Flexible hub updates between tasks associated with global informational connectivity changes

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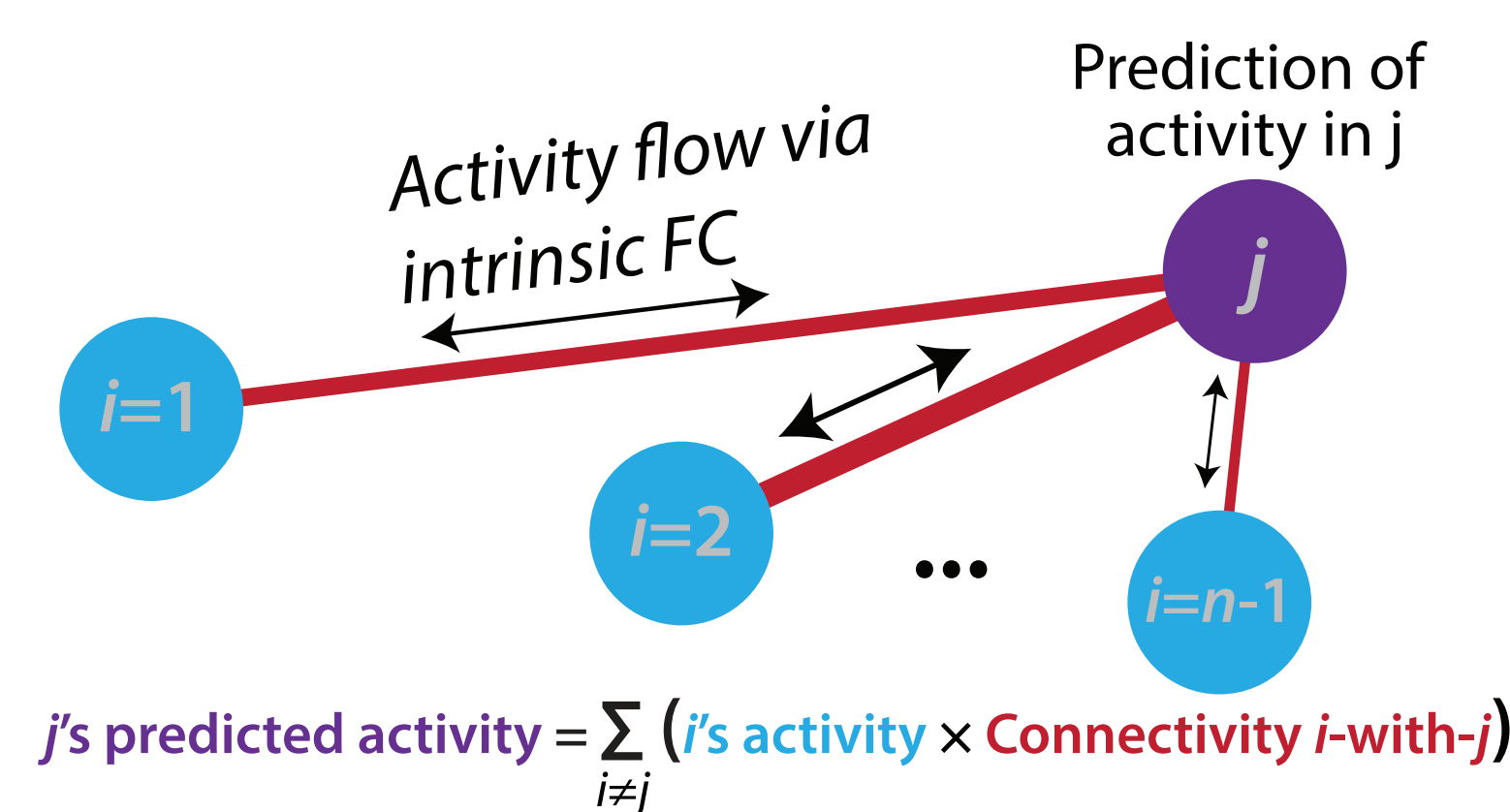