

Towards reproducible neuroimaging

Solutions for sharing and re-using brain imaging data

Camille Maumet

8 février 2024

Rapportrice

Carole Lartizien, CNRS, France

Rapportrice

Jeanette Mumford, Stanford University, USA

Rapporteur

Adam Thomas, NIMH, USA

Examinatrice

Sarah Cohen-Boulakia, University Paris Saclay, France

Examinatrice

Anne-Laure Boulesteix, LMU Munich, Germany

Présidente

Elisa Fromont, Rennes University, France

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)

A crisis in experimental research

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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

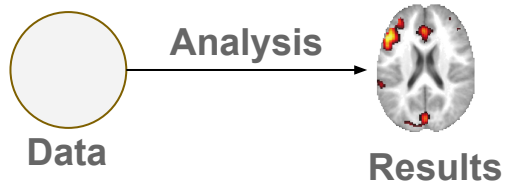


Reproducible research



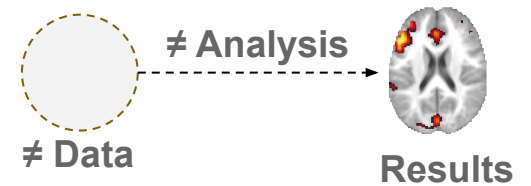
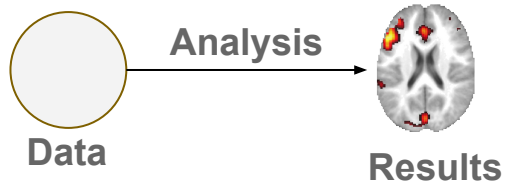
Reproducible research

Original study



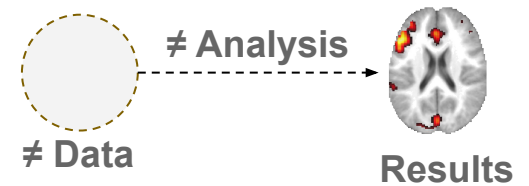
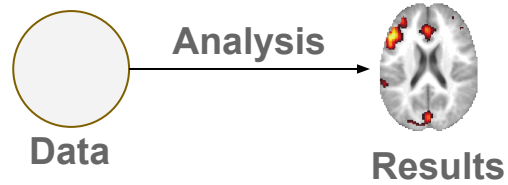
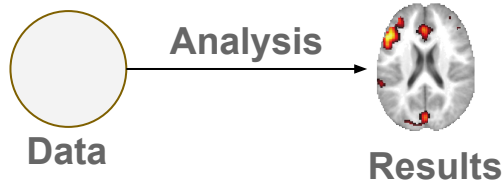
Reproducible research

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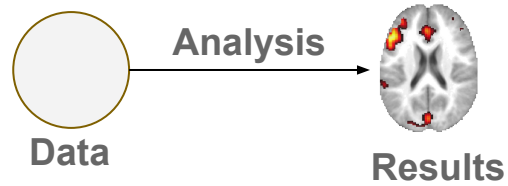
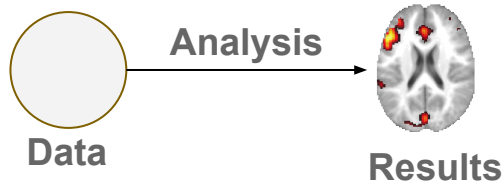
Reproducible research

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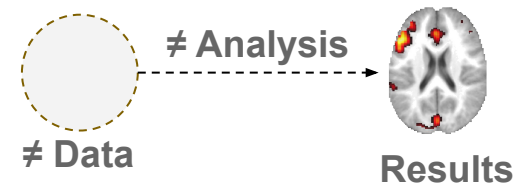


Reproducible research

Original study

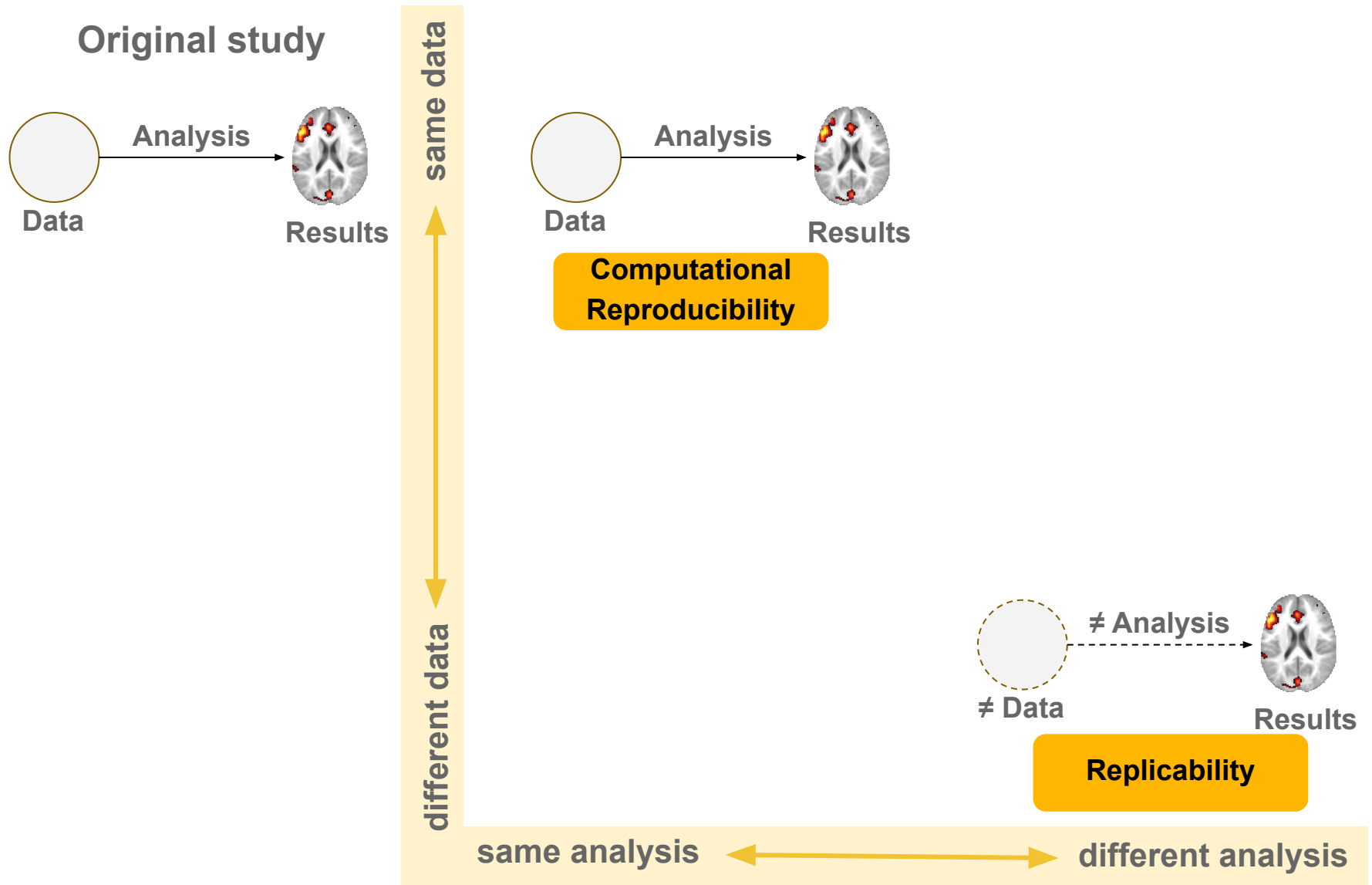


**Computational
Reproducibility**

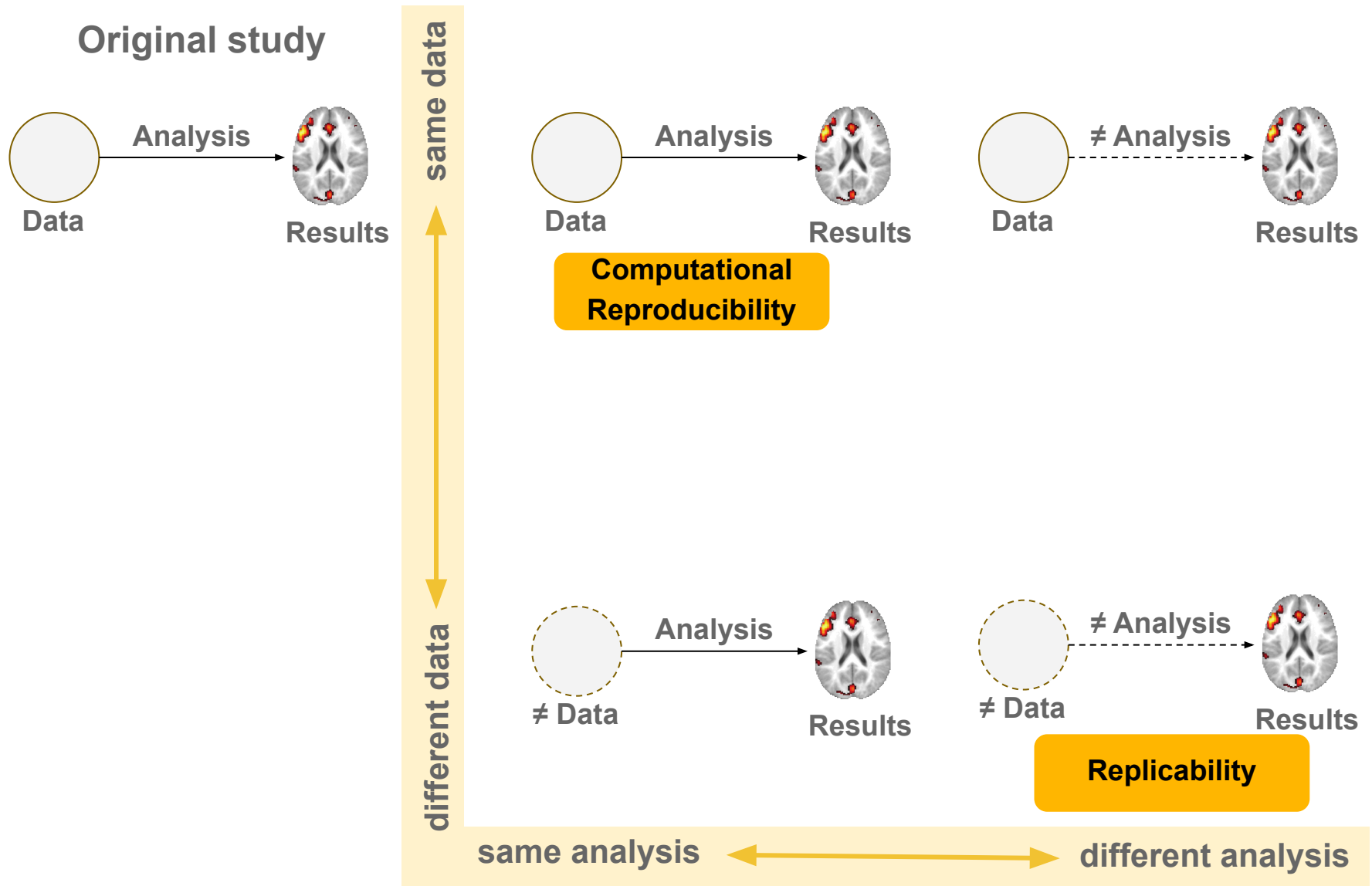


Replicability

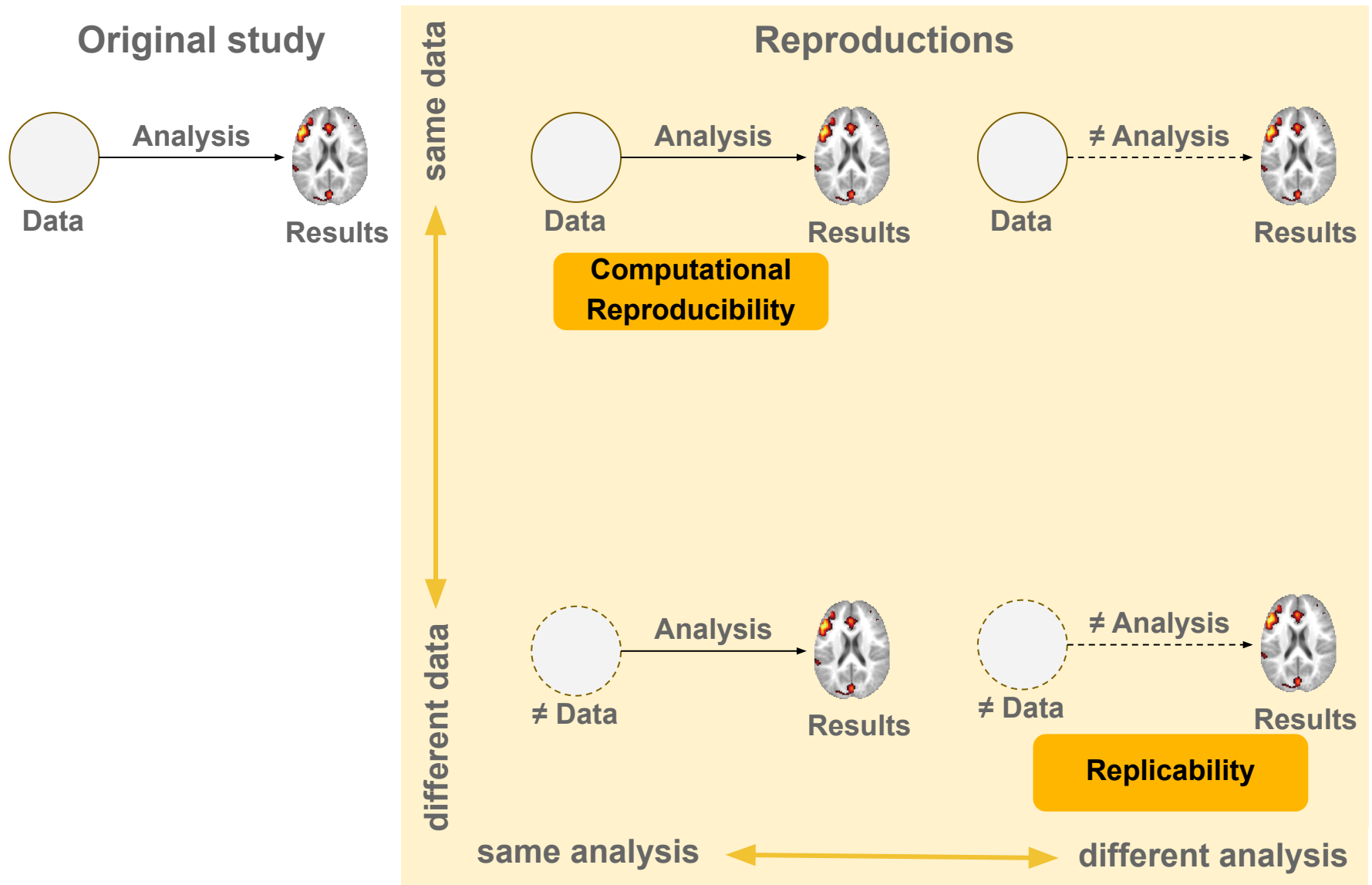
Reproducible research



Reproducible research



Reproducible research



Contributions



Towards reproducible neuroimaging
Solutions for sharing and re-using brain imaging data

≠ Data



≠ Analysis



**Opening up
neuroimaging data**



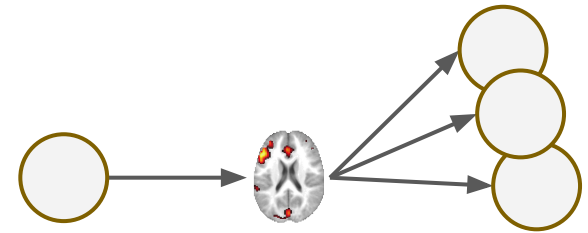
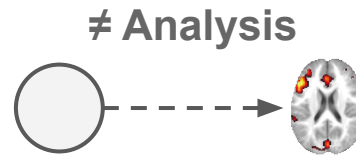
**On the vibration of
effects in
neuroimaging**

Contributions



Towards reproducible neuroimaging

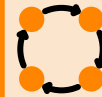
Solutions for sharing and re-using brain imaging data



Opening up
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On the vibration of
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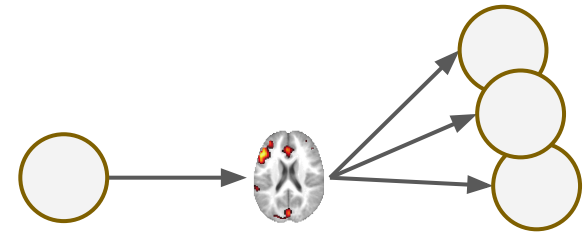
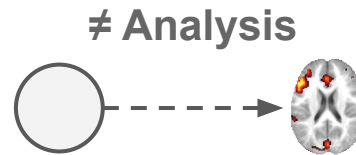
Reusing
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Contributions



Towards reproducible neuroimaging

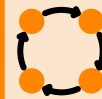
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Opening up
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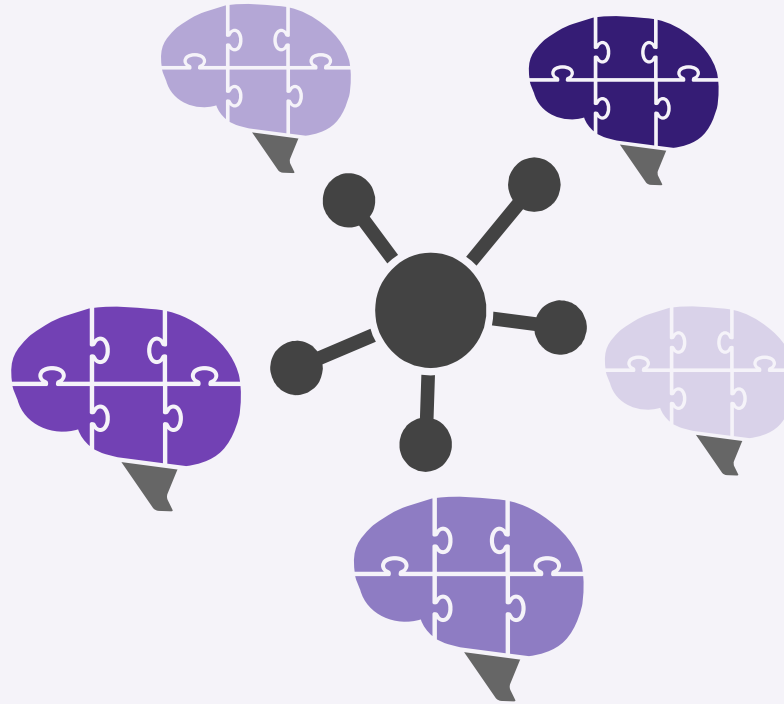


