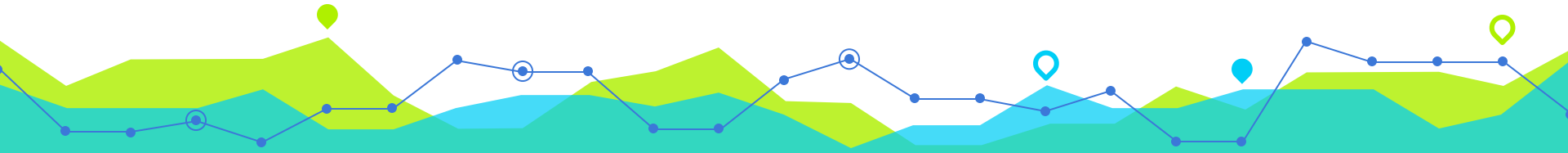


Temporal Multilayer Network Analysis of Marvel Heroes

Hercy Shen, Amy Shen, Ruiyao Xu, Allen Tong, Jim Liu, and Owen Sun

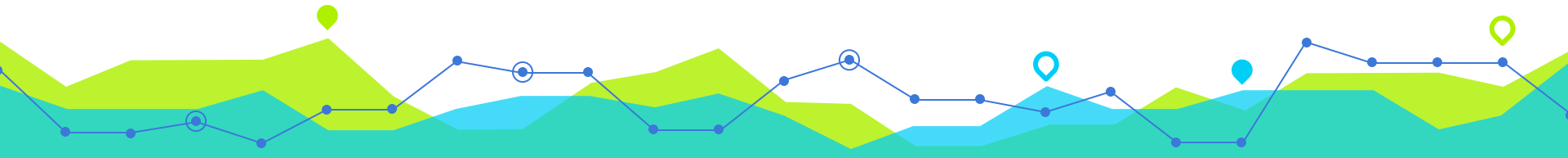
Related Work

- Comic characters analysis derives many techniques from the study of movie characters analysis, in which the dialogues and transitions are much harder to analyze.

- Both were developed from Social Network Analysis (SNA), and they exhibit properties similar to real-world social networks like Facebook friendships network.

- Traditional comic networks assign each character as a node, and an edge exists between two nodes if they have spoken or interacted in the same scene.

- Degree centrality or eigenvector centrality was then established. Centralities were used as benchmarks to cluster characters into communities as major, minor, or extra characters. [2] Past studies typically assign nodes above or below a certain threshold of centrality as major or minor characters.



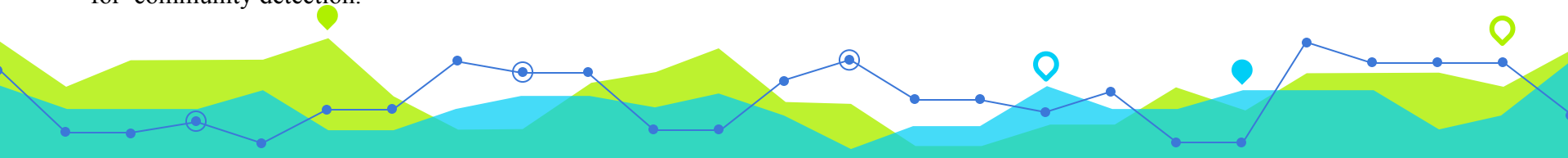
Limitation and Motivation

- Prior studies “manually” collect character interaction and scene transition data by organizing researchers and volunteers to watch the movies or read the comics. The final data was acquired by taking an average of all the responses.

- This process is error-prone because it relies on human judgement and requires extensive time and energy. [4] In addition, this is not feasible for large networks such as a series of comics. Further, they often have the oversimplified assumption that a network can be divided into two major communities.

- Motivation for our project: in real-world story writing, character and community relationships often develop over time. Current techniques of comic analysis often ignore the time component, and their approach of using simple centrality benchmark to cluster communities is not reliable for complex networks.

- Our methods will mainly focus on eigenvector-based methods for temporal network and using the Louvain algorithm for community detection.



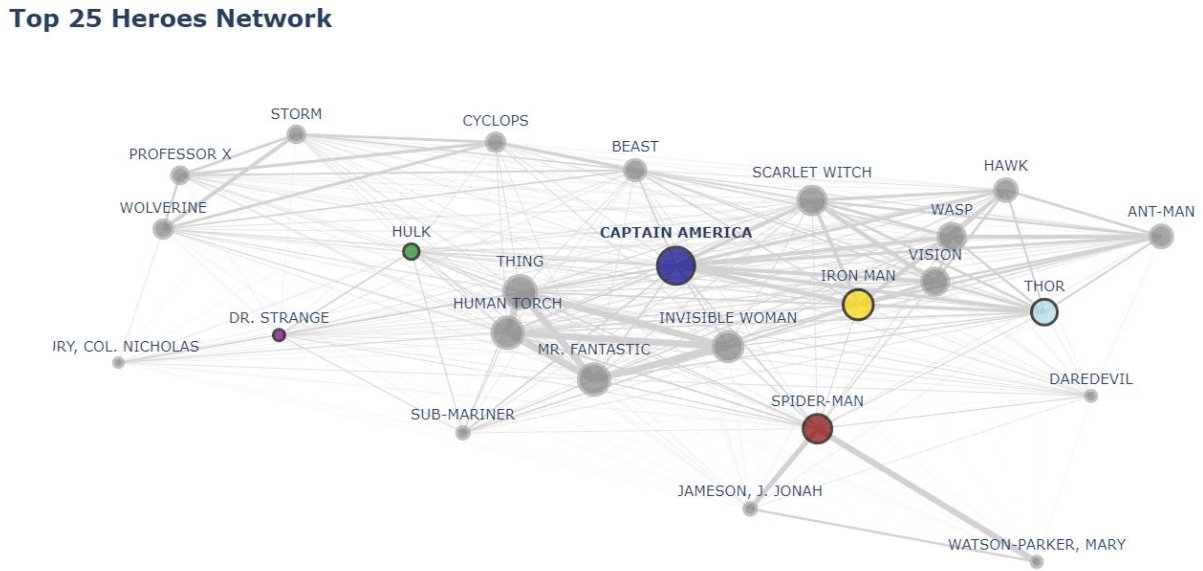
Dataset - General

- Marvel comics before 2002 [5]
- Nodes: heroes
- Edges: two heroes appear in same issue
    - Weighted - number of common issues

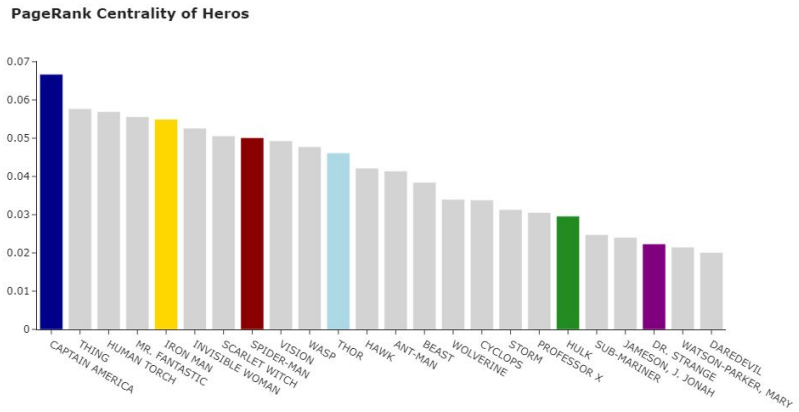
hero	comic
24-HOUR MAN/EMMANUEL	AA2 35
3-D MAN/CHARLES CHAN	AVF 4
3-D MAN/CHARLES CHAN	AVF 5
3-D MAN/CHARLES CHAN	COC 1
3-D MAN/CHARLES CHAN	H2 251
3-D MAN/CHARLES CHAN	H2 252
3-D MAN/CHARLES CHAN	M/PRM 35
3-D MAN/CHARLES CHAN	M/PRM 36
3-D MAN/CHARLES CHAN	M/PRM 37
3-D MAN/CHARLES CHAN	WI? 9
4-D MAN/MERCURIO	CA3 36

