Incognitus: Privacy-Preserving User Interests in Online Social Networks

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Abstract. Online Social Networks have changed the way we reach news and information. An increasing number of people use social networks not only for communicating with friends and colleagues, but also for their daily information needs. Apart from providing the users with personalized information in a timely manner, this functionality may also raise significant privacy concerns. The service provider is able to observe both the Pages a user is subscribed to and her interactions with them. The collected data can form a detailed user profile, which can later be used for several purposes; usually beyond the control of the user. To address these privacy concerns, we propose *Incognitus*: an approach to allow users browse Pages of OSNs without disclosing their interests or activity to the service provider. Our approach provides (i) an *incognito* mode of operation, when browsing privacy-sensitive content. In this isolated, offline mode no tracking mechanisms can monitor the user's behavior and no information can be leaked to the provider. At the same time, (ii) by using an obfuscation-based mechanism, *Incognitus* reduces the accuracy of the service provider when monitoring the interests of a user. Early results show that *Incognitus* has minimal bandwidth requirements and imposes negligible latency to the user's browsing experience.

1 Introduction

Online Social Networks such as Facebook, Twitter, Tumblr, Google+, Weibo, etc., do not constitute any more a platform solely used by the users for communication and social interaction. The so called model of "social broadcast", enables users, instead of searching and consuming news through traditional media or news websites, to have more personalized news delivered directly to them in a timely manner. According to a recent study [27], an increasing 67% of adults in the US get their news from social media; it was also found that social media now outperforms television as the major information source [31]. By providing a handy user interface, OSNs enable users, through a publish-subscribe model, to subscribe/follow information providers who maintain *channels (or Pages)*, and receive updates regarding the content they publish.

Of course all this handy and timely superabundance of information does not come for free. In exchange for their monetarily free services, OSN providers deliver targeted advertisements to their users. To provide better matched advertisements and suggestions, a wide spectrum of user social interconnections [22], activity and interactions [19] has to be monitored. The OSN by monitoring the user's interactions with the content of such Pages - *links clicked, photos viewed, videos watched* - it is able to create a very detailed profile for every user containing information related to interests and preferences, reconstructing consequently parts of her actual personality [33]. While recently there is an increased awareness about privacy on social networks and a desire for data protection regularization [1], there are incidents [29] indicating that the user might have to take additional steps to protect her privacy.

In this paper, we are interested in protecting content considered as privacy-sensitive. For example, content related to politics, sexual orientation, religion or health issues. This is, if a user follows a Page of a particular politician, the service may infer the user's political beliefs. We think that it is of user's the main interest to protect such sensitive information. Thus the objective of this paper is to help users that although interested in receiving updates about privacy-sensitive issues, may not be willing to disclose their personal preferences and interests. Even if these users avoid subscribing to particular privacy-sensitive Pages, thus choosing to manually fetch them every now and then, the service provider still can identify not only the fact that they requested for these Pages but also their interactions with the content.

The alternatives such a user has, is to hide her actual identity: by creating a second, disposable account to subscribe to the privacy-sensitive Pages she is interested in. Unfortunately, this approach would be subject to contamination, since information from different web browsing sessions, such as browser or device fingerprints [2, 7, 21] or persistent and synced cookies [13, 23] are able to correlate anonymous and eponymous browsing sessions revealing thus the true identity of the user [12, 24]. To make matters worse, in popular online social networks disposable accounts is not an option [6]. To remedy this problem, one might use a second account and a VM per browsing session over an anonymization network (such as Tor [10]) to hide the IP address aiming to finally limit cross-contamination. Of course, the applicability of such approach (i.e. combination of VM and Tor) in tablets and smartphones alongside the inconvenience it may cause to ordinary users, constitutes a practically non-applicable approach. The user can always stop using OSNs to protect her privacy; however, there are a lot of organizations, associations, groups or communities that leverage the ease of message broadcasting and audience gathering in social networking platforms and do not maintain websites of their own outside the OSN. In this work, we propose a method to allow OSN users to protect their interests, when anonymity is not feasible.

