Structural Group Unfairness

Measurement and Mitigation by means of the Effective Resistance

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https://arxiv.org/pdf/2305.03223.pdf

What is Social Capital?

Information is a resource

- Each person is a source of important information

Social Capital

- Networks, **relationships**, and norms of trust and reciprocity within a community or society **that facilitate cooperation and collective action**
- Power derived from your **social connections**

Structural Social Capital

- Social capital derived from the **position** of a person in a network [Burt]
- Position determines the **control, access and power to spread information**

Source: Google

The **Information Flow** in the network determines the social capital of individuals
Disparities on the position in the network → Disparities in the individual Social Capital
[Bashardoust 2023]

Burt, Ronald S . The network structure of social capital. *Research in organizational behavior* (2000)
Bashardoust, A et al. Reducing Access Disparities in Networks using Edge Augmentation. *FAccT* (2023)

Group Unfairness in Social Capital

Different Position in the Network → Disparities in Social Capital

[Arnaiz-Rodriguez et al, 2024]

Groups are distributed in the network in different ways
→ different flow of information on different groups
→ different social capital (Unfairness in Social Capital)

Structural Group Unfairness
SGU

Accurate Measurement of Information Flow

Effective Mitigation of Structural Group Unfairness

Burt, Ronald S . The network structure of social capital. *Research in organizational behavior* (2000)
Arnaiz-Rodriguez, Adrian, et al. Structural Group Unfairness: Measurement and Mitigation by means of the Effective Resistance. ***TrustLog (2024)***

Measure Group Social Capital via Information Flow

Information flow in the network determines the **node's information access and control**

- **Pairwise distances** between nodes

Previous work use metrics that

- **Fail to capture the global properties of the topology → Shortest-path**
- **Lack of theoretical interpretation and guarantees → IC**

We propose to use Effective Resistance (R_{uv}) as the pairwise distance metric

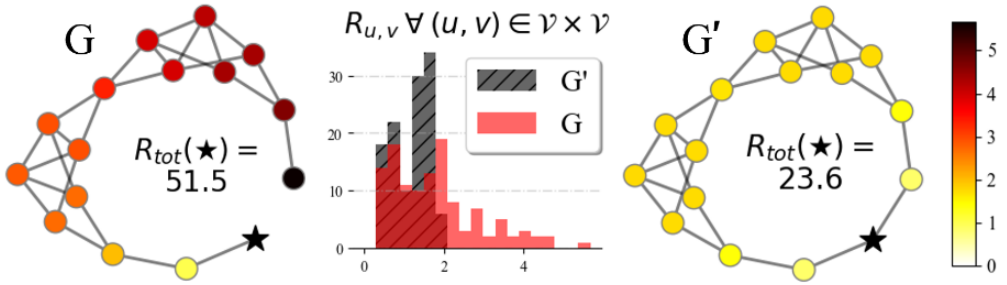
- **Pairwise information distance** based on Spectral Graph Theory
- Captures **global behavior** and **long-range** dependencies
- **R_{uv}** ∝ the *expected* time to reach **v** from **u** and come back to **u**
  - Average of *all existing paths* between u and v!

$$R_{uv} = (\mathbf{e}_u - \mathbf{e}_v)\mathbf{L}^{\dagger}(\mathbf{e}_u - \mathbf{e}_v)^{\top}$$

$$R_{uv} = \sum_{i>0} \frac{1}{\lambda_i} (\phi_i(u) - \phi_i(v))^2$$

$$R_{uv} = \sum_{i=0}^{\infty} \left(\frac{1}{d_u}(\mathbf{A}^i)_{uu} + \frac{1}{d_v}(\mathbf{A}^i)_{vv} - \frac{1}{\sqrt{d_u d_v}} 2(\mathbf{A}^i)_{uu} \right)$$

The more and shorter paths between a pair of nodes The smaller R_{uv} is



We define the (inverse) social capital of a single node as the total sum of all it's distances to everyone else

$$\mathrm{R}_{\mathrm{tot}}(u) = \sum_{v \in \mathcal{V}} R_{uv}$$

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Measures of Group Social Capital

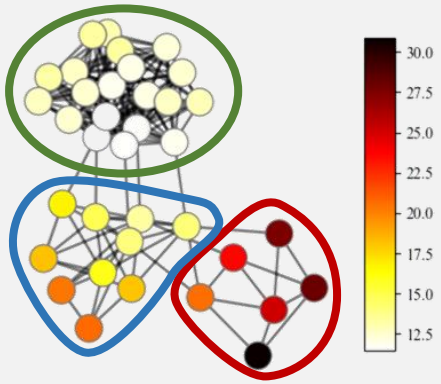
Group Isolation

*The **lower** the better*

$$\mathrm{R}_{\mathrm{tot}}(S_i) = \mathbb{E}_{u \sim S_i}\left[\mathrm{R}_{\mathrm{tot}}(u)\right]$$

Expected $\mathbf{R_{uv}}$ when sampling one node from group S_i and another node at random

