Analysis of an Internet Service or Product

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1. Summary

This assignment's purpose is to stimulate a reflection and detailed analysis around an Internet service, product or relevant technology. In order to do so, the analysis should address two different subjects: firstly, a technical analysis of said technology explaining what it is and how it works; secondly, an explanation of the social, economical and ethical consequences of the usage of that technology.

For our assignment, we chose to analyze Twitter so that we may understand how it generally works, how trends appear, how their lifecycle pans out and how the algorithm itself operates. We want to understand how the recommendation of topics, popular tweets and accounts to follow is computed to fit the likes of specific users. Finally, we want to explain some consequences of those mechanisms for end users. For instance, what are echo chambers and how they're formed as a result of the recommendation algorithm.

In a second phase of the report, we plan to create a new account on the website and test hands-on what happens to a brand new, clean slate account and how the recommendation algorithm and Twitter's trends gradually envelop the user and change what they're exposed to.

Lastly, we will turn our attention towards the social, economical and ethical nuances that surround Twitter usage. As is surely known, Twitter commonly hosts a variety of different debates and general discourse on all matters that become popular through the flux of trends. We are curious to see how people can be affected by this and in what ways. Furthermore, it will be interesting to discuss at further length the ethical implications of Twitter phenomena, which can include anything from fair use issues to matters of personal safety for its users.

Twitter is a powerful tool and, as such, its net good to its community depends heavily on how it is used and understood. We wish to shed a brighter light on the network's internal machinery, so that we may grasp more fully what its consequences are for the end users.

2. Framework

Twitter is a social network that has been around since 2006, becoming popular around 2009. It has, since then, been ubiquitous in the online social landscape, being the main stage for popular trends, social commentary and public opinion.

To briefly explain its usage, each user can tweet, given that a tweet can consist of simple text (with a character limit), one or multiple images, videos, links, among others, as well as a mix of all of them. Everyone will be able to see such tweets, unless the user chooses to narrow down their audience. The user can also restrict who can retweet (share) or reply to their tweets. The social network is equipped with a private messaging system that allows users to exchange private messages or create group chats. As well as following other users, one can also follow topics, which represent areas of interest (such as “Art”, “Soccer” or “Programming”).

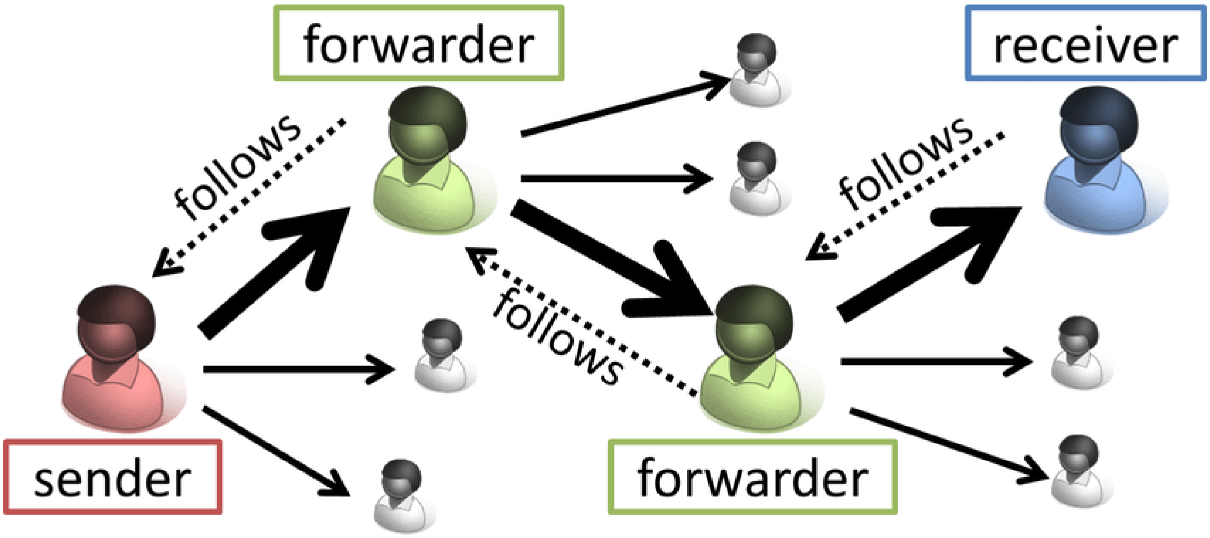

Figure 1: Basic Twitter Social Graph

3. The Inner Workings of Twitter

3.1. Trends

3.1.1. What makes a trending topic?

In order to start a conversation about trends on Twitter, it would be interesting to begin by looking into how Twitter determines which topics are trending. Upon entering the application, one can access the day's trending topics by going into the 'Explore' tab and looking at the 'For You' or 'Trending' sections. The topics will be immediately visible in order of decreasing popularity.

