BIDS stats model

BRAIN IMAGING DATA STRUCTURE

Specify all your analysis in a single file.

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CPP Lab

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Thanks to Chris Markiewicz and Alejandro de la Vega for letting me reuse some of their slides.

Context

Lack of standardization and poor methods reporting

- hinders reproducibility
- increase inefficiencies

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Data and process standardization allow for automation

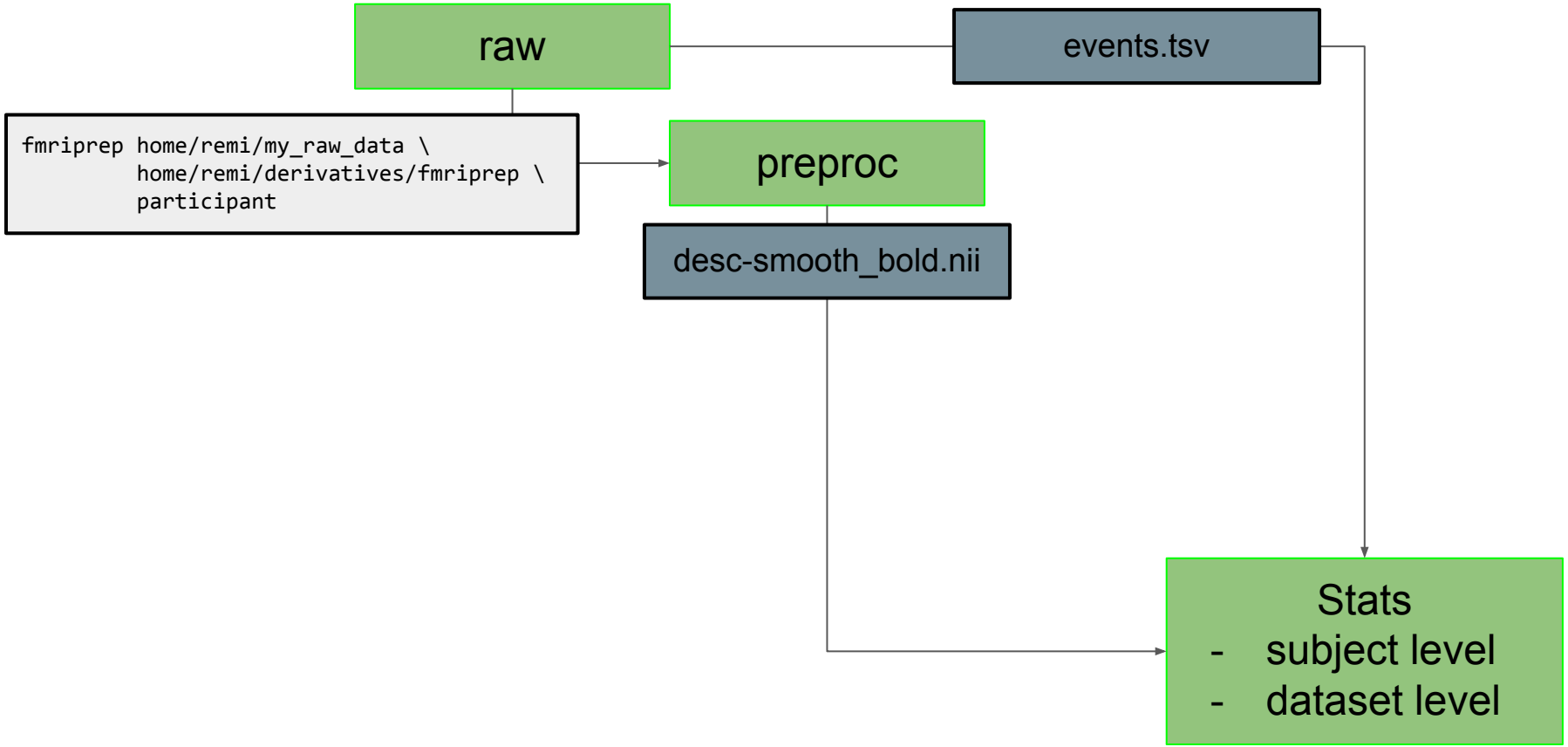
- E.g. BIDS and fmriprep

Problem

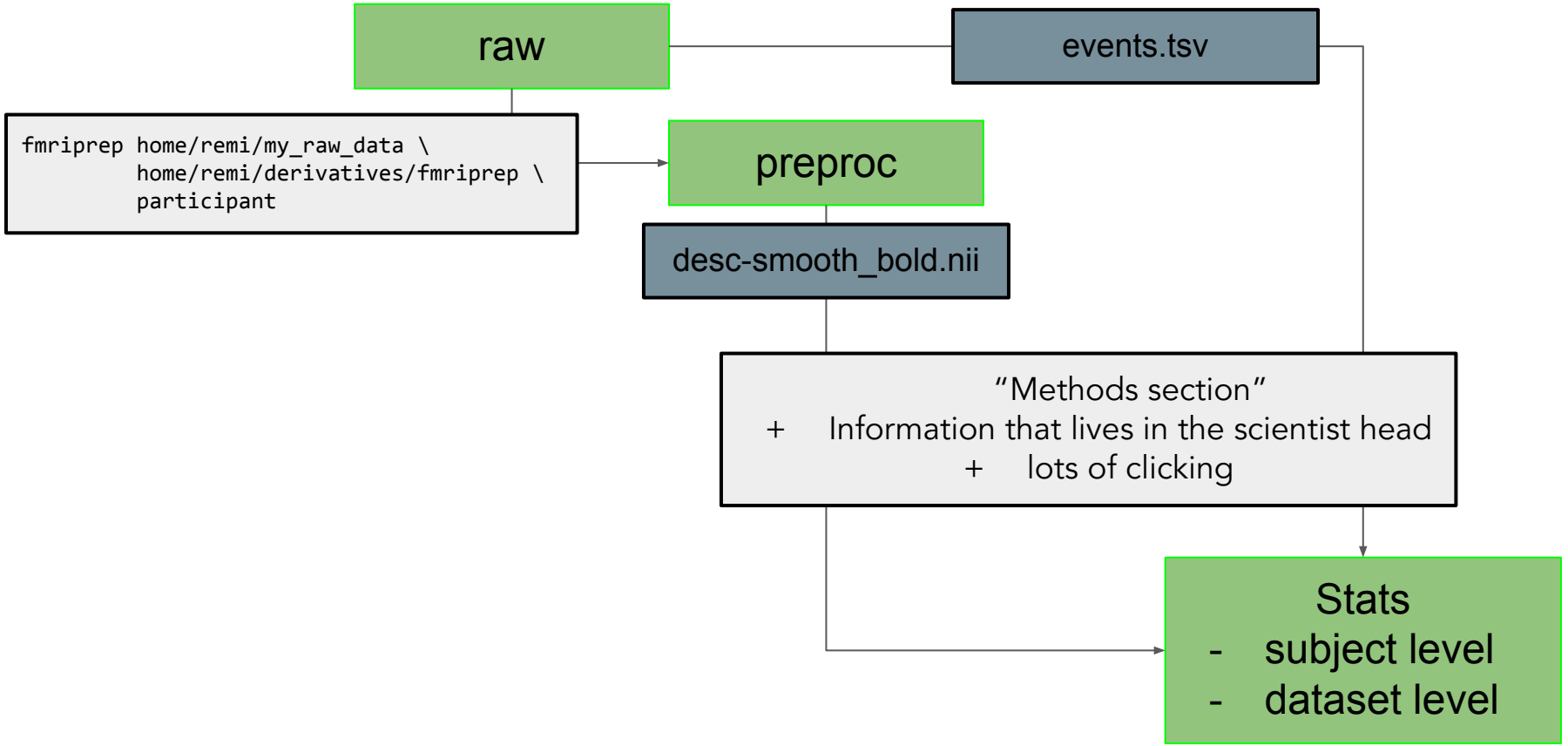
Data and preprocessing standardization are not enough.

- Large-scale efforts fail to reproduce results even with exact data (Botvinik-Nezer et al. 2020)
- fMRI data analysis workflows vary in idiosyncratic ways
- Flexibility in methods: large variety in hypothesis testing outcomes (Carp et al., 2012; Botvinik-Nezer et al., 2020)
- Methods are typically reported in verbal descriptions: difficult to replicate.
- Custom analysis: time-consuming, error-prone, and not accessible

Problem


raw
events.tsv
fmriprep home/remi/my_raw_data \
home/remi/derivatives/fmriprep \
participant
preproc
desc-smooth_bold.nii
Stats
- subject level
- dataset level

Problem


raw
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"Methods section"
+ Information that lives in the scientist head
+ lots of clicking
Stats
- subject level
- dataset level

Problem

Data and preprocessing standardization are not enough.

