



# Image-oriented economic perspective on user behavior in multimedia social forums: An analysis on supply, consumption, and saliency<sup>☆</sup>



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## ABSTRACT

This work addresses the novel problem of analyzing individual user's behavioral patterns regarding images shared on social forums. In particular, we present an image-oriented economic perspective: the first activity mode of sharing or posting on social forums is interpreted as supply; and another mode of activity such as commenting on images is interpreted as consumption. First, we show that, despite the significant diversity, images in social forums can be clustered into semantically meaningful groups using modern computer vision techniques. Then, users' supply and consumption profiles are characterized based on the distribution of images which they engage with. We then present various statistical analyses on real-world data, which show that there is significant difference between the images users supply and consume. This finding suggests that the flow of images on social network should be modeled as a bi-directional graph. In addition, we introduce a statistical approach to identify users with salient profiles. This approach can be useful for social multimedia services to block users with undesirable behavior or to identify viral content and promote it.

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## 1. Introduction

The importance of social multimedia services in our society has been increasing exponentially in recent years as a medium for culture, personal communication, news sharing, and commerce. In particular, diverse images and videos are shared through these services (e.g., Twitter, Flickr, Reddit, Instagram), which are consumed by other users. Such activities are facilitated via social structure (friends, communities etc.), as well as tools such as subscription-based data feeds. Accordingly, with shared goals of making these services more effective, researchers have been making rapid progress in understanding user behavior and content propagation. Notable studies include [2–5,13,16,18,19]. Nonetheless, most of the existing work focuses on textual data, and very limited study has been reported on user engagement with visual data and how images propagate on online social forums.

In this work<sup>1</sup>, we focus on the novel problem of analyzing individual user's behavioral patterns regarding visual multimedia

(i.e., images) shared on social forums. The wide adoption of camera-equipped personal devices has facilitated sharing of images on social media in recent years. Even on Twitter, which is designed for microblogs with short text, a large amount of tweets carry embedded images. For example, our own online collection of Twitter stream shows that approximately 19 percent of tweets carry multimedia data. Hence, the problem of understanding the type of visual content people post and engage with, is becoming more important than ever. To the best of our knowledge, although existing work [2–4,13,18] has studied certain aspects of images and videos on social media, analysis of individual user behavior regarding engagement with visual content has been lacking, and our work provides novel insights in this direction.

In particular, we introduce an image-oriented economic perspective on user activities in social multimedia forums: the first activity mode of sharing or posting is interpreted as 'supply'; another mode of activity such as commenting on images is interpreted as 'consumption'. Analysis of these two modes is important to understand content propagation better, as well as to provide improved personalized services to users. Towards this goal, we have conducted a data-driven analysis of two behavioral modes using the Reddit image dataset [13], which contains images shared on *reddit.com*. Reddit is a popular social forum where people upload posts, with or without images. Other users can comment on, vote up or down on each post. The dataset consists of a total of nearly 17K unique

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<sup>1</sup> This work was done while the authors were with Kitware Inc.

images, collected over a time span of 4.5 years. Additionally, for every image, it contains a metadata log with additional information, which makes it ideal for this research.

Novel contributions of this work include an approach to characterize users' supply and consumption profiles, and a statistical analysis result which showcases the differences between a user's two activity modes. In our approach, two profiles of a user are characterized as a distribution of image categories with which the user interacts. One challenge of analyzing images in social multimedia forums is that they are extremely diverse. For example, Fig. 1(a) shows randomly selected images from the Reddit image dataset, which exhibits significant variation. This work shows that even for an in-the-wild dataset such as Reddit image dataset, meaningful image clusters can be obtained based on visual features. Fig. 1(b) shows sample image groups, such as people, text clips, cartoons, and screen shots, obtained by the proposed approach. From these sample image groups, user profiles are computed as bag-of-words (BoW) representations of the categories, effectively capturing the image styles users prefer to supply and consume.

Finally, by comparing users' supply and consumption profiles, as much as ~ 40% of users are found to show fairly different supply and consumption patterns. This finding contradicts a baseline hypothesis that users are likely to post and comment on similar image categories, and suggests that personalization of social multimedia services needs to be optimized from both the angles, rather than pursuing a single model per user. Most existing research focuses only on consumption patterns [2,13,16,18,19]. To the best of our knowledge, this is the first study to concretely show that there can be significant differences between the two behavioral modes.