Reusing
neuroimaging data



Open Science

Fixing irreproducibility with **different data**



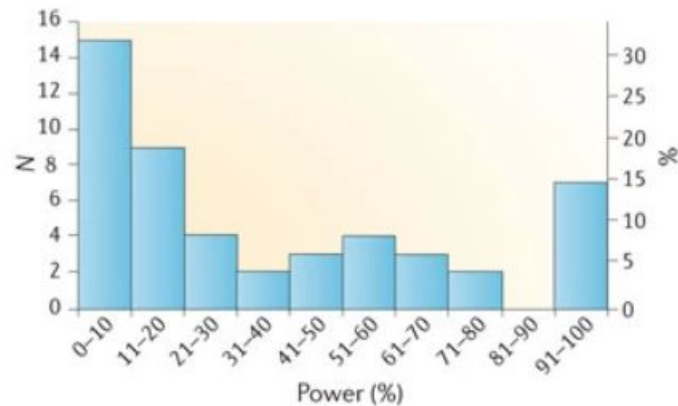
Opening up
neuroimaging **data**

Fixing irreproducibility with different data

Small samples

Low statistical power

Power of neuroscience studies



(Button et. al, 2013)

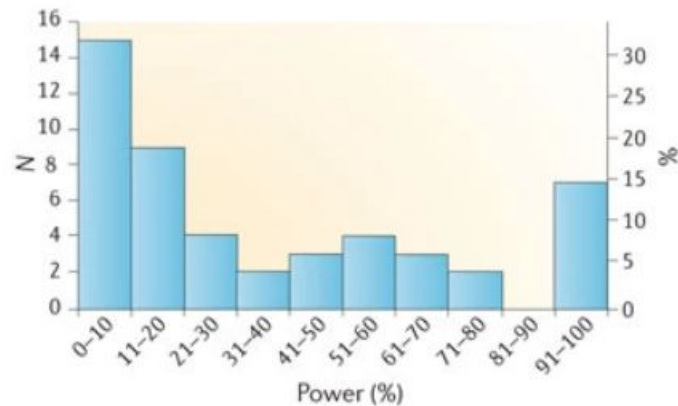
High rate of **false positives**
in the literature

Fixing irreproducibility with different data

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(Button et. al, 2013)

High rate of **false positives**
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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)

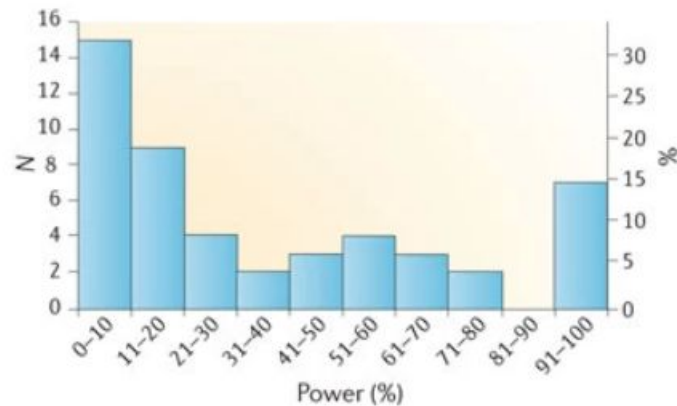
Lack of **generalisability**
and **fairness**

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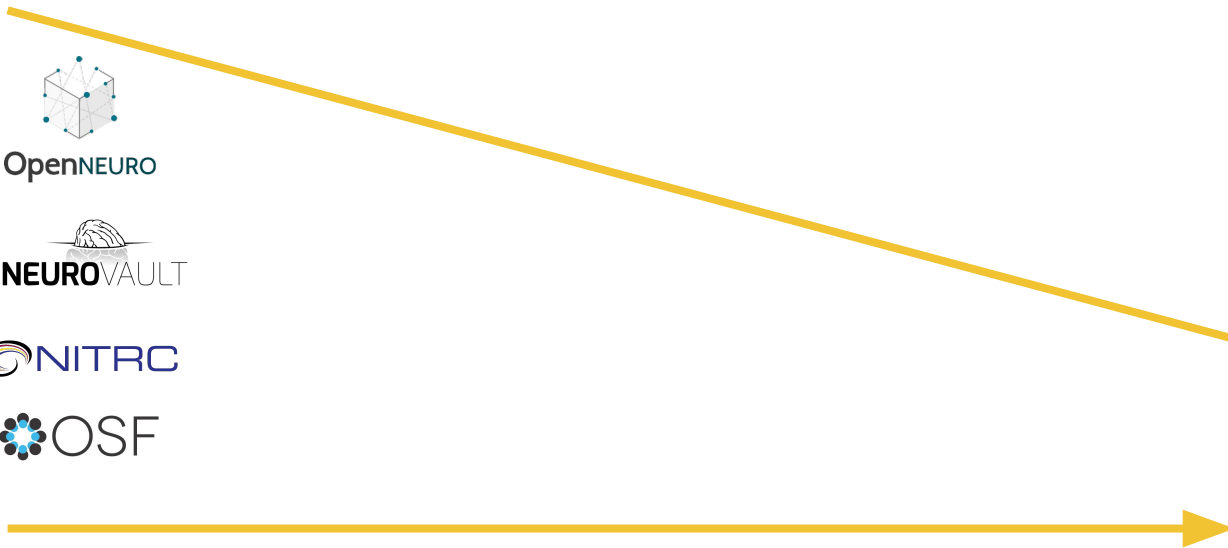
Lack of **generalisability**
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**Solution: Data
Sharing**

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

30 sub.



OpenNEURO



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HUMAN
Connectome
PROJECT

Cohort

100 000 sub.

biobank
improving the health of future generations

Neuroimaging data sharing

Single study

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OpenNEURO



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ABIDE
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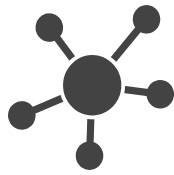
biobank[®]
improving the health of future generations

Contributions :



Opening up
neuroimaging data

Opening up neuroimaging data



Community standardization efforts



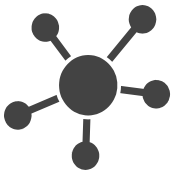
[Maumet* et al, Scientific Data 2016]
[Gorgolewski et al, Scientific Data 2016]

Data sharing and privacy



[Open Brain Consent, HBM 2021]

Opening up neuroimaging data



Community standardization efforts



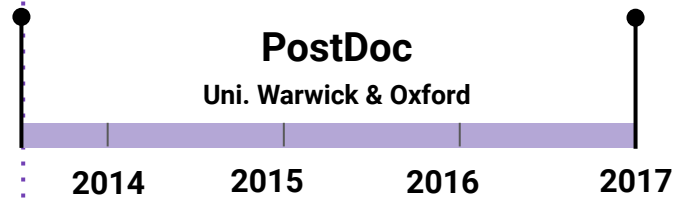
[Maumet* et al, Scientific Data 2016]
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Community standardization efforts



Community standardization efforts



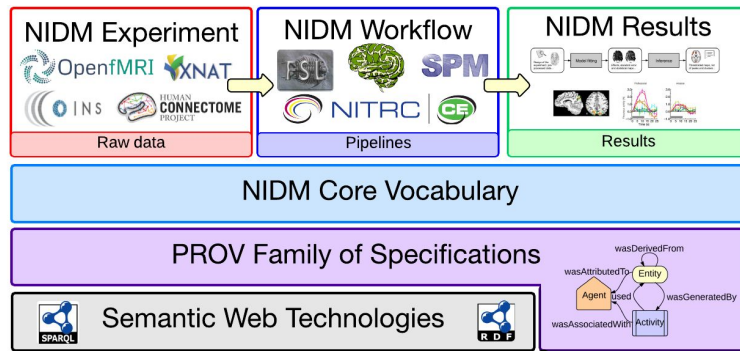
Jean-Baptiste Poline
Uni. Berkeley (USA)



David Keator
UCI (USA)

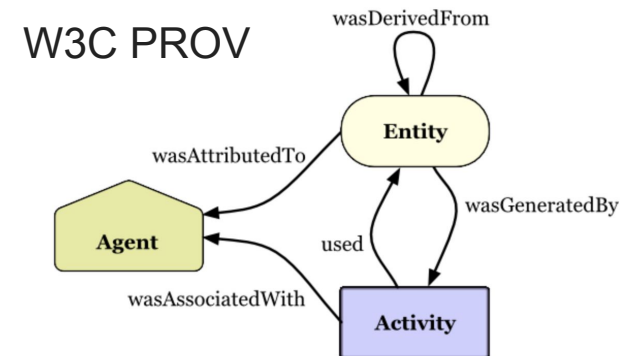


Neuroimaging Data Model
Semantic web



PostDoc
Uni. Warwick & Oxford

2014 2015 2016 2017



Community standardization efforts



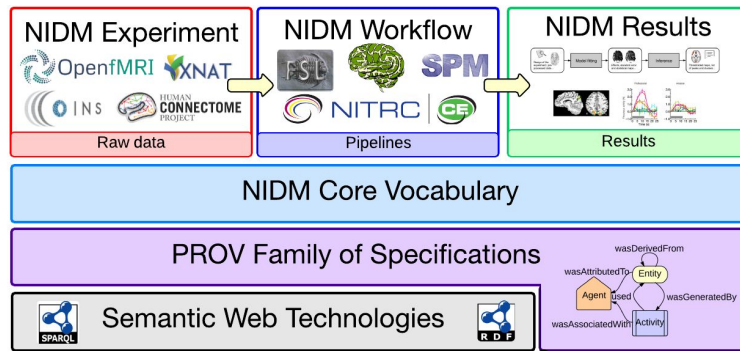
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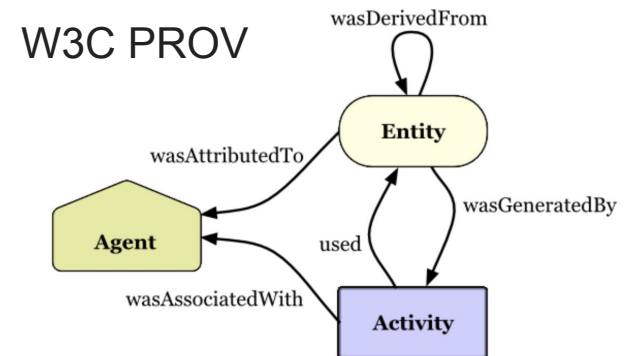


PostDoc
Uni. Warwick & Oxford

2014 2015 2016 2017



Tom Nichols
Uni. Warwick(UK)



Use-case: Neuro Meta-Analyses



[Maumet* et al, Sci Data 2016]

Community standardization efforts

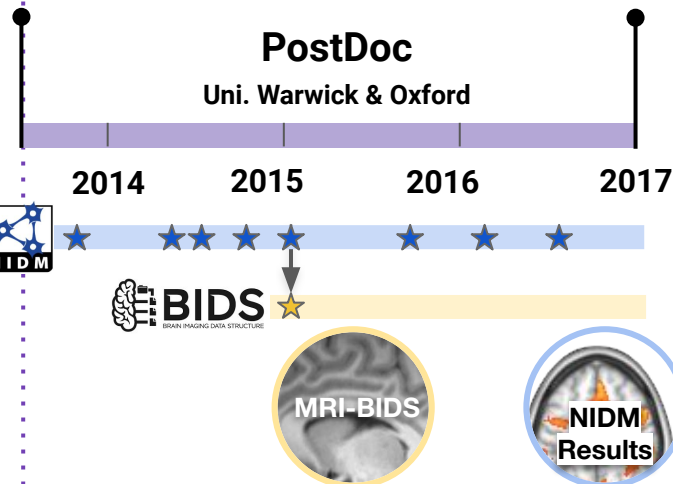


Chris Gorgolewski
Stanford Uni. (USA)



Brain Imaging Data Structure
File naming conventions + JSON sidecars

```
my_dataset/  
├── participants.tsv  
├── sub-01/  
│   ├── anat/  
│   │   └── sub-01_T1w.nii.gz  
│   └── func/  
│       ├── sub-01_task-rest_bold.nii.gz  
│       └── sub-01_task-rest_bold.json
```



[Gorgolewski et al, Sci Data 2016] [Maumet* et al, Sci Data 2016]

Community standardization efforts



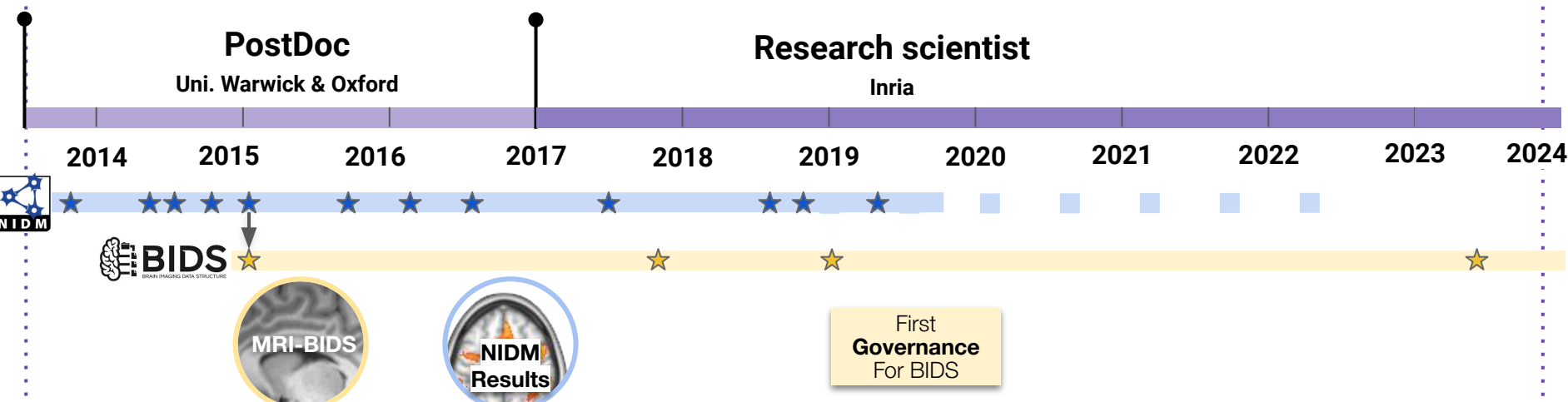
Chris Gorgolewski
Stanford Uni. (USA)



Brain Imaging Data Structure
File naming conventions + JSON sidecars

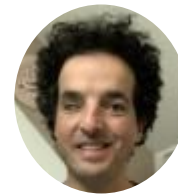
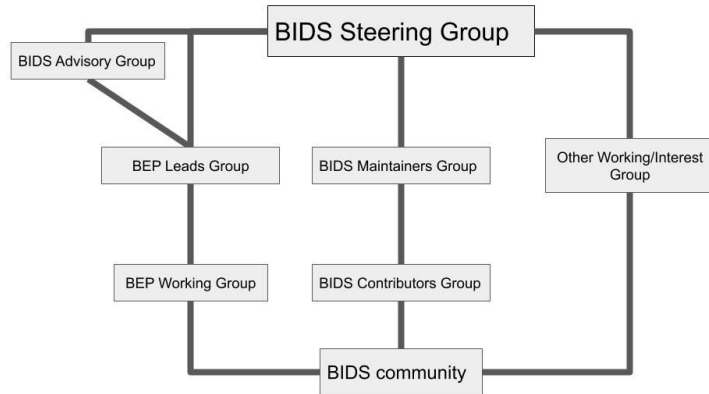
```
my_dataset/  
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│   ├── anat/  
│   │   └── sub-01_T1w.nii.gz  
│   └── func/  
│       ├── sub-01_task-rest_bold.nii.gz  
│       └── sub-01_task-rest_bold.json
```

>1 million BIDS-compliant images in 2024
Source: [MRIQC Api](#)



[Gorgolewski et al, Sci Data 2016] [Maumet* et al, Sci Data 2016]

Community standardization efforts



Ariel Rokem
Uni. Wash (USA)



Cyril Pernet
Copenhagen Uni. Hosp. (Denmark)



Yaroslav Halchenko
Dartmouth College (USA)



Dora Hermes
Mayo Clinic (USA)

BIDS steering Group

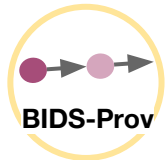
PostDoc
Uni. Warwick & Oxford

Research scientist
Inria

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024



First Governance For BIDS

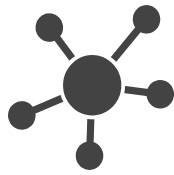


Elected on BIDS steering

[Gorgolewski et al, Sci Data 2016] [Maumet* et al, Sci Data 2016]

[Adon et al Ghosh* Maumet*, OHBM 2021]

Opening up neuroimaging data



Community standardization efforts



[Maumet* et al, Scientific Data 2016]
[Gorgolewski et al, Scientific Data 2016]

Data sharing and privacy



[Open Brain Consent, HBM 2021]

Data sharing and privacy

Are neuroimages anonymous?



Cyril Pernet
Copenhagen Uni Hosp
(Denmark)



Stephan Heunis
Rsrch Ctr Jülich
(Germany)

[Open Brain Consent, HBM 2021]

Data sharing and privacy



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Copenhagen Uni Hosp
(Denmark)



Stephan Heunis
Rsrch Ctr Jülich
(Germany)

Are neuroimages anonymous?



Name: Depont
First : Nathalie
Birth date : 10/11/1995
...

[Open Brain Consent, HBM 2021]

Data sharing and privacy



Cyril Pernet
Copenhagen Uni Hosp
(Denmark)



Stephan Heunis
Rsrch Ctr Jülich
(Germany)

Are neuroimages anonymous?



1. Removing directly identifiable information

[Open Brain Consent, HBM 2021]

Data sharing and privacy



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[Open Brain Consent, HBM 2021]

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Are neuroimages anonymous?



1. Removing directly identifiable information



2. Defacing

[Open Brain Consent, HBM 2021]

Data sharing and privacy



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Copenhagen Uni Hosp
(Denmark)



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(Germany)

Are neuroimages anonymous?



1. Removing directly identifiable information



2. Defacing



Anonymous (USA)

[Open Brain Consent, HBM 2021]

Data sharing and privacy



Cyril Pernet
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Are neuroimages anonymous?



