IPPO: A Privacy-Aware Architecture for Decentralized Data-sharing

Maurizio Aiello\(^1\), Enrico Cambiaso\(^1\), Roberto Canonico\(^2\), Leonardo Maccari\(^3\), Marco Mellia\(^4\), Antonio Pescapè\(^2\), and Ivan Vaccari\(^1\)

\(^1\) National Research Council (CNR-IEIIT), Italy name.surname@ieiit.cnr.it
\(^2\) University of Naples Federico II, Italy roberto.canonico@unina.it, pescap@unina.it
\(^3\) Università Cà Foscari di Venezia, Italy leonardo.maccari@unive.it
\(^4\) Politecnico di Torino, Italy marco.mellia@polito.it

Abstract

Online trackers personalize ads campaigns, exponentially increasing their efficacy compared to traditional channels. The downside of this is that thousands of mostly unknown systems own our profiles and violate our privacy without our awareness. IPPO turns the table and re-empower users of their data, through anonymised data publishing via a Blockchain-based Decentralized Data Marketplace. We also propose a service based on machine learning and big data analytics to automatically identify web trackers and build Privacy Labels (PLs), based on the nutrition labels concept. This paper describes the motivation, the vision, the architecture and the research challenges related to IPPO.

1 Introduction

Online advertising is characterized by a constant growth and it generated $49B in revenues in 2014, considering US alone [1]. Advertisements (ads for short) support important Internet services such as search engines, social media and user generated content sites. The ability to target individuals with specialized advertisements makes online ads success. For this reason, different tracking techniques are commonly adopted to profile each user and identify their interests based on their browsing history. As a result, the web is full of hidden tracking services that extract data from our online activity [2]. Although the recent introduction in Europe of the General Data Protection Regulation [3] is a strong attempt to protect users’ privacy, we steadily leak very personal information, while covert web companies build a profile of each of us, and sell information they collect [4]. The recent Facebook-Cambridge Analytica [5] scandal is just the top of the iceberg. The creepiest part which still sits under the sea consists of obscure tracking services, run by thousands of mostly never heard companies, which keep collecting data when we visit any website, from any device, from any place. They act as data brokers, monetising our profiles. Under another perspective, we observe that today web browsing is incomparably more complicate than only a few years ago. Web services are utterly complex, browsing platforms are extremely variegate and the attention span of users is very low, so that a web service to be successful must be intuitive and of immediate use. Service providers need data to design their services and to tailor them to the specific requirements of a single user. Therefore, data gathering is not only connected with privacy-invasive ads campaigns, it is needed to offer competitive web services on the Internet ecosystem in general.

This leads to two fundamental questions this paper address: is it possible to offer an economically sustainable alternative to the model made of (mostly) free services and privacy-infringing advertising? And, if we find an alternative to data brokers, how will on-line services collect enough data to tailor their on-line services?
To give an answer we can not operate only at the technical layer, we need to conceive new ecosystems that enable a fair exchange of data from the producers (the Internet users) to the consumers (the service providers that need to optimize their services) preserving both privacy and service availability. IPPO is an architecture that encompasses all the necessary components to propose an alternative: it monitors the behaviour of web services to deter the most intrusive forms of tracking, but it also enables users to create eventually anonymised data that they can willingly share with service providers. The service providers in turn can acquire data from the users (and with their explicit consent) to understand the user habits and improve their services, using a transparent and privacy-aware platform.

The rest of the paper is organized as follows: 2 goes deep into the motivations of IPPO, 3 explains the architecture we envision and 4 details all its components, 5 focuses on the Big Data Grinder, an example application to run on IPPO. Later on 6 discusses the impact we expect IPPO to have, and 7 introduces the research challenges we need to address to complete IPPO. Finally, 8 draws conclusions.

2 Motivations

We are nowadays used to receive targeted advertisements. After googling for a pair of sunglasses, automatically, sunglasses advertisements will pop-up in our navigation on websites we do not directly relate to Google, and e-shops will suggest us new pairs of sunglasses we did not consider before. The more tech-savvy people simply accept that in exchange of free services, we give away personal information, while the layman simply ignores to be part of this system. The only possibility to rebalance this flow of information today completely dominated by Internet Corporations is to give back to the users the ownership and control over their data, along with the choice and the freedom to take informed decisions, and tools to enforce policies at their will. The first step is to make it evident for them that data have a value, and that free on-line services are free, as long as we do not consider the value of the data that we give away. IPPO is grounded on the principle that people should be compensated for sharing their data. If people understand that data have an economic and tangible value, they will hardly give data away, and they will be actively engaged in protecting their data. Monetising data will finally add transparency in the web tracking ecosystem.