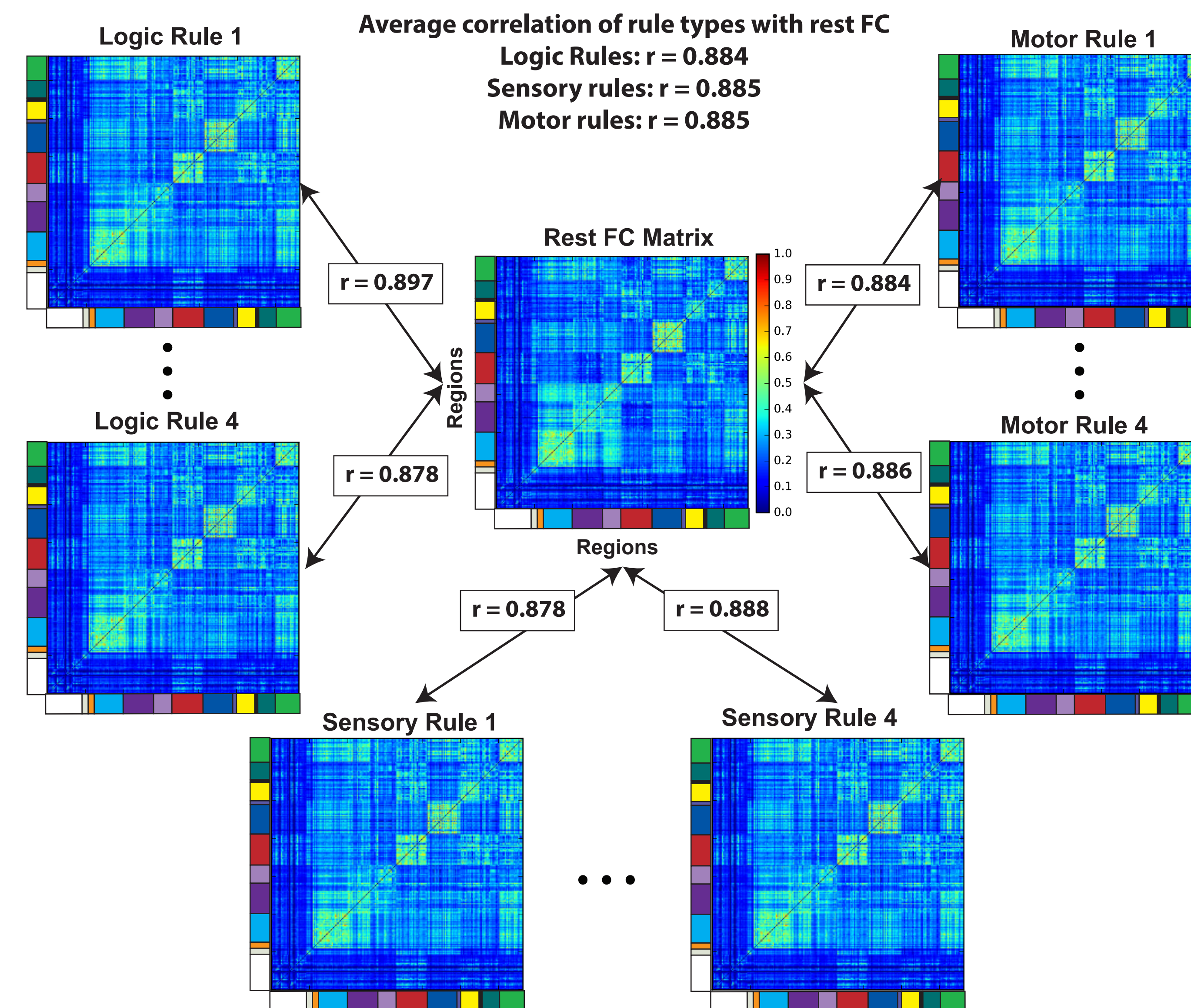[2]Behavioral and Neural Sciences PhD Program, Rutgers University, Newark, NJ

Does intrinsic functional connectivity carry task information?