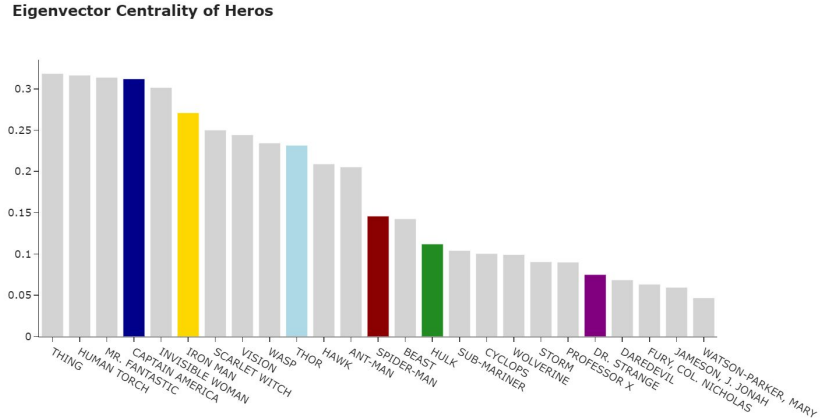
hero1	hero2
LITTLE, ABNER	PRINCESS ZANDA
LITTLE, ABNER	BLACK PANTHER/T'CHAL
BLACK PANTHER/T'CHAL	PRINCESS ZANDA
LITTLE, ABNER	PRINCESS ZANDA
LITTLE, ABNER	BLACK PANTHER/T'CHAL
BLACK PANTHER/T'CHAL	PRINCESS ZANDA
STEELE, SIMON/WOLFGA	FORTUNE, DOMINIC
STEELE, SIMON/WOLFGA	ERWIN, CLYTEMNESTRA
STEELE, SIMON/WOLFGA	IRON MAN/TONY STARK
STEELE, SIMON/WOLFGA	IRON MAN IV/JAMES R.
STEELE, SIMON/WOLFGA	RAVEN, SABBATH II/EL
RAVEN, SABBATH II/EL	FORTUNE, DOMINIC
RAVEN, SABBATH II/EL	ERWIN, CLYTEMNESTRA
RAVEN, SABBATH II/EL	IRON MAN/TONY STARK
RAVEN, SABBATH II/EL	IRON MAN IV/JAMES R.
IRON MAN IV/JAMES R.	FORTUNE, DOMINIC
IRON MAN IV/JAMES R.	ERWIN, CLYTEMNESTRA
IRON MAN IV/JAMES R.	IRON MAN/TONY STARK
IRON MAN/TONY STARK	FORTUNE, DOMINIC
IRON MAN/TONY STARK	ERWIN, CLYTEMNESTRA
ERWIN, CLYTEMNESTRA	FORTUNE, DOMINIC
PRINCESS ZANDA	BLACK PANTHER/T'CHAL
PRINCESS ZANDA	LITTLE, ABNER

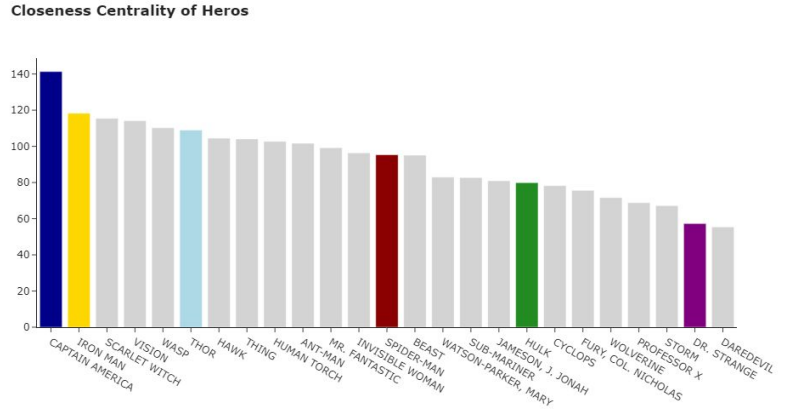
Visualization

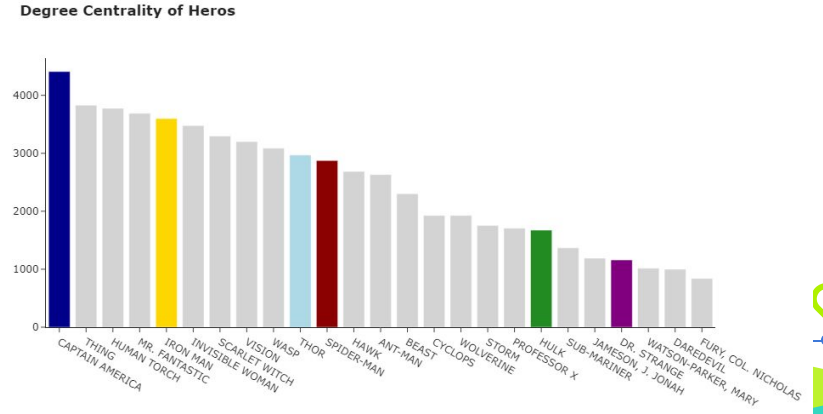


Centrality Visualizations



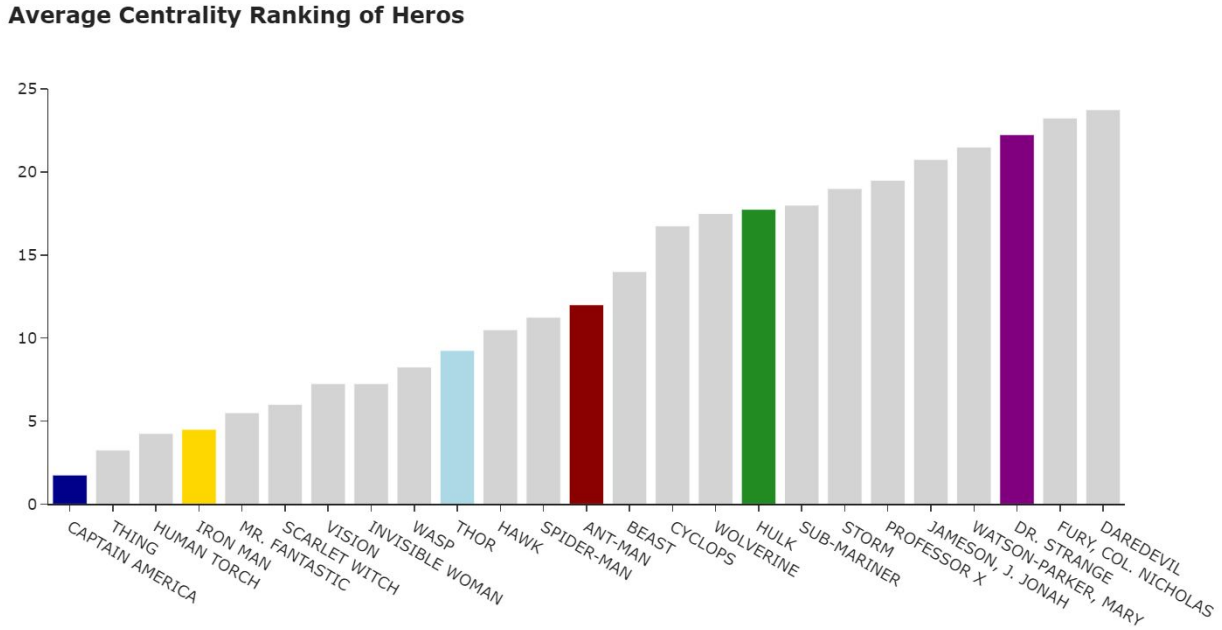






Average Centrality Ranking

- We compute the Average Centrality Ranking as the average of the rank of the 4 centralities