The first thing of note is that Twitter favors sharp spikes rather than gradual sustained growth when it comes to topic popularity. In other words, if a given topic grows considerably in a single day, it will certainly be more likely to reach the trending topics section than a topic that has experienced steady growth over the last month, for example. This also means that the trending topics aren't necessarily the ones that have "the most volume", as in the largest number of people discussing them, but rather the ones with the highest rate of incoming traffic across a short time period.

To be more precise, this traffic is expressed in terms of mentions (people using the topic's hashtag) and general engagement (people liking, retweeting or replying to tweets under the topic).

3.1.2. Tailoring trends

Another aspect to take into account is that not all users will see the same trending topics on their respective accounts. Each user's trending topics are determined by a variety of factors, including who they follow and their geography. Naturally, the kind of content they like to consume and their geographical location make sense as filters for which popular conversations they would be interested in.

One cannot have access to another location's trending topics unless the location settings are changed to a different place, but a user can choose to be shown their city's trending topics or stretch out the range to nationwide level.

The algorithm will then automatically tailor what is shown to which user depending on who they interact with and their interests.

3.1.3. Why trends?

A question that comes to mind at this stage is: why trends? Why would this mechanism bring benefits to the social network? The idea behind topics in general is to steer users towards conversation and away from on and off comments. This increases the individual users' engagement rates which, in turn, works as encouragement for continued usage of the application, maintaining its relevance on the Internet.

Topics will help people find their audience within the application. They're a way to interact and keep in touch with target groups and develop personal brands within certain communities, not to mention that, in a way, they function as news articles, keeping everyone up-to-date on the newest relevant events and conversations.

3.1.4. A trend's lifespan and lifecycle

The lifespan of a Twitter trend tends to be, on average, 11 minutes. This information might be somewhat surprising, as a considerable insurgence of conversation in a specific topic is necessary for it to trend, and one would expect that such a conversation would prolong itself for longer than just a few minutes.

It is, of course, possible that such trends come about, extending themselves for a whole day or even multiple days (the record being a total of 58 days for a hashtag related to the Italian edition of Big Brother). This is often the case for big events, such as controversial world news, politically charged debates or, as the previous example illustrates, reality television.

In the context of rapidly-unfolding events (such as natural disasters or political discussions), the conversation surrounding the topic will also evolve and morph quickly through time and, as such, have wildly varying lifespans. It is possible for them to die out at any point.

In terms of lifecycle, we've seen that the first phase of a soon to be trending topic is its fast climb into popularity, which tends to happen either right from the moment it is first created or not at all. We then come into the second phase: the trending timespan. A topic is only trending during its peak engagement period. As soon as its popularity begins to decay, it is removed from the trending topics list and said decay becomes exponential - it quickly fades into obscurity, giving its place to the newest hot debate.

3.2. Recommendation Algorithm

3.2.1. Who To Follow Service

3.2.1.1. Goal

The purpose of the WTF ("Who To Follow") service is to assist Twitter's users in discovering others to follow. It suggests other users that the user may have interest in following, taking into account shared interests, mutual connections, among other factors.

The problem has two different sides: informally speaking, they are "similar to" and "interested in". A user interested in video games is likely to follow @IGN, an American video game and entertainment media website. However, the user wouldn't be considered *similar* to IGN. Conversely, two users may be considered similar based on interests they share. For example, if they are both fans of the survival horror asymmetric multiplayer game Dead by Daylight, or if they follow many of the same users. According to the homophily principle (the tendency of individuals to associate and bond with similar others), similar users make good suggestions. In addition, WTF is used for search relevance, discovery, promoted products and other services.

The goal of this section is to explain the design of the system responsible for connecting millions of people on Twitter each day.

The following will be explained:
- The decision to build the service under the assumption the entire graph will fit in memory on a single machine;
- The service's end-to-end architecture, with the Cassovary in-memory graph processing engine at its core;
- The user recommendation algorithm for directed graphs based on SALSA;
- The limitations of the WTF architecture.

