

Topological Influences on Function in a Spiking Neural Network

Richard Watson
Nick Travers

Applied Mathematics, UC Davis

The Big Picture

How is function determined by structure?

How does connectivity influence causal flow?

What influence do topological properties of a brain-like network have on its patterns of activity?

This talk

- Investigative method
- Brains and “neural networks”
- The function of a spiking neural network
- Topologies and their generating processes
- Results
- Implications

Investigative method

Construct networks having specified topological properties.

Systematically perturb the structure of these networks.

Observe evolution of function as a property of topology and network size.

What is a Neural Network?

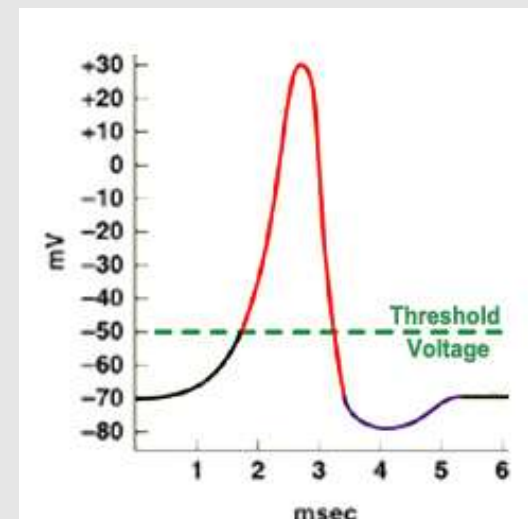
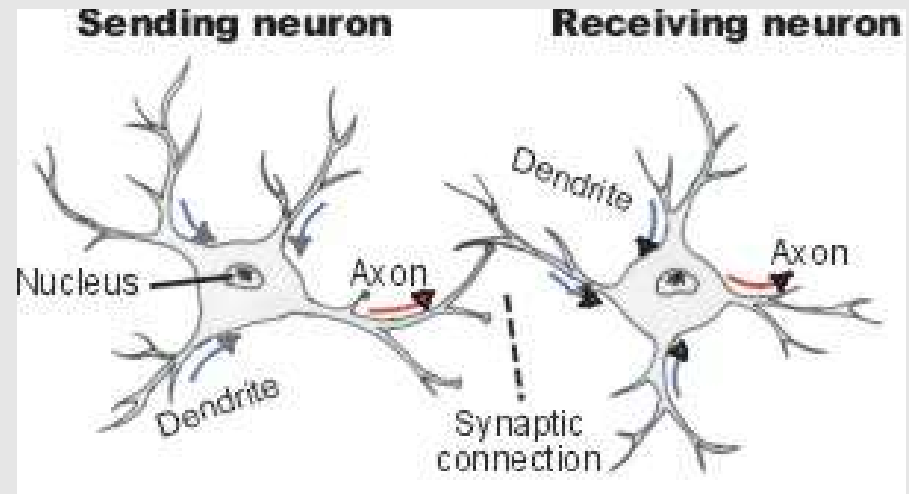
Nodes := neurons

Edges := electrical synaptic connections

Dynamics

Intra-neuronal dynamics

- Dendrite
- Axon
- Ions
- Membrane potential
- Resting potential
- Threshold
- Action potential/ 'Spikes'
- Synapse



Simulation Model

Nodes (uniform)