Dataset - Avengers

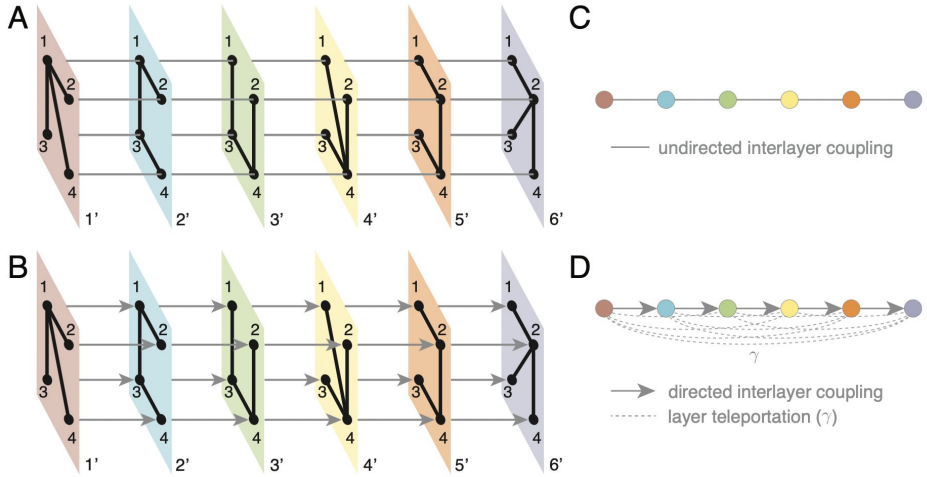
- Marvel comics - Avengers before 2002 [5]
  - Volumes 1, 2, 3
  - Annuals for years
- Eras [7, 8]
  - Silver age: 1961 - 1970
  - Bronze age: 1970 - 1984
  - Modern age: 1984 - 1997
  - Heroes relaunched: 1997 - 2004
- Nodes: heroes
- Edges: two heroes appear in same issue
  - Weighted - number of common issues

	hero	comic
84	ABSORBING MAN/CARL C	A 183
85	ABSORBING MAN/CARL C	A 184
86	ABSORBING MAN/CARL C	A 20/4
87	ABSORBING MAN/CARL C	A 270
88	ABSORBING MAN/CARL C	A 273
...	...	...
61178	PHARAOH RAMA-TUT	A 21/4
71356	SET	A 18/4
78065	STANKOWICZ, FABIAN	A 321/2
88719	VISION	A 20/3
88867	VISION	A 6/2

Temporal Networks

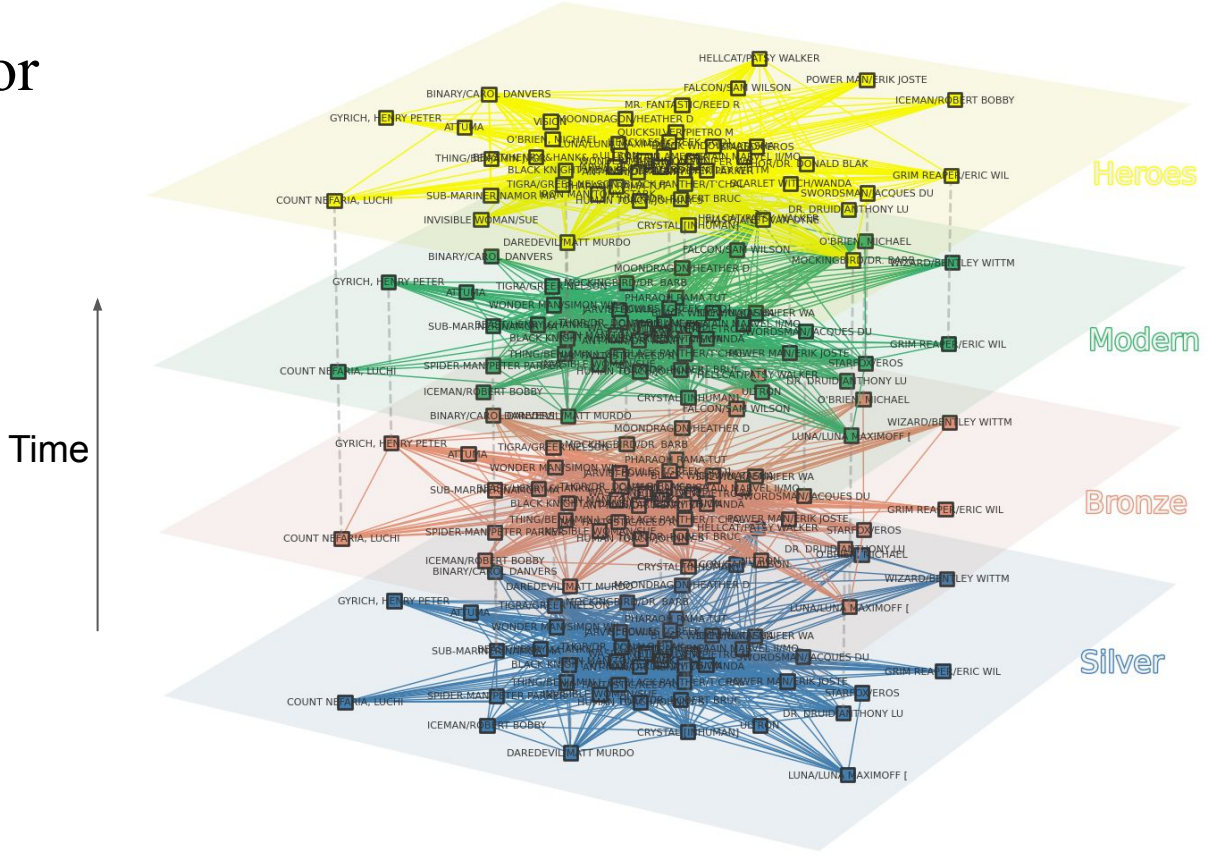
Temporal Network:

a sequence of adjacency matrices, each of which represents a time layer of a network at a different point or interval of time, coupled together to form a multilayer network.

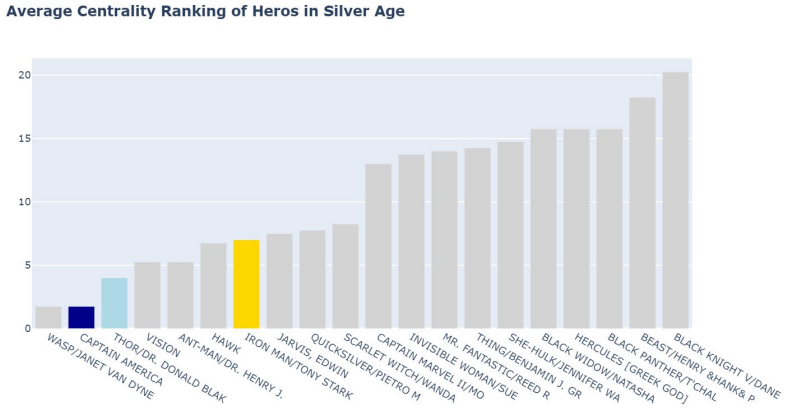


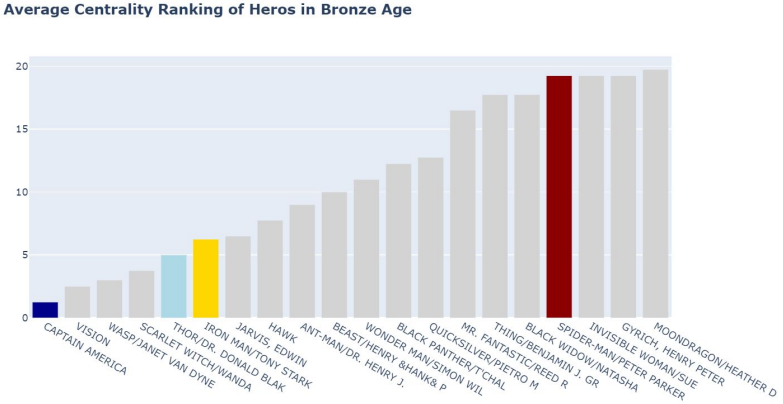
We represent the sequence of network layers, which constitute *time layers*, as a *continuous-time* network in which one bins the network's edges to form a sequence of time windows with interactions in each window

