AttentionFlow: Visualising Influence in Networks of Time Series

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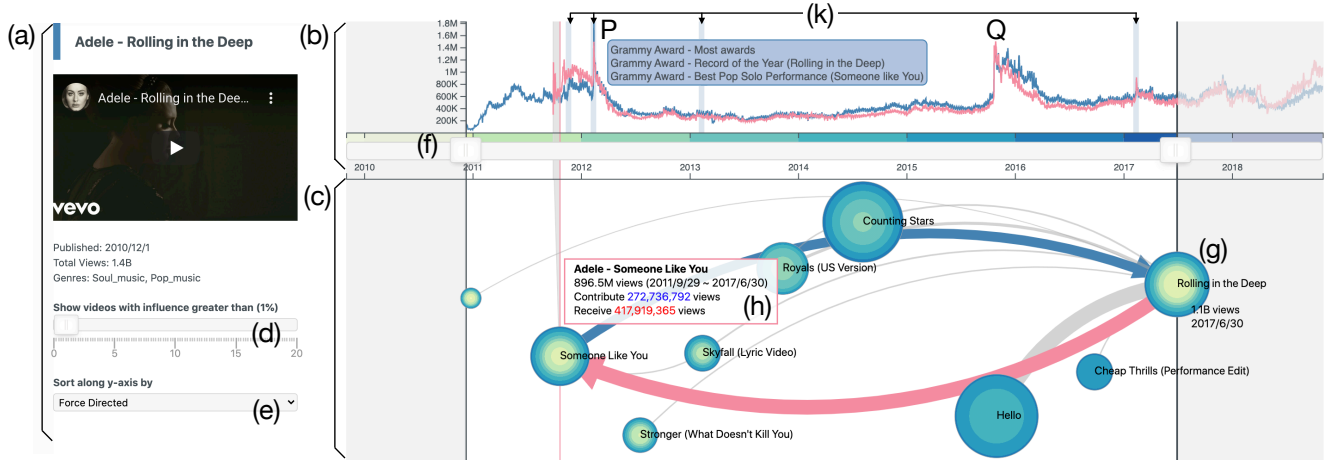
Figure 1: AttentionFlow visualises the attention series of an entity and the influence flowing over its ego network. The metadata view (a) provides high-level information about the ego node (g). The attention chart (b) presents two attention series of the ego and the hovered alter node, while the ego network (c) highlights the incoming and outgoing influence between them. Users can filter the alter nodes by setting the influence threshold (d), select a sorting criterion for the vertical axis (e), and define an observation window using the time slider (f). In this snapshot, we observe two spikes in the attention series of the music video *Rolling in the Deep* by Adele. The first spike (P) is related to the Grammy Awards of that year, while the second (Q) is due to the release of Adele's new song *Hello*. The remaining components are described in Section 4 and 5.

ABSTRACT

The collective attention on online items such as web pages, search terms, and videos reflects trends that are of social, cultural, and economic interest. Moreover, attention trends of different items exhibit mutual influence via mechanisms such as hyperlinks or recommendations. Many visualisation tools exist for time series, network evolution, or network influence; however, few systems connect all three. In this work, we present AttentionFlow, a new system to visualise networks of time series and the dynamic influence they have on one another. Centred around an ego node, our system simultaneously presents the time series on each node using two visual encodings: a tree ring for an overview and a line chart for details. AttentionFlow supports interactions such as overlaying time series of influence, and filtering neighbours by time or flux. We demonstrate AttentionFlow using two real-world datasets,

VevoMusic and WikiTraffic. We show that attention spikes in songs can be explained by external events such as major awards, or changes in the network such as the release of a new song. Separate case studies also demonstrate how an artist's influence changes over their career, and that correlated Wikipedia traffic is driven by cultural interests. More broadly, AttentionFlow can be generalised to visualise networks of time series on physical infrastructures such as road networks, or natural phenomena such as weather and geological measurements.

CCS CONCEPTS

• **Human-centered computing → Visualization systems and tools**; **Visual analytics**.

