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Acquisition and Development Programs through the Lens of System Complexity

15th Annual Acquisition Research Symposium
Acquisition Research Program
Naval Postgraduate School

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Stevens Institute of Technology

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Application to System of Systems

Complexity in Defense Acquisition

Complexity of the system of interest

Complexity of the enabling systems

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Complexity of the enterprise system

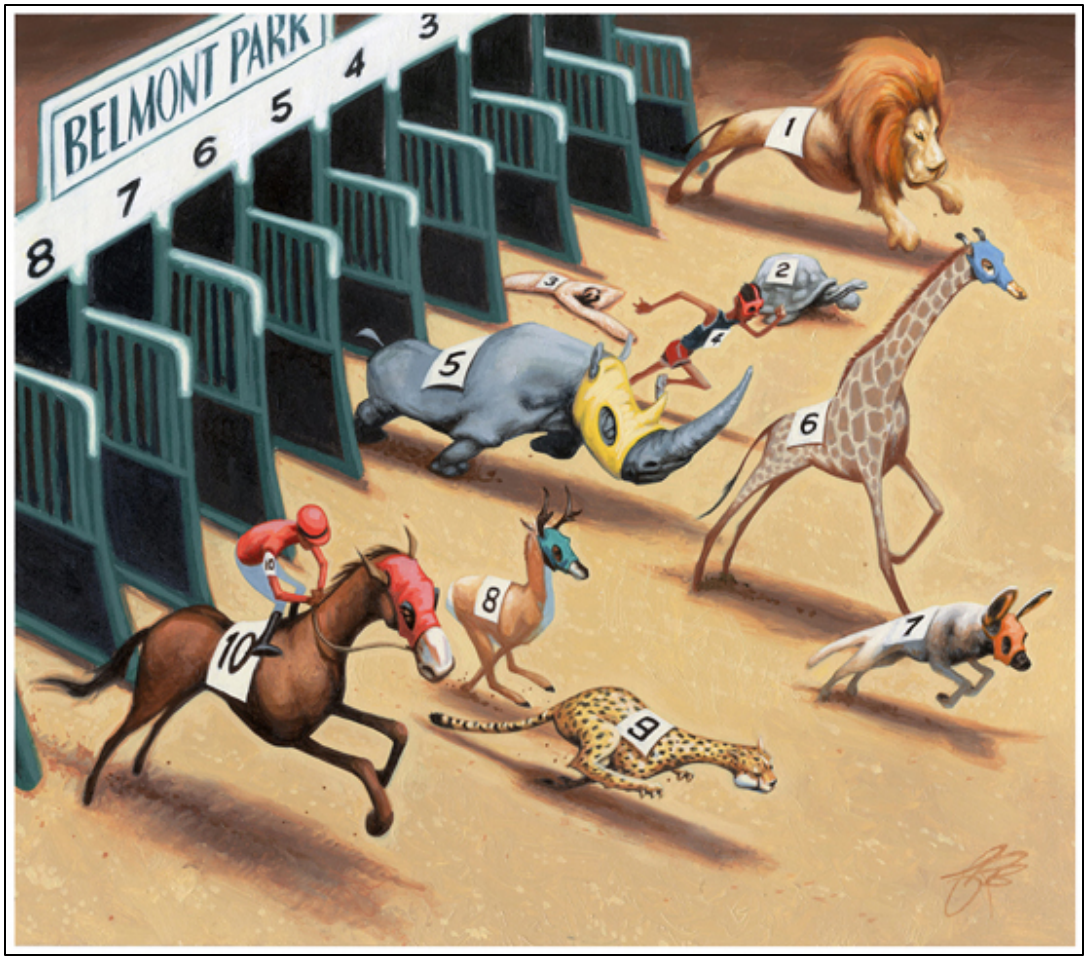
Predicting Performance through Structure

Structural Complexity

- Components
- Interfaces
- Topology

Dynamic Complexity

- Short-Term
- Long-Term



From System to Graph

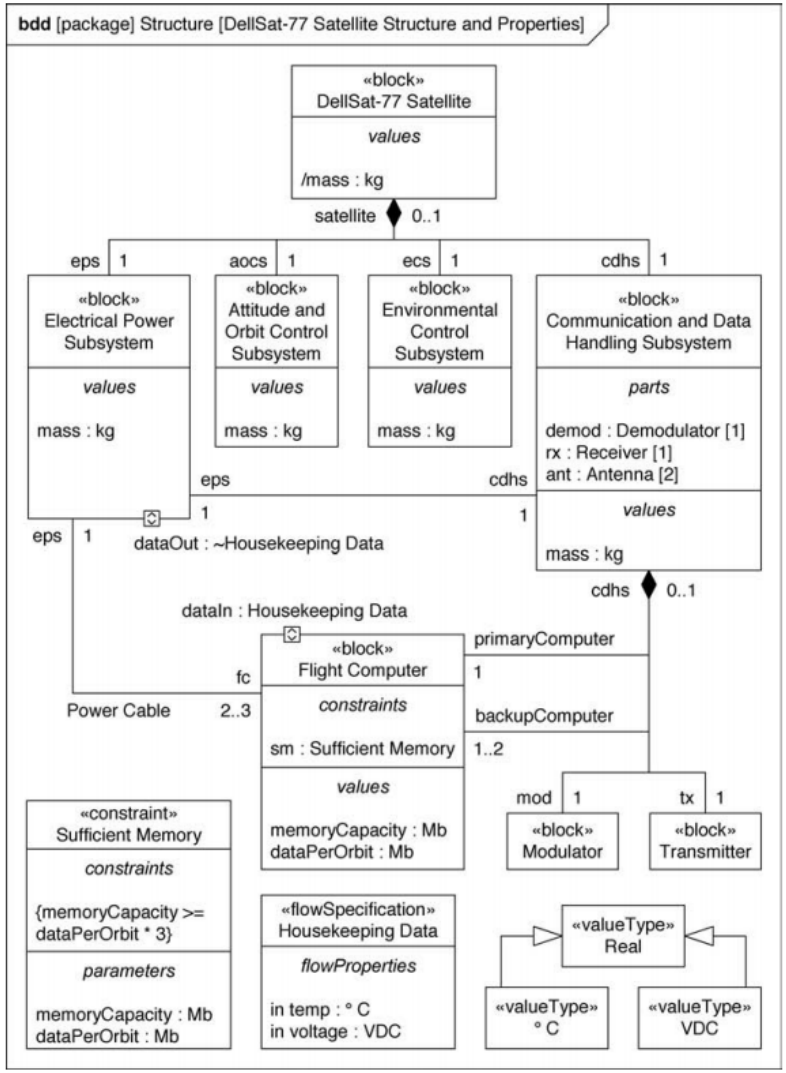
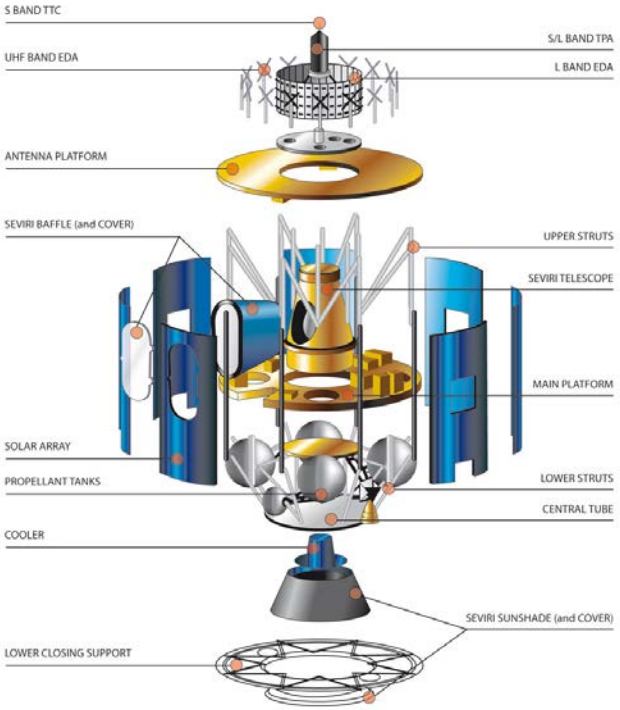
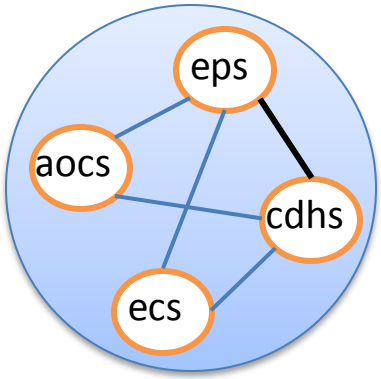


Figure 3.1 *A sample block definition diagram (BDD)*





SysML Structural Features

- Part properties (composition)
- **Reference properties**
- Value properties (parameters)
- Constraint properties
- **Ports**

Matrices

Weighted Adjacency Matrix: $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_n$

$$A(u,v) = \begin{cases} w(u,v) & if\ u \sim v, \\ 0 & otherwise. \end{cases}$$

Weighted Laplacian Matrix: $0 = \mu_1 \leq \mu_2 \leq \cdots \leq \mu_n$

$$L(u,v) = D(u,v) - A(u,v) = \begin{cases} d_v - w(u,v) & if\ u = v, \\ -w(u,v) & if\ u \sim v, \\ 0 & otherwise. \end{cases}$$

