Network and topic analysis of Grey's Anatomy

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Social network analysis and natural language processing can be used to investigate social structures in a variety of fields. Methods from these fields help focusing on and understanding the most important aspects of a network. Insights can be gained by inspecting the degree distributions, centrality measurements, term frequencies, community partitions, sentiments and developments over time.

One area of application is the analysis of social networks from television shows. In this paper we are showing that there is a stronger focus on romantic relationships than work connections and medical content for the show Grey's Anatomy.

As the show was previously criticized for being a romantic rather than medical show but is also known as the "most popular medical drama of all time" (1), it is interesting to investigate what is more important in the show, relationships or professional medical work. Using various methods from the social network analysis and natural language processing field, we quantified that relationships are more important compared to the medical topics of the show. This focus on human relationships that are the key aspects in our lives could also be an explanation of the shows ongoing success making it the second most popular show in the world in 2020 (2).

Even though the applied methods have their limitations that will be discussed in the final part of this work, this analysis is the first one able to demonstrate this observation based on data and it can be used as a groundwork for more detailed analysis. Also, the approach can easily be transferred to other shows and be the starting point of investigating what makes some shows more popular than others.

Social graphs and interactions | Grey's Anatomy | Network analysis | Text and sentiment analysis | Developments over time

Despite the reputation of simplicity of prime-time TV, the networks of relationships and story lines that develop over the seasons build a complex structure that is often not easy to follow. Especially Grey's Anatomy has a lot of character development in their currently 19 seasons ongoing show. But what makes the show so popular? Is it the insight into the daily life of medical professionals, the forbidden relationships between residents and attendings or the multiple catastrophes involving boat and plane crashes? **So, what is more important in the show - personal relationships or the professional medical work?**

To investigate this question further we used 2390 character descriptions and detailed summaries of the so far 406 episodes from Fandom (3). We also took the spin-off series Private Practice and Station 19 into consideration with another 1144 characters and 188 episodes. Based on this data we created a network with the characters as nodes connected to each other through links on their pages. Main parts of our analysis were network development over time, community detection and sentiment analysis.

In Results we go into more detail of how we collected the data, set up the network and carried out the main parts of our analysis. Furthermore we will present and visualize our findings and outcomes of our work.

Materials and methods

The Data. All the information about characters and episodes has been taken from Grey's Anatomy Fandom Wiki (3), using the MediaWiki API (5). For character's network analysis, the whole wiki page has been taken into consideration, while for text and sentiment analysis we used particular sections like *Full Summary*/*Short Summary* on episode pages, *Summary*/*Plots* on season pages or *History* on character's pages.

The Repository. The detailed analysis and results can be found in this Github repository(6).

Results

Basic network analysis. The first step for analyzing the Grey's Anatomy network is actually assembling the directed network by creating outgoing edges between a character x and a character y if in the Fandom page of x, y is mentioned and linked. As the Grey's Anatomy universe consists of three shows, Grey's Anatomy as the main show and the two spin-offs Private Practice and Station 19 (3), the character nodes were colored based on their main universe. The main universe for each character has been calculated using the outward links on its Fandom page. When a specific character is present in one of the shows' seasons, its page contains a link to a category group for that season, e.g. "Category:GA S11 Characters". For each character the number of occurrences in each show category is counted and normalized by the number of seasons. Finally, the main universe is defined based on the highest number of occurrences while the characters without any occurrences are dropped. For example if character x appeared in a_x of the 19 seasons of Grey's Anatomy, the Grey's Anatomy occurrence was $gao_x = \frac{a_x}{19}$ and the main universe was $max(gao_x, ppo_x, s19o_x)$. The resulting network and degree distribution can be seen in figure 1. The degree distributions reveal a power-law property for the network with few nodes that are highly connected and many nodes with only few connections (7).

Significance Statement

We are investigating the question of what is most important in the show Grey's Anatomy. While primary research of the show had a strong focus on the intimate relationships (4), there has not been a published more in dept analysis of character and episode descriptions, especially over time. We are performing this in dept analysis on our network consisting of over 3000 characters. We are using methods to investigate the network structure and process text from the detailed episode summaries to conduct sentiment and topic analysis.