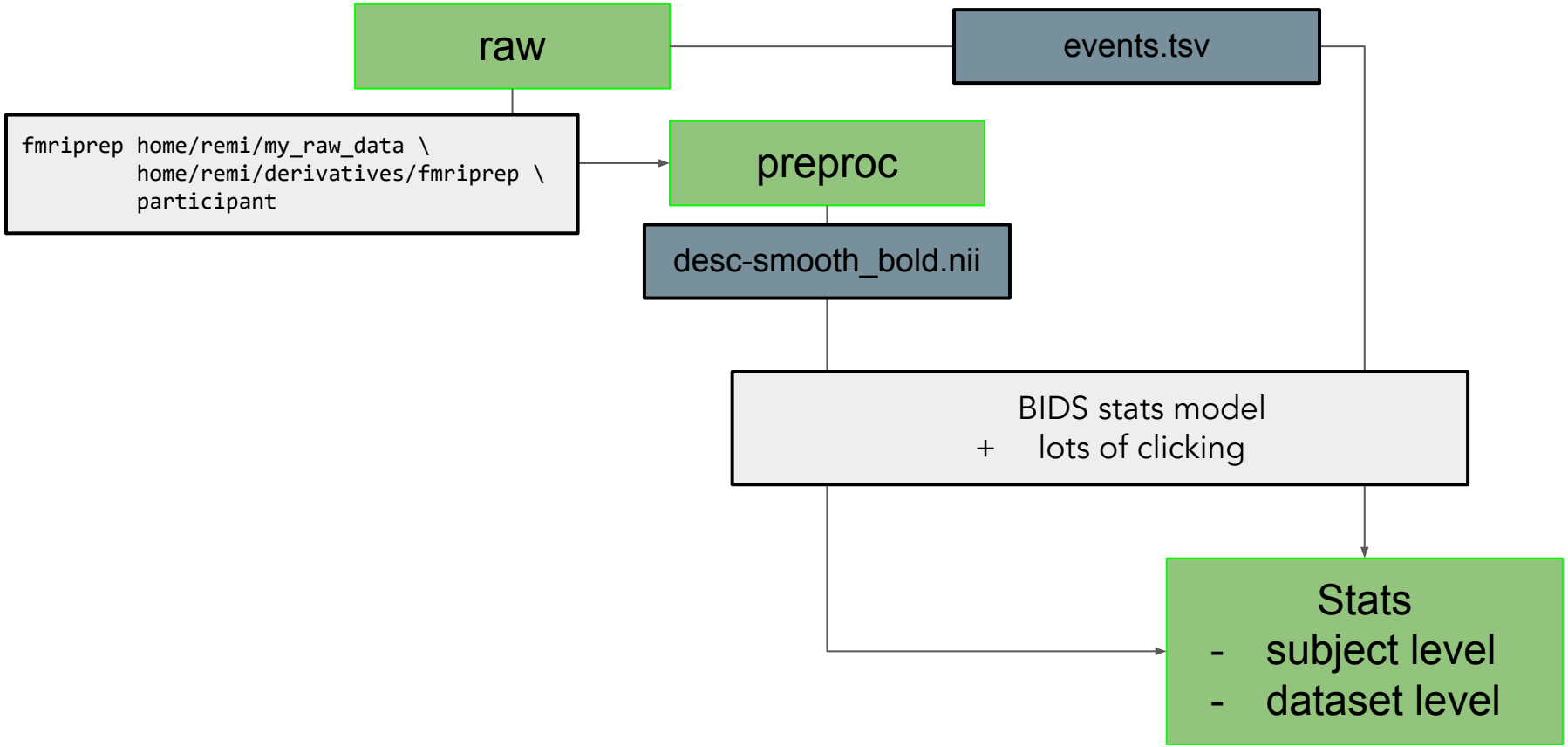
Missing piece: fMRI modeling

Aim

BIDS Stats Models

- describe how to fit statistical models for neuroimaging data
- machine-readable
- prescriptive (as in a recipe)
- sufficient to execute statistical models (given preprocessed BIDS dataset)
- implementation agnostic
- modality agnostic
- minimal configuration and intervention required from the user
- does not require to edit the input datasets

Problem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BIDS stats model
+ lots of clicking
Stats
- subject level
- dataset level

Aim

Run your entire univariate statistical analysis with:

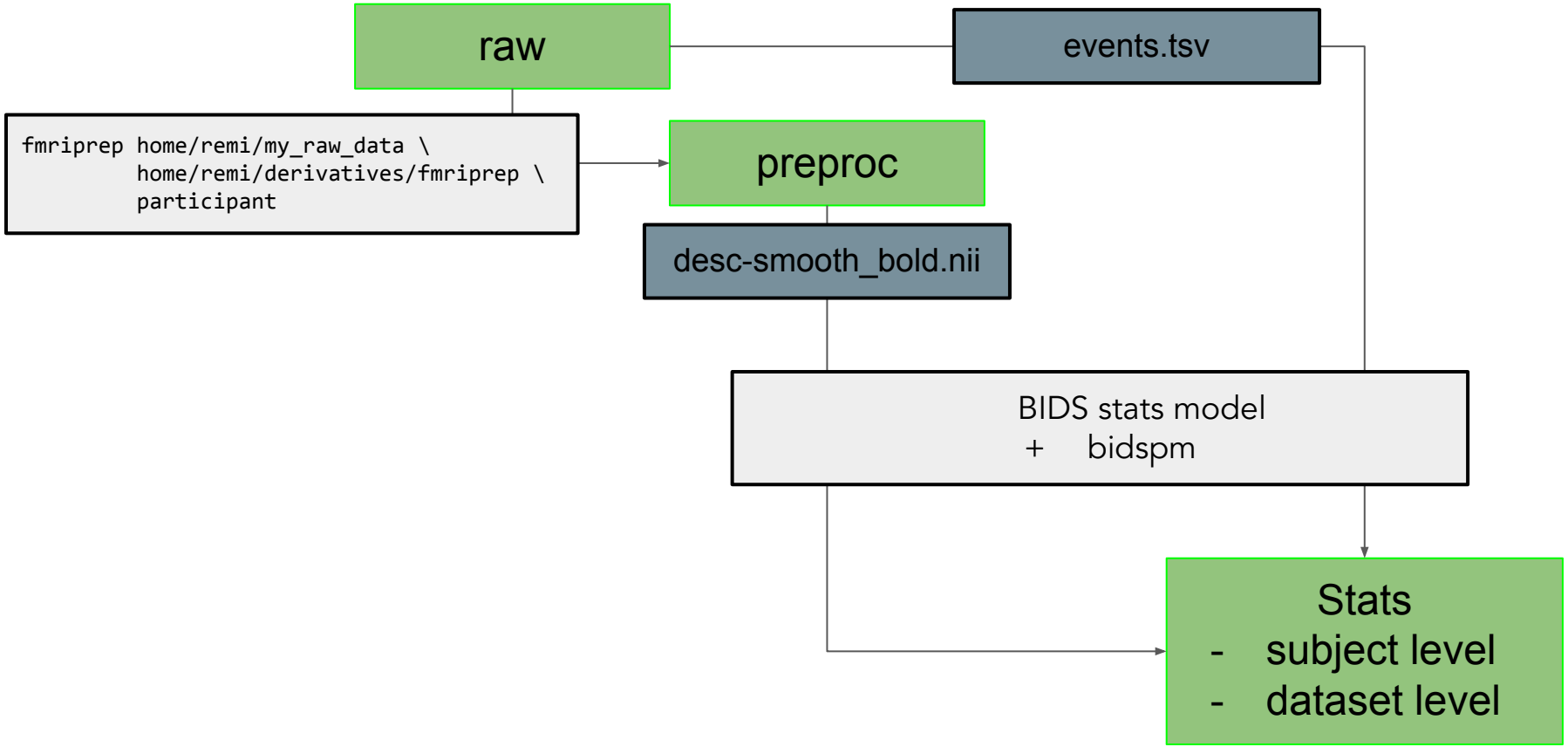
- 50 lines of code
- one JSON file

Implementations

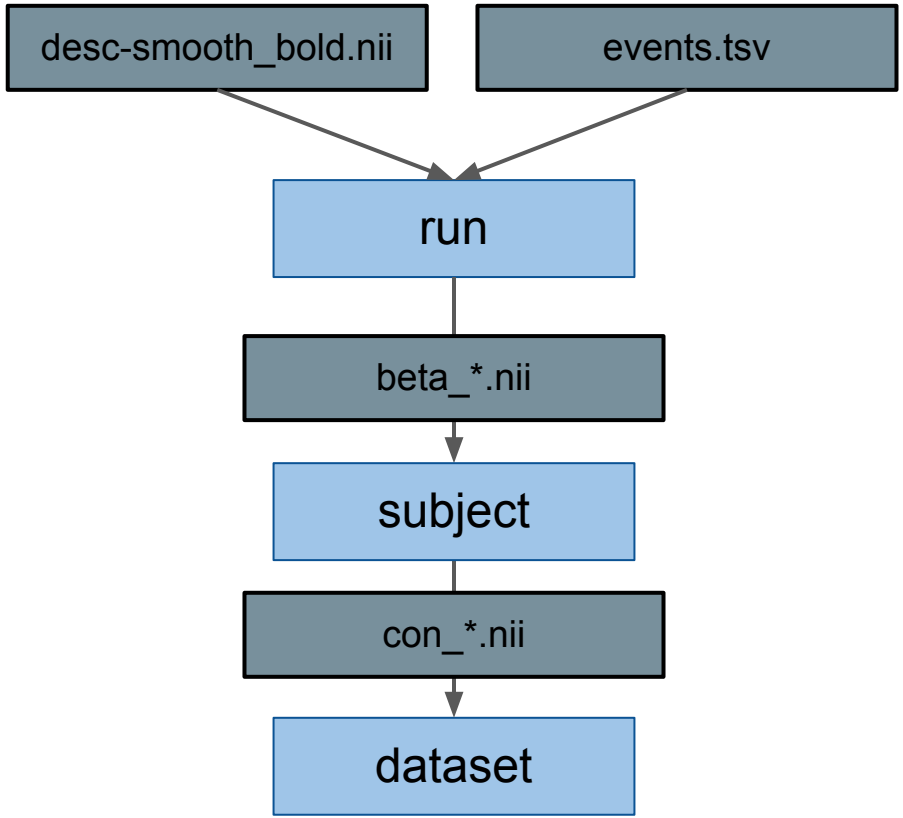
- Modality agnostic in theory
- VERY fmri centric in practice (for now)

- Actual implementations
  - Neuroscout (web interface, naturalistic stimuli datasets)
  - Fitlins (python)
  - Bidspm (matlab / octave, SPM)