There are two distinct cases able to disclose a user's interests: (i) the actual fact that the user follows, likes or subscribes to a specific Page, (ii) her interactions with this Page (navigating through past posts, watching videos or photos, etc.). In this paper, we propose *Incognitus*: an system to preserve the privacy of the users' interests against both of the above cases. Our approach is twofold; we provide an obfuscation mechanism and an incognito mode of operation. In our system, the user follows/subscribes to an additional number of Pages which are used as noise. These additional Pages will reduce the accuracy of the service provider while trying to distinguish the noisy Pages from the real ones. After concealing the actual subscription, our approach provides the user with an *incognito* mode of operation, in which she can switch to, whenever she wants to access a Page she considers as privacy-sensitive. In this isolated, offline mode of operation no requests or tracking mechanisms of the service provider can leak information about her activity and behavior. To summarize, in this paper, we make the following contributions:

1. We propose a methodology to preserve the privacy of the sensitive interests of a user while browsing an OSN. Our approach provides an isolated protected mode of operation where no user monitoring can be applied by the curious service provider.

2. To assess the feasibility and effectiveness of our approach, we implemented our system as an extension for the Firefox browser using Facebook as our case study.
3. We experimentally evaluate our prototype and we show that it has minimal bandwidth requirements and adds negligible latency to the user's browsing experience.

2 Threat model

In this paper, we assume the existence of an online social networking service, where there are several Pages maintained by organizations, authorities, corporations, groups or individuals (e.g. journalists, politicians, activists, doctors, etc.) to publish content and inform their audience about a particular subject. Such published content may include photos and albums, articles, posts, links to external webpages, videos, etc. The users, in order to access this content and have updates delivered to their newsfeed in a timely manner, have to subscribe themselves to the Page.

Furthermore, we assume that the service provider is capable of recording the user's activity at any time by observing her online interactions with a Page's content. This way, this provider knows: *When the user watches what video and for how long?, When she browses what photo?, On which photos she spends more time?, What articles she reads?, What posts she reads and if she unfolds its related comments.* Consequently, the service provider is able to determine with high accuracy the interests of the user, not only by monitoring what Pages she is subscribed to but also by observing her interactions while visiting these Pages.

All this collected information about the users' interests, is property of the social networking service and can be considered as an asset in case of future acquisition by another company [16,28]. In addition, this information could be later sold to advertisers [4, 26], or could be used for a variety of purposes beyond the control of the users. We consider this tracking capability as a potential concern for the users' privacy and therefore in this paper, we develop the proper mechanisms to conceal the user activity in a social networking service, when it regards content she considers as sensitive.

In this work, we assume an honest online social networking service provider, which may try to find the user's interests in order to display more personalized recommendations and advertisements that match the interests of the user. Therefore, it will not try to "cheat" by actively interfering with the process users are employing to protect their privacy, or try to gain more information than what a user is willing, or required, to give. As a result, we assume a service provider that tries only passively to gain knowledge, based on data given by their users. We think that this assumption is valid, since social networking service providers do not want to be hostile against their own users jeopardizing thus their reputation.

Our approach, aims to preserve the privacy of users who use OSNs to fulfill their daily information needs, users who use OSNs to get timely personalized news and not for communicating purposes. As a consequence, in this paper we assume users that act as consumers of information, without being interested in posting, sharing (or reacting [15] at) any information related to the sensitive Page she is interested in. Such actions could allow a service provider by deploying term extraction algorithms to identify the actual interests of the user.

3 Design Overview

The motivation behind our work is to build an offline incognito mode, to which the user can switch every time she feels like browsing a privacy-sensitive Facebook Page. In this isolated mode, no trackers would be able to monitor her behavior and interactions. In order for the user to browse this content, her browser needs to fetch the entire Page leaking this way to the service provider the fact that she is interested in navigating to this Page. As a consequence, the service provider can associate her interests with the related subject of the Page. To remedy this privacy infringement and reduce the accuracy of such association, we use an obfuscation-based approach, where we introduce noise, by encouraging the user to retrieve n more Pages used as noise.