[1] L.S.H.(Author One) focused on the developments over time, W.E.S. (Author Two) on the text and sentiment analysis and F.M.B. (Author Three) on the network and community analysis.

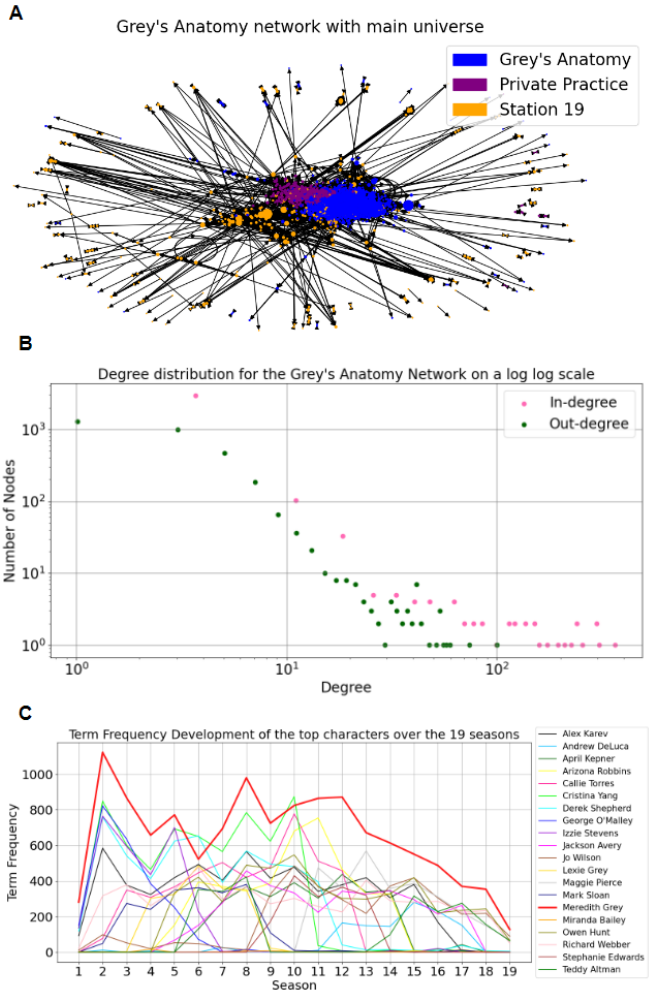

Fig. 1. Overview of the Grey's Anatomy network and its main nodes. (A) The Grey's Anatomy network contains 3124 character nodes connected through 12824 links with Grey's Anatomy as the main show in blue. (B) The in- and out-degree distribution reveals a power-law property for the network with few nodes that are highly connected and many nodes with only few connections. (C) The term frequency development of the main character nodes (with degree over 100) supports Meredith Grey in red as the main character which is also indicated by her node having the highest in- and out-degree in the network as well as degree development over time.

Main character analysis. Further analyses on the highly connected nodes that represent the top characters underline that the show deserves its name *Grey's* Anatomy as Meredith Grey proves to be the main character based on the in- and out-degree for the whole network, the degree centrality development over the 19 seasons as well as the term frequency of her being mentioned in the episodes of the main show. The latter can be seen from the red line in the last plot in figure 1 and was calculated by counting the occurrence of each top 20 characters first name in the episode summaries.

Only in season 6 Cristina Yang and Derek Shepherd are mentioned more than Meredith. In season 6 when Cristina has major issues in her relationship and Derek becomes Chief of Surgery (8) and in season 10 when Cristina leaves Seattle (8). Even with them having the highest term frequencies in these seasons, they are the central characters in Meredith's life with Derek being her husband and Cristina being "her person" (9) so the plot is still evolving around her.

Community detection. To get an insight into the community structure and relationships we performed community detection and visualized them with wordclouds. We investigated three different ways of dividing the network into partitions.
The first one was using the Louvain algorithm to detect the best possible partition based on modularity (10). Modularity is used as a measurement of how well the network is divided into partitions. High modularity indicates dense connections between nodes in a partition and sparse connections between nodes in different groups. The higher the modularity, the higher the community structure (7). The modularity achieved with this algorithm lays around 0,58. Furthermore we created partitions manually based on the category and series the character belongs to (Patient, Nurse, Doctor, Firefighter, Other). The modularity of dividing the network by categories was negative, which indicates that there are no dense connections inside those groups. The modularity based on the different series was around 0,33. Nevertheless we also looked into overlapping communities for the network using the Percolation method (11). This method creates communities as union of k-cliques that only can be reached trough adjacent k-cliques that share k-1 nodes.

