

Goodbye Tracking? Impact of iOS App Tracking Transparency and Privacy Labels

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ABSTRACT

Tracking is a highly privacy-invasive data collection practice that has been ubiquitous in mobile apps for many years due to its role in supporting advertising-based revenue models. In defence of user privacy, Apple introduced two significant changes with iOS 14: App Tracking Transparency (ATT), a mandatory opt-in system for enabling tracking on iOS, and Privacy Nutrition Labels, which disclose what kinds of data each app processes. So far, the impact of these changes on individual privacy and control has not been well understood. This paper addresses this gap by analysing two versions of 1,759 iOS apps from the UK App Store: one version from before iOS 14 and one that has been updated to comply with the new rules.

We find that Apple's new policies, as promised, prevent the collection of the Identifier for Advertisers (IDFA), an identifier used to facilitate cross-app user tracking. Smaller data brokers, who used to engage in some of the most invasive data practices, will now face higher challenges in tracking users – a positive development for privacy. However, the number of tracking libraries has – on average – roughly stayed the same in the studied apps. Many apps still collect device information that can be used to track users at a group level (*cohort tracking*) or identify individuals probabilistically (*fingerprinting*). We find real-world evidence of apps computing and agreeing on a fingerprinting-derived identifier through the use of server-side code, thereby violating Apple's policies and exposing the limits of what ATT can do against tracking on iOS. This is especially concerning because we explicitly refused opt-in to tracking in our study, and consent is a legal requirement for tracking under EU and UK data protection law. We find that Apple itself engages in some forms of tracking and exempts invasive data practices like first-party tracking and credit scoring from its new rules, and that

the new Privacy Nutrition Labels were often inaccurate. This is in conflict with the company's marketing claims and the resulting expectations of many iOS users.

Overall, our observations suggest that, while Apple's changes make tracking individual users more difficult, they motivate a counter-movement, and reinforce existing market power of gatekeeper companies with access to large troves of first-party data. Making the privacy properties of apps transparent through large-scale analysis remains a difficult target for independent researchers, and a key obstacle to meaningful, accountable and verifiable privacy protections.

CCS CONCEPTS

• **Security and privacy** → **Privacy protections**; *Economics of security and privacy*; • **Networks** → Mobile and wireless security.

KEYWORDS

mobile apps, Apple, iOS, data protection, privacy, platform policies, gatekeeper power, App Tracking Transparency, Privacy Nutrition Labels

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1 INTRODUCTION

Tracking, the large-scale collection of data about user behaviour, is commonplace across both mobile app ecosystems, Android and iOS. While some see tracking as a *necessary evil* to making apps available at lower prices by showing users personalised advertising and selling their data to third parties [11, 36], tracking can have highly disproportionate effects on the lives of individuals and society as a whole [46, 54]. As a countermeasure, Apple introduced the *Apple Tracking Transparency* (ATT) framework – alongside mandatory *Privacy Nutrition Labels* [27, 28] – with iOS 14, see Figure 1.

The emergence of more robust privacy measures in everyday technology is partly motivated by the emergence of new data protection and privacy laws around the globe, particularly the GDPR

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in the EU and UK since May 2018 [31]. Among other aspects, the GDPR protects any data that can be related to individuals (“personal data”), and mandates a legal ground for any processing of such personal data. This legal obligation has the effect that app tracking, which usually classifies as “high-risk” data processing, needs prior user consent [30, 40]. Additionally, the 2009 ePrivacy Directive, which regulates data processing in electronic systems in the EU and UK, also requires consent to tracking [9, 30]. Despite these legal requirements, a large proportion of apps engaging in tracking have in the past been observed not to seek the required prior user consent [30, 40, 45]. Beyond Europe, many countries have been introducing similar data protection and privacy laws, increasing the pressure on tracking practices in apps and the makers of smartphone ecosystems to implement robust safeguards for personal data.

Starting with iOS 14.5 in April 2021, iOS apps must now ask users for explicit permission before tracking them, see Figure 1a. If an iOS user asks an app not to track, then this has the direct effect that this app cannot access the Identifier for Advertisers (IDFA) anymore. The IDFA is a random, unique identifier provided by the operating system to apps for tracking users across multiple sessions of a single app and across apps. Additionally, apps are obliged to stop certain tracking practices under the Apple’s App Store policies (see more in Section 5). Preliminary data suggests that the vast majority of users (between 60% and 95%) choose to refuse tracking when asked for it under the new system [4, 19, 25]. Although users could previously opt-out from the use of the IDFA, the use of this feature was low, since it was off by default and not very visible in the system settings of iOS devices [51].