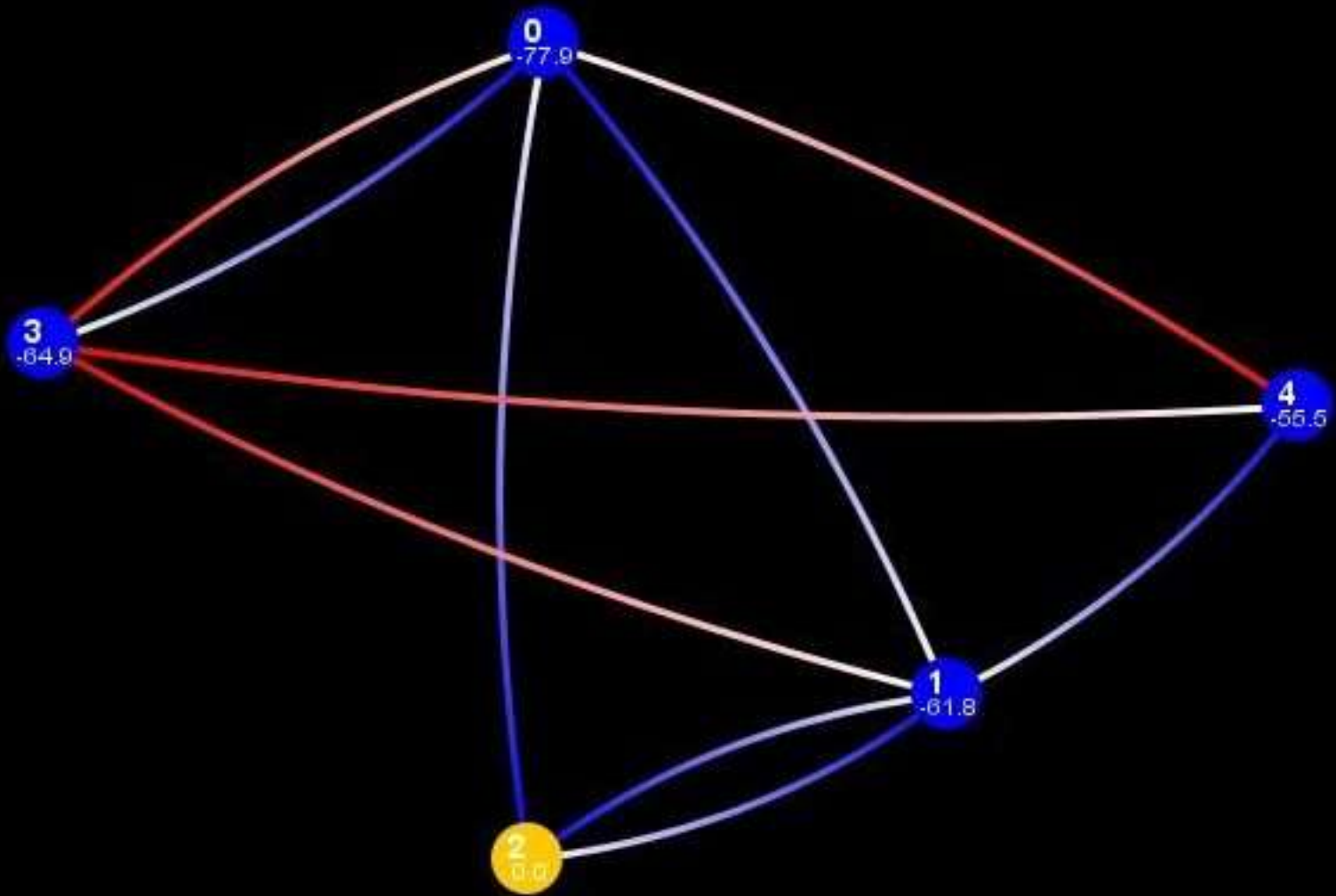
- Electrical potential
- Resting potential (0), threshold (3), reset potential (-1)
- Decay constant (small)

Directed Edges (uniform)

- Excitatory (+1)

Firing

- Spikes and reset potential
- Propagation of action potential



Run 0

0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0

Sub Critical

1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1
1 1 1 1 1 1

Super Critical

Information!

1	0	0	1	0	0	1	1	1	1	1	1
0	1	0	0	0	1	1	0	1	0	0	1
1	0	1	0	1	0	1	0	1	0	1	1
0	0	1	1	0	0	1	1	1	0	0	1
1	1	0	0	1	0	1	1	0	1	1	1
0	0	1	0	0	1	1	1	0	0	0	1
1	1	0	1	1	0	1	1	0	0	1	1
0	1	0	0	0	1	1	1	0	1	0	1
1	1	0	0	1	0	1	0	0	0	1	1
0	1	0	0	0	1	1	1	0	0	0	1
1	1	0	0	1	0	1	1	0	0	1	1
0	1	0	0	0	1	1	1	0	1	0	1
1	1	0	0	1	0	1	1	0	0	1	1
0	1	0	0	0	1	1	1	0	1	0	1
1	1	0	0	1	0	1	1	0	0	1	1
0	1	0	1	0	1	1	1	0	0	0	1

**Note: (1) Highly Sensitive to Parameters
(2) Chaotic + Repetitive Patterns**

How do we study graph 'function' ?

(1) Feed Inputs

(2) Observe Outputs

How to compare functionality of two different graphs?

