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Newcastle University

The vulnerability of spatially-complex infrastructure networks

Robson C., Barr S.L., James P. and Ford A.

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Critical infrastructures

- Way of life
- Gatwick - 2013[1]
- 2003 Blackouts
  - Italy
    - ~57 million people
  - USA & Canada[2]
    - ~50 million people
    - 4 days

1: McMillan, David 2014; 2: Allianz 2011

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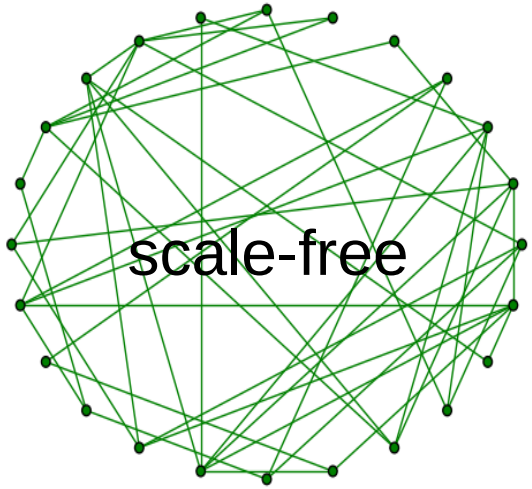
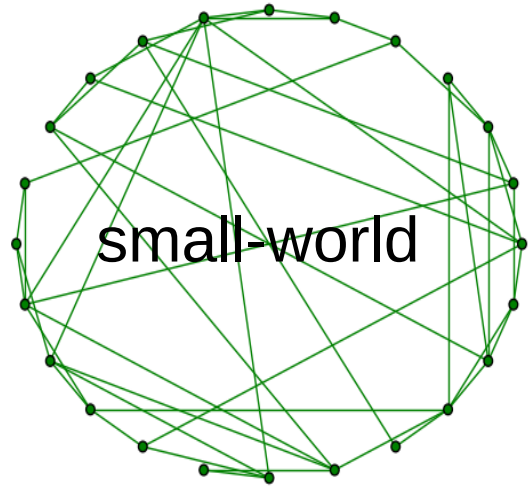
Representing infrastructures

- Random, scale-free & small-world





- Hierarchies

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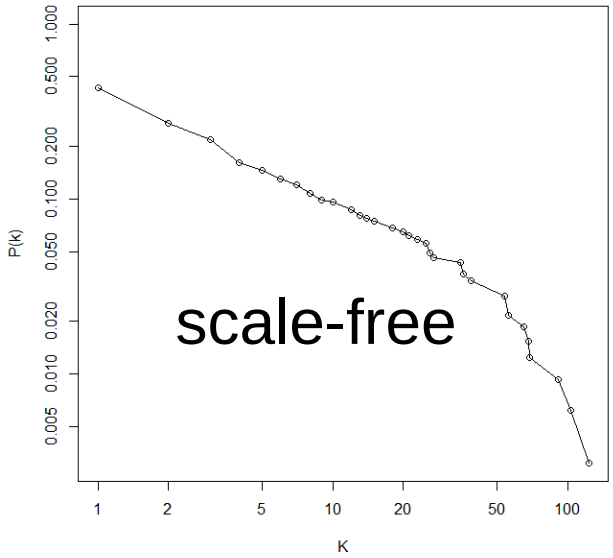
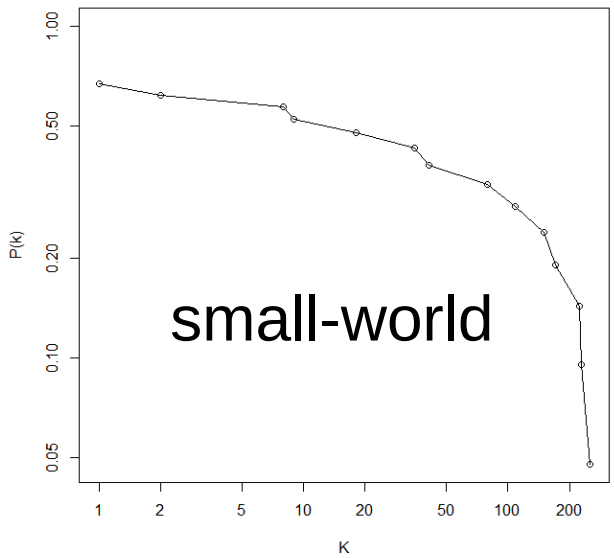
Representing infrastructures

- Random, scale-free & small-world





- Hierarchies

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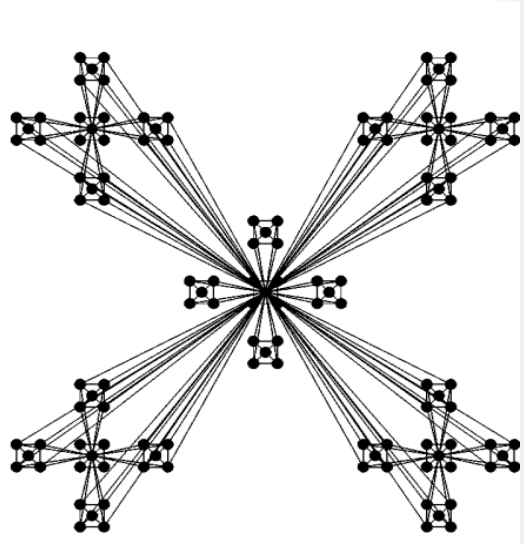
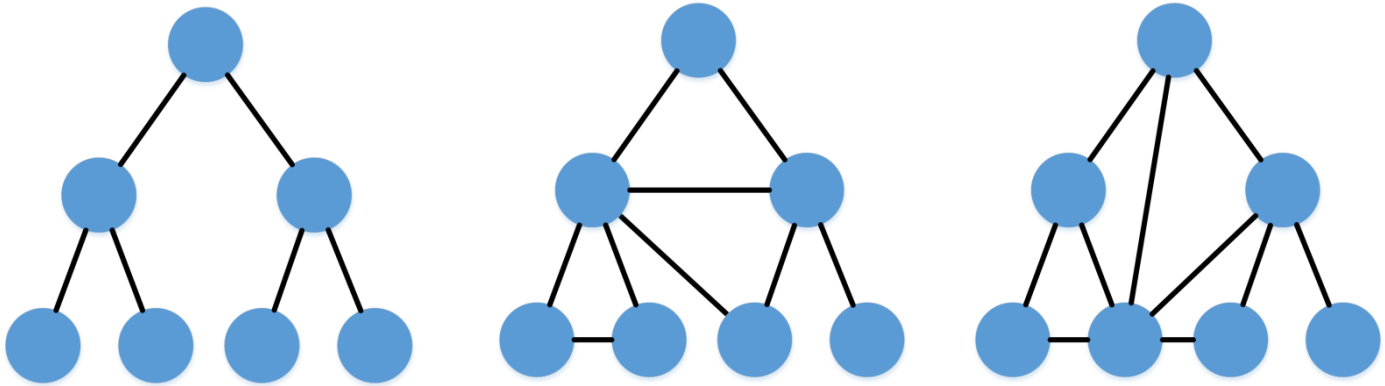
Hierarchical networks