Based on the partitions we created files for each community consisting of the character pages. Using TF-IDF (12) we calculated the most important words of each community compared to the other files and visualized them with wordclouds. As can be seen from figure 2 the focus of the wordclouds is on specific character names. An interesting finding was that especially the romantic relationships were shown in the visualizations, for example for April and Jackson. This result is an indicator that relationships are possibly more important in the show, since the connections between the couples of the show seem to be very dense in the network structure.

Since the modularity of dividing the network by series was a lot higher than dividing it by category, we decided to divide the network by series and focus mainly on the characters from Grey's Anatomy in our further analysis.

Fig. 2. Wordclouds of four communities created with the Louvain algorithm. The names of the characters in romantic relationships are the most prominent words in the wordclouds presented, i.e. "Jackson and April" or "Jo and Alex".

Text analysis over time. To take a deeper look at the relationships and the couples in the show that were revealed in the word clouds from the community detection above, the term frequency of two couples were investigated further. Meredith and Derek were chosen as the first couple as Meredith is the main character and Jackson and April as the second as they appeared in the word clouds and are introduced to the show around the same time in season 6. Their term frequency development can be seen in figure 3 below.

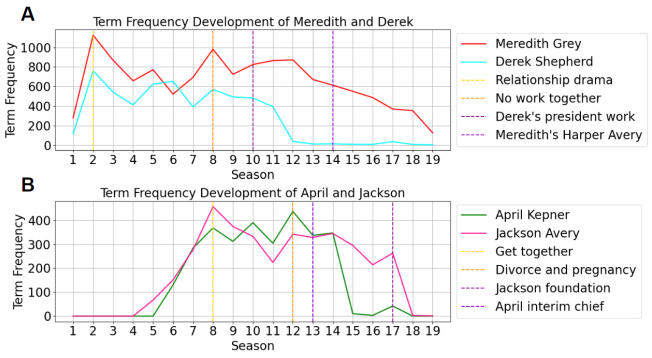

Fig. 3. Term Frequency Development and main events for two couples. (A, B) Both figures show that couples in the show can be identified by a similar term frequency development peaking at the same seasons and that their relationship milestones in orange lead to higher peaks compared to their purple career milestones.

In the analysis of the top characters and the figure 3, the first evident finding is that the term frequency development reveals a similar pattern for the couples in the show as they are mentioned together when developing their relationships. Also, it can be seen that they peak at the same seasons.

When analysing this pattern further through reading their development in the peak seasons, we discovered the second interesting finding that their main peaks are their main relationship milestones and crises. Concretely, this is highlighted by the orange horizontal lines in figure 3. The first plot shows that Meredith and Derek have their two main crises in season 2, in which they separate as Derek tries to save his marriage and then they reconnect, and season 8 where they cannot work together anymore. It is also worth noting that these main peaks were main crises and for example their wedding in season 5 shows a peak but not a major one which fits to the dramatic nature of the show (13). A similar pattern can be observed for April and Jackson having an on-off relationship in season 8 and their divorce and pregnancy in season 12 (8).

Connected to our research question whether personal or professional life is more important, we also investigated their professional milestones to compare them to their relationship milestones. The third finding from this analysis that is highlighted with the purple lines in 3 is that the characters peak higher in their mentions for their personal rather than professional development. For example, Derek works for the US president in season 10 and Meredith wins the main medical award in the show in season 14 and still they are mentioned less than during their relationship drama. Again a similar result can be observed for Jackson and April in the second plot of figure 3 but in contrast to other characters a peak can be observed when Jackson's career peaks.