KEYWORDS

Networks of time series; Influence visualisation; Ego network

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1 INTRODUCTION

Attention series measure user interests towards an online item over time, such as visits to a website, posts in a community, and searches on a topic. When multiple attention series are related, they can exert mutual influence on one another, forming an influence network. For example, traffic on a web page influences linked pages [3], posts in an online community influences related communities [5], and the degree to which a social group accepts an idea influences other social groups [9]. By visualising influence in networks of attention series, we can separate exogenous and endogenous influences, identify attention series that have substantial influence, and understand the network response to external shocks.

One line of related works aims to visualise snapshots of influence between entities. IdeaFlow [9] visualises how ideas flow within and across multiple social groups by modelling the lead-lag relationships in text clusters. Situ [3] combines flow visualisation and anomaly detection to identify suspicious network traffic. Shin et al. [7] propose a flower-like metaphor for visualising the intellectual influence between academic entities. These methods assume the network to be static and focus on visualising events or flow rather than the complete time series. Another line of works focuses on visualising network evolution. To visualise a scholar's temporal collaboration graph, egoLines [12] chooses a subway map metaphor, while egoSlider [11] uses a series of juxtaposed glyphs. Unlike our work, the networks in these visualisations are presented as multiple snapshots and nodes do not represent individual time series. Moreover, several approaches have been developed for visualising multiple time series, including stacking [4] and clustering [6]. Bak et al. [1] propose Growth Ring Maps where time series are presented as circles with radially varying colours. By contrast, we take on the challenge of simultaneously visualising multiple time series, the degree of influence between these series, and the dynamic network structure on which this influence acts. To the best of our knowledge, no research has addressed these three angles at once.

We develop AttentionFlow, a new system for visualising the dynamic influence flow in an ego network with time-series nodes. It is so named to reflect the common use case of visualising time series of user attention in online networks. AttentionFlow visualises how the time series of a focal node (the ego) and its direct neighbours (the alters) influence each other. For each node, we encode the time series in two visual styles. A tree ring encoding allows many time series to be compared simultaneously which is useful for identifying common patterns and interesting dynamics. A line chart encoding allows a detailed comparison of two time series. The chart also contains a set of markers, each of which corresponds to a real-life event that could have influenced the time series. The ego network is presented as a node-link diagram which shares the time axis with the line chart, allowing network structure changes to be visually compared with the time series. The position of an alter node on the time axis indicates when it starts to influence the ego node. The two main interactions are: (1) hovering over an alter node to show the detailed line chart for that node, and (2) moving the time slider to select an observation window. As the window shifts, the ego network structure changes, showing or removing nodes depending on their influence flows and the dynamic graph structure.

AttentionFlow is preloaded with two large-scale networked time series datasets: a network of 31K music videos induced by the YouTube recommender system [10] and a network of 366K Wikipedia web pages induced by hyperlinks [8]. Our case studies demonstrate that AttentionFlow helps explain sudden surges in the attention series by visualising both external and internal influences.

The main contributions of this work are:
- AttentionFlow, a new interactive web app for visualising a dynamic network of mutually influencing time series[1].
- A novel combination of visual elements that simultaneously display the time series of nodes, the time-varying network structure, and the magnitude of influence flowing along edges.
- Case studies that use AttentionFlow to interpret view count time series from YouTube and Wikipedia networks.

2 NETWORKS OF ATTENTION SERIES

AttentionFlow is a general system for visualising multiple time series with a network structure. Each node in the network consists of a univariate time series and other semantic metadata. Directed edges model the flow of influence from source nodes to target nodes, with a weights quantifying the strength of influence. The network can be dynamic: edges can appear and disappear and edge weights can vary over time.

We use AttentionFlow to visualise two datasets: VevoMusic [10], a YouTube recommendation network of music videos; and WikiTraffic [8], a hyperlink network of Wikipedia articles. In VevoMusic, there are 31K nodes, each containing daily view counts for a music video from its creation date to November 2018. If a video's recommendation list contains the link of another video, we add an edge from the former to the latter. This results in 45K edges. We create the artist-to-artist network by aggregating all videos from each of the 2.3K artists. In WikiTraffic, we have 366K pages and 22M edges with traffic data from July 2015 to June 2020. A directed edge is added if a page appears as a hyperlink on another page.