Recent evidence suggests that functional connectivity (FC) architectures during rest and task are highly similar (Cole et al., 2014). Despite this, FC patterns from the frontoparietal network (FPN) can flexibly represent task information through widespread task FC changes (Cole et al., 2013). Here we use activity flow mapping (Cole et al., 2015) to test the hypothesis that in addition to task FC, intrinsic FC architecture shapes the flow of task information.

Activity flow via intrinsic FC

Prediction of activity in j

j's predicted activity $= \sum_{i \neq j} (i$'s activity $\times$ Connectivity i-with-$j)$

Hypothesis: Intrinsic FC architecture shapes the flow of task information from flexible hubs to task-related networks.

Methods

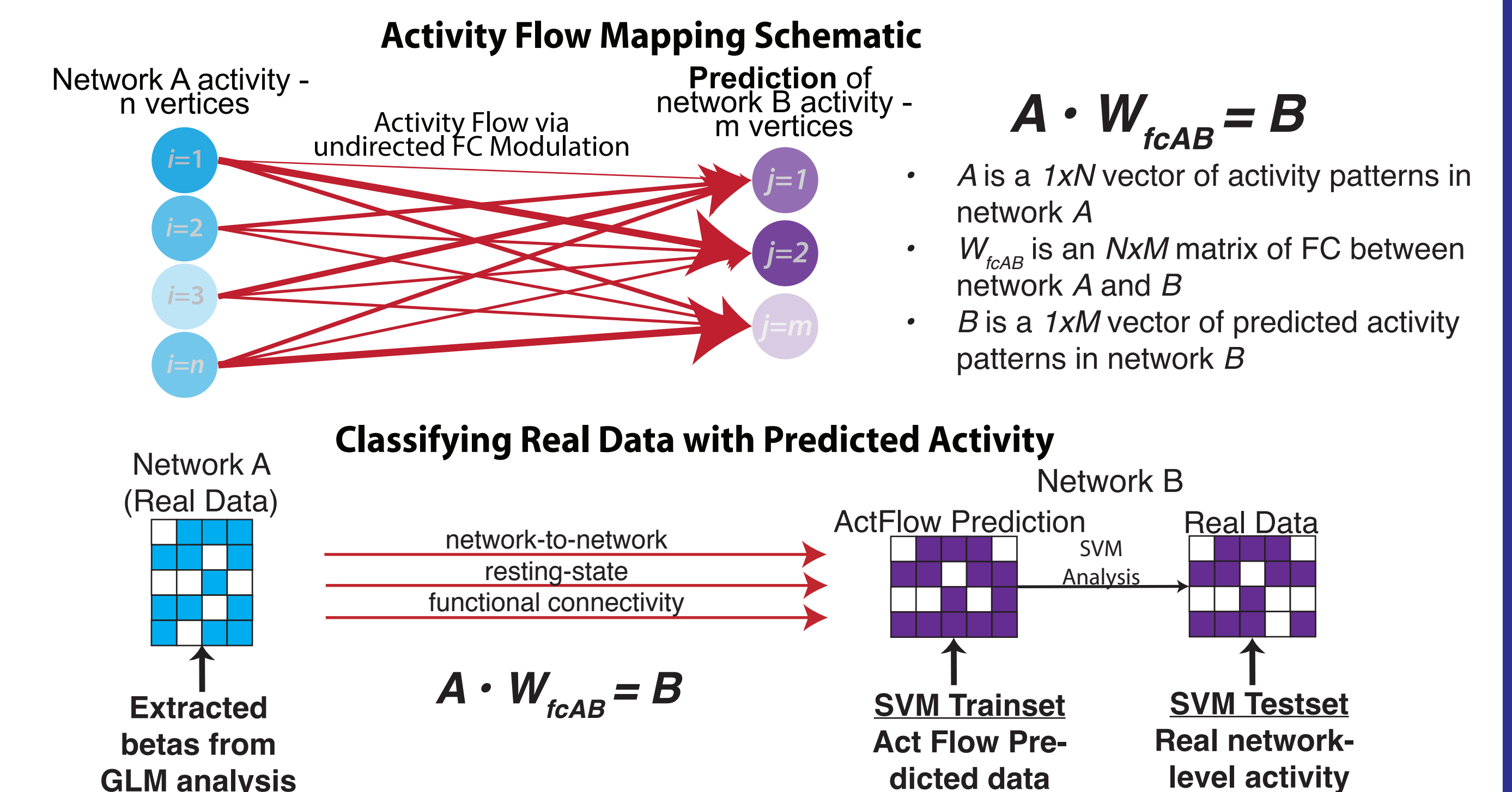### C-PRO Cognitive Paradigm

Task 1
Logic rule 1
Sensory rule 2
Motor rule 1

BOTH VERTICAL LEFT INDEX

Instructions | Trial

Rule set 1 description:
If BOTH stimuli are VERTICAL, press your LEFT INDEX finger

Answer: TRUE (Left index finger)

Logic Rules
1. Both
2. Not Both
3. Either
4. Neither

Task 2
Logic rule 1
Sensory rule 3
Motor rule 2

BOTH HI PITCH LEFT MIDDLE

