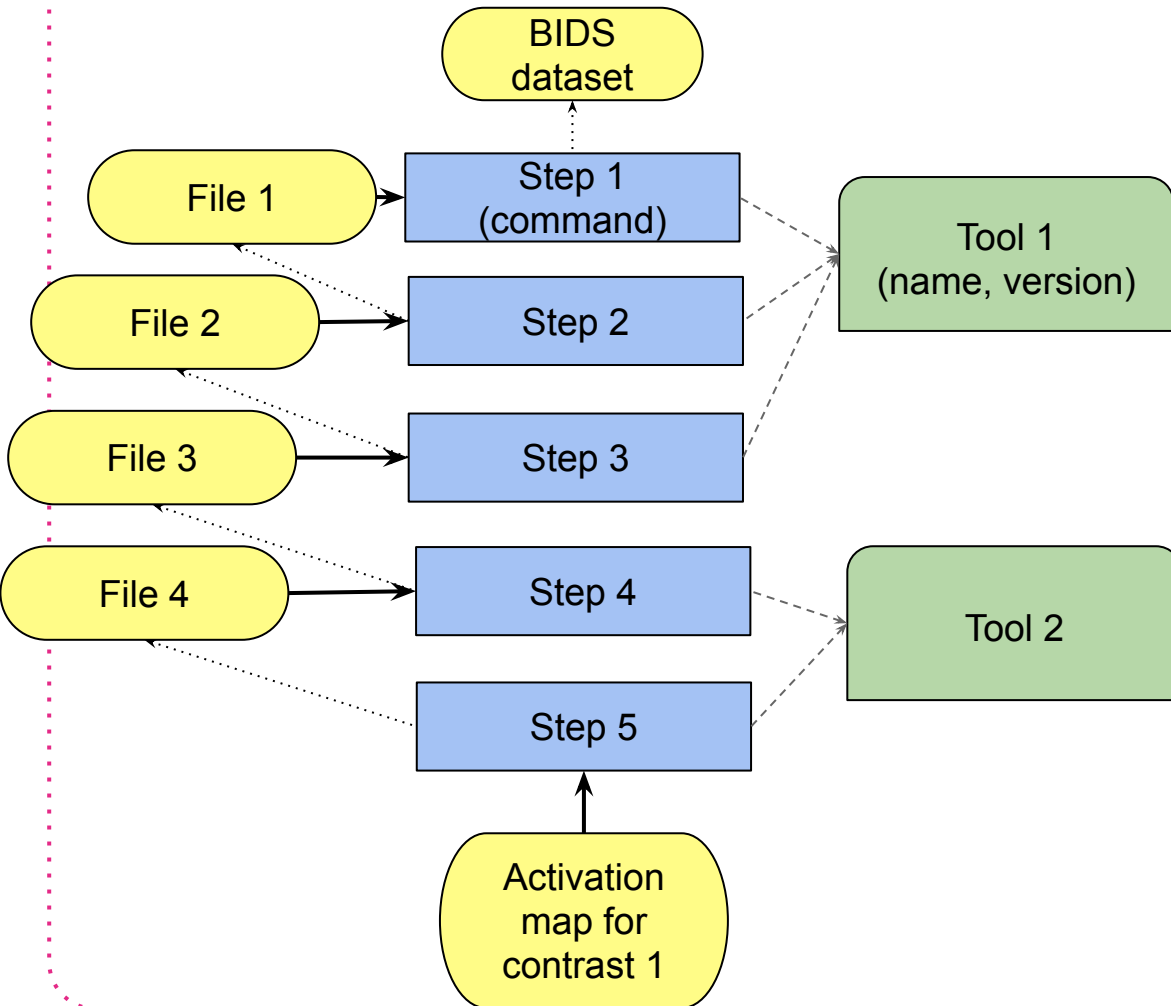
A previously widely-used **parameter is no longer considered as best practice**

Provenance Use Case 2 **Dealing with unwanted variability**

A previously widely-used **parameter is no longer considered as best practice**

A bug was found in a given tool **version**, can we retrieve all corresponding results?