1. Removing directly identifiable information



2. Defacing



Anonymous (USA)

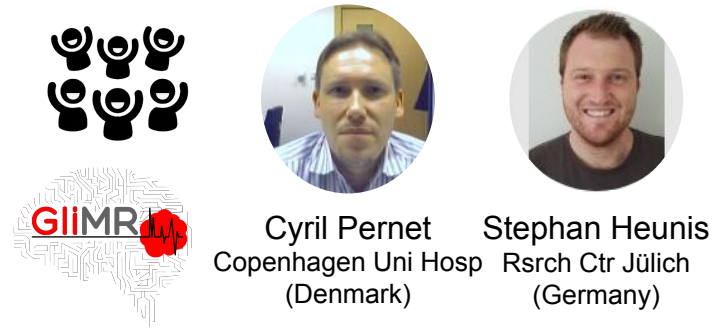


Not anonymous (EU)

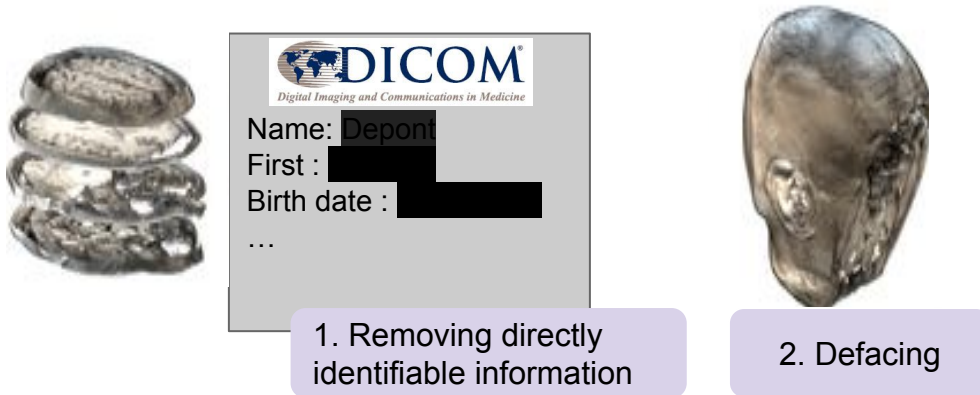
General Data Protection Regulation (GDPR) → Individualisation

[Open Brain Consent, HBM 2021]

Data sharing and privacy



Are neuroimages anonymous?



- ✓ Anonymous (USA)
- ✗ Not anonymous (EU)

General Data Protection Regulation (GDPR) → Individualisation

Open Brain Consent GDPR edition

Consent form

Signed by participants

"[...] data might also be used for other future research projects in the field of medical and cognitive neuroscience."

Data User Agreement

Signed by researchers

"[...] I will not attempt to [...] retrieve the identity of the study participants."

13 languages

Bosnian, Czech, German, Greek, Spanish, Finnish, French, Italian, Dutch, Norwegian, Portuguese, Turkish



Anne Hespel
CHU Rennes

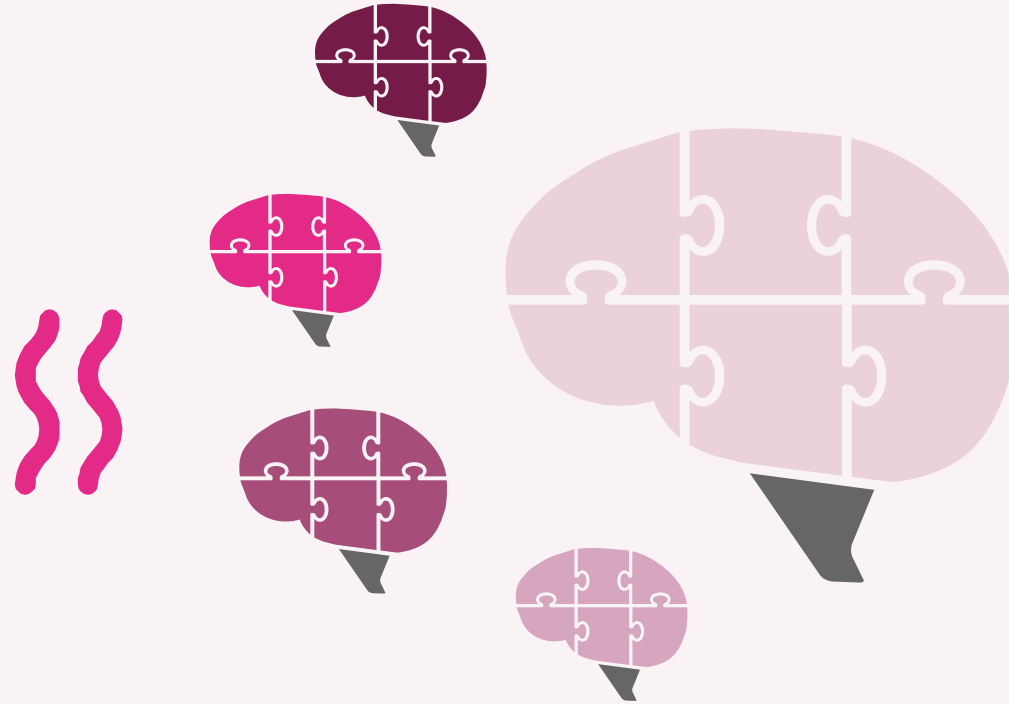


Elise Bannier
CHU Rennes

French

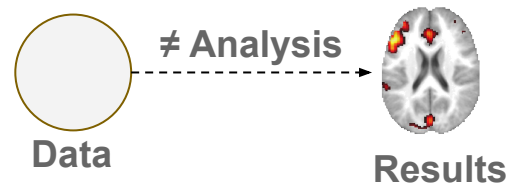
[Open Brain Consent, HBM 2021]

Investigating irreproducibility with **different analyses**

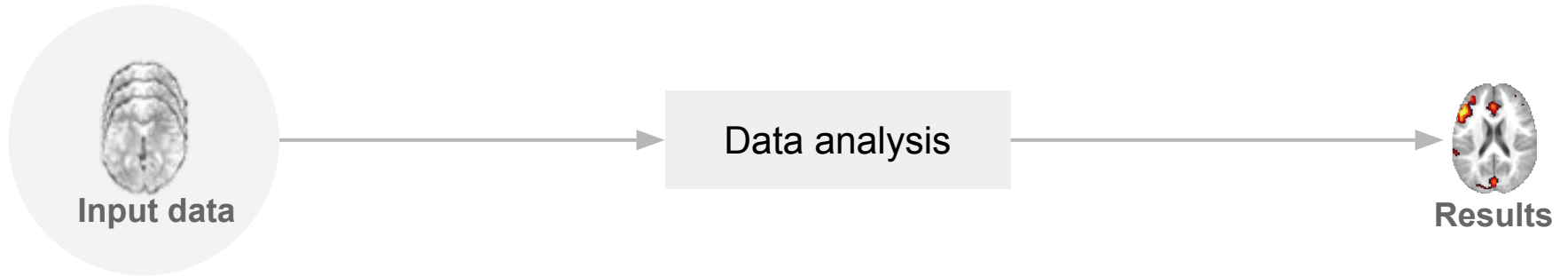


2- On the **Vibration of effects** in neuroimaging

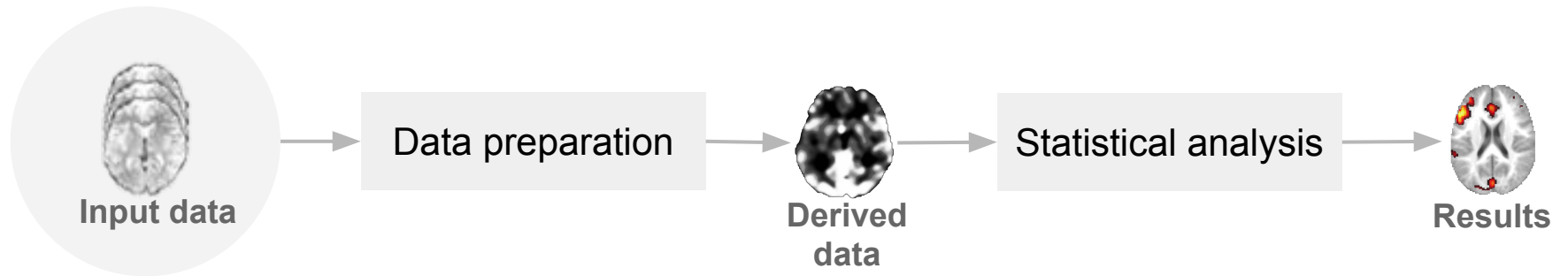
A multiplicity of analysis pipelines



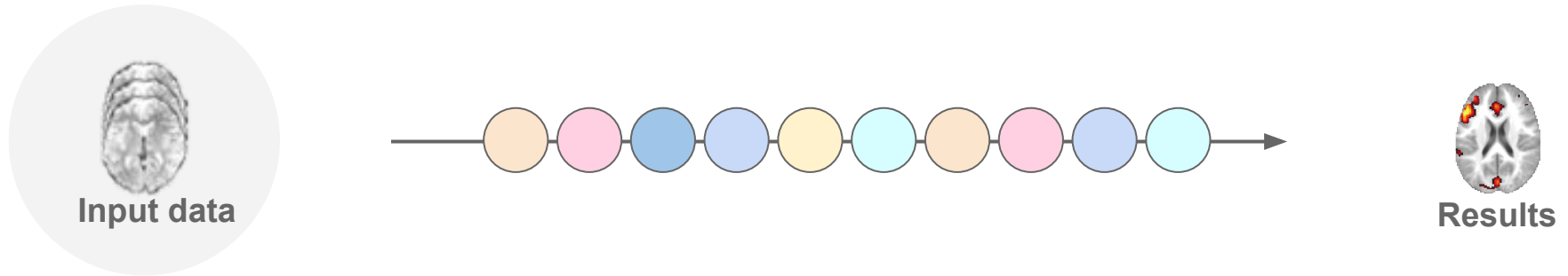
A multiplicity of analysis pipelines



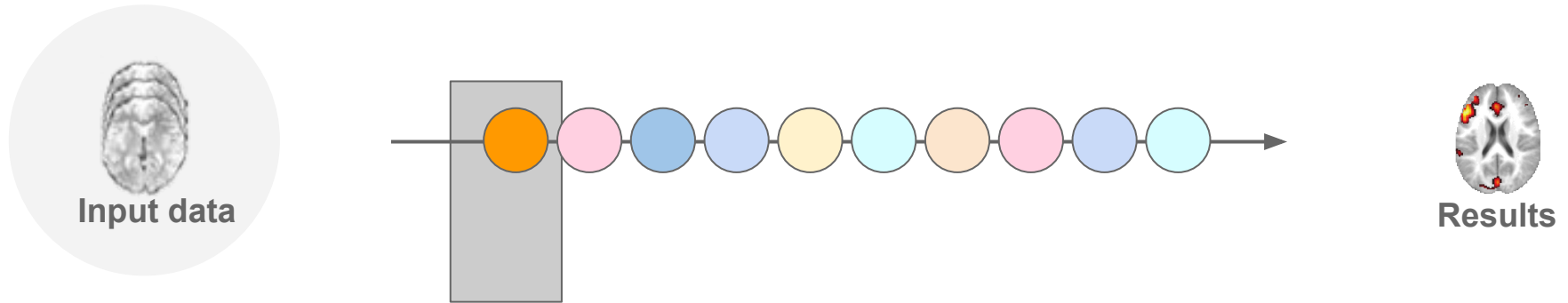
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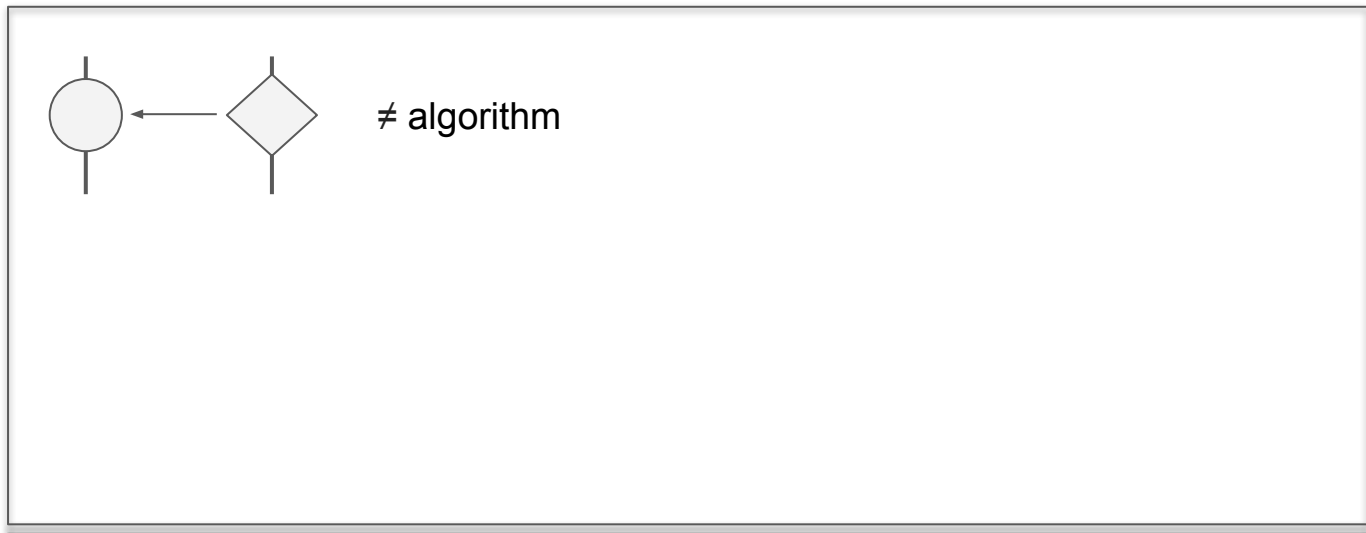
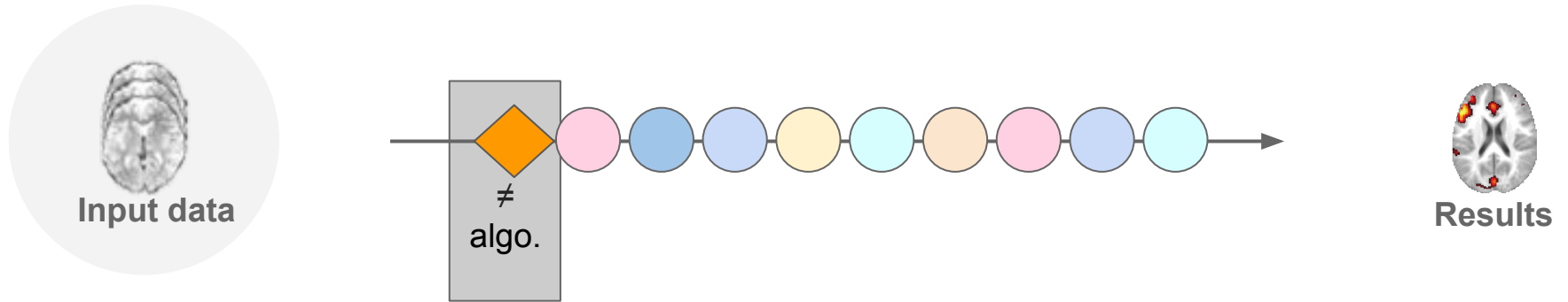
A multiplicity of analysis pipelines



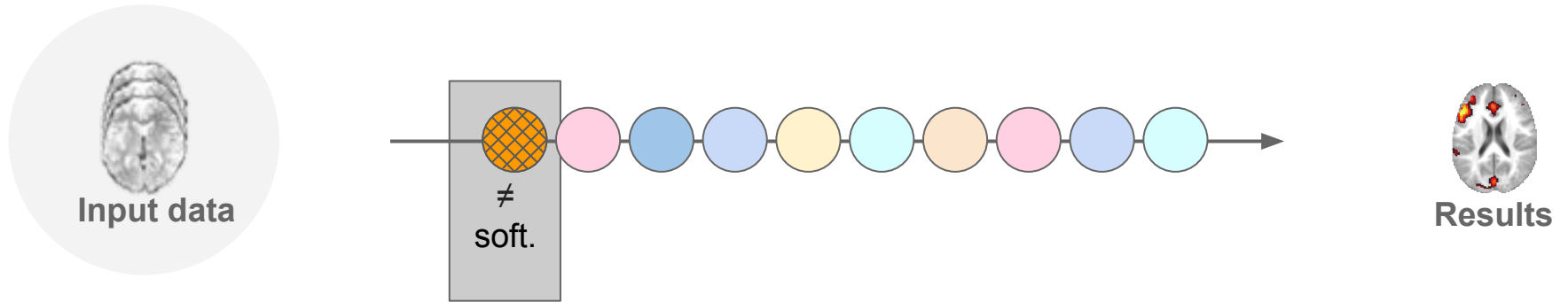
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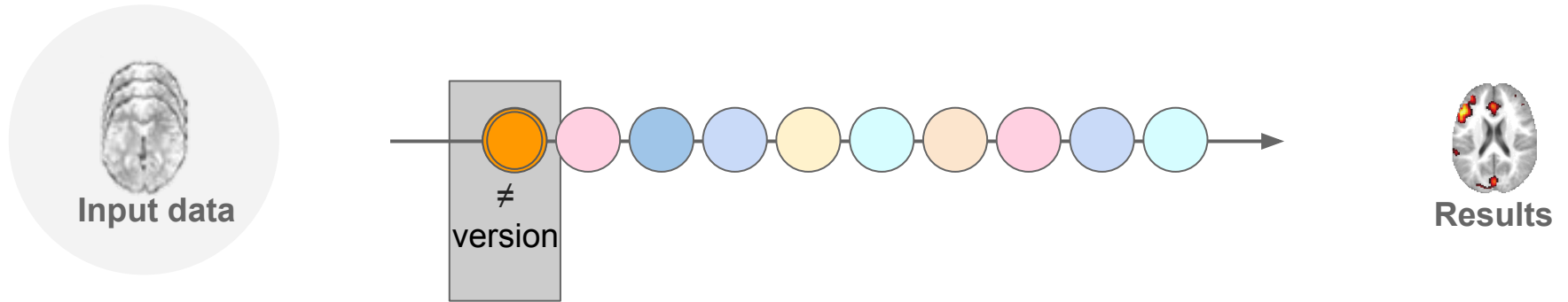
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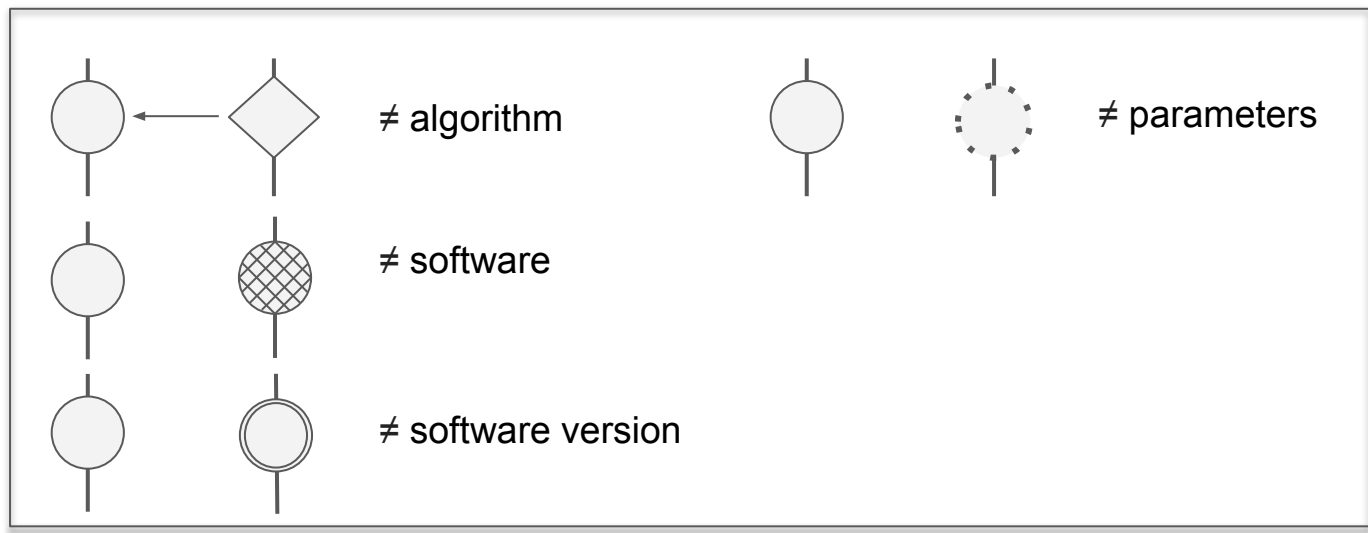
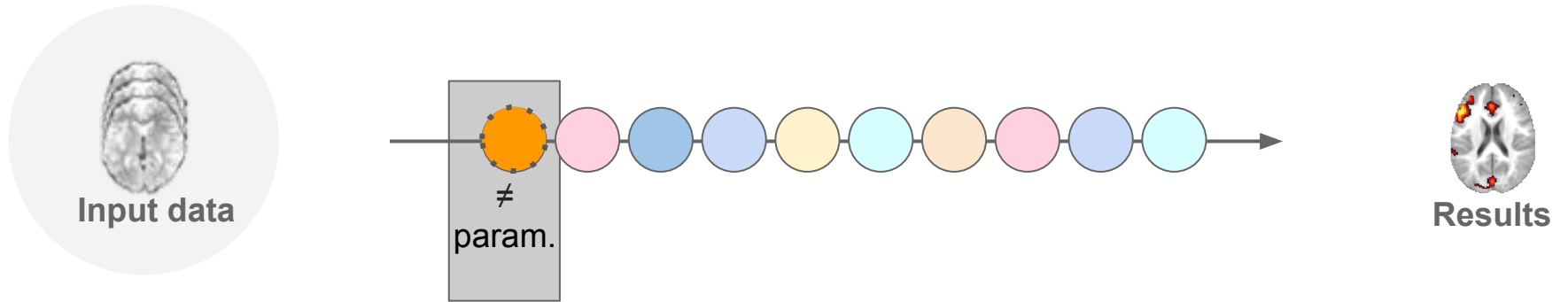
A multiplicity of analysis pipelines