Implementations

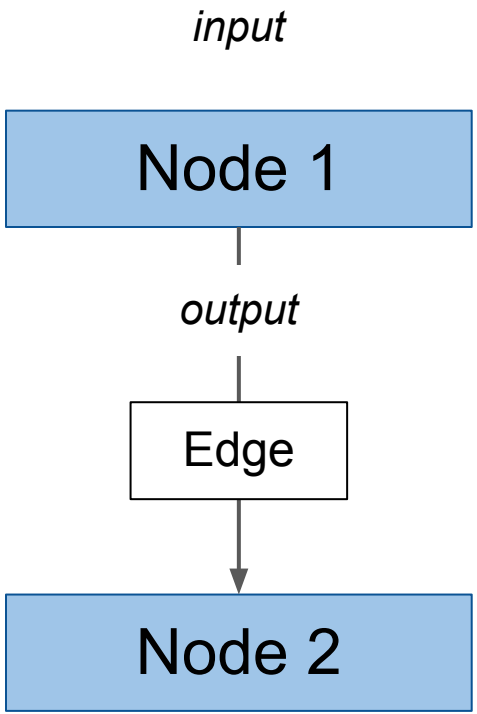


Mass univariate analysis (SPM)

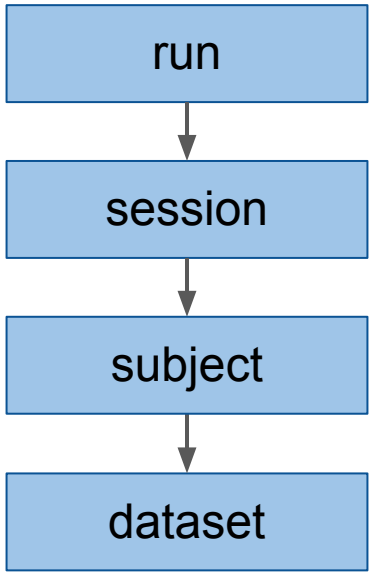


BIDS stats model - DAG

- Directed acyclic graph

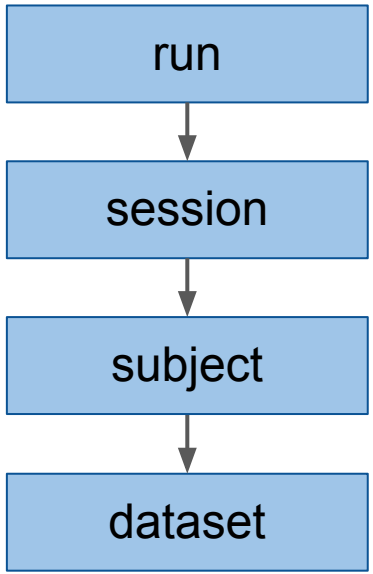


BIDS stats model - DAG



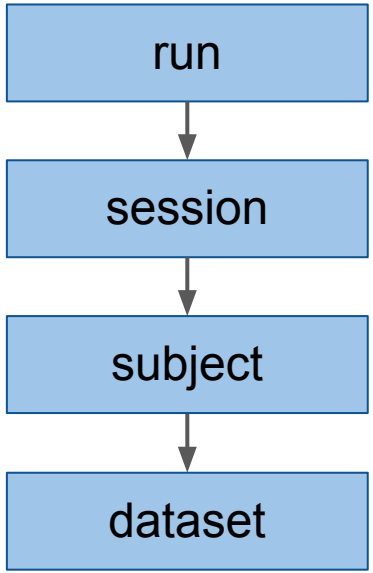
BIDS stats model - DAG

Basic summary statistics with four nodes

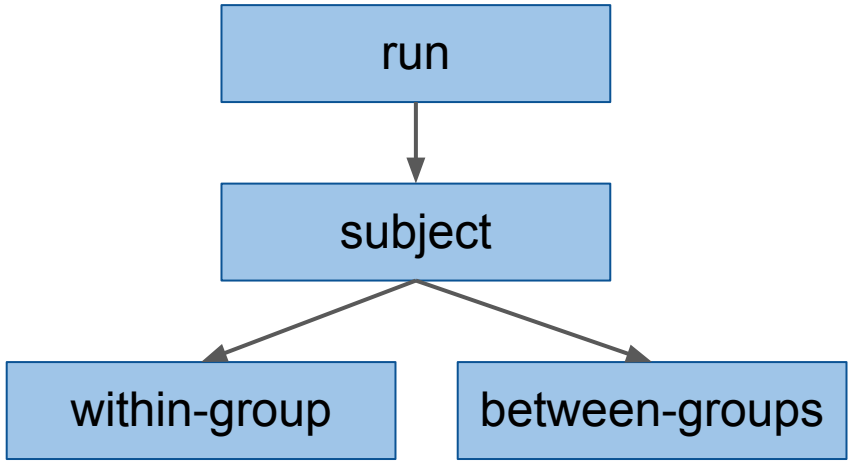


BIDS stats model - DAG

Basic summary statistics with four nodes



Multiple dataset-level nodes from the same run and subject level estimates.



