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Network Analysis Class

Final Project: Marvel Universe's X-Men Leader Successor

– INTRODUCTION –

Marvel Studios was named number 11 as one of the world's most innovative companies of 2018 by Fast Company ("The World's 50 Most Innovative," 2018). This is quite an honor putting it in league with companies such Apple, Amazon, Netflix, and Spotify. In fact, Marvel Studios recently broke box office records with the release of its most recent film *Avengers: Infinity War* on April 27, 2018 which had the highest opening weekend in United States with box office sales of 250 million dollars, beating the previous title holder, *Star Wars: The Force Awakens,* with the previous record of 248 million dollars (Petrakovitz, 2018). The company's real innovation lies in how they link their movies through their characters creating an underlying universe. (LaPorte, 2018). These linkages and connections from movie to movie via characters is much like a network structure. The relevancy of Marvel Studios as an innovation leader combined with its movie linkages' resemblance to a network structure are the main reasons we chose to study the Marvel Universe for the semester final project.

– DATA SET, BACKGROUND RESEARCH, AND RESEARCH QUESTION –

The Marvel Universe network data set that we found was a version of a data set put together by Ricardo Alberich, Joe Miro-Julia, and Francesc Rosselló for their article titled, "Marvel Universe Looks Almost Like a Real Social Network" (2002). The authors found that while not all the network measures matched a real-life collaboration network the Marvel Universe resembled other collaboration networks and demonstrated a scale-free distribution with small world properties (Alberich, Miro-Julia & Rosselló, 2002). In selecting a research question on which to focus, we first conducted background research on what had already been studied regarding this data set. Various network visualizations, studies that ran general

community detection algorithms to find teams, studies that found the most popular superheroes and local bridges in the overall network were found. So, the question became what novel thing could we do with this data set? We chose to focus on one of the superhero teams in the Marvel Universe, the X-Men. Using network analysis, we wanted to determine who would be the next leader of the X-Men if their current leader, Professor X, died. Since Alberich, Miro-Julia, and Rosselló determined that this network did resemble a real social network it would serve as a good test of whether leadership succession could be determined by a network analysis. In many situations with real network data, fuller contexts and node attributes are not always known. For example, if we extracted a Twitter network data set how much information would we know about each node? If data was extracted based off a user account, one might have background information on the selected user, but probably not on every follower or person the user is following. The Marvel Universe data set is unique in that each character, or node, has a rich history of information easily accessible. While this is not information in the data set itself, many attributes could easily be researched online given the popularity of the Marvel superhero characters. Therefore, this data set has a ground truth that results from analysis can be compared to for validity.

– INITIAL DATA EXPLORATION AND SUMMARY STATISTICS –

Data Set

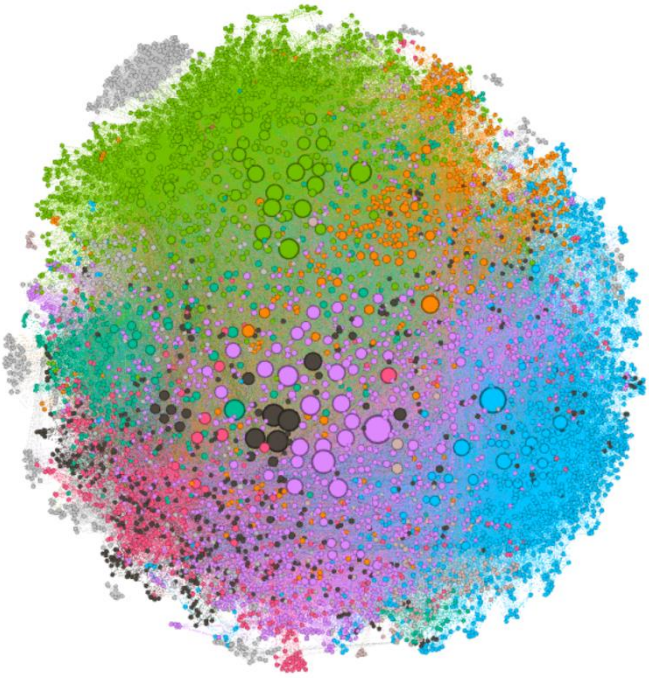
As mentioned above, the data set used for this study was created by Ricardo Alberich, Joe Miro-Julia, and Francesc Rosselló (Kaggle, 2017). They created this network data set using information from The Marvel Chronology Project which is "an effort to catalog every actual appearance by every significant character in the Marvel Universe…" as stated on their website (The Marvel Chronology Project, n.d., para 1). This data set was created using co-appearances in comic books in the Marvel Universe dated after 1961. The co-appearances were used to construct a bipartite graph connecting superheroes to issues of comic books in which they appeared. This bipartite graph then could be collapsed into a single type node graph of connected superheroes based on co-appearances. We were able to find a pre-processed data file that had

already collapsed the data into a single node superhero network on Kaggle.com that originally cited the pre-processed data file to the website http://syntagmatic.github.io/exposedata/marvel/ (Kaggle, 2017).

