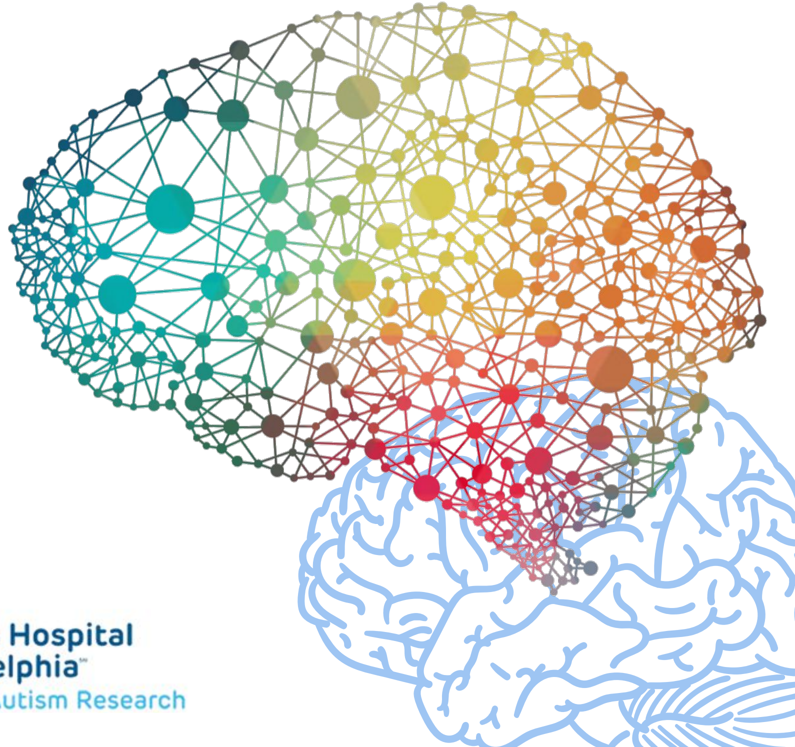
Structure-Function Coupling in Brain: Subnet Communicability

Jonathan Parlett · Abhishek Jeyapratap · Ali Shokoufandeh
Birkan Tunc · Yusuf Osmanlioglu

