

Characterizing Group-Level User Behavior in Major Online Social Networks

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ABSTRACT

In this paper, we conduct a detailed measurement study to characterize and compare the “group-level” behavior of users in Facebook, Twitter and Google+. We focus on Popular, Cross (with account in three OSNs) and Random group of users in each OSN since they offer complementary views. We capture user behavior with the following metrics: user connectivity, user activity and user reactions. Our group-level methodology enables us to capture major trends in the behavior of small but important groups of users, and to conduct inter- and intra-OSN comparison of user behavior. Furthermore, we conduct temporal analysis on different aspects of user behavior for all groups over a two-year period. Our analysis leads to a set of useful insights including: (i) The more likely reaction by Facebook and Google+ users is to express their opinion whereas TW users tend to relay a received post to other users and thus facilitate its propagation. Despite the culture of reshare among Twitter users, a post by a Popular Facebook user receives more Reshares than a post by a Popular Twitter user. (ii) Added features in an OSN can significantly boost the rate of action and reaction among its users.

Keywords

OSNs, Measurement, User Popularity & Activity & Reactions, Connectivity

1. INTRODUCTION

Major Online Social Networks (OSNs) such as Facebook or Twitter are among the most popular services on the Internet with billions of subscribers and hundreds of millions of daily visitors. OSNs enable individual users to connect to other participating users, disseminate any information

through the network while collecting the reactions from other users without any geographic or time constraint. These unique capabilities have motivated different entities, ranging from individuals and celebrities to companies and sport teams, to join OSNs often with different goals. For example, OSNs enable individual companies to closely interact with their customers and obtain feedback on their products. The growing popularity of major OSNs has effectively turned them into “online societies” with a profound impact on the social, political and economical aspects of our daily lives.

Despite the growing importance of large OSNs, the basic aspects of user behavior with respect to generating information and reacting to received information are not well understood. In particular, some basic characteristics of *user activity* (e.g. How often do users publish an original post or reshare an existing post? What type of posts are more common?) or user reactions (e.g. How large is the number of reactions (of different types) to a post? Whether the type of posts affects the level of reaction? Whether user reactions to a post facilitate its propagation or offer local feedback?) are generally unknown in a large OSN. Shedding any light on these fundamental questions not only informs current users of an OSN that to what extent this OSN might serve their goals but also enables non-member entities to assess whether they should join this OSN. To underscore the importance of these issues, it is worth noting that many companies pay large premium in order to develop strategies for managing their connections, activity and received user reactions in a major OSN.

Characterizing user behavior in major OSNs is challenging primarily because the distribution of most user characteristics is very skewed and shows a wide variations [?]. Since the absolute majority of participating users in a major OSN have a small degree and low (or moderate) level of activity, characterizing user population presents the behavior of “the crowd”. However, such analysis does not provide any insight on the behavior of tiny but important fraction of users (e.g. users with a very large degree). In the face of these difficulties, a large body of prior empirical research on OSNs has often focused on specific characteristics of a single OSN such as user connectivity [?, ?, ?], evolution of OSN size [?] or user behavior [?, ?]. To our knowledge, none of the prior studies have characterized the key aspects of user behavior

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for different groups of users in multiple OSNs through active measurement.

In this paper, we characterize the “group-level” behavior of users in three major OSNs, namely Facebook (FB), Twitter (TW) and Google+ (G+). The first contribution of this paper is our methodology for group-level data collection and characterization of user behavior. Toward this end, we focus on the following three interesting groups of users that capture important and complementary subsets of user population in each OSN as follows: *Popular* users with a very large number of followers, *Cross* users with a verified account in all three OSNs, and *Random* users. Focusing on group-level (as opposed to user-level) behavior of users has two important advantages: (i) It allows us to identify major group-level trends and characteristics despite variations that might exist among users in each group, (ii) One can meaningfully compare the behavior of similar groups across different OSNs. Furthermore, comparing different groups within each OSN often offers valuable insights. We consider three sets of metrics to characterize different aspects of individual users’ behavior in each group: *the connectivity* of the user to the network, *the activity* of the user with respect to publishing posts, and *the reactions* of other users (e.g. likes and comments) to the user’s posts.

The second contribution of this paper is a detailed measurement study that presents a head-to-head, group-level comparison between FB, TW and G+. We carefully populate the three target groups in each OSN, collect their information using customize crawlers and characterize their group-level user behavior using our three sets of metrics as we present in Section 2. In particular, focusing on the Cross group presents a novel approach to investigate user behavior in the ecosystem of these three OSNs. Using the collected information for users in target groups, we conduct group-level analysis of user behavior by examining their connectivity and account age (in Section 3), different aspects of user activity (in Section 4.1) and several aspects of user reactions (in Section 5). We explore the correlations between different aspects of user behavior in Section 6. In Section 7, we conduct temporal analysis on the daily rate of actions and reactions for each group in different OSNs to examine their short-term evolution and identify the key events that influence user behavior. We discuss the related work in Section 8. Section 9 concludes the paper and summarizes our future plans.

Some interesting highlights of our head-to-head, group-level comparison of major OSNs are as follows:

User Activity: User activity is skewed in all groups and the decreasing order of activity among groups in each OSN is Popular, Cross and Random. Popular FB and G+ users exhibit a rather similar rate of activity which is roughly an order of magnitude less than Popular TW user. Cross users publish posts on TW and FB at a much higher rate than G+. One-third of TW and G+ users and one-fifth of FB users have probably abandoned their OSN or at least they do not actively publish. In each OSN, Random users publish more original posts whereas Cross and Popular users primarily relay the post from other users. All TW users generally reshare post much more often than G+ users. Cross users have a tendency to publish “Link” post while Popular (FB and G+) groups publish “Photo” post more often than other groups

User Reaction: Only published posts by Popular groups in all three OSNs attract a non-negligible number of reactions where roughly 10% of posts receive 80% of all reactions of any type. The number of reactions (of any type) to posts by Popular FB users is a couple of orders of magnitude larger than Popular G+ users. The culture of reaction varies among users in different OSNs. FB and G+ users are more likely to react by expressing their own opinion through Likes and Comments whereas TW users more often tend to relay a post to other users and thus facilitate its propagation. Despite this difference in the culture of reaction, a post by a Popular FB user typically receives 75% more Reshares than a post by Popular TW user. However, the significantly larger activity rate of Popular TW users results a higher rate of daily reaction for them. The number of reactions seem to be correlated with post type which is decreasing in the following order: Photo, Video, Text and Link

Temporal Analysis: The daily rate of activity in all groups exhibits a persistent growth with a higher pace for Popular and Cross groups during the past two years. The activity of all TW groups is consistently higher than the corresponding FB group and a couple of order of magnitude larger than the corresponding G+ groups. The introduction of new features by different OSNs (in particular FB) has led to a significant and long-term increase in the activity of their users. This growth in the activity is driven by the increasing number of users and the higher rate of activity among them. The rate of Likes is much higher for FB groups. As a result of two newly-added features by FB, the rate of observed Reshare reaction by FB users has dramatically increased and clearly surpassed the observed rate by TW users despite the fact that resharing is a native feature in TW. Cross users publish post on TW at a higher rate than FB but receive a larger rate of Likes, Comments and even Reshares from FB users.