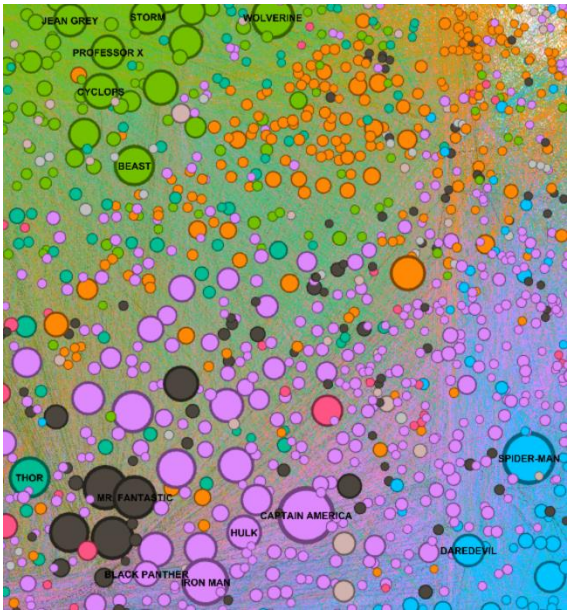
Initial Visualization

Before conducting any analysis, we first explored the data to get a sense of the general structure of the network. The original data set had 6,426 nodes and 574,467 undirected, multiple edges. The graph was simplified to remove multiple edges by weighting each edge with a value of one and then summing all multiple edges so that there would only be one edge with a varying weight depending on the number of co-appearances. After simplifying the graph there were still 6,426 nodes but only 167,207 edges. These edges had weights that ranged from 1 to 1,894. The next thing we wanted to do was get a quick visualization of the data set. Using R, the visualization produced did not convey a sense of the network due to its large size. Therefore, we exported the simplified graph's node and edge lists into Gephi to obtain a visualization. Below, in figures 1 and 2 are the network graphs we created, a total and detail view respectively. The nodes are sized by degree centrality. The graph is colored by communities detected in Gephi using the "modularity" function. The detail view labels several of the head super-heroes.

1. Marvel Universe - Network Graph
Produced in Gephi



2. Marvel Universe - Network Graph (Detail)
Produced in Gephi



From these visualizations we get a real sense of the enormity of the network.

Network Summary Statistics

Next, we wanted to check various summary statistics of the network. We first calculated the density and average degree of the network. The density was 0.0081, meaning that only 0.81% of all possible edges between nodes actually had edges. This shows that even though the network is large, the density is not very high. Additionally, we wanted to know the average number of super-heroes to which characters were connected. The mean degree was 52.04 and the median degree was 20. The degree of super-hero connections ranged between 1 and 1,906. The global clustering coefficient was 0.1945 which means that approximately 19.45% of connecting triples closed to form triangles. Next, a census of connected components was performed. The results are listed in the table numbered 3 below.

3. Census of Connected Components

# of Nodes	2	7	9	6408
# of Component this Size	1	1	1	1

We can see that most of the nodes (99.7%) are in the giant component. We extracted the giant component and calculated the diameter and average path length which were 15 and 2.64 respectively. These are relatively small distances for such a large network and demonstrates the interconnectedness of the characters in the Marvel Universe. Below, in the table numbered 4, is a chart that summarizes the network statistics discussed.