Instructions | Trial

Rule set 2 description:
If BOTH stimuli are HI PITCH, press your LEFT MIDDLE finger

Answer: TRUE (Left middle finger)

Sensory Rules
1. Red
2. Vertical
3. Hi Pitch
4. Constant

Task 64
Logic rule 4
Sensory rule 1
Motor rule 1

NEITHER RED LEFT INDEX

Instructions | Trial

Rule set 64 description:
If NEITHER stimulus is RED, press your LEFT INDEX finger [other finger, same hand if false]

Answer: FALSE (Left middle finger)

Motor Rules
1. Left Index
2. Left Middle
3. Right Index
4. Right Middle

fMRI Methods
- n = 32
- Multiband fMRI sequence
- TR = 785ms; 2mm isotropic voxels

Scan Parameters
- 8 task runs
  - 16 miniblocks per run (128 total)
  - 3 trials per miniblock (384 total)
- 14 minute resting state scan (eyes open)

Preprocessing
- Human Connectome Project minimal preprocessing pipeline
- All analyses done on the surface

Network Definitions
- Gordon et al. (2014) network definitions

Functional Connectivity Analyses
- Nuisance regression: motion, white matter, ventricle timeseries

Activity Pattern Extraction
- Beta-series approach (Rissman et al., 2004)

Network Definitions (Gordon et al., 2014)