2. METHODOLOGY & DATASETS

Characterizing user behavior is challenging because user attributes often exhibit a very skewed distribution in major OSNs. Therefore, any characterization of the overall user population in an OSN would primarily represent a significant number of low-degree and moderately active users. Clearly such characterization does not reveal much about other important group of users (e.g. users with a high node degree) if they only compose a very small fraction of total user population. Furthermore, the characteristics of individual users in a specific group may also significantly vary. To cope with these issues, we conduct our analysis at the group-level rather than user-level since the collective characteristics of users in a group offer a more reliable measure of their behavior. We consider the following three groups of users that intuitively represent complementary subsets of user population in each OSN:

- *Random Users* provide a global view of user population that primarily represents a large fraction of typical users with moderate to low connectivity and activity (i.e. the crowd).
- *Popular Users* attract the largest number of followers in an OSN and thus represent the most visible (i.e. well connected) accounts in an OSN.

Table 1: Basic characteristics of the collected datasets for Random, Cross and Popular accounts in all three OSNs.

OSN	Dataset	Crawl Information		Aggregate Information for Users Per Group						Per-User Average Information	
		Start date	Duration	#Posts	#Followers	#Friends	#Likes	#Comments	#Reshares	#Followers	#Collected Posts
FB	Popular	3/12/2013	9 days	14.4 M	19.4 B	-	21.3 B	1.8 B	2.9 B	2.6 M	1.6 K
	Cross	4/27/2013	3 days	3.85 M	620 M	-	447 M	37.8 M	33 M	84.5 K	525
	Random	4/28/2013	2 days	902 K	8.1 M	-	6.3 M	1.1 M	1.6 M	1102	123
TW	Popular	4/28/2013	5 days	20.1 M	6.9 B	136 M	4.5 B	-	13 B	947 K	18 K
	Cross	4/28/2013	4 days	7.9 M	220 M	6.4 M	78.4 M	-	188 M	30 K	3 K
	Random	4/28/2013	2 days	997 K	264 K	414 K	175 K	-	320 K	36	358
G+	Popular	5/27/2013	1 days	7.1 M	1.5 B	5.4 M	358 M	116 M	40 M	200 K	966
	Cross	5/27/2013	1 days	435 K	83.5 M	874 K	4.9 M	1.3 M	669 K	11 K	59
	Random	5/27/2013	1 days	22 K	77 K	120 K	18 K	7 K	2.6 K	10	3

- *Cross Users* represent samples of users that have an account in all three target OSNs. Having a concurrent footprint in all three OSNs suggests the particular interest among these users and a special role that they might play in the overall ecosystem of major OSNs.

Considering these three groups in each OSN enables us to conduct meaningful comparisons between different groups within each OSN or similar groups across different OSNs without the need for capturing a complete snapshot of individual OSN which is not often feasible. While we generally refer to an account in each OSN as a “user”, each account can clearly represent many other entities ranging from celebrities and politicians to companies and sport teams. Next we briefly describe our techniques for populating each group.

Random Users: Given various constraints for data collection from each OSN, we need to use a different approach to select random users in each OSN: For G+, we have collected a snapshot of the largest connected component (LCC) of the network and selected a random subset of LCC users. FB offers two types of accounts: (i) *regular accounts* and *fan pages*. Regular accounts are created by individual users and their number of friends is limited to only 5K¹. Fan pages, however, are created by individuals, groups and companies in order to broadcast information to their fans as they do not have any limitation on the number of followers. In order to properly compare inter- and intra-OSN comparison between groups, we only focus on random fan pages (or pages) in FB. FB provides an indexed list of all the fan pages², that allows us to easily identify a random subset of these users. Finally, we select random TW users by examining random IDs that are associated with valid users [?]. Toward this end, we monitor TW’s public timeline to detect some of the newly generated accounts and use a conservative estimate for the valid range of ID space.

Popular Users: This group includes accounts with a very large number of followers (i.e. popular users). In G+, we have selected accounts from the LCC with the largest number of followers. Since capturing a complete snapshot of TW and FB is not feasible due to their large size and the limitations imposed by their APIs, we have relied on external sources³ to obtain sorted lists of 20K most popular users. We have crawled the reported 20K most popular users in each OSN to collect their up-to-date number of followers and determine their proper ranking within the list. Our approach to identify popular users is reasonable since (i) very popular users in major OSNs are often well-known in the marketing

and social-media communities, and (ii) potentially missing few popular users from this group should not qualitatively affect our analysis.

Cross Users: Identifying users that have an account in all three OSNs is a non-trivial task. To achieve this goal, we leverage the explicit links that G+ users provide to their FB and TW accounts in their profiles. We examined all G+ users within its LCC and identified all G+ users with explicit links to their TW and FB accounts. We filtered users who provided more than one links to another OSN⁴ and identified 7.3K G+ accounts with exactly one link to FB and TW. We have manually inspected some of these “triplet accounts” and confirmed that they are associated with the same individual user or company in all cases.

While we have a large number of random and popular accounts from all three OSNs, we limited the number of users in all groups to 7.3K (i.e. the size of the Cross group) in order to ensure a proper comparison.

2.1 Collected Information

We have developed a separate crawler for each OSN that uses its API features to collect the following information for the selected users in each group:

- *User Profile:* The profile provides the number of followers and friends and (in some OSNs) the creation time of user account. If account creation time is not explicitly specified in the profile, we use the time of first user post as a good estimate for its creation time.

- *Account’s Activity:* all the public posts (or tweets) generated by the user along with their timestamps. This information enables us to classify collected posts based on their content into five categories: “text”, “video”, “photo”, “link” and “other”⁵. Examples of Other post types are check-in in FB and Hangout in G+. One limitation in collecting account activity is that Twitter only provides the last 3,200 tweets for each user. This implies that the captured tweet history for very active Twitter users could represent a limited recent window of time. We discuss the implications of this limitation on our analysis in Section 7. Throughout the paper we use the terms post and tweet interchangeably.

- *Reactions to Posts:* For any captured public post, we also collect all the following types of public reaction to the post: (i) Likes (in FB), +1s (in G+) and Favorites (in TW) are reactions by other users who indicate their interest to a post; (ii) Shares (in FB), Reshares (in G+) and Retweets (in TW) are reactions by which a user relays a received post to her followers; (iii) Comments on a post are (positive or negative) reactions by other users. Note that TW support for

¹We recall that connections between FB users are bidirectional. Thus, the number of followers and friends for each user is the same.

²<https://www.facebook.com/directory/pages>

³www.socialbakers.com, www.alianza.com, www.twitaholic.com

⁴Our closer inspection revealed that some of these users improperly set these links, e.g. listing links to their favorite accounts in another OSN.

⁵Twitter only supports “text” and “link” type of posts.