4. Summary of Network Statistics

Metric	Density	Mean Deg	Median Deg	Min/Max Deg	Clust Coeff	Diameter Giant Comp	Ave Path Length Giant Comp
Value	0.0081	52.04	20	1 / 1,906	0.1945	15	2.64

– "WISDOM OF THE CROWD" AND ANALYSIS –

Straw Pole

Before we got into the network analysis of the research question, we wanted to conduct a straw poll that surveyed fans to see what they thought. It would be a sort of "wisdom of the crowd" hypothesis. We put together a two question survey using the website Survey Monkey. One question posed our research

question, “If Professor X were to die or become otherwise unable to lead the X-Men which Marvel Universe character would be the best successor?” The answer selections were multiple choice with four of the most popular X-Men (two men and two women) listed by name, as well as a write in option under the selection “Other.” We determined the four popular X-Men to be included as answer choices from a discussion of two fans (myself and a friend) which we decided were Jean Grey, Wolverine, Cyclops, and Storm. The “Other” write in option allowed participants to respond with any character they wished, which would make-up for popular characters not accounted for in the named multiple choice answers. The second question sought to check the Marvel Universe knowledge of the participant by asking, “Do you primarily read comics or watch movies related to the Marvel Universe?” The brevity of the survey was purposeful to encourage maximum participation by making it very low effort to respond by not including any participant demographic or follow up questions. We found this method adequate since it was not meant as a scientific survey but rather was a straw poll. The survey was conducted from the 18th to 22nd of April 2018. The link to the survey (https://www.surveymonkey.com/r/7TJZV7K) was posted on five different subreddits on Reddit. The specific subreddits were /r/comicbooks, /r/marvelstudios, /r/marvel, /r/xmen, and /r/samplesize. The link to the survey was also e-mailed to several friends. Due to the specific nature of the subreddits the survey generated a lot of interest in the first few days of posting.

The results were collected on April 22nd, 2018 and the SurveyMonkey summary graphs, numbered 5, are pictured on the next page. There were 243 respondents of which 97.12% were either knowledgeable of the Marvel Universe through the comic books, movies, or both. The character that had the most votes was Cyclops with 40.33% or 98 votes. The runner up was Storm with 25.51% or 62 votes. Next came Jean Grey and then Wolverine with 16.05% (39 votes) and 9.47% (23 votes), respectively. There were 21 “Other” responses ranging from unknown characters such as Gold Balls to other popular X-Men such as Jubilee. The character Beast obtained the highest number of write ins with 6 votes which was 2.47% of the votes. Overall, we would say that the crowd was “wise” in that the majority had knowledge of the Marvel Universe and that the “wisdom of the crowd” selection for the next leader of the X-Men would be Cyclops.

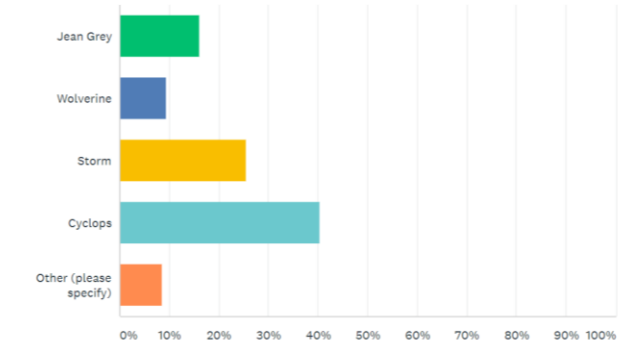
5. Marvel's X-Men Leader Successor Survey Results

Conducted on SurveyMonkey

Q1

If Professor X were to die or become otherwise unable to lead the X-Men which Marvel Universe character would be the best successor?

Answered: 243 Skipped: 0

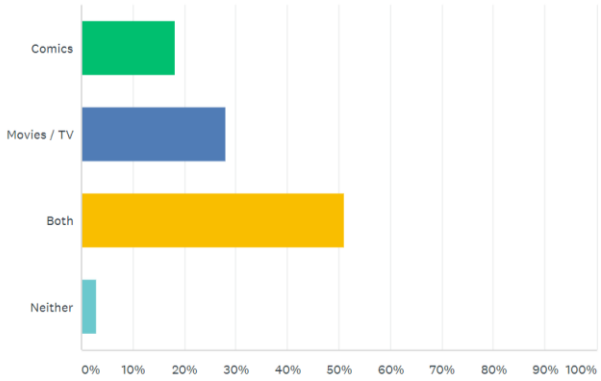


ANSWER CHOICES		RESPONSES	
Jean Grey		16.05%	39
Wolverine		9.47%	23
Storm		25.51%	62
Cyclops		40.33%	98
Other (please specify)	Responses	8.64%	21
TOTAL			243

Q2

Do you primarily read comics or watch movies related to the Marvel Universe?