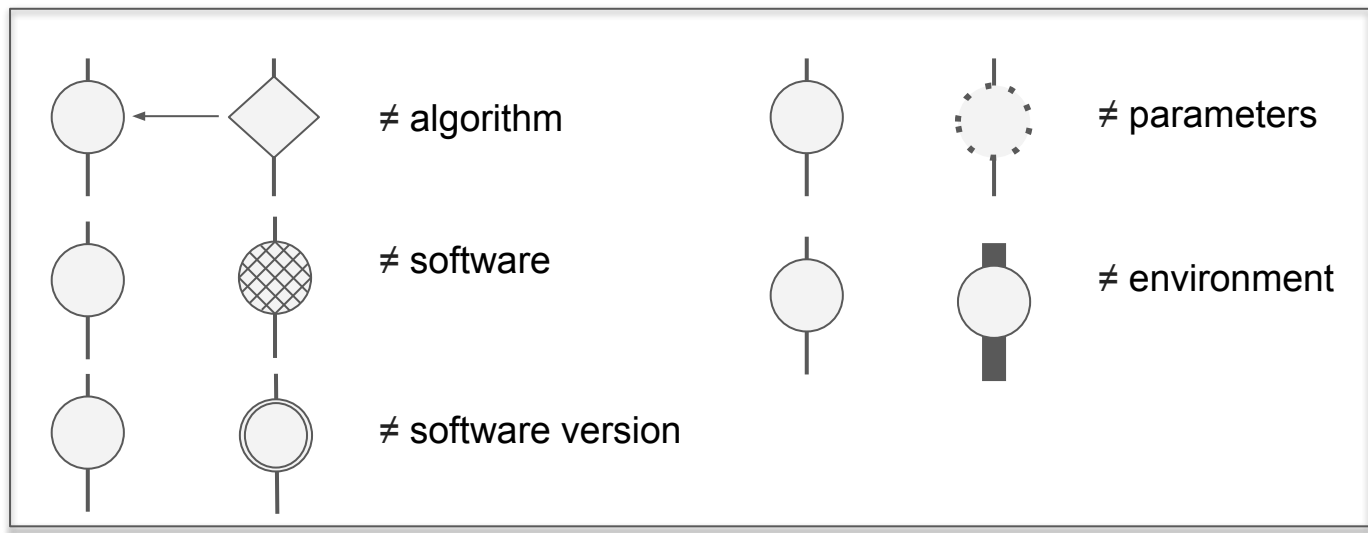
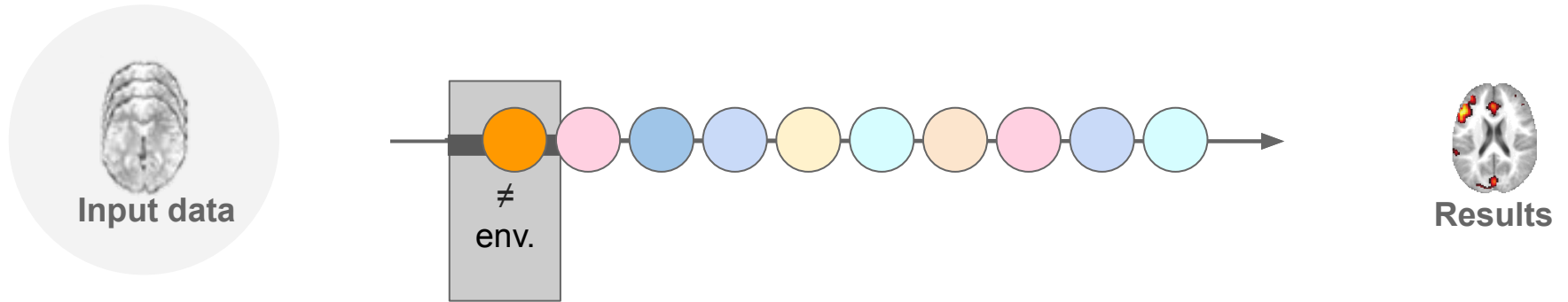
A multiplicity of analysis pipelines



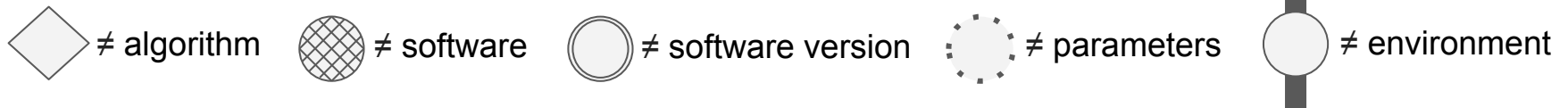
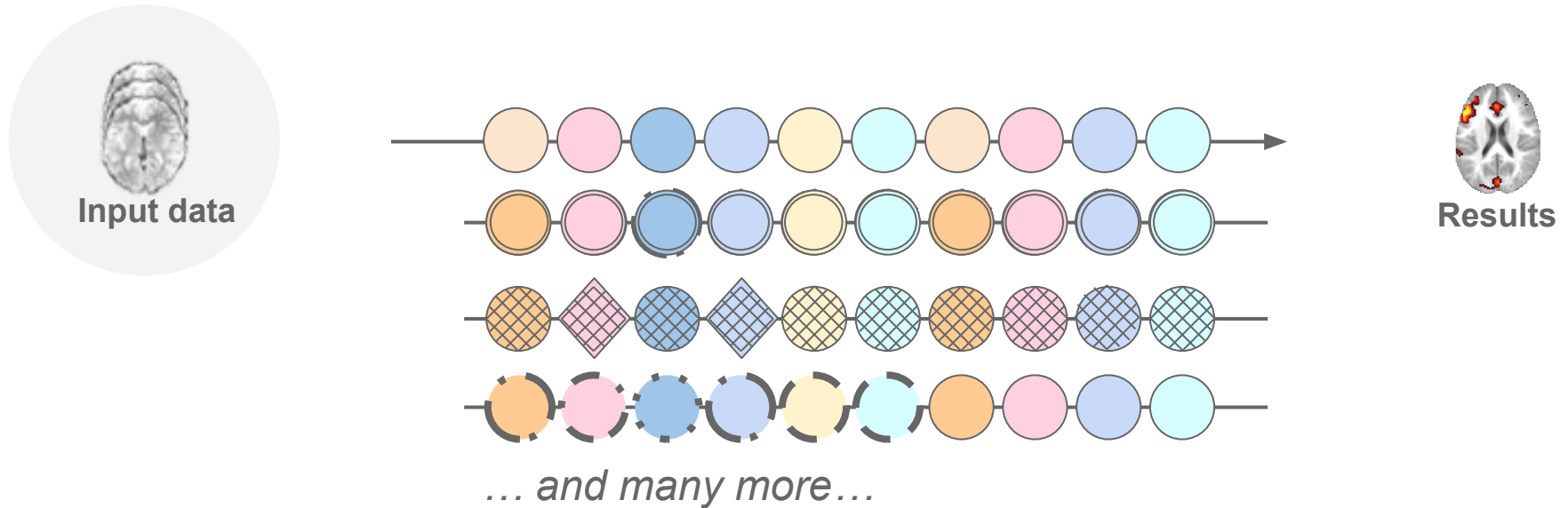
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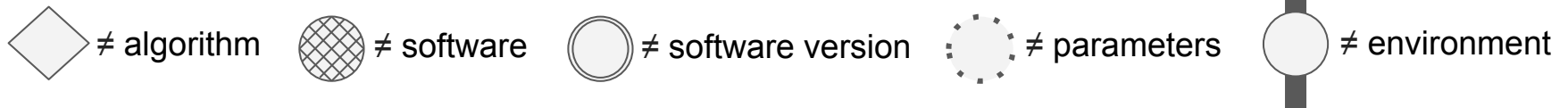
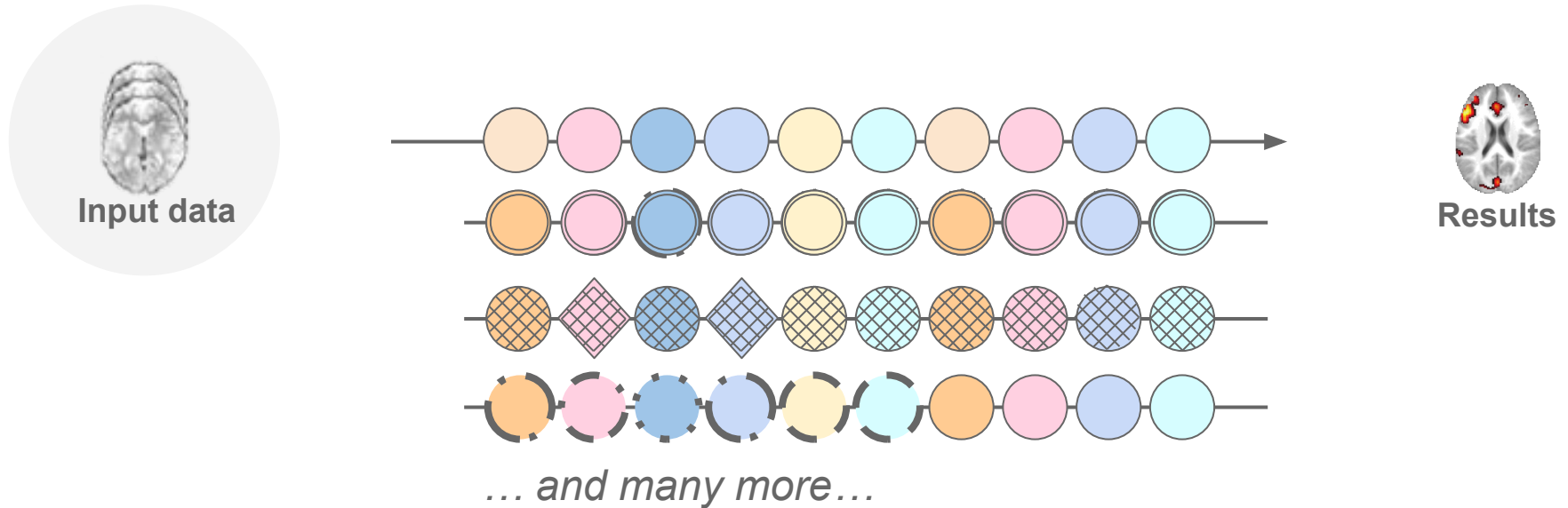
A multiplicity of analysis pipelines



A multiplicity of analysis pipelines



A multiplicity of analysis pipelines



Contributions :

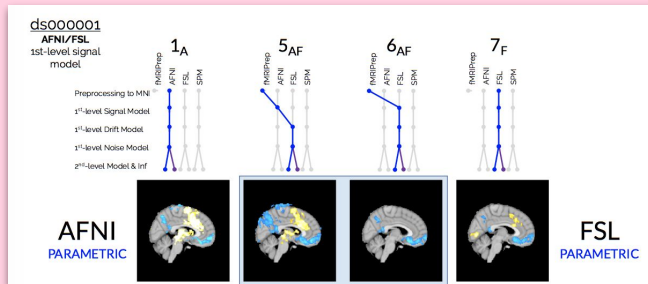


On the vibration of effects in neuroimaging

On the vibration of effects in neuroimaging

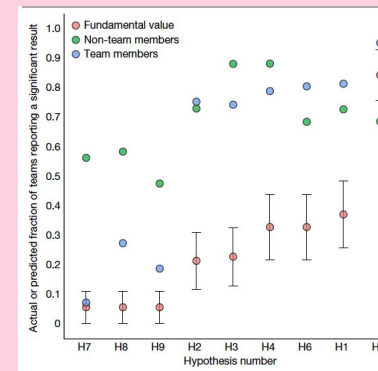


Variability across neuroimaging software



[Bowring Maumet* Nichols*, HBM 2019]
[Bowring Nichols* Maumet*, HBM 2021]

Variability across neuroimaging experts

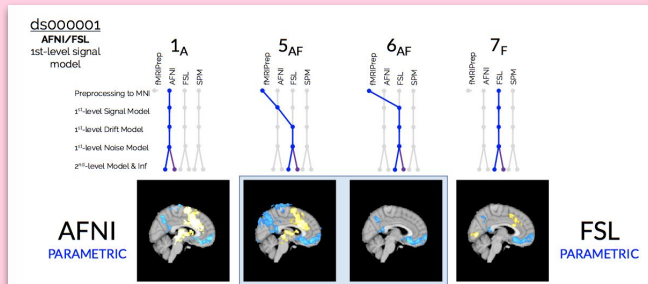


[Botvinik-Nezer et al, Nature 2020]



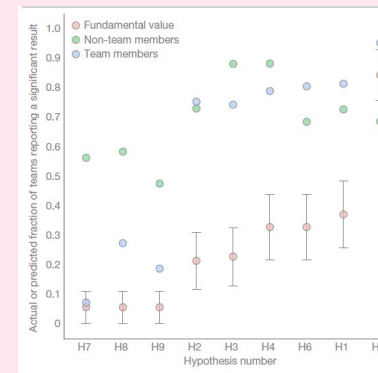
On the vibration of effects in neuroimaging

Variability across neuroimaging software



[[Bowring](#) [Maumet*](#) [Nichols*](#), HBM 2019]
[[Bowring](#) [Nichols*](#) [Maumet*](#), HBM 2021]

Variability across neuroimaging experts



[[Botvinik-Nezer et al](#), Nature 2020]

Variability across neuroimaging software

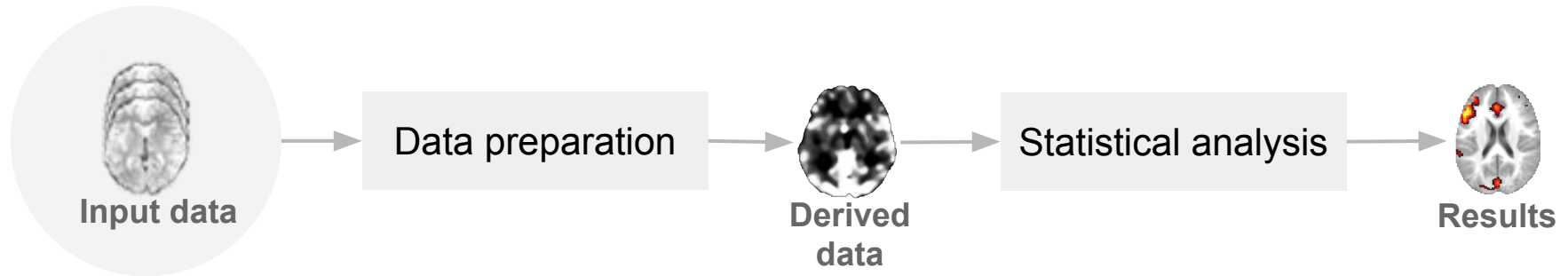


Alex Bowring



Tom Nichols
Oxford Uni. (UK)

Principles of functional MRI



Variability across neuroimaging software



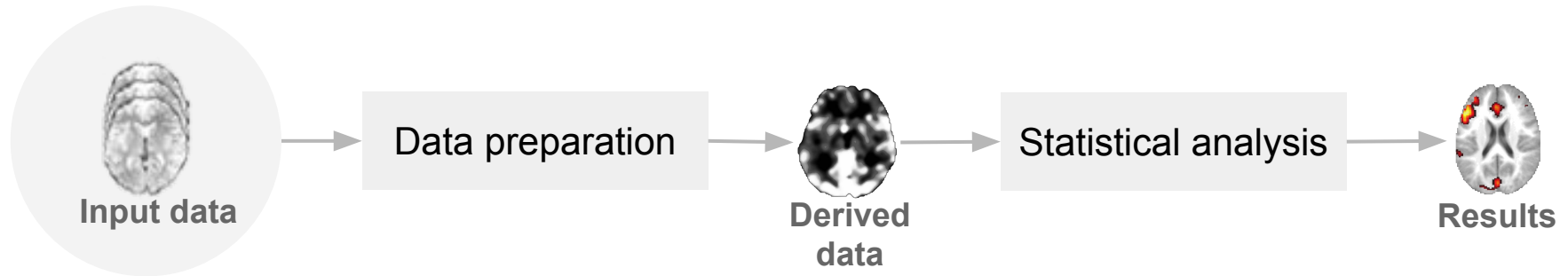
Alex Bowring



Tom Nichols

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Principles of functional MRI