Two different metrics:

(1) First to Fire (few output nodes)

(2) Hamming distance (all nodes)

$$\min_n \sum_m N1(m)N2(m-n)$$

$$-\max_offset < n < \max_offset$$

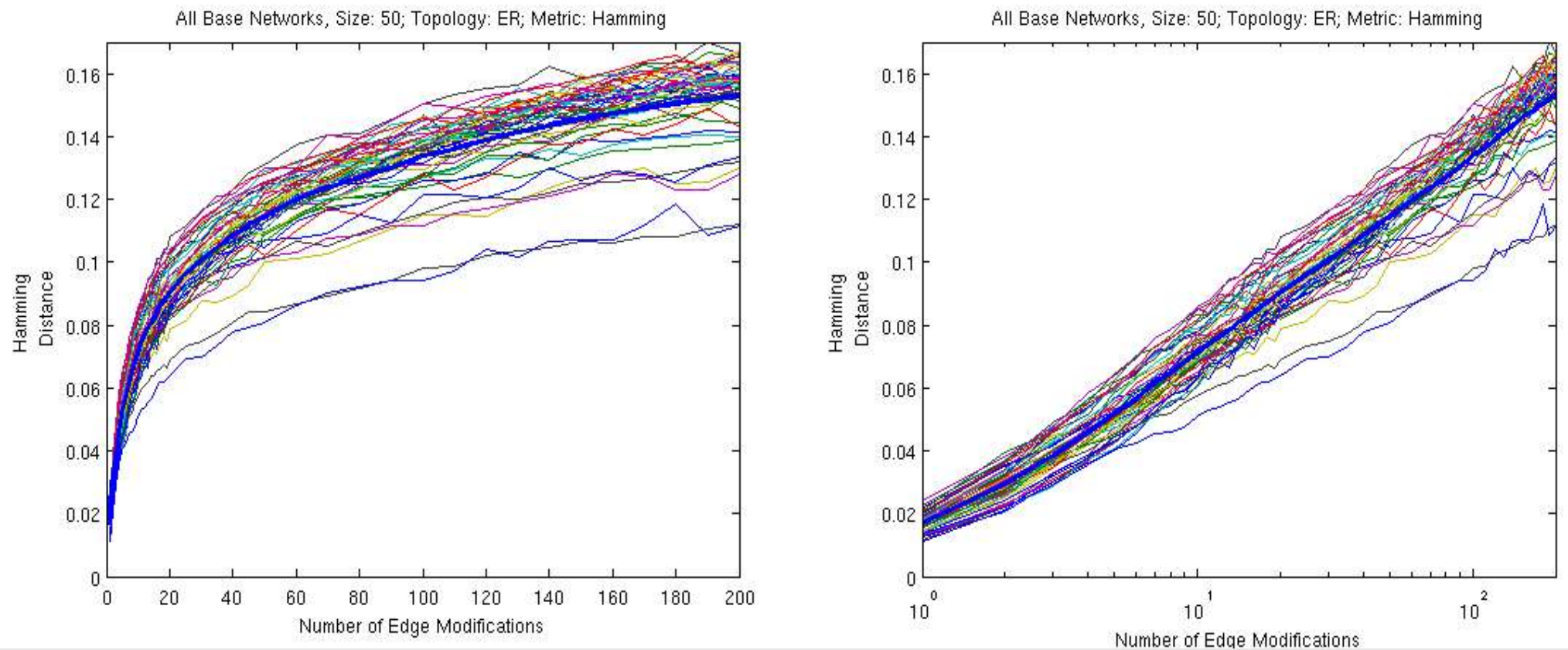
Methods of Investigation

Generate a 'reference' network

Mutate k edges randomly

Observe $\Delta f(k)$

ER-graphs , N = 50 (Hamming metric)