- Infrastructure is hierarchical[1]
- Hierarchical communities[2]
- Trees, HR+ and HR





1: Yerra and Levinson, 2005; Svendsen and Wolthusen, 2007
2: Ravasz and Barabasi ,2003

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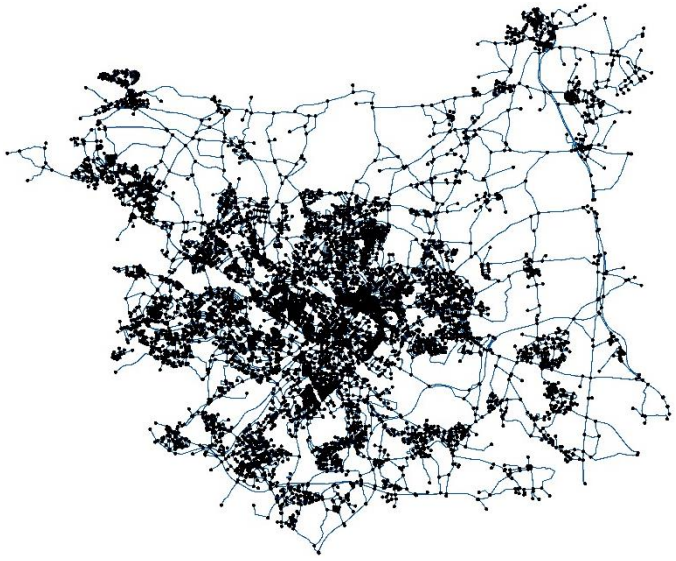
Graph spectrum/suite

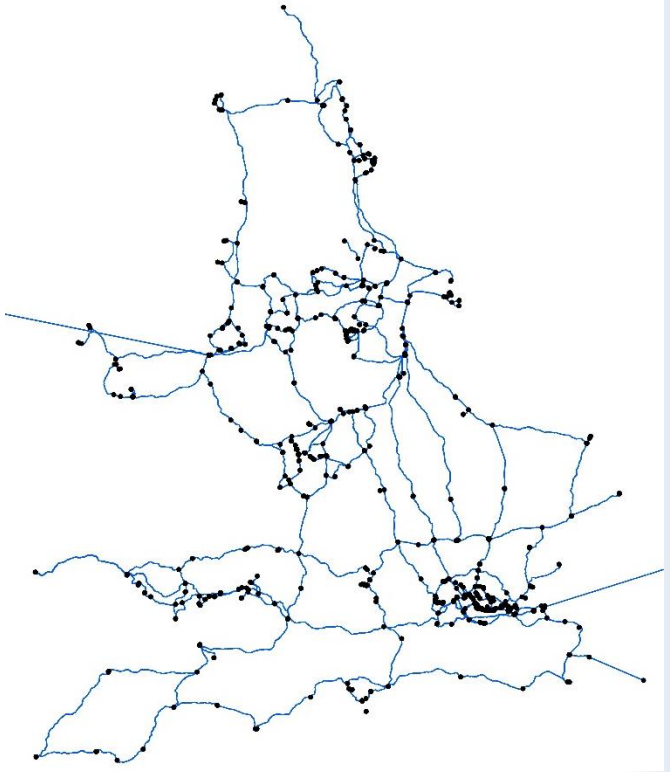
- 8 network types; 1000 realisations

ER GNM WS BA HR+ HR HC TREES

Random ← → Hierarchical

- Energy, transport etc.





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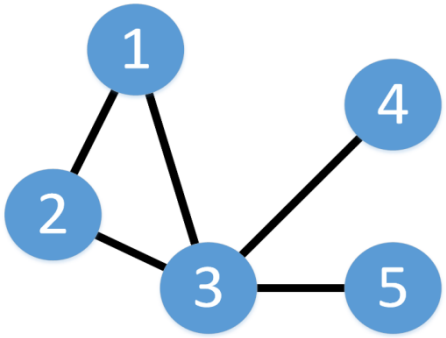
Metrics