Answered: 243 Skipped: 0



ANSWER CHOICES	RESPONSES	
Comics	18.11%	44
Movies / TV	27.98%	68
Both	51.03%	124
Neither	2.88%	7
TOTAL		243

Data Reduction

The next step that we took was to reduce the data set. In reviewing the character nodes in the data set there were many minor and obscure characters. For example, characters such Saja and Desadia have only one degree. In terms of the Marvel Universe data set this means that these characters only had co-appearances with one other character. If you consider that this data was put together from co-appearances from 1961 to approximately 2002, this would make these two very minor characters, being that in about 40 years these two characters only shared a single other co-appearance. A similar thought process can be applied to edge weights. What does it mean to have a low edge weight such as one? This means that the two characters connected with this edge only shared a single coappearance in 40 years. Again, this would imply that these characters' connection is not very strong and rather minor. We experimented with different data reduction combinations deleting edges with weights 1 to 10 and nodes with degrees from 1 to 10. We decided that deleting nodes with a degree less than 10 would be pruning minor characters. The first quartile for the degree value in the data set is 10, so this corresponds to deleting the bottom 25% of the nodes with the least connections. Further, we also decided to delete edges with a weight less than or

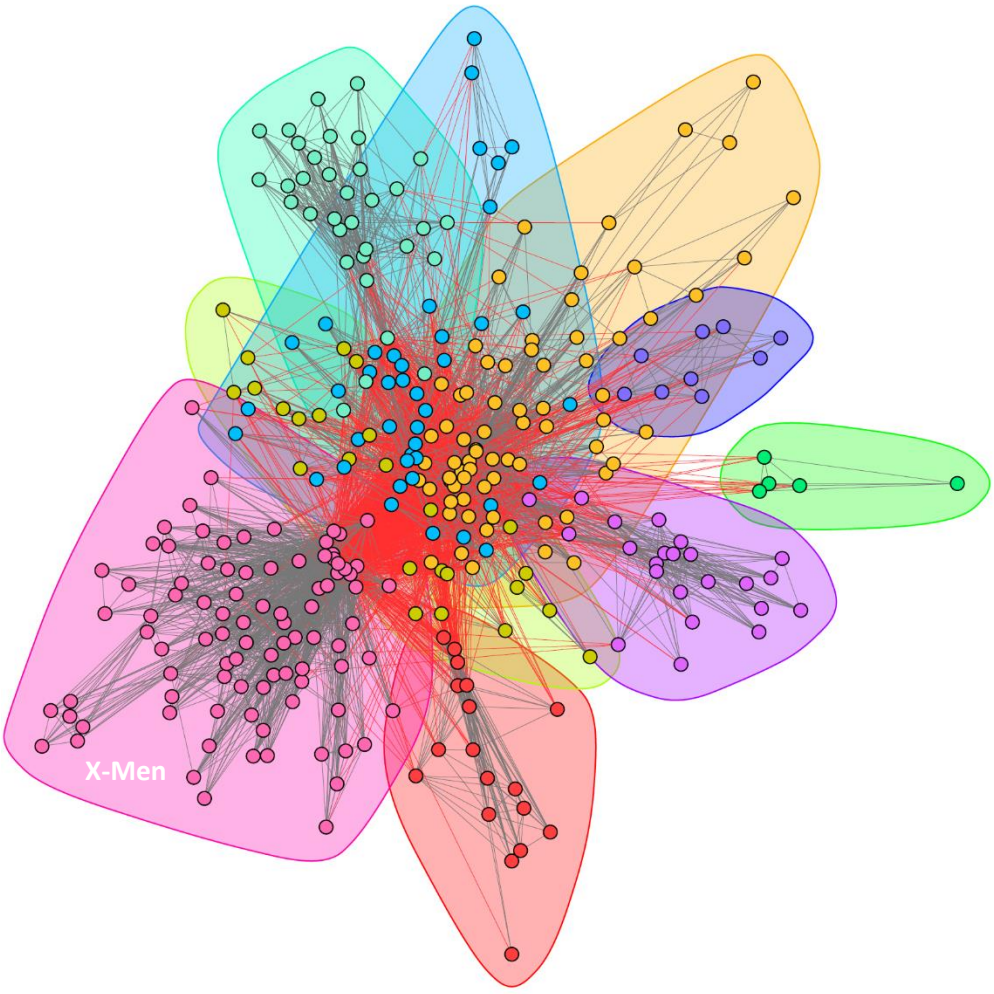
equal to 10 because this would correspond to connections who have co-appeared only 10 times in 40 years of comic books and thus have too minor or weak connections. The minimum edge weight is 1 and the maximum is 1,894. The 3rd quartile value for edge weight was 3. Therefore, by deleting edges with a weight of 10 and less we kept less than 25% or only the top, strongest, and most meaningful connections. These data reductions greatly reduced the graph leaving 319 nodes which was 4.96% of the original nodes in the simplified graph. The final edge count for the reduced graph was 5,095 which was 3.05% of the original edges based on the simplified graph. The reduced graph then served as one of top most characters, only keeping major players and connections.