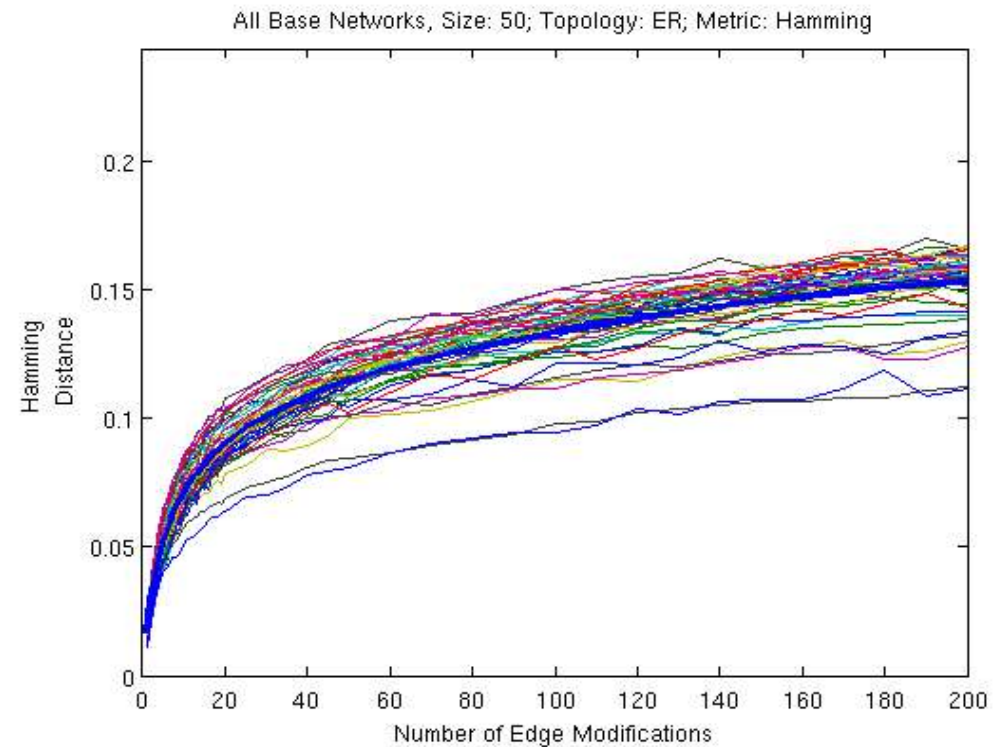
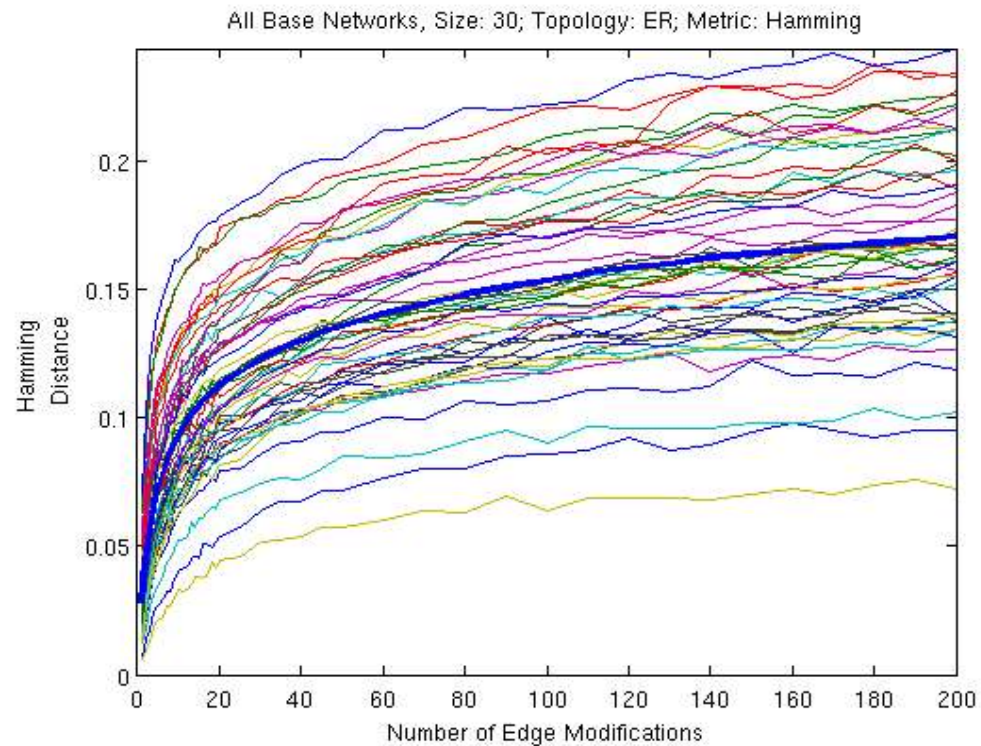