3.1 Concealing user's subscriptions

Assume a user interested in a Page P, which deals with a privacy-sensitive issue: for example, the electoral campaign of a candidate. As soon as the user subscribes herself to this Page, the social network can consider with high probability that she is interested in the associated political party and hence infer her political preferences. In *Incognitus*, to reduce this certainty of the service provider when predicting the interests of its users, we encourage the user to subscribe, along with the Page P, to an additional number of $n-1$ Pages, which act as noise. By obfuscating this way her choices, the service provider will get subscribe requests for n Pages without being able to accurately identify the Page she is actually interested in.

Parameter n practically defines the amount of noise introduced in the user's profile. By fine tuning this obfuscation number, users are able to achieve the level of privacy they are comfortable with. Very small values of n may increase the confidence of a service provider and disclosure the actual interests of the user. On the other hand, very high values of n may skyrocket the overhead and the bytes downloaded in her browser, since *Incognitus* will download more noise Pages and content.

Selection of noise: All such noise Pages are randomly chosen from a publicly accessible list *SP* of "privacy-sensitive" Pages, which is shared among all users. In *Incognitus*, these $n-1$ noise Pages are chosen randomly with uniform probability from *SP*. As a consequence, when a user subscribes to n Pages (i.e. P+noise) the probability for the service provider to identify the one the user is actually interested in, is $1/n$. Note at this point that apart from the P, the $n-1$ noise Pages are not fake and also privacy-sensitive. It is apparent, that users enable *Incognitus* to specifically conceal Pages that consider sensitive, the use of non sensitive Pages as noise would help the service provider easily filter out those Pages. By using the same *SP* list for all users, *Incognitus* allows for every Page a user may use as noise, to appear some other users that are indeed interested in it and hence subscribed to it.

Of course, not all Pages enjoy the same popularity. In case of a user interested in a very popular Page (e.g. 30% of the total users are already subscribed to it), a service provider may pinpoint the very popular Page among the $n-1$ others and assume that most probably this Page is the one the user is interested in. To mitigate such cases, instead of uniform selection of noise Pages, one can use a proportional selection, already proposed in related studies [25], based on the size of the Pages' audience. This would lead to a selection of noise Pages with similar popularity to the Page the user is actually interested in.

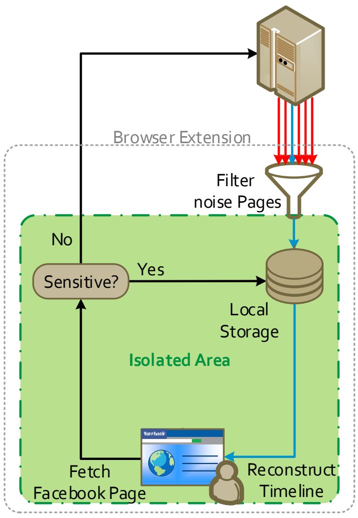

Fig. 1: High level overview of Incognitus. Incognitus provides the same browsing experience, while the user is able to browse the privacy-sensitive content incognito.

3.2 Concealing user's interactions

Apart from the subscriptions of a user to Pages, her interests can be also leaked by monitoring her behavior, while browsing a Page. Specifically, even after obfuscating her subscriptions, the service provider may track her interactions (e.g. clicks, mouse hovers etc.) and distinguish which Pages she fetches to use as noise and which Pages she fetches because she is actually interested in.

To remedy this leak, *Incognitus* stores the entire content of a privacy-sensitive Page locally (e.g. posts, videos, photos, etc. along with their metadata) and whenever the user browses this Page, it intercepts the HTTP requests to the web server and instead retrieves the content from the disk. As a consequence, an isolated offline mode is created allowing the user to interact with the content (e.g. view a photo) without allowing the service provider to learn about it. To achieve the same user experience, *Incognitus* reconstructs the user's NewsFeed by transcoding on-the-fly incoming components. This way, in case of privacy-sensitive content (e.g. posts) originated from privacy-sensitive Pages the links to the associated components will point to the local stored files.