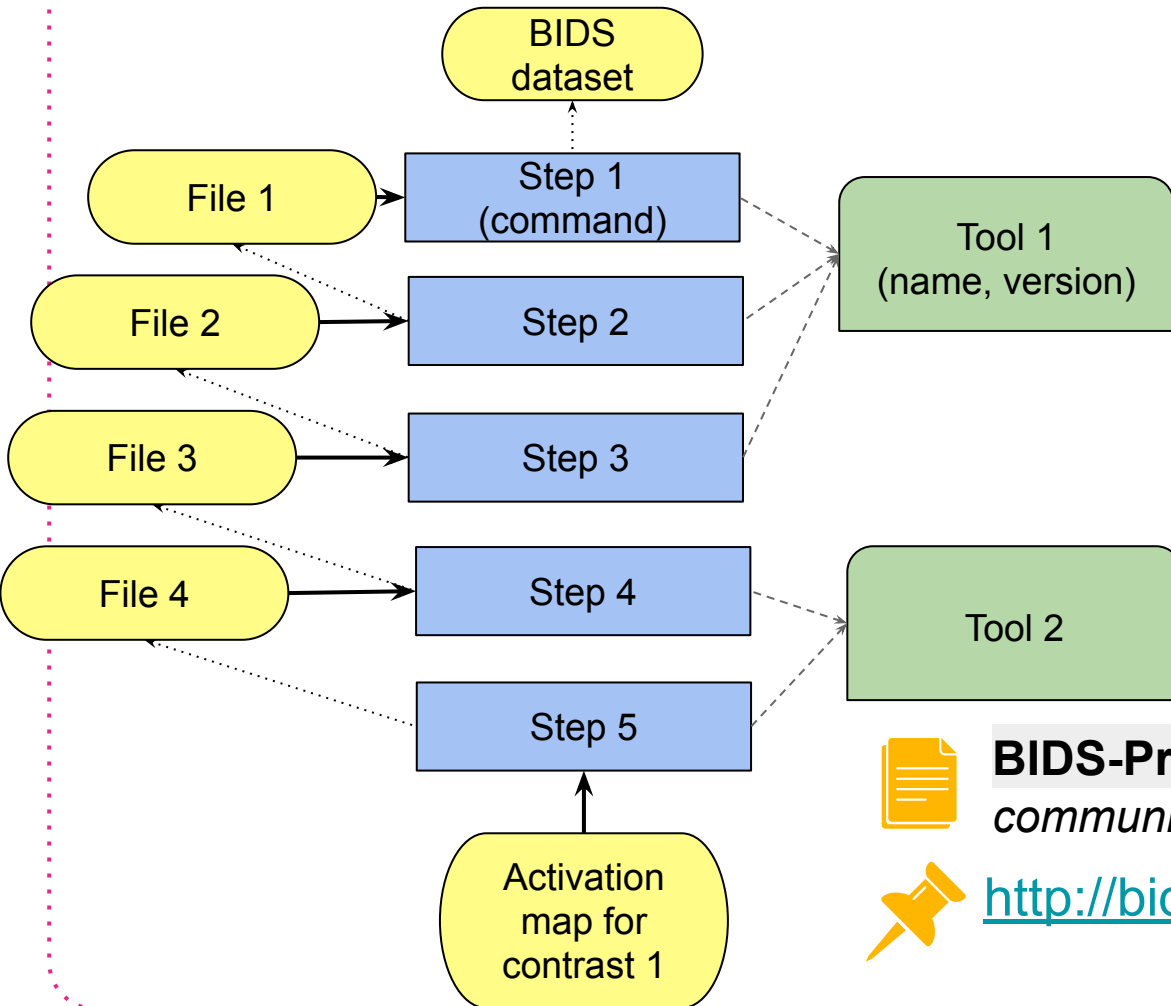
Provenance Use Case 2 **Dealing with unwanted variability**



A previously widely-used parameter is no longer considered as best practice

A bug was found in a given tool version, can we retrieve all corresponding results?

Provenance Use Case 3 Exploring factors impacting analytical variability



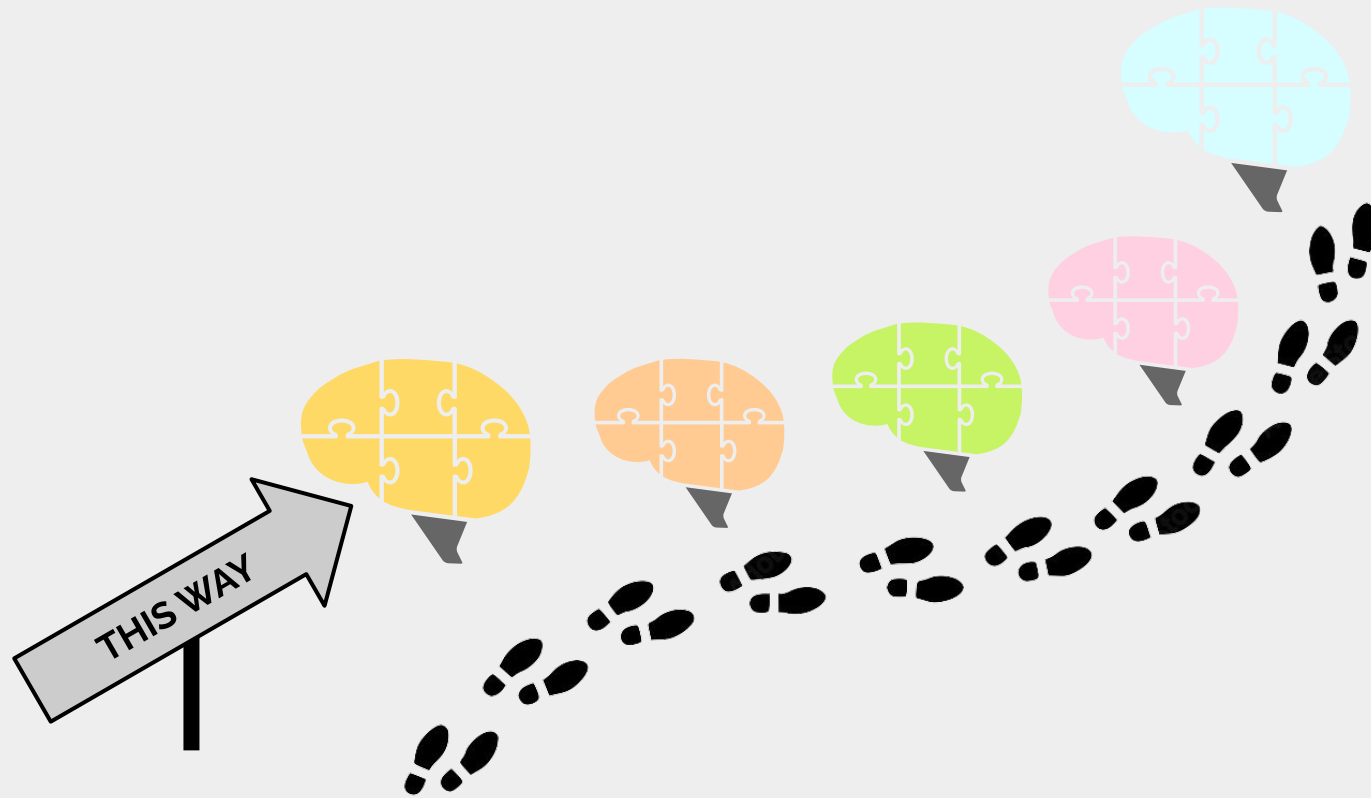
Are my conclusions dependant on the **size of the smoothing kernel** used at Step 5?



