ALEJANDRO DE LA VEGA

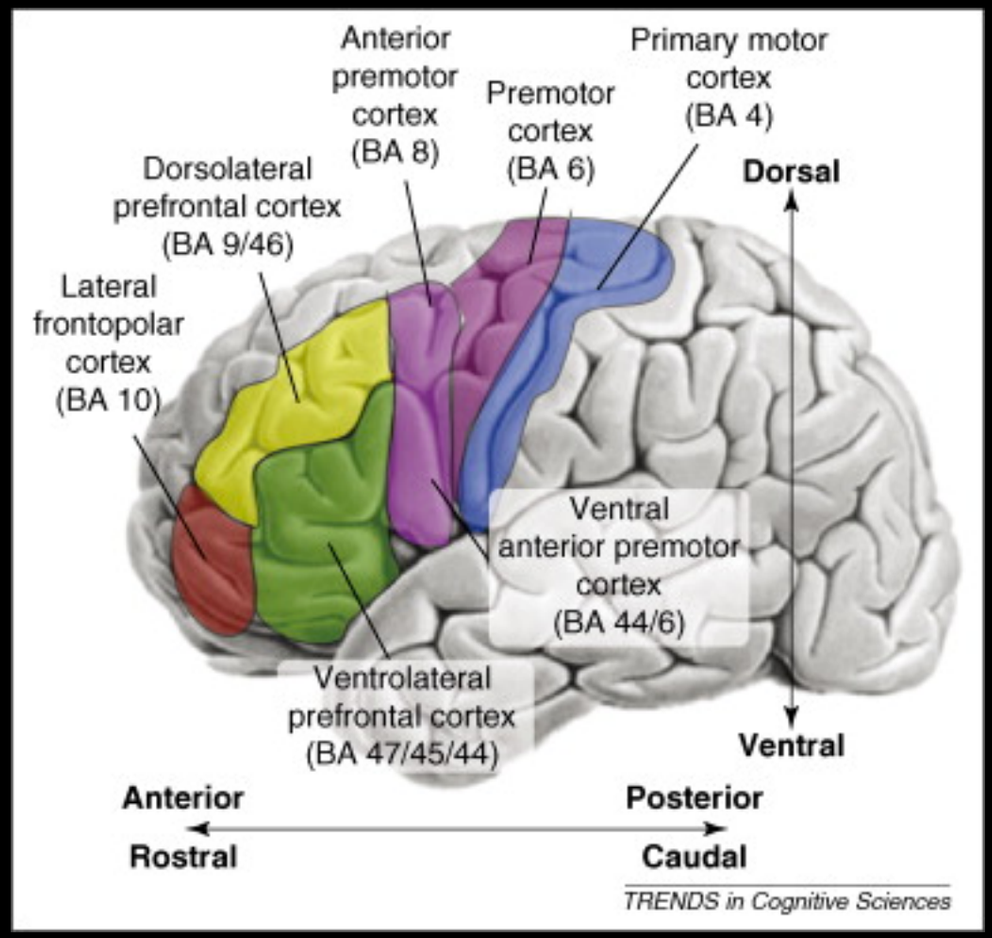
DIFFERENTIATING COGNITIVE CONTROL NETWORKS IN THE BRAIN

CONTROL SYSTEMS IN THE BRAIN

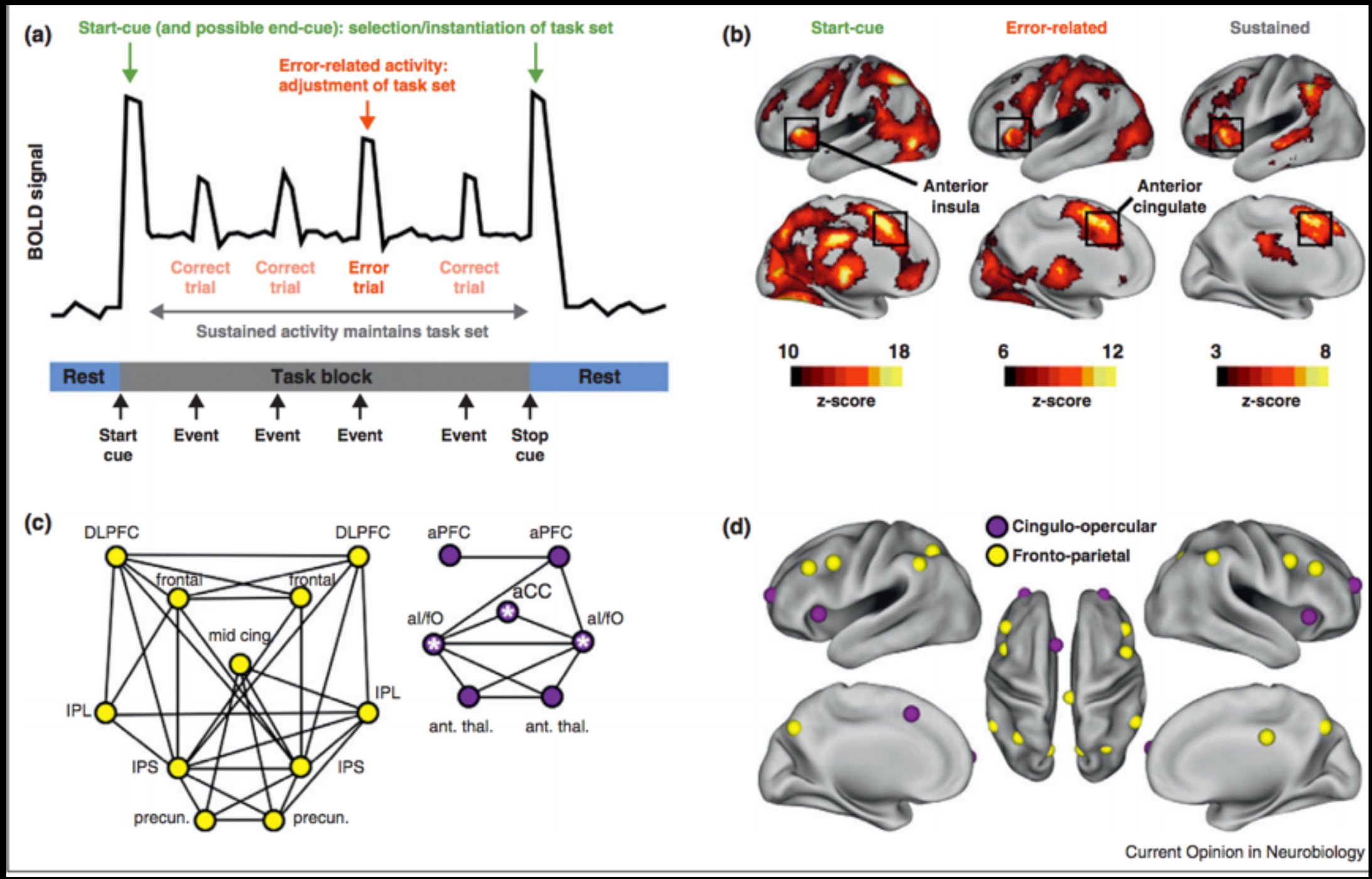
- Humans have ability to learn new tasks, flexibly adapt to ever changing environmental demands
- If rules of task change, healthy humans adapt quickly
- Control systems in the brain flexibly adapt connections to subservient regions to adapt to changing demands
- Which brain systems are responsible?