Text and topic analysis. To investigate the prevalent topics and themes of the show further, the TF-IDFs were calculated for the seasons using the nltk library (12). The word clouds of the TF-IDFs for selected seasons that were discussed before show interesting insights can be seen in figure 4 below. The word clouds indicate that there are seasons where personal relationships play a significant role. Concretely, the word clouds of season 2, 7 and 10 reveal terms related to personal matters such as "relationship", "pregnancy" or "baby" and show couples in the foreground such as "Callie", "Mark" and "Arizona" in season 7 where they have a baby together (8) or "Christina" and "Shane" who have a romance in season 10 (8). In contrast to that, the other three seasons in figure 4 evolve more around medical topics. In season 6 Seattle Grace Hospital (the main hospital of the show) merges with another hospital (Mercy West) (8), in season 8 the main residents of the show take their medical board exams (8) and in season 17 the main topic is the covid pandemic (8) explaining more medical terms in the word clouds such as "doctors", "residents", "hospital" or "pandemic".

When training a Latent Dirichlet Allocation model (14) on the season summaries, prevalent topics and words around relationships and medicine are revealed. However, what is interesting in this analysis is that these themes are not clearly separated by the model but appear together in various topics. This could be an indication that private and professional lives are highly intertwined which also corresponds with the content of the show as many doctors have relationships between each other, happening in the workplaces or even with their bosses for example Cristina and Meredith as interns in season 2 with the attendings Preston and Derek (8).

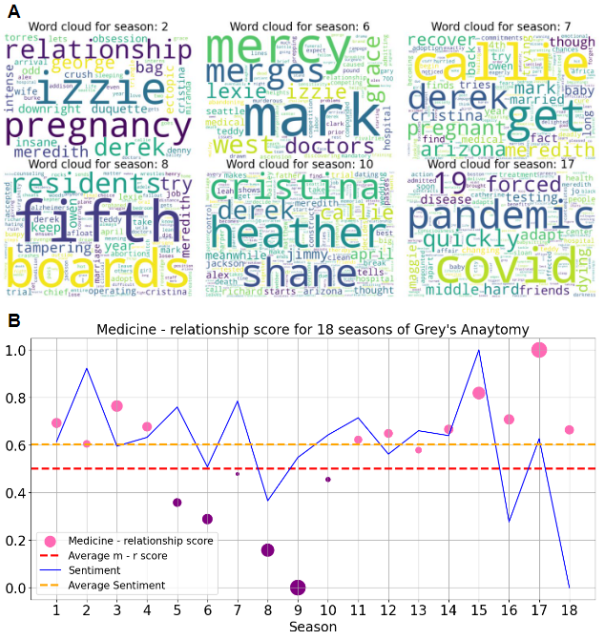

Fig. 4. Prevalent words and topics in the Grey's Anatomy seasons. (A) The TF-IDF wordclouds for the season summaries reveal the importance of relationships of for example season 2, 7 or 10 and the medical focus of for example season 6, 8 or 17. (B) The importance of relationship (pink) vs medicine (purple) was calculated with a custom relationship-medicine score revealing a similar pattern as the custom sentiment score (blue) that relationships are more important in most seasons (pink).

Medicine - relationship score. To investigate this observation further, we tried to quantify the importance of relationship vs medicine in the Grey's Anatomy seasons. As there is no defined algorithm for this, we decided to define our own custom medicine - relationship score. For this, we calculated the frequency distribution for the combined season and episode text. Using the most common words, two lists with medical and relationship related words were created. During this process, we tried to choose the most distinctive terms for each list. For instance, "hospital" and "surgery" were added to the medical and "love" or "relationship" to the relationship list. However, "heart" or "bed" were not chosen as they could be related to for example a heart surgery or a broken heart. To calculate the medicine - relationship score, the initial score of 0 was increased by 1 if a word from the relationship list and decreased by 1 if a word from the relationship list was discovered in the text. After computing the score for each season, it was mapped to a [0,1] range. The closer the score is to 0, the more a season is about medicine and the closer to 1 it is the more prevalent relationships are in the seasons.