Edge weights, which represents the influence strength of the source node on the target node, are estimated by different methods in VevoMusic and WikiTraffic. For VevoMusic, Wu et al. [10] use ARNet, a regression model that learns edge-specific weights on the network over time. The displayed edge strength correspond to the estimated number of daily views flowing on the edge. For WikiTraffic, Tran et al. [8] use the multi-head attention scores from the neural forecasting model RADflow as a proxy for influence. Both models empirically outperform previous state-of-the-art methods, thus giving credence to the usefulness of these weights.

3 VISUALISATION DESIGN

AttentionFlow focuses on the ego network rather than the entire network in order to show how the temporal changes in attention correlate with the influence around an ego node. We introduce two representations of nodes: an attention chart and a tree ring.

The *attention chart* is a line chart for visualising the amount of attention an ego attracts over time and providing detailed temporal patterns such as peaks and valleys. It also allows users to compare trends of the ego with an alter node by overlaying their attention time series on the same panel. In Figure 1b, the attention chart of an
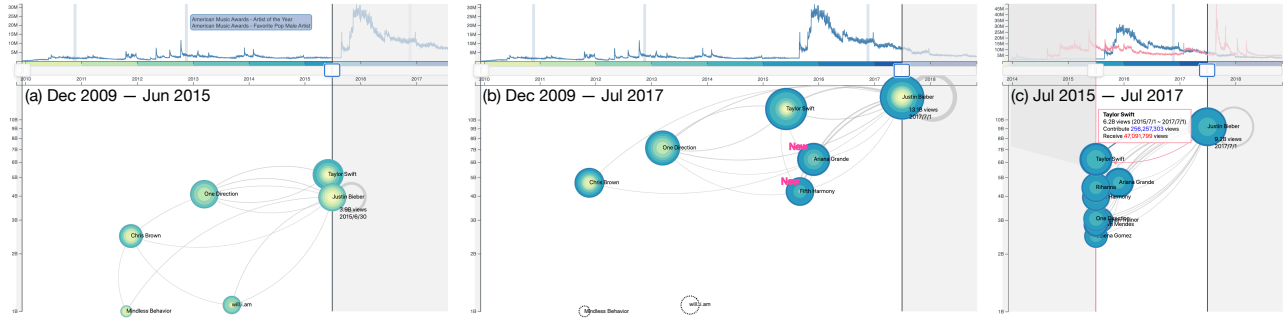

Figure 2: Artist network page for Justin Bieber, showing neighbouring artists with more than 1% influence. Nodes are sorted along the vertical axis by their total views. We show three network snapshots: (a) Dec 2009 – Jun 2015, before Bieber published *Sorry*; **(b) Dec 2009 – Jul 2017, two years after it was published; and (c) Jul 2015 – Jul 2017, non-overlapping two years after (a).**

alter (pink) is overlaid on top of the chart of the ego (blue), showing that *Someone Like You* has a similar attention trend to *Rolling in the Deep*. We provide a time slider to select an observation window, which plays an important role in determining the sizes and colours of the elements described below.

The *tree ring* provides a coarse view of the attention series and allows us to quickly compare the temporal trends of all nodes in an ego network. We split the lifetime of a node into calendar years (though other time units could also be used) each of which is assigned a colour. The size of the whole node denotes the magnitude of attention within the observation window. The size of each ring represents the amount of attention within the corresponding year. In Figure 1, *Rolling in the Deep* has a timeline spanning over 8 years (2010–2017), hence its node has 8 rings, with the innermost ring mapping to the attention in 2010 and outermost ring mapping to 2017. Meanwhile, *Hello* has a shorter timeline of 3 years. It has the biggest ring in the centre while the peripheral rings are much thinner, indicating that it has an attention spike immediately after its release and receives comparatively little attention in later years.