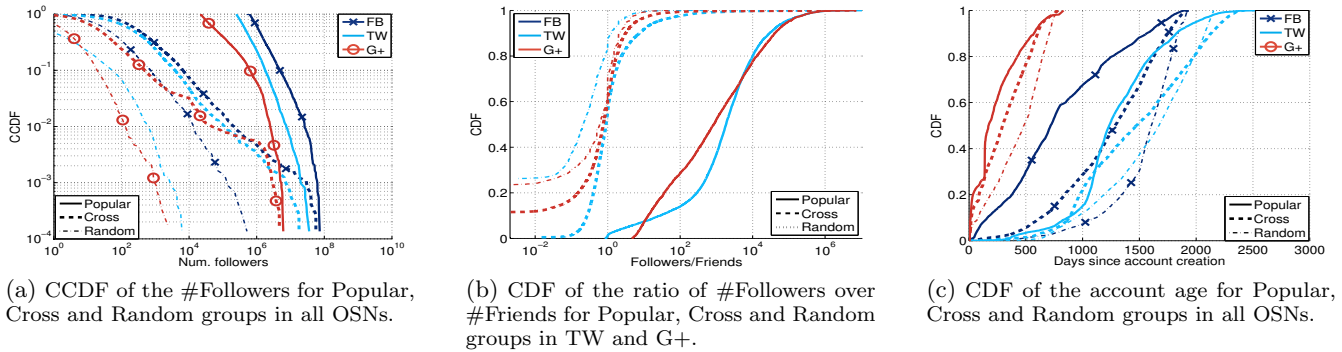


Figure 1: Basic user characteristics in different groups of each OSN.

comment reactions does not exist in TW API. For clarity of discussion in the rest of the paper, we will refer to these types of reactions as Likes, Reshares and Comments, respectively. Further details about our crawlers and their performance is available in the related technical report [?].

We re-emphasize that our crawlers only collect publicly available information. Prior studies have reported that 6-8% of Twitter accounts are private [?, ?] whereas roughly 33% of posts in G+ are public [?]. Furthermore, all the posts published by FB pages are public by definition. Table 1 summarizes the basic information for the datasets associated with our three target groups in each OSN in three sections as follows: (i) the start time and duration of crawl for each dataset, (ii) the aggregate number of posts (and some other attributes) among users in each group, and (iii) per-user average of number of followers and posts. The provided user types by FB users reveal that Cross users compose of more than 150 FB account types (with a skewed distribution among them) and the top three types are Musician band (12%), Local business (9%), and Artist (4%). While we have selected each dataset independently, there is a negligible number of overlapping users (< 50) between the popular and cross groups in each OSN.

3. CONNECTIVITY & ACCOUNT AGE

In this section, we briefly examine the connectivity of individual users and their account age. These basic characteristics of target groups not only provide useful context for the rest of our analysis but can also be viewed as a part of group-level behavior. Figure 1(a) depicts the CCDF of the number of followers for users in each target group using a log-log scale. Groups associated with each OSN are shown with a different colors using a different line type for each group. Figure 1(a) demonstrates that the distribution of number of followers (i.e. out-degree) among users in each group is much less skewed than the entire user population as it was reported in prior studies (e.g. [?, ?, ?, ?]). Furthermore, Popular users in all OSNs exhibit a larger variations in their out-degree. We observe a clear separation in the popularity of groups in different OSNs where FB is the most and G+ is the least popular among similar groups. For instance, the median number of followers among Popular FB, TW, and G+ users are 1.92M, 490K and 41K, respectively. Figure 1(b) presents a complementary aspect of user connectivity by depicting the CDF of the ratio of #followers to #friends for individual users in TW and G+ group. This figure clearly illustrates that the connectivity of Popular users

is very imbalanced as they have thousand times more follower. The connectivity of Cross users is relatively more balanced and this group contains users with more followers and users with more friends. The Random group also has a relatively balanced connectivity but its fraction of users with more friends is larger than Cross group.

Figure 1(c) shows the CDF of account age (i.e. the time between the account creation and our data collection time⁶) for users in each group. We observe that accounts in TW groups are rather older than FB and much older than groups in G+. Interestingly, the relative age of accounts among three groups in each OSN is similar, with Random accounts are generally older and Popular accounts are generally younger than other groups.

4. USER ACTIVITY

This section focuses on the group-level analysis of user activity in the three OSNs from a few different angles. By “activity”, we refer to a user action that leads to the generation of a post (or tweet). The published post can be original or reshare of another user’s post.

4.1 Average Activity Rate

We use the average post rate of a user in terms of the number of posts per day as the basic indicator of her level of activity which is independent of her account age. Figure 2 shows the summary distribution of activity rate among users in each target group for all three OSNs using the boxplot format (representing 5th, 25th, 50th, 75th and 95th percentiles) with log scale y axis. This figure reveals the following interesting points: First, within each OSN, the relative order for user activity from high to low is Popular, Cross and Random group. This relative ordering is more pronounced in TW and G+. The activity rate within each group often varies around two orders of magnitude. The skewness in the distribution of activity rate in all groups varies among different groups. In all popular groups as well as cross group in FB, the top 20% of users generate roughly 66% of daily posts. However, the top 20% of users in the cross groups in TW and G+ and random group in FB are responsible for 80%-90% of all posts in their group. The contribution of users in random G+ and TW is the most skewed with 5% of users responsible for 90% of the posts. Second, comparing the activity rate of popular users across three OSNs indicates that popular

⁶Since FB and G+ do not explicitly provide the account creation time, we estimate it using the time of the first post.

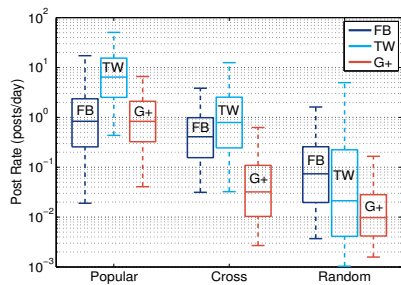


Figure 2: CDF of avg. number of daily posts per user

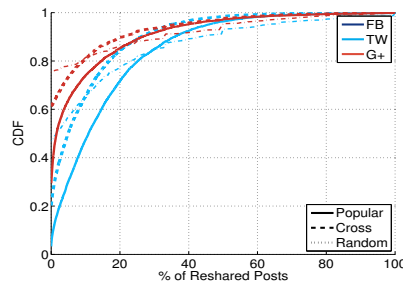


Figure 3: CDF of avg. percentage of reshared posts per user

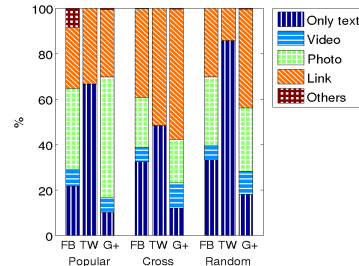


Figure 4: Percentage of post of each type for FB, TW and G+

FB and G+ users exhibit a rather similar rate (with respect to the median and the range of values) which is roughly an order of magnitude lower than popular TW users. Third, the activity rate of cross users on TW is the highest (with the median value of 1 post/day) which is followed by their posting rate on FB (with the median value of 1 post every 2.5 days). These users post on their G+ accounts at a much lower rate of once a month. Fourth, among the Random groups, FB is the most active one which is followed by TW and G+. For example, a typical FB, TW and G+ user publishes 0.07 posts/day, 0.02 posts/day, and 0.01 posts/day, respectively. Random TW users show a significantly larger variation in their activity rate compared to user in other Random groups.