Weighted Normalized Laplacian Matrix: $0 = \nu_1 \leq \nu_2 \leq \cdots \leq \nu_n \leq 2$

$$\mathcal{L}(u,v) = D^{-1/2} L D^{-1/2} = \begin{cases} 1 - \dfrac{w(u,v)}{d_u} & if\ u = v, \\ -\dfrac{w(u,v)}{\sqrt{d_u d_v}} & if\ u \sim v, \\ 0 & otherwise. \end{cases}$$

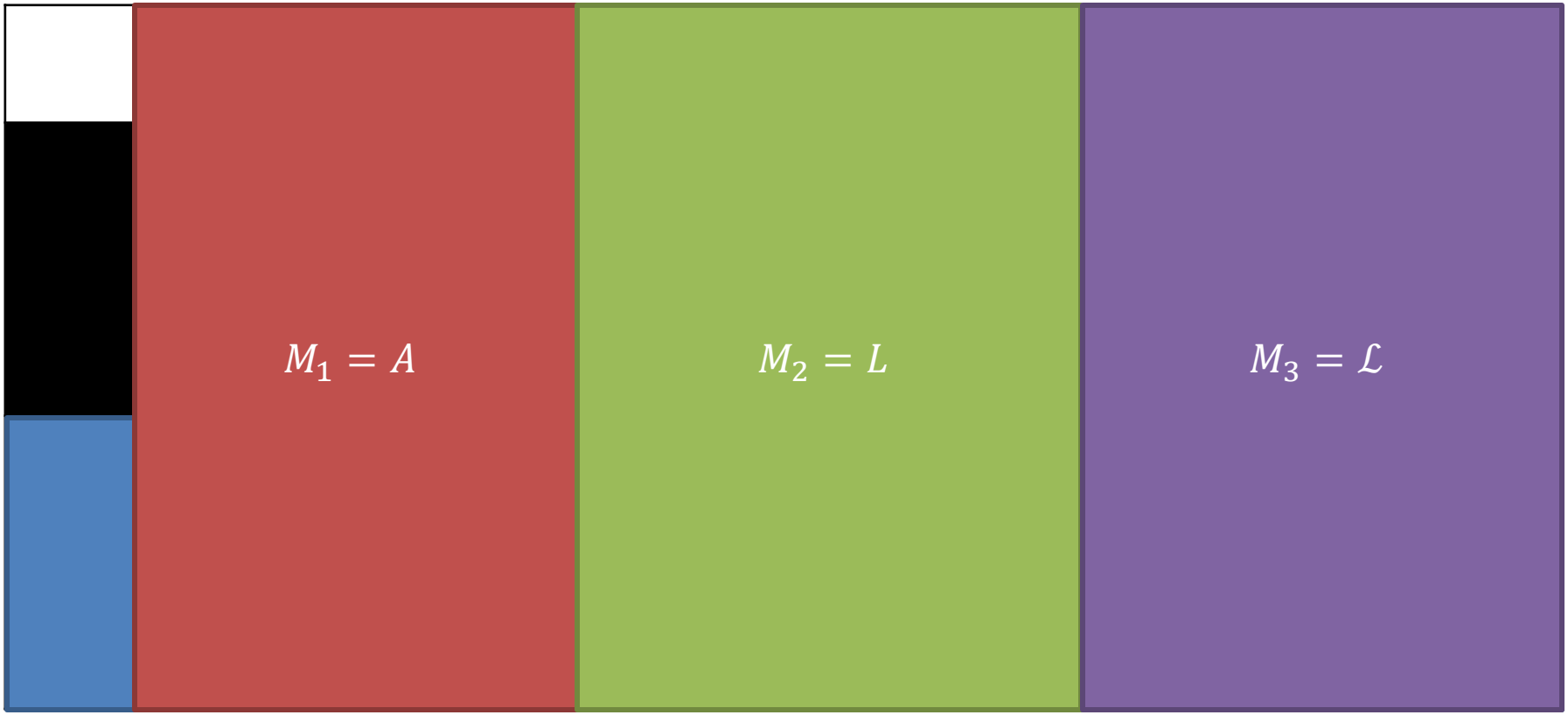
And other definitions for directed graphs

Spectral Structural Complexity Metrics

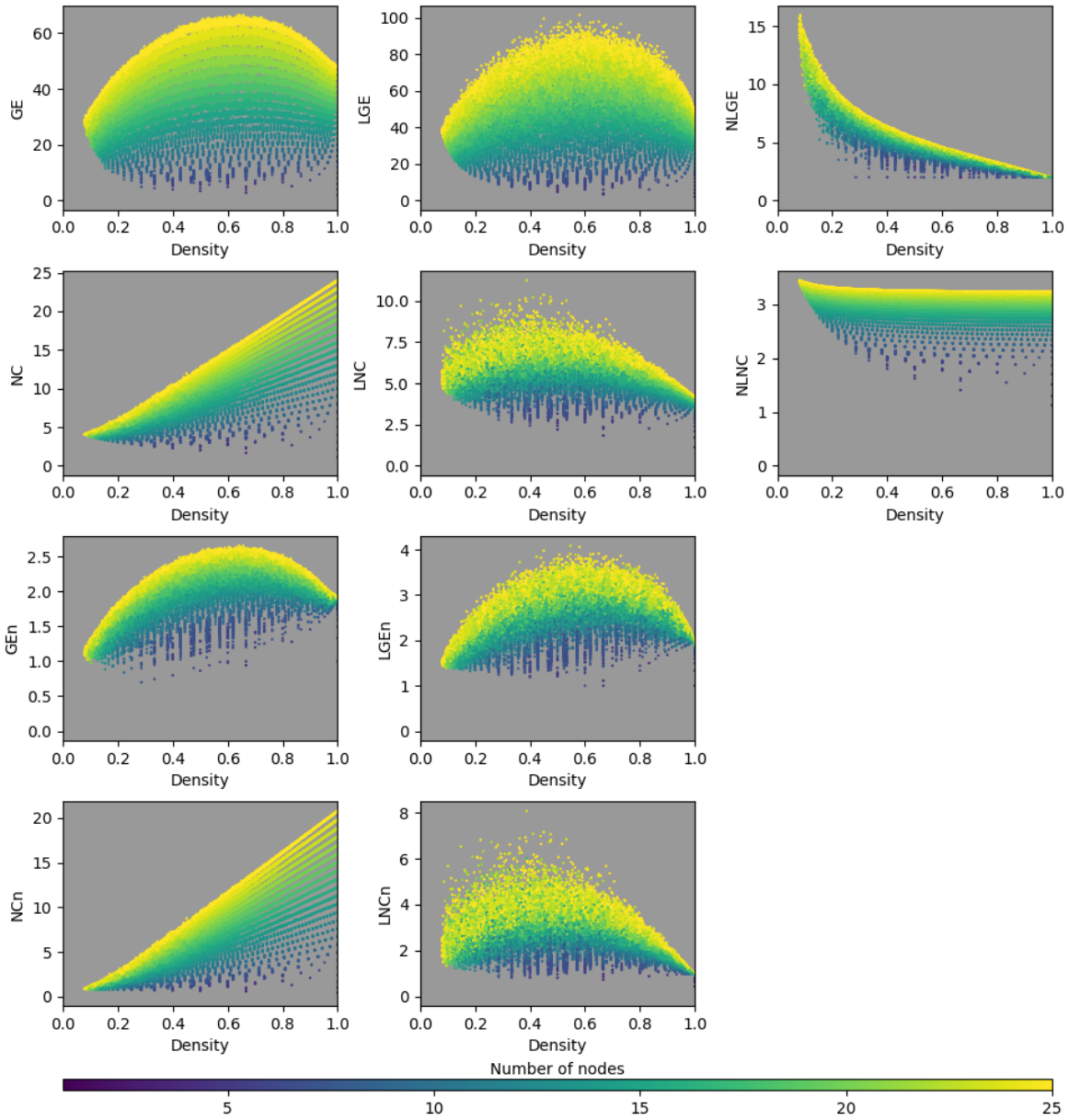
Graph Energy and Laplacian Graph Energy (Gutman)	$E_A(G) = \sum_{i=1}^{n} \lvert\lambda_i\rvert \qquad E_L(G) = \sum_{i=1}^{n} \left\lvert \mu_i - \frac{2m}{n} \right\rvert$
Generalized Graph Energy (Cavers)	$E_M(G) = \sum_{i=1}^{n} \left\lvert \lambda_i(M) - \frac{tr(M)}{n} \right\rvert$
Structural Complexity (Sinha)	$C(n,m,A) = \underbrace{\sum_{i=1}^{n} \alpha_i}_{C_1} + \underbrace{\left(\sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} A_{ij} \right)}_{C_2} \underbrace{\gamma E(A)}_{C_3}$
Natural Connectivity (Wu)	$N_A(G) = \ln\left(\frac{1}{n} \sum_{i=1}^{n} e^{\lambda_i} \right)$