3.2.1.2. Twitter Graph

The Twitter graph is composed of vertices that represent users. They are connected by directed edges, representative of the "follow" relationship. It is important to note its asymmetricity, as a user can follow another without being followed by them.

As of August 2012, the graph contained over 20 billion edges, with only active users considered. Power law distributions of both vertex in-degrees and out-degrees were verified.

The graph is stored in FlockDB, a graph database that uses MySQL as the underlying storage engine. Gizzard is the framework used to handle replication and sharding. FlockDB is the system of record for the state of the graph. The entire system handles hundreds of thousands of reads per second and tens of thousands of writes per second.

Unfortunately, FlockDB and Gizzard are not appropriate for the types of access patterns frequently seen in large-scale graph analytics and graph recommendation computing algorithms. As opposed to simple get/put queries, many graph algorithms involve large sequential over many vertices, followed by self-joins. These operations are mostly not time sensitive, thus being able to be considered batch jobs, unlike manipulations tied to user action (e.g., adding a follower), which feature tight latency bounds. Thus, WTF needed a processing platform different from FlockDB/Gizzard.

This architecture parallels the well-known OLTP vs. OLAP distinction in databases and data warehousing. Database architectures evolved to separate OLTP and OLAP workloads on separate systems, connected by an ETL (extract-transform-load) process that periodically transfers data from the OLTP to OLAP components. FlockDB and Gizzard serve the OLTP role, handling low-latency user manipulations of the graph.

3.2.1.3. Hadoop

Hadoop was a clear choice for a MapReduce implementation, thanks to its popularity and widespread adoption. A production data analytics platform around Hadoop had already been built by the analytics team. However, there were many shortcomings related to PageRank:

- Relatively high startup costs of MapReduce jobs, placing a lower bound on iteration time;
- Stragglers in the reduce phase, created by scale-free graphs whose edge distributions follow power laws;
- Shuffling of the graph structure from the mappers to the reducers at each iteration;
- Serialization of the PageRank vector to HDFS, along with the graph structure, at each iteration (the fault tolerance provided comes at the cost of performance).

To cope with these shortcomings, a few optimization “tricks” for graph algorithms in MapReduce were proposed. Most issues can be addressed in a more principled manner through the extension of the MapReduce programming model.

Finally, the WTF project demanded an online serving component, which Hadoop does not provide. In spite of the fact that user recommendations can be computed as offline batch jobs, a low-latency result serving mechanism was still necessary.

3.2.1.4. Memory

The decision to perform in-memory processing on a single server was due to how complex it would be to have a partitioned distributed graph processing engine, in spite of the existence of parallel graph partitioning tools. Hash partitioning, a naïve approach, would be suboptimal for large amounts of traffic. Unsatisfactory partitions would be yielded due to the Twitter graph's power law distribution of vertex degrees. Additional issues would be fault tolerance, replication, load balancing, coordination, dynamic failover, etc.

In-memory processing on a single server guaranteed speed of execution for WTF, ease of scaling with a growing user base and lower cost. Nevertheless, there was the limitation of the amount of memory available in the server, which could limit the sophistication of algorithms used. The risk was deemed acceptable, given the reduced engineering effort.

3.2.1.5. Cassovary

Cassovary is the in-memory graph processing engine used by WTF. It is written in Scala, which targets the Java Virtual Machine. Cassovary makes the assumption there is enough memory to hold the entire graph. The latter is immutable once loaded into memory and, consequently, no persistence mechanisms are provided. Replication is used to achieve fault tolerance, by running many instances of Cassovary. Thanks to immutability, the layout of in-memory data structures can be optimized statically at startup. Cassovary provides graph access through vertex-based queries, which are sufficient for an ample range of graph algorithms. To achieve efficient access, the outgoing edges for each vertex are stored in an adjacency list. Cassovary is multi-threaded: each query is handled by a different thread.

Cassovary stores the graph as optimized adjacency lists, storing the adjacency lists of the vertices in large shared arrays and keeping indexes into these shared arrays. These optimizations allow the rapid fetching of all outgoing edges of a vertex and the sampling of random outgoing edges efficiently.