Intuition: average distance to everyone for the nodes of the group



$\mathrm{R}_{tot}(\boldsymbol{S}) = 12.3$ - *BETTER*
$\mathrm{R}_{tot}(\boldsymbol{S}) = 16.6$
$\mathrm{R}_{tot}(\boldsymbol{S}) = 25.9$ - WORST

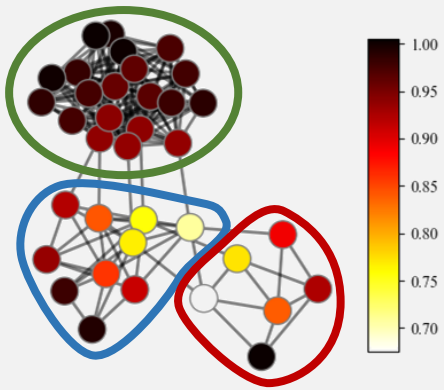
Group Diameter

*The **lower** the better*

$$\mathcal{R}_{\mathrm{diam}}(S_i) = \mathbb{E}_{u \sim S_i}\left[\max_{v \in \mathcal{V}} R_{uv}\right]$$

Expected **worst-case $\mathbf{R_{uv}}$** when sampling one node from group S_i and another node at random

Intuition: average maximum distance for the nodes of the group



$\mathcal{R}_{diam}(\boldsymbol{S}) = 0.97$ - WORST
$\mathcal{R}_{diam}(\boldsymbol{S}) = 0.87$
$\mathcal{R}_{diam}(\boldsymbol{S}) = 0.85$ - *BETTER*

Group Control

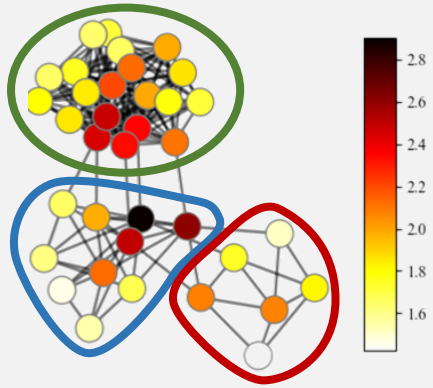
*The **higher** the better*

$$\mathrm{B_R}(S_i) = \mathbb{E}_{u \sim S_i}[\mathrm{B_R}(u)]$$

$$\mathrm{B_R}(u) = \sum_{v \in \mathcal{N}(u)} R_{uv}$$

Expected **Information bottleneck** (similar to node's Ricci curvature)

Intuition: average information control for the nodes of the group



$\mathrm{B_R}(\boldsymbol{S}) = 1.96$
$\mathrm{B_R}(\boldsymbol{S}) = 2.00$ - *BETTER*
$\mathrm{B_R}(\boldsymbol{S}) = 1.77$ - WORST

Measures of Structural Group Unfairness (SGU)

Based on Rawlsian concept of Fairness, SGU measures the social capital gap for the most disadvantaged group

Isolation Disparity

$$\mathrm{R}_{\mathrm{tot}}(S_i) = \mathrm{R}_{\mathrm{tot}}(S_j),\ \forall\, i, j \in SA.$$

$$\Delta\,\mathrm{R}_{\mathrm{tot}} = \max_{i,j \in SA}(\mathrm{R}_{\mathrm{tot}}(S_i) - \mathrm{R}_{\mathrm{tot}}(S_j)).$$

Diameter Disparity

$$\mathcal{R}_{\mathrm{diam}}(S_i) = \mathcal{R}_{\mathrm{diam}}(S_j),\ \forall\, i, j \in SA.$$

$$\Delta\,\mathcal{R}_{\mathrm{diam}} = \max_{i,j \in SA}(\mathcal{R}_{\mathrm{diam}}(S_i) - \mathcal{R}_{\mathrm{diam}}(S_j)).$$

Control Disparity

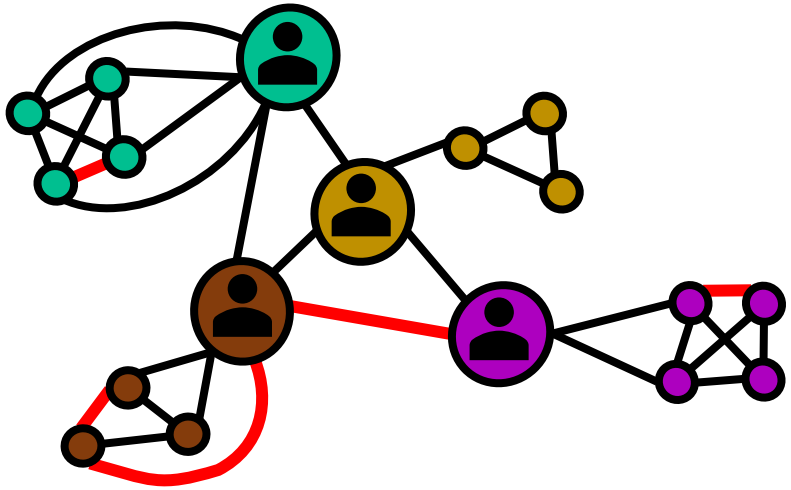
$$\mathrm{B}_{\mathrm{R}}(S_i) = \mathrm{B}_{\mathrm{R}}(S_j) = 2 - \frac{2}{|\mathcal{V}|},\ \forall\, i, j \in SA.$$

$$\Delta\,\mathrm{B}_{\mathrm{R}} = \max_{i,j \in SA}(\mathrm{B}_{\mathrm{R}}(S_i) - \mathrm{B}_{\mathrm{R}}(S_j)).$$