On the other hand, web services need user data to design, run and improve the service they offer. Top service providers (such as Google, Facebook, Amazon to name a few) nowadays are in a position to directly collect users’ data. Smaller companies can instead buy this data from the data brokers that offer them user profiles. Data are used for a variety of reasons, to offer personalized content, to improve user experience, or to give geolocalized information, but also to train anti-spam algorithms or intrusion detection systems. IPPO wants to provide eventually anonymised data sources for data consumers, i.e., those who need data to improve their systems, bypassing the data brokers, and under the full control of the data producers (i.e., the end users). Data-sets will be produced and shared by the end user, e.g., using a browser plugin, and publicly sold in a distributed marketplace. The data consumers will access this marketplace and buy the data they need for their goals. The user will be compensated for sharing data, and targeted services may be acquired. No intermediary is needed, and no aggressive user profiling is required. Everything will be consolidated using smart contracts.

Targeted advertisement requires user profiling, and thus our architecture lets end user to control whether to offer eventually anonymised data. This may disfavour the targeted advertising industry. Indeed, we strongly believe that user profiling is an approach that implies too many negative externalities to be socially sustainable on the long run, and we propose a viable
alternative with a healthier approach.

3 IPPO Overall Architecture

The IPPO architecture is depicted in 1 and is made of three main components: (i) IPPO Agents perform data collection, anonymisation and sharing. Agents are envisioned as plug-ins that directly run in the users devices, and/or middleboxes placed as, e.g., virtual network functions in corporate networks. (ii) a Distributed Data Marketplace (DDM) is an open, decentralized storage platform in which users publish anonymised navigation traces, combined to a Blockchain to empower a real data marketplace. The DDM offers any third party the ability to “buy&sell” data using digital contracts. (iii) third Parties can acquire data-sets to perform data-analysis on the data-sets.

As an example of third-party application we propose the Big Data Grinder (BDG), a system that runs scalable machine learning based algorithms to automatically identify traffic from/to trackers (later on referenced to as “tracking traffic”). The BDG performs automatic auditing of web services, and identifies privacy threats or involuntary leakage of personal information. The BDG produces feedback to the users in two forms:

- Privacy Labels and Privacy Factor: graphical representation to communicate to non-experts the privacy cost of online services. Privacy Labels translate the results of the auditing algorithms into simple and tangible metrics (better explained in 5) to indicate both which information a website collects, and the cost of accessing it.

- Filtering Rule-Sets: the BDG can produce also rule-sets that can be enforced directly on the clients machines. Agents could even support specific plug-ins from trusted third parties to perform specific actions.

The next sections will describe in details each component, and the related research challenges.

4 IPPO Components

4.1 IPPO Agents

Data is initially collected by the IPPO Agents, of three kinds: (i) browser plug-ins or mobile apps, which the user freely installs. They access unencrypted data even in HTTPS sessions,
allowing total visibility on web traffic; Data is collected in anonymised form, thanks to anonymisation techniques like differential privacy that make it possible to share such raw data, while guaranteeing end-user privacy. Data-sets are encrypted, annotated with meaningful automatically generated meta-data, stored in the DDM, and announced on the Blockchain (described later on). (ii) A companion instrument to user agents are automatic bots, which scrape the web at scale. Bots can form a basis for a wide data-collection, and can also reproduce user browsing, so that once a browser agent has realized a traffic trace, the agent can trigger one of the available active probes (headless browsers) to partly repeat the browsing session. In this case, new data-sets related to the initial one can be published in the DDM. (iii) Agents can also be installed on middleboxes and from privileged positions (like corporate internal proxies) they generate large, aggregated traffic data-sets.

### 4.2 The Distributed Data Marketplace

The concept of DDM rebalances the current disparity of power on the Internet: instead of a handful of big players with their walled gardens, an open marketplace where users can make their data (literally) count. The DDM is made of two components:

- **IPPO Distributed Storage**: it provides a decentralized storage for the encrypted data-sets. IPFS could be the natural choice for this component, as it enables a truly decentralized and cryptographically robust file system imagined to scale to millions of nodes. Users will store their anonymised data-sets in the storage, encrypted with a unique key, which
will be revealed only to the buyer of the data. After the acquisition the data-set can be removed from the storage, or left in the storage for future transactions.