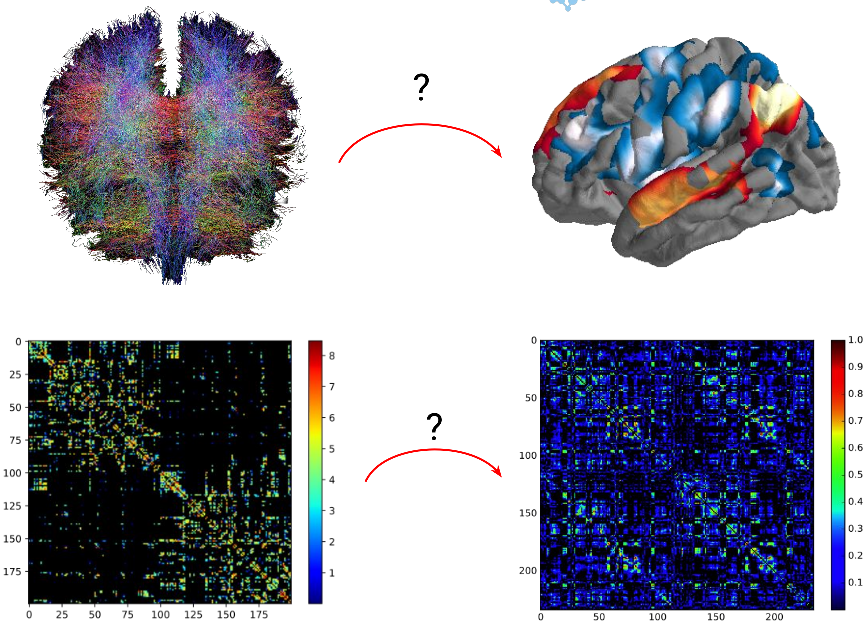


DREXEL UNIVERSITY
College of
Computing &
Informatics

Children's Hospital of Philadelphia
Center for Autism Research

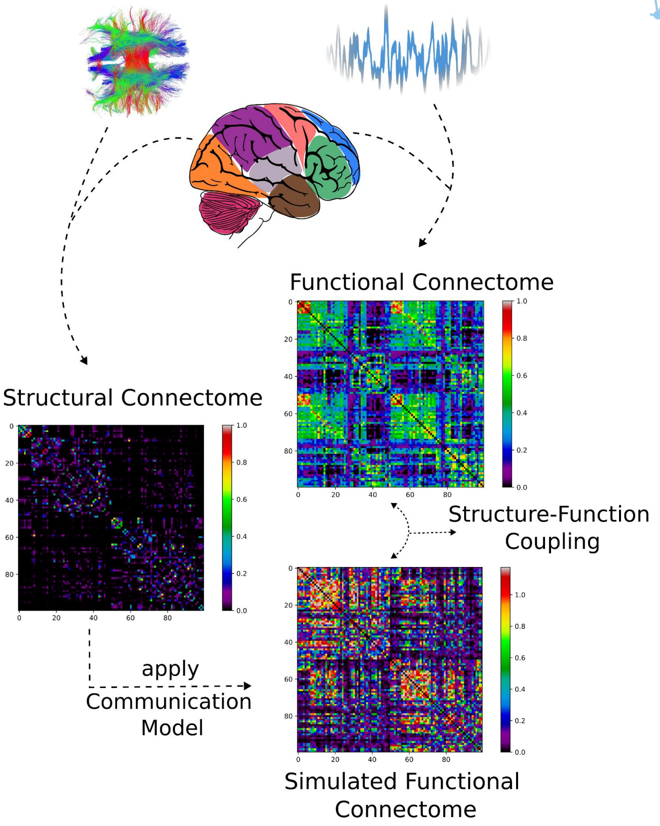
Communication in the Brain

- Functional interaction exists between anatomically unconnected brain regions
  - How does this indirect communication occur?
  - What is the correct communication model?
- Following previous literature, we propose a model of signal propagation in brain networks



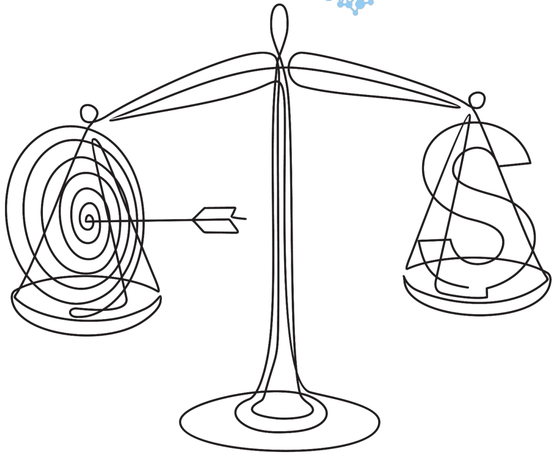
Structure-Function Coupling (SFC)

- ❑ **Communication models**
  - ❑ provide a framework to simulate function using structure
- ❑ **Structure-function coupling**
  - ❑ similarity between empirical and simulated functional connectivity
  - ❑ commonly measured by Pearson's correlation coefficient (r)