BIDS stats model - overview

BIDS stats models are a JSON file with 3 components:

1. Basic metadata

2. Input selectors
   a. BIDS entities and metadata

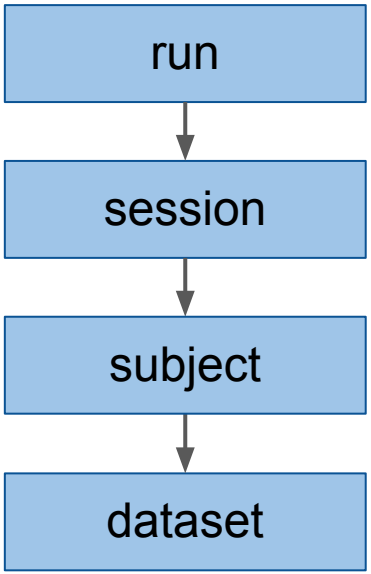
3. Computational graph
   a. Nodes correspond to estimators
   b. Edges connect nodes

```
{
  "Name": "MyModel",
  "BIDSModelVersion": "1.0.0",
  "Description": "Simple motor model",

  "Input": {"task": "motor"},

  "Nodes": [...],
  "Edges": [...]
}
```

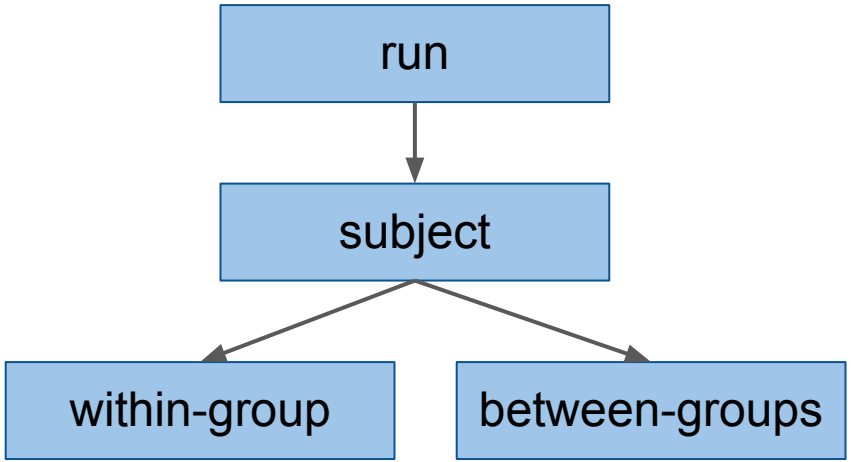
BIDS stats model - edges




```
{
  "Nodes": [
    {"Name": "run", …},
    {"Name": "session", …},
    {"Name": "subject", …},
    {"Name": "dataset", …}
  ],
  "Edges": [
    {"Source": "run", "Destination": "session"},
    {"Source": "session", "Destination": "subject"},
    {"Source": "subject", "Destination": "dataset"}
  ]
}
```

BIDS stats model - edges

```
{
  "Nodes": [
    {"Name": "run", ...},
    {"Name": "subject", ...},
    {"Name": "within-group", ...},
    {"Name": "between-groups", ...}
  ],
  "Edges": [
    {"Source": "run", "Destination": "subject"},
    {"Source": "subject",
     "Destination": "within-group"},
    {"Source": "subject",
     "Destination": "between-groups"}
  ]
}
```



BIDS stats model - Nodes

Inputs

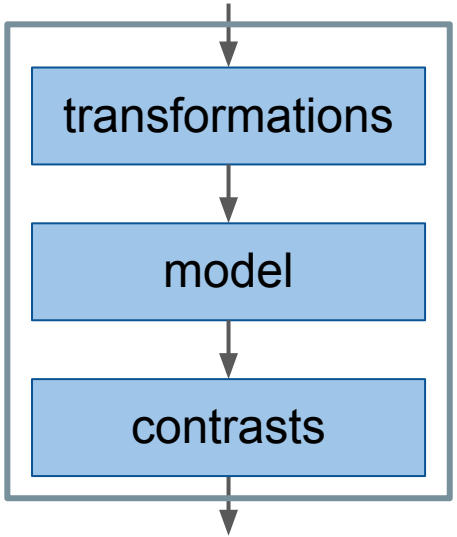
- Variables from input dataset(s)
- Images
  - Run-level: BOLD series
  - Higher-level: Contrast maps

Transformations

- Manipulate input variables:
  - Example: Filter certain rows of events.tsv

Outputs

- Images: Contrast maps



BIDS stats model - Nodes

Nodes properties:

- Level:
  - "Run", "Session", "Subject" or "Dataset"
- Name: Unique name for edges
- GroupBy:
  - Variables that identify subsets of inputs
  - Easier (for me) to think of as splitting
  - Similar to the GroupBy operation in R or pandas dataframes.

```
{
  "Level": "Run",
  "Name": "Run",
  "GroupBy": ["run", "subject"],
  "Model": {...},
  "Contrasts": [...],
}
```

BIDS stats model - design matrix

Given the variables available in:

- events.tsv (raw)
- timeseries.tsv (derivative)

We define a design matrix in `Model.X`.