Of course, whenever *Incognitus* downloads the content of a Page P to store it locally, and in order for the content request of Page P to remain obfuscated, it also downloads the content of the rest $n-1$ Pages as well (although it does not need to store it). This way, the service provider will see a bunch of identical HTTP requests for content, being unable to identify the noise requests. Such *update* operation of *Incognitus* is performed asynchronously in the background, so it cannot degrade the user's browsing experience by imposing additional latency.

The delta approach: It's easy to anticipate that downloading bulk content from multiple pages, every time a user browses Page P, may put an unbearable load to the browsing experience, causing a significant increase not only to the rendering latency but also to the required bandwidth. To avoid such overhead, *Incognitus*, on the background and periodically, downloads any possible recent updates of Page P and stores them locally. This way, whenever a user needs to fetch P, the browser extension will use the pre-fetched content from the disk and thus render the content in zero time. In addition, by using the delta approach *Incognitus* downloads less bytes from the network, avoiding re-fetching content every time the user browses P. Note again that like above *Incognitus* does not download only the deltas of Page P but the deltas of all n privacy-sensitive Pages the user has subscribed to.

In summary, we can see in Figure 1 a high level overview of the internal design of *Incognitus*. It periodically (i) retrieves the deltas from all n Pages, (ii) filters them to discard the noise (i.e. posts from noise Pages) providing the exact same browsing experience as before and (iii) stores locally the content of P (i.e. html, images, photos, videos, json files etc.). When the user opens her NewsFeed, the served html gets transcoded and the links of the components, originated from P, are rewritten to point to the local stored content.

4 Implementation

In order to evaluate the feasibility and efficiency of *Incognitus*, we have implemented an extension for the popular browser of Mozilla Firefox. Our prototype implementation is built using the Firefox Add-on SDK [20] and is developed using Javascript along with JQuery and Mutation Summary libraries [32].

As a case study, we used the OSN of Facebook. In this social network, we assume users interested in subscribing to Facebook Pages. Facebook Pages [9] are for businesses, brands and organizations to share content and can be customized by publishing stories, hosting events, adding apps and more. A user who subscribe to a Page can get timely updates directly delivered in her account's NewsFeed. On Facebook, a NewsFeed is a list of updates on user's Facebook home page. NewsFeed includes status updates, photos, videos, links, app activity and Likes from people, Pages and groups that the user is subscribed to on Facebook.

In *Incognitus* browser extension, the user can subscribe to a sensitive Page, by using the standard Facebook Like button (either from inside the Facebook platform or from a website by using the appropriate Facebook widget). To achieve the same user experience, in *Incognitus* we intercept all Like requests and check whether they correspond to a Page considered as sensitive (i.e. if the corresponding Page is included in the SP). If so, the extension based on the n parameter set by the user, on the background, randomly selects the additional $n-1$ Pages from the list SP of sensitive Pages, which will be used as noise. Finally it sends a Like request to each one of the n (real and noise) sensitive Pages. The browser extension, internally, keeps the list of the noise Pages it has used and the real Page with which they are associated.

5 Performance Evaluation

In this section we present our findings from several performance measurements of our system. We performed the experiments on a PC equipped with an AMD FX-6300 processor (3.5 GHz, 8MB L3 Cache) and 8GB RAM. We populated the set S with 60