BIDS-Prov will soon be open for community feedback!



<http://bids.neuroimaging.io/bep028>



Which solutions **for** **practitioners?**

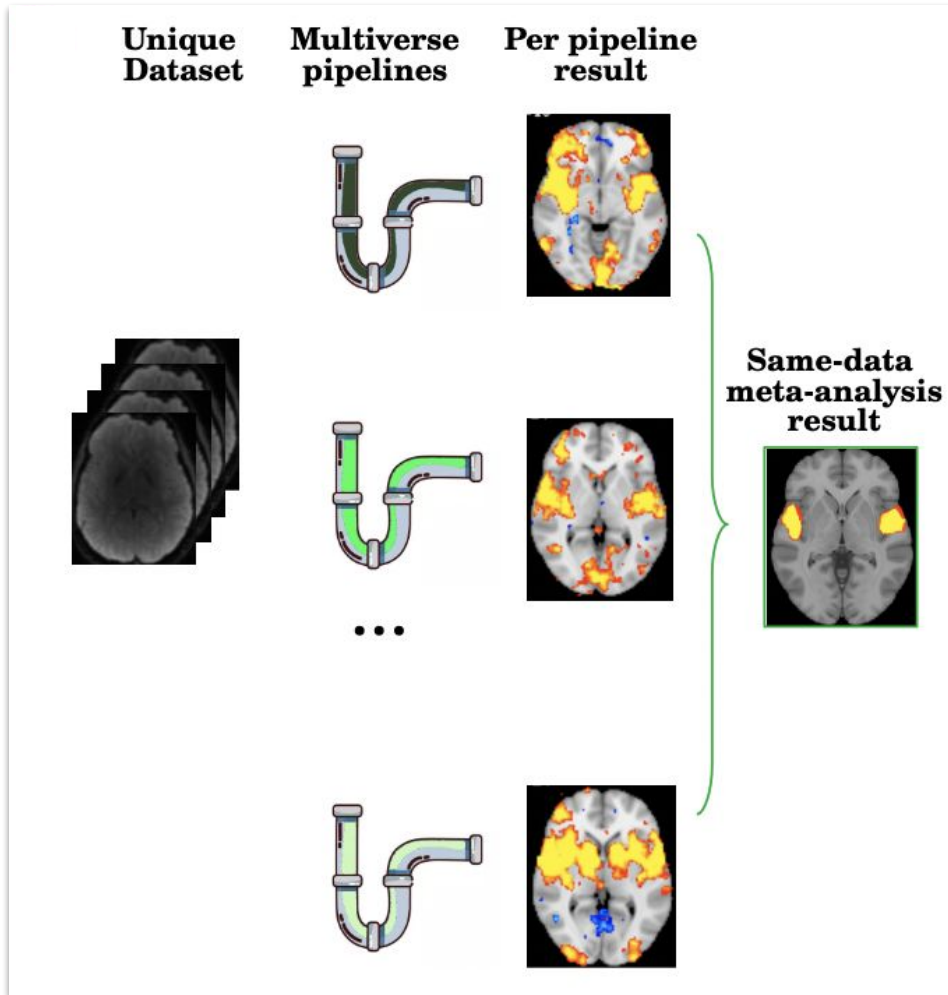
Same data meta-analysis



Jérémy
Lefort-Besnard



Tom Nichols
Oxford Uni. (UK)