Community Detection

Our final graph represents the major players of the entire Marvel Universe. Our research question involves the team X-Men in the Marvel Universe. Therefore, we needed a way to identify the X-Men characters in order to conduct further analysis. Applying community detection algorithms on the data set solved this problem. We applied several community detection algorithms including Louvain, spinglass, leading eigen, fast-greedy, walktrap, and label propagation. The community detection algorithms were producing similar results with the number of clusters ranging from 8 to 13 and the number of X-Men identified ranging from 81 to 95. Label propagation and leading eigen were identifying similar X-Men as the other community detection algorithms but were not distributing the other nodes well. Rather, they were clumping most of the rest into one big group. Therefore, we did not use either of these two algorithms as our final method. In order to decide between the other four, we applied the community significance function that was included in our lab 3 sample code by Professor Tafti in the IDS 564: Social Networks class (2018). Spinglass and walktrap were producing the lowest proportion of significant communities, 7 out of 13 (54%) and 6 out of 12 (50%) respectively. This left two, Louvain and fast-greedy, both of which were producing similarly significant clusters, 6 out of 9 (67%) and 6 out of 8 (75%) respectively. Both were also identifying the same 92 X-Men. We decided to use the Louvain community detection algorithm because even though it had a slightly smaller proportion of significant communities compared to fast-greedy, it

produced the median number of communities, nine, among the six algorithms tested. We then examined the character names in each cluster and identified the X-Men team as well as the other groups including the Avengers, Alpha Flight, Thor, Spiderman, Fantastic Four, Defenders, Squadron Supreme, and Thunderbolts. The Marvel Universe Wiki was used to help identify teams of lesser known characters (n.d.). Finally, we plotted the reduced network graph with the Louvain community detection algorithm pictured below, the graph numbered 6. The X-Men team is labeled in the graph and colored pink.

6. Marvel Universe Reduced Network Graph
Community Detection using the Louvain Algorithm



<u>What Makes a Good Leader?</u>

Since, our research question involved who would be the next leader of the X-Men, we had to answer the question: What makes a good leader? We decided the three essential aspects of being a good leader were as follows. First, a team member needs to be a core member of the team if they were to be the

next team leader. One cannot be a minor member of the team and be selected as the next leader. Secondly, a good team leader would be able to connect with other major teams in the Marvel Universe such as the Avengers or Fantastic Four. Often times, these major teams join forces to defeat an enemy and being connected to these other major teams would be very important. The third essential quality is that a team leader needs to have positive relationships with other members of the team. A team leader should have a good rapport with the other members so that these members would respect and listen to the leader's direction.

Network Approach and Metrics

Once we had an understanding of the qualities that make a good team leader we needed to translate this to a network approach. What network metrics could we use to evaluate these qualities? The first quality of being a core member of the team could be evaluated using a centrality measure on just the characters in the X-Men cluster. We chose to use eigen centrality as it is a more complicated measure of centrality related to prestige and power (Jackson, 2008). It not only measures a node's influence by its own connections but also by how well-connected and important its neighbors are (Jackson, 2008).

The second quality of being able to connect to other teams could be measured by the betweenness centrality of the X-Men characters in relation to the entire reduced Marvel Universe data set. The definition of betweenness is the "number of shortest paths that an edge or node lies upon between all other pairs of nodes in the network" (Tafti, 2018, slide 27). So betweenness centrality is a measure of how well a node serves as a bridge to other nodes in the network. We used the method for calculating betweenness centrality outlined in Professor Tafti's IDS 564: Social Networks class lab 2, where betweenness centrality was calculated using the inverse log of edge weight for shortest path calculations (2018).

The third quality of having positive relationships with other team members can be studied through a structural balance analysis of the network. While this data set did not have information on the positive and negative relationships of edges between the heroes, this information can be researched using fan sites

such as the Marvel Universe Wiki. Once researched we can assign each link with a positive or negative sign depending on whether there is mutual antagonism between any sets of characters.