G	$R_{tot} \downarrow$		$\mathcal{R}_{diam} \downarrow$		$\mathrm{B}_{\mathrm{R}} \uparrow$	
Facebook (female)	221.4	$\Delta\,\mathrm{R}_{\mathrm{tot}}$	2.29	$\Delta\,\mathcal{R}_{\mathrm{diam}}$	1.93	$\Delta\,\mathrm{B}_{\mathrm{R}}$
Facebook (male)	**179.8**	41.62	**2.25**	0.042	**2.03**	0.107
UNC28 (female)	608.6	$\Delta\,\mathrm{R}_{\mathrm{tot}}$	2.11	$\Delta\,\mathcal{R}_{\mathrm{diam}}$	1.99	$\Delta\,\mathrm{B}_{\mathrm{R}}$
UNC28 (male)	**586.3**	22.4	2.11	0.006	**2.00**	0.009
Google+ (female)	564.1	$\Delta\,\mathrm{R}_{\mathrm{tot}}$	1.31	$\Delta\,\mathcal{R}_{\mathrm{diam}}$	1.81	$\Delta\,\mathrm{B}_{\mathrm{R}}$
Google+ (male)	**287.7**	276.4	**1.24**	0.078	**2.32**	0.51

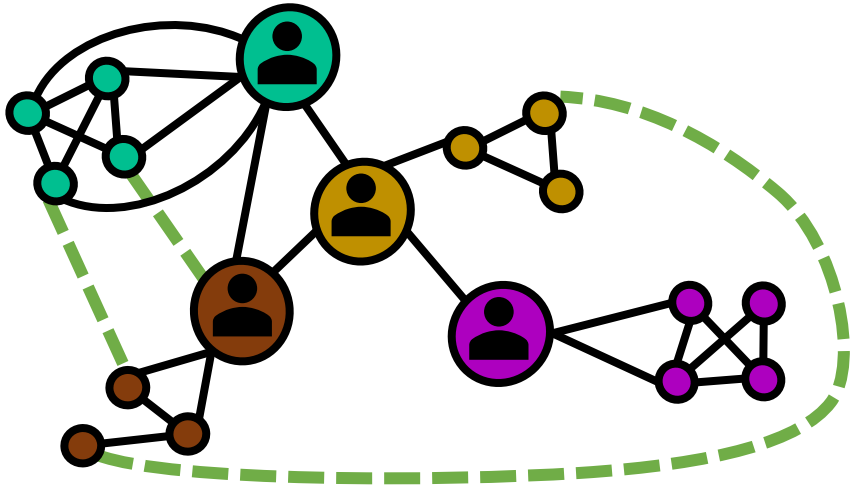
Group social capital and SGU in real-world online social networks. Group with the largest social capital is highlighted in bold.

How to mitigate SGU?



Common RecSys → similarity → segregation, polarization

RecSys maximize engagement → Same SGU



Create **weak connections** improves the information flow

Reduces polarization, discrimination and **isolation**

Improves diversity and connects minorities

Unifies the information control

Granovetter. The strength of weak ties: A network theory revisited. *Sociological theory* (1983)
Burt. 2004. Structural holes and good ideas. *American journal of sociology* (2004)
Arnaiz-Rodriguez, et al. Structural Group Unfairness: Measurement and Mitigation by means of the Effective Resistance. (2024)

ERG: Edge Augmentation to mitigate SGU

- Use **Effective Resistance informed edge addition** reduce the disparities in social capital between groups and individuals **while also improve the social capital for all groups**