The *time-aligned ego network* emphasises the correlation between temporal changes in the attention and influences from the alter nodes. It is drawn below the attention chart so that they share the same timeline. We define the *influencing time* of a node to be the time when the edge connecting it to the ego has a normalised influence above a set threshold. We adapt the timeline network layout introduced in EdgeMaps [2] to the setting where the alter nodes are placed according to their influencing times. When the influence threshold is set to zero, the influencing time becomes either the start time of the observation window or the creation time of the node, whichever comes later. Increasing the influence threshold will either move an alter node to the right, or hide it if its influence falls below the threshold. The user can interactively move the ego node along the timeline, defining the right boundary of the observation window (Figure 2). Edge width is calculated based on the amount of influence flowing from the source node to the target node, normalised by the maximum influence in the ego network.

Figure 2 (a–b) shows an example network in two different time periods. In the earlier period (a), the ego node, *Justin Bieber*, connects to five alter nodes because their edges have influence above the threshold. After two years (b), *Mindless Behavior* and *will.i.am* are no longer influential to the ego and thus disappear. Meanwhile, two new alter nodes, *Ariana Grande* and *Fifth Harmony*, appear in

the network. Time-varying attributes such as node attention (node size and vertical position) and the amount of influence (edge width) are visually changing from (a) to (b).

4 NAVIGATING ATTENTIONFLOW

We implement AttentionFlow to allow users to search for entities of interest, and explore their temporal trends by interactively changing the time periods and thresholds. The frontend is rendered in D3.js and the backend uses the Neo4j graph database. Users can access the visualisation of an entity by searching for its name (e.g. the video name or the artist name), or by clicking on the corresponding node in the ego network of another entity.

Figure 1 presents the main visualisation layout for *Rolling in the Deep* (g), a popular music video from Adele. It consists of three components: a metadata view, an attention chart, and a time-aligned ego network. The *metadata view* (a) shows an ego's attributes such as the title, the embedded snippet, the creation time, and the genres. Below the description of the attributes, two controllers can be used to alter the network layout. The influence slider (d) sets the influence threshold, defaulting to 1%. The drop-down box (e) provides five criteria for sorting nodes along the vertical axis: force-directed (default), total views, incoming views, outgoing views, or categories. The *attention chart* (b) visualises the attention series of an ego (blue) and a hovered alter node (pink). The period between the alter's creation and influencing time is coloured in grey, indicating the time that it takes to reach the chosen influence threshold relative to the ego node. A time slider (f) is located on the horizontal axis to select an observation window. The left handle changes the start time of the observation, while the right handle changes the position of the ego (g). The periods outside the selected time range are greyed out. The *time-aligned ego network* (c) changes dynamically when users interact with the time slider and the influence slider. When hovering over an alter, the edges between the alter and the ego are highlighted, the alter's attention series is revealed on the attention chart, and an information card (h) pops up.

5 EXPLAINING INFLUENCE ON VEVOMUSIC

AttentionFlow can incorporate domain-specific datasets to help users interpret trend changes. It draws the event indicators on the attention chart as shown in Figure 1(k). For example, AttentionFlow uses a list curated from Wikipedia to show music awards related to

VevoMusic. *Rolling in the Deep* received a surge of attention at the beginning of 2012 (Figure 1P). Hovering on the event indicator near the peak tells us that the 54th Annual Grammy Awards happened on the day before and Adele received three Grammys that year. The alignment between the ego network and the attention chart helps us see the correlated attention spikes easily. At the end of 2015 (Figure 1Q), *Rolling in the Deep* received another sudden surge after a long period of stable attention. Examining the network view, the *Hello* node is aligned with the time of the spike. One can hover over *Hello* to have the video's time series added to the attention chart. A thick edge pointing from *Hello* to *Rolling in the Deep* is highlighted, suggesting that the latter regained popularity in late 2015 because *Hello* was released. Furthermore, Adele's other video, *Someone Like You*, exhibits a similar tree ring to the ego but with thick edges in both directions. By hovering over it, we discover that *Someone Like You* has an almost identical attention series to *Rolling in the Deep*, with both benefiting from the release of *Hello*.