4.2 Abandoned Accounts

The average activity rate of a user only offers a coarse measure of the overall rate that a user generates posts over the age of her account. More specifically, the activity rate does not directly indicate whether a user regularly visit her account to publish post or not. For example, a user might be very active for a period of time and then never login to her account. While it is difficult to reliably determine whether a user has really abandoned her account, the ratio of the time since a user’s last post to her average inter-post time offers a good estimate for the likelihood that the user has abandoned her account. For instance, account of a user who publishes one post a week on average but has not published for the last 20 weeks, can be view as abandoned. If we assume that the ratio of 20 or more indicates an abandoned user, then roughly 35% of all TW and G+ users and 20% of all FB users have abandoned their OSNs. A more conservative ratio of 40 reduces the percentage of abandoned users to 10% for all OSN.

4.3 Posting vs. Resharing

To gain a deeper insight on the activity of different group of users, we examine the fraction of their reshared posts, i.e. posts that they relayed from other users. This demonstrates to what extent users in each group publish original posts instead of propagating other users’ posts. Since FB API does not provide this information, we only consider TW and G+ for these analysis. Figure 3 plots the fraction of original posts by individual uses in different groups in G+ and TW. The fraction of Random, Cross and Popular user that only send original posts are 83%, 65% and 40% in G+ and 60%, 30% and 18% in TW, respectively. The fraction of Random, Cross and Popular users that only send original posts are

75%, 61% and 29% in G+ and 48%, 24% and 5% in TW, respectively. Therefore, in each OSN, Random users send most original posts while Popular users send the least. In short, users in each G+ group clearly publish more (often double) original posts than the corresponding group in TW.

4.4 Types of Posts

We now examine the activity of users in different groups with respect to post type. Each vertical bar in Figure 4 depicts the fraction of all posts in each group across different post types, namely “Text”, “Video”, “Photo”, “Link” and “Others”. We recall that TW users only generate two types of posts, “Text” or “Link”. This figure demonstrates the following points about the type of generated posts by all users in each group: (i) The combination of “Text”, “Photo” and “Link” posts represent more than 85% of posts in all FB and G+ groups. Despite its increasing contribution in the Internet traffic [?], the “Video” posts only comprises 6%-11% of posts in these OSNs. (ii) Popular G+ users show a clear preference for “Photos” which makes up more than half of their total posts. (iii) “Link” is the dominant post type among Random G+ and all Cross users. (iv) We observe a larger fraction of “Text” posts among users in all FB groups (21-33%) than the corresponding G+ groups (10-18%). This suggests that users in all FB groups are more likely to express themselves using text posts than G+ users. (v) Popular and Random TW users show a clear preference for “Text” posts that makes up roughly half of posts among cross TW users.

We also examined the fraction of post types across all posts by individual users in each group and observed that this fraction generally follows the distribution of all published posts by each group (Figure 4). Furthermore, we did not observe any measurable correlation between the activity rate of a user and its tendency to publish certain type of posts.

The summary of our main findings on group-level analysis of user activity is as follows: User activity is skewed in all groups and the relative order of activity among groups in each OSN is Popular, Cross and Random. Popular FB and G+ users exhibit a similar rate of activity which is roughly an order of magnitude less than Popular TW users. Similarly, Cross users publish posts on TW and then FB at a much higher rate than G+. FB and G+ group are the most and least active among the Random groups, respectively. Up to one-third of TW and G+ users and one-fifth of FB users might have abandoned their OSN or at least they do not actively publish. TW users generally reshare other users’ post

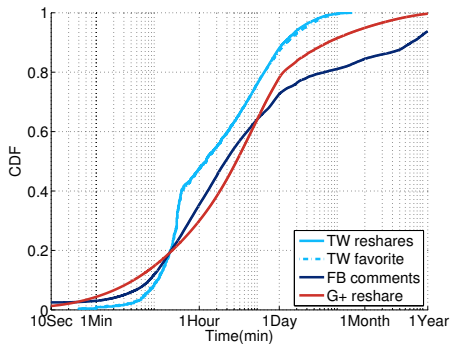


Figure 6: The distribution of the time between post creation and reaction across different target OSNs

much more often than G+ users. However, in each OSN, Random users publish more original posts whereas Cross and Popular users primarily relay the post from other users. Cross users have a tendency to publish "Link" posts while Popular (FB and G+) groups publish "Photo" posts more often than other groups.

5. USER REACTIONS

One of the main motivation for different entities (e.g. companies, brands, celebrities, politicians) to join an OSN is to obtain other users' reactions to their post. The level and type of reaction by users in an OSN depends on many factors including the popularity of certain type of reactions (i.e. its culture), its offered features for user reaction and possibly the content of a post. Therefore, characterizing user reactions in an OSN provides a valuable insight on how and why different group of users publish their information at that OSN. Toward this end, we consider user reactions at the group-level as a key aspect of behavior for individual groups in this section. In particular, we examine three types of reactions to each posts, namely Likes, Comments, and Reshares, as we described in Section 2. We do not consider Comments for posts in TW since its API does not provide this information.

Prior studies have reported that a significant majority of reactions to a post, regardless of its popularity, occurs within a short window (e.g. a day) after it is published [?, ?]. To validate this observation in our datasets, Figure 6 presents the distribution of time between creation of a post and individual reactions (of a certain type) across all posts of all users in our target groups.⁷ The figure focuses on the Reshare and Comment for G+ and FB, and Reshare and Like for TW. While the timestamp of the mentioned reactions are available for FB and G+, these information is not explicitly available in TW. In order cope with this limitation, we monitored all TW users in all three groups and collected their posts repeatedly every one hour for a week. This allows us to capture the number of new reactions that appear every hour. As the figure shows, 75% of all reactions to posts in TW, G+ and FB arrive within 0.5, 1 and 2 days, respectively. The short duration of the reaction window to individual posts implies that the level of reaction to

⁷We focus on a specific type of reaction for which timestamp information is available or can be obtained in some other ways.

a post can be properly measured by the absolute number of reactions rather than its rate.

5.1 Post-Level Reaction

We start by examining the distribution of the number of reactions (of each type) to individual posts across all generated posts by users in each group that are shown in three plots of Figure 5. This figure reveals the following important points: First, for any type of reaction, only posts of Popular users typically receive a significant number of reactions. In fact, except for the number of Likes for roughly half of the post from Cross and Random FB users, published posts by all other non-Popular users only receive a negligible number of reactions of any type. Furthermore, the distribution of reaction per posts across all groups are very skewed with roughly 10-15% of posts attracting 80% of all reactions. Second, we observe that posts by Popular FB users typically attracts one to two orders of magnitude more reactions than posts by Popular G+ users for any type of reactions. Popular TW users attract the lowest number of Likes. Surprisingly, despite the fact that Reshare is a common reaction type in TW, posts by Popular FB users receives more Reshares than posts by Popular TW users. Third, for posts by Popular FB users, the median number of Likes, Comments and Reshares is 625K, 60K and 44K, respectively. We observe a very similar trend between different types of reactions to posts by Popular G+ users. In contrast, the typical number of received Reshares for published posts by TW users is more than three times larger than the number of received Likes. We note that Like and Reshare reactions require a similar effort (i.e. one or two clicks depending on the OSN) while Comments demand more effort (i.e. writing some text) from reacting users. Furthermore, given the large number of followers for Popular users, the observed reaction to their post offers a reliable view of user reactions in an OSN. Therefore, these results collectively suggests that FB and G+ users are more interested to express their own opinion through Like and Comment reactions rather than relaying a post to other users. In contrast, TW users three times more likely to relay a post and facilitate its propagation throughout the TW network. Despite this difference in the culture of reaction, a post by a Popular FB user receives 75% more Reshares than a post by Popular TW user.