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

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

Validity of mega-analyses in neuroimaging

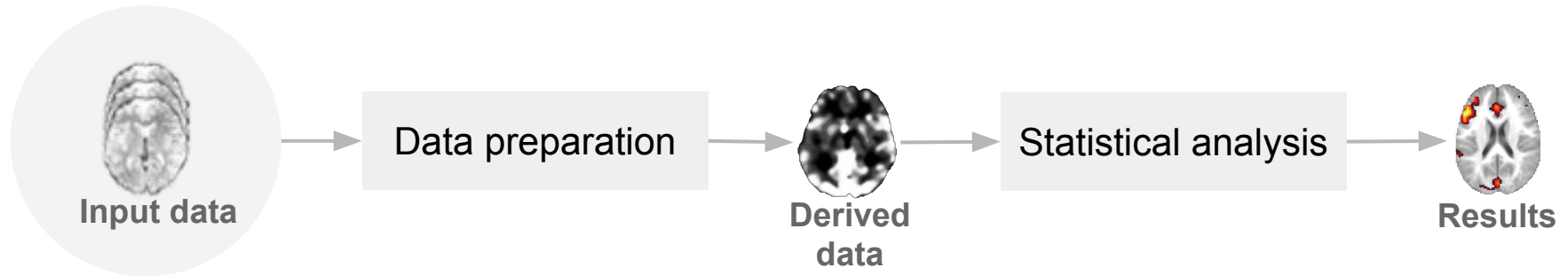


Xavier
Rolland



Pierre
Maurel

Multi-stage functional MRI analysis



Validity of mega-analyses in neuroimaging

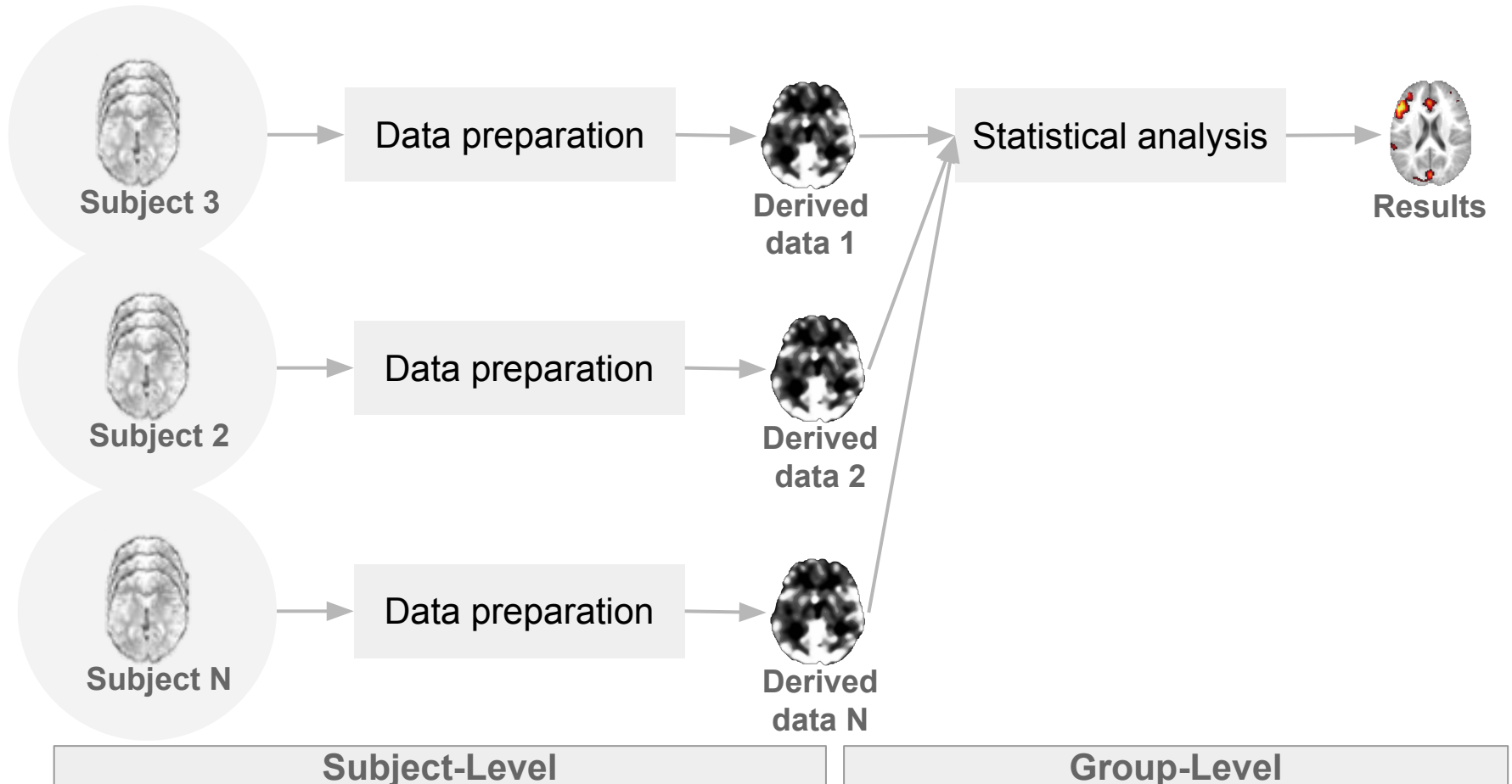


Xavier
Rolland



Pierre
Maurel

Multi-stage functional MRI analysis



Validity of mega-analyses in neuroimaging

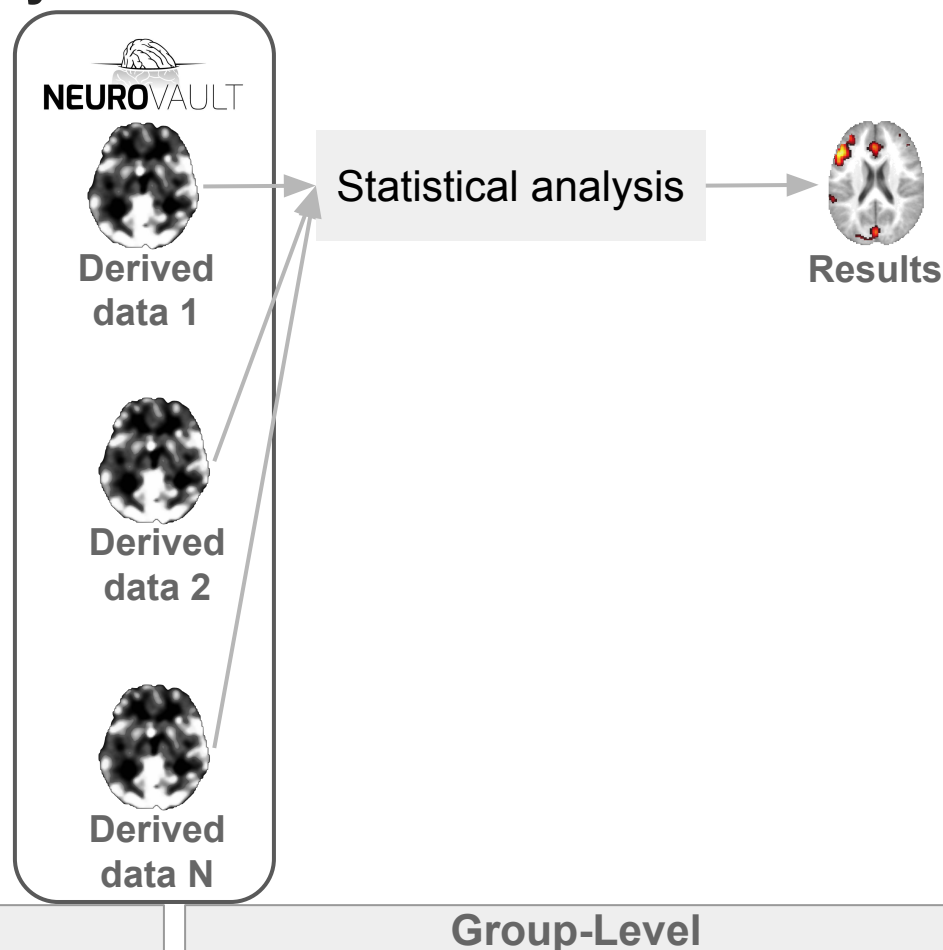


Xavier
Rolland



Pierre
Maurel

Multi-stage functional MRI analysis



Validity of mega-analyses in neuroimaging