Random walks, which lie at the core of plenty of graph recommendation algorithms, are implemented in Cassovary using the Monte-Carlo method, where the walk is carried out from a vertex by repeatedly picking a random outgoing edge and updating a visit counter. This approach is well known to approximate the stationary distribution of random walk algorithms such as personalized PageRank. While the convergence rate is not as fast as that of a standard matrix-based implementation, the memory overhead per individual walk is quite low, since it's only necessary to maintain the visit counters for vertices that are actually visited. This allows Cassovary to make use of multi-threading to parallelize many random walks.

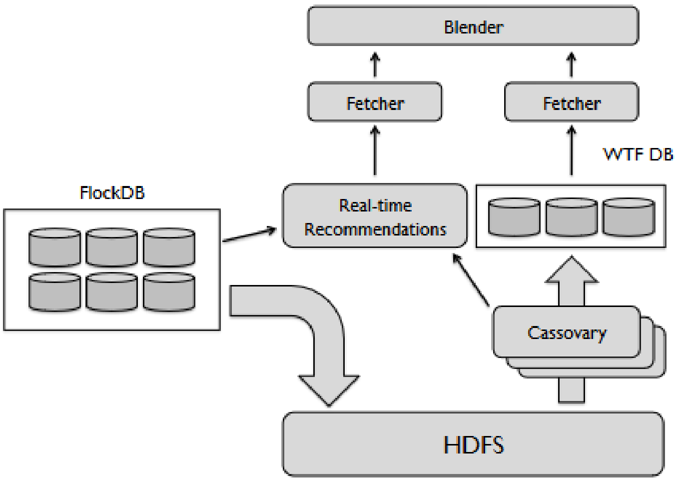

Figure 2: Overall architecture of Twitter's "Who to Follow" user recommendation service

3.2.1.6. Circle of Trust

The Circle of Trust (CoT) is a technique that underlies many of the user recommendation algorithms. Given a set of parameters like the number of random walk steps to take, the reset probability, the CoT makes content for the users in one's circle of trust upweight in relation to others. Also, CoT is the basis for the SALSA algorithm.

The random walk is made from scratch every time, gaining the advantage of always having fresh results, as well as dynamically adjusting the parameters and the target of personalization based on the particular application, for instance, it is just as easy to compute the circle of trust for a set of users as it is for a single user.

3.2.1.7. SALSA for User Recommendations

As mentioned in section 3.2.1.1, the "follow" relationship is asymmetric. This differs from social networks like Facebook, where the consent of both participating members is required, thus making the relationship symmetric. Consequently, much of the literature on user recommendation assumes undirected edges. Twitter's case is more analogous to the user-item recommendations problem, but with a twist: the "item" is another user.

Following lengthy experimentation, an effective user recommendation algorithm was developed, based on SALSA (Stochastic Approach for Link-Structure Analysis), originally developed for web search ranking. It belongs to the same family of random-walk algorithms as PageRank and HITS. It constructs a bipartite graph from a collection of websites of interest (two sides, "hubs" and "authorities").

In contrast to a "conventional" random walk, each step in the SALSA algorithm traverses two links (one forward and one backward). SALSA was adapted for user recommendations as shown in Figure 3. The "hubs" side is populated with the user's circle of trust, which is computed based on the previously described egocentric walk. Approximately 500 top-ranked nodes from the user's circle of trust are used. The "authorities" side is populated with users that the "hubs" follow.

After the construction of the graph, multiple SALSA iterations are run, assigning scores to both sides. Next, the vertices on the right side are ranked by score and treated as standard user recommendations. The ones on the left side are ranked as well; this ranking is interpreted as similarity. These suggested recommendations could also be presented, given the homophily principle, despite being qualitatively different. These are also used as a source of candidates for Twitter's "similar to you" feature.

Thus application of SALSA mimics the recursive nature of the problem itself. A user *u* is likely to follow users who are followed by users similar to *u*. These are, in turn, similar to *u* if they follow similar users. The SALSA iterations operationalize this idea by providing users similar to *u* on the left side and similar followings of the ones on the right side. Equitable distribution of scores out of the nodes in both directions is ensured by the random walk. In addition, the construction of the bipartite graph ensures similar users are chosen from the circle of trust of the user, which is the product of a good user recommendation algorithm (personalized PageRank).