Spectral Structural Complexity Metrics

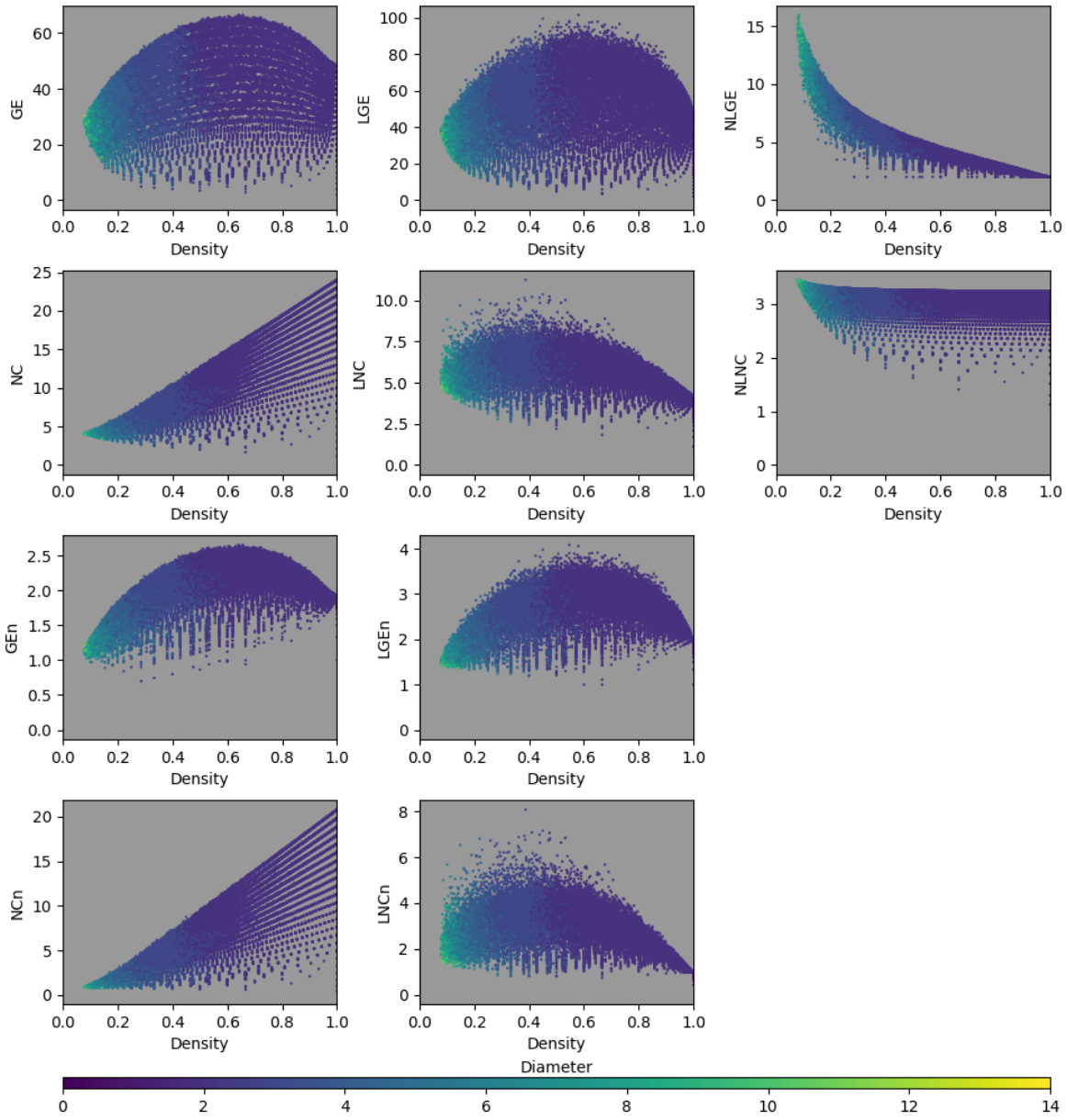
$$C(S) = f\left(\gamma \sum_{i=1}^{n} g\left(\lambda_i(M) - \frac{tr(M)}{n}\right)\right)$$