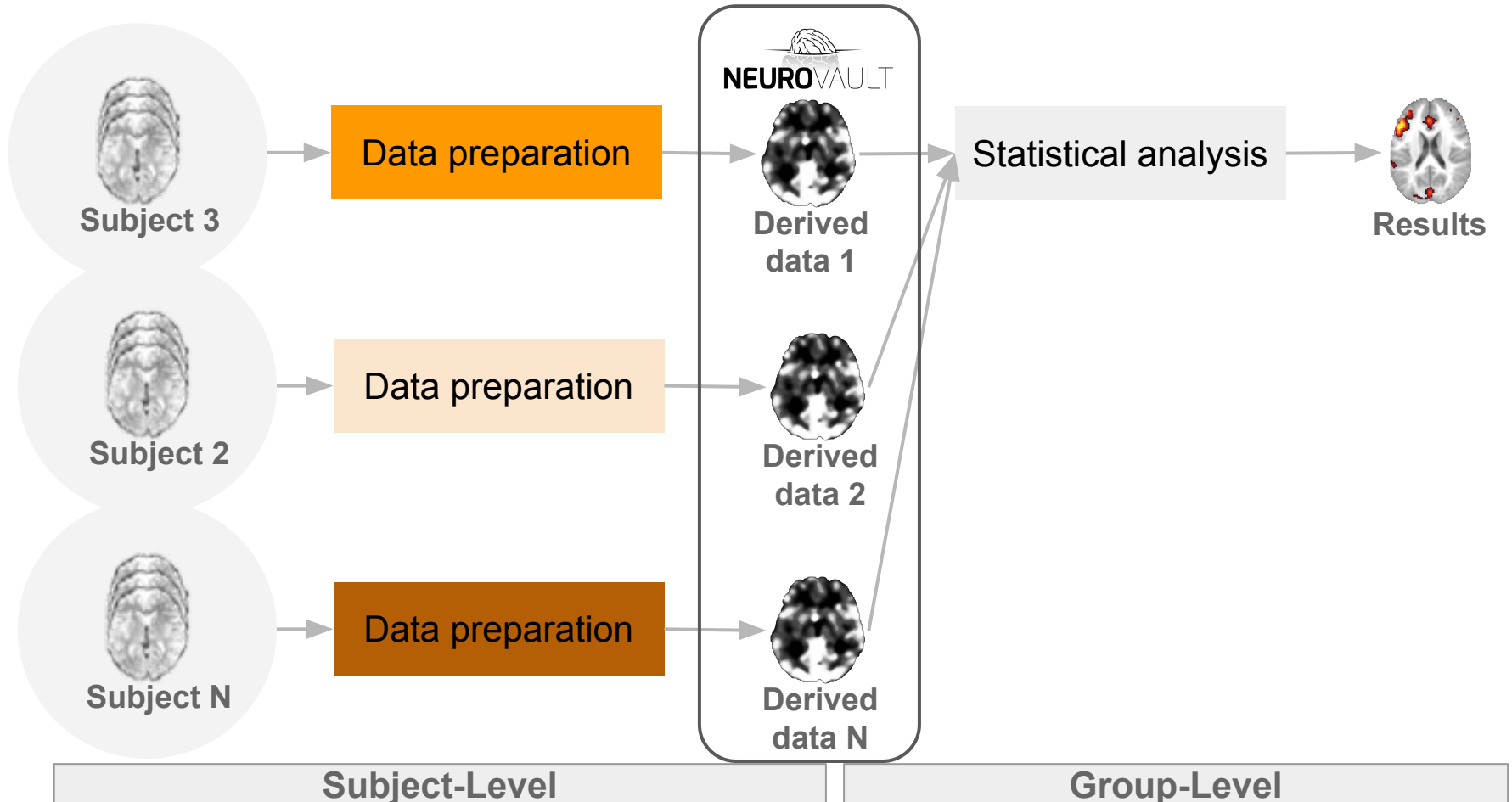


Xavier Rolland



Pierre Maurel

Multi-stage functional MRI analysis



Validity of mega-analyses in neuroimaging

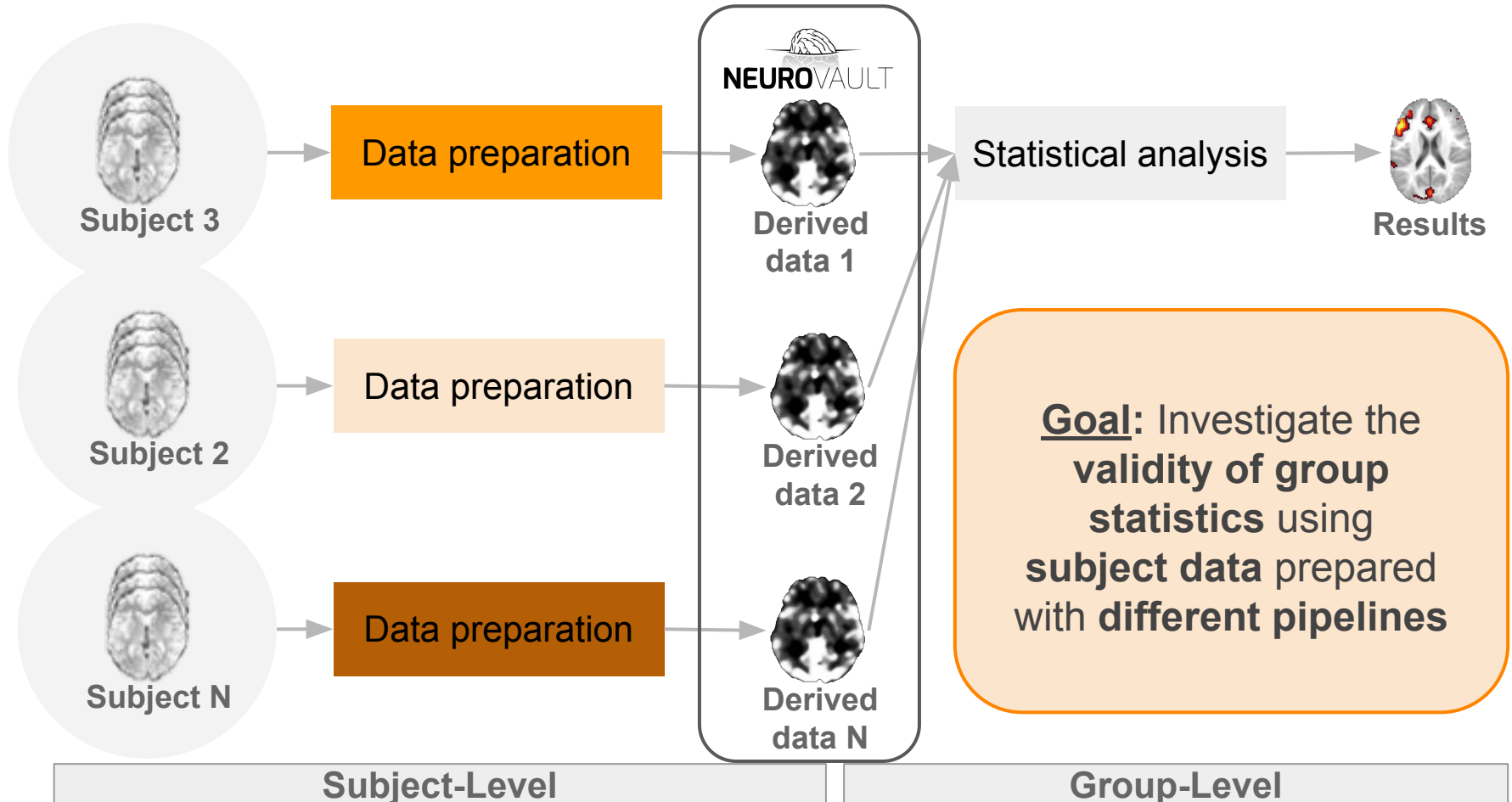


Xavier Rolland



Pierre Maurel

Multi-stage functional MRI analysis



Validity of mega-analyses in neuroimaging



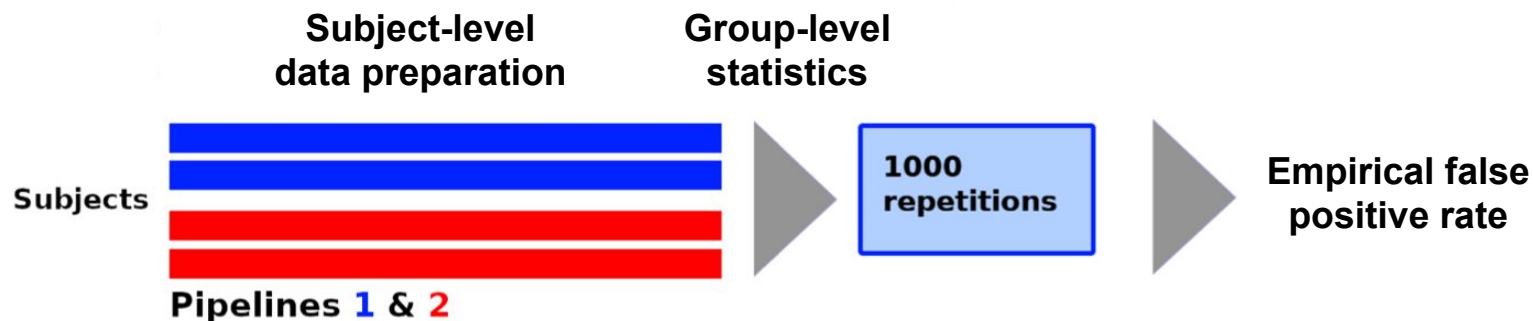
Xavier
Rolland



Pierre
Maurel

Goal: Investigate the **validity of group statistics** using **subject data** prepared with **different pipelines**

- HCP Young-Adult (1000 subjects)
- **3 pipeline variations**
 - Spatial smoothing: 5 or 8 mm
 - Modelling of the brain response: with/out derivative