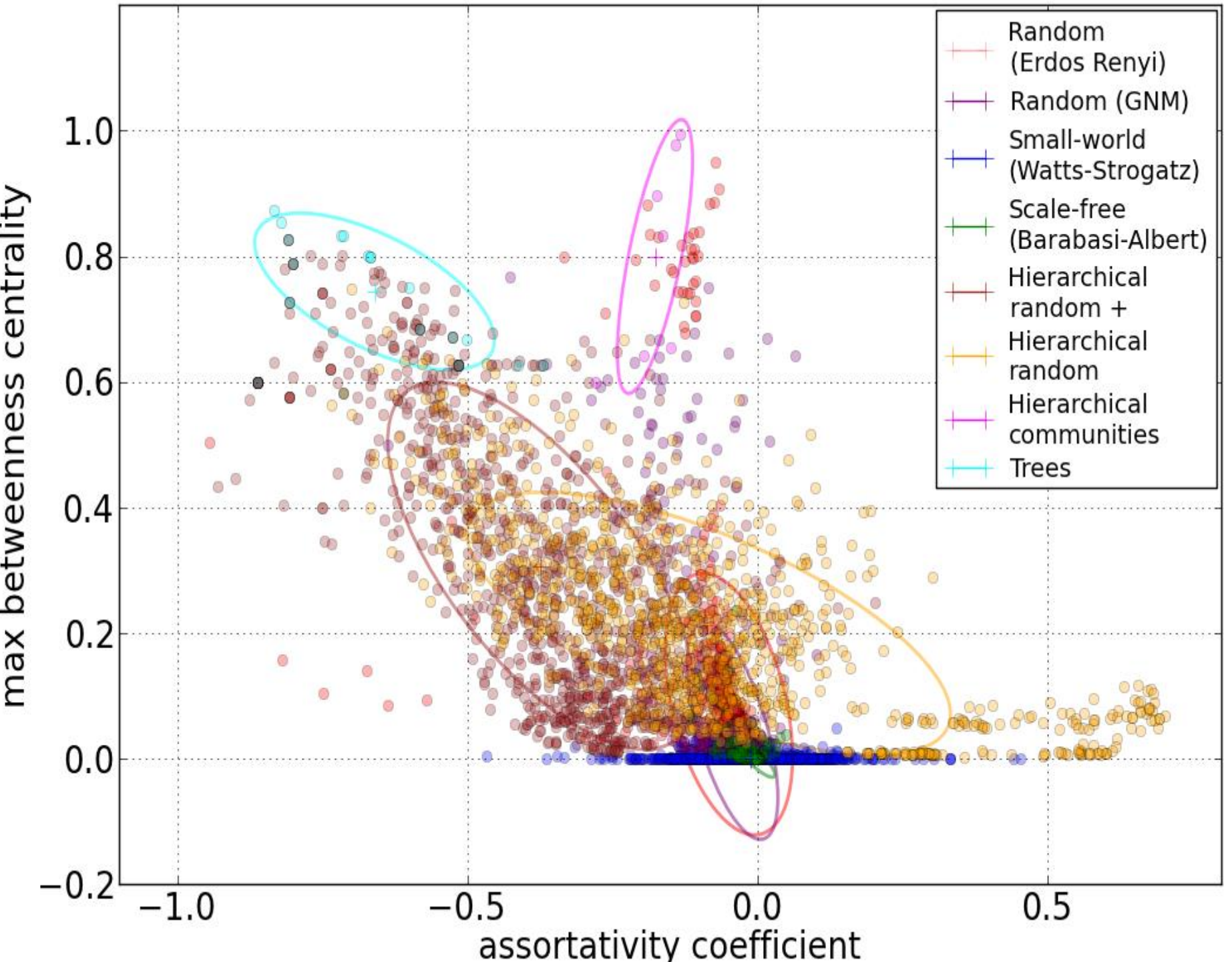
- Betweenness
  - Number of shortest paths passing through a node/edge[1]
- Assortativity (via node degree)
  - The similarity of a node to its neighbours[2]

Betweenness:
Node 3: 0.83

Assortativity: -0.80



1: Brandes 20012; 2: Newman, 2003


Random
(Erdos Renyi)
Random (GNM)
Small-world
(Watts-Strogatz)
Scale-free
(Barabasi-Albert)
Hierarchical
random +
Hierarchical
random
Hierarchical
communities
Trees
max betweenness centrality
assortativity coefficient
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−1.0
−0.5
0.0
0.5

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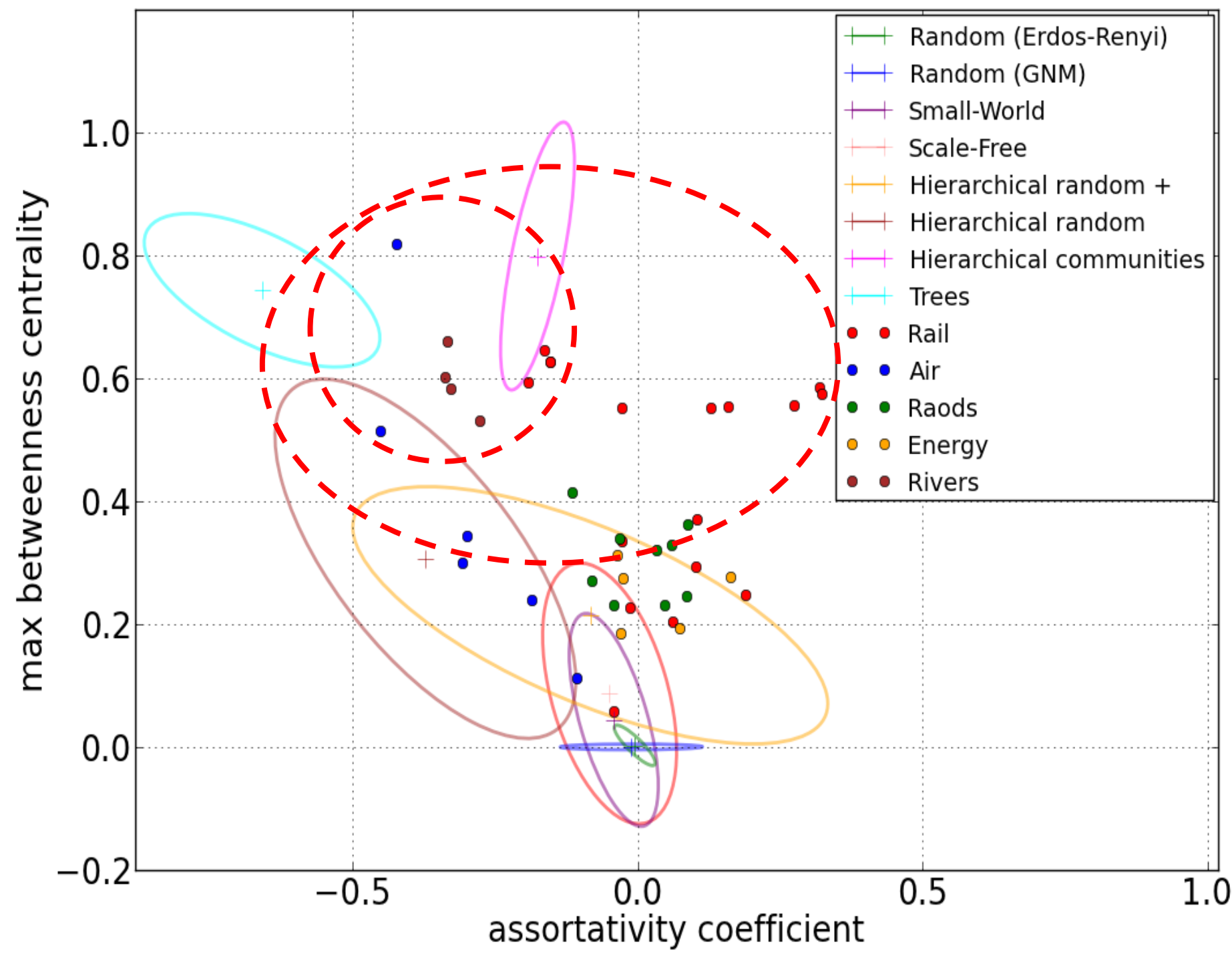
Transformed divergence