- Problem defined as a budgeted **densifier** problem

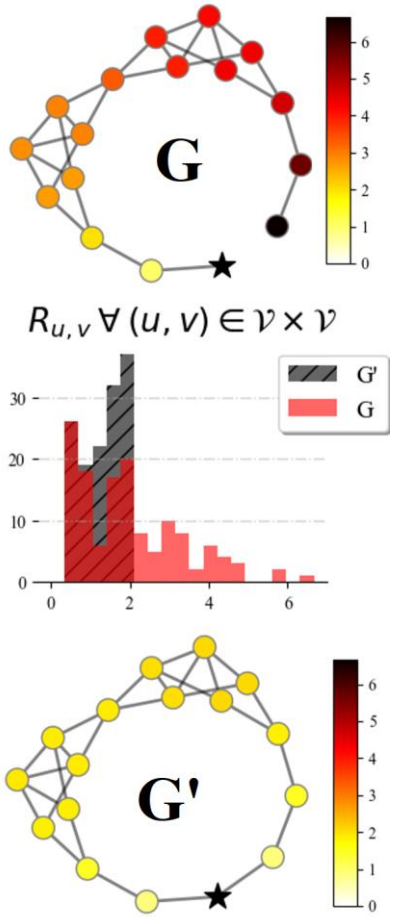
$$G' = \min_{G'=(\mathcal{V},\mathcal{E}')} \mathbb{E}_{u,v\sim V\times V}\left[R_{uv}\right] \quad \text{s.t.} \quad |\mathcal{E}' \setminus \mathcal{E}| = B \quad \mathcal{E} \subset \mathcal{E}'$$

Add the edge between nodes with **maximum R_{uv}**
on which (at least) one endpoint on the discriminated group

– Maximum ER edges allow to connect minorities –

As ER is heavily theoretically grounded,
this simple approach is effective and provides strong insights:

– Theoretically a greedy optimal desnsifier wrt Information Flow -
– E.g.: Adding *max* R_{uv} improve the robustness and over-squashing (proxies of Information Flow) –



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Experiments on Real World: Group SC and SGU

Results on 3 real-world online social networks: Facebook, UNC and Google+

(a) Facebook (B=50)

	Δ R_{tot}	Δ $\mathcal{R}_{diam}$	Δ B_R
G (original)	41.62	0.042	0.107
Random	38.7	0.039	0.108
DW	36.3	0.031	0.104
Cos	28.7	0.029	0.120
ERG	**10.3**	**0.009**	**0.098**

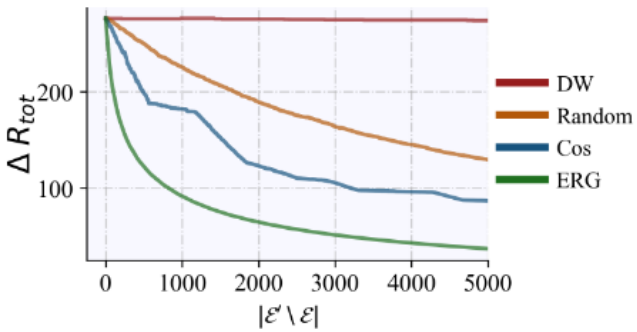
(b) UNC28 (B=5000)

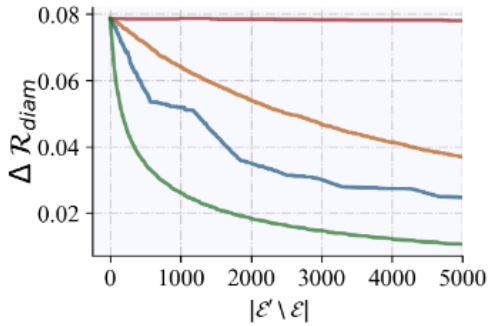
	Δ R_{tot}	Δ $\mathcal{R}_{diam}$	Δ B_R
G (original)	22.4	0.006	0.009
Random	19.8	0.005	0.014
DW	22.2	0.006	0.004
Cos	19.1	0.005	0.102
ERG	**8.8**	**0.002**	**0.003**

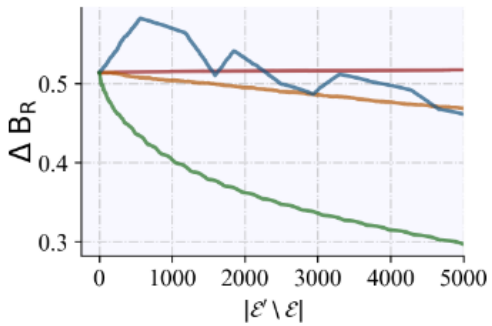
(c) Google+ (B=5000)

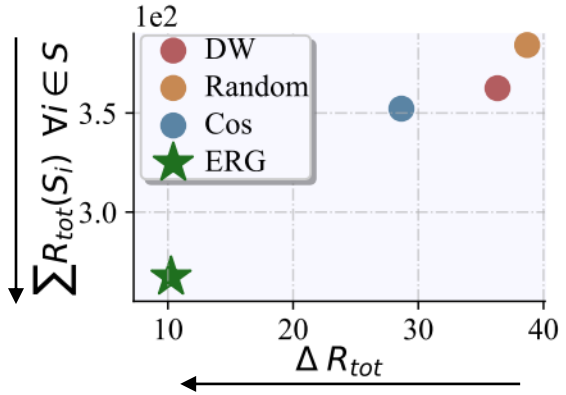
	Δ R_{tot}	Δ $\mathcal{R}_{diam}$	Δ B_R
G (original)	276.4	0.078	0.51
Random	129.4	0.037	0.47
DW	274.1	0.078	0.51
Cos	86.8	0.025	0.47
ERG	**37.1**	**0.011**	**0.29**