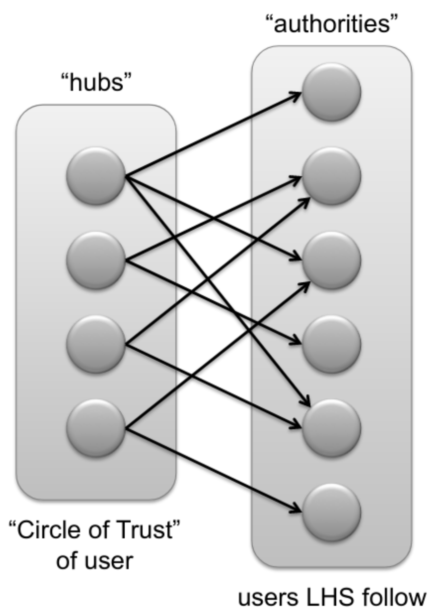

Figure 3: Illustration of SALSA-based algorithm for generating user recommendations.

3.2.1.8. Evaluation

Continuous evaluation is critical to the long term success of any system and monitoring core metrics isn't enough. To better reach that goal, it is necessary to tweak old algorithms and experiment with new ones.

There are two types of evaluations:

- Offline experiments on retrospective data: An evaluation that would most likely use a graph snapshot from a time period. Relevant parameters and metrics would be computed against the current model.
- Online A/B testing on live traffic: A small fraction of live users are subjected to alternative treatments, like algorithms. Then, it's analyzed what metrics are relevant.

In the beginning, WTF worked almost exclusively on A/B testing, because it had the need to experiment to match production conditions as much as possible and applying the algorithm in a live section has allowed the evaluation of the entire context, not only the algorithm itself.

The downside of A/B, however, is that it needs sufficient traffic to accumulate in order to draw reliable conclusions, which limits the speed at which we can iterate. Because of that negative aspect, it was a necessity to implement offline experiments as well.

4. Empirical Experimenting

In this section, we created a brand new email account and Twitter account to explore what Twitter has to show. At first, it suggested some general topics to follow with the goal of providing content for the timeline. Then, it displayed a list of popular accounts to follow as well. However, in this last part, the user is forced to follow an account, without providing a way to search. You must choose one from the list, as the continue button is disabled if until you have selected something. Nevertheless, it is possible to get around this by refreshing the page, but this is not what an end-user has in mind at first glance.

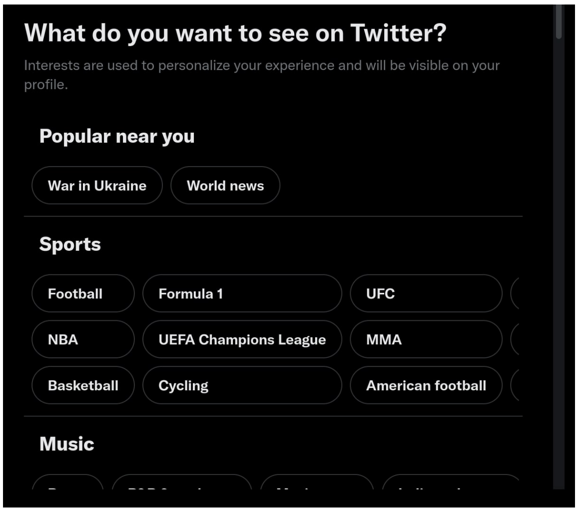

Fig. 4: Initial topics to follow when creating a new account.

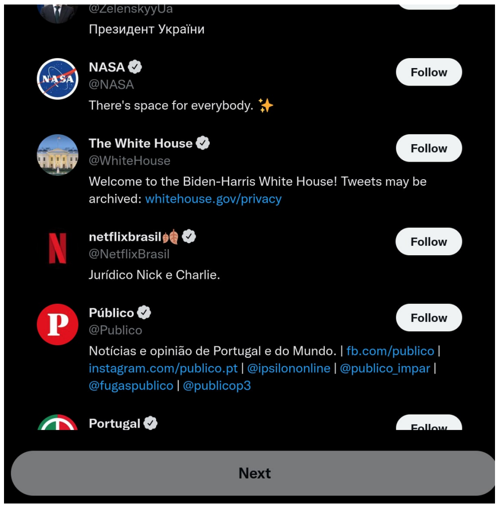

Fig. 5: Initial accounts to follow when creating a new account.

Because Portugal is the region where this account was created, there were a lot of Portuguese accounts to follow. There were also popular American ones. The empty timeline had no content, since we had not followed anything, but there is a list of "starter recommendations", as well as current trends. To start, we followed Cristiano Ronaldo's account and soccer-related themes immediately started to pop up on our timeline.