	ER	GNM	WS	BA	HR+	HR	HC	TREES
ER	-	99.8	99.48	100.00	100.00	100.00	100.00	100.00
GNM	-	-	100.00	100.00	100.00	100.00	100.00	100.00
WS	-	-	-	9.97	91.98	99.49	99.98	100.00
BA	-	-	-	-	57.71	87.78	99.89	99.91
HR+	-	-	-	-	-	32.82	99.99	95.63
HR	-	-	-	-	-	-	99.85	73.98
HC	-	-	-	-	-	-	-	100.00
TREES	-	-	-	-	-	-	-	-


Random (Erdos-Renyi)
Random (GNM)
Small-World
Scale-Free
Hierarchical random +
Hierarchical random
Hierarchical communities
Trees
Rail
Air
Raods
Energy
Rivers
max betweenness centrality
assortativity coefficient
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.5
0.0
0.5
1.0

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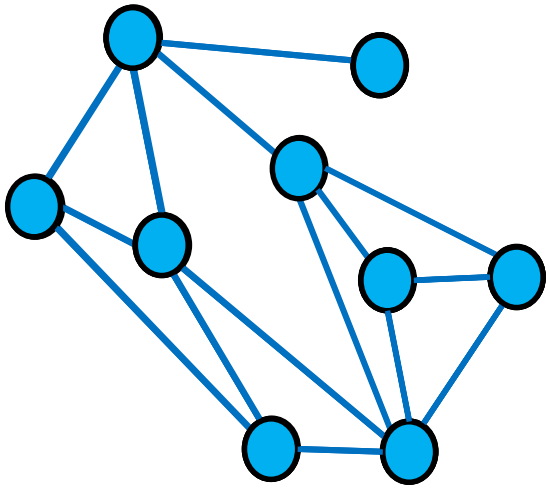
Failure modelling

- Random



- Degree

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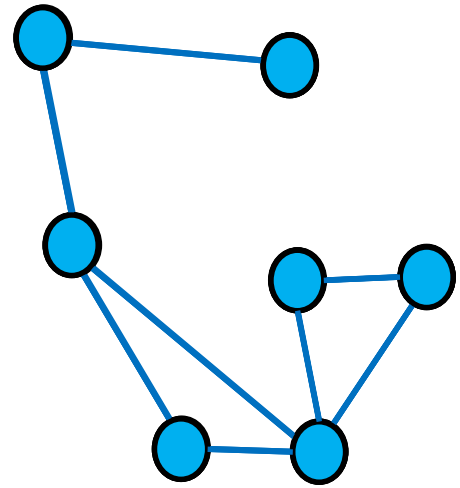
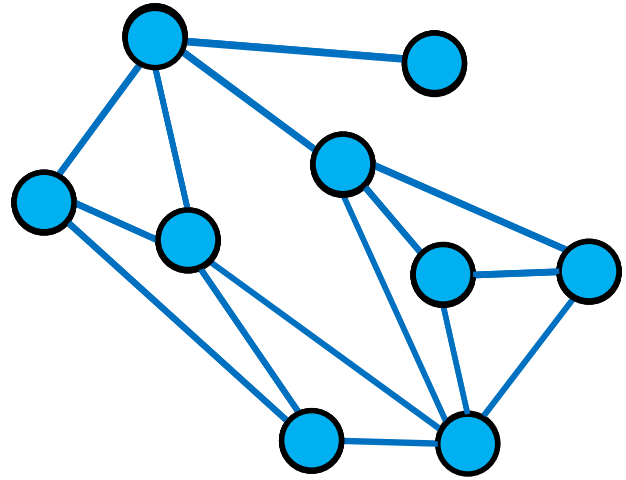
Failure modelling

- Random



- Degree



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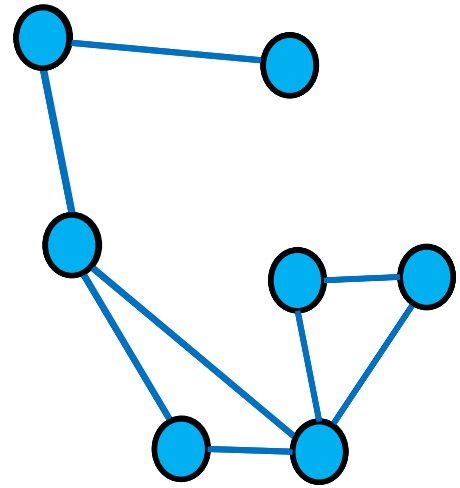
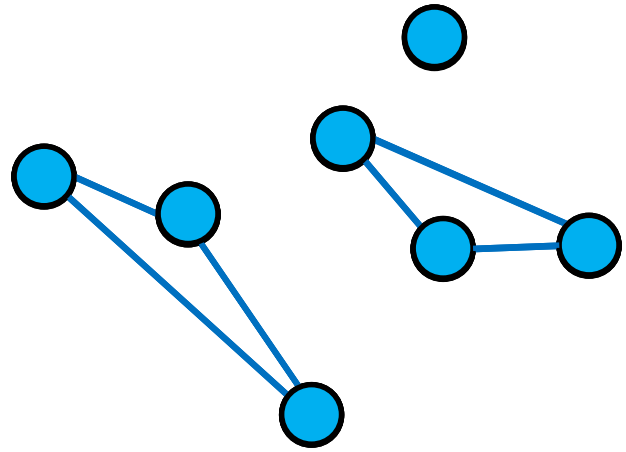
Failure modelling