Eigen and Betweenness Centrality Analysis

To begin the eigen and betweenness centrality analysis we first selected the top 10 X-Men evaluated by highest degree within the X-Men cluster. We decided to narrow the pool of potential next leaders for analysis to these top 10 X-Men. Next, the eigen and betweenness centralities were calculated as described in the previous section for these top 10 X-Men. The eigen centrality was calculated for all 92 X-Men in the X-Men cluster and normalized to a zero one scale based on the values for all 92. Since the betweenness centrality measures purpose was to find X-Men that served as bridges to the entire Marvel Universe this metric was calculated on the entire reduced Marvel Universe data set. However, when normalizing the data to a zero one scale we only based the normalization on the 92 X-Men in the X-Men cluster as they were the only contenders being included for the spot as the next leader of the X-Men. Therefore, zero one scale normalization was consistent for both eigen and betweenness centrality and based on the values for the 92 X-Men in the X-Men cluster.

The results of the analysis are in the table numbered 7 on the next page. Looking at the results, first we see that in the top 10 X-Men are many of the popular characters such as Cyclops, Storm, Wolverine, Colossus, Rogue, Beast, Jean Grey, Nightcrawler, and Angel. The only surprising character in the top 10 X-Men was Cannonball II, which is an X-man that we were not familiar with before the study. He ranked 5 out of 10 beating such characters as Rogue, Beast, and Jean Grey. However, upon looking him up in the Marvel Universe Wiki (n.d.), we learned that he is in fact a member of the X-Men.

Looking at the results from the eigen centrality, the top two core members of the X-Men are first Cyclops with a normalized eigen centrality of 1.0000 and second Storm with a value of 0.9448. Wolverine came in a very close third with a normalized eigen centrality of 0.9420. The top X-Men that act as bridges among other teams in the Marvel Universe are Wolverine in first place with the top normalized betweenness centrality value of 1.000. Next, came Beast with a normalized betweenness centrality

measure of 0.6493. These betweenness centrality measures are not as close in value amongst top leader candidates as the values for eigen centrality. In fact, Cyclops is the character in third place for betweenness centrality and his score drops down to 0.3529.

7. Eigen and Betweenness Centrality Results
Top 10 X-Men – Normalized to a 0 - 1 Scale

# of Degree	Rank	X-Man	Eigen Centrality	Betweenness Centrality
75	1	CYCLOPS	1.0000	0.3529
72	2	STORM	0.9448	0.1886
71	3	WOLVERINE	0.9420	1.0000
68	4	COLOSSUS II	0.8314	0.1498
60	5	CANNONBALL II	0.3715	0.0679
58	6	ROGUE	0.6161	0.0740
56	7	BEAST	0.7637	0.6493
56	8	JEAN GREY	0.7981	0.0140
55	9	NIGHTCRAWLER	0.6591	0.1356
54	10	ANGEL	0.7243	0.0289