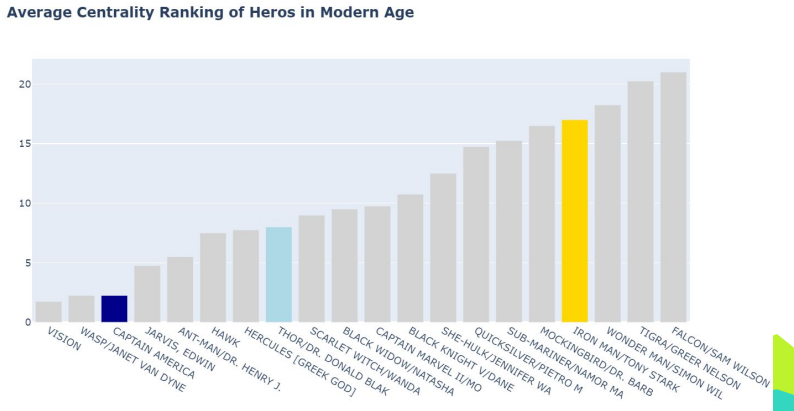
Initial Visualization for Temporal Network

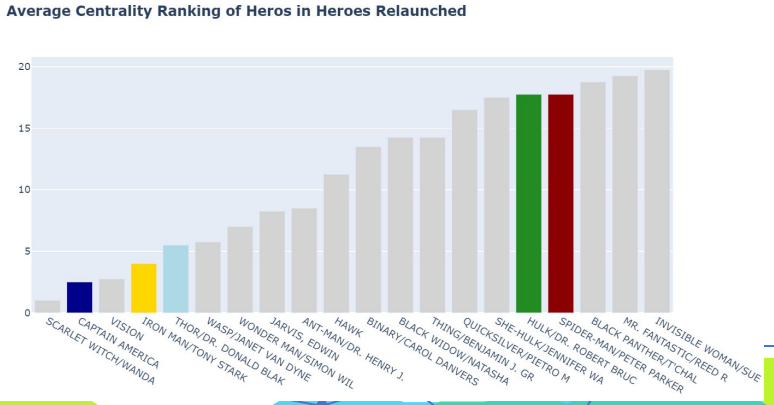


Centrality of each layer of the Temporal Network



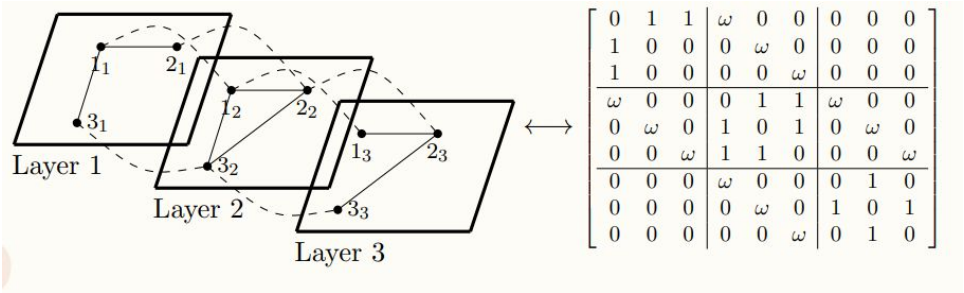






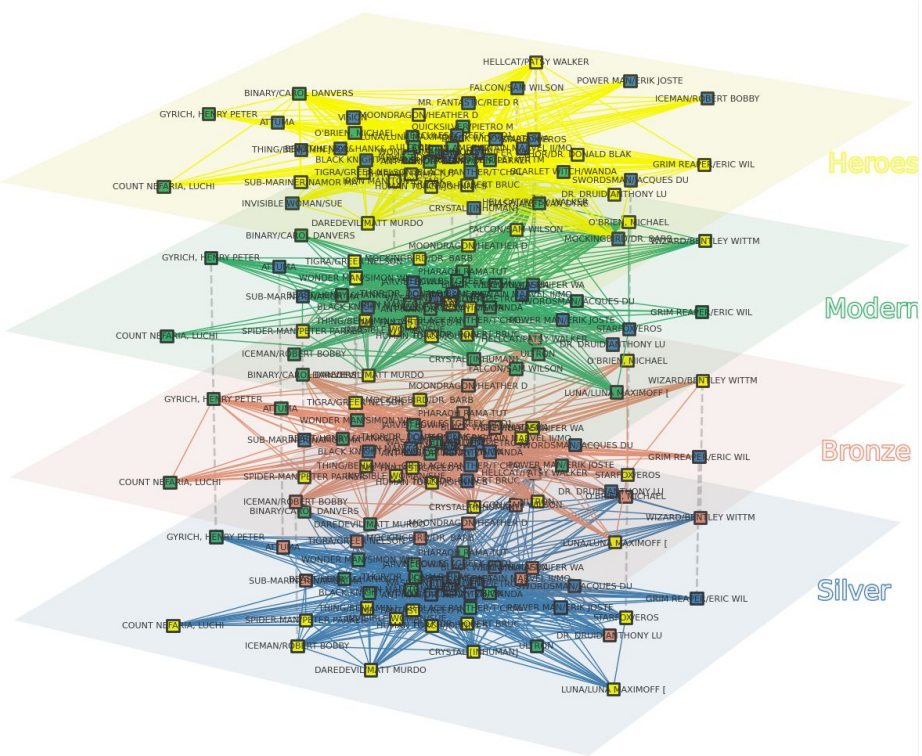
Community Detection in Temporal Multilayer Networks

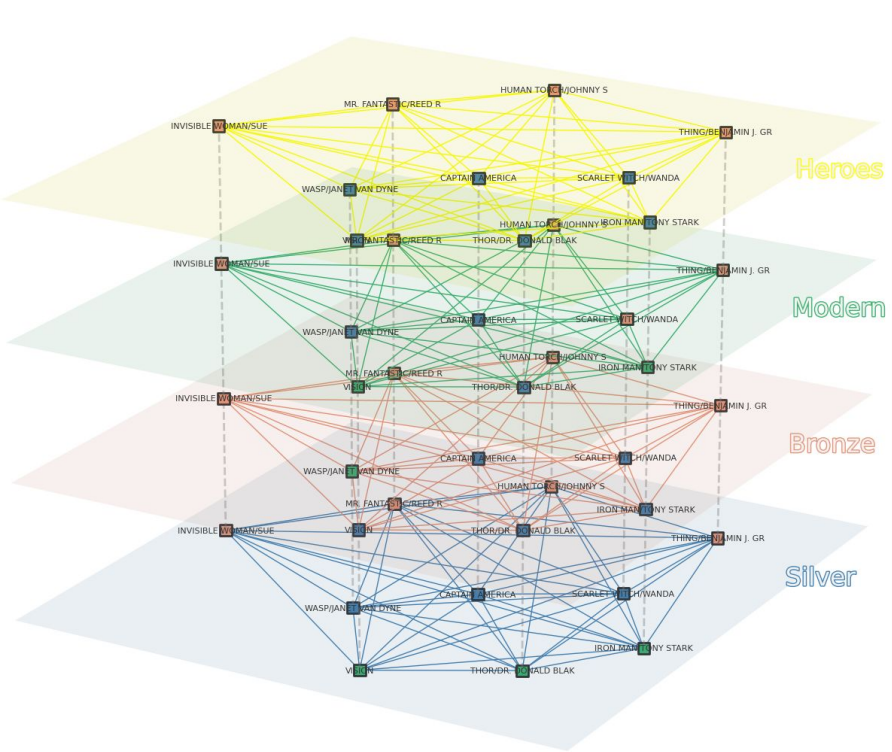
- Find communities algorithmically by optimizing “multislice modularity”
- GenLouvain Version 2.2 [6]
  - coupling = 0.5



$$Q_{\text{multislice}} = \frac{1}{2\mu}\sum_{ijsr}\left\{\left(A_{ijs} - \gamma_s\frac{k_{is}k_{js}}{2m_s}\right)\delta_{sr} + \delta_{ij}C_{jsr}\right\}\delta(g_{is}, g_{jr})$$