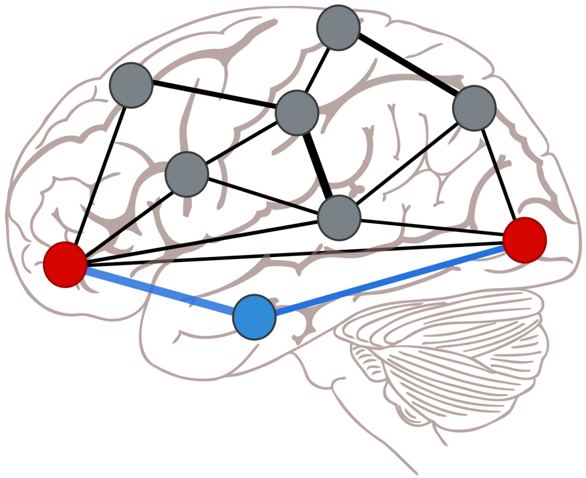
Communication Models: Quality of Service

- Two competing factors: efficiency and robustness
- **Efficiency:** use the least amount of energy to propagate signal
  - Communicate through single shortest path
- **Robustness:** communication should withstand local connectivity failures by allowing redundancy
  - Communicate through multiple paths simultaneously



Communication Models: Shortest Path

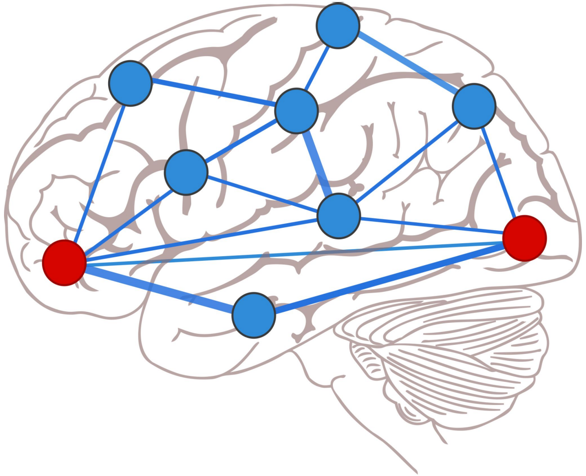
- Due to the brain’s efficient wiring economy, the brain was assumed to utilize a very efficient communication model.
  - The de facto model has been **shortest path**
- **Pros:**
  - **Very efficient** as signal need only propagate over single optimal path
- **Cons:**
  - **Not robust** as it lacks **redundancy** in message passing, making it vulnerable to localized lesions
  - requires each region to have **global knowledge** of the network for optimal message passing



Shortest (strongest) Path

Communication Models: Communicability

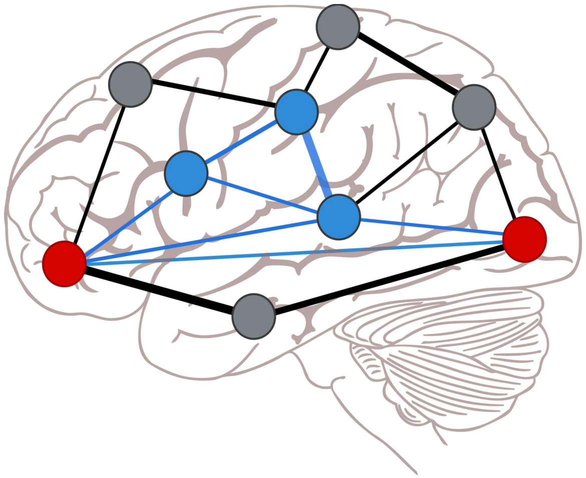
- **Diffusive** communication models are shown to more accurately reflect the functional dynamics of the brain
  - propagate signal through multiple pathways between regions **concurrently**
- **Communicability** is the state of the art diffusive model
  - propagates signal through all possible pathways between regions
- **Pros:**
  - **Very robust** since local perturbations to connectivity has minimal consequences on communication due to high redundancy
- **Cons:**
  - **Highly inefficient** as more energy is required to propagate signal over multiple pathways