- Blockchain with Smart Contracts support: when a user generates a new data-set from a browsing session they also add references and detailed meta-data, automatically extracted from the traffic session, in the DDM Blockchain. Smart contracts represent the gateway to access the data-sets. Third parties negotiate with the smart contract the access to the data-sets in exchange of cryptocurrency for the owner.

The DDM must be anonymous so that third parties can not correlate different browsing sessions of the same user (unless she allows it). Techniques like non-interactive zero-knowledge proofs will be the key enablers to realize the DDM.

4.3 Third Parties

One key observation is that many market sectors for on-line services can be classified as oligopolies. Search engines and security appliances are only two examples in which a handful of players take the vast majority of the market. Big players enjoy a dominating position also because they have access to enormous databases that they use to train and optimize their services. With IPPO we envision that interested third parties will use the DDM to access to data-sets that are on the market. We believe that the DDM will make it possible also for newcomers and start-ups to access enough data to start their business and re-balance market sectors that are pathologically unfair. Third parties interested in these data-traces may be of many kinds. For instance, most of the security appliances on the market today include algorithms for identifying malicious traffic, and need to be trained on existing data-traces. Similarly, software providers that specialize in user experience need to have detailed traces of user actions when using specific popular services.

One specific third party we detail in the rest of the paper is the BDG, a platform that can utilise data-traces and give back to the users understandable feedback on the privacy level of their browsing habits, plus, rule-sets for filtering out invasive trackers. We describe the BDG in the next section.

5 The Big Data Grinder

One of the most troubling issue with on-line trackers is the complete lack of transparency and the sense of disempowerment that users feel when they realize the amount of information they unwillingly give away while browsing. This is even worse in the corporate environment, in which employees daily disclose protected information that is collected by data brokers. A data broker can, for instance, inform company X that the employees of its competitor company Y daily search for job offers, and that a number of them is leaving the company.

The BDG tries to produce an informed feedback to users, made of a privacy score for the services they use and also for their browsing habits. We propose to revive a concept that was introduced several years ago: the idea of Privacy Labels (PLs). Originally, they were conceived for illustrating in a simple way the service terms – the EULA – to users [6]. Here we instead propose to use them to inform users about the service they contact. PLs are similar to nutrition or energy labels, but for privacy. They contain indications about the trustfulness of web services and can be used as a public “privacy fingerprint” of an online service. How to form and fill information in Privacy Labels is however far from being easy. In our vision, the BGD elaborates the data-sets in order to extract from the user traces the tracking traffic, and produces simple
metrics that the common people can understand, e.g., number of contacts with trackers, cost in data volume, battery consumption, etc. In 2 the BDG is broken down in all its components; a first module applies machine learning algorithms to automatically identify tracking traffic and a second module analyses this traffic and estimates the impact of such traffic in terms of understandable metrics. These metrics take into consideration the time that was spent to load unwanted contents, and thus the usability impairment generated by tracking traffic, the amount of Bytes of unwanted traffic that the user had to download, and the consequent depletion of battery, especially useful on mobile devices. In general, these are only some of the metrics that can be used to characterize the impact of tracking traffic in a tangible way. In different contexts (for instance, the corporate context) some other metrics can be of interest and could be included in the privacy labels.

In this model, the BDG acquires data-sets from the DDM and publishes PLs for users that want to know what is the “privacy fingerprint” of a specific service. The final goal of this strategy is to increase (or create) awareness in the users about the services they are using, and helping the interested users in choosing the one (among the available ones) that is more respectful of their privacy.

The BDG can offer also personalized services, analysing traffic from the browsing sessions that a customer makes available. In this case it is the customer that makes available its data traces and potentially pays for a personalized service. We envision two of these services, first, the BDG can produce per-user labels, showing how trackers impacted user navigation. When aggregated on a per-user base, they become the Privacy Factor, which measures the exposure of the user to web tracking and the incurred cost. Second, the BDG could produce rule-sets that can be given back to the users to enforce filtering of tracking traffic. These rule-sets can be used by security services like firewalls, antispam filters, DDoS mitigation services etc. This architecture is depicted in 2 which summarises the architecture of the BDG in all its components.