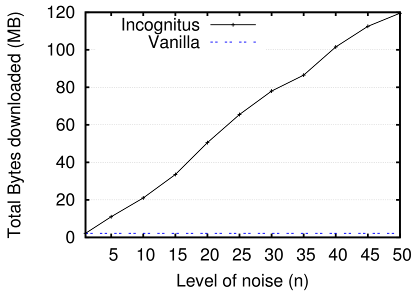

Fig. 2: Total Bytes downloaded as a factor of the different level of noise

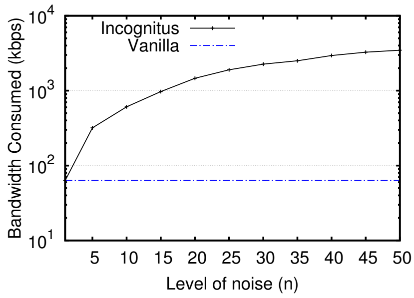

Fig. 3: Average bandwidth consumption as a factor of the different level of noise

Pages of categories we personally consider as privacy-sensitive: medical diseases, political parties, sexual preferences, etc.

Bandwidth consumption: Its easy to anticipate that the introduction of noise leads to an increased bandwidth consumption in order to obfuscate the actual transmitted information. The traffic volume that is generated depends on the noise level the user has chosen; specifically, on the value of parameter n. This parameter practically denotes that, with our system, the user roughly downloads n times more bytes.

Our first experiment is to monitor the traffic generated from the user's browser when visiting a sensitive Page, for several values of n. In this experiment, we measure the consumed bandwidth in the worst case: when the user visits the Page for the first time and there is no pre-stored content on her disk. At Figure 2, we can observe the total bytes downloaded and at Figure 3 the traffic load generated, for different levels of noise, both by a user who subscribes to a sensitive Page. Moreover, we include the vanilla case $n = 1$, when *Incognitus* is disabled. We noticed that the bandwidth consumed is reasonably low comparing to the vanilla case, adding less than one order of magnitude overhead in case of $n = 10$.

It is worth to recall at this point, that these results regard the first fetch of a Page where no data are stored on disk. After the first fetch, the delta approach is used as we describe at Section 3. Then, *Incognitus* periodically downloads the updates from all sensitive Pages, both noise and real ones. This way, we are able to reduce both the latency imposed and the bandwidth consumed, since we retrieve the content from the disk instead of fetching data from the Facebook server. In the following experiment we measure (i) the total bytes downloaded when the user browses P without having any content pre-fetched on disk and (ii) the average bytes downloaded periodically with the delta approach.

To quantify the bandwidth consumption over time we perform measurements with our prototype for 30 minutes. Specifically, we subscribe to a sensitive Page and fetch it for the first time, without having any content previously stored on the disk. In Figure 4, we plot the results of this experiment using 3 different values of n, the vanilla case (n=1), a low one (n=5), and a higher one (n=25). As we see, there is an increased spike at the beginning, when the browser downloads the content for the first time, after that

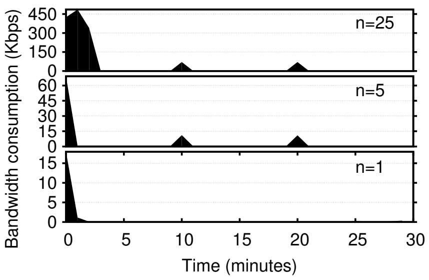

Fig. 4: Bandwidth consumed as a factor of time for the initial fetch and the delta updating mechanism.

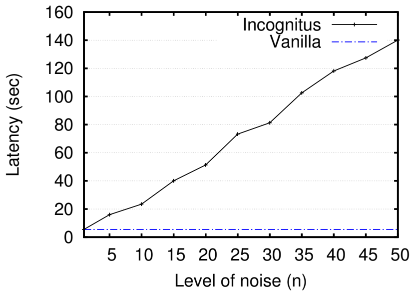

Fig. 5: Average rendering latency as a function of different level of noise, the first time a user browses a sensitive Page.

the bandwidth consumed is close to zero. In this figure, we also see the periodic delta mechanism at 10th and 20th minute where *Incognitus* checks for updates.