- ERG significantly reduces SGU
- ERG is effective even adding few links
- **Reduces SGU while improving the social capital of all groups**









Arnaiz-Rodriguez, Adrian, et al. Structural Group Unfairness: Measurement and Mitigation by means of the Effective Resistance. (2024)

Take-home ideas

Social Networks are very useful to analyze social dynamics or make predictions about people and their relationships

Specific [Arnaiz-Rodriguez, Curto and Oliver 2024]:

Your position on a **social network** defines the access, spread-power and control of information you have

↓

Social Capital

It is not trivial to **quantify SC** and to **align the** literature in sociology and graph theory/fairness

↓

Quantitative sociology-aligned measures of social capital based on graph theory

Effective resistance: isolation, diameter and control

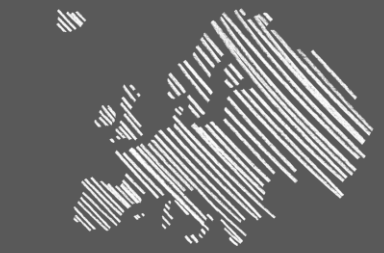
There are Social Capital inequalities not trivial to fix

↓

Fix it using an edge augmentation strategy based on the weak**est** links

ERG: Adding the edge that maximizes the information flow on the whole network

Arnaiz-Rodriguez, Adrian, Georgina Curto, and Nuria Oliver.
"Structural Group Unfairness: Measurement and Mitigation by means of the Effective Resistance." *TrustLoG at WWW.* (2024)



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e l l i s

Extra: More Baselines

(a) Facebook (B=50)

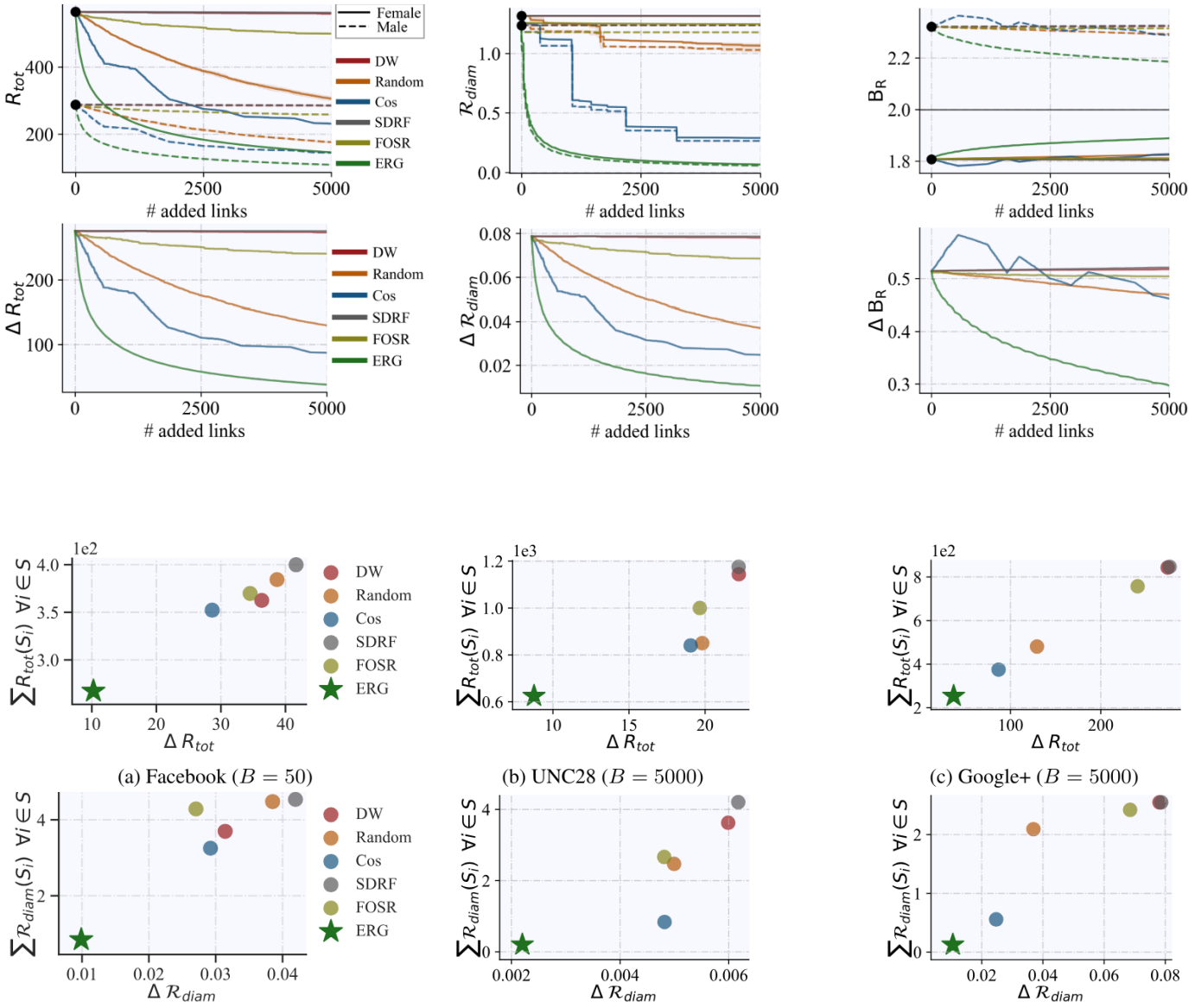
G (original)	Δ R_{tot} 41.62	Δ $\mathcal{R}_{diam}$ 0.042	Δ B_R 0.107
Random	38.7	0.039	0.108
SDRF	41.6	0.042	0.106
FOSR	34.5	0.027	0.109
DW	36.3	0.031	0.104
Cos	28.7	0.029	0.120
ERG	**10.3**	**0.009**	**0.098**
S-DW	43.6	0.041	0.103
S-Cos	41.4	0.042	0.105
S-ERG	41.6	0.042	0.107