LATERAL PREFRONTAL CORTEX

- Frontoparietal Control Network
  - LPFC, Posterior parietal cortex
  - Thought to be useful for learning new tasks
    - Flexibly adapts connectivity to subservient brain regions
- Top-down LPFC signals of task goals bias down-scale information flow (e.g. response mappings)



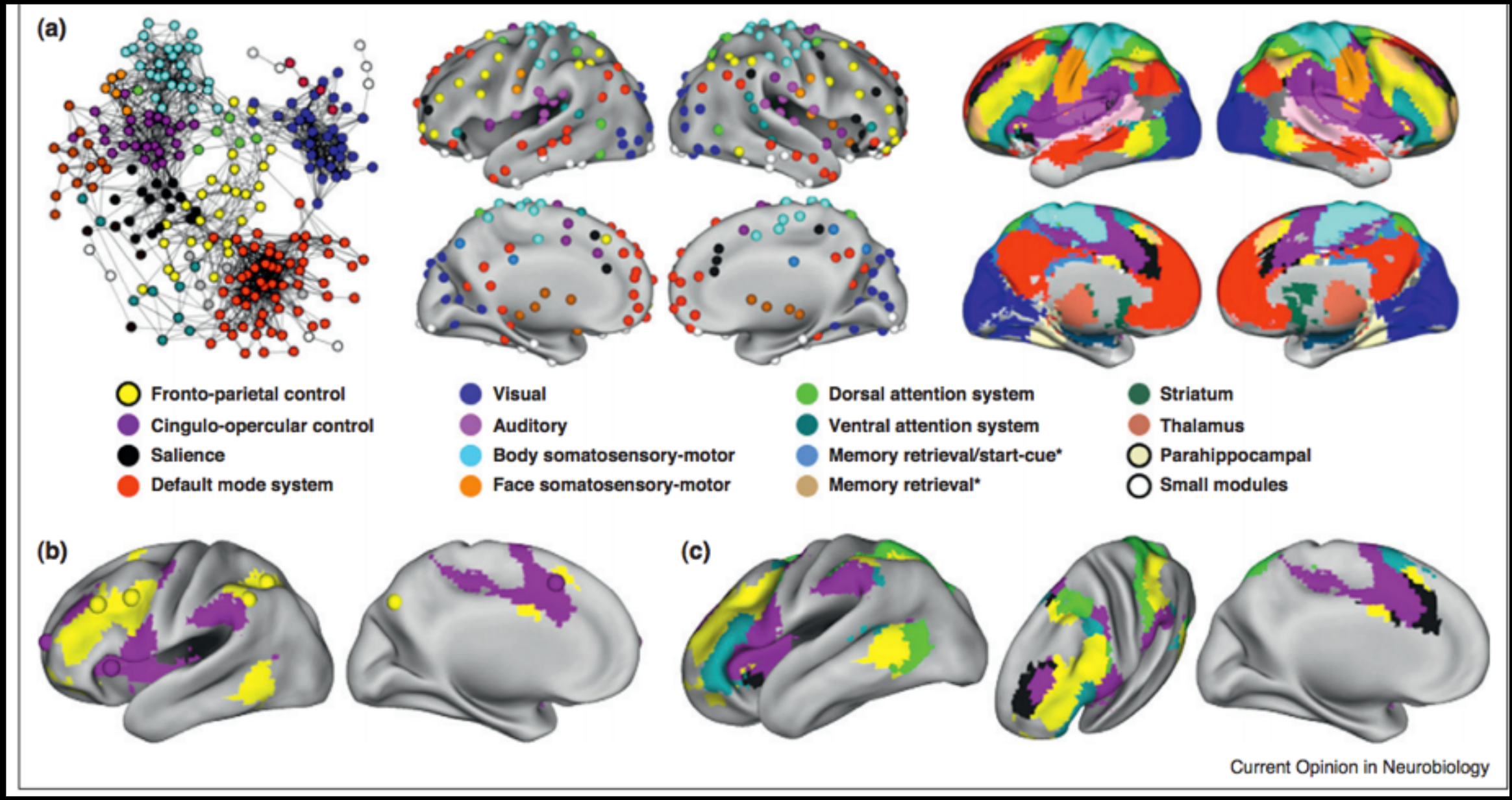
CHARACTERISTICS OF CONTROL SYSTEMS (PETERSEN) - INSULA/MPFC



“The cingulo-opercular system contains regions that display start-cue, error-related, and sustained activity, whereas the fronto-parietal system contains regions that displayed start-cue and error-related activity but not sustained activity during task set maintenance”

RESTING STATE NETWORKS

- Resting state correlations thought to reflect "real" task dynamics
  - Regions that have similar patterns, fire together during task
  - Can be used to reveal network organization of the brain
- Results less dependent on specific tasks selected



- The two systems separate
  - In addition, salience (arousal) vs cingulo-opercular network
  - Other arguments that insula (therefore mpfc) is involved in focal attention (Nelson)
- Fronto-parietal is near middle of graph

\WHICH SYSTEM IS THE CONTROLLER?

- How do insula/mpfc and dlpfc differ in how they implement control?

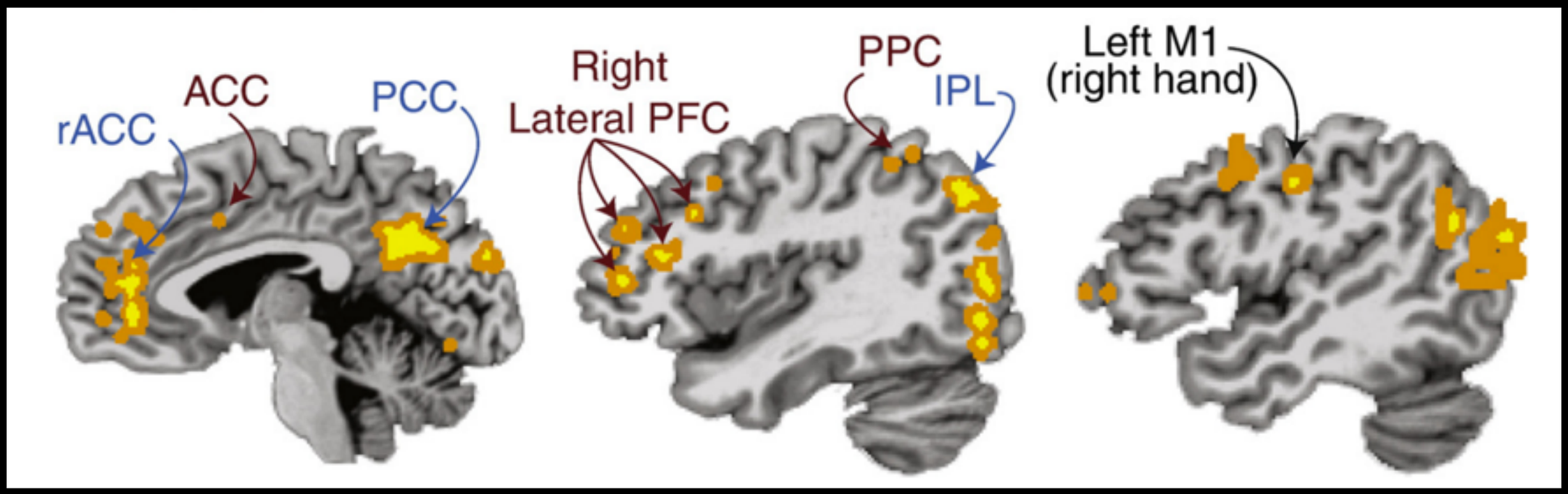
- What other characteristics would a control region have?