HRF parameters:

- What to convolve
- With what HRF

Options:

- high pass filter,
- inclusive mask

```
{
  "Name": "Run",

  "Model": {

    "X": ["ev1", "ev2", "confound1", "confound2", 1]

    "HRF": {
         "Variables": ["ev1", "ev1"],
         "Model": "spm"
    },

    "Options": {
            "HighPassFilterCutoffHz": 0.0078,
            "Mask": {"suffix": ["mask"], "desc": ["brain"]}
    },

    "Software": {
            "SPM": {
             "SerialCorrelation": "AR(1)"
            }
    }

  }
}
```

BIDS stats model - contrasts

Contrasts are the output of a node.

The `Contrasts` list is a weighted sum of betas for t contrasts (F contrast supported too).

To output individual betas, the `DummyContrasts` object constructs a contrast with one condition and weight `[1]` for each beta.

```
{
  "Name": "Run",
  ...
  "Contrasts": [
    {
      "Name": "ev1_vs_ev2",
      "ConditionList": ["ev1", "ev2"],
      "Weights": [1, -1],
      "Test": "t"
    }
  ],
  "DummyContrasts": {
    "Conditions": ["ev1", "ev2"],
    "Test": "t"
  }
  ...
}
```

BIDS stats model - subject level

Average beta images from the run level.

```
{
  "Level": "Subject",
  "Name": "subject_level",
  "GroupBy": [
    "contrast",
    "subject"
  ],
  "Model": {
    "X": [
      1
    ],
    "Type": "glm"
  },
  "DummyContrasts": {
    "Test": "t"
  }
}
```

BIDS stats model - dataset level

Average across all subjects

```
{
  "Level": "Dataset",
  "Name": "dataset_level",
  "GroupBy": [
    "contrast"
  ],
  "Model": {
    "X": [
      1
    ],
  },
  "DummyContrasts": {
    "Test": "t"
  }
}
```

Average by Group

```
{
  "Level": "Dataset",
  "Name": "within_group",
  "GroupBy": [
    "group"
    "contrast"
  ],
  "Model": {
    "X": [
      1
    ],
  },
  "DummyContrasts": {
    "Test": "t"
  }
}
```

2 samples T-test

```
{
  "Level": "Dataset",
  "Name": "between_groups",
  "GroupBy": [
       "Contrast"
       ],
  "Model": {
       "X": [
      1,
      "group"
      ]
  },
  "Contrasts": [
    {
     "Name": "blind_gt_control",
     "ConditionList": [
        "Group.blind",
        "Group.control"
     ],
     "Weights": [
        1,
        -1
     ],
     "Test": "t"
    }
  ]
}
```

BIDS apps CLI

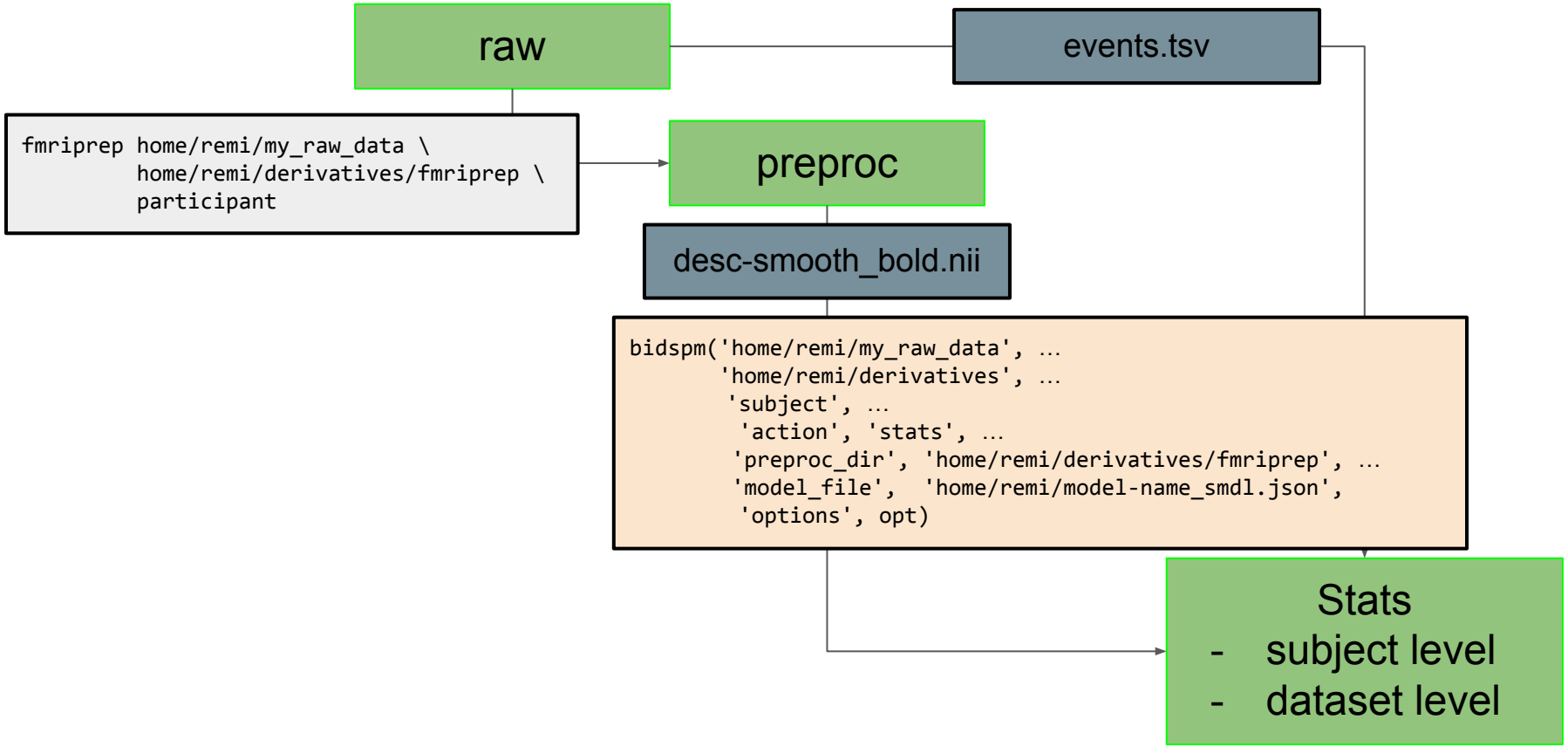
```
bids-app /bids-directory /output-directory participant [OPTIONS]
```

```
fmriprep /data/raw /data/processed/ participant --participant-label pixar001 [OPTIONS]
```

```
fitlins /data/raw /data/stats dataset --derivatives /data/processed/fmriprep --model model-name_smdl.json [OPTIONS]
```

```
bidspm(raw_data, output, 'subject', …
        'pariticipant_label', {'01', '02'}
        'action',      'stats', ...
        'preproc_dir', bidspm_preproc, ...
        'model_file',  'home/remi/model-name_smdl.json',
        'options', opt)
```