- Random



- Degree



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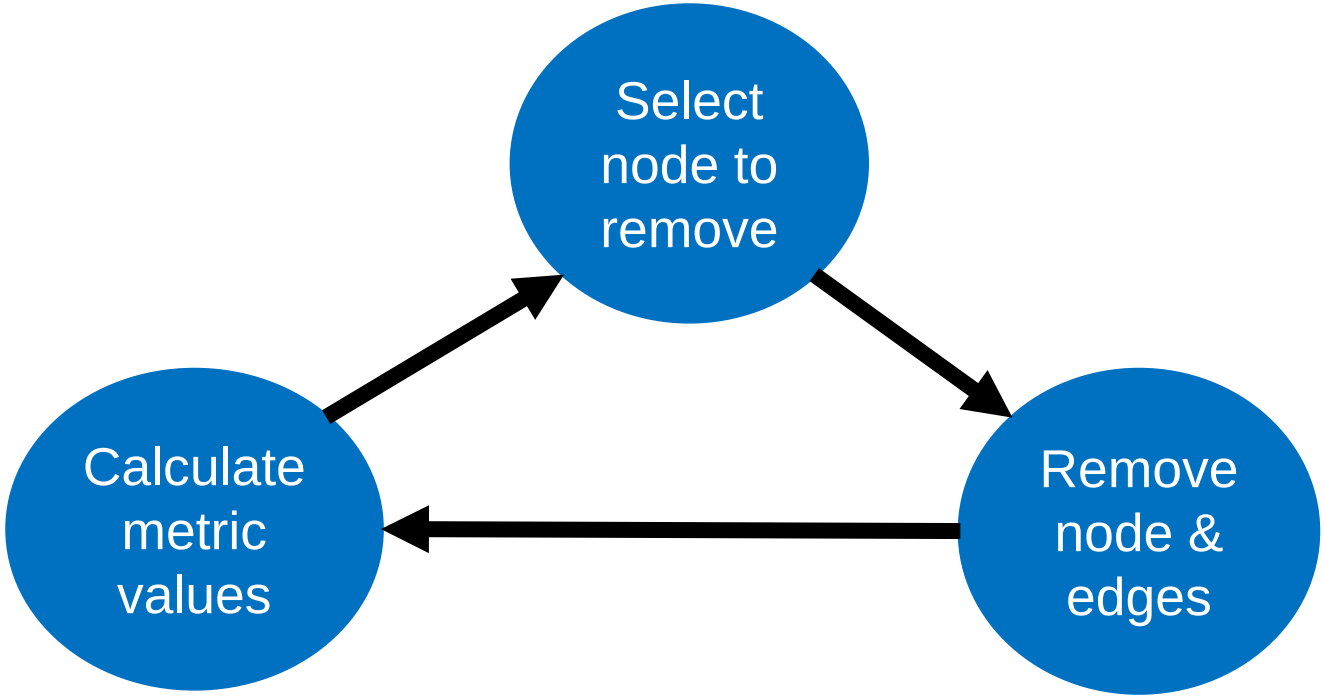
Failure modelling



APL, number & size of components

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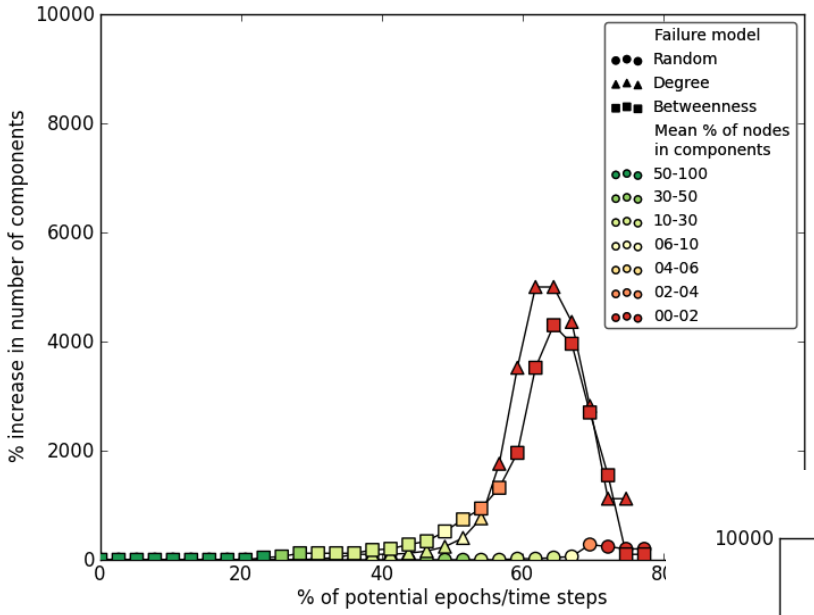
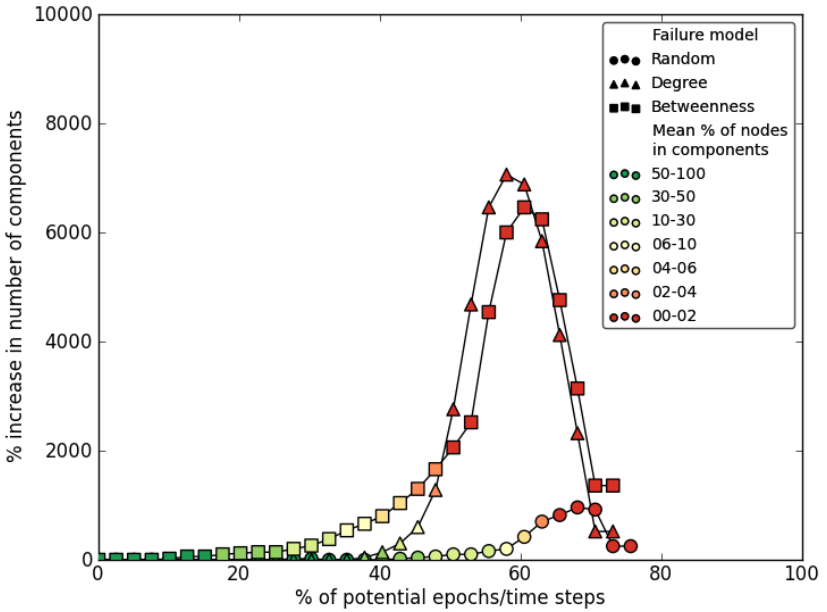
Non-hierarchical response