 - Correction for subject motion: 0,6, 24 covariates



Validity of mega-analyses in neuroimaging



Xavier
Rolland

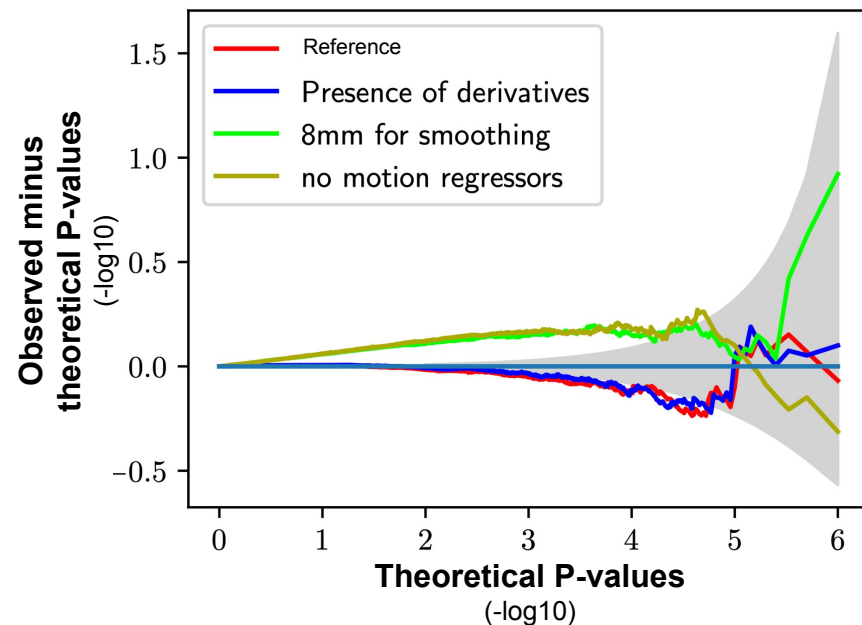


Pierre
Maurel

"Reference" pipeline :

- canonical HRF
- smoothing 5mm
- 24 motion regressors

- P-p plots (Bland-Atlman)



Conclusion: Invalidity of the mega-analyses for multiple variations studied (e.g. different smoothing, 1+ variation)

[Rolland Maurel Maumet, ISBI 2022]

Leveraging large and open datasets



Elodie
Germani



Elisa
Fromont

Shared data with limited metadata



500 000+ images

A variety of fMRI tasks, preprocessing and analysis
Minimal metadata required.

Leveraging large and open datasets



Elodie
Germani



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Fromont

Shared data with limited metadata



500 000+ images

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Minimal metadata required.

Goal: Can we take advantage of a large pool of unlabelled data to help answer new research questions?

Leveraging large and open datasets



Elodie
Germani



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Fromont

Shared data with limited metadata

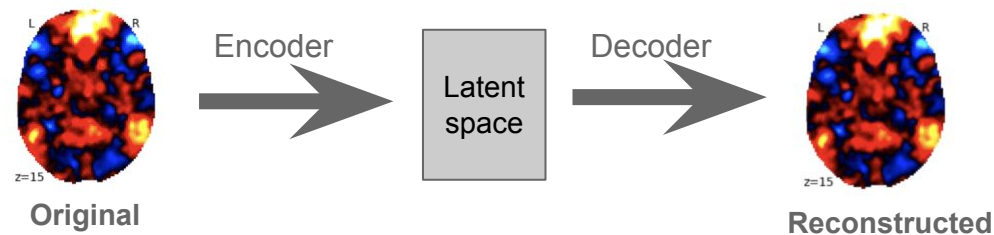


500 000+ images

A variety of fMRI tasks, preprocessing and analysis
Minimal metadata required.