  - High connectivity with the rest of the brain

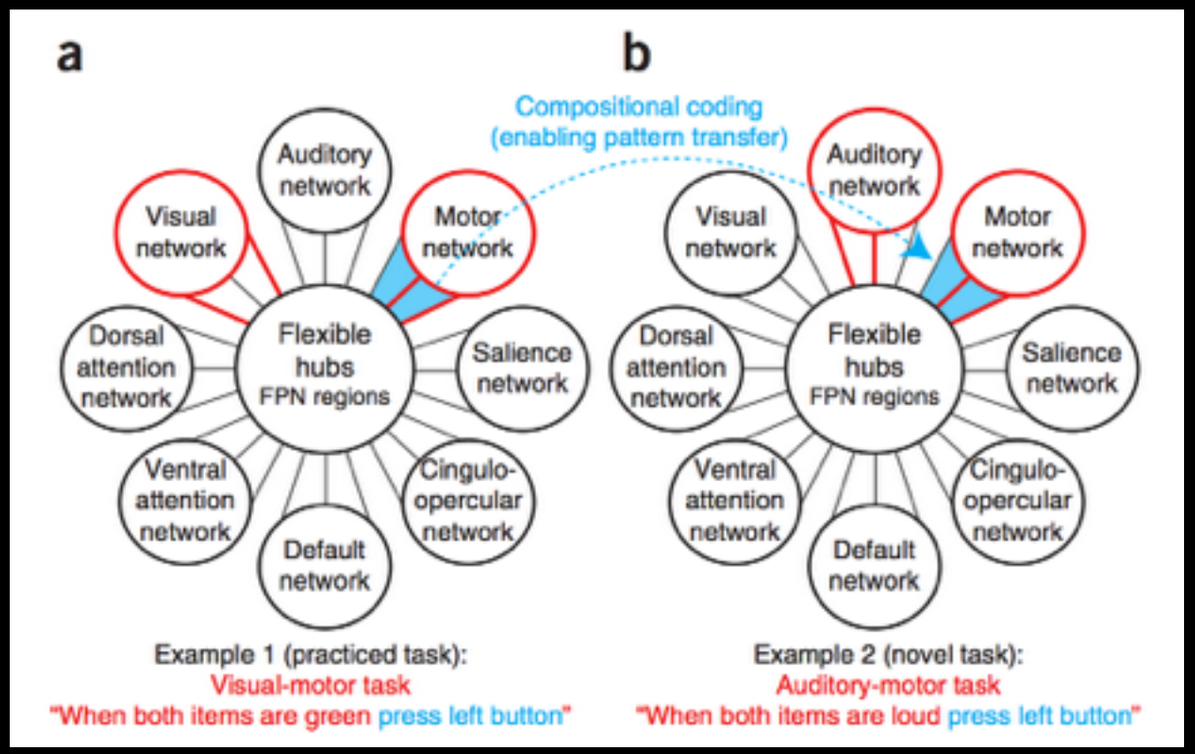
  - Flexible connectivity across tasks (with different subservient processors)

GLOBAL CONNECTIVITY AT REST

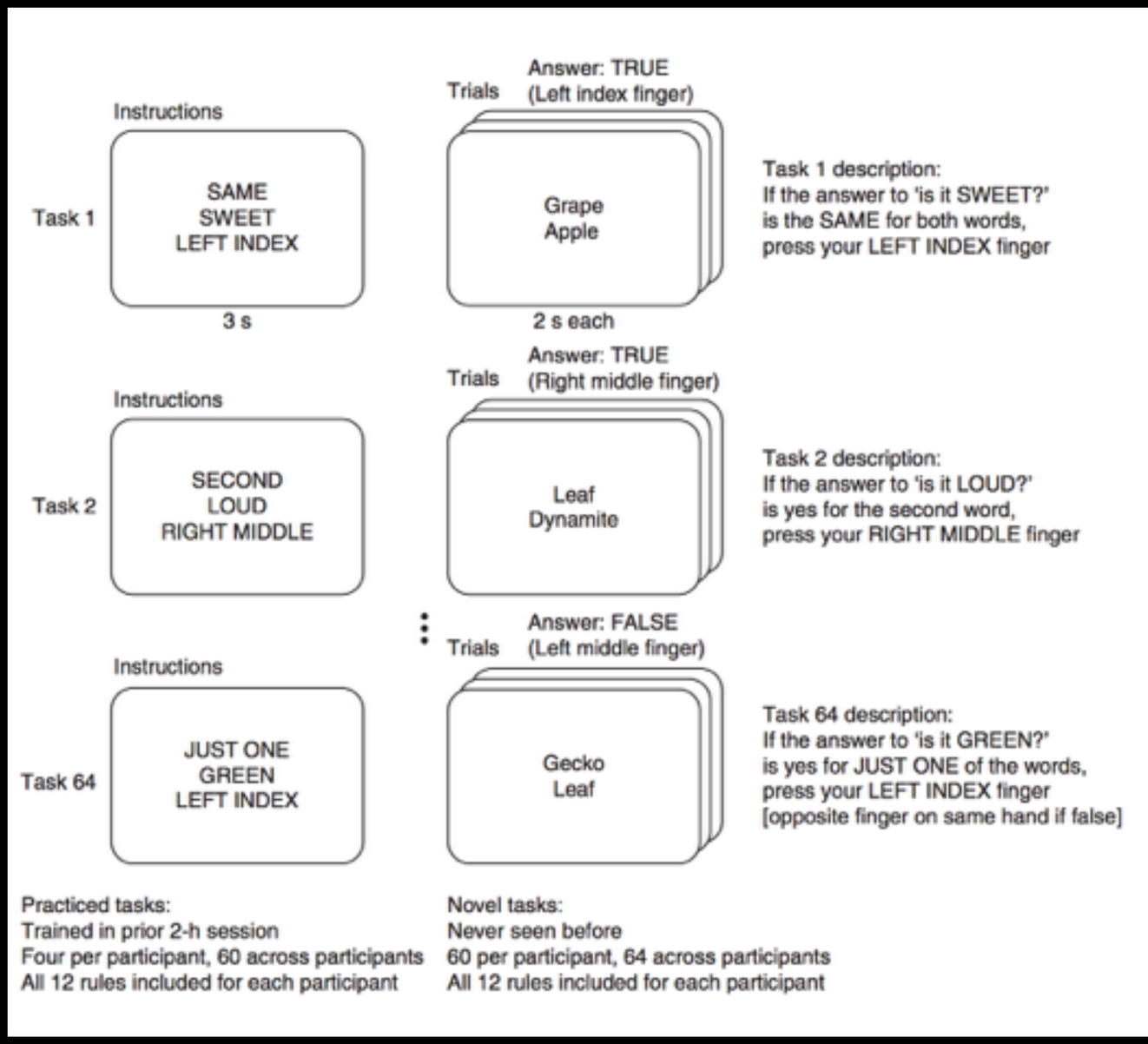
- Which regions have the highest mean connectivity at rest?
  - Conjunction of two connectivity measures from Cole (2010)