5.2 Daily User-Level Reaction

Reactions can also be viewed at the daily basis for each user which shows the aggregate number of reactions that a user receive to all her published posts in one day. We refer to this view as the daily user-level reaction which is clearly a byproduct of the user's average daily published rate and the average number of reactions (of each type) to each post. Figure 7 shows the distribution of daily user-level reactions across users in each group. These distributions exhibit trends that are qualitatively similar to the distribution of post-level reaction (shown in Figure 5). The only exception is the distribution of daily user-level Reshares that is shown in Figure 7(c). Comparing the distribution of daily user-level and post-level Reshare for Popular FB and TW users reveal the following interesting point. Posts by Popular FB users typically attracts more Reshares than posts by Popular TW users. However, because of a significantly larger activity rate among Popular TW users (demonstrated in Figure 2), the daily user-level reaction for Popular TW

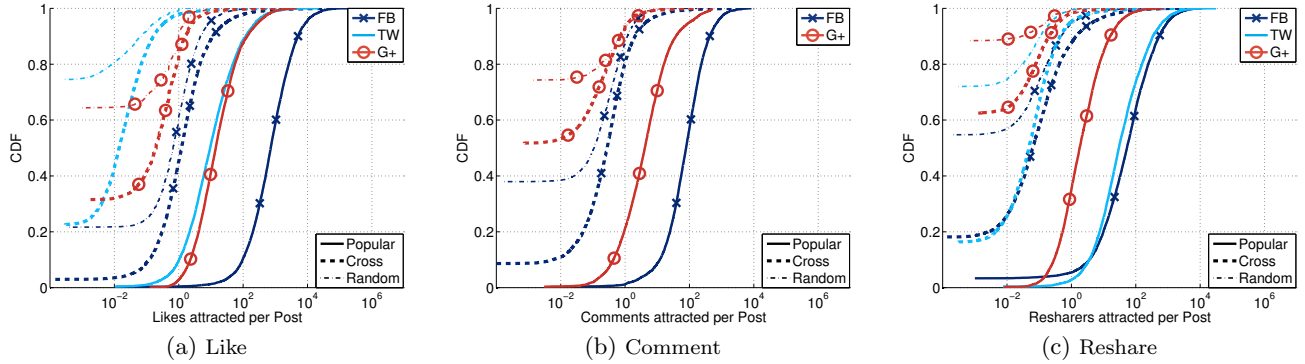


Figure 5: CDF of average number of reactions received per user per post

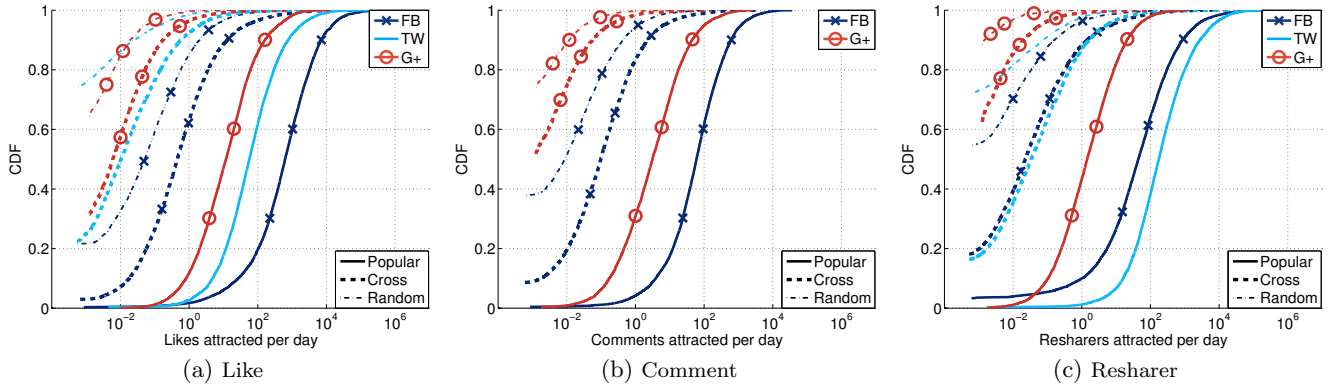


Figure 7: CDF of average number of daily reactions to posts of individual users

users is larger than that for Popular FB users as shown in Figure 7(c).

An interesting aspect of user-level reaction is the level of balance in the number of reactions (of any type) to different posts of individual users. To elaborate on this issue, consider two user u_1 and u_2 that have a different number of posts but the same average reaction of 50 per post. u_1 receives no reaction to half of her posts and 100 reactions to each one of the other half whereas u_2 receive 40 reactions per post to half of her posts and 60 reactions to each one of the other half. In this example, the number of reactions for u_2 are more balanced than u_1 . We use Jain’s fairness index [?] to quantify the level of (im)balance (or fairness) in the number of reactions across posts of a single user. The value of 1 for Jain’s index indicate perfect balance whereas smaller values signals a more imbalanced reactions among posts of a user. Figure 8 depicts the summary distribution of Jain’s index only among users (with more than 10 posts)⁸ in each candidate group. This figure reveals that (i) the degree of reactions to posts is generally imbalanced, i.e. the index is less than 0.5 for a majority of users, (ii) TW users, especially in Cross and Random groups, exhibit a very imbalanced level of reactions whereas G+ users, in particular half of the Popular group, receive a rather balance reaction to their post, (iii) the level of balance in reactions is particularly diverse among Popular FB users.

5.3 Effect of Content Type on Reactions

⁸For a user with a smaller number of post, the index could be very noisy

We investigate whether certain type of post by a particular group of users might trigger a larger number of reactions. Toward this end, we split all generated posts by each group of users based on their types and examine the distribution of the number of reaction (of each type). Figure 9 depicts the summary distribution of Likes across posts of each type published by all users in popular group in each OSN. This figure clearly illustrates that the number of Likes is similarly decreasing among different types of post in the following order Photo, Video, Text and Link for all OSNs (only text and Link for TW). This trend is much more pronounced in FB. We carefully explored the results for various combinations of groups and reaction types and discovered a rather similar trend among them as well. The results are available in our related technical report [?].