Variability across neuroimaging software



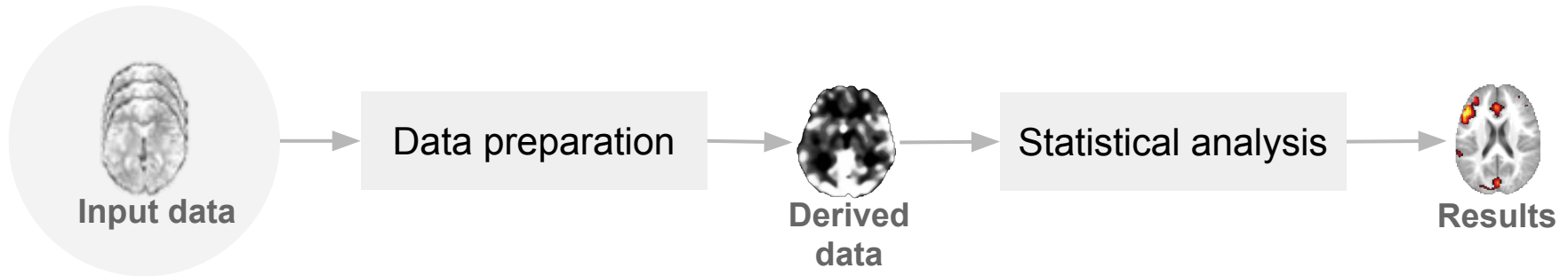
Alex Bowring



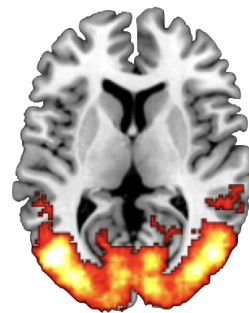
Tom Nichols

Oxford Uni. (UK)

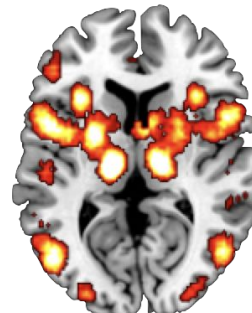
Principles of functional MRI



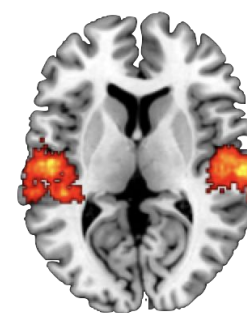
fMRI results: Activations maps



 Visual



 Hand motion



 Music

Variability across neuroimaging software



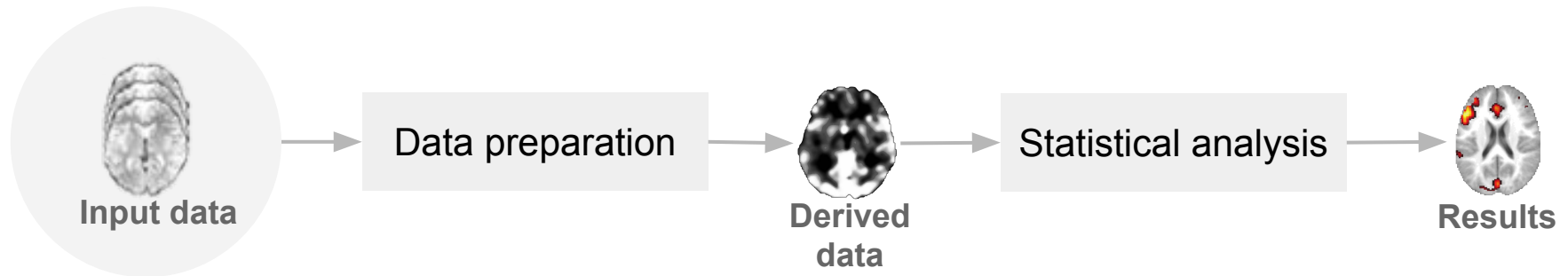
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Principles of functional MRI



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

Variability across neuroimaging software



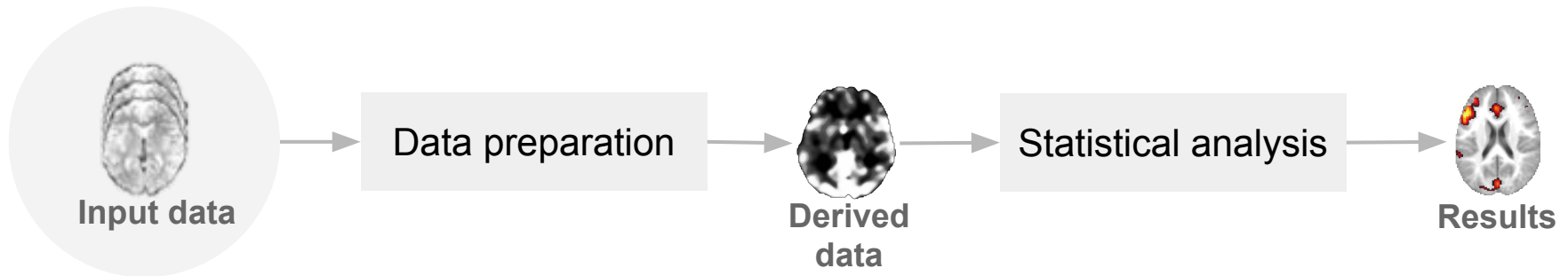
Alex Bowring



Tom Nichols

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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

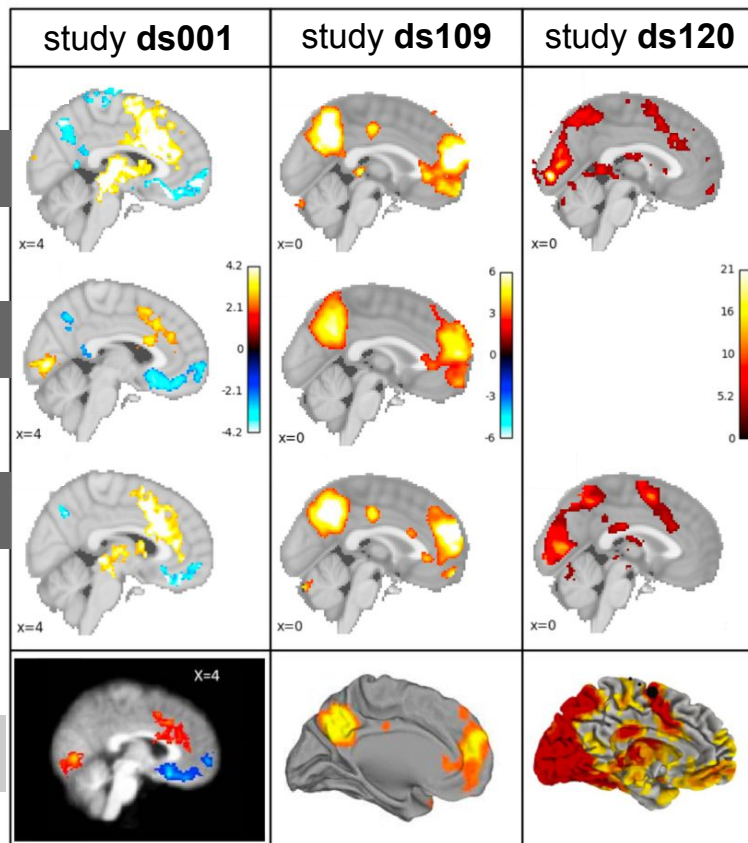


Alex Bowring



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- Variability in the activation maps



[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software

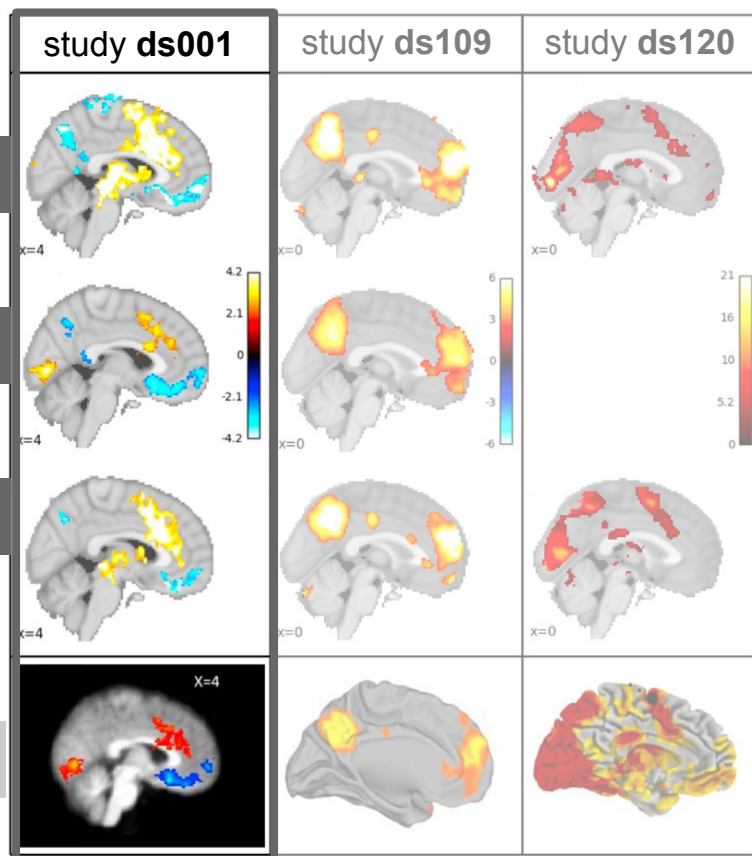


Alex Bowring



Tom Nichols
Oxford Uni. (UK)

- Variability in the activation maps



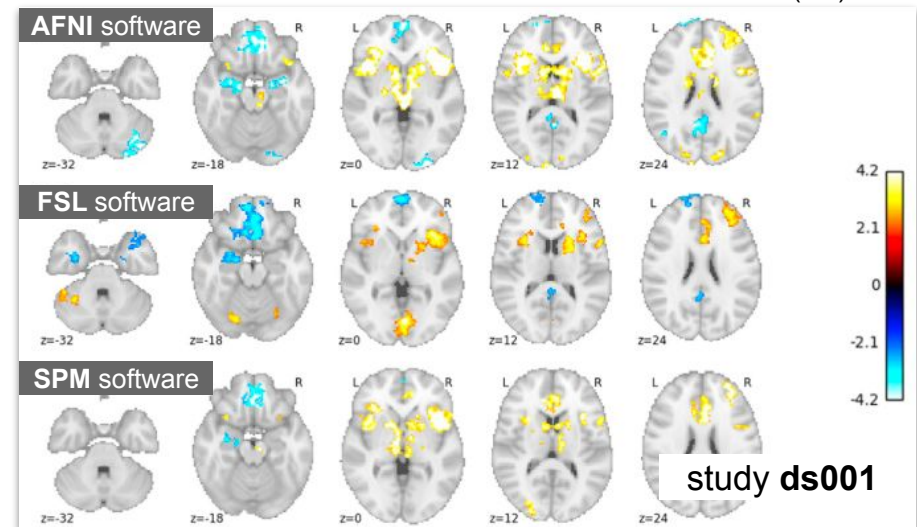
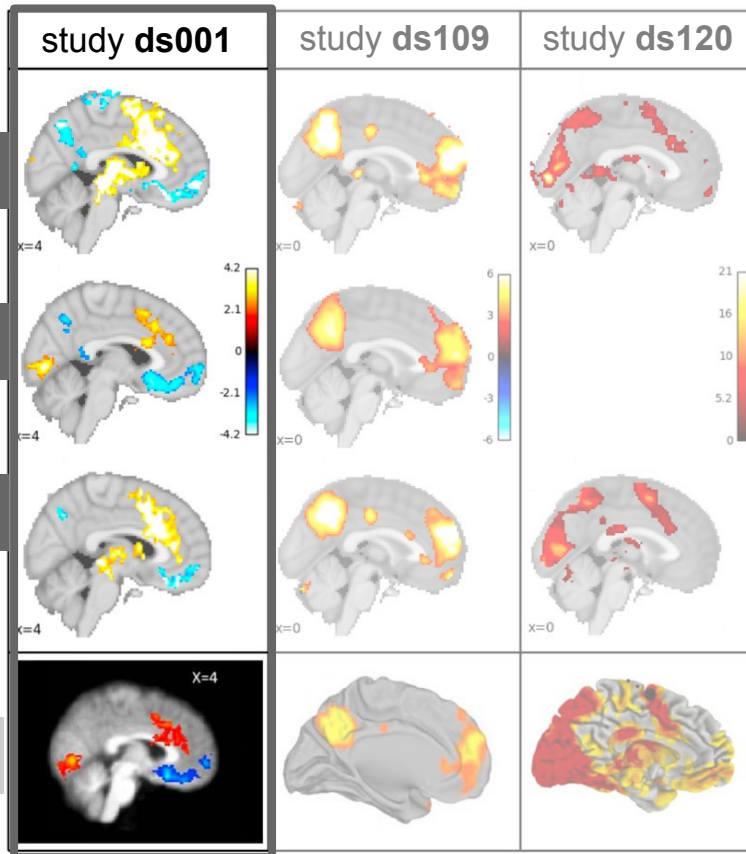
[Bowring Maumet* Nichols*, HBM 2019]

Variability across neuroimaging software



Alex Bowring Tom Nichols
Oxford Uni. (UK)

- Variability in the activation maps



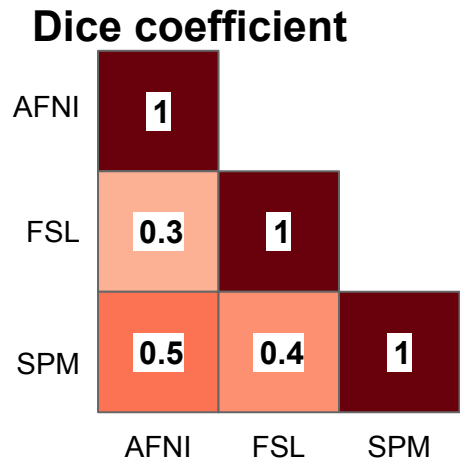
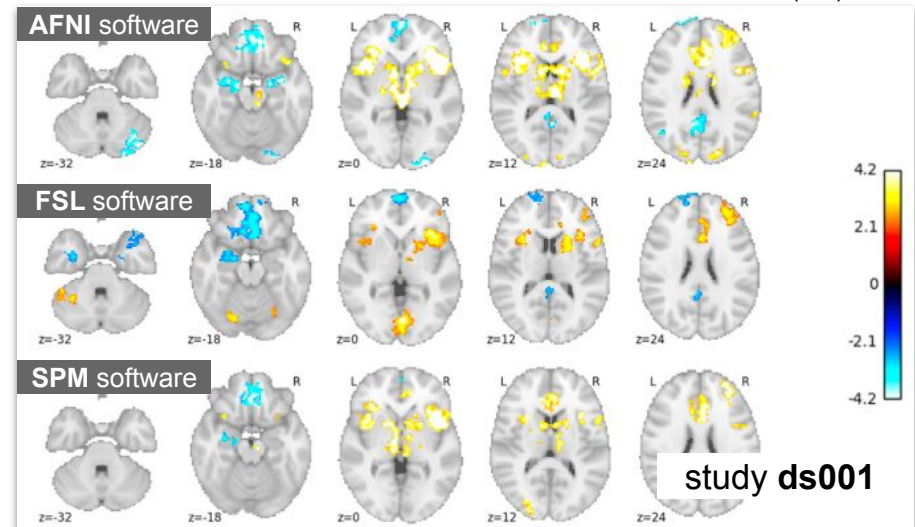
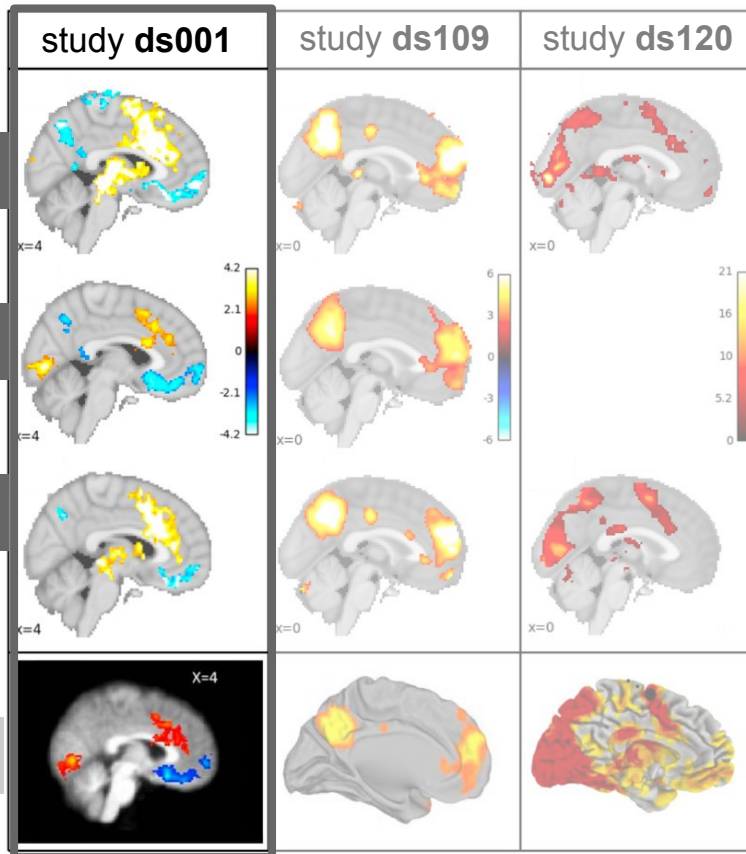
[Bowring Maumet* Nichols*, HBM 2019]

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

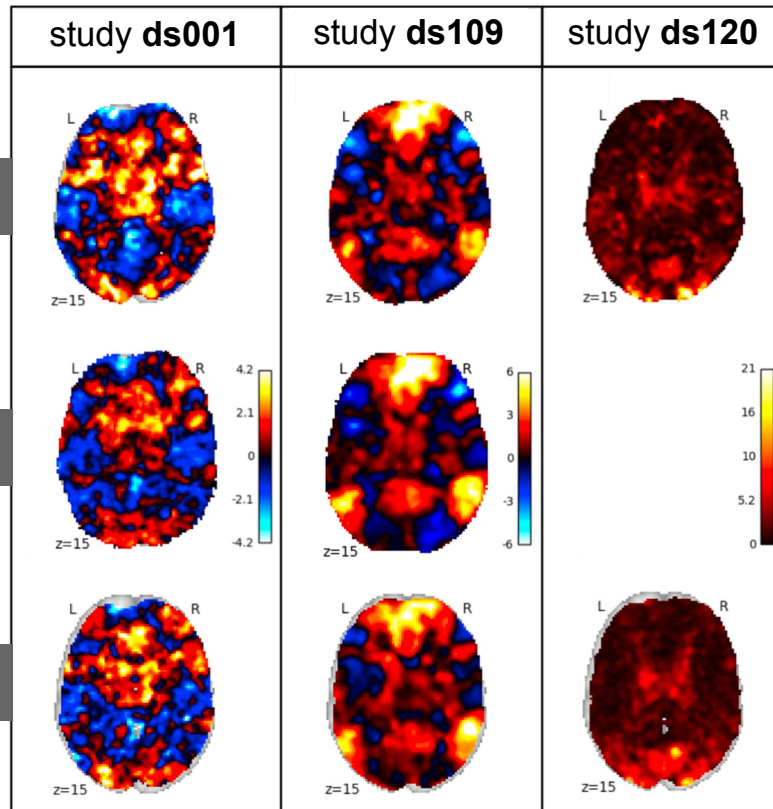


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Tom Nichols
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- Variability in the unthresholded statistic maps