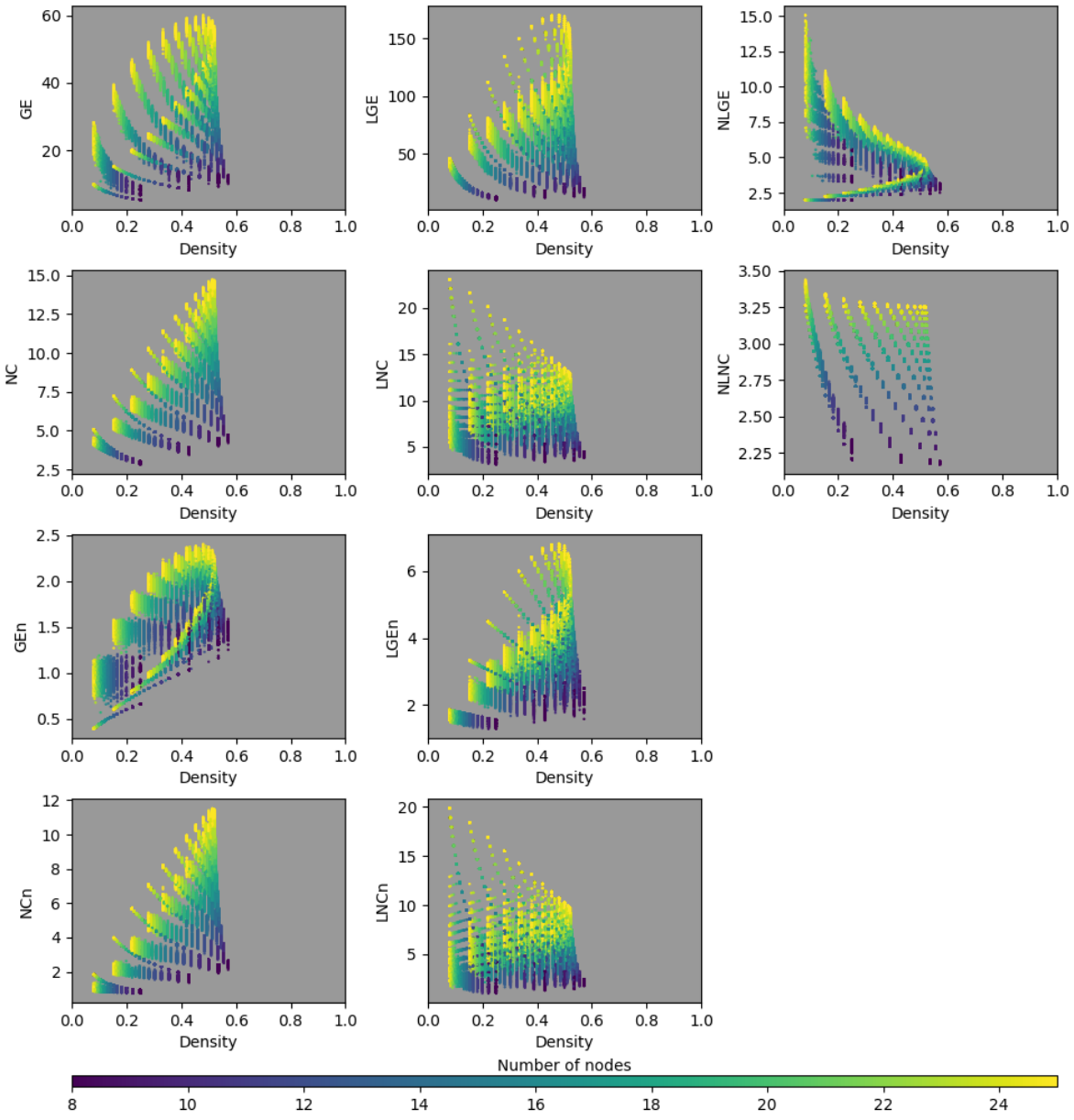
Erdos-Rényi


GE
LGE
NLGE
NC
LNC
NLNC
GEn
LGEn
NCn
LNCn
Density
Number of nodes
5
10
15
20
25

Erdos-Rényi



Barabási-Albert



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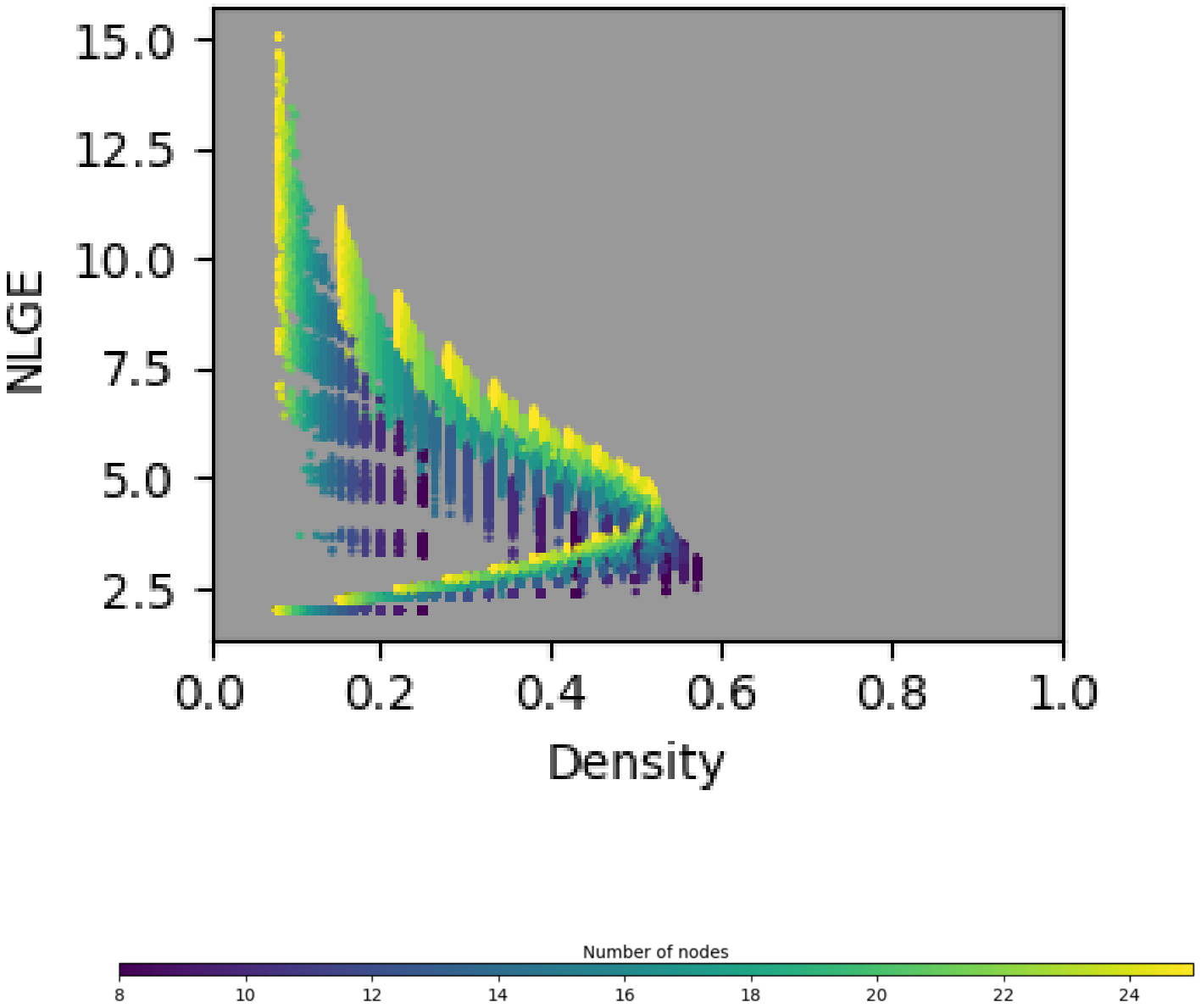

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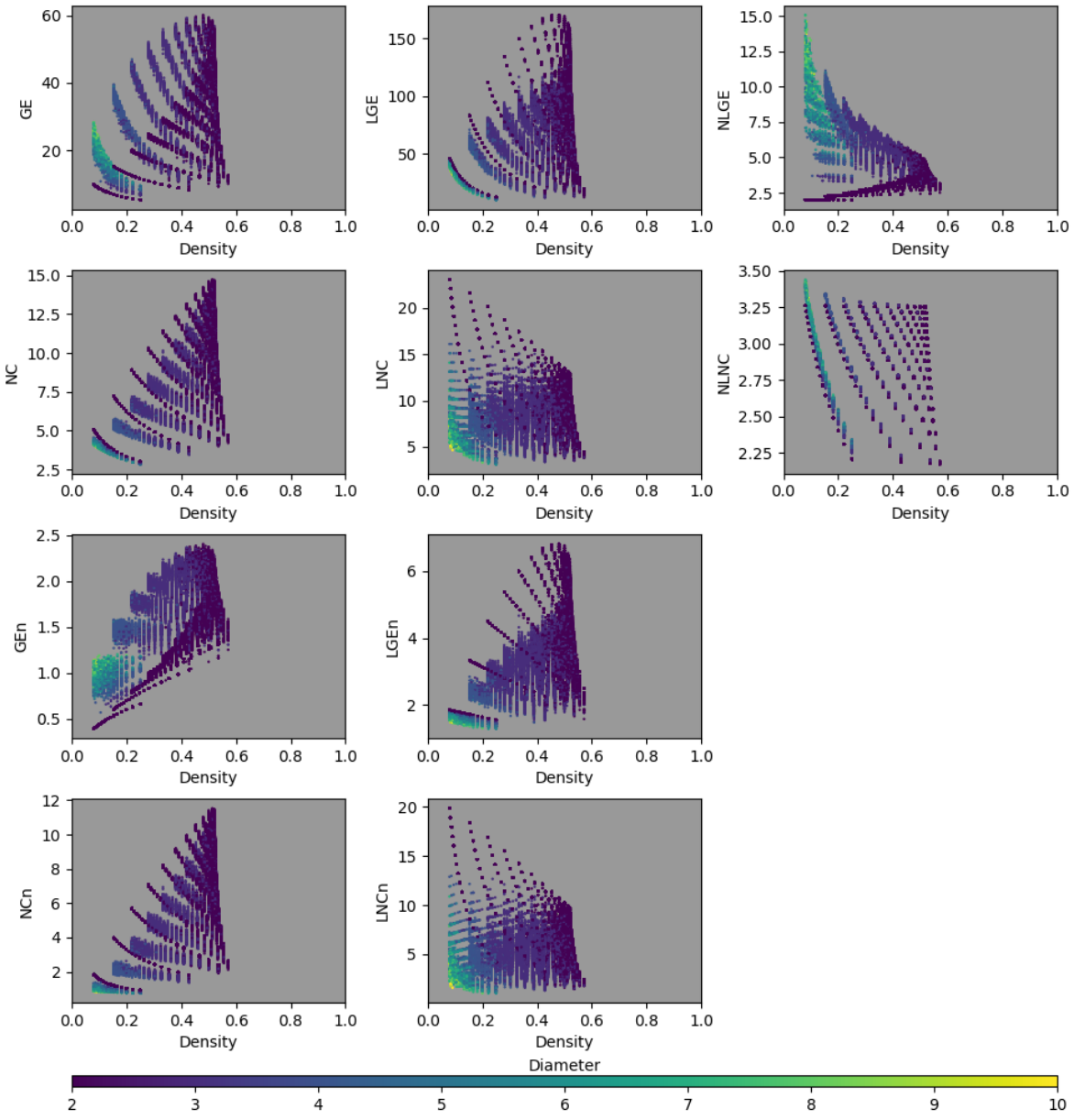

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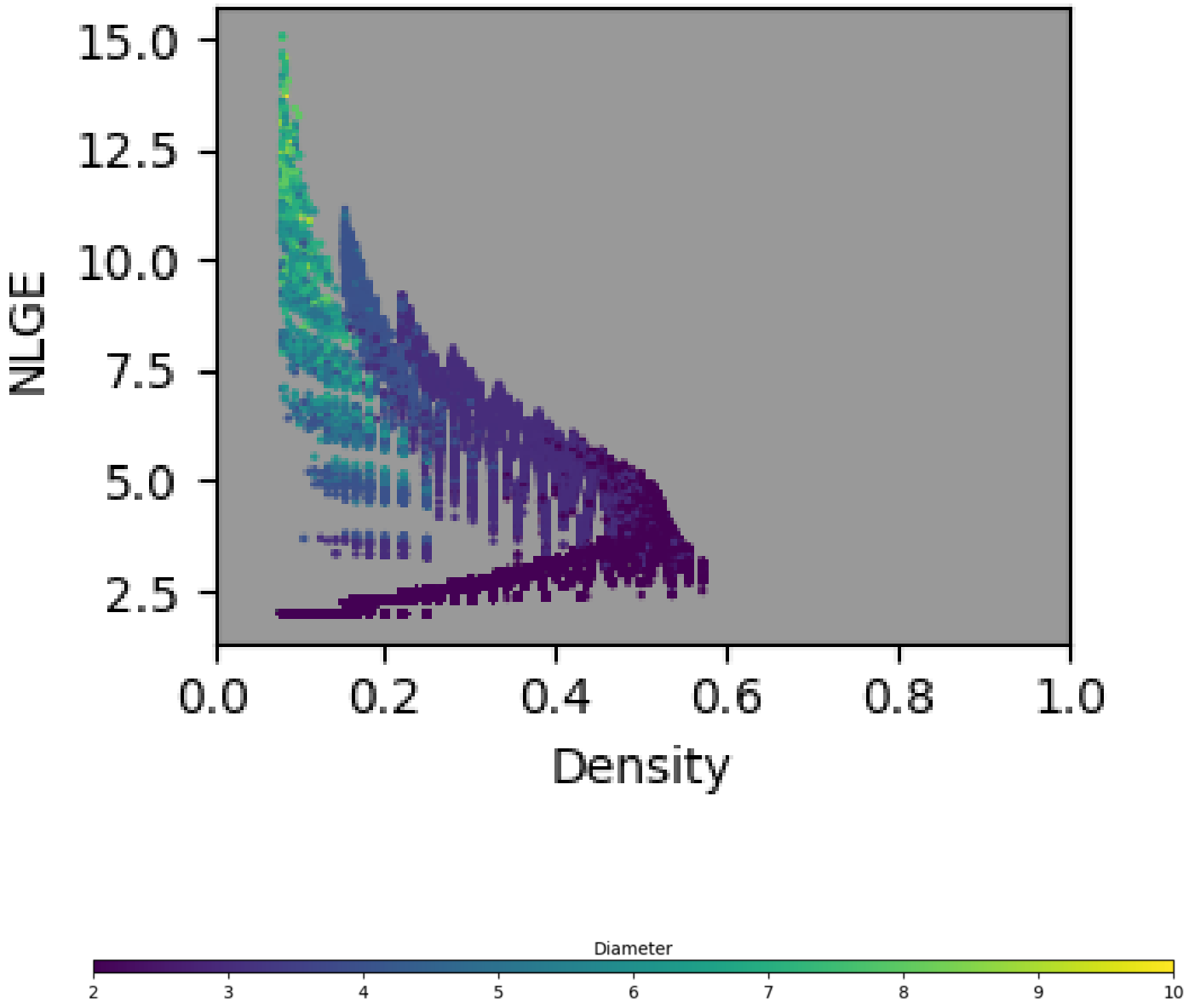