Implementations



BIDS stats model - advanced

- What HRF to use?
- What type of confounds to include?
- Should I scrub my data?

Choose a model in principled manner without data peeking / double-dipping / p-hacking.

Bayesian model comparison (MACS toolbox)

BIDS stats model - advanced

Bayesian model comparison (MACS toolbox)

12 different BIDS stats models

HRF

- HRF
- HRF + temporal
- HRF + temporal + dispersion

Confounds

- None
- CSF + WM

Scrubbing

- no outlier removal
- with outlier removal

```
opt = opt_stats_subject_level();

models = opt.toolbox.MACS.model.files

for i = 1:numel(models)
  opt.model.file = models{i};
  bidsFFX('specify', opt);
end

bidsModelSelection(opt, 'action', 'all');
```

BIDS stats model - advanced

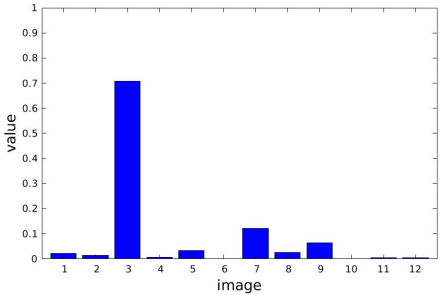
Bayesian model comparison (MACS toolbox)

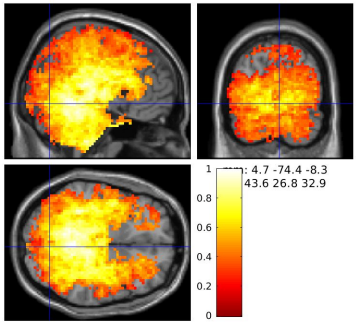
moddel 03:

No Derivative

With Tissue Confounds

No Scrubbing



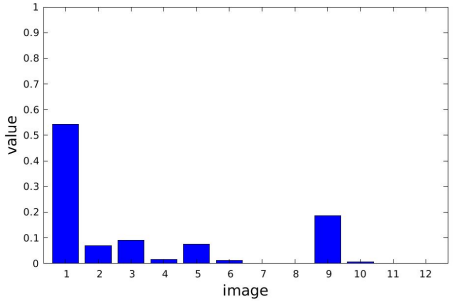


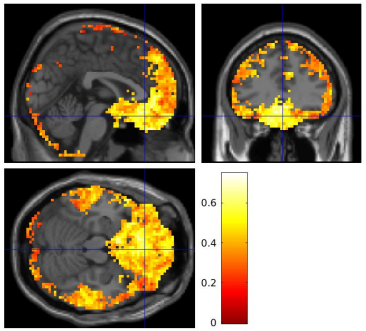
model 01:

No Derivative

No Tissue Confounds

No Scrubbing





BIDS stats model - demo

- Set up
  - Grab dataset from openneuro
  - Copy preprocessed BOLD files and smooth them

- Create default model
  - Validate it: Validator

- Run BIDS app command

BIDS stats model - resources

BIDS stats models and where to find them

- Zoo
- demos
- tests

Specification:

- Walkthrough
- JSON 101

Variable transformations specification:

- bids-matlab
- Pybids-transforms-v1