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



Alex Bowring

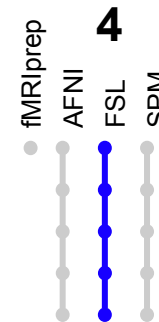
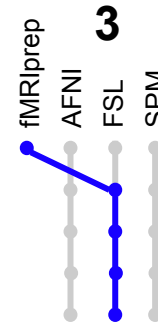
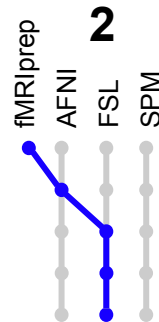
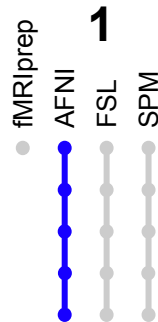


Tom Nichols
Oxford Uni. (UK)

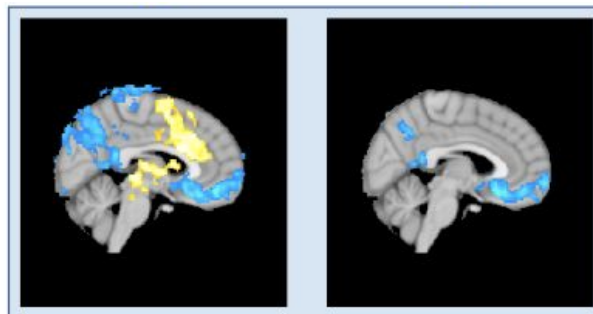
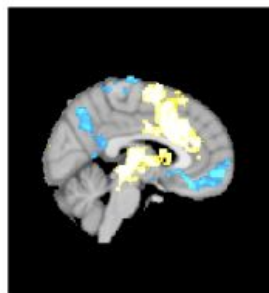
Goal 2: Investigate how remaining differences in software implementations can explain the observed differences

study ds001

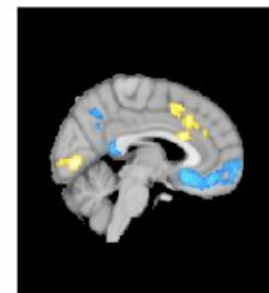
1. Preprocessing
2. Subject-level Signal
3. Subject-level Drift
4. Subject-level Noise
5. Group-level Stat



AFNI
software



FSL
software



[Bowring Nichols* Maumet*, HBM 2021]

Variability across neuroimaging software



Alex Bowring

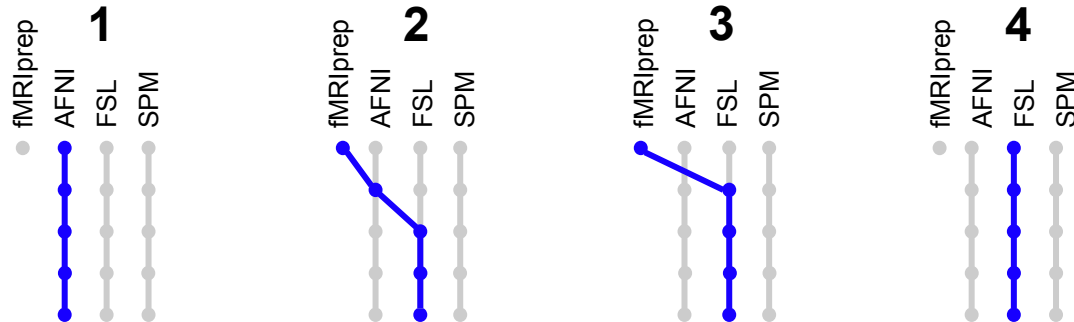


Tom Nichols
Oxford Uni. (UK)

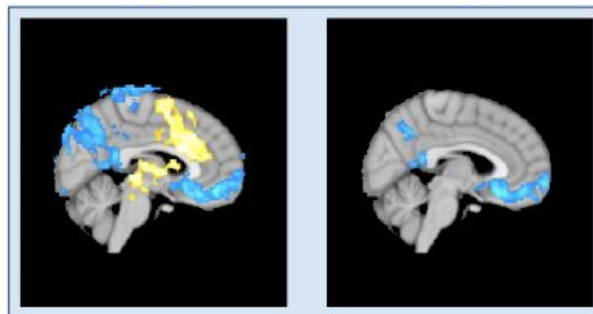
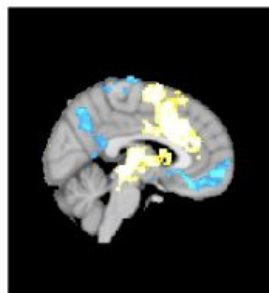
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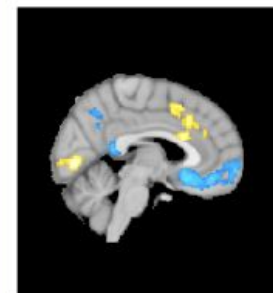
1. Preprocessing
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AFNI
software



FSL
software



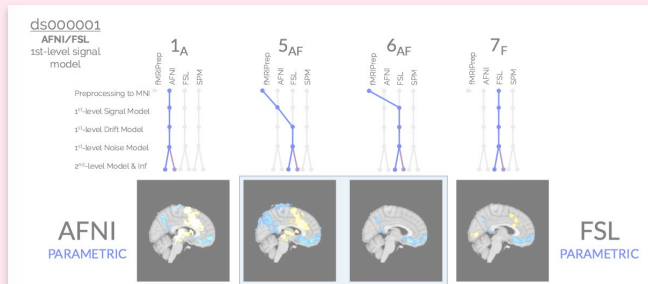
Conclusion: 1 main contributing factor was found but different for each study

[Bowring Nichols* Maumet*, HBM 2021]



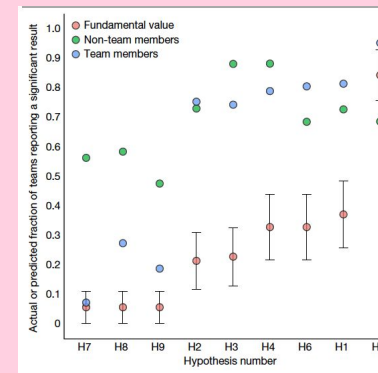
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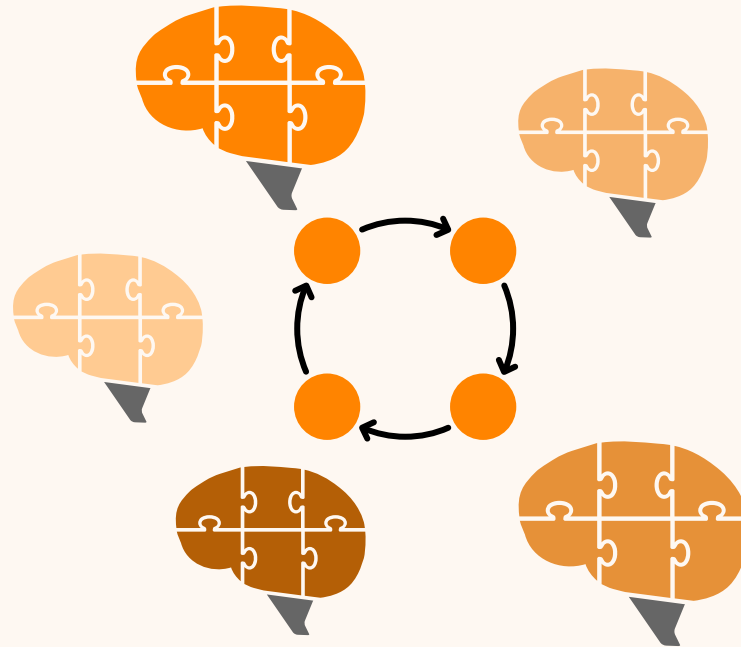
[Bowring Maumet* Nichols*, HBM 2019]
[Bowring Nichols* Maumet*, HBM 2021]

Variability across neuroimaging experts



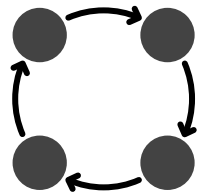
[Botvinik-Nezer et al, Nature 2020]

A consequence of a more reproducible research

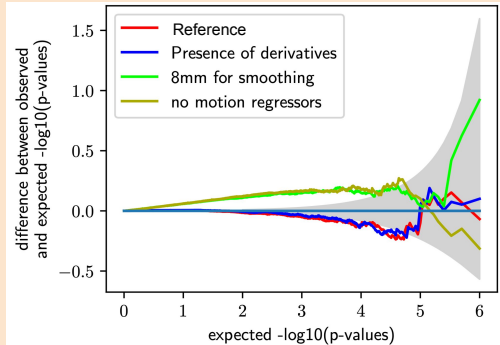


3- Reusing neuroimaging data

Reusing neuroimaging data

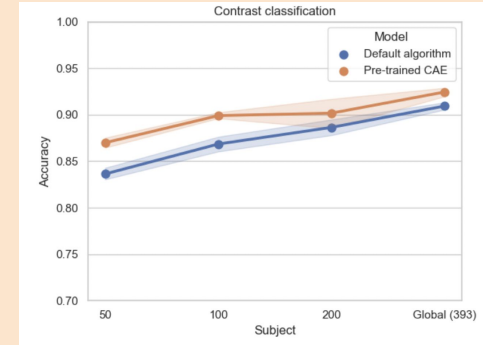


Validity of mega-analyses



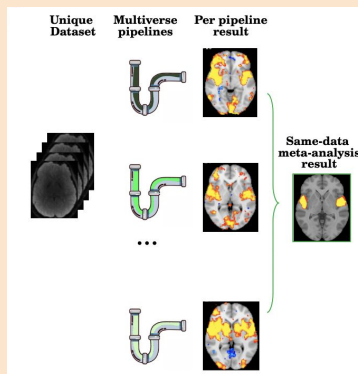
[[Rolland Maurel](#) **Maumet**, ISBI 2022]

Leveraging large datasets



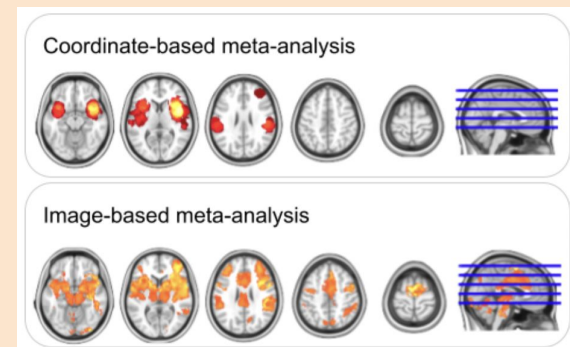
[[Germani Fromont*](#) **Maumet***, Gigascience 2023]

Multiverse analyses



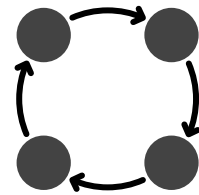
[[Lefort-Besnard](#) **Nichols*** **Maumet***, OHBM 2024]

Meta-analyses

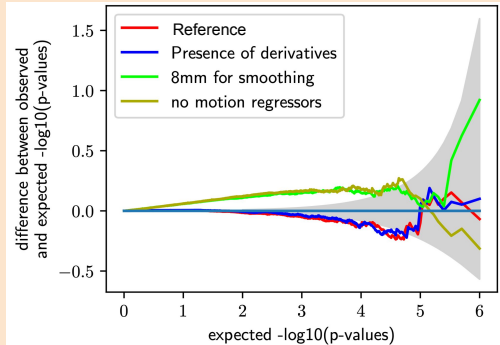


[**Maumet*** and Nichols, in prep]

Reusing neuroimaging data



Validity of mega-analyses



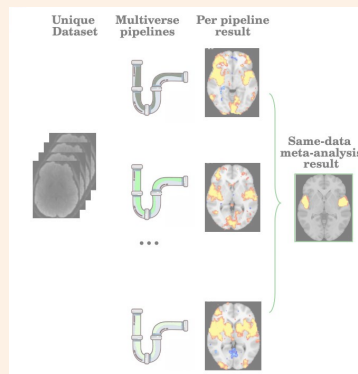
[[Rolland Maurel Maumet](#), ISBI 2022]

Leveraging large datasets



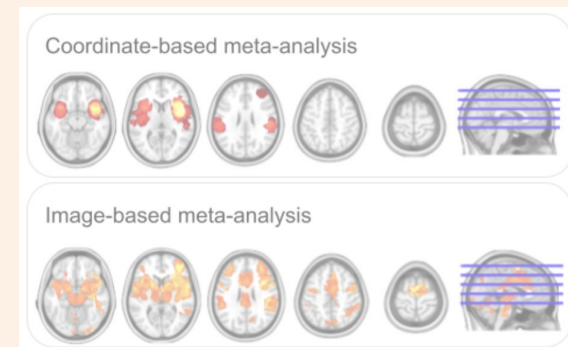
[[Germani Fromont* Maumet*](#), Gigascience 2023]

Multiverse analyses



[[Lefort-Besnard Nichols* Maumet*](#), OHBM 2024]

Meta-analyses



[[Maumet*](#) and Nichols, in prep]

Validity of neuroimaging mega-analyses

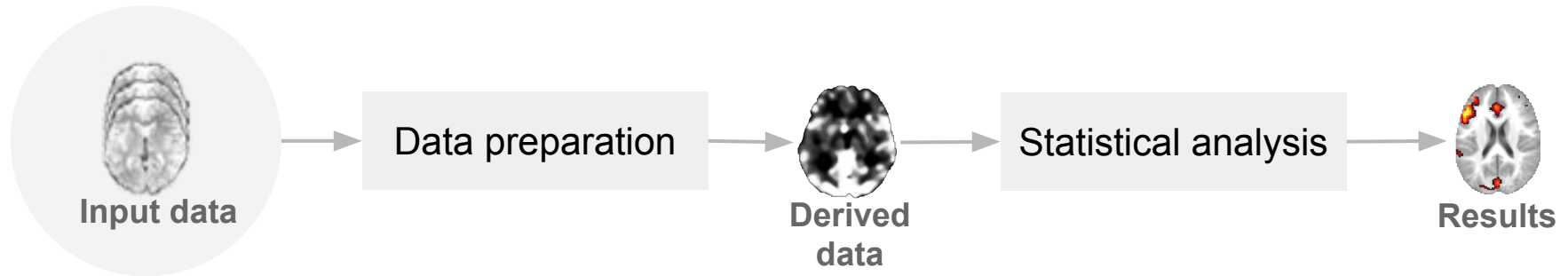


Xavier
Rolland



Pierre
Maurel

Multi-stage functional MRI analysis



Validity of neuroimaging mega-analyses

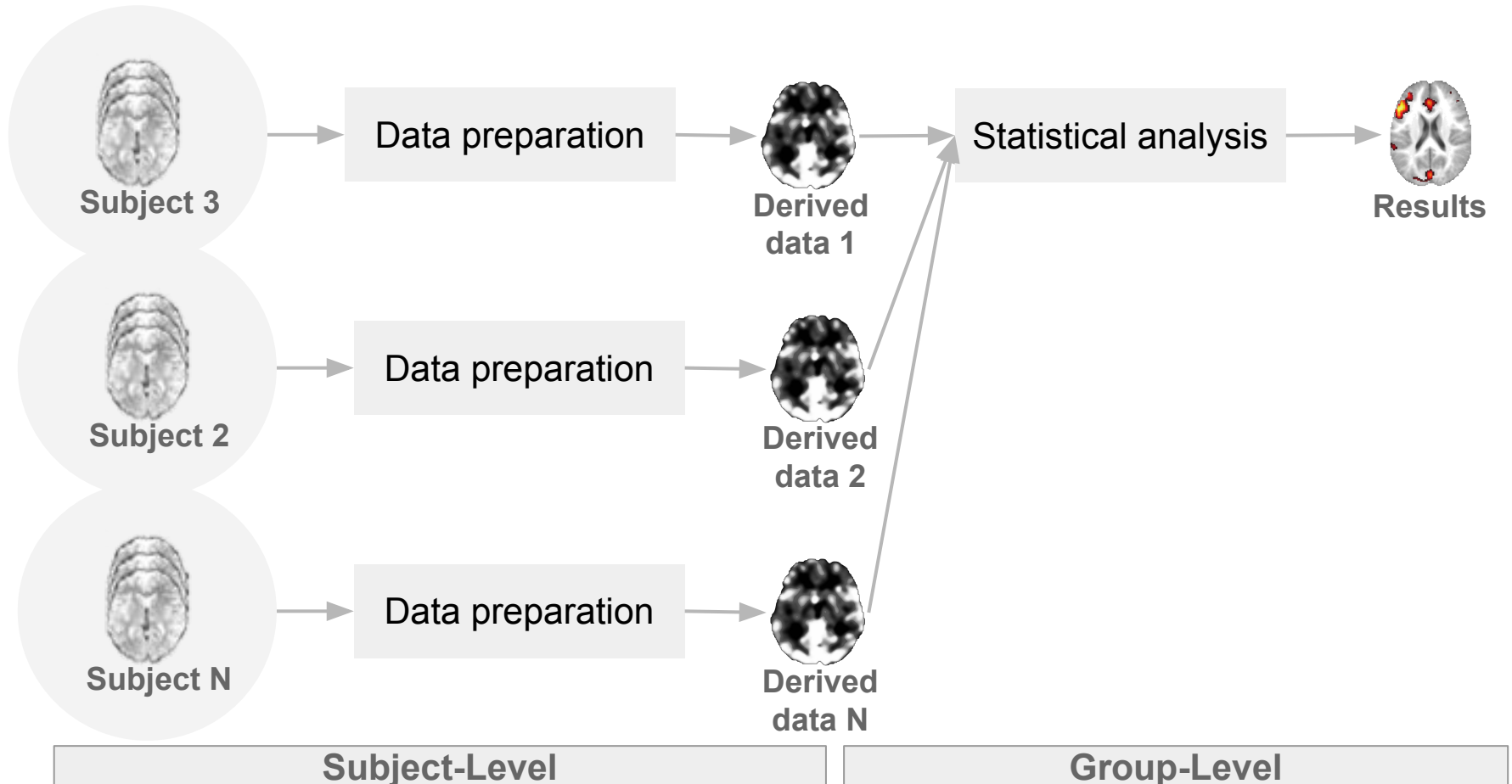


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Multi-stage functional MRI analysis