Communicability

Proposed Model: Subnet Communicability

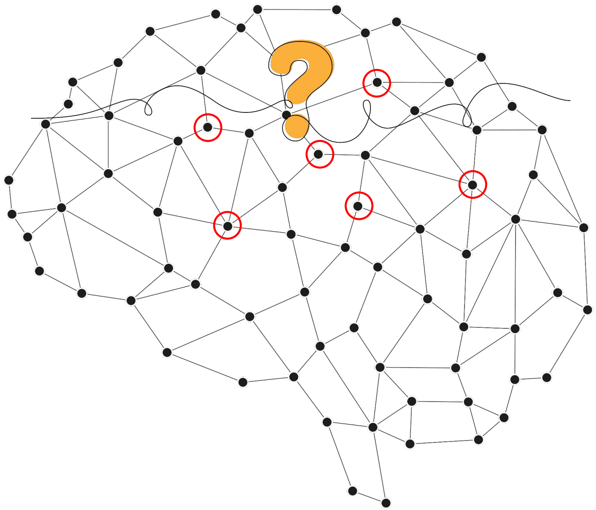
- **Subnet Communicability:** a balance between efficiency and redundancy in communication
  - pick a **small subset** of nodes to serve as backbone
  - propagate signal **diffusively** through paths utilizing these nodes
- Adjusting the subnetwork size
  - Fewer messages are sent in diffusion through a smaller subnetwork
  - Large subnetwork: more **redundancy**, less efficiency.
  - Small subnetwork: less redundancy, more **efficiency**.



Subnet Communicability

Which subnetwork?

- Subnet communicability is parameterized by the set of nodes constituting the subnetwork
- Which subnetwork do we use as a communication backbone?
  - Determine the **optimal size** of subnetwork
  - Determine the **set of nodes** leading to best structure-function coupling