FPN | DAN | VIS | CON | SAL | RTSPL
DMN | VAN | AUD | SMH | SMM | CP
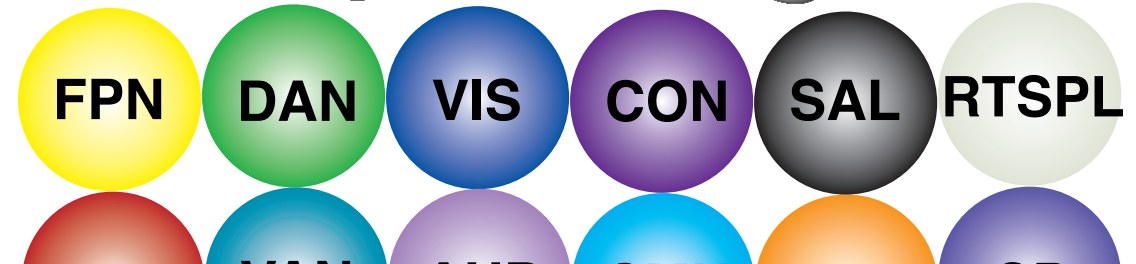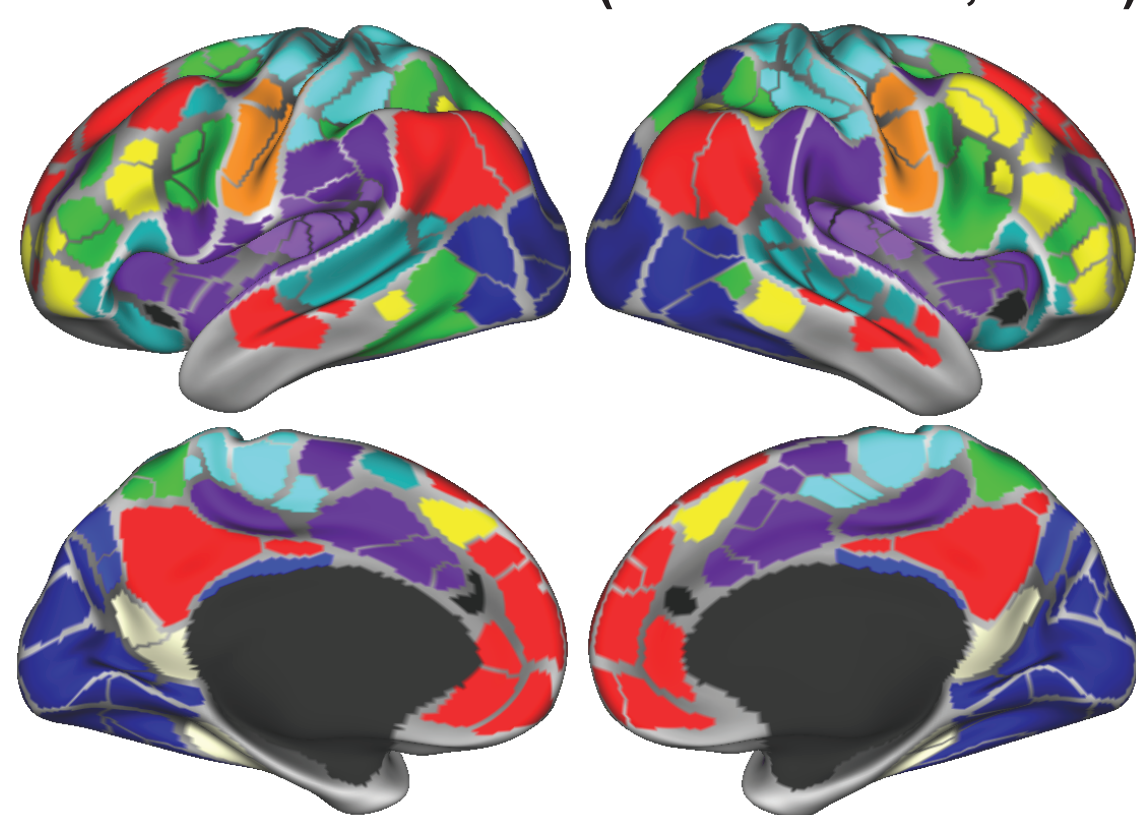
FPN: Frontoparietal; DAN: Dorsal Attention; VIS: Visual; CON: Cinguloopercular; SAL: Salience; RTSPL: Retrosplenial; DMN: Default Mode; VAN: Ventral Attention; AUD: Auditory; SMH: Somatosensory-hand; SMM: Somatosensory-mouth; CP: Cingulate-precuneus

Similarity of task rule functional connectivity patterns with intrinsic resting-state architecture

Average correlation of rule types with rest FC
Logic Rules: r = 0.884
Sensory rules: r = 0.885
Motor rules: r = 0.885