Our main findings from group-level analysis of different types of user reactions can be summarized as follows: Only published posts by Popular groups in all three OSNs attract a non-negligible number of reactions where roughly 10% of posts receive 80% of all reactions of any type. The number of reactions (of any type) to post by Popular FB users is a couple of orders of magnitude larger than Popular G+ users. The culture of reaction varies among users in different OSNs. FB and G+ users are more likely to react by expressing their own opinion through Likes and Comments whereas TW users more often tend to relay a post to other users and thus facilitate its propagation. Despite this difference in the culture of reaction, a post by a Popular FB user receives 75% more Reshares than a post by Popular TW user. However, a significantly larger activity rate for Popular TW

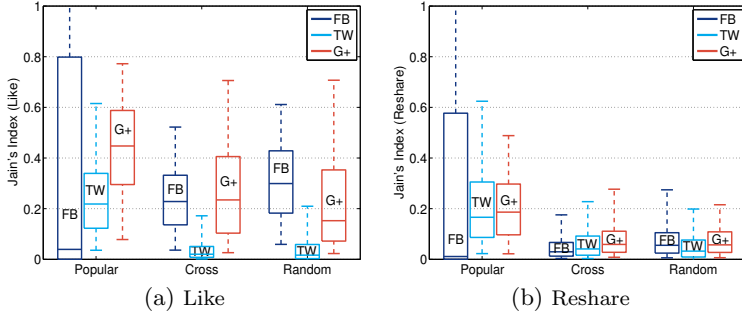


Figure 8: The balance in distribution of reaction across the posts of a single user measured using Jain’s Fairness Index

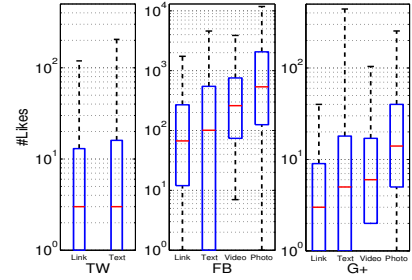


Figure 9: Distribution of Like reactions to each type of post generated by all users in the Popular group in FB, TW and G+

Table 2: Rank (Spearman) correlation between popularity, activity and reactions of users in each dataset.

		FB			TW			G+		
		Popular	Cross	Random	Popular	Cross	Random	Popular	Cross	Random
#Followers	PostRate	0.00	0.49	0.61	-0.04	0.60	0.54	-0.05	0.31	0.03
#Followers	#ResharePerPost	0.26	0.62	0.59	0.41	0.69	0.58	0.18	0.44	0.23
#Followers	#CommentPerPost	0.30	0.62	0.68	-	-	-	0.14	0.52	0.32
#Followers	#LikePerPost	0.32	0.70	0.74	0.44	0.66	0.47	0.18	0.52	0.31
PostRate	#ResharePerPost	0.27	0.31	0.52	-0.16	0.48	0.41	0.03	0.43	0.30
PostRate	#CommentPerPost	0.08	0.18	0.47	-	-	-	-0.02	0.30	0.08
PostRate	#LikePerPost	0.14	0.19	0.44	-0.22	0.49	0.31	0.00	0.26	0.13
#ResharePerPost	#CommentPerPost	0.74	0.59	0.52	-	-	-	0.80	0.53	0.32
#ResharePerPost	#LikePerPost	0.86	0.71	0.59	0.90	0.75	0.63	0.85	0.58	0.42
#CommentPerPost	#LikePerPost	0.90	0.87	0.78	-	-	-	0.90	0.61	0.51

users leads to a higher rate of daily user-level reaction to Popular TW users. The number of reaction to posts of individual users are generally imbalanced in particular for TW users. The number of reactions seem to be correlated with post type which is decreasing in the following order: Photo, Video, Text and Link

6. CORRELATION BETWEEN USER ACTIONS, REACTIONS AND CONNECTIVITY

In previous sections, we have separately analyzed group-level connectivity, activity and reactions of users in three major OSNs. In this section, we explore the correlation between each pair of these user attributes. This analysis reveal any strong relationship among these attributes and could explain the underlying causes for some of our findings. Table 2 shows the results for the Rank Correlation (RC) [?] between #followers, post rates, and the rate of different types of reactions for users in individual target groups within each OSN. Note that RC measures the correlation between the rank of a group of users based on two different characteristics. The RC value changes between -1 (ranks are reversed) and 1 (ranks are the same) where 0 indicates that ranks are independent. The rest of the section discusses the correlation between different pairs of attributes among users of each group of different OSNs.

- **Connectivity vs. Activity:** We observe that these two user characteristics are not correlated for Popular groups in all OSNs ($RC \leq |0.05|$). However, they exhibit a moderate correlation among users in Cross and Random groups especially for TW and FB ($0.49 \leq RC \leq 0.61$).

- **Connectivity vs. Reactions:** These two characteristics exhibit a high correlation in FB and TW Cross and FB Random groups ($0.59 \leq RC \leq 0.75$) and moderate correlation in TW Random and Popular as well as G+ Cross groups.

This suggests that only in these groups having more followers leads to a larger rate of reactions of any types. For other groups, the correlation between connectivity and reaction rate is generally positive but low ($RC < 0.32$).

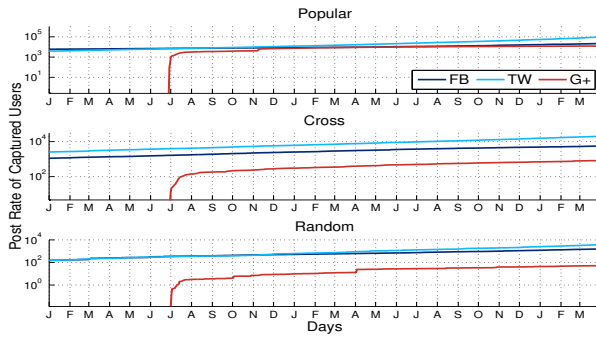
- **Activity vs. Reactions:** Interestingly, only FB Random and TW Cross groups show a moderate correlation between these two characteristics ($0.44 \leq RC \leq 0.52$). In contrast, there is not correlation between activity and any type of reaction for Popular G+ group and even low negative correlation for Popular TW group. All other groups show low positive correlation.

- **Different Types of Reactions:** The RC between different types of reactions indicate that a very significant positive correlation between all pairs in all Popular groups. In fact, the correlation between all pairs of reactions is at least moderate or high in all Cross group and only slightly lower in all Random groups.

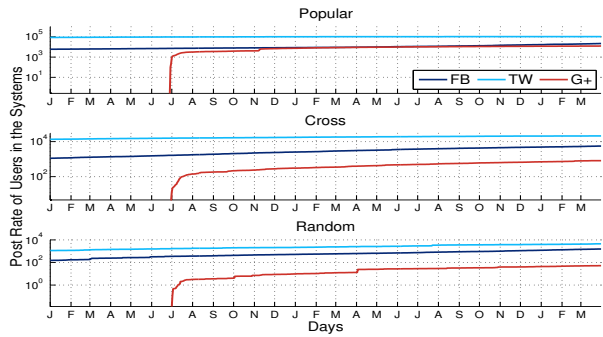
In summary, increasing the number of connection has a moderate effect on the rate of activity and received reaction only in a few groups. Higher activity by a user does not generally lead to more reactions from others. Different types of reactions are generally correlated and this is more pronounced in Popular and then Cross groups.