The result of this analysis can be seen in the scatter plot in figure 4. It becomes evident that most, 13 of 18, are seasons above the threshold of 0.5 in pink indicating that these seasons focus more on relationships than medicine. Only 5 seasons (27.78%) are mostly medical. Some of the more medical seasons were already observed in the word clouds such as 6 or 8 and in season 9, the most medical season, the main characters take over the hospital (8). However, especially season 17, the most relationship based season according to the medicine-relationship score, was expected to be a medical season as it evolves around the Covid pandemic (8). The fact that is was not identified by the score as a medical season could be explained by the fact that the usual medical expressions were probably not used much as there were not many surgeries or procedures but testing and illness related to the pandemic and these were not fully captured by the usual frequent medical words. In addition to that, Meredith revisited her most important relationships to dead characters in a dream being sick from Covid throughout the season (8) which could also explain the high relationship score.
The medicine - relationship score gives an indication of the prevailing importance of relationships over medicine in Grey's Anatomy and gives a plausible result for the seasons. However, it is also highly dependent of the chosen words that were used to define the medical and relation based field.

Medicine - relationship score and sentiment. As we would expect relationship words and seasons to have higher sentiment value containing words such as "relationship", "love" or "family", we decided to also add the sentiment values of the seasons and the average sentiment across the seasons. The sentiments were calculated by applying the custom method for the sentiment score based on a list of words with happiness score as described in the sentiment analysis and the resulting sentiment development can be seen from the blue line in figure 4. It is worth noting that the sentiment curve shows a similar development with a general decrease in sentiment until season 8, increase until season 15 and an up and down from season 16 to 18. As both methods work with lists of words, this similarity is not surprising but it underlines that even using different methods with different goals, supporting results are achieved.

Sentiment analysis. In order to deepen the understanding of the sentiment, a detailed sentiment analysis on the characters and seasons has been performed. Sentiment value calculated from a text can provide information about the writer's attitude towards described subjects. Depending on the tool used, it will usually produce a numerical value in a specified range that will enable categorizing the text into either negative, neutral or positive attitude group.
Two separate methods were used to calculate sentiment values - NLTK's SentimentIntensityAnalyzer and a custom method based on a data set of average happiness of words (15). What was immediately noticeable was that the choice of the tool is incredibly important for the analysis - the results received from both methods were completely different. In order to accurately compare them, we mapped the values into [0,1] range for both methods.

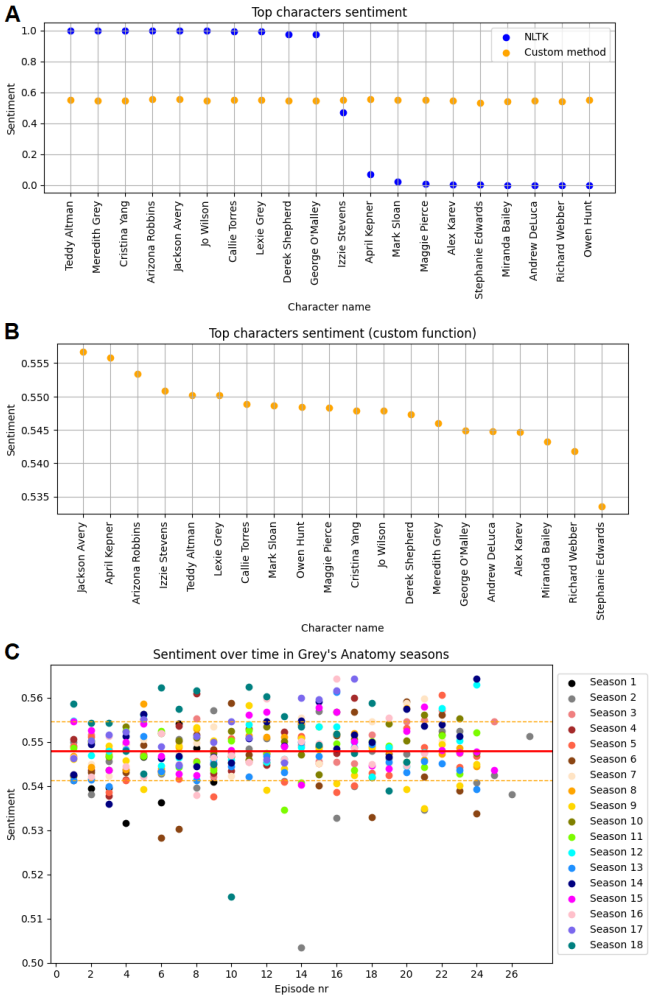

Fig. 5. Sentiment values for Grey's Anatomy top characters and episodes. (A) Comparison of NLTK (blue) and custom method (orange) sentiment values for top characters' history. (B) Top characters' history sentiment values shown only for custom method, Y axis scaled for visibility. (C) Sentiment values progression through episodes for each Grey's Anatomy season. Red line notes the average, yellow lines show the standard deviation range.