Validity of neuroimaging mega-analyses

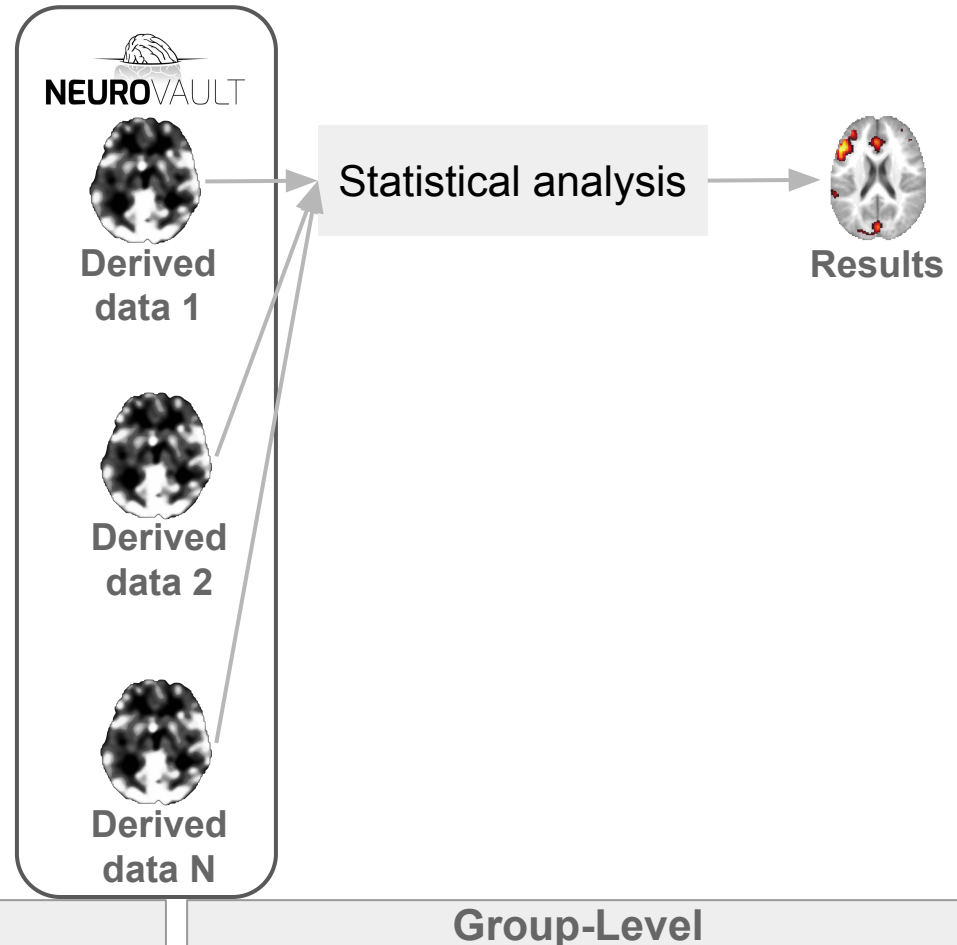


Xavier Rolland



Pierre Maurel

Multi-stage functional MRI analysis



Validity of neuroimaging mega-analyses

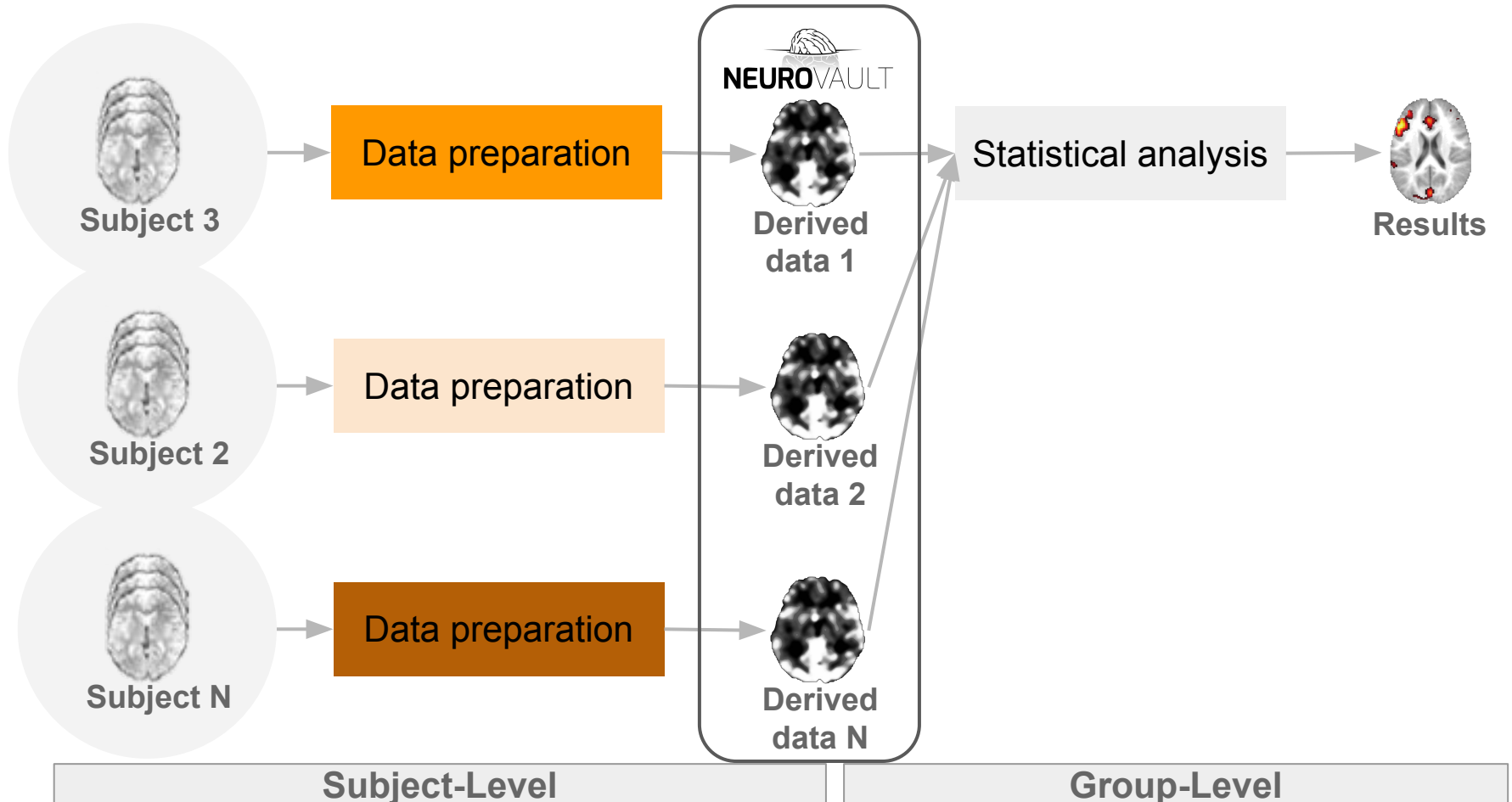


Xavier Rolland



Pierre Maurel

Multi-stage functional MRI analysis



Validity of neuroimaging mega-analyses

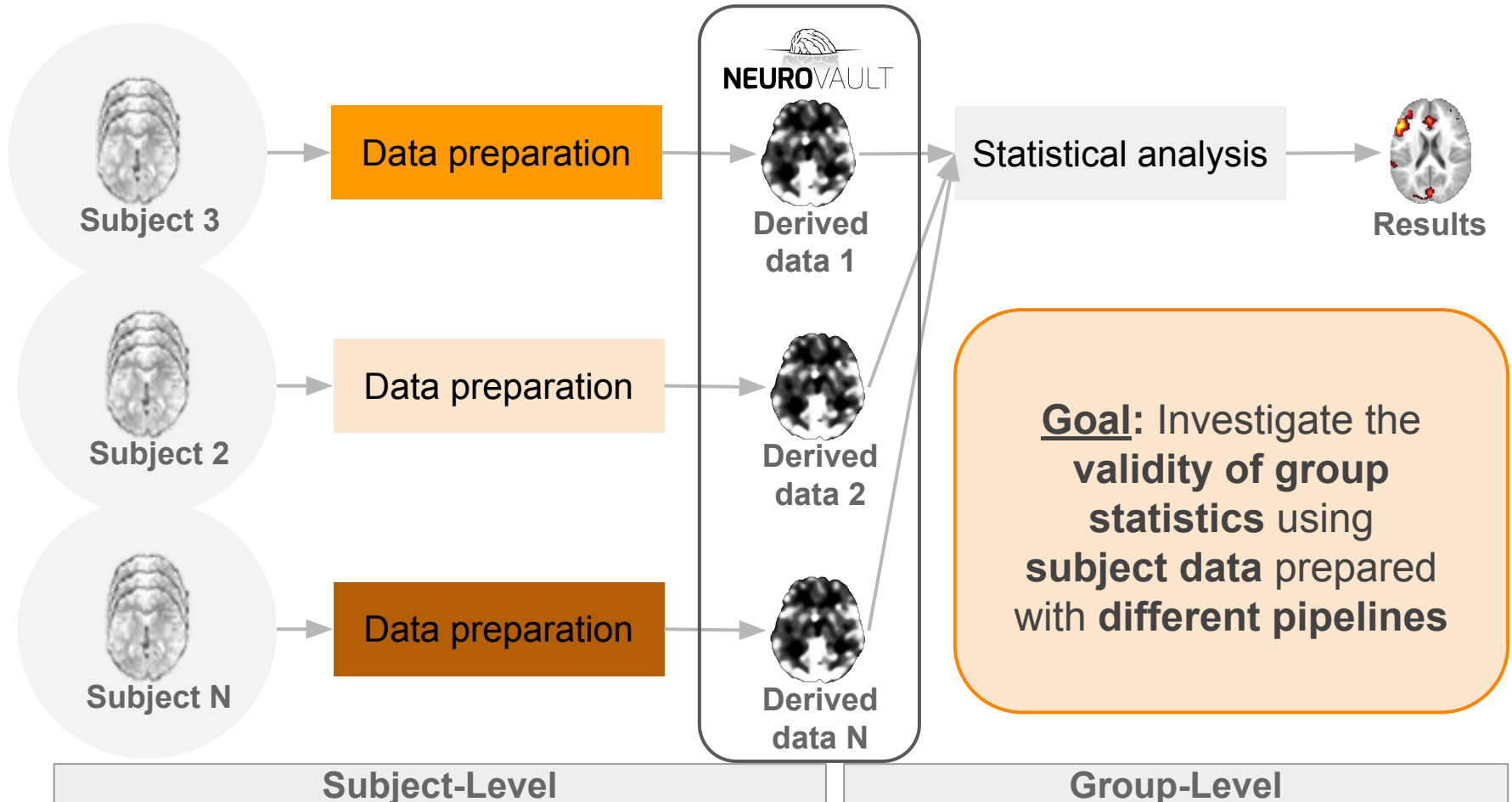


Xavier Rolland



Pierre Maurel

Multi-stage functional MRI analysis



Validity of mega-analyses in neuroimaging



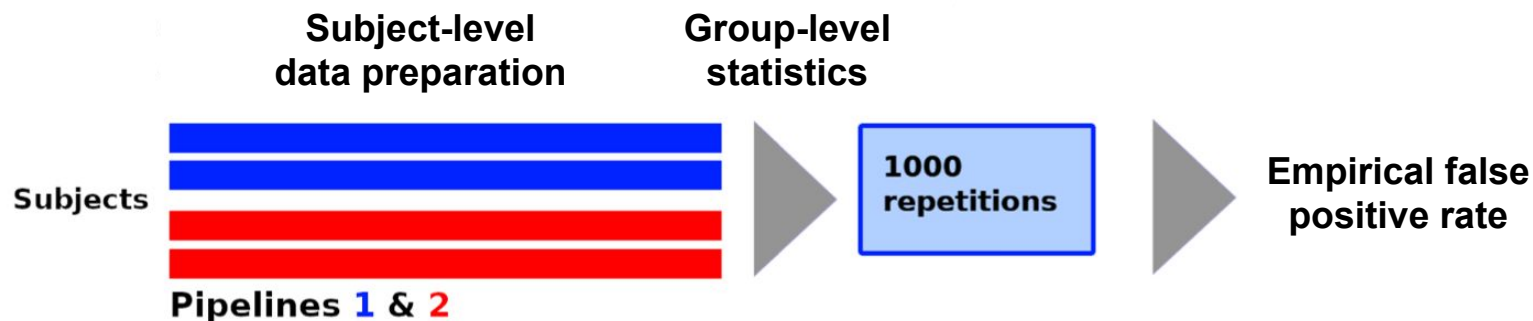
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Rolland



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

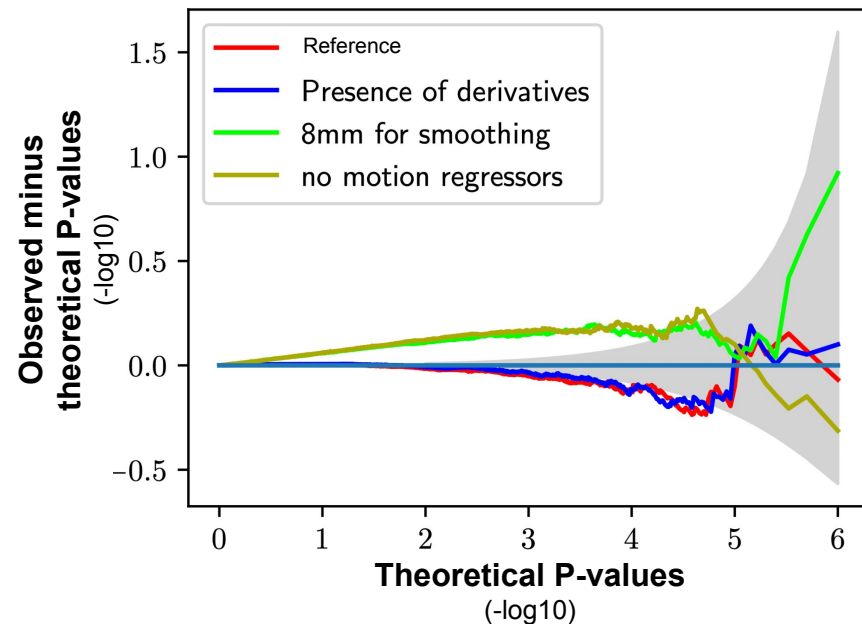


Pierre
Maurel

"Reference" pipeline :

- canonical HRF
- smoothing 5mm
- 24 motion regressors

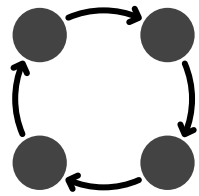
- P-p plots (Bland-Atlman)



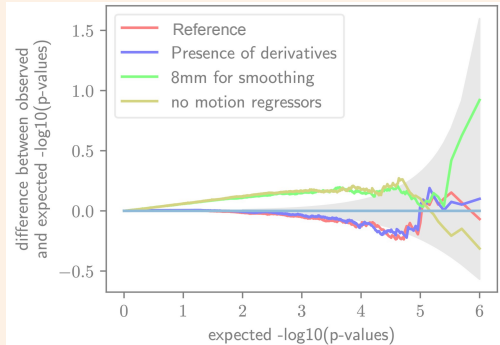
Conclusion: Invalidity of the mega-analyses for multiple variations studied (e.g. different smoothing, 1+ variation)

[Rolland Maurel Maumet, ISBI 2022]

Reusing neuroimaging data

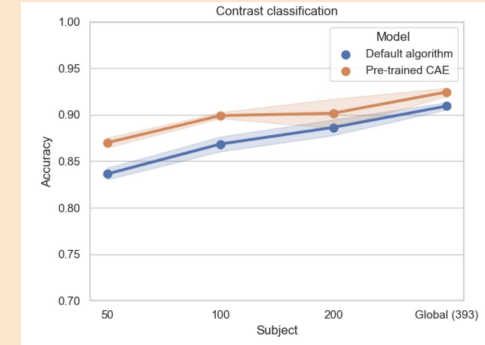


Validity of mega-analyses



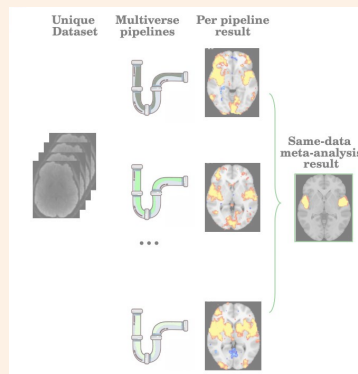
[[Rolland Maurel Maumet](#), ISBI 2022]

Leveraging large datasets



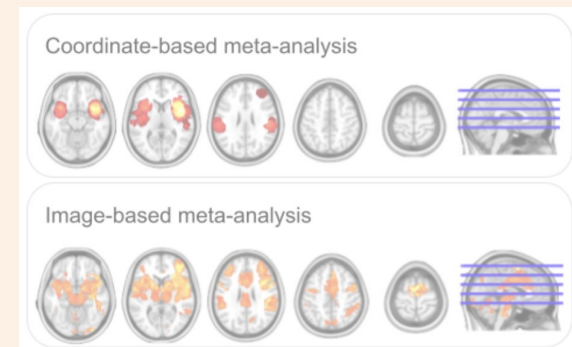
[[Germani Fromont* Maumet*](#), Gigascience 2023]

Multiverse analyses



[[Lefort-Besnard Nichols* Maumet*](#), OHBM 2024]

Meta-analyses



[[Maumet*](#) and Nichols, in prep]

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



Elisa
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?