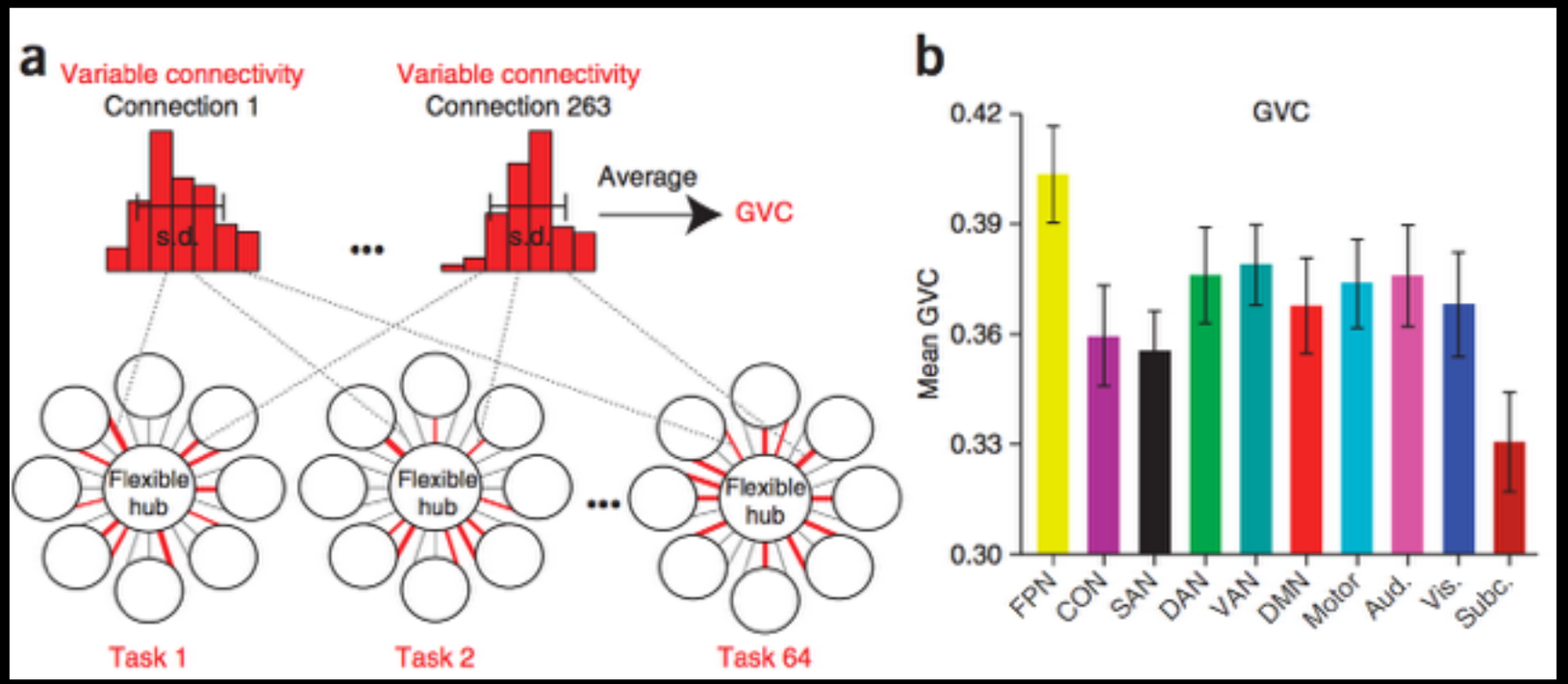
GLOBAL CONNECTIVITY ACROSS TASKS (COLE 2014)

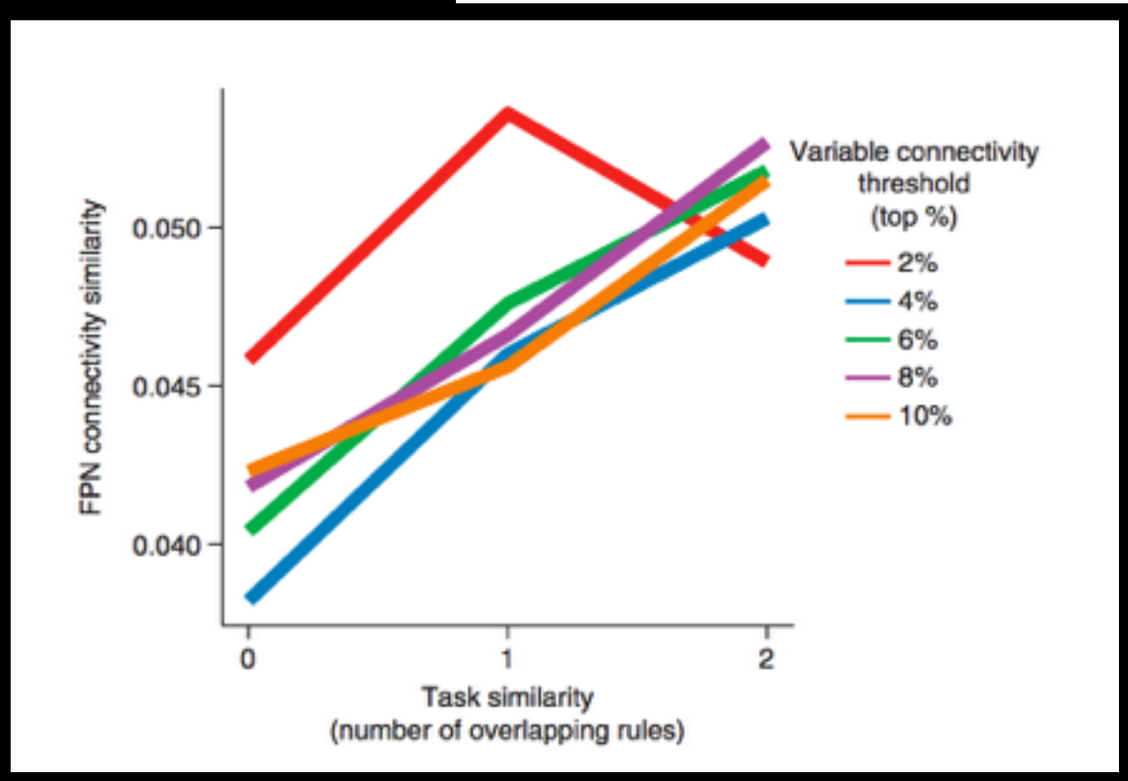


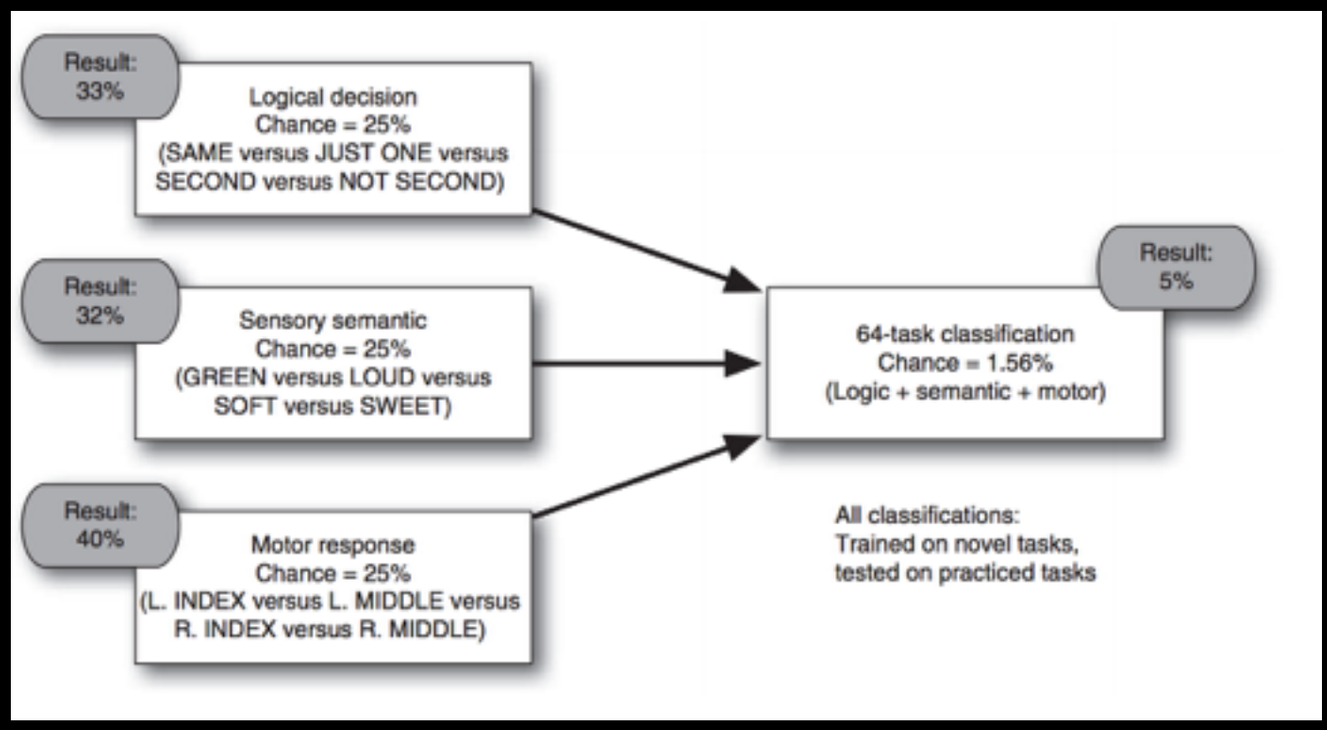
- Idea: Perform many (64) tasks and compute global connectivity



RESULTS


a
Variable connectivity
Connection 1
Variable connectivity
Connection 263
s.d.
s.d.
Average
GVC
Flexible hub
Flexible hub
Flexible hub
Task 1
Task 2
Task 64
b
GVC
Mean GVC
0.42
0.39
0.36
0.33
0.30
FPN
CON
SAN
DAN
VAN
DMN
Motor
Aud.
Vis.
Subc.