Goal: Can we take advantage of a large pool of unlabelled data to help answer new research questions?

- Step 1: Build a model-agnostic representation of fMRI statistic maps



- Step 2: Fine-tune a classifier (predicting cognitive process:



Leveraging large and open datasets



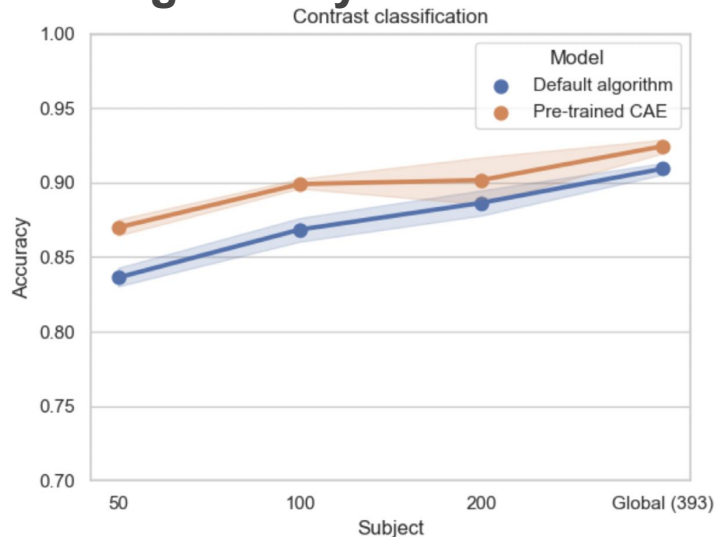
Elodie Germani



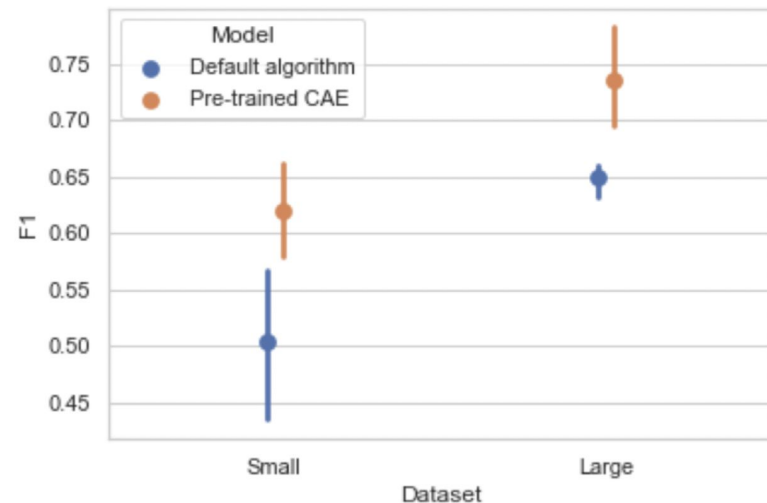
Elisa Fromont

- Tested on two datasets:
 - **Single large study** (HCP Young adult) 23 tasks x 787 subjects
 - **Collection of studies** (Brainpedia) 29 studies, 36 tasks, 826 subjects

Single study



Collection of studies



Conclusion: The pre-trained classifier always performed better especially when the problem was complex (small samples, heterogeneity).

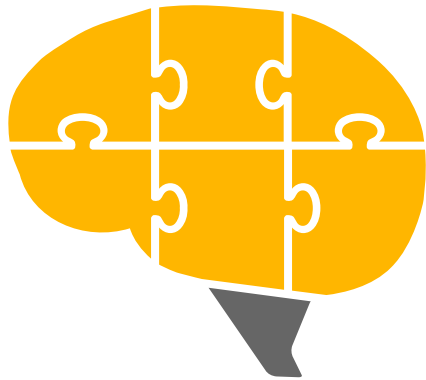
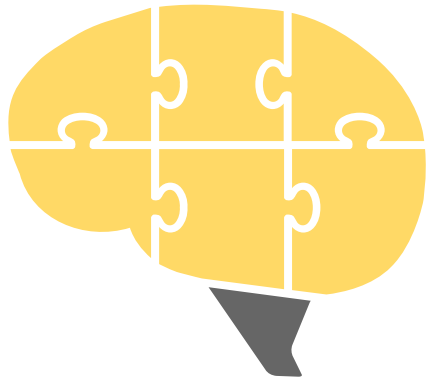
[[Germani Fromont*](#) [Maumet*](#), Gigascience 2023]

Feb 20, 2024



McGill

QLS SQV
QUANTITATIVE LIFE SCIENCES SCIENCES QUANTITATIVES DU VIVANT



Towards reproducible neuroimaging across different analysis pipelines

Camille Maumet

Thank you!

Credit: Presentation template and icons by [SlidesCarnival](https://www.slidescarnival.com/), adapted



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