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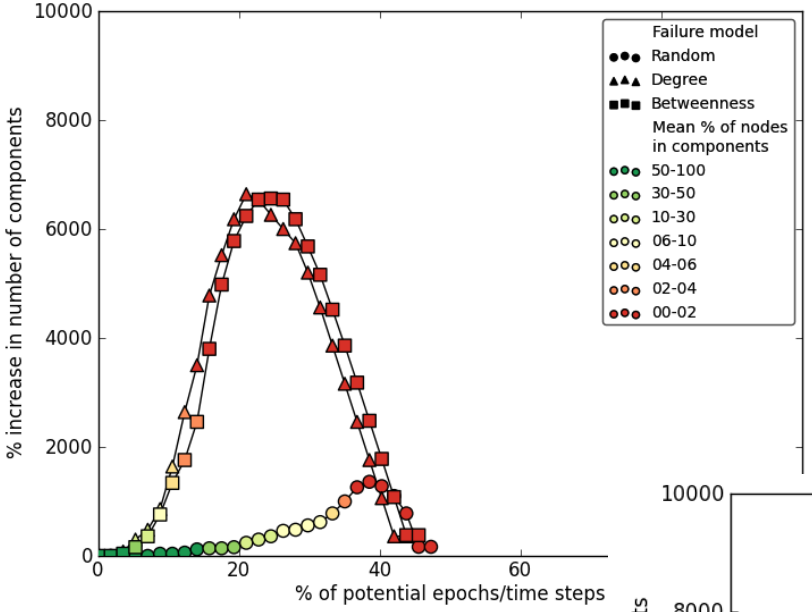
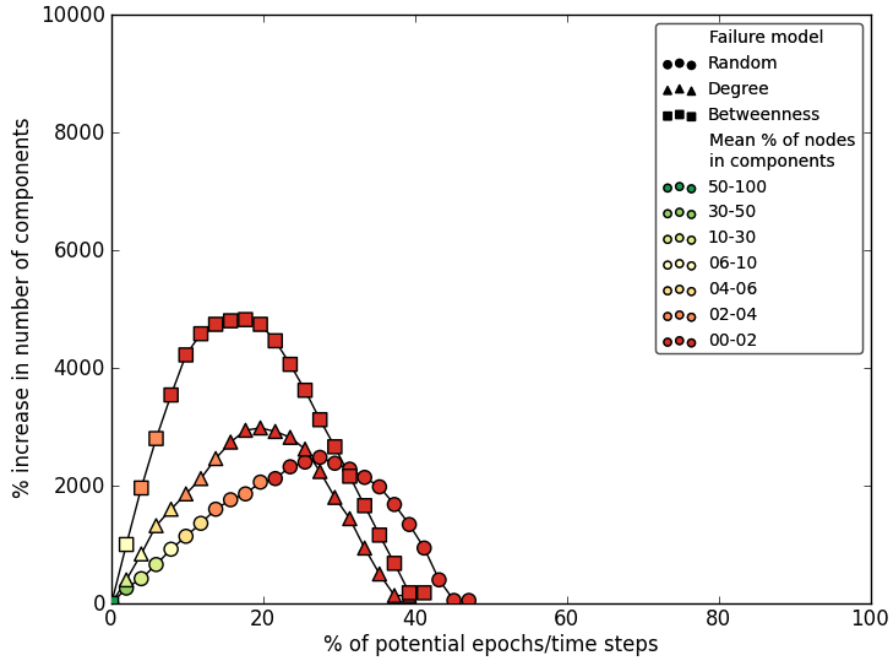
Hierarchical response