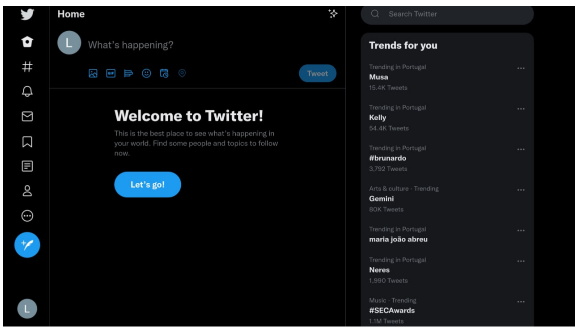

Fig. 6: Timeline without any followers.

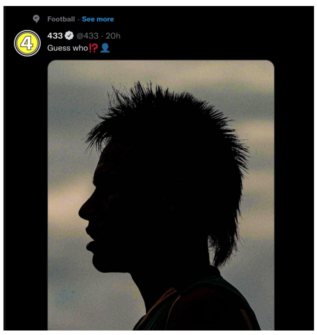

Fig. 7: Timeline with soccer related topics after following Cristiano Ronaldo's account.

With the objective of finding how long it took to fall into an echo chamber, we began to follow US Republicans' accounts. It is very likely that in normal use it would take a longer time to get similar results, but the point is that it is quite easy to reach echo chambers.

After following Lauren Boebert, Madison Cawthorn and Rep. Andy Biggs, along with the previously followed Cristiano Ronaldo, strong one-sided opinions about trans people began to show up. After following random accounts on the "Who to follow" section, we found ourselves in a strong right-wing social circle.

Fig. 8: Tweet against trans people on the timeline.

Fig. 9: Anti-vax adjacent tweet on the timeline.

Fig. 10: A verified user expressing a radical opinion, with reference to the death penalty.

It must be noted that, at that moment, we were still following soccer-related accounts to mix things up. We concluded it was fairly easy to get a specific, and sometimes extremist timeline, leading to echo chambers.

5. Social and Economic Implications

5.1. Social Implications - Twitter as the World Stage

5.1.1 - The Twitter Character Limit…

(The effects of Twitter on interpersonal conversation)

One of Twitter's defining features is its **character limit** on posts, which has been steadily increasing since its inception. Restricting people to **280** characters at a time might not seem like much more than a quirk, but in reality, it has served to intensify the already complicated relation between social media and healthy interpersonal communication.

5.1.1.1 - … And How Nuance Became A Thing Of The Past

(How polarized hyperbole becomes the norm)

Arguably the most immediately apparent consequence, in 280 characters (often) there isn't enough space for nuance and context for most affirmations will be thrown out of the window, distilling opinions to their most basic forms, turning them into hyperbole. Conveying complex topics in such a limited space is a recipe for disaster, since simplifying these will often lead to loss of essential information. Overtime, these simplifications layer over each other, turning into outright lies or misinformation, content and users becoming more and more polarized, and along the way truth is lost in favor of easily digestible talking points.

5.1.1.2 - … And How Outrage Became A Thing Of The Present

(The fall of discussion and defeating logic with defensiveness)

Nowadays, the highest-valued metric in modern social media is **interaction.** A post's worth is measured in how big a response it obtained, measured via multiple metrics such as 'Likes' and 'Shares' (Particular nomenclature varies across platforms but the base concept doesn't.) among many others, this data being some of the most valuable resources a social media platform can harvest. However, the attention generated doesn't need to be good - any reaction is a good reaction, in Twitter's eyes

As explained before, Twitter's algorithms value sharp spikes in interest. Well, there's nothing that gets as big an explosive reaction as negative attention. Be it drama or an outrageous take, it has long been exploited by, among other examples, populist movements, and Twitter too takes advantage of it. As stated previously, and relevant here, the short format doesn't allow for complex, nuanced discussion, instead favoring short, sharp attacks.

Instead of nuanced, constructive discussion, where your opinions and ideas are challenged but ultimately both sides come out more robust, more well-informed after being exposed to differing perspectives, Twitter enables and promotes hyperbolic clashes of ideas where no one is truly trying to listen and learn, but to get their opinion to prevail over the others at all cost, becoming more defensive and aggressive, closing channels of communication and writing off swaths of people with different opinions as extremists with whom no debate is possible.