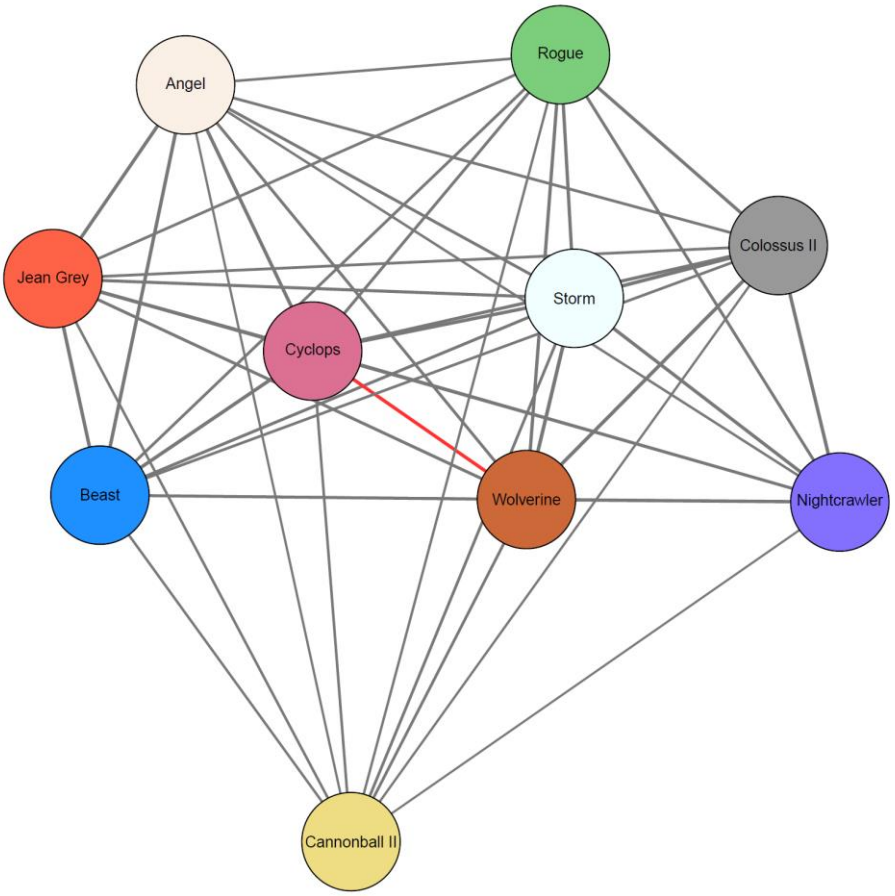
Structural Balance Analysis

For the structural balance analysis, we took a sub-graph of the top 10 X-Men listed in table 7. Since the data set did not contain information regarding the positive and negative relationships between characters we researched this information online using the Marvel Universe Wiki (n.d.). The only negative link that we were able to find amongst these top 10 X-Men was between Cyclops and Wolverine. An online article from the popular entertainment website ScreenRant encapsulated their antagonism the best in their article entitled, “Wolverine’s 18 Greatest Enemies in Comic Book History” (Blunden, 2016). In this article, author Fred Blunden ranks Cyclops as number 18 of Wolverine’s enemies and states: “As soon as Wolverine joined the X-Men, he began to butt heads with team-leader Cyclops. Their very different approaches to conflict aside, their rivalry for the heart of Jean Grey gave the two heroes an added edge to their hostility” (2016, para. 3).

On the next page in figure 8 is the sub-network graph of the top 10 X-Men with positive relationship edges colored grey and negative relationship edges colored red. We can clearly see in the graph that the only negative relationship is the one between Cyclops and Wolverine. This graph is a

complete graph with every one of the top characters being connected to every other top member. If Wolverine and Cyclops' relationship were positive we would have a strongly balanced network amongst the top 10 X-Men and all would belong to one faction of mutual friends. Introducing this one negative connection adds unbalanced triangles into the network and transforms it into a structurally unbalanced one.

8. Structural Balance Sub-Network Graph Top 10 X-Men
Positive Relationships Edges Grey / Negative Relationship Edges Red



There are 120 possible triangles in this graph, the combination of 10 X-Men in groups of 3. Every triangle involving both Wolverine and Cyclops, of which there are 8, becomes an unbalanced one. This makes 8 out of the 120 triangles or 6.67% unbalanced. While this might not seem like a large percentage it is amplified by the fact that Cyclops and Wolverine are two of the top X-Men, ranking one and three respectively. This one negative relationship is preventing the group from being a fully harmonic team.

– RESULTS AND CONCLUSION –

X-Men Leader Successor Selection

Once the centrality and structural balance analysis had been conducted we needed to synthesize the findings to answer our research question: Who would be the next leader of the X-Men if their current leader, Professor X, died? In order to make a selection we started by averaging the eigen and betweenness centrality measures. There were two methods of averaging that we could use. We could either average the zero one normalized scores or we could rank the characters for each centrality measure and average the ranks. We calculated the results for both methods and the results are in the two tables numbered 9 and 10 on the next page.

If we made the selection based on averaging the centrality scores Wolverine would be the top choice and in second place would be Beast. What drew Beast upward was that his betweenness centrality zero one normalized score was much higher than the rest of the X-Men, other than Wolverine. Since both measures were averaged equally, Beast benefited and members such as Cyclops and Storm were essentially penalized slightly for having much lower betweenness centrality scores.

However, if we make the selection based on averaging how each character ranked for each centrality measure, Cyclops and Wolverine would tie for first place and Storm would come in second place. With this method even a slightly lower amount for a score from another member would cause a fully lower rank value. For example, Storm only beats Wolverine on eigen centrality by 0.0028, however this causes a full rank difference of 2 to 3 respectively. This is the same rank difference (of 1) that Cyclops and Storm have given a difference in eigen centrality of 0.0552. This makes larger differences in scores, as Beast has in betweenness centrality, less powerful as each character only needs to beat the next one to achieve the next higher ranking.