While potentially good for user privacy, the ATT has been reported to have vastly increased Apple’s share of overall advertising on iOS – as part of its Apple Search Ads on the App Store – and to have decreased the share and efficacy of ads from competing companies. The reason for this, as argued by Eric Seufert and others, is that Apple’s own tracking technologies do not fall under Apple’s definition of tracking [37]. It has also been reported that, as a result, many marketing companies have been shifting advertising budgets from iOS to Android advertising [16]. The Financial Times estimated that the loss for leading tech companies from the new policy would be around \$10bn [18], but also reported that companies deemed the “effect of Apple’s privacy changes was less than feared” [14]. Apple’s new rules might represent an important shift in the mobile advertising ecosystem towards more user privacy and market concentration.

Despite Apple’s new rules, some apps may try to circumvent them so as to continue to engage in lucrative collection and sharing of personal data. This might sometimes be in violation of Apple’s App Store policies, but both the automatic and manual review on the App Store can sometimes fail to pick up such violations and not enforce its policies [1, 21, 34, 38, 59]. The refusal to respect users’ consent to tracking might not only be in violation of Apple’s own rules, but also defy the expectations of many end-users and potentially violate existing legal requirements relating to consent to tracking.

In addition to the changes relating to the ATT, app developers must now also self-declare what types of data they collect from users, and for what purposes – called *Privacy Nutrition Labels* [27,

28], see Figure 1. As such, these privacy nutrition labels aim to make it easier for end-users to understand the data practices of apps, instead of having to study lengthy privacy policies, which few users do [35]. There is, however, a risk that many users will just ignore the new (and potentially oversimplified) privacy labels (as they commonly do with privacy policies [35]), might gain a false sense of security, might misunderstand the consequences for their privacy (which tends to be highly individual [41]), and that developers may not honestly self-declare their actual data practices [58]. Despite these concerns, privacy nutrition labels have the potential to shift developers’ existing data practices towards being more privacy-preserving, through increased transparency and end-user awareness.

Based on the above observations, this paper analyses the following research questions:

- (1) What impact have the ATT and Privacy Nutrition Labels had – thus far – on tracking, particularly on the extent and quality of such tracking?
- (2) To what extent do apps disclose their tracking practices in their Privacy Nutrition Labels?
- (3) What implications do the ATT and Privacy Nutrition Labels have for the power relations between the actors in the digital advertising system, including mobile OS providers, digital advertisers, app developers and marketers?

To analyse these questions, this paper analyses privacy in 1,759 iOS apps, for each of which we downloaded two versions: one from before ATT and one that has been updated to comply with the new rules relating to tracking. We use a combination of app code and network analysis to gain rich insights into the data practices of the studied apps.

The remainder of this paper is structured as follows. We first review related work in Section 2. Next, we introduce our app download and analysis methodology in Section 3. We turn to the results from our app code and network analysis in Section 4. We discuss our findings in Section 5 and the limitations of our study in Section 5.1. We conclude the paper and outline direction for future work in Section 6.

2 BACKGROUND

2.1 Related work

Previous research extensively studied privacy in mobile apps. Two main methods have emerged in the academic literature: dynamic and static analysis.

Dynamic analysis observes the run-time behaviour of an app, to gather evidence of sensitive data leaving the device. Early research focused on OS instrumentation, i.e. modifying Android [12] or iOS [1]. With growing complexity of mobile operating systems, recent work has shifted to analysing network traffic [22, 43, 45, 47, 48, 48, 49, 54]. This comes with certain limitations. One problem is limited scalability, since every app is executed individually. Another issue is that not all privacy-relevant parts of apps may be invoked during analysis, potentially leading to incomplete results.

Static analysis dissects apps without execution. Usually, apps are decompiled, and the obtained program code is analysed [10, 24]. The key benefit of static analysis is that it can analyse apps quickly, allowing it to scale to millions of apps [5, 8, 55, 57]. However, static



(a) Apple Tracking Transparency (ATT).

(b) Privacy Nutrition Label.

Figure 1: Overview of Apple's new privacy measures, introduced with iOS 14. Source: <https://developer.apple.com/app-store/user-privacy-and-data-use/>

analysis can involve substantial computational effort and – unlike dynamic analysis – does not allow the observation of real data flows because apps are never actually run. Programming techniques, such as the use of code obfuscation and native code, can pose further obstacles. This is especially true for iOS apps, which are often harder to decompile – compared to Android – and are encrypted by default [32].

The analysis of privacy in iOS apps has traditionally been done much more rarely than of Android apps because it is significantly more difficult [5, 60]. Key reasons include the closed-source nature of the Apple ecosystem; the use of exotic, Apple-only programming tools (Xcode) and languages (Objective-C and Swift); as well as the encryption of iOS apps by default (Apple FairPlay DRM). The encryption of iOS apps by Apple – even of free ones – is particularly problematic for research efforts because it drives researchers into legal grey areas of copyright law [32]; by contrast, Google only encrypts *paid* apps (not free ones) when downloaded from its Play Store. As a result, recent work by Kollnig et al. [32] was the first large-scale app privacy analysis study on iOS apps since 2013 [1]. These authors managed to avoid legal problems relating to copyright law by conducting part of the analysis on-device through using the popular app instrumentation tool Frida.