Logic Rule 1

Logic Rule 4

Rest FC Matrix
Regions

Motor Rule 1

Motor Rule 4

r = 0.897 | r = 0.884
r = 0.878 | r = 0.886

Sensory Rule 1

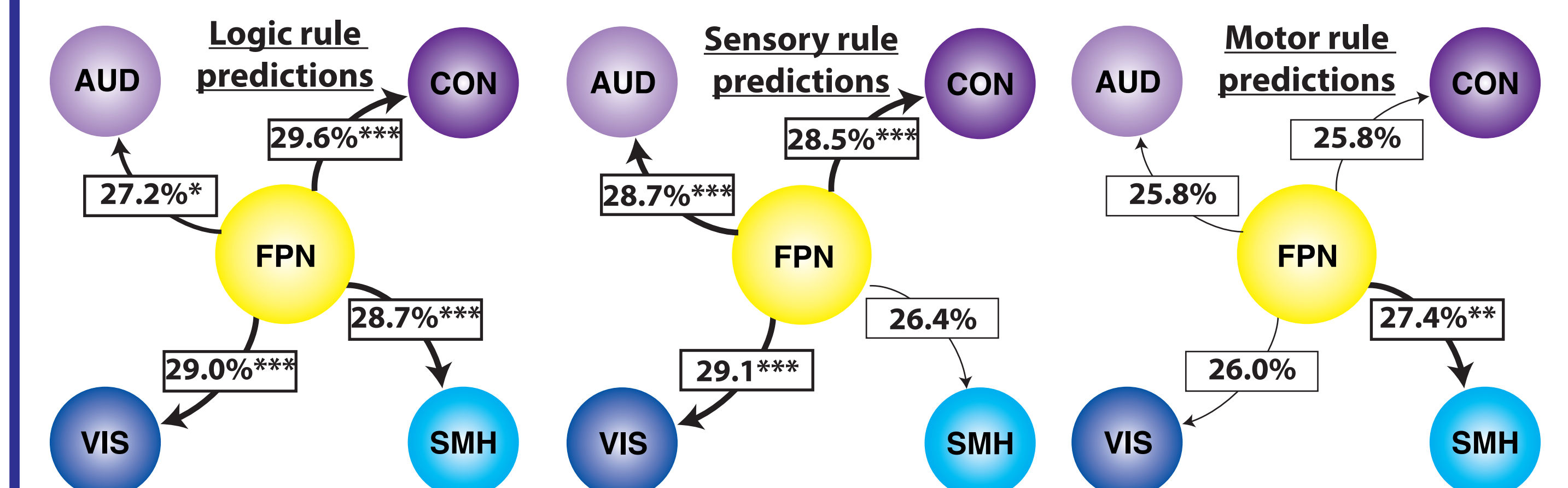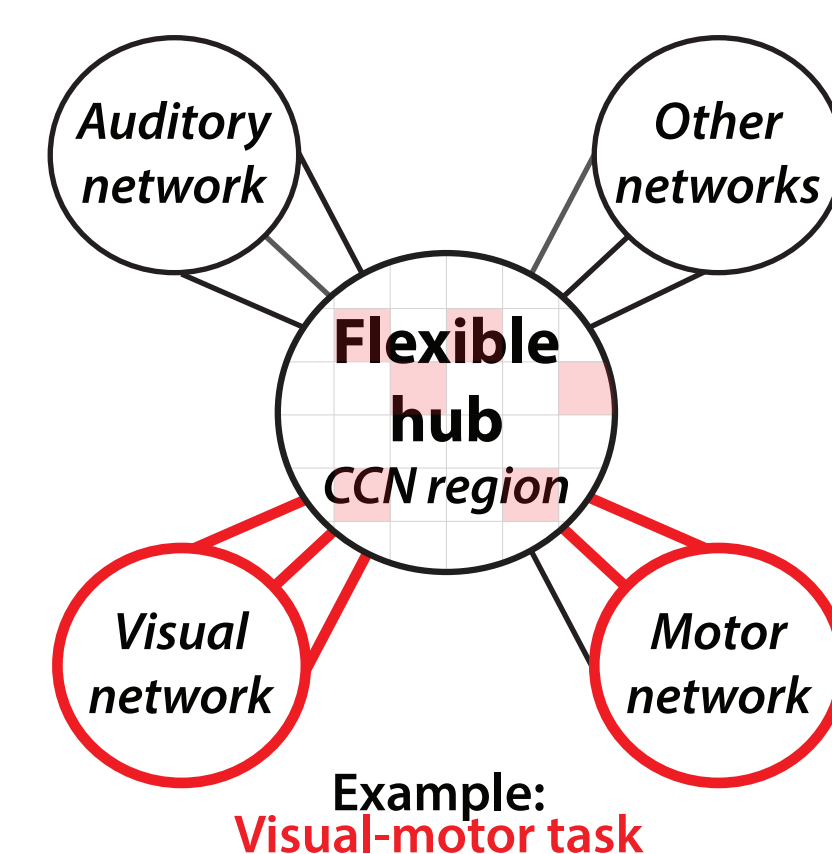Sensory Rule 4