AttentionFlow also provides the same visual layout for the artist network, which helps us track both the attention an artist receives on YouTube and the evolution of their influence network. Figure 2 presents three time periods of *Justin Bieber* surrounding the release of his biggest hit song *Sorry* in 2015: (a) 2009-15, the six years before *Sorry*, (b) 2009-17 that includes two years post *Sorry*, and (c) 2015-17, the two years after *Sorry*. We set the influence threshold to 1% and sort the vertical axis by total view counts The publication of *Sorry* was a big turning point as he gained 9.2 billion views within two years of *Sorry*'s release. The visualisation reveals (perhaps surprisingly) that the three American Music Awards in 2010, 2012, and 2016 did not have much affect on the attention trends. In (a), five artists influenced Bieber. Two years after *Sorry* was released (b), two artists disappeared and are replaced by two more popular artists. The remaining alters and the ego node moved upwards as they gained more views from (a) to (b). Bieber gained more views than Taylor Swift in these two years. Comparing the non-overlapping periods of (a) and (c) tells us that Bieber gained more attention in the later two years than the previous six years. As he received more influence from other artists in the later periods, Bieber's influence on his own videos decreases as shown by a thinner self-loop.

6 EXPLAINING WIKITRAFFIC

AttentionFlow can also visualise traffic flows between web pages. Figure 3 presents the attention chart and the time-aligned ego network of *Adam Driver*'s Wikipedia page, at an influence threshold of 2%. We use film award data from IMDb to draw events related to the ego. *Adam Driver* made his debut in 2010 but did not become widely recognised until he was cast as *Kylo Ren* in *Star Wars: The Force Awakens* in 2015. The attention series of *Adam Driver* (blue) is highly correlated with the recent Star Wars films, getting a surge in traffic after the release of *The Force Awakens* in 2015, *The Last Jedi* in 2017, and *The Rise of Skywalker* in 2019. In particular, the thick edges between Driver and *The Force Awakens* indicates substantial traffic flows between these two pages. The page of *Kylo Ren* shows a similar attention series (pink) to *Adam Driver*, especially before 2018. However, Driver received a higher number of page views over time as he gained more popularity from films outside the Star Wars franchise. Driver's attention chart also shows more peaks than *Kylo*
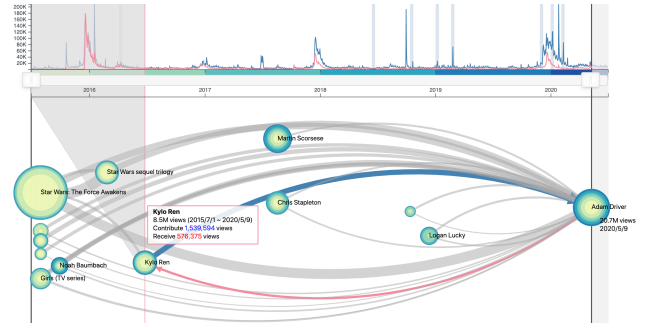

Figure 3: AttentionFlow visualising the attention series of the Wikipedia page for *Adam Driver,* an actor who gained wider recognition for playing *Kylo Ren* in the *Star Wars* series. The influence threshold is set to 2%.

Ren, as these correspond not only to releases of Star Wars films but also to the release of his other films and to his award nominations.

7 CONCLUSION

AttentionFlow is a system for visualising networks of time series, with a novel combination of multiple interactive visual elements including line charts, tree rings, and dynamic ego networks. We present three case studies to explore the influence networks of videos and artists on YouTube, as well as Wikipedia traffic of cultural entities. The system allows us to better understand the effects of new nodes, the effects of external events, and to interpret the factors affecting an artist's career. Future work includes deploying this system to networks of time series beyond online attention, and improving network layout to reduce node overlap while preserving the notion of time.

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