Function changes rapidly on first few modifications

Diminishes as k increases

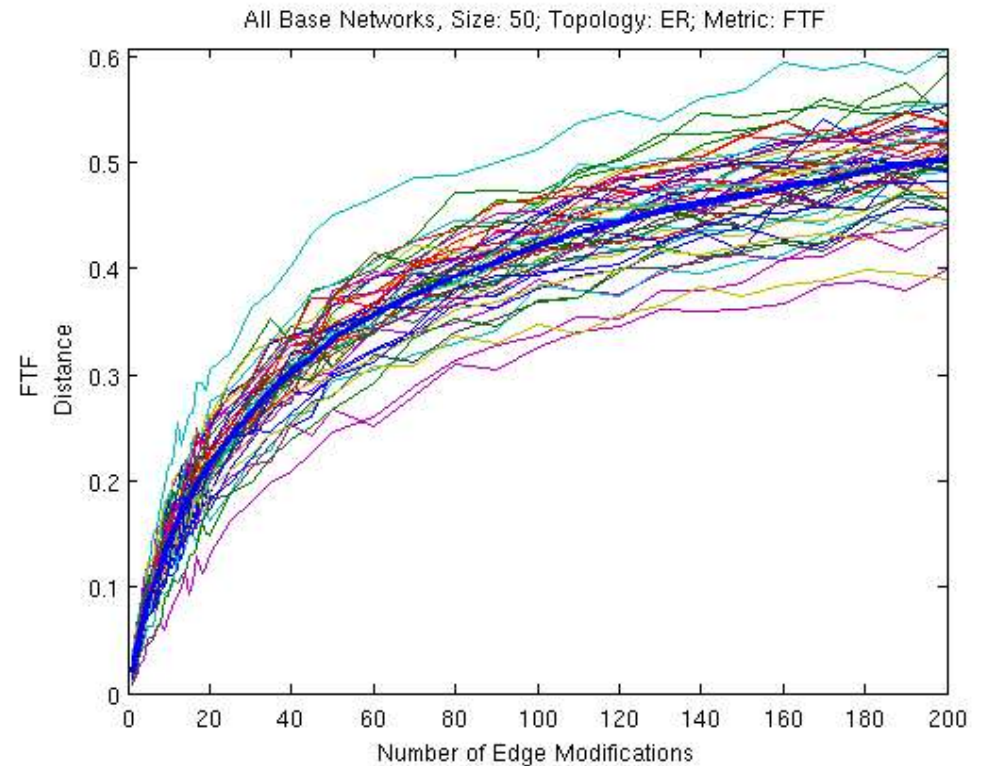
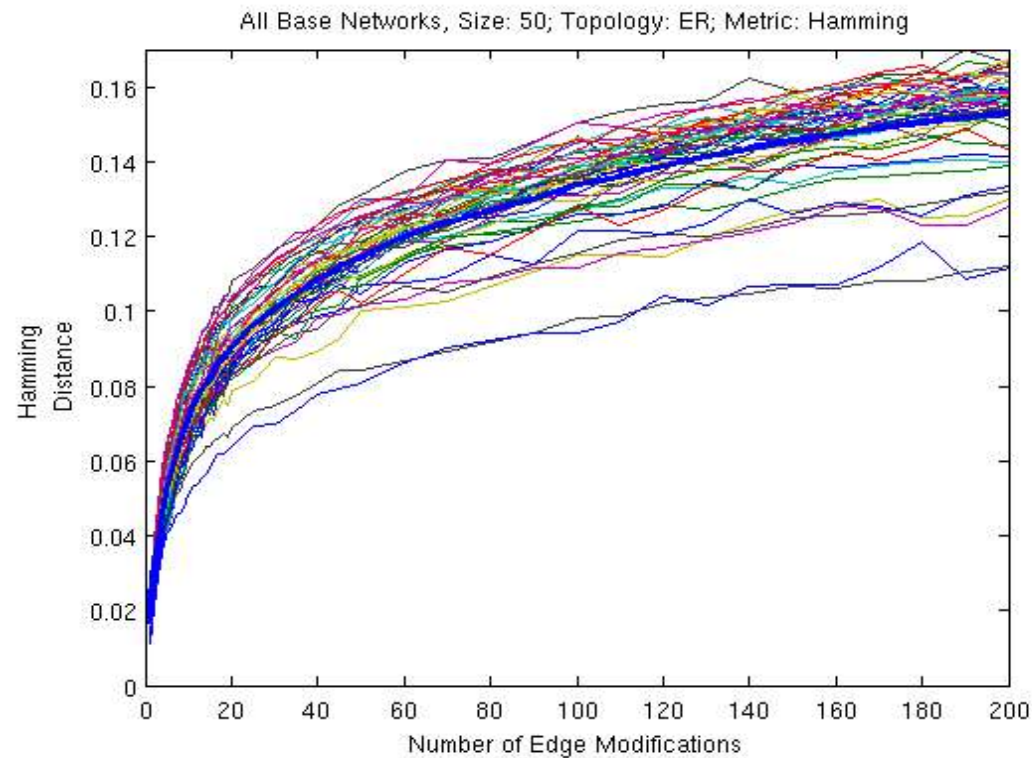
$$\Delta f(k) \sim \log(k)$$