FPN connectivity similarity
0.050
0.045
0.040
0
1
2
Task similarity
(number of overlapping rules)
Variable connectivity threshold (top %)
2%
4%
6%
8%
10%


Result: 33%
Logical decision
Chance = 25%
(SAME versus JUST ONE versus SECOND versus NOT SECOND)
Result: 32%
Sensory semantic
Chance = 25%
(GREEN versus LOUD versus SOFT versus SWEET)
Result: 40%
Motor response
Chance = 25%
(L. INDEX versus L. MIDDLE versus R. INDEX versus R. MIDDLE)
64-task classification
Chance = 1.56%
(Logic + semantic + motor)
Result: 5%
All classifications:
Trained on novel tasks,
tested on practiced tasks

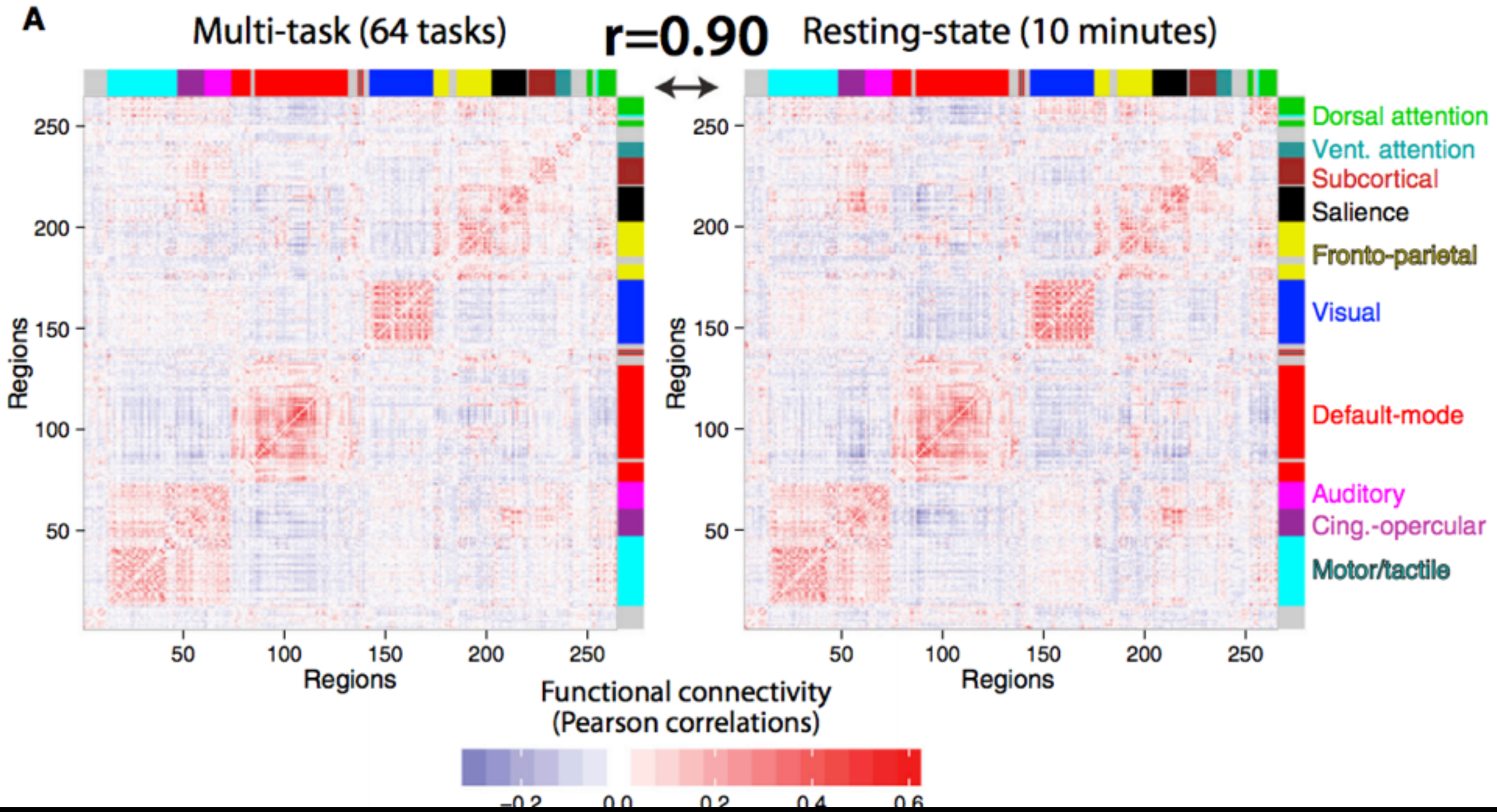
CRITICISMS

- 64 ‘tasks’ are surprisingly similar
  - All involve changing rule to response mapping
  - Probably not representative of space of possible cognitive processes
  - Bias towards LPFC having highest global connectivity