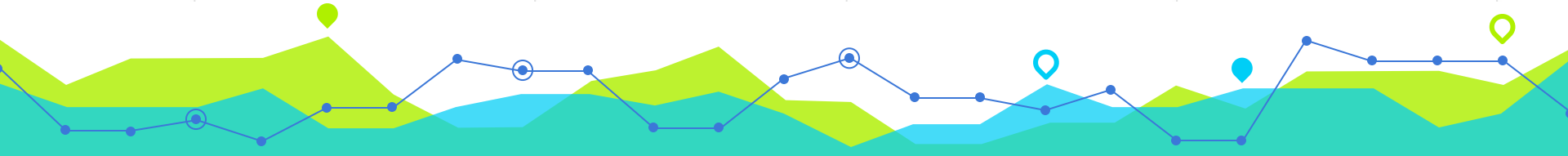
Communities in Different Layers





Interpretation of Community Related to Comics

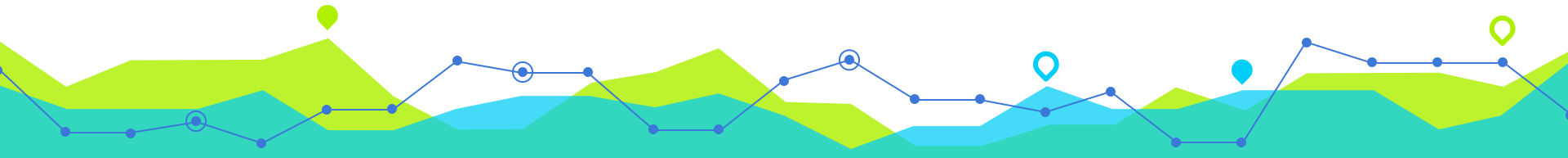
layer1	ANT-MAN/DR. HENRY J.	ATTUMA	BEAST/HENRY &HANK& P	COUNT NEFARIA, LUCHI
Silver	BLACK WIDOW/NATASHA	CAPTAIN MARVEL II/MO	BINARY/CAROL DANVERS	CRYSTAL [INHUMAN]
	CAPTAIN AMERICA	DR. DRUID/ANTHONY LU	BLACK KNIGHT V/DANE	DAREDEVIL/MATT MURDO
	GRIM REAPER/ERIC WIL	FALCON/SAM WILSON	BLACK PANTHER/T'CHAL	HULK/DR. ROBERT BRUC
	HAWK	HELLCAT/PATSY WALKER	GYRICH, HENRY PETER	HUMAN TORCH/JOHNNY S
	HERCULES [GREEK GOD]	MOCKINGBIRD/DR. BARB	IRON MAN/TONY STARK	ICEMAN/ROBERT BOBBY
	POWER MAN/ERIK JOSTE	MOONDRAGON/HEATHER D	JARVIS, EDWIN	INVISIBLE WOMAN/SUE
	QUICKSILVER/PIETRO M	O'BRIEN, MICHAEL	PHARAOH RAMA-TUT	LUNA/LUNA MAXIMOFF
	SCARLET WITCH/WANDA	SHE-HULK/JENNIFER WA	SPIDER-MAN/PETER PARKER	MR. FANTASTIC/REED R
	SWORDSMAN/JACQUES DU	SUB-MARINER/NAMOR MA	STARFOX/EROS	THING/BENJAMIN J. GR
	WASP/JANET VAN DYNE	TIGRA/GREER NELSON	THOR/DR. DONALD BLAK	
		WIZARD/BENTLEY WITTM	ULTRON	
			VISION	
			WONDER MAN/SIMON WIL	
	martial arts	different state	has special object	mutations



layer2	BLACK KNIGHT V/DANE	BLACK WIDOW/NATASHA	ANT-MAN/DR. HENRY J.	CAPTAIN MARVEL II/MO
Bronze	BLACK PANTHER/T'CHAL	HELLCAT/PATSY WALKER	ATTUMA	CRYSTAL [INHUMAN]
	CAPTAIN AMERICA	HERCULES [GREEK GOD]	BEAST/HENRY &HANK& P	HUMAN TORCH/JOHNNY S
	DR. DRUID/ANTHONY LU	ICEMAN/ROBERT BOBBY	BINARY/CAROL DANVERS	INVISIBLE WOMAN/SUE
	GRIM REAPER/ERIC WIL	MOONDRAGON/HEATHER D	DAREDEVIL/MATT MURDO	LUNA/LUNA MAXIMOFF [
	HAWK	PHARAOH RAMA-TUT	FALCON/SAM WILSON	MOCKINGBIRD/DR. BARB
	HULK/DR. ROBERT BRUC		GYRICH, HENRY PETER	MR. FANTASTIC/REED R
	IRON MAN/TONY STARK		JARVIS, EDWIN	O'BRIEN, MICHAEL
	MOCKINGBIRD/DR. BARB		SUB-MARINER/NAMOR MA	SHE-HULK/JENNIFER WA
	SCARLET WITCH/WANDA		POWER MAN/ERIK JOSTE	SPIDER-MAN/PETER PARKER
	STARFOX/EROS		WONDER MAN/SIMON WIL	WIZARD/BENTLEY WITTM
	QUICKSILVER/PIETRO M		ULTRON	TIGRA/GREER NELSON
	THOR/DR. DONALD BLAK		VISION	THING/BENJAMIN J. GR
	WASP/JANET VAN DYNE		SWORDSMAN/JACQUES DU	