Different Graph Sizes



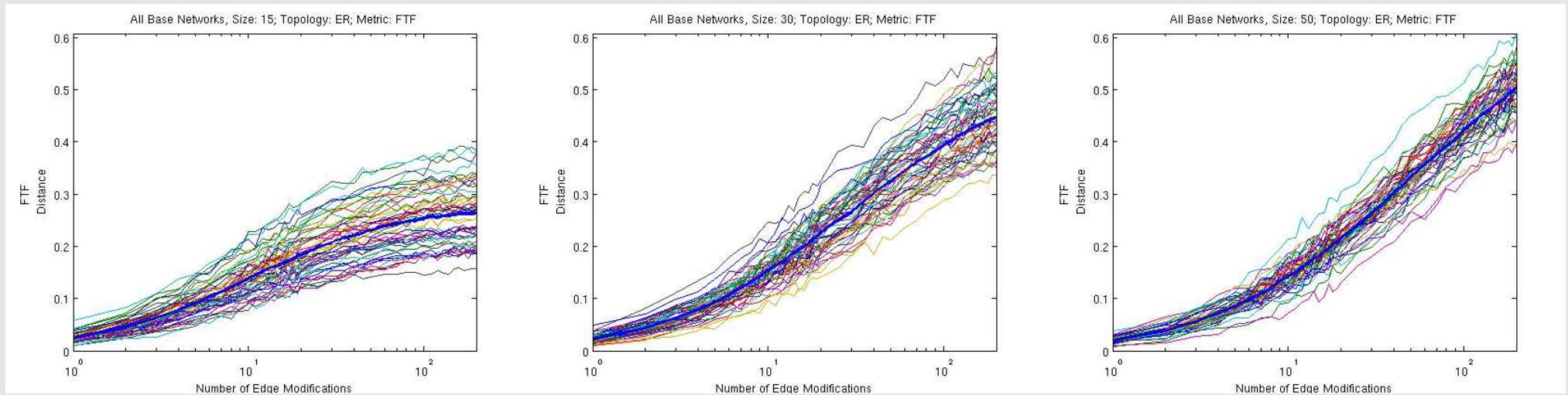
Smaller n = Higher Variability

Different Metrics



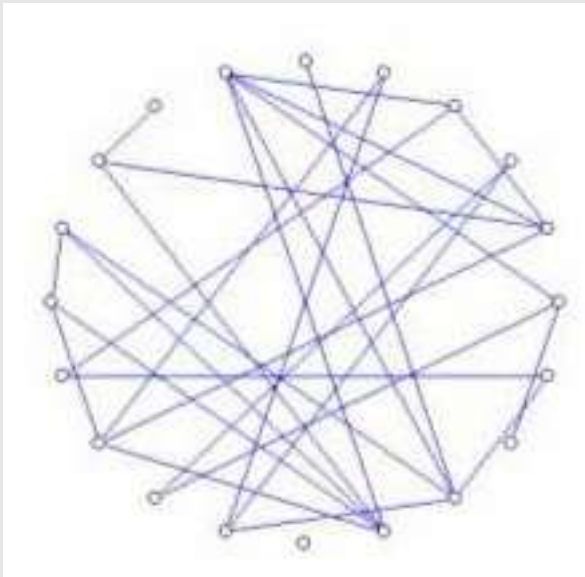
Similar qualitative behavior for both metrics