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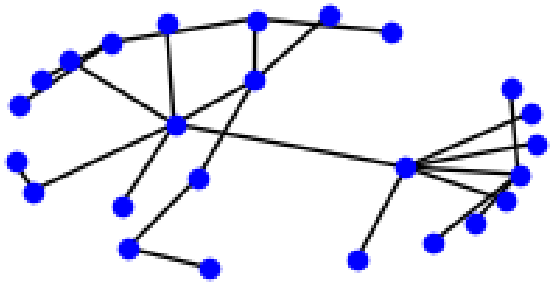

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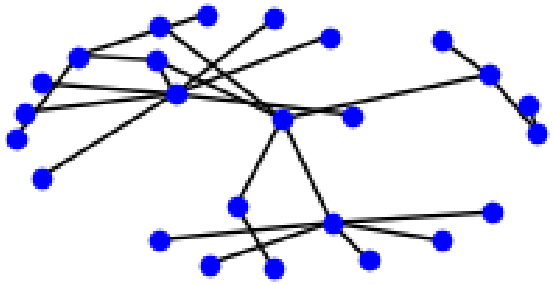

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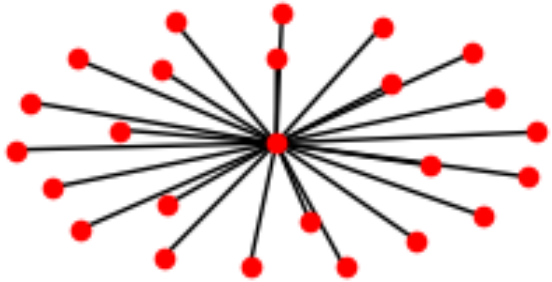

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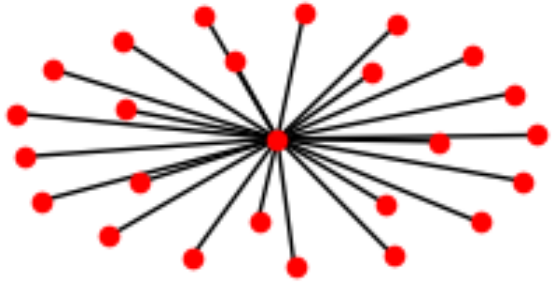

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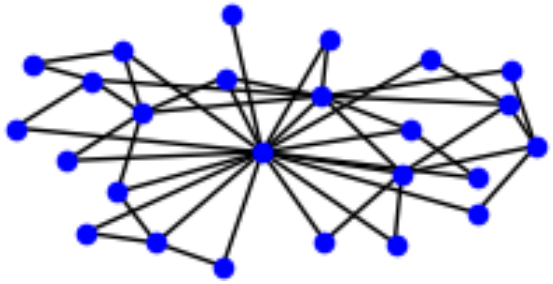

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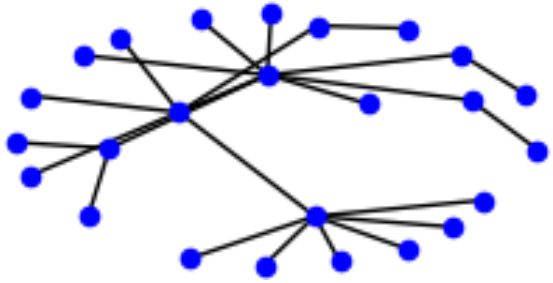
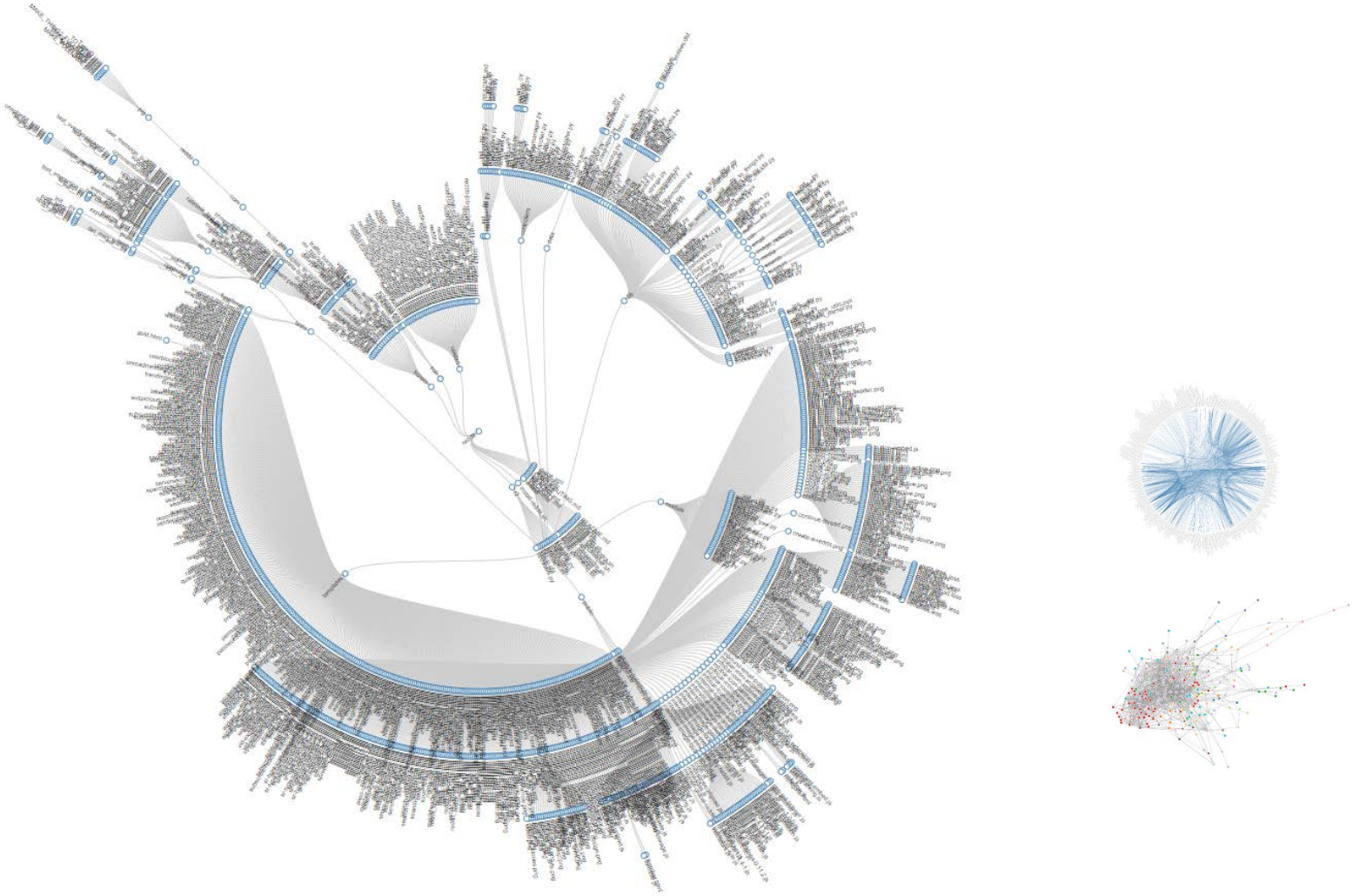
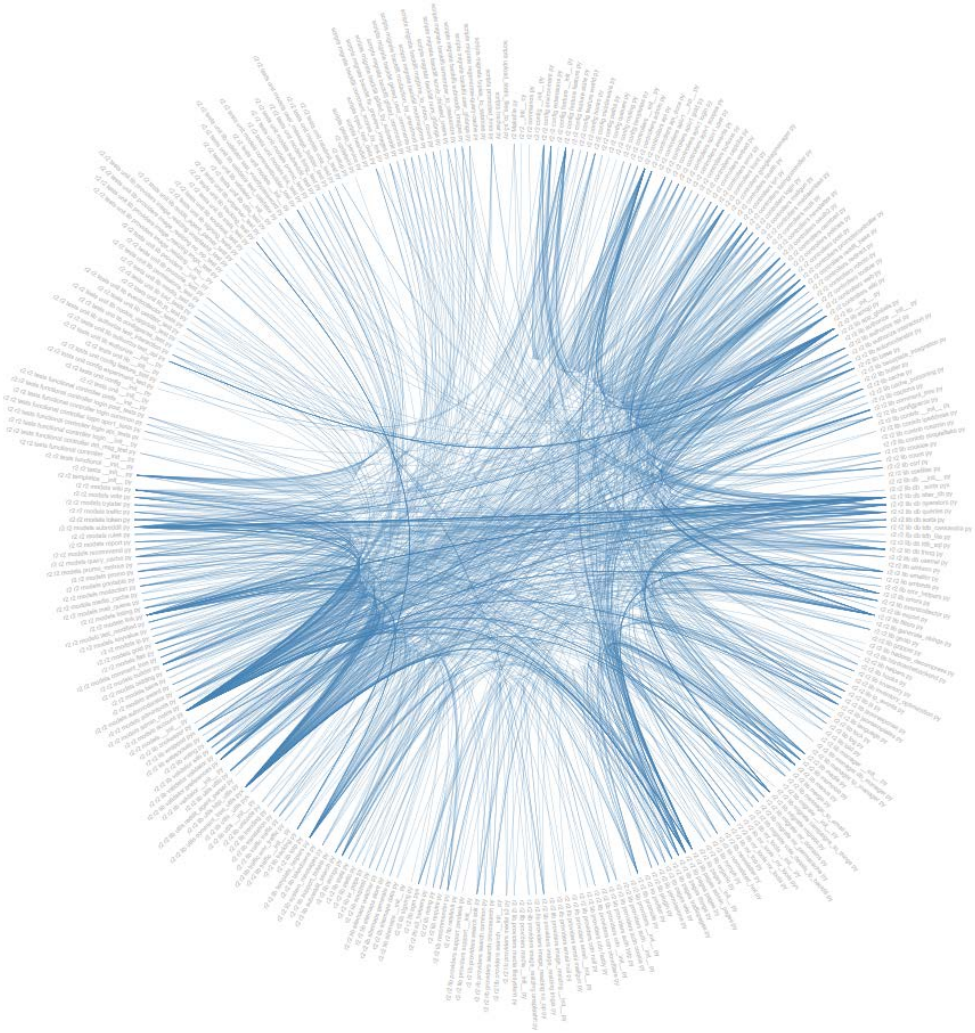