5.1.1.3 - … And How Isolation Became A Thing Of The Future

(Echo Chambers and how being so connected has never made us more separated)

By completely writing off differing ideas (that have since been reduced to a husk of what they might once have been, hyperbolized and simplified to an unhealthy degree), we end up with people closed off to new ideas, and since social media preys on some of our most hard-wired needs for **social validation**, our brains being very receptive to information that confirms their previous biases. And thus, the dreaded **echo chamber** is born. We've discussed how these are created, but what are they exactly?

An echo chamber is essentially a closed-off group where there is one "valid" set of ideas that are endlessly repeated and reaffirmed, bolstering and encouraging those who agree while completely shutting out any disagreement. Along the way, criticism is silenced and the polarization mentioned before intensifies.

These isolated bubbles of thought, besides being very easy targets to manipulate and weaponized as misinformation super-spreaders, appeal to the very tribal nature of the human being - "You're either with us, or against us." - which goes against the original idea of "social" networks. Instead of connecting us with people different from ourselves, opening our minds to new ideas and enriching our knowledge of the world, communication breaks down, people are pushed further apart and we, so sure in our absolute beliefs, reject any outside challenge.

Twitter is definitely not unique in this regard, but it has certain characteristics that do exacerbate this extremely dangerous phenomena - people aren't radicalized in a day, but Twitter certainly enables and hastens it. (Engagement brings the platform profit, after all. If people are busy arguing, they won't notice nor care about their data being harvested.)

5.1.2 - Virtual Influencers, Online Celebrities, and real-world consequences

(When all voices are equal, no one is)

Twitter and other social networks take great pride on “giving everyone a voice”. However, this couldn’t be much farther from the truth. Someone with a larger following inherently has a larger outreach, and due to the closeness of twitter, (Everyone is a search away) far more influence.

Never before has someone been able to amass a horde of rabid followers as easily, who mostly follow every instruction. As such, drowning someone out is a matter of numbers and being the loudest voice in the room, not being correct or even truthful.

People with already large followings in the real-world find themselves having a huge sway online over people more qualified to talk about a certain topic, and since with a following comes credibility, a very disproportionate capability to influence, sometimes in malicious ways. With this comes a huge social responsibility that’s often ignored, sometimes in ignorance, others in malice.

However, people online aren’t held up to the same standards as offline. Casual manipulation takes place at all times (Mentioning a product when you have a following of millions, even in passing, is an endorsement of said product, even unintentionally) and not only in a marketing way, but also in behaviors and opinion. Masses are easily swayed when faced with a sea of discording voices.

5.2. Economic Implications - Twitter as a Promotion Platform

Twitter has evolved past being just a social platform, with many people and corporations using it to promote their activities, be it business or other endeavors. Indeed, Twitter is a marketing goldmine and any well-known businesses are sure to have an online presence there, to maintain a good public image and reach out to new audiences. In fact, Twitter offers a feature called “Promoted Tweets”, which allows users to pay to have a tweet exposed to more users, essentially advertising their accounts. Besides, a Tweet can reach thousands of people for a fraction of the price of a TV commercial or billboards on streets, making it a much more accessible avenue for marketing.

In the last decade, more and more brands have joined Twitter, as a new way to reach potential customers. By capitalizing on trends, such as putting their own spin on a popular “meme”, or commenting on current events and interacting with users directly, they generate traffic and draw attention, getting a boost for participating in trends.

Fig. 11 - A tweet from Domino’s Pizza capitalizing on Wordle’s popularity

Among those who promote on Twitter, there are also influencers – people with large followings who accept sponsored deals to divulge the sponsor’s product to their follower base, therefore “influencing” them. Internet personalities can garner a sizable audience, who trust their opinions and lifestyle choices. These users provide a valuable means for marketers to expand their reach to new audiences, beyond the scope of what traditional ads can accomplish as it's not just the content of the advertisement that matters, but who is advertising it, which carries a significant weight to the effectiveness of the ad.

But promotion doesn’t stop on a few accounts’ activity. While an account with a large following may be effective, the sway the word of many holds cannot be underestimated. Hearing a recommendation from a brand or influencer may not be enough to convince some people, but a multitude of users vouching for the same thing can be more persuasive. This sort of “word of mouth” promotion strategy is often employed in a platform like Twitter, sometimes through less ethical means like bot accounts and paid actors.

Finally, marketing on a social media platform like Twitter can be targeted, meaning users see promoted material based on their interests, which Twitter infers from their followed accounts, liked tweets, and other data they may collect.

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