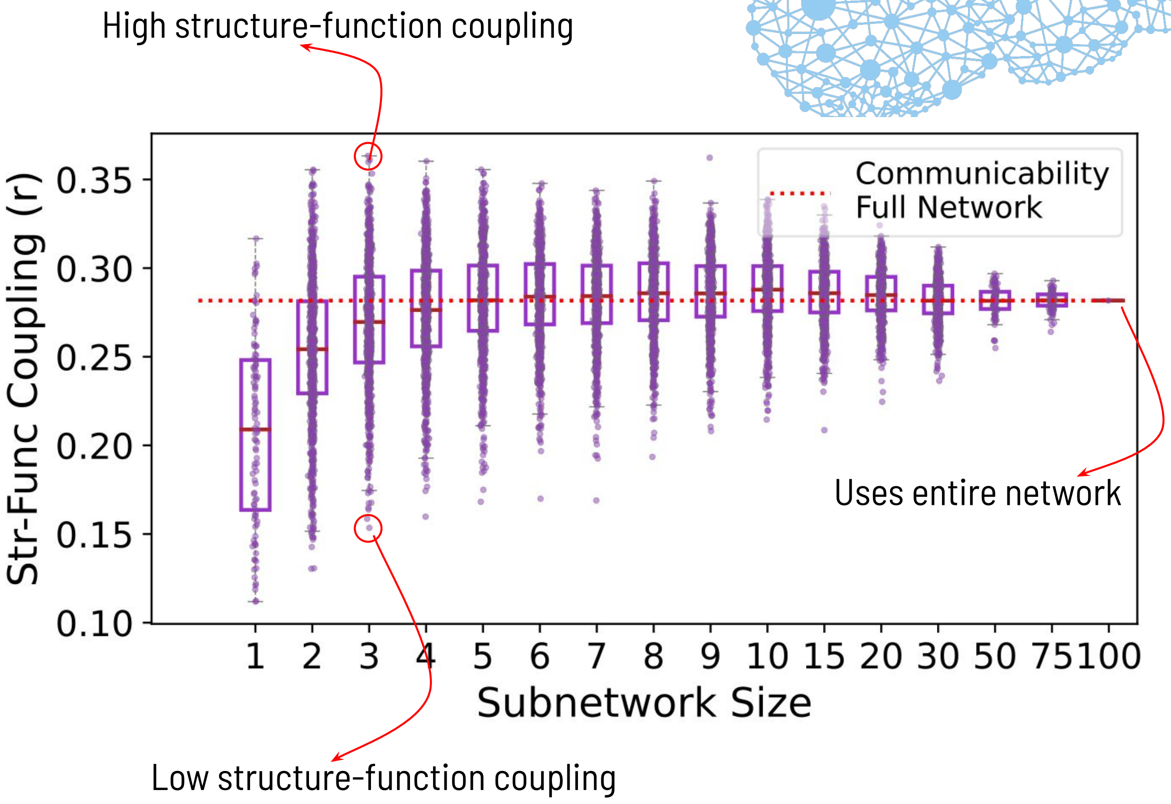
Dataset

Dataset:

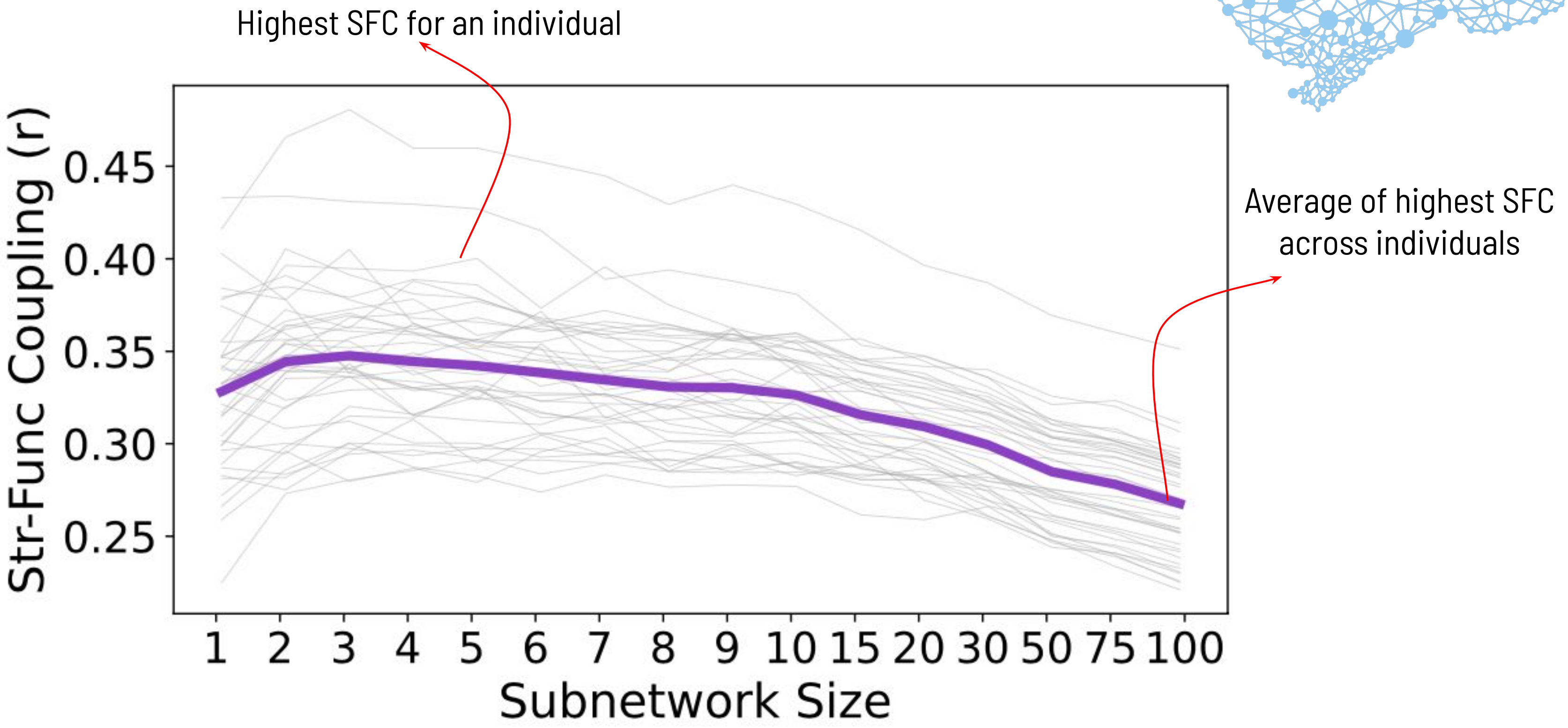
- ❏ 200 individuals from young adult dataset of HCP data
- ❏ Structural (DWI) and resting state functional (rs-fMRI) data
- ❏ Connectomes obtained using Schaefer atlas with 100 and 200 ROIs