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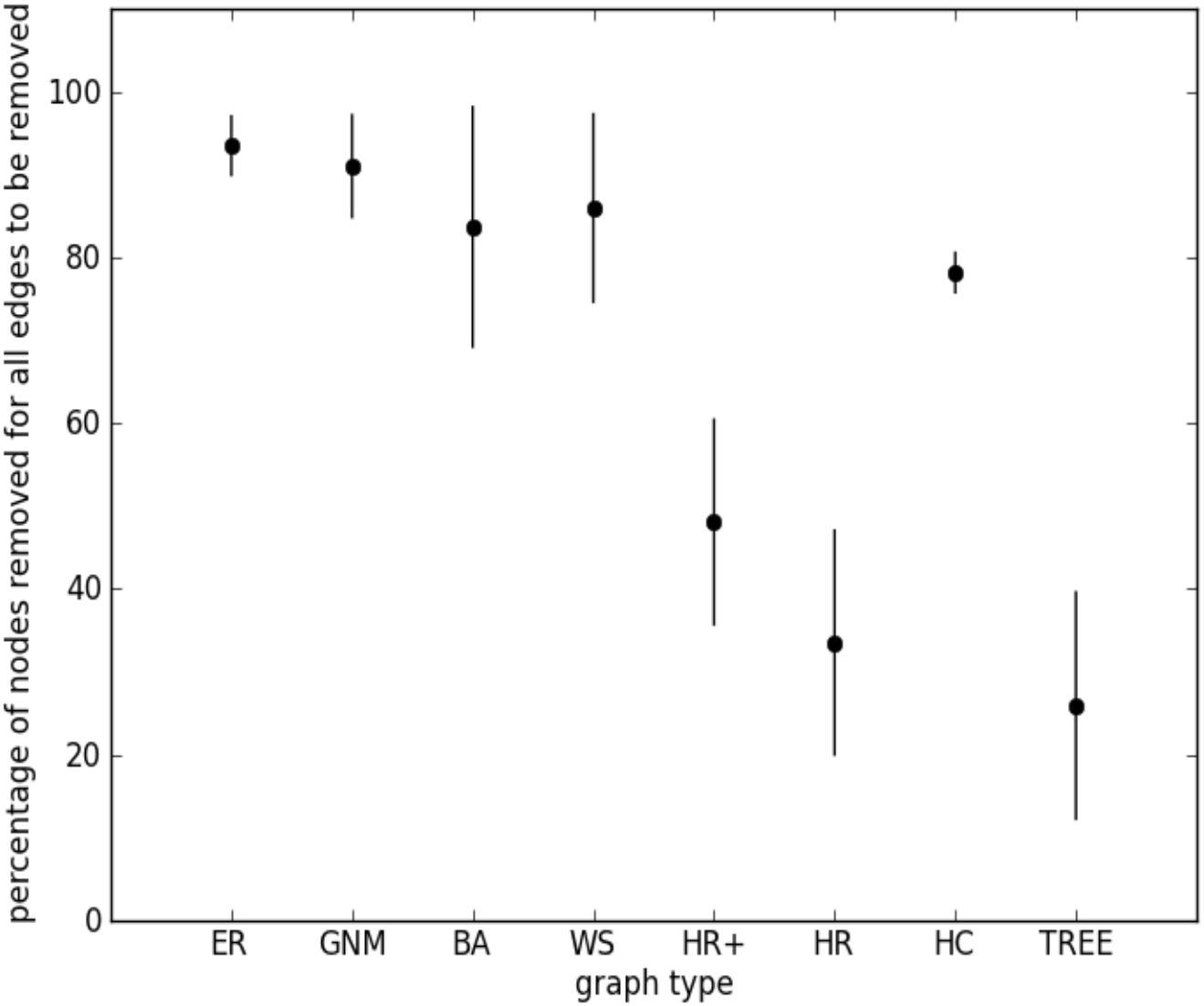
Synthetic networks



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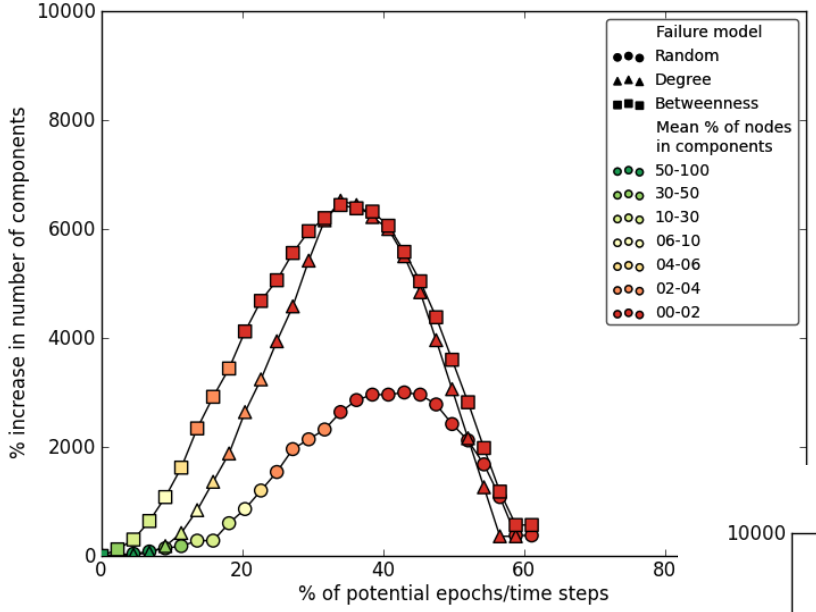
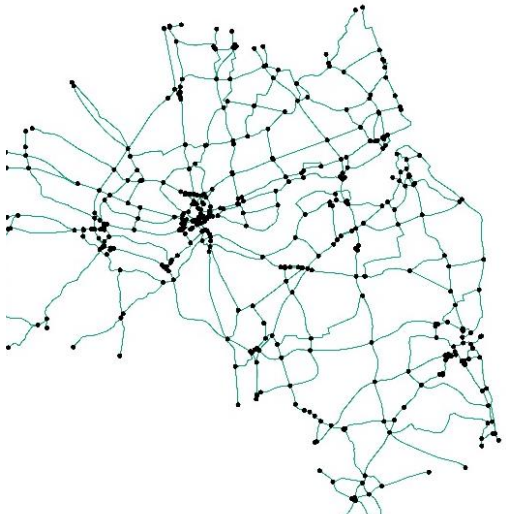
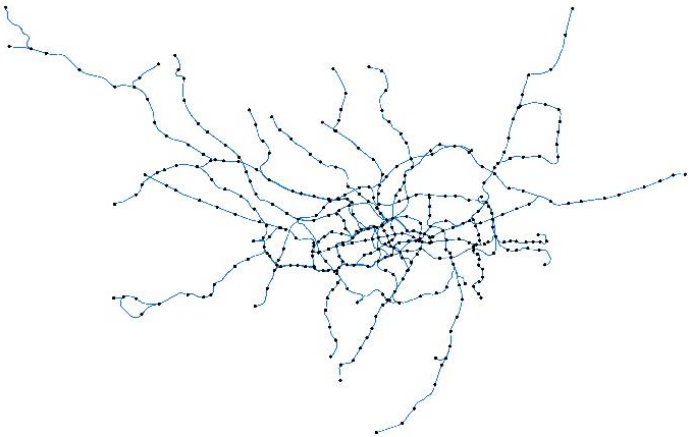
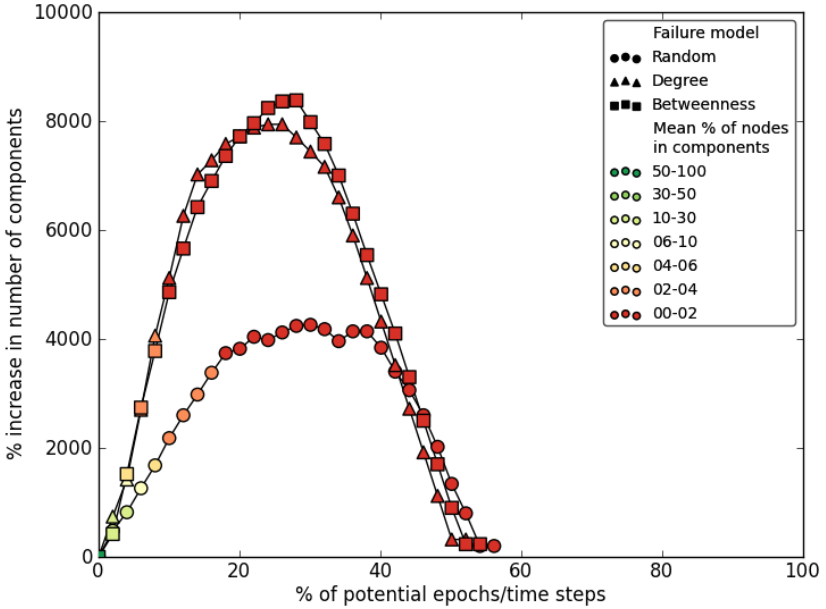
Infrastructure response