Leveraging large and open datasets



Elodie
Germani



Elisa
Fromont

Shared data with limited metadata

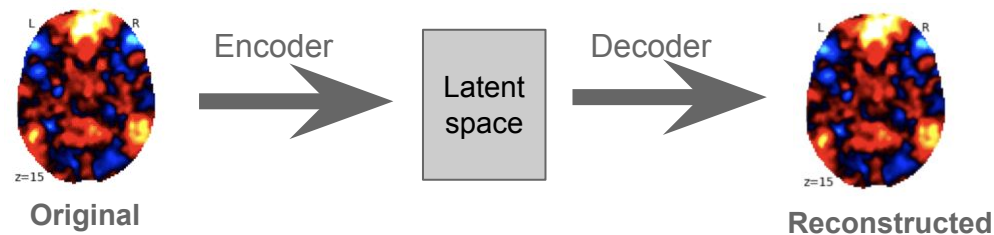


500 000+ images

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

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



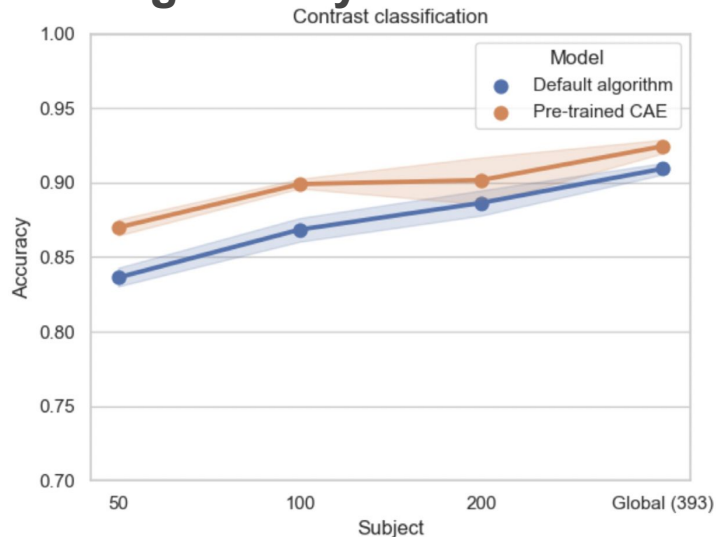
Elodie Germani



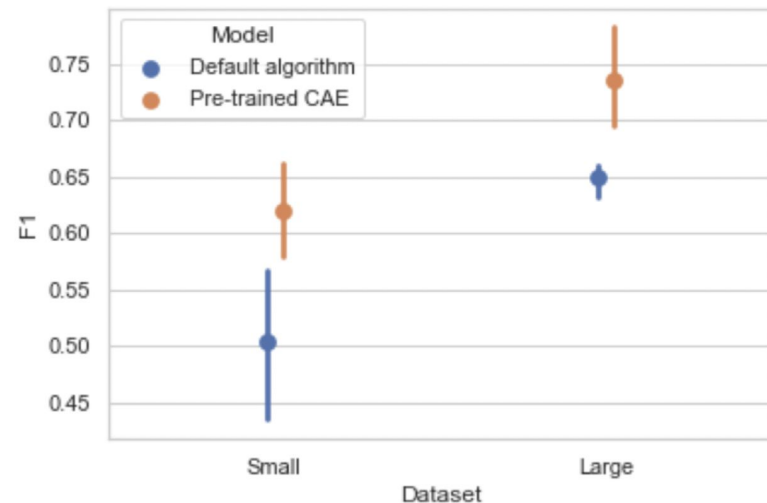
Elisa Fromont

- 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



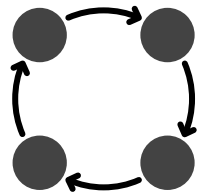
Collection of studies



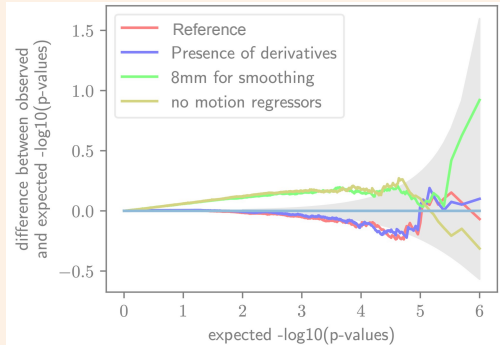
Conclusion: The pre-trained classifier always performed better especially when the problem was complex (small samples, heterogeneity).

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

Reusing neuroimaging data

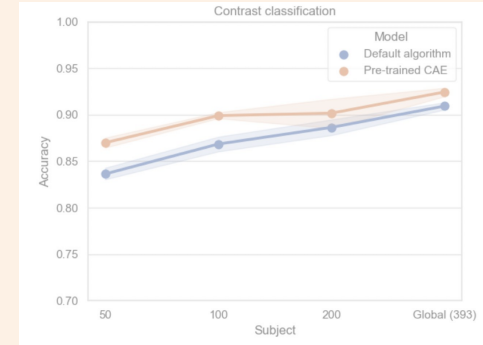


Validity of mega-analyses



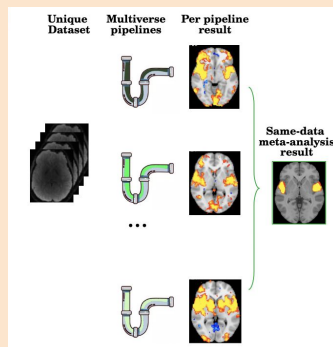
[[Rolland Maurel Maumet](#), ISBI 2022]

Leveraging large datasets



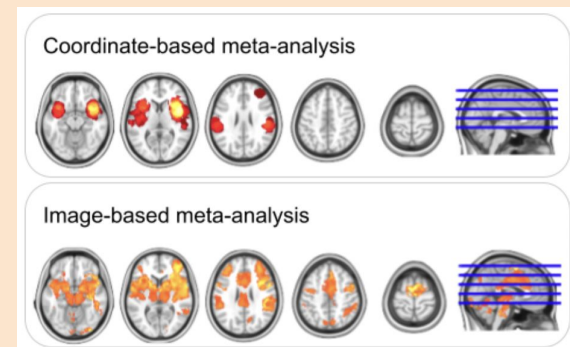
[[Germani Fromont* Maumet*](#), Gigascience 2023]

Multiverse analyses

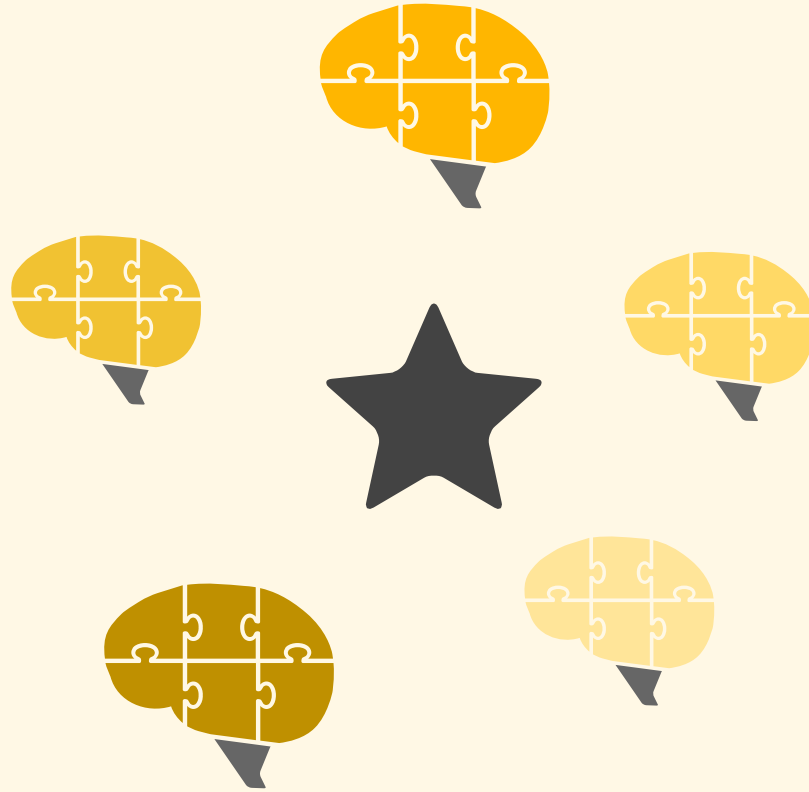


[[Lefort-Besnard Nichols* Maumet*](#), OHBM 2024]

Validity of meta-analyses

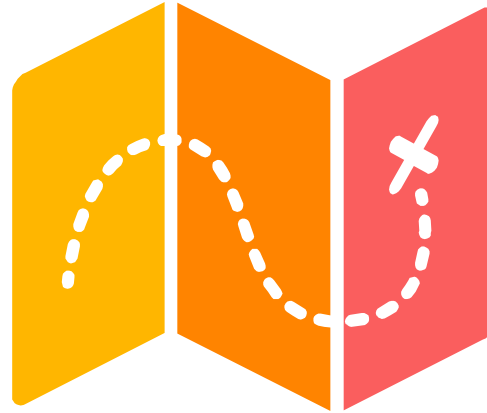


[[Maumet*](#) and Nichols, in prep]



Open Science

A journey into Open Science



Step 1

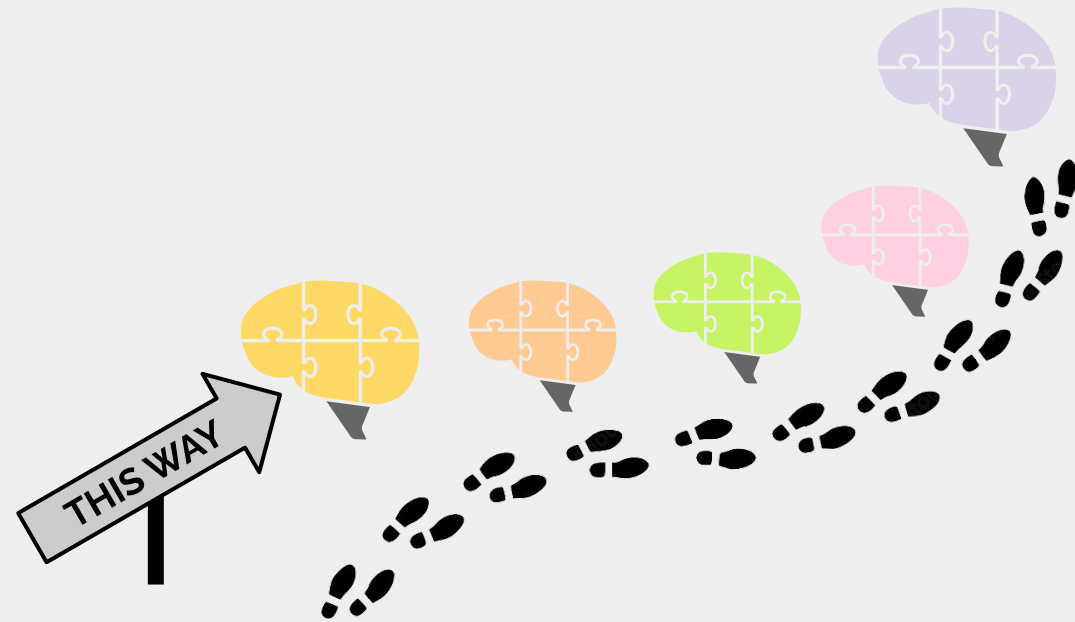
More
reproducible
research

Step 2

More
collaborative
research

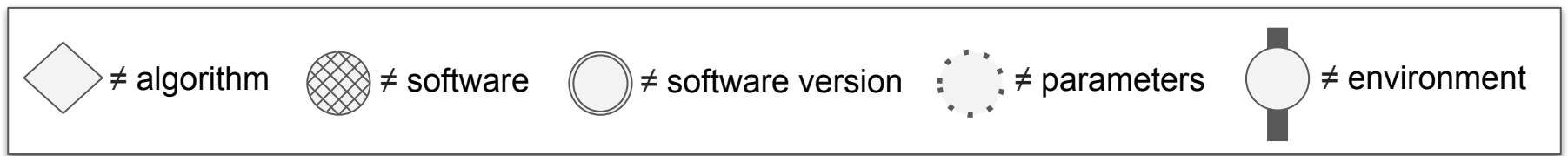
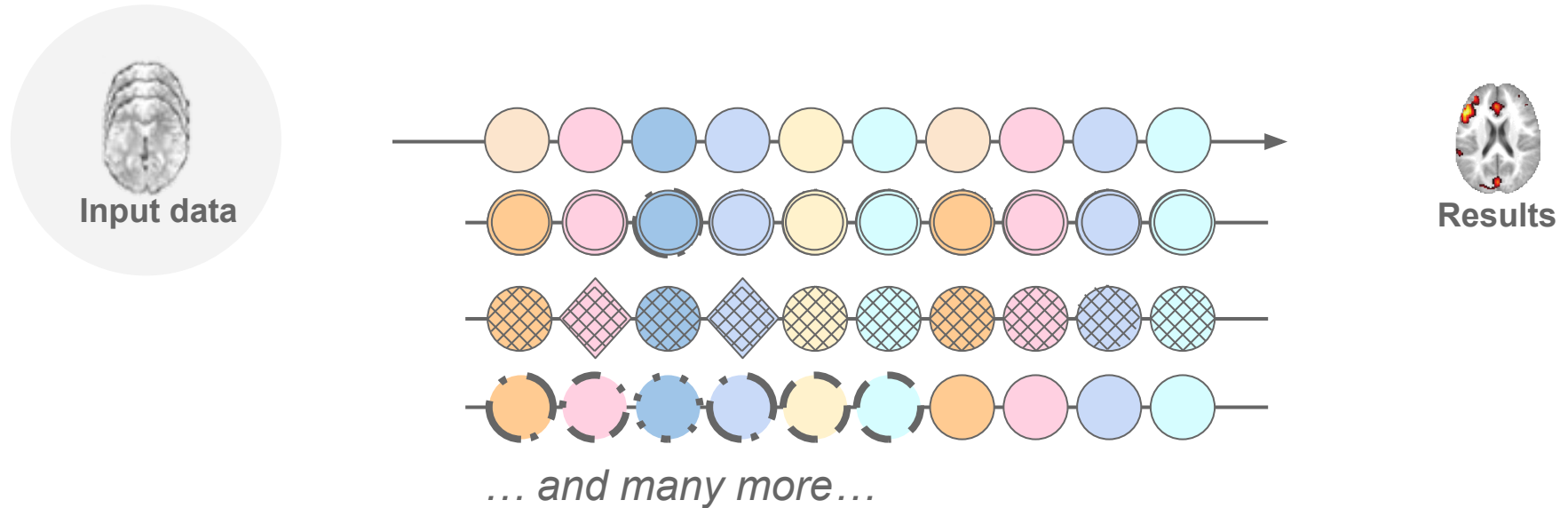
Step 3

More
inclusive
research



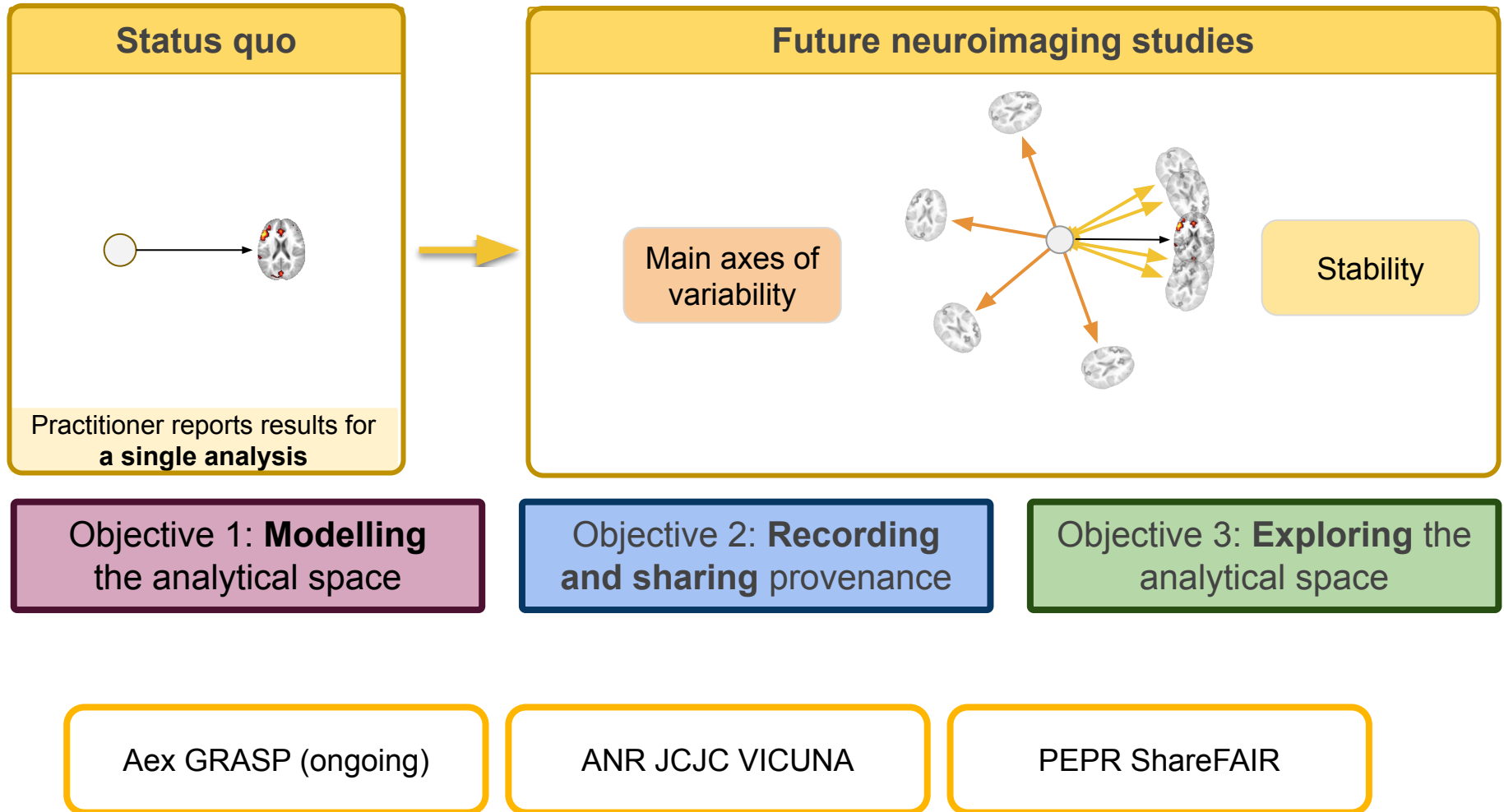
Future research

A very large analysis landscape



10³⁰ alternative pipelines...

Research program



Thank you!



Pierre Maurel
Christian Barillot



Elisa Fromont



Elodie Germani



Xavier Rolland



Greg Kiar

PhD students



Freya Acar



Ruth Pauli



Alex Bowring



Beatrijs Moerkerke



Tom Nichols

PostDocs



Jérémy Lefort-Besnard



Aya Kabbara



Alexandre Pron



Sofia Strubbia



Mahmoud Hassan



Olivier Dameron



Alban Gaignard



Anne Siegel

Student interns

Emma Redor, Thomas Agasse-Lafont, Nina Forde, Natacha Perez



Isabelle Bonan



Simon Butet



Fanny Degeilh

Research engineers



Thomas Betton



Boris Clenet



Aurélien Cornet



Hermann Courteille



Cyril Regan



Rémi Adon

Thank you!



Pierre Maurel
Christian Barillot



Elisa Fromont



Elodie Germani



Xavier Rolland



Greg Kiar

PhD students



Freya Acar



Ruth Pauli



Alex Bowring



Beatrijs Moerkerke



Tom Nichols



Jérémy Lefort-Besnard

PostDocs



Aya Kabbara



Mahmoud Hassan



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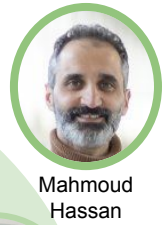
Thank you!



PhD students

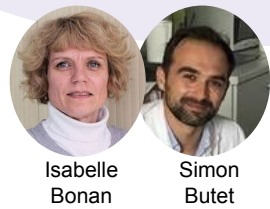


PostDocs



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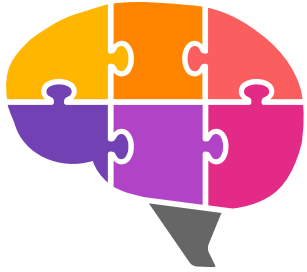


Aurélien Cornet



Rémi Adon

Soutenance pour l'obtention de l'**Habilitation à Diriger les Recherches**



Towards reproducible neuroimaging
**Solutions for sharing and
re-using brain imaging data**

Camille Maumet



**Opening up
neuroimaging data**



**On the vibration of
effects in
neuroimaging**



**Reusing
neuroimaging data**



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