Which Subnetwork?

- Structure function coupling is affected by:
  - Size of the subnetwork
  - The nodes that constitute the subnetwork

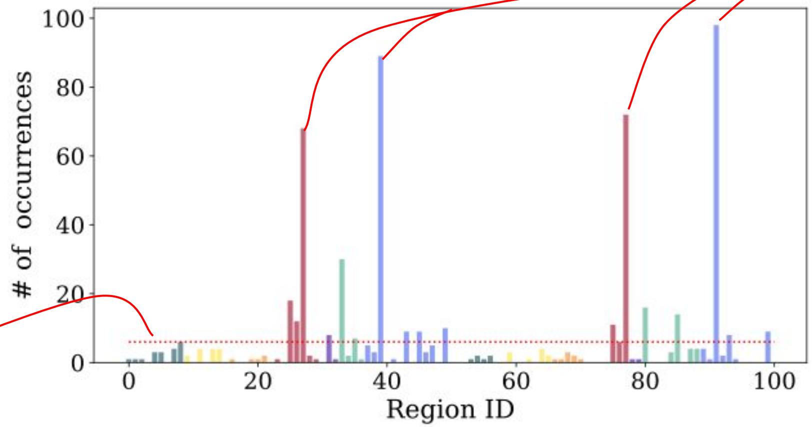


What Size?



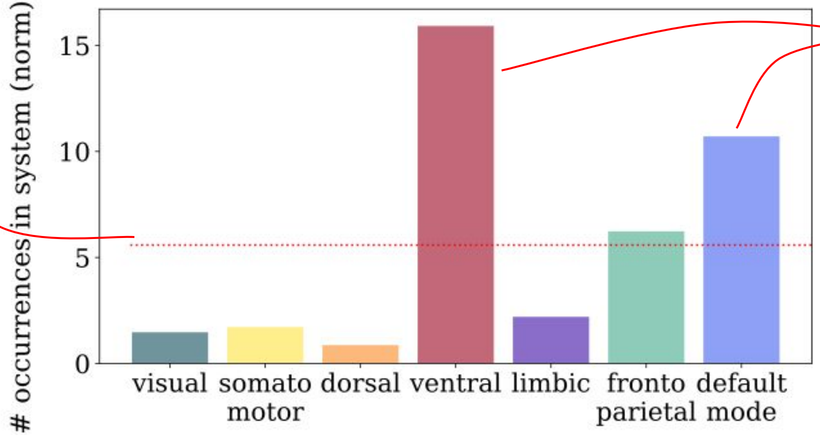
Highest SFC for an individual
Average of highest SFC across individuals
Str-Func Coupling (r)
0.45
0.40
0.35
0.30
0.25
1
2
3
4
5
6
7
8
9
10
15
20
30
50
75
100
Subnetwork Size

Which Nodes?