7. TEMPORAL ANALYSIS

So far we have examined average user activity and received reaction during the time that a user has been in an OSN. These average metrics provide an overall measure of user behavior but do not reveal any information on the short term evolution of user activity and reaction. In this section, we examine the temporal evolution of group-level user activity and reactions in different OSNs to compare these characteristics of different groups over time and identify any



(a) Sum of post-rates for captured users



(b) Sum of post-rates for users in the three OSNs

Figure 10: The sum of the average post rate of users in the three systems in comparison to the sum of the post rate of users that we can collect their post in each day. The picture shows the effect of 3,200 accessible tweets.)

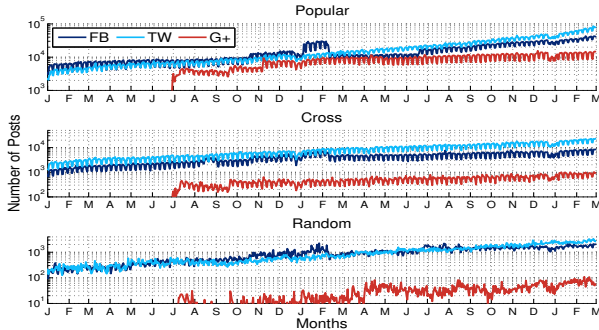


Figure 11: Aggregate number of posts per day (Jan. 1st 2011 - March 1st 2013)

event that affected user behavior. Toward this end, we focus on daily activity or reaction over a 26-months measurement window between Jan. 1st 2011 and March 1st 2013. We note that Twitter API only provides the last 3,200 tweets published by a user. We refer to a user who has published more than 3,200 tweets during our 26-months measurement window as a *saturated user*. Saturated users make up 65%, 17% and 2% of users in Popular, Cross and Random TW groups, respectively. The collected 3200 tweets for 90% of saturated users in Popular (and Cross) groups represent a recent window of user activity whose length is uniformly distributed over our measurement window. Figure 10 shows the sum of post rate of users that we can capture for each day in comparison to users that are actually in the three system. As the figure shows, the as we go back in time, we lose TW users with post rate. Figure 10(b) shows that the average daily post rate of users in twitter is higher than all three systems, However, when drawing occlusion from Figure 10(a), which only shows the daily observable post rate we would conclude that post rate of TW users have been lower in the past, which is wrong conclusion. Hence temporal users figures can not be exactly used to compare post rate of users.

In summary, the incomplete history of activity for saturated users indicates that the activity (and their associated reactions) for Popular and Cross TW users is underestimated in our analysis and the error is larger for earlier months. We carefully consider this limitation of TW datasets in our analysis.

7.1 Evolution of Daily Activity

We start by exploring the temporal evolution of the aggregate number of daily published posts by all users in individual groups that are shown in Figure 11 with a log-scale y axis. This figure unveils a few interesting points: First, the saw-tooth pattern in all lines is due to the roughly 30% lower level of activity during weekends compared to weekdays for all groups. Second, the activity rate for all groups exhibits a generally growing trend over time but the slope of increase is much higher among Popular and Cross groups. The activity rate for any TW group is consistently higher than the corresponding FB group despite the fact that the rate for TW represents a lower bound (because of the saturated users). In fact, the gap in the activity of Popular TW and FB groups in the last few months of our measurement appears to be widening. Third, we observe a significant jump in the activity of all G+ groups shortly after Jun. 21, 2011 when the system was released. After this initial surge, all G+ groups exhibit a slower growth in their activity rate compared to other groups and even appear to be flat during some periods of time. For the activity rate of both Cross and Random groups, we can observe a significant gap between G+ and other two OSNs that has persisted during the life-time of G+ system. This indicates that Cross users clearly prefer to publish their posts in TW and FB rather than G+. The activity rate of the Popular G+ group has initially increased in multiple steps till it reaches close to the rate of Popular FB and TW groups (around Feb-Jun of 2012) and has become seemingly flat during the last nine months. This has led to an increasing gap between the activity of Popular G+ users and other Popular groups. With the current growth patterns, it seems unlikely that G+ groups can close the gap in activity with the corresponding group in FB or TW. Our closer inspection of activity in all groups showed that both the increase in the number of active users and the growth in the average activity of participating users has contributed to the growing trend in their activity over time. Fourth, the time of some of the noticeable changes in the activity rate of different groups appear to be aligned with and thus must be caused by the following events:

- (i) *Introduction of Timeline Feature by FB (Jan. 2012):* The short-term increase in the activity of all FB groups around Jan-Feb. 2012 appears to be caused by to the newly-introduced timeline feature that allows users to publish their historical posts.
- (ii) *Introduction of Interface with 3rd-Party Website by FB (Jun. 2012):* The step-like increase in the ac-

tivity of Popular FB users is apparently triggered by a new feature that allows users to share a post through a 3rd party website and collects associated reactions on users' FB accounts.

- (iii) *Introduction of New G+ Features:* The step-like increases in the activity rate of Popular and Cross G+ group are aligned with release of certain G+ features during the first few months after its release [?].
- (iv) *Holiday Season:* The small drop in the activity of users in all groups during the last two weeks of Dec. due to the holiday season.

It is intriguing that the introduction of new features in FB leads to a significant and long-term increase in user activity whereas new features in G+ appear to create a short-term excitement among users that quickly fades away.

7.2 Evolution of Daily Reaction

We now turn our attention to the temporal evolution of aggregate daily reactions of each type to posts by all users in each group that is shown in Figure 12. We can observe that all types of reactions to most groups (except for some G+ groups) exhibit a steady growth with time. Apart from the initial major jump in reactions for all G+ groups, their growth is slower than the corresponding groups in other OSNs. The main findings for each type of reactions can be summarized as follows:

Like: Like is known to be a very popular type of reaction among FB users. Figure 12(a) confirms this observation and shows that the daily rate of Likes by users in all FB groups is a couple of orders of magnitude larger than other OSN. The sudden increase in the rate of Likes for posts in all FB groups in Jun. 2012 is aligned with the addition of 3rd party feature by FB. Interestingly, the introduction of timeline feature by FB does not seem to have a measurable effect on its rate of Likes despite its impact on the activity rate.

Reshares: Among all three OSNs, resharing is the most common type of reaction in Twitter (retweeting). This observation coupled with the higher activity rate for all TW groups (reported in Figure 11) suggest that TW groups should attract the highest rate of Reshares. However, the daily rate of Reshare for all groups in Figure 12(c) depicts a different picture. Between Jan.-Sep. 2011, the rate of attracted Reshare by Popular and Cross TW groups is significantly higher than the corresponding groups in FB and G+⁹. However, the introduction of the timeline and 3rd-party features by FB has dramatically boosted the rate of Reshares for published posts by all FB groups since Sep. 2011. These step-like increases are particularly visible in the number of Reshares for posts of Popular groups. Interestingly, as a result of these two features, the rate of Reshare reactions for all FB groups has clearly surpassed (or reached the same level as) the corresponding TW groups despite the strong culture of Resharing (i.e., Retweeting) among TW users. We note that while the activity and reaction rates for TW groups in the last few weeks of our measurement window are very accurate, they are still lower than (or equal

⁹Since the TW rates could be greatly underestimated during this period, the actual gap in received Reshares between TW and other OSNs must be even larger than what Figure 12(c) suggests.

to) the rate of corresponding FB groups. Therefore, any potential error in the activity or reaction rate of TW groups does not affect the above conclusions.