Different Metrics II

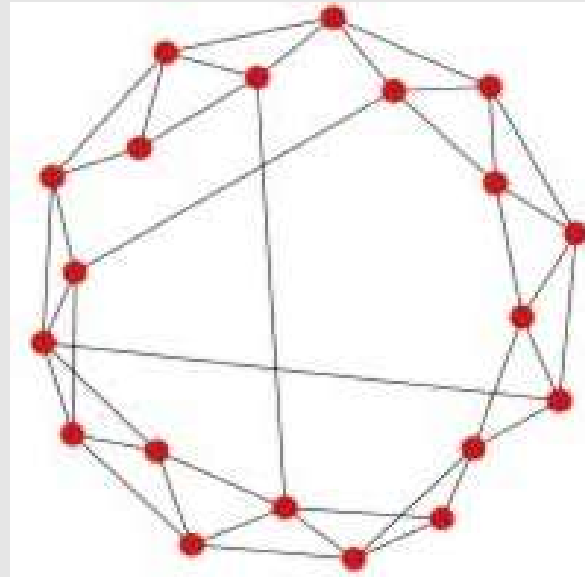


FTF shows sigmoidal behavior on log-linear scale
Network size vs. $\Delta f(k)$

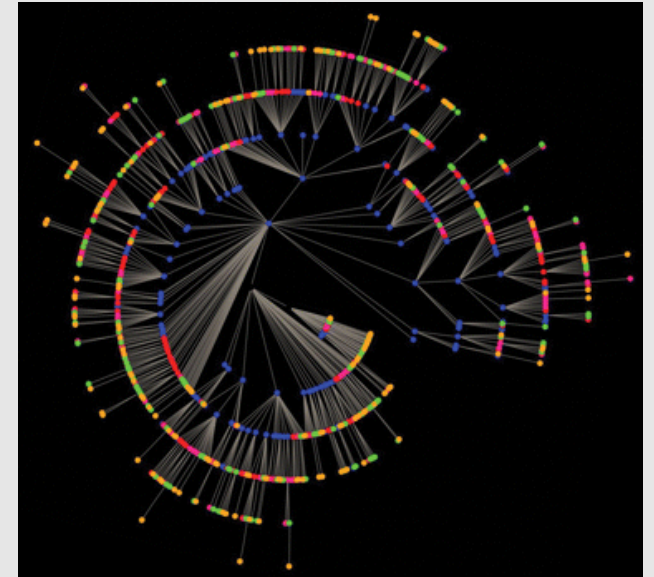
Different Topologies



Erdos-Renyi



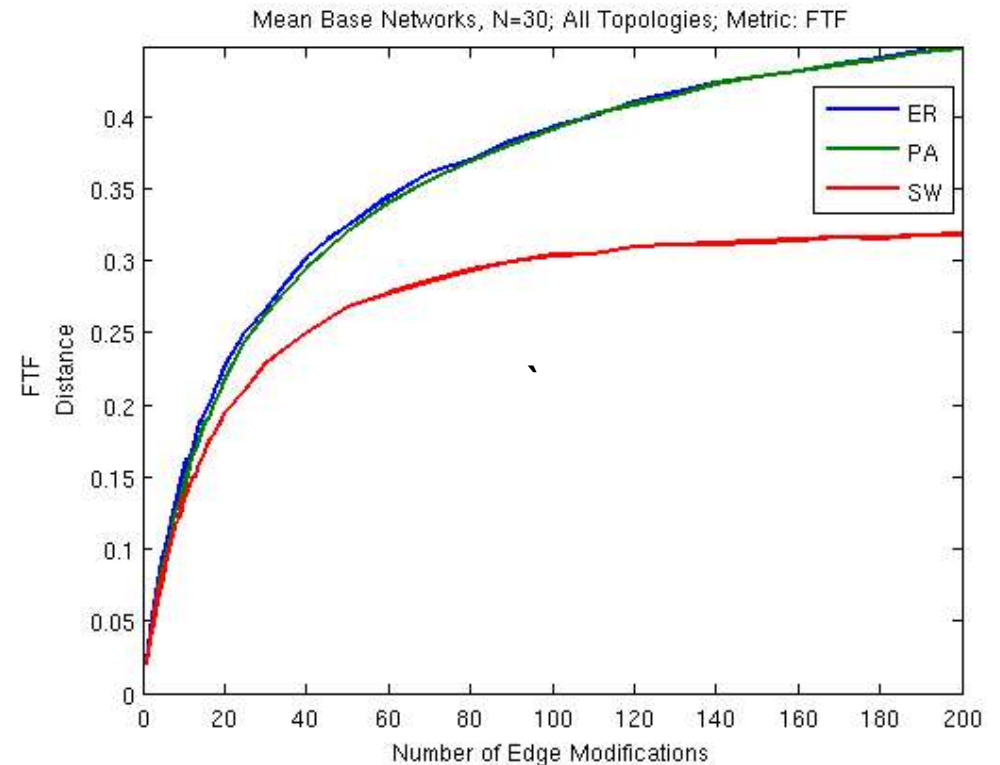
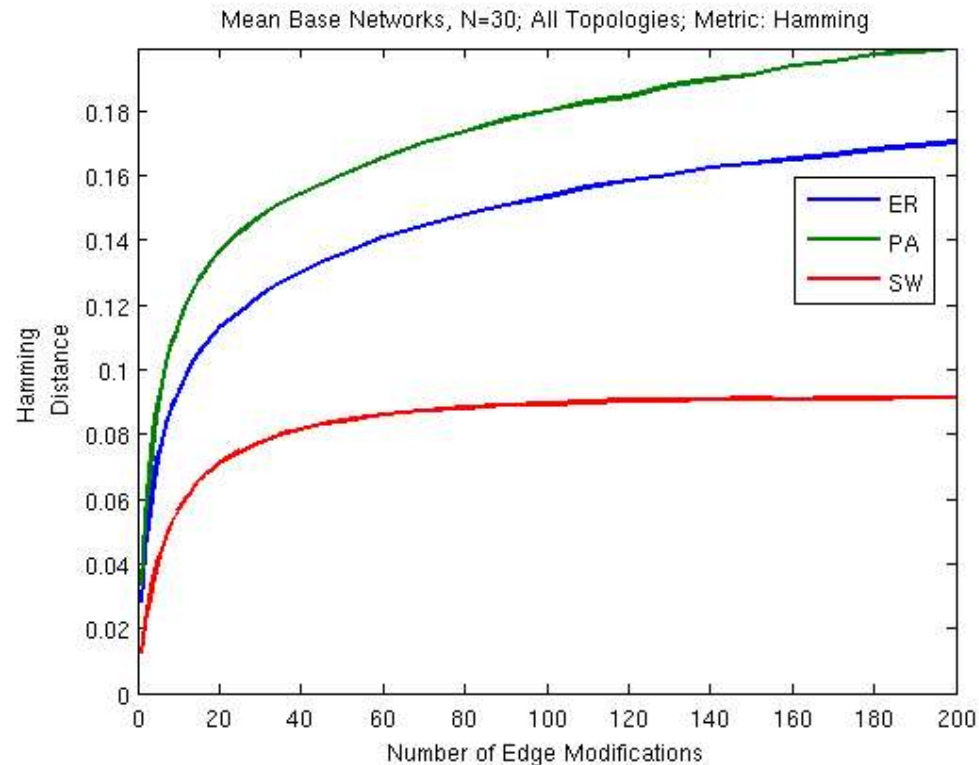
Small World



Preferential Attachment

Modify graphs while maintaining outlink distribution.

Different Topologies II



ER and PA show comparable $\Delta f(k)$
SW plateaus more quickly and at a lower value

Summary

$\Delta f(k)$ slows as k increases

$\Delta f(k)$ is smaller for smaller N and saturates at a lower value of k

$\Delta f(k)$ shows higher variability for smaller N

$\Delta f(k)$ for SW graphs is substantially lower than is corresponding $\Delta f(k)$ for ER/PA graphs

Discussion and Implications

Adaptability vs. Robustness

Smaller networks exhibit a greater range of adaptability

Future Directions

Larger N

Larger k-max

Excitatory connections

Function compositions (modules)

Directed graph evolution (towards function)

References

(1) '**Effects of topology on network evolution**', Panos Oikonomou* and Philippe Cluzel*

Nature Physics 2, 532 - 536 (2006) doi:10.1038/nphys359

(2) '**Fast computation with spikes in a recurrent neural network**' Dezhe Z. Jin* and H.

Sebastian Seung, Phys. Rev. E 65, 051922 (2002).