As another contribution, we present a *statistical approach to identify users with salient profiles*, despite the inherent multi-modal nature of user bases on social forums. By definition, a salient user exhibits a unique profile. Identifying such users can be beneficial for social media services in multiple ways. For example, such a user may be a trend setter who can potentially create viral content that social media services may want to consider promoting heavily and draw new users. In other cases, such a user may be posting illegal or prohibited content that is outside the norm of the common user base. One difficulty in identifying salient users is that the users of social media services are very diverse. There are multiple communities with different interests, which naturally creates a multi-modal distribution of user profiles. We propose a detection method to identify salient users, which is based on non-parametric kernel density estimation framework [7]. Finally, we show that certain users' profiles can change dynamically over time and that the proposed method can be extended to be used in such scenarios, providing the ability to identify trending images which contribute the most towards user saliency. We showcase the usefulness of the proposed methods through qualitative experimental results.

The remainder of the paper is organized as follows. In Section 2, related work is reviewed. Section 3 describes the methodologies utilized to characterize individual user's supply and consumption profiles. It also presents our analysis on the similarities and differences between these two behavioral modes. Finally, Section 4 introduces our proposed approaches for salient user detection and key images based on the images supplied by users.

## 2. Related work

Several researchers such as [9], [16] and [19] have studied the problem of modeling and predicting the popularity of posts on Twitter. Majority of work in this direction has been focused only on text content of tweets, and analysis of visual content accompanying tweets has been disregarded. In [9] and [16], the authors studied content propagation to predict retweet counts at the community level. The work of [19] is closer to ours, in that they take a user-centric

approach and predict retweet likelihood on an individual basis. However, they, too, focus on text input only.

Some previous works analyze visual content on social forums to understand the propagation of content across social networks. [2] exploited embedded multimedia content in a tweet to predict retweet counts. Notable works also include [3] and [4] which analyze content posted on Youtube and Flickr, respectively. They learn the patterns of popularity and propagation by taking into account factors such as the amount of time passed since the post was made and the network of the person posting the content. [18] analyzed Flickr and Youtube content to understand the nature of social interactions engendered by visual multimedia. [13] introduced the Reddit image dataset, which is also used in this work. They proposed a model to predict the popularity of a post based on several factors, which include the time a post was made, similarity to other viral posts, title etc. They, however, did not analyze the visual content itself, which is the primary focus of this work. Further, all of these studies view the posts at the community level and do not look into the patterns related to individuals. In this work, we take a more user-centric approach and focus on discovering supply and consumption patterns for individuals.

There has also been work which makes use of user-supplied image tags on online photos as a source of data to aid image understanding. [14] use crowd-sourced Flickr image metadata such as tags, captions, collections etc. to annotate new images with semantic labels. [12] worked towards improving image search via a personalized visual attribute classifier. [15] used groups and tags for photos on Pinterest. They analyzed and compared user behavior patterns across text (Twitter) and image (Pinterest) based social networks. However, a lot of visual content on social media is shared without any tags or accompanying text. In many cases, user-supplied tags may not directly refer to the semantic content of the photo they are sharing, e.g., a simple comment such as 'Look at this!'. Thus it becomes necessary to analyze the visual content on its own.

To the best of our knowledge, the only work focusing on understanding user behavior patterns by analyzing the visual properties of the photos they share online is [10]. They first use low-level visual features to obtain an initial clustering of images. The clusters so obtained are then cleaned up and assigned to one of the eight pre-defined categories by manual annotation. The users are then clustered into five types based on the content of photos they have shared. Similar to them, we too, cluster the images using low-level features to begin with, and use these clusters to characterize user behavior. However, our work presents more detailed analysis beyond [10]. We build two types of profiles for each user, based on the distribution of the images that they share (supply) and engage with (consume). Further, we also study the temporal patterns of time-varying user behaviors and introduce non-parametric statistical approach to detect salient users and trending content.

Existing work on saliency detection for social multimedia services includes [8] and [1]. They formulate the problem as that of detecting network nodes which exhibit abnormality in terms of structural patterns and connectivity. Rather than focusing on network properties, our saliency detection approach aims to detect salient users based on the actual visual content they supply and consume.

## 3. Personalized image economy: models and analysis

In this section, we introduce our framework to characterize users' supply and consumption profiles. We also present our findings which showcase the difference between users' two behavioral modes through a statistical analysis of user logs from the Reddit image dataset. The Reddit image dataset consists of a total of 16,736 unique images which have been resubmitted multiple times. There are a total of 132,307 submissions, i.e., each image has been posted 7.9 times on average. Each image post is accompanied with an html page consisting of the communication happening around the post

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