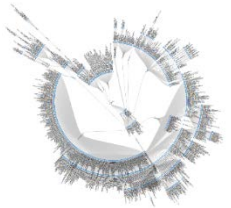
Diameter = 5

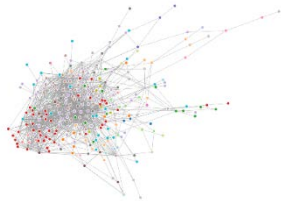
Reddit Codebase – Hierarchy



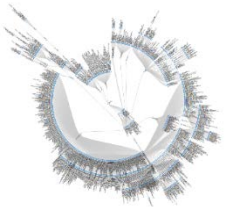
Reddit Codebase – Connections







Reddit Codebase – Topology



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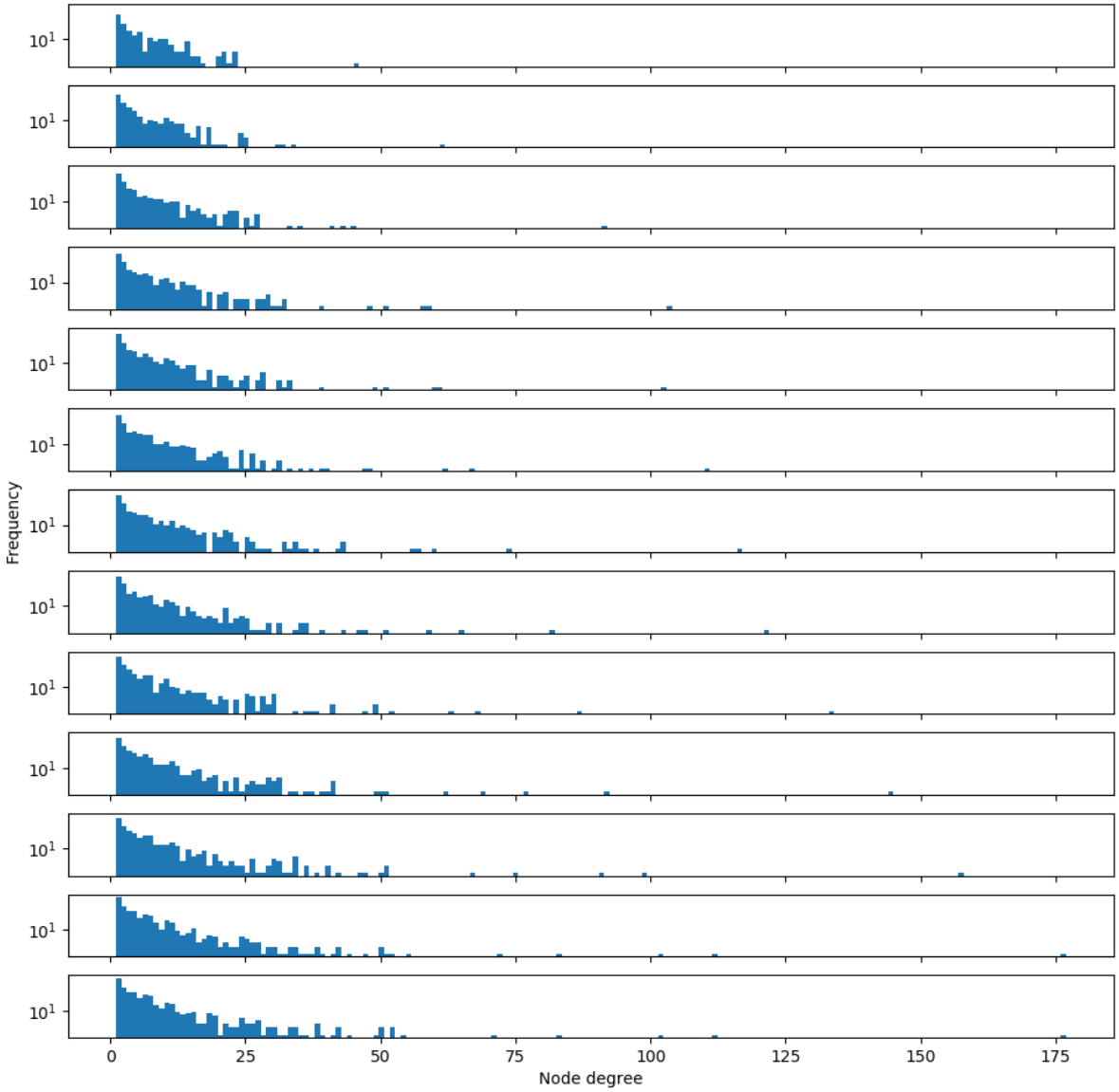
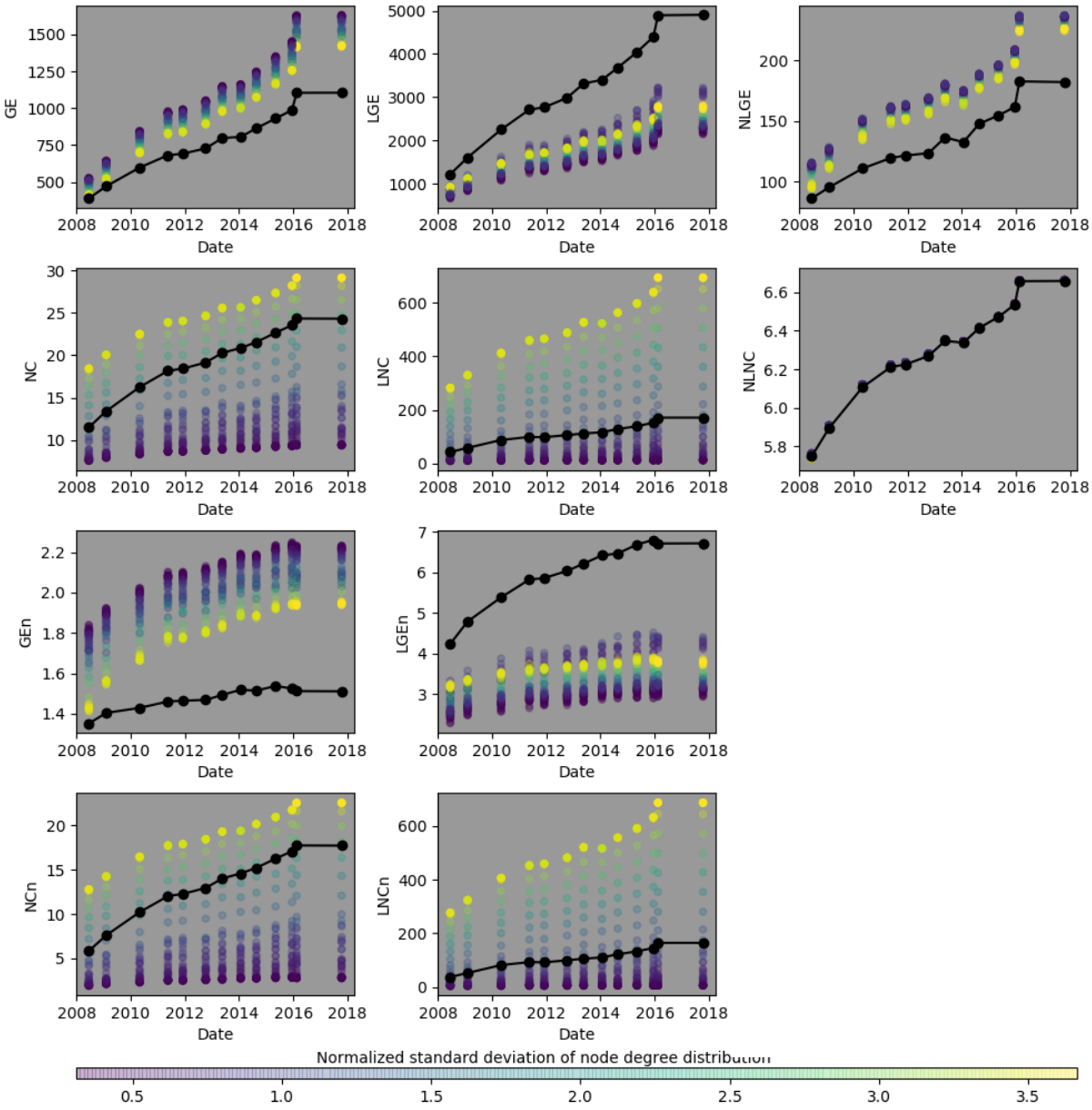