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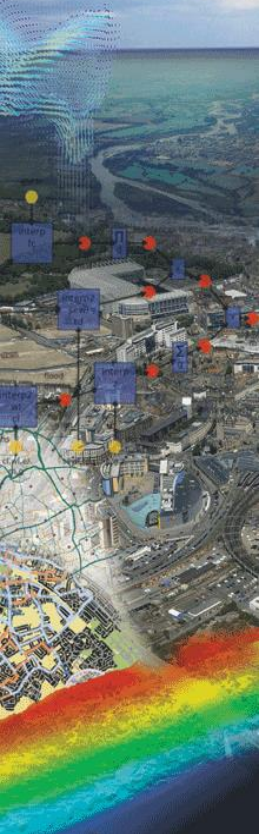
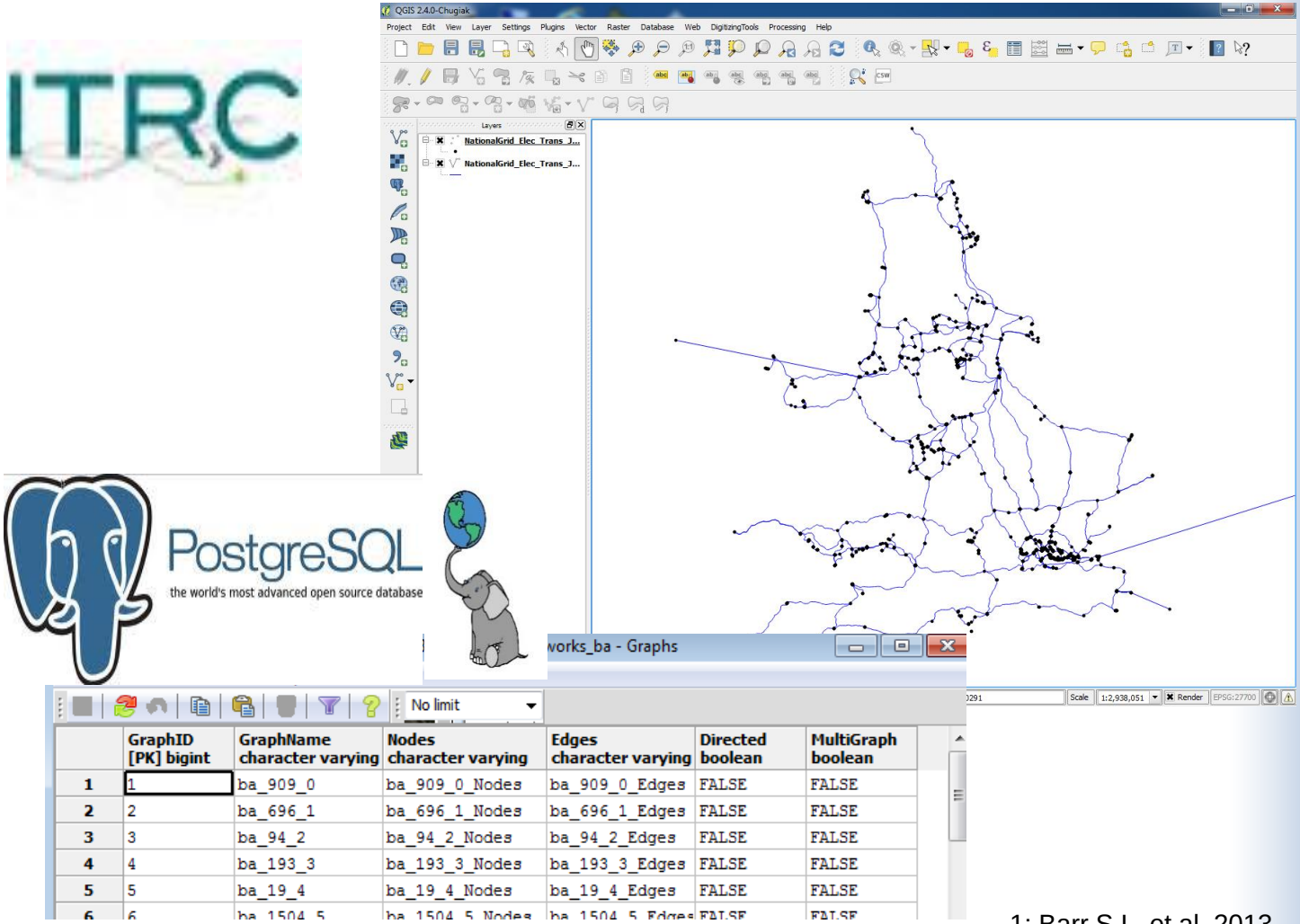
Software framework

- PostgreSQL; Networkx; nx_pgnet[1]; QGIS





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1: Barr S.L. et al, 2013

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Conclusions

- Characteristics of hierarchical networks
- Hierarchically-organised networks exhibit a greater vulnerability
- Infrastructure networks can be hierarchical affecting their resilience to perturbations
- Software tools for the analysis of complex spatial infrastructures

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Thank you for listening

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http://research.ncl.ac.uk/geospatial/