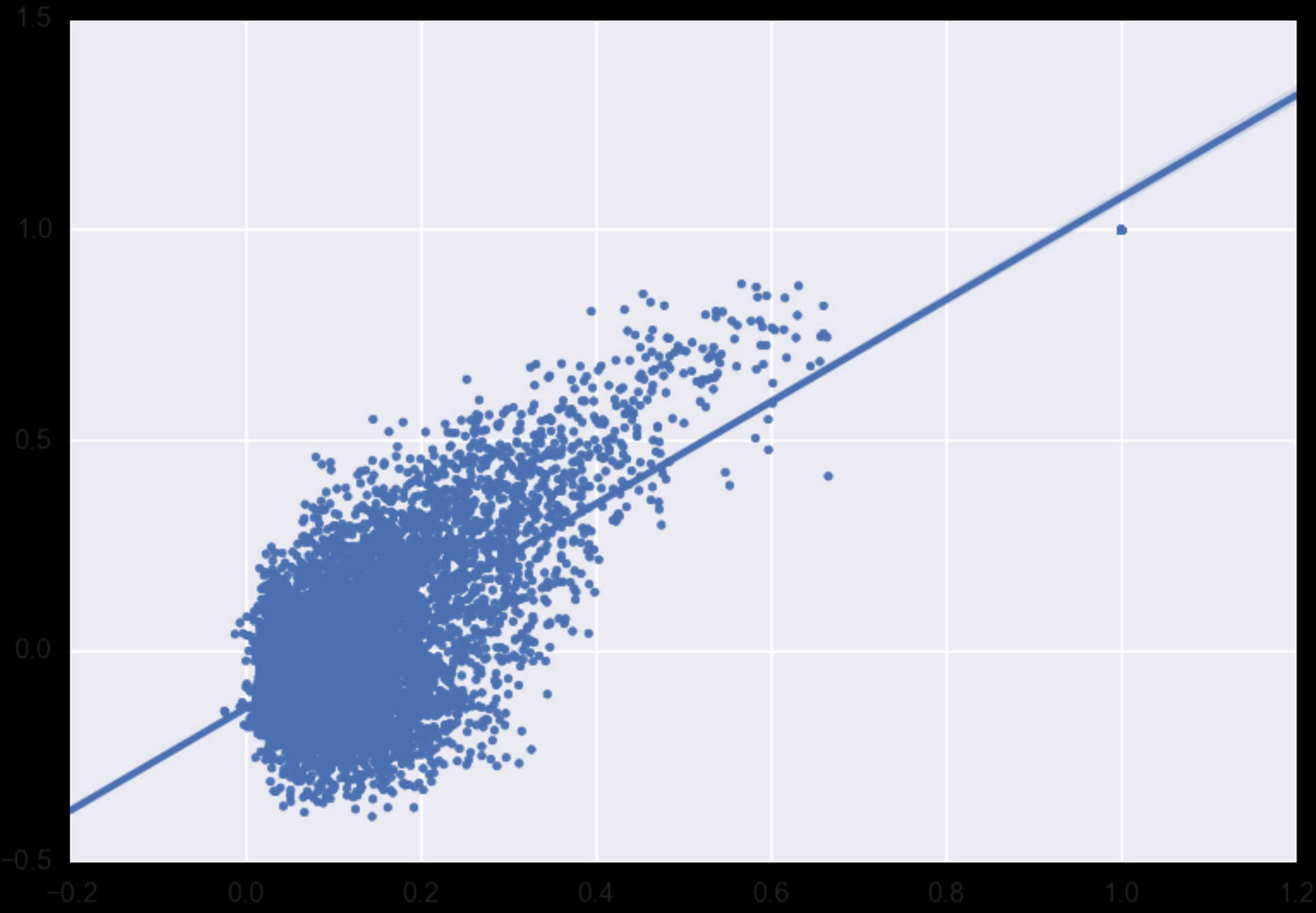
EXISTING DIVERSITY

PRESENT STUDY

- Existing large-scale neuroimaging databases span a wide range tasks and cognitive processes (over 10k studies)
- However, these data are low resolution (can’t compute connectivity)

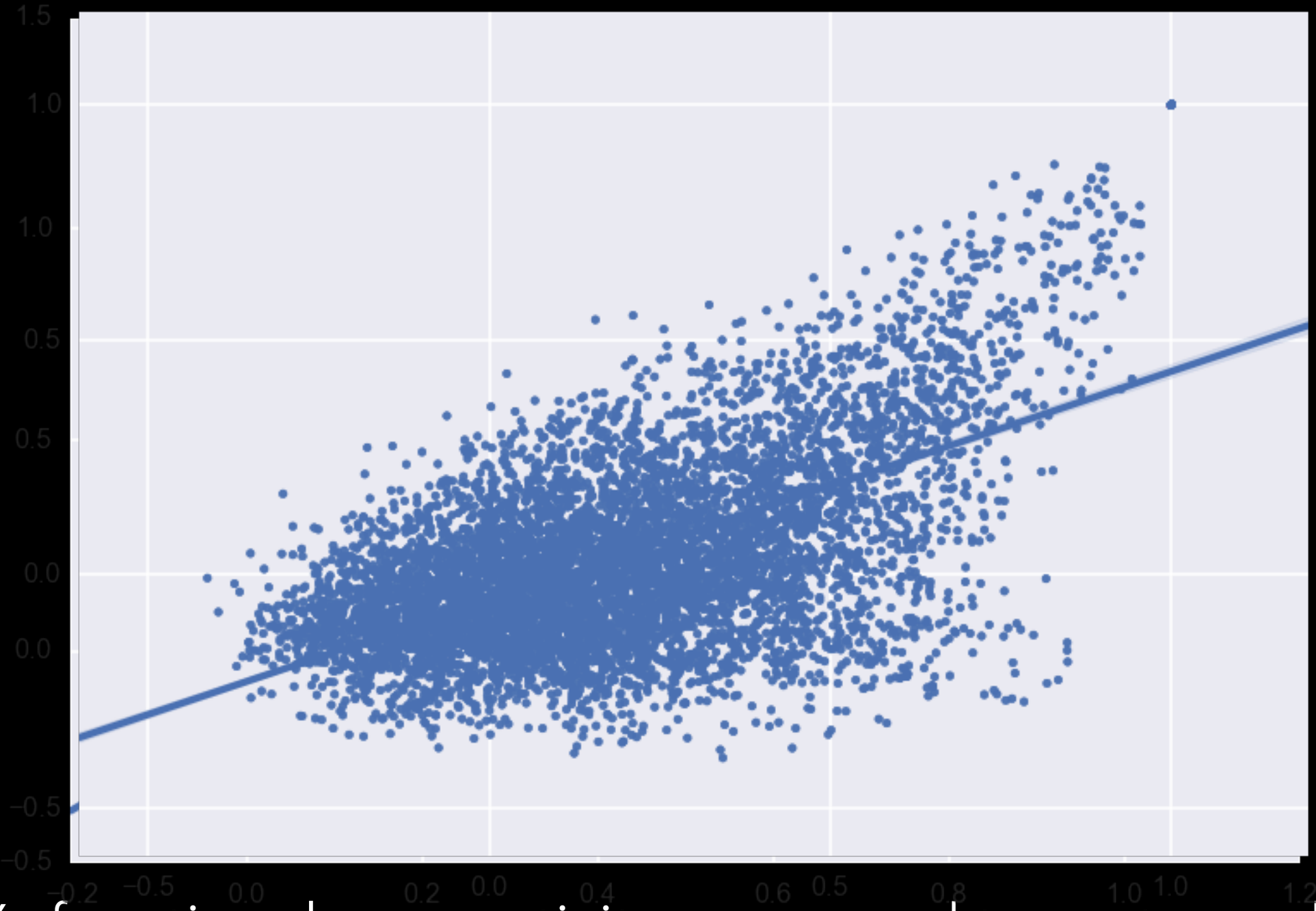

A
Multi-task (64 tasks)
r=0.90
Resting-state (10 minutes)
250
200
150
100
50
Regions
50
100
150
200
250
Regions
Dorsal attention
Vent. attention
Subcortical
Salience
Fronto-parietal
Visual
Default-mode
Auditory
Cing.-opercular
Motor/tactile
Functional connectivity
(Pearson correlations)
−0.2
0.0
0.2
0.4
0.6

RESTING STATE → META-ANALYTIC



r = .7, functional connectivity compared to coactivation

RESTING STATE → M-A FUNCTION



r = .6, functional connectivity compared to meta-analytic functional distance

META-ANALYTIC GLOBAL CONNECTIVITY

- Goal: Calculate exact measure of meta-analytic global connectivity from Cole
- If FPN is truly the most flexible network, should show highest global connectivity, across diverse set of tasks

NEW DIVERSITY MEASURES

- Moreover, if FPN is a “flexible hub”, one would expect it to be involve in the greatest amount of cognitive processes, as it is modulating them

- However, existing diversity measures are only based on the correlational weights between cognitive functions and region. Purely a measure of “randomness” of the functional descriptors of a region

- But, they do not tell us how many functions are needed to characterize a region activity

DIVERSITY EXAMPLE

- Entropy high diversity example
  - [Memory, EF, Audition, Vision, Motor, Pain]
  - [1, 0.5, 0.1, 1.5, 1.2, 1]
- Low diversity example
  - [1, 1, 0, 0, 0]
- However, this does not tell us how constant this pattern is *across* studies, and how diverse of a model is necessary to explain a regions' activity