(b) UNC28 (B=5000)

G (original)	Δ R_{tot} 22.4	Δ $\mathcal{R}_{diam}$ 0.006	Δ B_R 0.009
Random	19.8	0.005	0.014
SDRF	22.2	0.006	0.007
FOSR	19.7	0.005	0.017
DW	22.2	0.006	0.004
Cos	19.1	0.005	0.102
ERG	**8.8**	**0.002**	**0.003**
S-DW	20.6	0.006	0.008
S-Cos	22.1	0.006	0.019
S-ERG	22.3	0.006	0.004

(c) Google+ (B=5000)

G (original)	Δ R_{tot} 276.4	Δ $\mathcal{R}_{diam}$ 0.078	Δ B_R 0.51
Random	129.4	0.037	0.47
SDRF	276.1	0.079	0.52
FOSR	240.7	0.068	0.50
DW	274.1	0.078	0.51
Cos	86.8	0.025	0.47
ERG	**37.1**	**0.011**	**0.29**
S-DW	272.5	0.078	0.49
S-Cos	236.0	0.067	0.47
S-ERG	276.4	0.079	0.52



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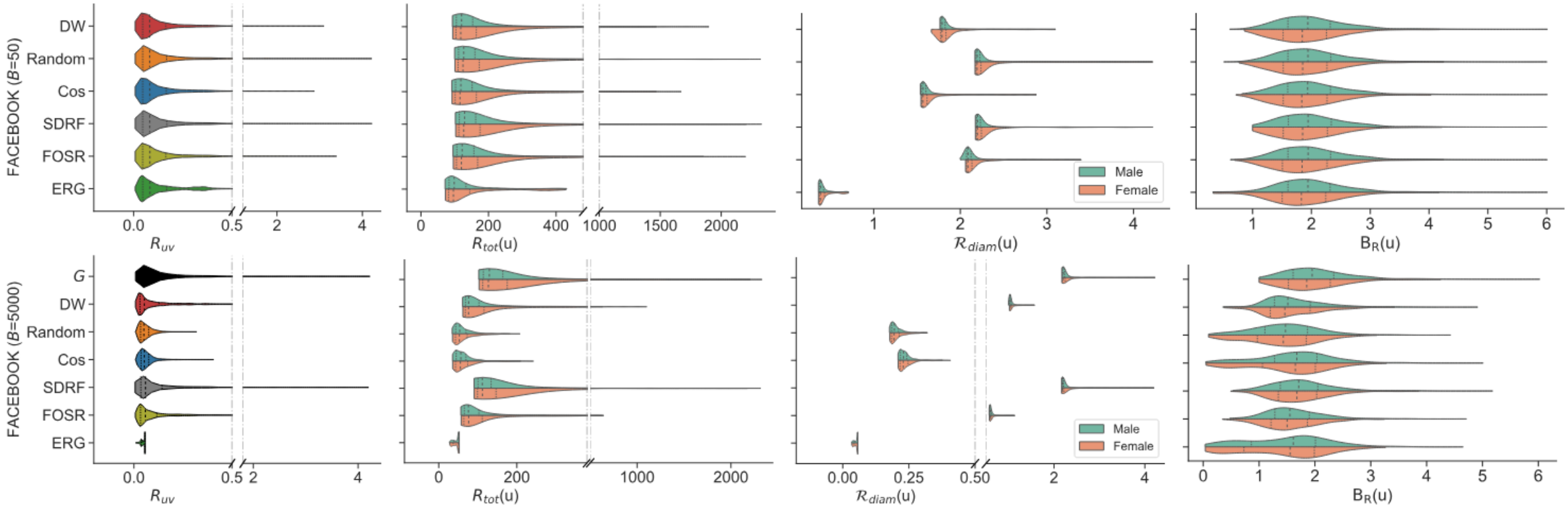
Extra: More Results – Metrics Distribution