6 Impact and Outlook

As we already mentioned we are perfectly aware that a large part of the Internet ecosystem today is financed by the ads industry. Weather this is an economically sustainable model, or it is just an armed race to the best and most precisely targeted advertisement campaign, it is under discussion [7]. What is instead becoming clear is that basing the Internet economy on profiling people is becoming socially unsustainable [8]. Our ultimate goal is to propose a model enabling a different cash flow (or cryptocash flow for whatever difference it may make). Money, instead of going from advertisers to web-services will flow from data consumers to the users and then back to tailored services. Those that need the data will acquire them directly at the source, the Internet users. Users will then spend their resources in services. The more data they share, the more currency they own, the more personalized services they will be able to acquire.

Of course this does not preclude the possibility of using ads, if a user wants to receive targeted advertisement, they will be able to share data about their shopping preferences or search results, and let third party companies to produce tailored feedback. The main difference here, is that users will be aware that data have an economic value, and they will decide to trade data for money, and not passively accept to be profiled without even knowing this happens.

In this design, the BDG perfectly fits as a companion component that unveils in an understandable way the trade-offs of the current system. The user needs knowledge of her data flow in order to defend her right to privacy. Due to current web technologies, gathering such
knowledge is beyond the layman possibilities and often precluded also to the expert: the aim of the BDG is to reduce such obscurity. Moreover, the current lack of clear exposition of key privacy-related characteristics of the services gives the user a blurred picture of the offer, with little or no apparent choice in matter of privacy, effectively downplaying its importance. The DBG will contribute to a raise awareness on users’ right to privacy protection, and produce usable and tailored filters they can actually enforce.

7 Going beyond the SoA: a Research Agenda

While the IPPO goals and architecture are very ambitious, it is based on a solid background of existent research, which must be improved and organized in a single system. This section reviews the relevant state of the art and outlines the challenges that still need to be solved to arrive to a real implementation of IPPO.

7.1 Data Collection

IPPO agents need to collect data in real time and anonymise it before publishing it on the DDM. One way of doing this is using browser plug-ins or Apps that can access the traffic in real time. While this has been realized in the past, [9] making data collection scale is not trivial. Anonymising data is even more complex, as anonymisation should be “future proof” and thus, the recent advancements in differential privacy are the basis for the realization of the IPPO agents [10].

7.2 Realizing the DDM

The DDM is a complex system comprising a distributed data sharing platform and a blockchain with support for smart contracts. While there are working models for both these components, they also bring a relevant amount of complexity. Coupling blockchains with a distributed data storage has been recently proposed [11, 12], at it is at the fundamentals of the StorJ solution, proposing an Open Source solution for to decentralize cloud data storage, as well as of the Filecoin cryptocurrency. Although such approaches are particularly interesting, they are prone to scalability issues, and the unique combination of requirements of the DDM (in terms of privacy for the users, support for economic transactions, robustness, etc.) makes its design a real research challenge. Users will need to store their data-sets in a fully anonymous blockchain (and not only pseudonymous as in most of the mainstream blockchains used in the real world). Proposals based on zero-knowledge proofs, as in the zk-SNARK protocol recently made their way to working systems (as in the Zcash system [13]). But yet mixing full anonymity, distribution and protection from data tampering is an open issue.

7.3 The BDG

Identifying tracking traffic, and data trackers is still a completely open challenge. Most of current solutions rely on manually pre-computed list of trackers, and very little research has been done in the automatic identification of trackers. A promising approach is to apply supervised machine learning to the analysis of DOM structure [14], or HTTP requests [15], or fingerprinting [16]. Similarly, [17] manually examines 2,600+ javascript tracking tools, and designs a supervised classifier to automatically flag abuse. Given the unknown nature of tracking services, the real challenge is to primarily rely on unsupervised machine learning algorithms, such as
clustering and text mining, to process traces and highlight tracking traffic. Not only traffic itself can be analysed, but also web page code (javascript in particular) to look for possibly malicious code inserted to fingerprint users and exfiltrate data.