Comments: The number of daily Comments for FB groups is much larger than G+ groups. The boosting effect of two FB features is not as visible in the daily Comments of FB groups except for the 3rd-party feature among Popular FB users. While the number of Comments for all FB groups has increased during our measurement period, the slope of this increase is significantly lower than other reactions types for FB groups. The daily rate of comments for G+ groups remains significantly lower than FB groups and does not exhibit much growth for Cross and Random groups. The rate of Comments for Popular G+ groups only show sudden increases that are clearly triggered by added features and promotional events during the first six months after G+ was launched.

Note that any increase in the daily rate of reaction for each group is a byproduct of the increase in the daily number of posts by its users and the growth in the average number of reactions to their posts. Our careful examination of these two factors indicated that the daily activity of users in each group is the primarily contributing factor that determines the rate of received reactions (of any type) by the users. The perfect temporal alignment between the sudden increase in the activity in FB and G+ groups with the sudden growth in the rate of some reaction types, is another evidence that user activity is the main determining factor for the rate of reaction.

The main findings of our temporal analysis can be summarized as follows: The activity in all groups exhibits a persistent growth with a higher pace for Popular and Cross groups during the past two years. This growth in the activity is driven by the increasing number of users and the higher rate of activity among them. The activity of all TW groups is consistently higher than the corresponding FB group and a couple of order of magnitude larger than the corresponding G+ groups. The introduction of new features by different OSNs (in particular FB) has led to a significant and long-term increase in the activity of their users. The rate of Likes is much higher for FB groups and seems to have been affected only by the introduction of 3rd-party feature. As a result of two newly added features by FB, the rate of observed Reshare reaction by FB users has dramatically increased and clearly surpassed the observed rate by TW users despite the fact that resharing is a native feature in TW. Cross users publish post on TW at a higher rate than FB but receive a larger rate of Likes, Comments and even Reshares from FB users.

8. RELATED WORK

The research community has dedicated a fair amount of work to study OSNs in the last years. The conducted studies can be classified into three broad classes:

Connectivity properties & social graph: The connectivity properties of the social graph for Facebook [?, ?, ?], Twitter [?, ?], Google+ [?, ?, ?] and other less popular OSNs [?] have been carefully analyzed by the referred works. Interestingly, Magno et. al [?] and our previous paper [?] compare the connectivity properties of the social graph of FB, TW and G+. The results presented in those studies along with the results in this paper depict a complete comparison study of the activity and connectivity of these OSNs.

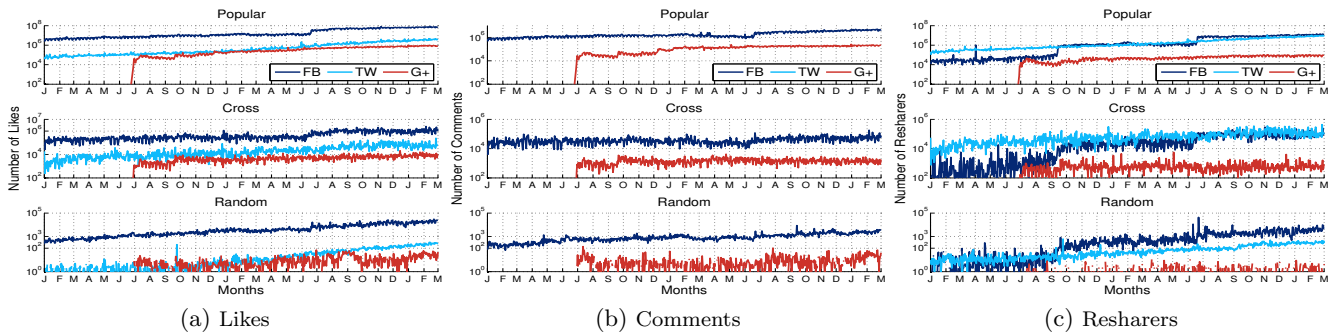


Figure 12: Aggregate number of reactions per day (Jan. 1st 2011 - March 1st 2013)

Users' Behavior in Online Social Networks: Users' behavior needs to be characterized from real data collected from OSNs. In particular, previous works have used two different strategies: Passive measurements [?, ?] vs. Active measurements [?, ?, ?]. The former captures traces of traffic or click streams that allow the reconstruction of the behavior of users whereas the latter uses crawling techniques similar to those described in this paper. In particular, Gyarmati et al. [?], in accordance to our paper, used active measurements to characterize users' activity in few different OSNs. The main differences between the two papers are: First, Gyarmati et al. analyzed less popular OSNs such as Bebo, MySpace, Netlog, and Tagged. Second, they defined activity as the time a user stays on the system whereas in our paper activity is related to the posts contributed by the user. Furthermore, they do not characterize users' reactions which, as we have demonstrated, are key features.

Temporal Evolution of OSN properties: Previous works have studied the evolution of the relative size of the network elements for G+ [?] or Flickr and Yahoo [?]. Furthermore, other works have analyzed the evolution of the social graph properties [?, ?, ?, ?, ?, ?, ?], the evolution of the interactions between users [?] and the evolution of users' availability over time [?]. In addition in our previous work we have analyzed the evolution of users' activity in MySpace and Twitter [?] and G+ [?]. This paper substantially extends our prior work by presenting a complete characterization and comparison study of the overall activity (i.e., actions and reactions) of the three major OSNs over a period of approximately two years.

9. CONCLUSIONS

This paper presents a measurement-based characterization of group-level user behavior in three major OSNs, Facebook, Twitter and Google+. We consider Popular, Cross and Random groups of user in our analysis as they reveal a complementary view of user population. Our group-level approach to characterize user-behavior enables us to compare the behavior of users in similar groups across different OSNs or the behavior of users in different groups of a particular OSN. We consider several aspects of user connectivity, user activity and user reactions as three key dimensions of user behavior in our analysis. We also conduct temporal analysis to examine short-term changes in group-level user behavior and their potential causes. Our analysis provide a set of interesting and insightful findings such as the following examples: (i) Only published posts by Popular groups in

all three OSNs attract a non-negligible number of reactions with a very skewed distribution among Popular users. (ii) The number of reactions (of any type) to posts by Popular FB users is a couple of orders of magnitude larger than Popular G+ users. (iii) The more likely reaction by FB and G+ users is to express their own opinion whereas TW users tend to relay a received post to other users and thus facilitate its propagation. Despite the culture of reshare among TW users, a post by a Popular FB user receives more Reshares than a post by Popular TW user. (iv) Added features in an OSN can significantly boost the rate of action and reaction among its users.

We plan to extend this work in the following directions: First, we plan to examine post content to gain a deeper insight on the published content and associated context by individual users in each group. Second, we are conducting a more detailed study on Cross group to better determine their publishing strategy in different OSNs and identify whether they use multiple OSNs for a similar or complementary purposes.

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