How should we factor in the structural balance analysis? This decision was a bit more subjective. One could have a variety of methods for penalizing the average scores based on the amount of structural imbalance that each character introduced into the network. Deciding on an actual value of this penalization would be somewhat arbitrary and could greatly affect the results. For example, if one penalized Wolverine

9. X-Men Leader Selection

Averaging the Score for Eigen and Betweenness Centrality

# of Degree	Rank	X-Man	Eigen Centrality	Betweenness Centrality	Average
71	3	WOLVERINE	0.9420	1.0000	0.9710
56	7	BEAST	0.7637	0.6493	0.7065
75	1	CYCLOPS	1.0000	0.3529	0.6764
72	2	STORM	0.9448	0.1886	0.5667
68	4	COLOSSUS II	0.8314	0.1498	0.4906
56	8	JEAN GREY	0.7981	0.0140	0.4060
55	9	NIGHTCRAWLER	0.6591	0.1356	0.3974
54	10	ANGEL	0.7243	0.0289	0.3766
58	6	ROGUE	0.6161	0.0740	0.3451
60	5	CANNONBALL II	0.3715	0.0679	0.2197

10. X-Men Leader Selection

Averaging the Ranking for Eigen and Betweenness Centrality

# of Degree	Rank	X-Man	Eigen Centrality	Eig. Rank	Betweenness Centrality	Bet. Rank	Average
75	1	CYCLOPS	1.0000	1	0.3529	3	2.0
71	3	WOLVERINE	0.9420	3	1.0000	1	2.0
72	2	STORM	0.9448	2	0.1886	4	3.0
56	7	BEAST	0.7637	6	0.6493	2	4.0
68	4	COLOSSUS II	0.8314	4	0.1498	5	4.5
55	9	NIGHTCRAWLER	0.6591	8	0.0140	6	7.0
56	8	JEAN GREY	0.7981	5	0.0679	10	7.5
58	6	ROGUE	0.6161	9	0.1356	7	8.0
54	10	ANGEL	0.7243	7	0.0740	9	8.0
60	5	CANNONBALL II	0.3715	10	0.0289	8	9.0

and Cyclops in the rank averaging calculations by 0.5 subtracted from the total, they would both still be tied for first place. If you increase the penalization to 1.0 then there would be a three-way tie for first place between Wolverine, Cyclops, and Storm. We decided picking a penalization amount would be too arbitrary with no real basis for the specific amount of the penalty. Therefore, we decided to take a more subjective approach using reasoning. Elevating either Cyclops or Wolverine to the head position would most likely aggravate the structural imbalance introduced by their negative relationship even further. Therefore, we decided to remove both Cyclops and Wolverine from the running. Since these two characters were in the top places for both methods of averaging the centrality measures, we opted to select the characters who came in second place. Therefore, Beast would be selected by the method averaging the scores and Storm the by the method averaging the rank.

Conclusion

Based on the network analysis we were able to answer our research question and determine that Storm and Beast tie as the best next leader of the X-Men. Key to this insight was the structural balance analysis that was only made possible by having access to a large amount of information outside the original network data set from the Marvel Universe Wiki. We were able to use this widely available information on the characters as a ground truth set. In addition to adding the key information for the structural balance analysis, it provided validation information. For example, we were able to assess the community detection findings and confirm that the characters were classified into their proper team affiliation. We could go further into the ground truth to investigate certain aspects of our results as well. For example, why do Beast and Wolverine have such high betweenness centrality scores as compared to other top X-Men such as Cyclops and Storm? Researching these characters' histories, it turns out that both Wolverine and Beast left the X-Men and were part of other teams for a period of time. Wolverine was part of Alpha Flight and the Avengers and Beast was part of the Avengers. Cyclops and Storm are more squarely rooted in the X-Men.

Finally, comparing this result to the straw poll conducted, we found somewhat similar but not the same results. Recalling the results of the survey Storm was in second place with 25.51% of the votes and Cyclops was in first place by far with 40.33%. Wolverine was in third place with 9.47% of the votes and Beast was in fifth with only 2.47% of the votes. Jean Grey who placed third in the survey with 16.05% of the votes was in sixth or seventh place in the network analysis (depending on which averaging technique was used and before Wolverine and Cyclops were removed from the running). Part of the similarity in the results of the network analysis and the straw poll was that the survey respondents were intuitively knowledgeable of the network by being fans of the storylines. Overall, the three network factors of eigen centrality, betweenness centrality, and structural balance allowed us to determine who should be the next best leader of the X-Men.

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