We analysed characters' sentiment value based on their Fandom page *History* section. The custom method returned similar values (between ≈ 0.534 and ≈ 0.557), all of them being close to the middle of the scale.

It means that the characters' history can be classified as *neutral*. On the contrary, results of the NLTK method turned out to be very polarized - with most values falling on two opposite sides of the scale, making them either *positive* or *negative*. Only one character sentiment was *neutral* - Izzie Stevens.

The stark difference in scores visible in figure 5A, might come from the primary purpose of the tool - NLTK's method has been developed mainly to score social media content (16), while our custom function is much simpler and judges the sentiment by the compound "happiness" of the words. With that in mind we decided to use the custom method for further analysis.

Upon closer look at the custom method results, as shown on figure 5B, it's visible that the character with the happiest story on the show has been Jackson Avery (followed by his partner, April Kepner), while the saddest turns our to be Stephanie Edwards' story. What's interesting is that Stephanie used to also be romantically linked to Jackson Avery (8). However, their relationship did not end well which points in the direction of the characters' stories being more important to their happiness than career. Of course the differences in sentiment values aren't substantial, so the results should be considered quite carefully. In addition, two people who have been in a relationship are also next to each other on the top character sentiment value scale - the main character Meredith Grey and her husband Derek Shepherd, further pointing out that two characters happiness is closely related to each other.

Looking at the sentiment over time in figure 5C we can also see that the overall episode sentiment stays within the range of 0.5 and 0.57, with the average being just below 0.55 (marked by a red line) and the standard deviation of around 0.007 (marked with orange lines). Some episodes are more distinguishable - S02E14 and S18E10 being close to the bottom of the scale, while S14E24 has the highest sentiment value. However, after analysis of the summary of those episodes we can safely assume that their values are probably caused by the author's attention to details while writing the summary and not due to events in the episode. What is interesting is that there is no particular pattern to the sentiment progress during the seasons - not many end on a "happier" episode and there are no usual, dramatic setbacks introduced at any point in the season.

Discussion

Limitations. The main limitation of this analysis is that the Fandom pages of the characters and episodes are collectively written by non professional authors and modifications are not reviewed. (17) Even though the collaborative nature of the website is supposed to lead to high accuracy and reliability of the pages, the quality of the pages and so the quality of the underlying data for this analysis is not ensured systematically. Moreover, several decisions were taken in the data processing in accordance to the purpose of the analysis. Examples for this are the main show assignment described in the basic network analysis or the cleaning of the text for calculating the TF-IDF and creating the word clouds. Even though these decisions were taken based on the knowledge about natural language processing (18), the pre-processing could be improved further. For instance, the text could be standardized further by for example stemming which would however also decrease the readability and understanding of the words or transforming the words into nouns. More thorough processing could have improved the results of the analysis but would have also been significantly more time consuming. With the limited project time, we decided to focus on the analysis but it could be a major improvement for future work. One final limitation of this project is that some of the methods especially the medicine - relationship score are highly dependent of individual definitions of for example relationship words.

Future work. Given the amount of data and the defined access through the Wikipedia API, the presented results can built the groundwork for further work on network and topic analysis. For instance, the analysis did not only reveal the prevalence of relationships but especially the text analysis also underlined the importance of socially and politically relevant topics in the show such as abortion, the covid pandemic or immigration. Addressing these essential matters is reportedly a focus of the shows' writers (13) and could contribute to the shows popularity (19) which is another potential interesting future investigation that would for example require a comparison to other shows or an analysis of reviews of the show. Finally, the analysis reveals clear weaknesses with high potential in natural language processing. What comes so natural to us humans so for example telling if a text is more about relationships or medical details, is not easy to do automatically and for greater amounts of data with existing frameworks. Getting the main themes and essence of the text which goes beyond a sentiment or topic analysis of the text could be useful in many contexts.

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