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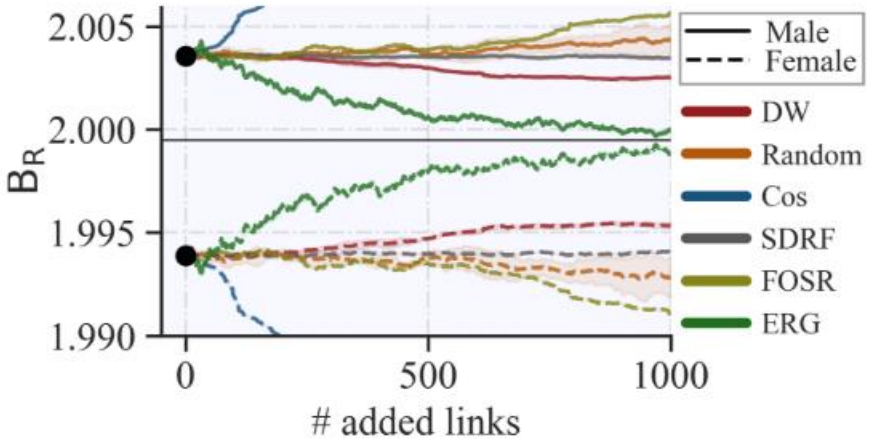
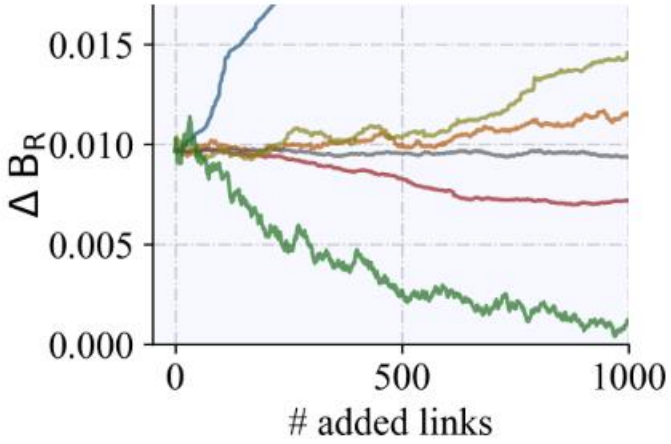
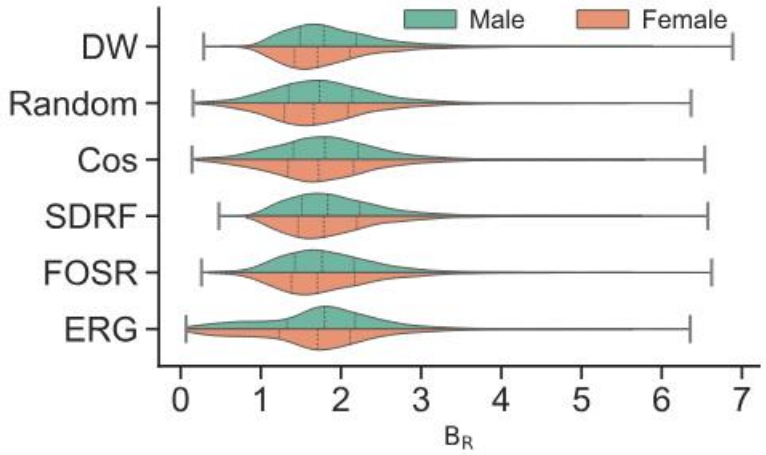
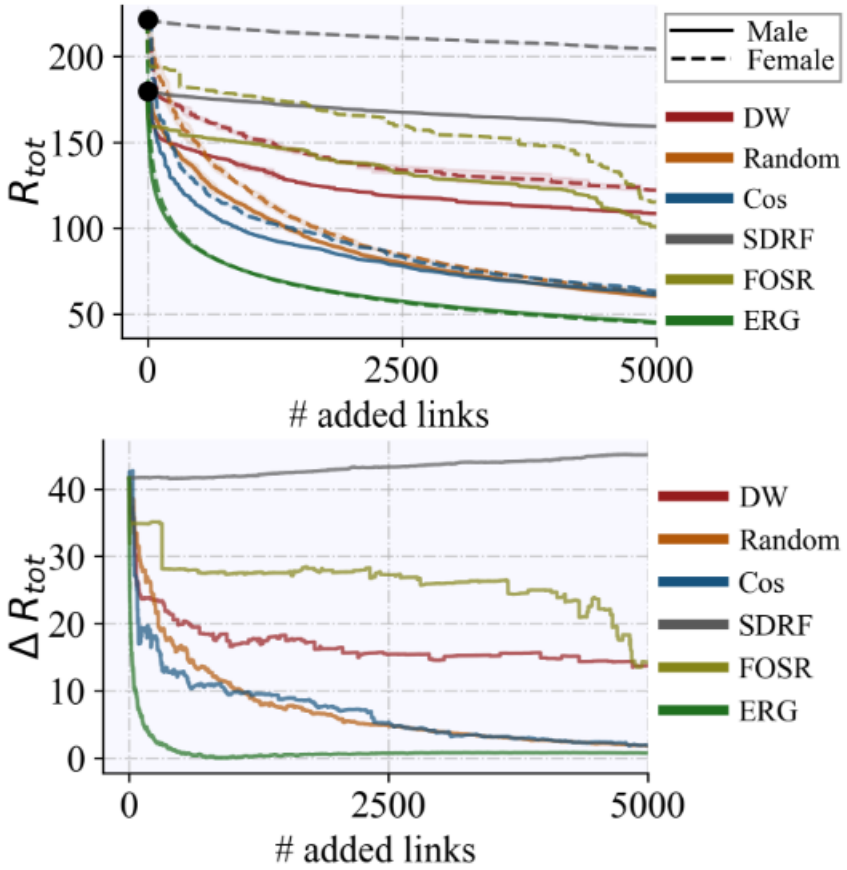
Extra: More Results – Control Evolution