PREDICTIVE DIVERSITY

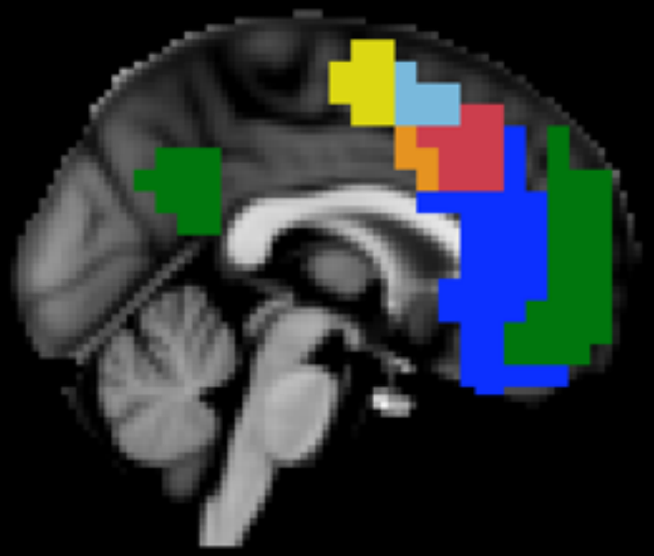
- One region's associations w/ functions across studies
- Low diversity: Motor cortex
  - All you need to know is that the study involved motor processes
- Higher diversity: vmpfc
  - Could be activated by: memory, emotion, social processes… AND these will vary across studies (not just within)

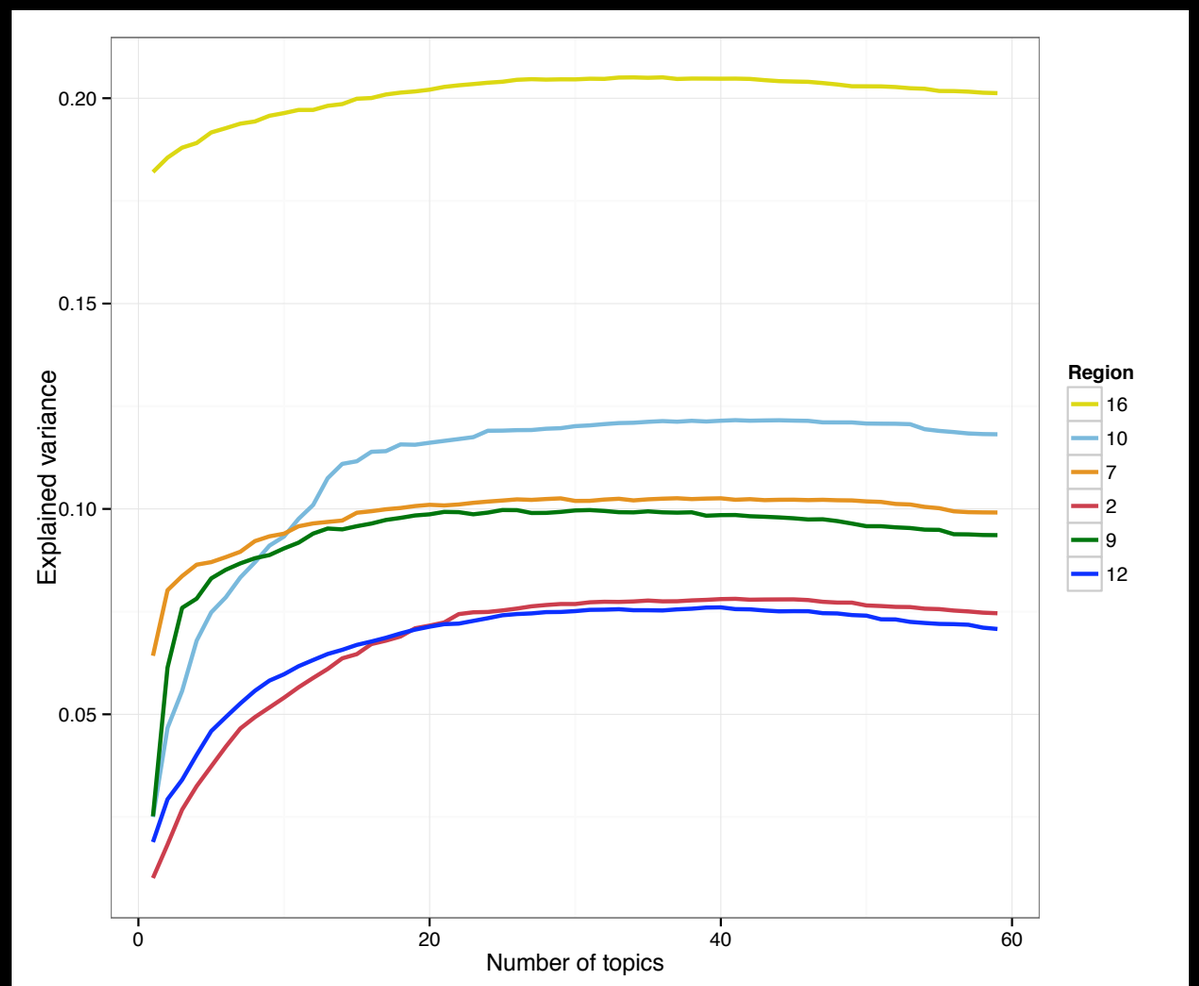
PREDICTIVE DIVERSITY

- Predictive diversity is defined by how complex of a semantic model is necessary to successfully predict if a study activated a region

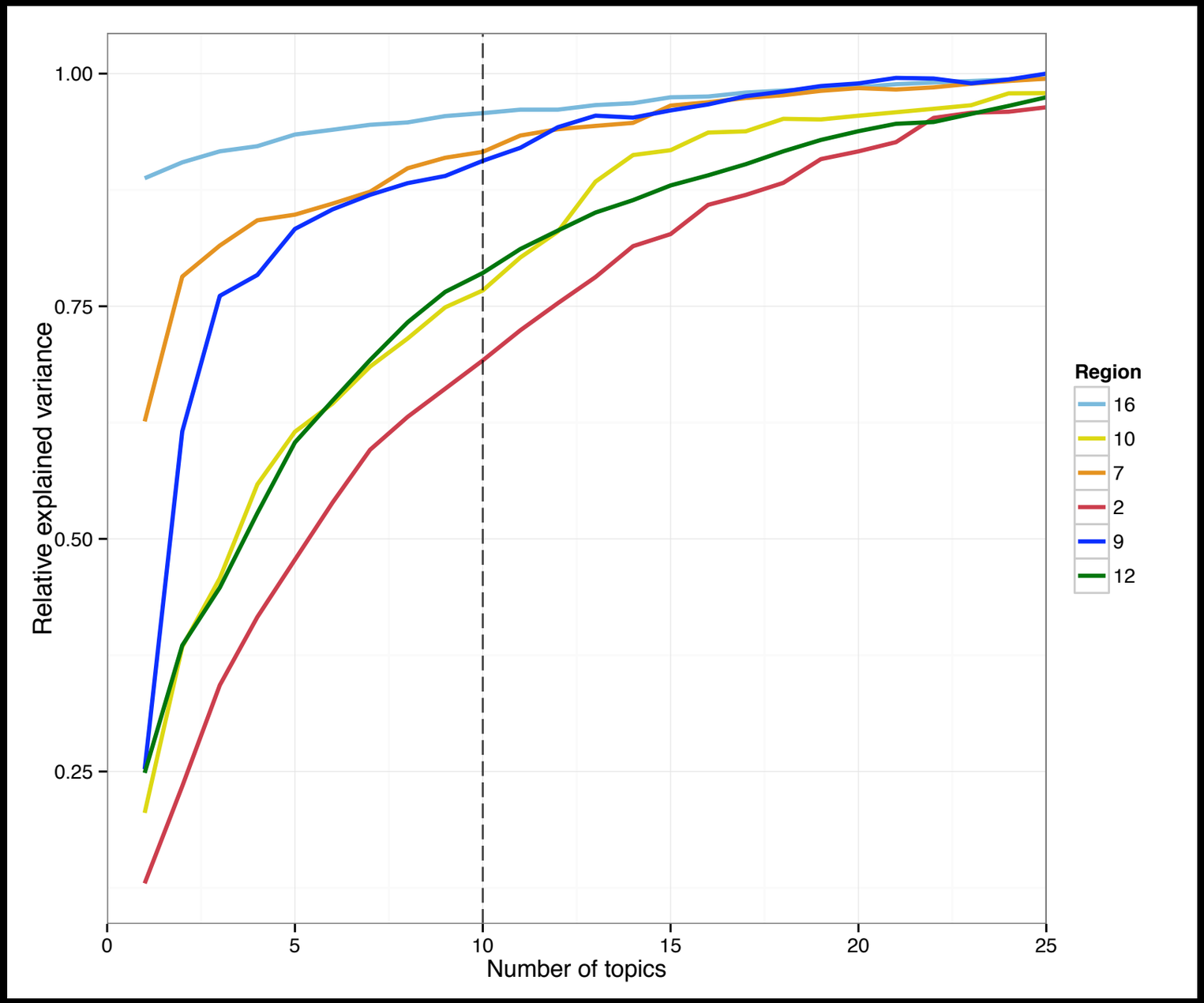
- That is, do you need to know about many features or few?