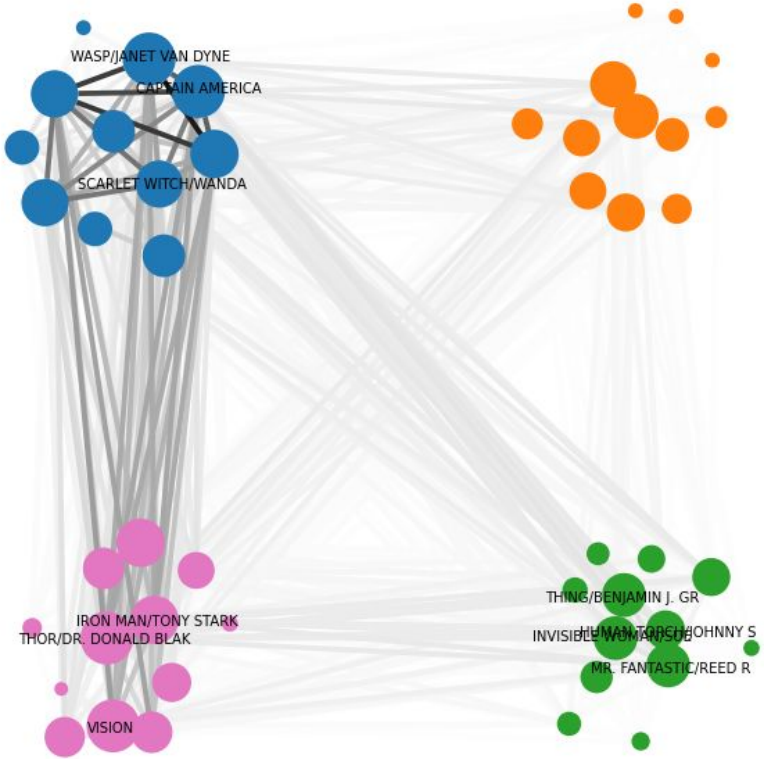
layer3	ATTUMA	ANT-MAN/DR. HENRY J.	DAREDEVIL/MATT MURDO
Modern	BLACK KNIGHT V/DANE	BEAST/HENRY &HANK& P	FALCON/SAM WILSON
	CAPTAIN AMERICA	BINARY/CAROL DANVERS	HAWK
	CAPTAIN MARVEL II/MO	BLACK PANTHER/T'CHAL	HELLCAT/PATSY WALKER
	DR. DRUID/ANTHONY LU	BLACK WIDOW/NATASHA	HULK/DR. ROBERT BRUC
	JARVIS, EDWIN	COUNT NEFARIA, LUCHI	HUMAN TORCH/JOHNNY S
	POWER MAN/ERIK JOSTE	CRYSTAL [INHUMAN]	INVISIBLE WOMAN/SUE
	SHE-HULK/JENNIFER WA	GRIM REAPER/ERIC WIL	MOCKINGBIRD/DR. BARB
	STARFOX/EROS	GYRICH, HENRY PETER	MOONDRAGON/HEATHER D
	SUB-MARINER/NAMOR MA	HERCULES [GREEK GOD]	MR. FANTASTIC/REED R
	THOR/DR. DONALD BLAK	ICEMAN/ROBERT BOBBY	O'BRIEN, MICHAEL
	WASP/JANET VAN DYNE	IRON MAN/TONY STARK	SCARLET WITCH/WANDA
		LUNA/LUNA MAXIMOFF [	SPIDER-MAN/PETER PARKER
		PHARAOH RAMA-TUT	THING/BENJAMIN J. GR
		QUICKSILVER/PIETRO M	TIGRA/GREER NELSON
		SWORDSMAN/JACQUES DU	WIZARD/BENTLEY WITTM
		ULTRON	WONDER MAN/SIMON WIL
		VISION	

layer4	ATTUMA	ANT-MAN/DR. HENRY J.	DAREDEVIL/MATT MURDO
Heroes	BEAST/HENRY &HANK& P	BINARY/CAROL DANVERS	DR. DRUID/ANTHONY LU
	BLACK KNIGHT V/DANE	CAPTAIN AMERICA	GRIM REAPER/ERIC WIL
	BLACK PANTHER/T'CHAL	COUNT NEFARIA, LUCHI	HELLCAT/PATSY WALKER
	BLACK WIDOW/NATASHA	GYRICH, HENRY PETER	HULK/DR. ROBERT BRUC
	CAPTAIN MARVEL II/MO	IRON MAN/TONY STARK	HUMAN TORCH/JOHNNY S
	CRYSTAL [INHUMAN]	JARVIS, EDWIN	INVISIBLE WOMAN/SUE
	FALCON/SAM WILSON	PHARAOH RAMA-TUT	MOCKINGBIRD/DR. BARB
	HAWK	POWER MAN/ERIK JOSTE	MR. FANTASTIC/REED R
	HERCULES [GREEK GOD	SCARLET WITCH/WANDA	SPIDER-MAN/PETER PARKER
	ICEMAN/ROBERT BOBBY	THOR/DR. DONALD BLAK	SWORDSMAN/JACQUES DU
	LUNA/LUNA MAXIMOFF [	ULTRON	THING/BENJAMIN J. GR
	MOONDRAGON/HEATHER D	VISION	
	O'BRIEN, MICHAEL	WASP/JANET VAN DYNE	
	QUICKSILVER/PIETRO M	WONDER MAN/SIMON WIL	
	SHE-HULK/JENNIFER W		
	STARFOX/EROS		
	SUB-MARINER/NAMOR MA		
	TIGRA/GREER NELSON		
	WIZARD/BENTLEY WITTM		

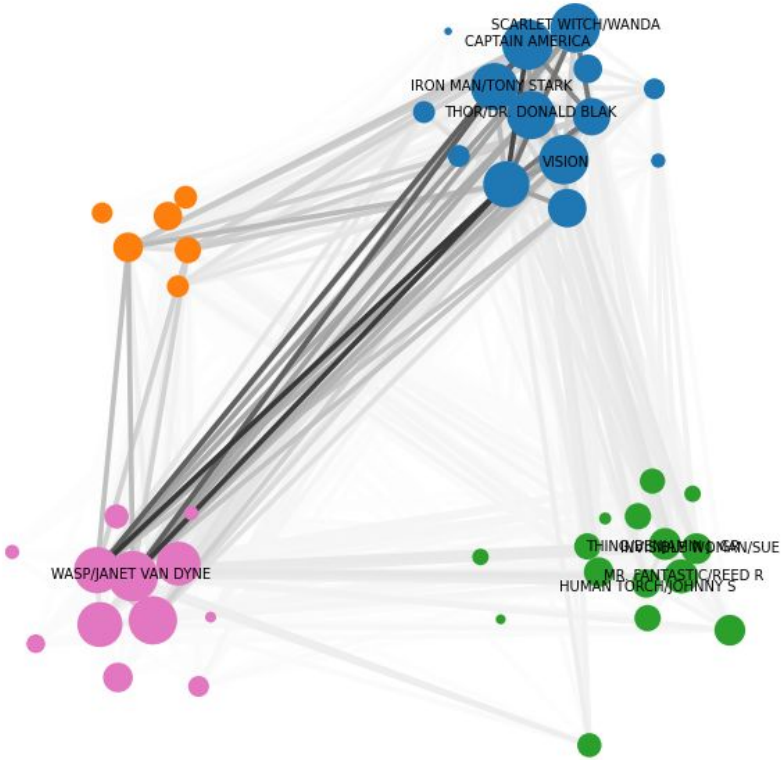


Node size is proportional to node centrality value
Node color corresponds to community partition