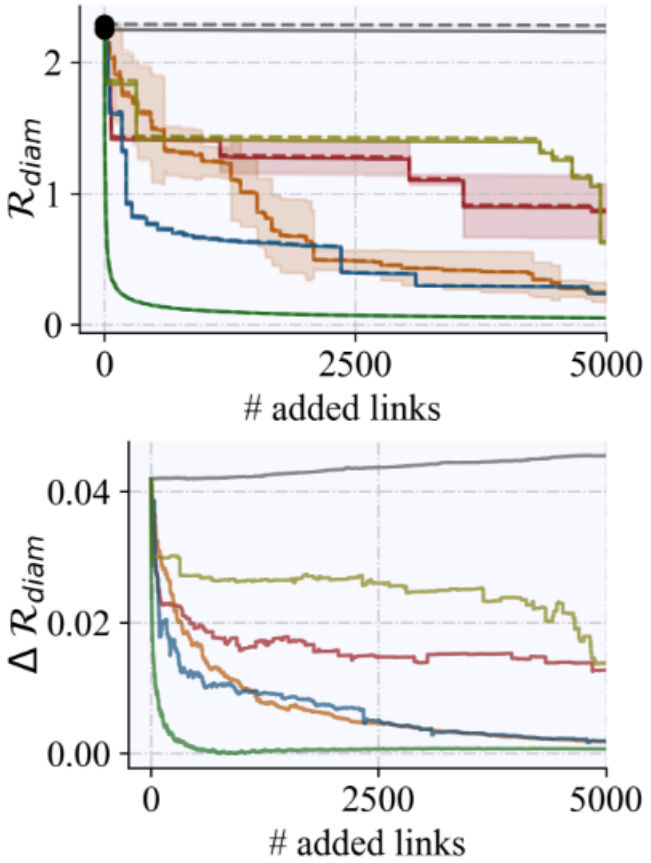


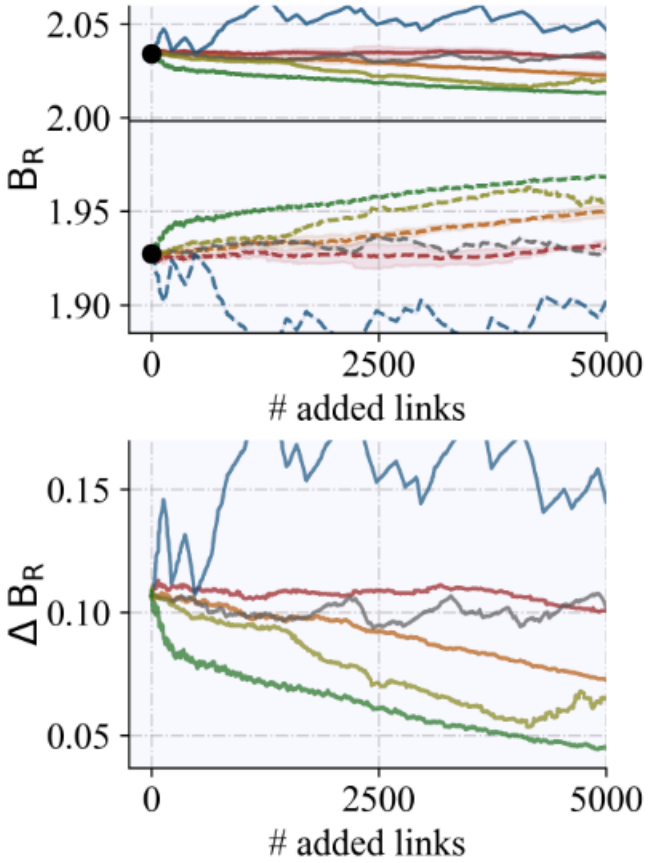




Extra: More Results – Large Budget







Effect on the Network Structure