VMPFC DIVERSITY

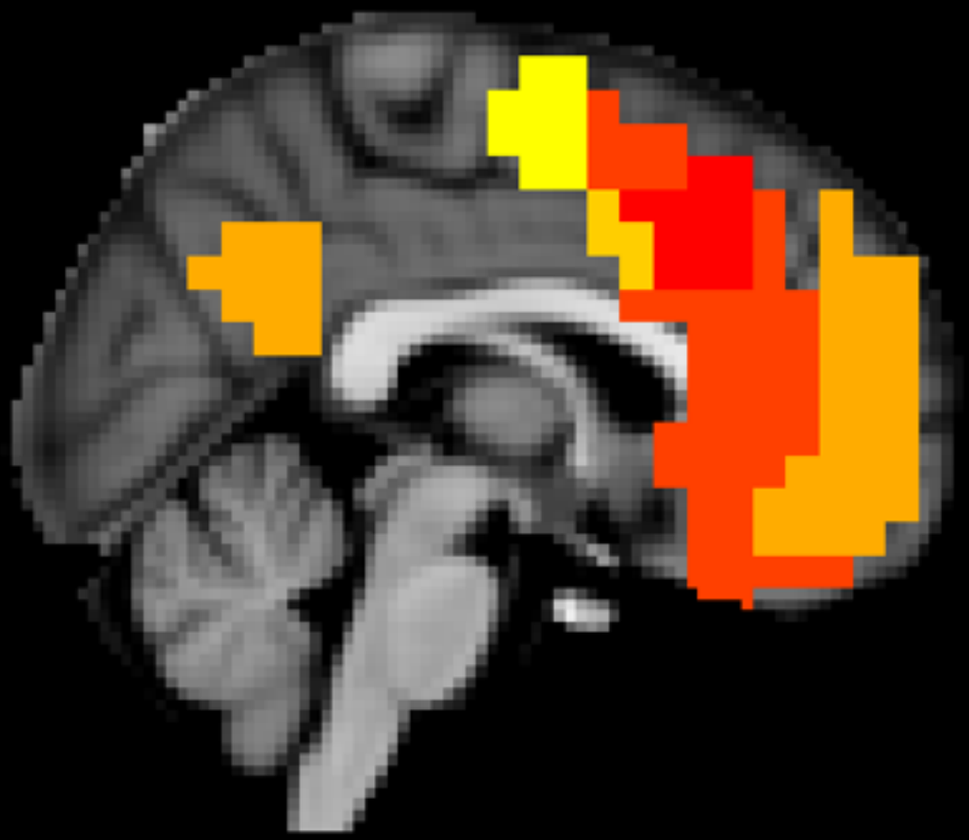


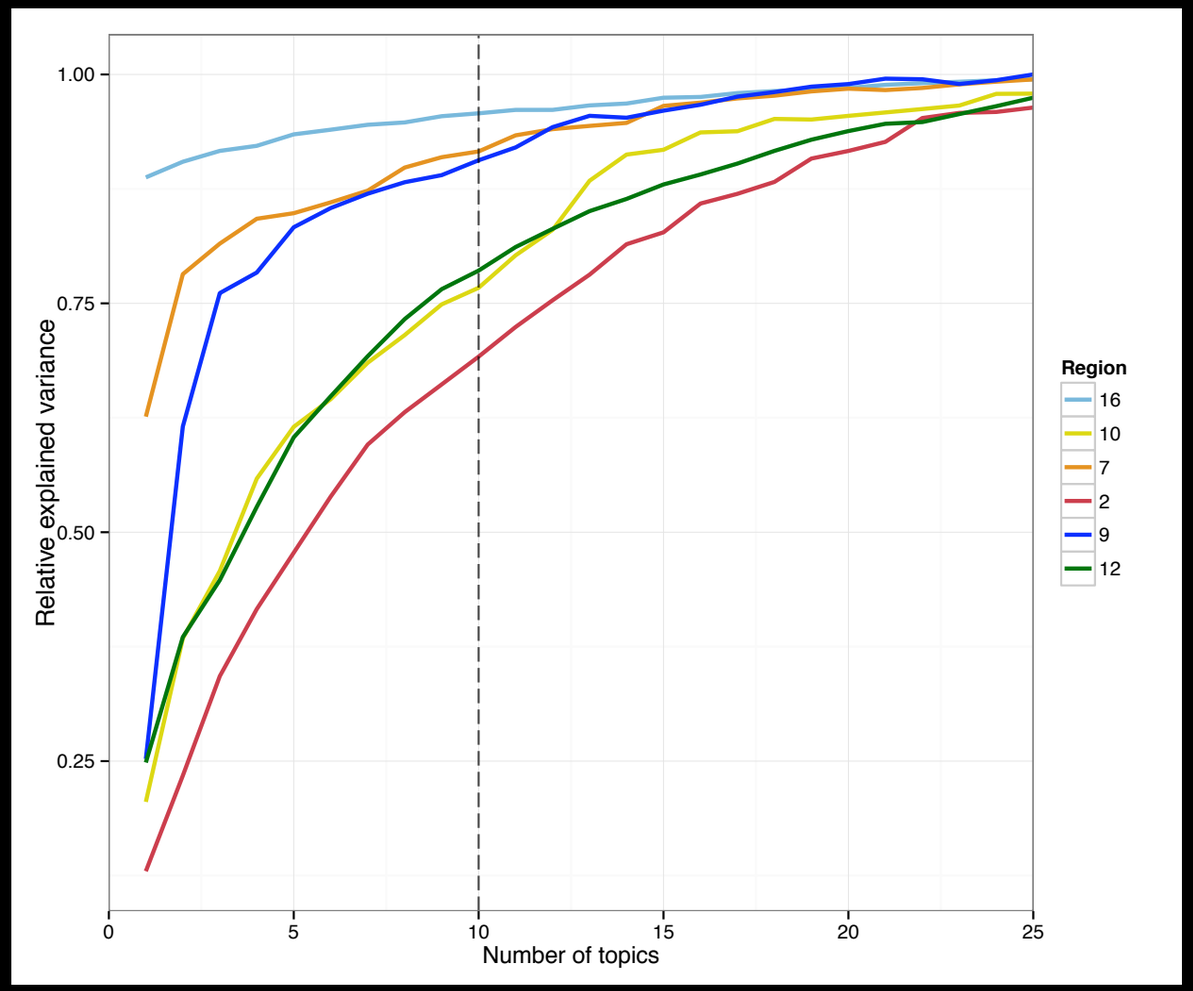


VMPFC DIVERSITY



VMPFC DIVERSITY





DIVERSITY MAPS TO GRAPH THEORY MEASURES

- Diversity measure correlates with participation graph theoretic measures in resting state, with the additional benefit of spanning many tasks

DIVERSITY AND CONNECTIVITY ACROSS DOMAINS

- Leverage diversity of Neurosynth's database to get better estimates of how diversity and connectivity changes depending on the cognitive domain
- Threshold database using terms that corresponds to a type of study (e.g. memory, or stroop)
- Calculate change in connectivity and diversity measures
- Do FPN findings only hold for cognitive control tasks?