Another open challenge is how to define methodologies and models to measure and extract the cost of tracking traffic from labeled traces. One way to do this is comparing the access to the same service with and without third-party services, which is a strategy that can extract i) the extra data usage cost due to tracking, ads or analytics services, ii) the QoE impairments, e.g., the extra cost to load/render a web page, iii) Energy consumed by mobile terminals. Re-browsing services with IPPO agents is a viable solution for those services that can be browsed without private credentials, but we need to define machine learning models to generalise and predict the cost on other web services.

8 Conclusions

This paper describes IPPO, an architecture for giving back to the users the control on their data. We believe that the only way to rebalance the current disparity of power on the Internet is to gradually abandon the ads-based revenue model that dominates the market of on-line services. For this reason, we propose a different model in which the users will generate and share anonymised data-sets, and sell them on a distributed marketplace. We also propose one specific application that exploits the availability of data to give to the users feedback of various types on how the services they navigate respect their privacy, or expose data to data trackers.

The architecture that we proposed is the first step towards the implementation of our vision, and still, there are many unsolved research issues we need to address before the system can be really implemented. In the paper, starting from our background and the current state of the art, we propose some research directions that must be followed to make IPPO reality.

Further work on the topic may address implementation issues and feasibility of IPPO, by evaluating computational and storage costs of the proposed system, in order to analyse the efficiency of the proposed system, compared to current solutions.

References

[1] N. Korula, V. S. Mirrokni, H. Nazerzadeh, Optimizing display advertising markets: Challenges and directions., IEEE Internet Computing 20 (1) (2016) 28–35.
[2] M. Falahrastegar, H. Haddadi, S. Uhlig, R. Mortier, The rise of panopticons: Examining region-specific third-party web tracking, in: International Workshop on Traffic Monitoring and Analysis, 2014.
[3] P. de Hert, V. Papakonstantinou, The new general data protection regulation: Still a sound system for the protection of individuals?, Computer Law & Security Review 32 (2) (2016) 179–194.
[4] H. Metwalley, S. Traverso, M. Mellia, S. Miskovic, M. Baldi, The online tracking horde: a view from passive measurements, in: International Workshop on Traffic Monitoring and Analysis, 2015.
[5] C. Cadwalladr, The great British Brexit robbery: how our democracy was hijacked, The Guardian 20.
[6] P. G. Kelley, J. Bresee, L. F. Cranor, R. W. Reeder, A nutrition label for privacy, in: Proceedings of the 5th Symposium on Usable Privacy and Security, 2009.
[7] T. Blake, C. Nosko, S. Tadelis, Consumer heterogeneity and paid search effectiveness: A large-scale field experiment, Econometrica 83 (1).
[8] B. Schneier, Data and Goliath: The hidden battles to collect your data and control your world, W. W. Norton & Company, 2015.
[9] H. Metwalley, S. Traverso, M. Mellia, S. Miskovic, M. Baldi, Crowdsurf: Empowering transparency in the web, ACM SIGCOMM Computer Communication Review 45 (5).

[10] H. Ebadi, D. Sands, G. Schneider, Differential privacy: Now it’s getting personal, in: Acm Sigplan Notices, Vol. 50, ACM, 2015, pp. 69–81.

[11] Y. Chen, H. Li, K. Li, J. Zhang, An improved p2p file system scheme based on ipfs and blockchain, in: Big Data (Big Data), 2017 IEEE International Conference on, IEEE, 2017, pp. 2652–2657.

[12] M. Ali, J. C. Nelson, R. Shea, M. J. Freedman, Blockstack: A global naming and storage system secured by blockchains, in: USENIX Annual Technical Conference, 2016.

[13] M. Peck, A blockchain currency that beat s bitcoin on privacy, IEEE Spectrum 53 (12).

[14] J. Bau, J. Mayer, H. Paskov, J. C. Mitchell, A promising direction for web tracking countermeasures, Wokshop on Web 2.0 Security & Privacy.

[15] T.-C. Li, H. Hang, M. Faloutsos, P. Estathopoulos, Trackadvisor: Taking back browsing privacy from third-party trackers, in: International Conference on Passive and Active Network Measurement, 2015.

[16] Y. Cao, S. Li, E. Wijmans, Browser fingerprinting via os and hardware level features, in: Proceedings of Network & Distributed System Security Symposium (NDSS), 2017.

[17] M. Ikram, H. J. Asghar, M. A. Kaafar, A. Mahanti, B. Krishnamurthy, Towards seamless tracking-free web: Improved detection of trackers via one-class learning, Symposium on Privacy Enhancing Technologies.