Browsing Latency: The most important aspect that can degrade the browsing experience of a user is latency: the time needed to render and show to the user the content she is waiting for. In the following experiment, we set out to explore the delay imposed by *Incognitus* when the user visits a privacy-sensitive Page. In this experiment we inspect the worst case scenario: when the user fetches the Page as soon as she subscribes to it and therefore no data were previously local stored. In this scenario, *Incognitus* before reconstructing the web-page the user requested to see, has to download the set of n noise Pages and filter the noise content. As a consequence, we fetch a sensitive Page P with our browser extension enabled and we measure the time it takes to load the Page's full content. We run the experiment 100 times for different noise levels and in Figure 5 we plot the results. As expected, the higher amount of noise we add, the larger the imposed latency is. We see that for n=10 the additional latency is about 22 seconds, which we believe its unable to harm the users browsing experience; at the same time the privacy of her interests is preserved.

6 Related Work

Our work's foundations lie in the concept of k-anonymity [30]. K-anonymity provide privacy guarantees that the individuals who are the subjects of a released dataset cannot be re-identified. With K-anonymity an individual cannot be distinguished from at least k-1 individuals whose information also appear in the data. L-diversity [18] and [17] extend k-anonymity by handling some of the weaknesses.

TrackMeNot [11] is a Firefox add-on designed to achieve privacy in web search by obfuscating user's queries within a stream of programatically-generated decoys. For each real query submitted to the search engine, TrackMeNot also submits additional queries to confuse the search engine and introduce doubt for the user's real queries. TrackMeNot utilizes the same idea (i.e. obfuscation) to protect user's privacy when using a search engine, although it has one fundamental difference: the set of possible queries is not limited to a finite set as Facebook Pages do. So there is a good possibility that a user submits a rare query, which would enable the search engine to accurately find her interests. Moreover, an adversary may be able to find a user's interests by studying successive sequences of queries [3] and make use of clustering approaches [8].

In [25] authors propose k-subscription to conceal the user's interests in microblogging services. Their approach relies on introducing noise in order to decrease the disclosure probability of the service provider. The propose and evaluate two algorithms to compute the necessary amount of noise that needs to be used based on the popularity of the channel the user is interested in following. Although k-subscription is related to our work, it assumes that users subscribe to a channel using the standard mechanism (e.g., follow) that the microblogging service offers. In *Incognitus*, we assume users that may avoid subscriptions thus browsing content from Pages manually and we assume service providers that deploy more aggressive behavioral tracking techniques, monitoring any action the user may perform with a Page's content.

Single sign-on (SSO) services (like Facebook Connect [5]) often improve the user's browsing experience by offering a convenient way to register to third party web sites and adding a social dimension to the user's experience. But their existence and popularity also raise significant privacy concerns, since third party Web sites are granted access to personal information. In addition, the social network can observe the Web sites that the user visits as well. To mitigate that problem, SudoWeb [14] proposes a system that enables users to surf the Web using downgraded sessions with the single sign-on platform, i.e., stripped from excessive or personal information, and with a limited set of privileged actions. Although both SudoWeb and *Incognitus* belong to the domain of privacy-preserving browsing, SudoWeb focus on enhancing the user's privacy when visiting third party Web sites and not when browsing an OSN.

7 Conclusion

Online social networks have changed the way we fulfill our daily information needs. However, using OSN's for information consumption is a double-edged sword. The low cost and timely access to information comes with a cost to user's privacy: the online social network provider is able to collect information regarding its users' interests, which sometimes may regard privacy-sensitive topics.

To cope with this situation, we propose *Incognitus*: a tool to (i) allow users browse Pages with privacy-sensitive content in an offline mode, without disclosing their interactions to the service provider. And at the same time, (ii) by using an obfuscation-based mechanism conceal the privacy-sensitive topics a user is interested in, thus reducing the accuracy with which the service provider can determine the user's interests. We implemented our approach by developing a browser extension for the popular Firefox browser with Facebook as case study. Our experimental evaluation shows that *Incognitus* has minimal bandwidth requirements and imposes negligible latency for a normal amount of noise, when at the same time is able to adequately preserve the privacy of the actual interests of the user.

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