r = 0.878 | r = 0.888

Regions

- We replicated findings from Cole et al. (2014), demonstrating that FC architecture during specific task rules were highly similar to intrinsic resting-state FC architecture.

The frontoparietel network flexibly represents task rule information

via Task Functional Connectivity

FPN task FC represents task information
A previous study demonstrated that the FPN can flexibly represent task information via out-of-network task FC (Cole et al., 2013).

Auditory network | Other networks

Flexible hub CCN region

Visual network | Motor network

Example: Visual-motor task

via Activity Patterns

FPN activity patterns represents all rule types via MVPA analysis
We performed 4-way classifications on each of the 3 rule types from the C-PRO cognitive task.

Logic Rule Classification
Both vs. Either vs. Neither vs. Not Both
Sensory Rule Classification
Hi Pitch vs. Constant vs. Vertical vs. Red
Motor Rule Classification
Left Index vs. Left Middle vs. Right Index vs. Right Middle
Chance = 25.0%
FDR-corrected
p < 0.05 - *
p < 0.01 - **
p < 0.001 - ***

FPN

Logic rule Accuracy = 34.7%***
Sensory rule Accuracy = 33.1%***
Motor rule Accuracy = 29.6%***

Does intrinsic functional connectivity architecture also carry task information between flexible hubs and task-related networks?

Flexible hubs relay task information via intrinsic functional connectivity pathways

Method - Predict downstream activity patterns via activity flow mapping
Predicting downstream activity patterns via intrinsic FC and upstream activity patterns.

Activity Flow Mapping Schematic

Network A activity - n vertices

Activity Flow via undirected FC Modulation

Prediction of network B activity - m vertices

$$A \cdot W_{fcAB} = B$$

- A is a $1 \times N$ vector of activity patterns in network A
- W_{fcAB} is an $N \times M$ matrix of FC between network A and B
- B is a $1 \times M$ vector of predicted activity patterns in network B

Classifying Real Data with Predicted Activity

Network A (Real Data)

Extracted betas from GLM analysis

network-to-network resting-state functional connectivity

$$A \cdot W_{fcAB} = B$$

Network B

ActFlow Prediction | SVM Analysis | Real Data

SVM Trainset Act Flow Predicted data
SVM Testset Real network-level activity

Results: Activity flow mapping classifications via SVMs

Logic rule predictions
AUD | CON | FPN | VIS | SMH
27.2%* | 29.6%*** | 28.7%*** | 29.0%***

Sensory rule predictions
AUD | CON | FPN | VIS | SMH
28.7%*** | 28.5%*** | 26.4% | 29.1***

Motor rule predictions
AUD | CON | FPN | VIS | SMH
25.8% | 25.8% | 27.4%** | 26.0%

- Task-specific activity patterns modulated by network-to-network FC can predict downstream activity patterns in task-related networks.
- **Predicted data can be used to classify real data.**
- Successful classifications on real data **depend on FPN mappings onto task-related networks**.

Summary & Conclusions

- Intrinsic resting-state FC is highly similar to task-evoked FC architectures (Cole et al., 2014)
- *Does intrinsic FC between FPN and task-related networks carry task information?*
  - **Yes - FPN activity and intrinsic FC can explicitly** *shape* **task-specific activity patterns in content-related networks**
- Intrinsic FC patterns complement task FC, and offer novel insight into how information flows and is shaped between flexible hubs and task-related networks