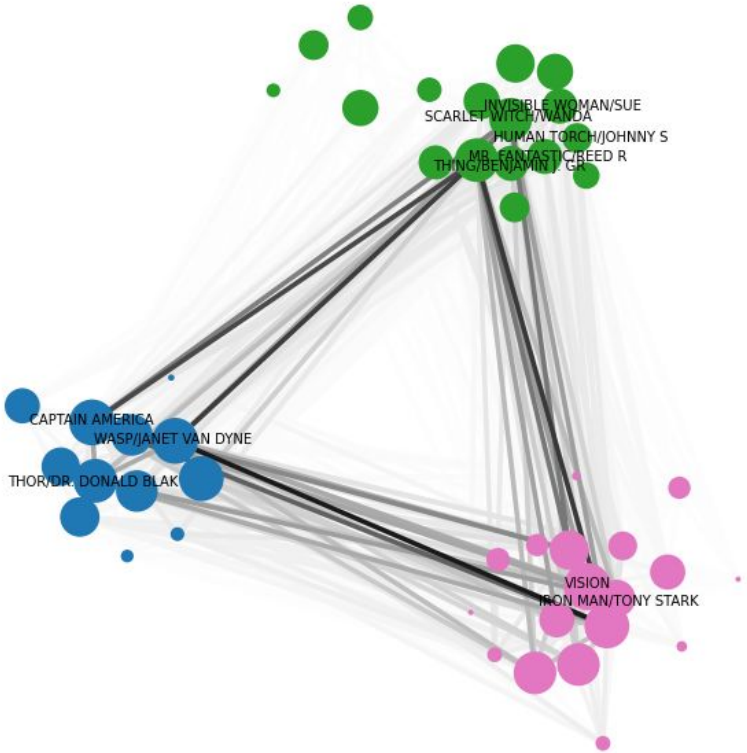
Silver



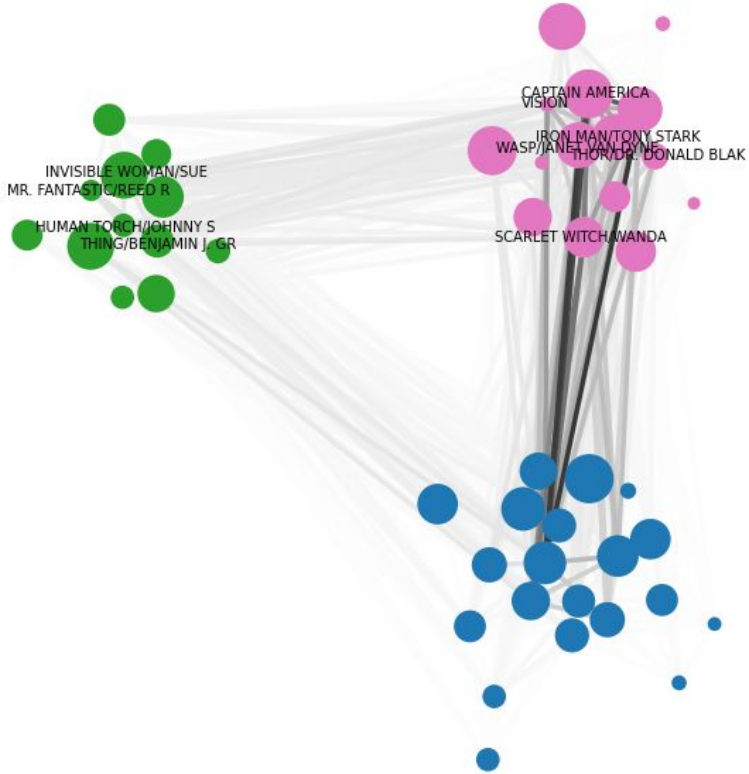
Bronze



Modern



Heroes Relaunched



Supracentrality Matrix Construction

Notation:

- Centrality Matrix C(A): defined by some function of adjacency matrix A.
- Parameter ω: scales the weights of the interlayer coupling to control the strength of the connection between time layers.
- Interlayer-adjacency $T \times T$ matrix $\tilde{A}$: where the entry encodes the coupling from time layer t to time layer t'.

Supracentrality matrix $NT \times NT$ C(ω):

$$\mathbb{C}(\omega) = \hat{\mathbb{C}} + \omega\hat{\mathbb{A}} = \begin{bmatrix} \mathbf{C}^{(1)} & \mathbf{0} & \mathbf{0} & \dots \\ \mathbf{0} & \mathbf{C}^{(2)} & \mathbf{0} & \dots \\ \mathbf{0} & \mathbf{0} & \mathbf{C}^{(3)} & \ddots \\ \vdots & \vdots & \ddots & \ddots \end{bmatrix} + \omega \begin{bmatrix} \tilde{A}_{11}\mathbf{I} & \tilde{A}_{12}\mathbf{I} & \tilde{A}_{13}\mathbf{I} & \dots \\ \tilde{A}_{21}\mathbf{I} & \tilde{A}_{22}\mathbf{I} & \tilde{A}_{23}\mathbf{I} & \dots \\ \tilde{A}_{31}\mathbf{I} & \tilde{A}_{32}\mathbf{I} & \tilde{A}_{33}\mathbf{I} & \dots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix},$$

For a temporal network with N nodes and T time layers.

We require the set of nodes to be the same for all time layers.

It encodes two distinct types of connections:

the layer-specific centrality entries $\{C_{(t)}\}$ in the diagonal $_{ij}$ blocks relate centralities between nodes in layer t; and entries in the off-diagonal blocks encode coupling between layers. [9]

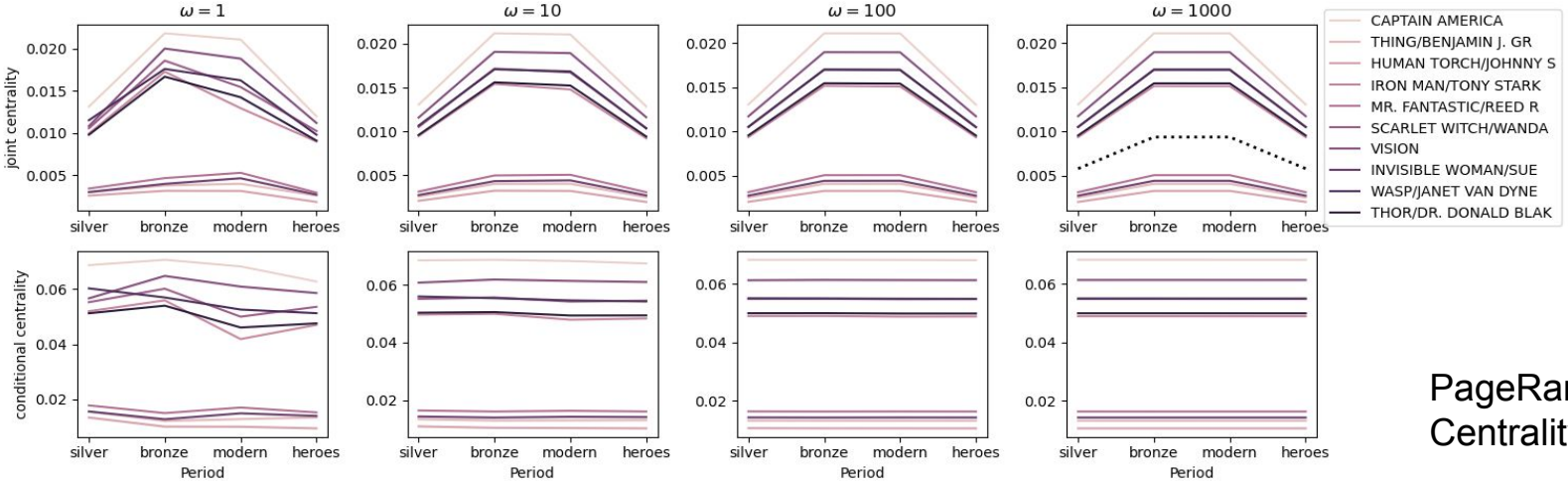
Joint vs Conditional Centrality

After constructing supracentrality matrix, we compute and interpret the dominant *eigenvector* of C(ω)

Joint centrality: measure the centrality of each node-layer pair (*i*,*t*), the centrality of node *i* in time layer *t*, it reflects the importances of both node *i* and layer *t*

Conditional centralities: measure a node's centrality at time *t* relative only to the other nodes' centralities in that particular time layer *t*

Results



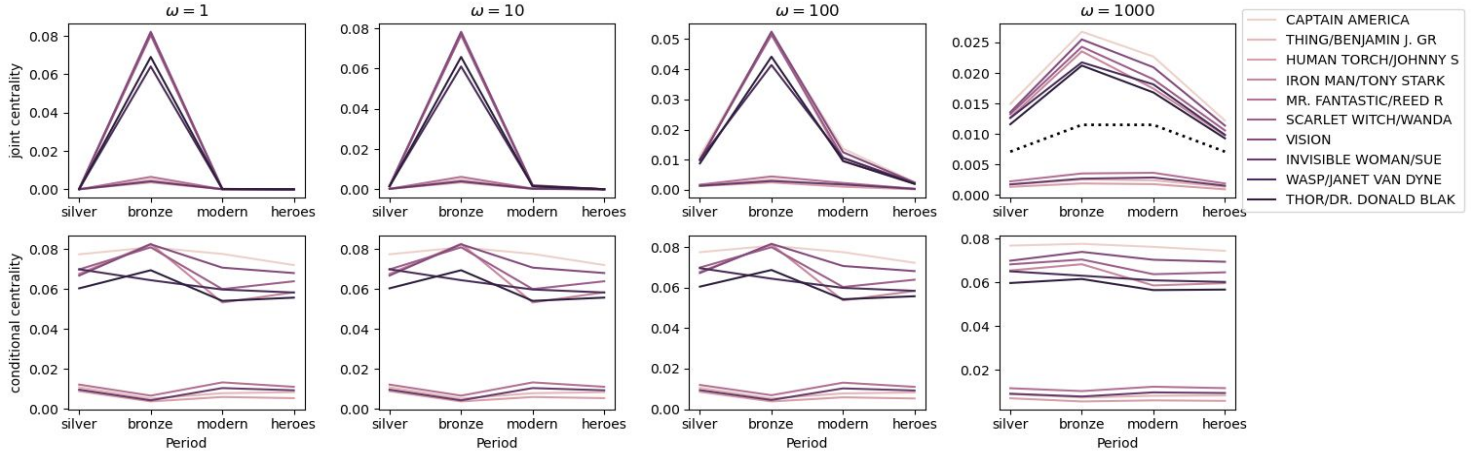
PageRank Centrality

Larger values of ω yield smoother conditional-centrality trajectories.