Reddit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LGE
NLGE
NC
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NLNC
GEn
LGEn
NCn
LNCn
Date
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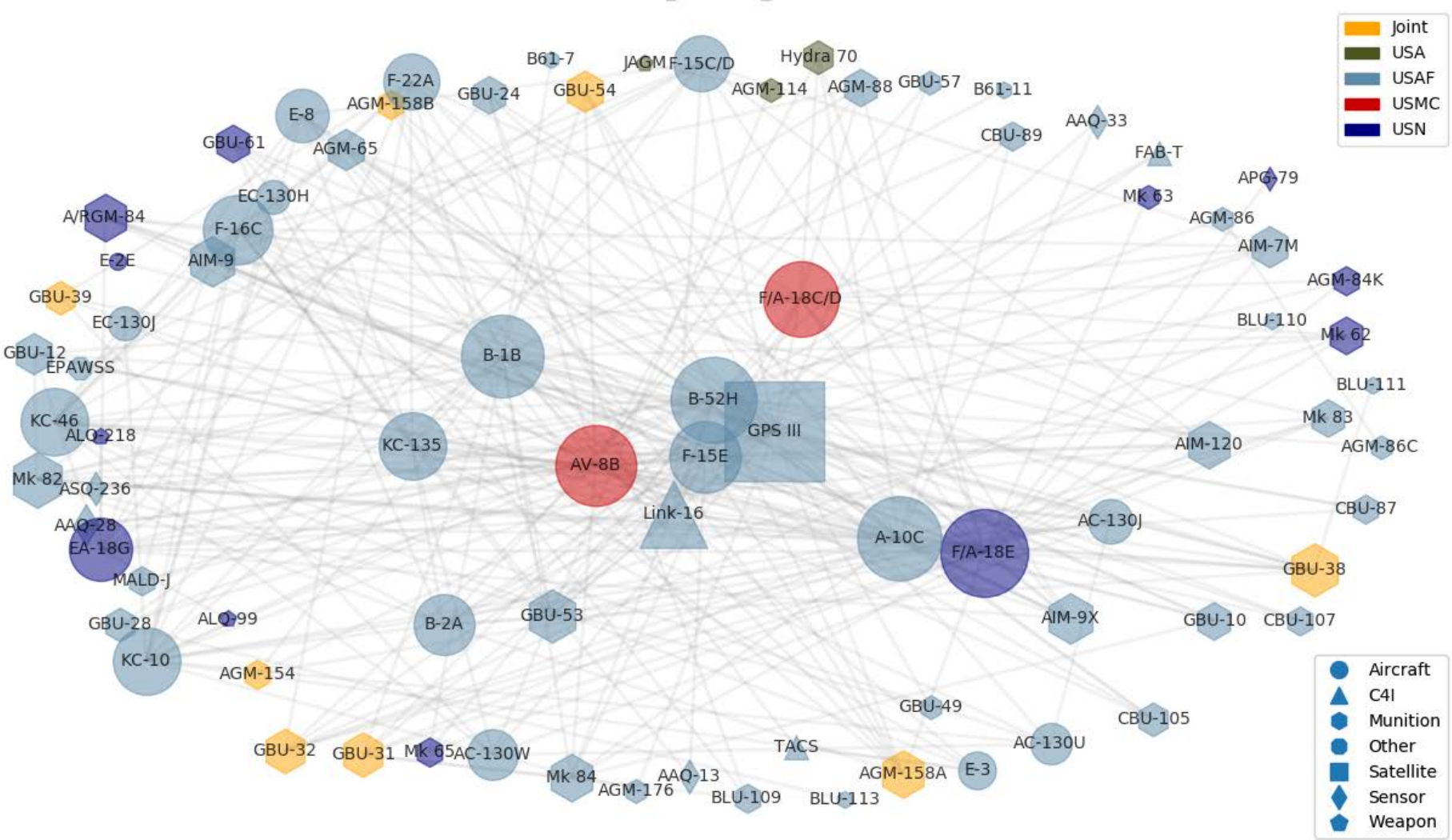
Normalized standard deviation of node degree distribution
0.5 1.0 1.5 2.0 2.5 3.0 3.5

TACAIR - 2005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JAGM
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GBU-54
AGM-114
AGM-88
GBU-57
B61-11
E-8
GBU-61
AGM-65
CBU-89
AAQ-33
FAB-T
APG-79
MK 63
EC-130H
A/RGM-84
F-16C
AGM-86
E-2E
AIM-9
AIM-7M
AGM-84K
GBU-39
F/A-18C/D
EC-130J
BLU-110
Mk 62
GBU-12
EPAWSS
B-1B
BLU-111
B-52H
KC-46
GPS III
Mk 83
ALQ-218
KC-135
AV-8B
F-15E
AIM-120
AGM-86C
Mk 82
ASQ-236
Link-16
CBU-87
AAQ-28
A-10C
AC-130J
EA-18G
F/A-18E
GBU-38
MALD-J
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ALQ-99
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Mk 84
AAQ-13
AGM-158A
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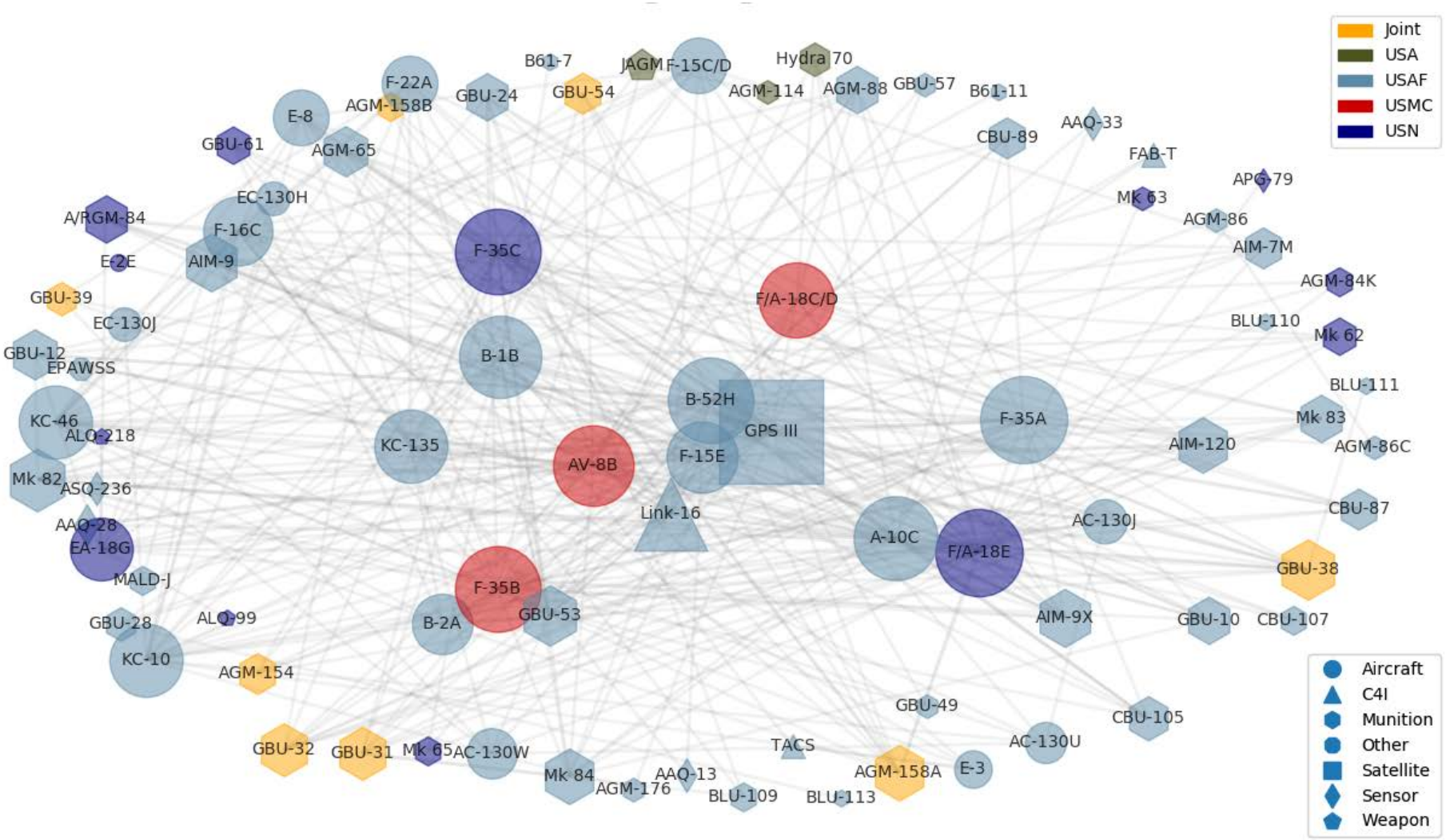
Aircraft
C4I
Munition
Other
Satellite
Sensor
Weapon