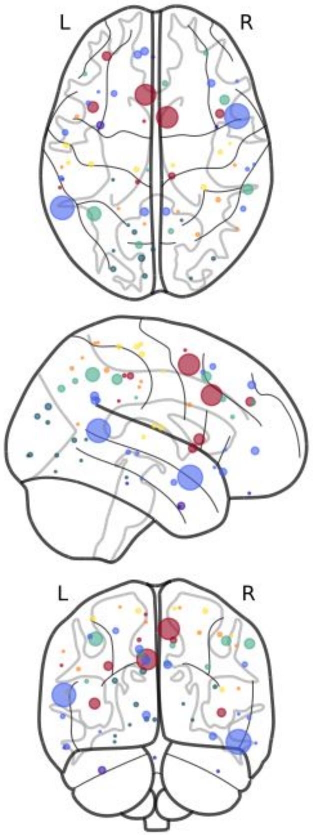


Regions that are consistently over represented across the dataset

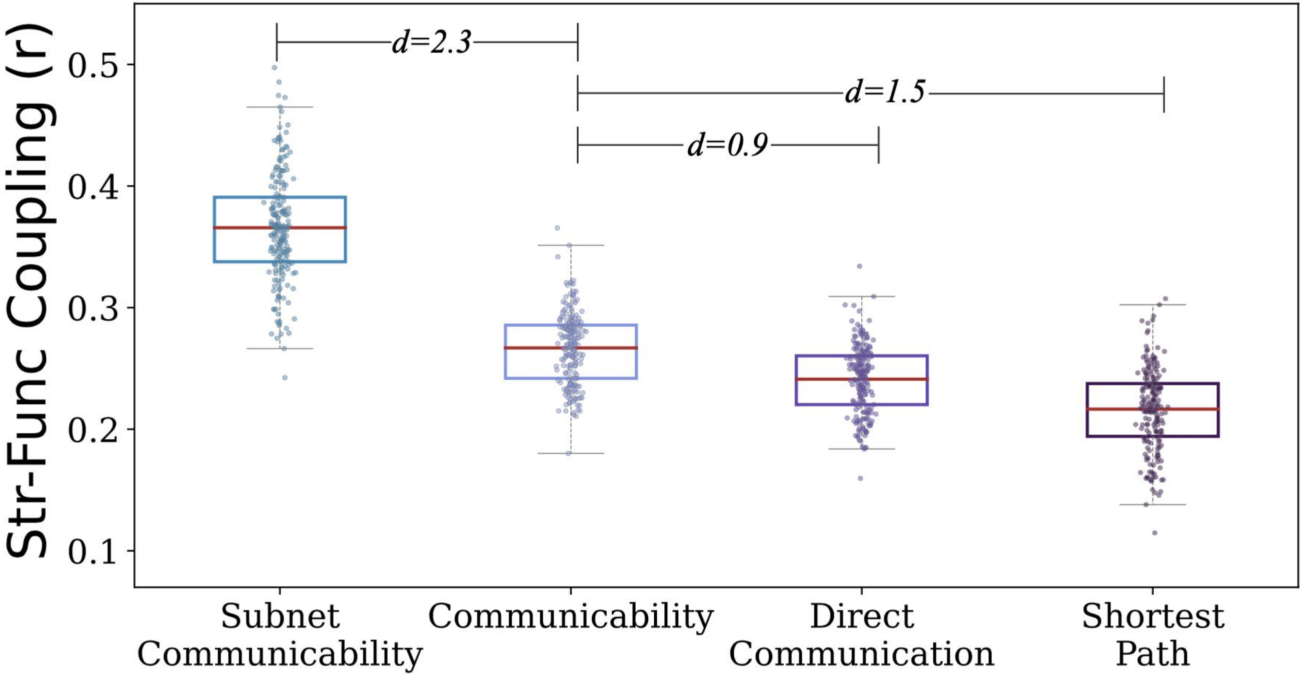
Expected frequency of occurrence by chance



Systems that are consistently over represented across the dataset



Comparison of Models



Conclusions

- Subnet communicability:
  - “communication in the brain diffuses through a small backbone subnetwork”
  - better explains the functional dynamics in the brain
  - balances efficiency and robustness of communication in the brain
- Questions?