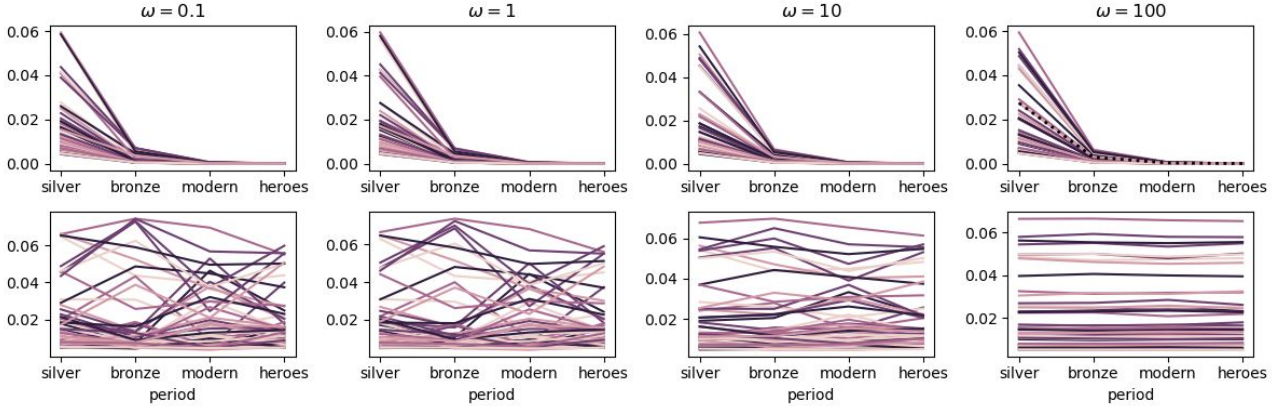
More temporal changes observed with small ω.

Bronze age comprises more issues of comics, and experiences more interactions between heros.

Captain America still remains the most important hero.



Eigenvector centrality

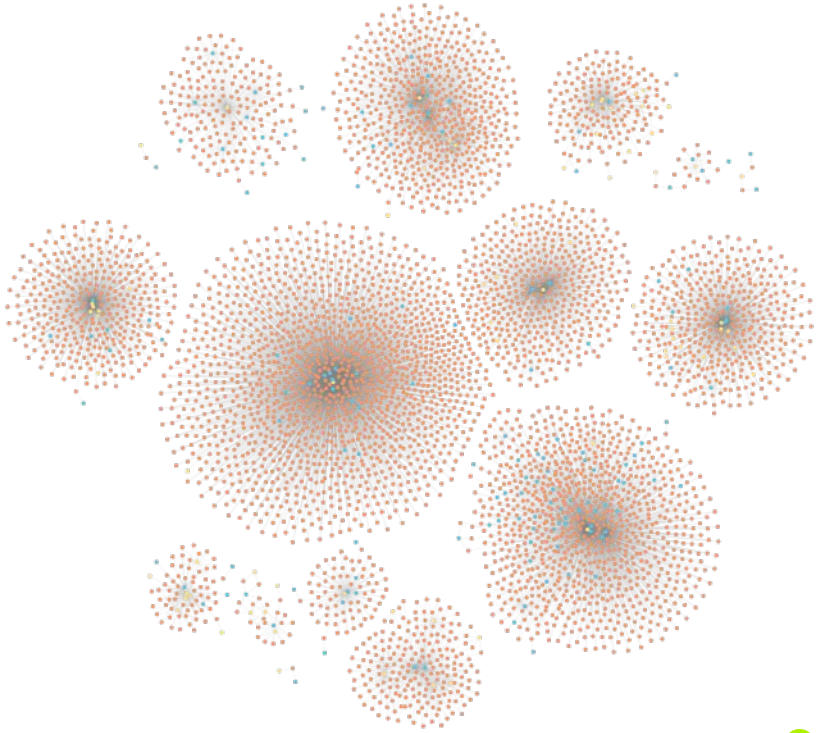


Directed interlayer coupling

higher joint centralities of earlier time layers in comparison to undirected coupling.

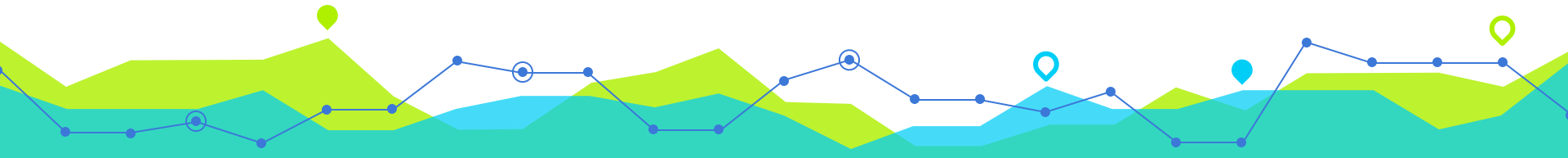
Limitations of Modularity maximization in temporal multilayer networks

1. Lack of interpretability
2. Coupling parameter
    a. The choice of coupling parameter
    b. Uniform coupling may cause misleading values of persistence



Limitation and conclusion

- We note a significant change in the modern era: comics have entered a “dark age” in which a shift in fan tastes steered productions to focus on dark heroes or anti-heroes such as Scarlet Witch or Wolverine. This stylistic shift also added vigilante elements to traditional characters.
- Although the modularity function is deterministic, we can’t guarantee a consistent solution due to how the algorithm searches the space of solutions when running the Louvain algorithm.
- Contrary to our anticipation, characters we believed to be minor roles in fact have higher centrality than some major characters.
- In addition, due to the limitation of time and resources, we weren’t able to label weights according to character relationships in a careful manner. Ideally, characters who are for example, siblings should be weighted more than characters who are just friends. However, this involves carefully reading the comic and observing character relationships, which were carried out by many sophisticated studies.



Reference and Acknowledgement

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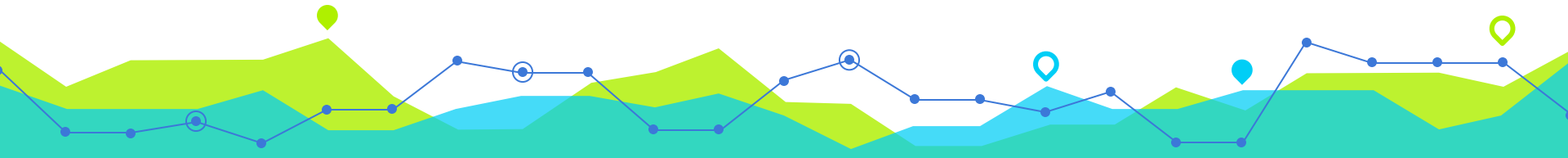

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