TACAIR - 2018


Joint
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USAF
USMC
USN
Aircraft
C4I
Munition
Other
Satellite
Sensor
Weapon
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JAGM
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Hydra 70
F-22A
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GBU-24
GBU-54
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B61-11
E-8
GBU-61
AGM-65
CBU-89
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FAB-T
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BLU-110
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Mk 62
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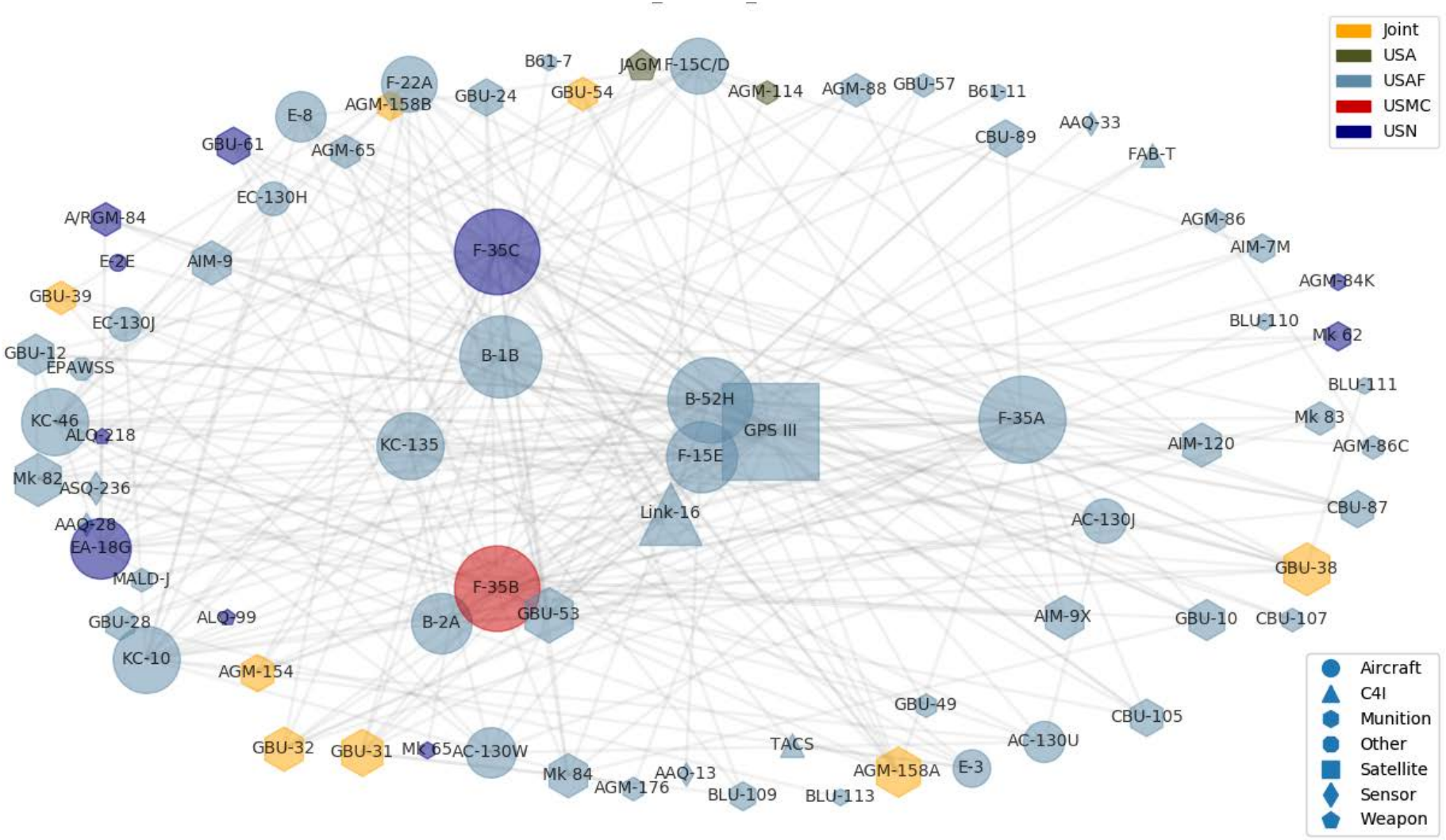
Joint
USA
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USMC
USN
B61-7
JAGM
F-15C/D
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AGM-158B
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AGM-88
GBU-57
B61-11
E-8
GBU-61
AGM-65
CBU-89
AAQ-33
FAB-T
EC-130H
A/RGM-84
F-35C
AGM-86
AIM-7M
E-2E
AIM-9
AGM-84K
GBU-39
EC-130J
BLU-110
Mk 62
GBU-12
EPAWSS
B-1B
BLU-111
B-52H
GPS III
F-35A
KC-46
ALQ-218
KC-135
F-15E
Mk 83
AIM-120
AGM-86C
Mk 82
ASQ-236
Link-16
CBU-87
AAQ-28
EA-18G
AC-130J
MALD-J
F-35B
GBU-38
GBU-28
ALQ-99
B-2A
GBU-53
AIM-9X
GBU-10
CBU-107
KC-10
AGM-154
GBU-49
CBU-105
GBU-32
GBU-31
MK 65
AC-130W
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AC-130U
Mk 84
AAQ-13
AGM-158A
E-3
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BLU-113
Aircraft
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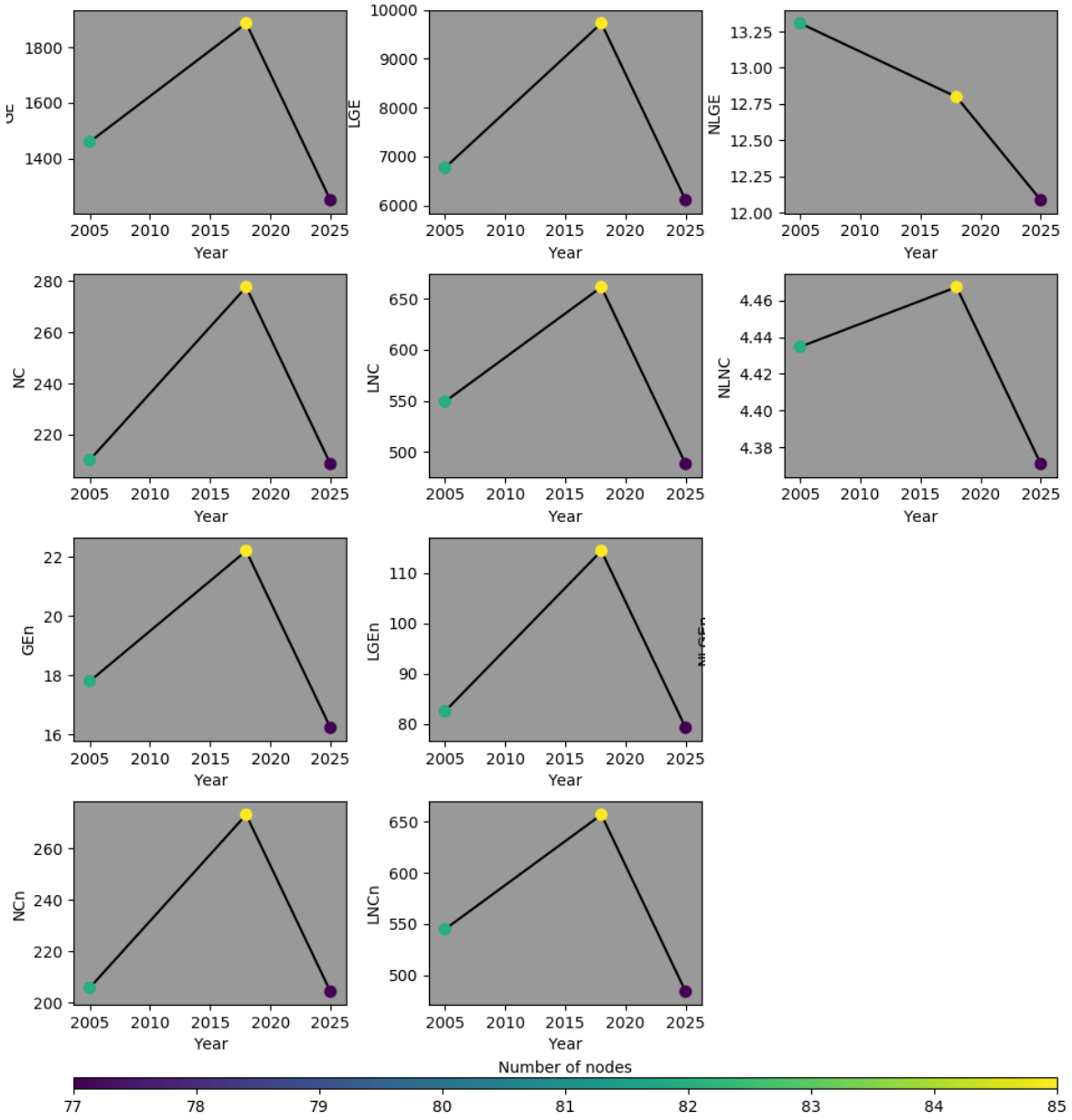
Other
Satellite
Sensor
Weapon

TACAIR


LGE
NLGE
NC
LNC
NLNC
GEn
LGEn
NCn
LNCn
Year
Number of nodes
77
78
79
80
81
82
83
84
85

Conclusion

Development of spectral structural complexity metrics

- Understanding of the features of metric formulations

Application to software system

- Analysis of evolution of software systems

Application to system of systems

- Analysis of evolution of network
- Analysis of effect of JSF
- Analysis of effect of subsequent retirement of legacy systems

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