In this paper, we follow the methodology by Kollnig et al., who used a combination of both approaches – dynamic and static analysis – so as to generate rich insights into the privacy practices of the studied apps. We discuss our methodology for this paper in more detail in Section 3.

2.2 Regulation of App Platforms

The centrality of app platforms – i.e. Apple's iOS and Google's Android ecosystem – makes them a target for effective privacy regulation, however such regulation is limited [52, 61]. The US Federal Trade Commission (FTC) established some baseline rules for app stores in 2013. They strongly recommended to app platforms to require just-in-time consent for sensitive data access, to seek privacy policies from app developers, and to implement system-wide opt-out mechanism from data collection [13]. Whilst no law,

Google and Apple followed many of the recommendations, and have not seen further public recommendations from the FTC since.

In the EU and UK, there exists no targeted regulation of app stores. The Regulation on platform-to-business relations (P2BR) contains general provisions for online intermediaries, including app stores, but does little to enact better privacy protections [61]. Data protection law, such as the General Data Protection Regulation (GDPR) and the ePrivacy Directive, arguably places the responsibility for user privacy with the app developers, not usually with app platform providers – although this is subject to ongoing debate. Indeed, the lack of data protection obligations for the entire software development process – not just for deployment – has been widely criticised [7, 26].

In the absence of targeted regulation, some prominent companies have taken the dominance of app platform providers to the courts. In the case *Epic Games v Apple* running since 2020, a judge largely found no monopolistic behaviour of Apple, but did identify some anticompetitive conduct in Apple's business practices. The judge ordered Apple to allow app developers to inform app users of alternative payment methods. Both Apple and Epic Games have appealed the ruling. In the EU, following a complaint of Spotify against Apple from 2019, the European Commission identified multiple anticompetitive aspects about Apple's ecosystem in a preliminary ruling – the case is, however, still ongoing. Meanwhile, Apple has lowered the share it takes from App Store revenues of small developers (making less than \$1 million per year) from 30% to 15%. In South Korea, the parliament amended the Telecommunication Business Act, aiming to force app stores to allow alternative payment methods and reduce commissions [44].

In sum, there currently exist few legal obligations for app platforms. Instead, they are encouraged to self-regulate their conduct. The following analysis shall shine a light on how the recent policy changes by Apple, a highly prominent example of this self-regulation, have affected the actual privacy practices of mobile apps.

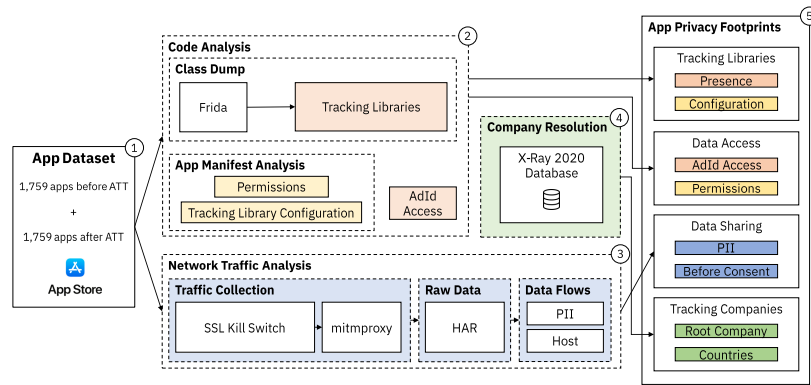


Figure 2: Overview of our analysis methodology (Section 3): First, (1) we select and download 1,759 apps from before the introduction of the ATT, and 1,759 from after. We then perform a (2) Code Analysis to detect tracking libraries in the app code, a (3) Network Traffic Analysis to analyse tracking domains contacted at the first app start and the sharing of personal data, and a (4) Company Resolution to analyse the companies behind tracking. The results of this analysis (Section 4) are detailed App Privacy Footprints (5) of the downloaded apps.

3 METHODOLOGY

In this section, we describe our analysis methodology (depicted in Figure 2), which follows the one previously used for a comparative analysis of iOS and Android apps’ privacy practices by Kollnig et al. [32]. We therefore keep our description of the methodology short and refer the reader to the original paper for details.

3.1 App Selection and Download

This section details our process for selecting and downloading apps from the Apple App Stores (step 1 in Figure 2) For the selection of apps, we revisited the same 12,000 iOS apps that were previously analysed by Kollnig et al. [32]. These apps were selected by first generating a large list of apps available on the Apple App Store between December 2019 and February 2020. The authors then downloaded a random subset ($n = 12,000$) of those apps that were last updated since 2018 so as to focus on apps currently in use. We re-downloaded those apps that were updated to comply with Apple’s ATT and privacy label rules, in October 2021. This resulted in a dataset of 1,759 *pairs* of apps, one from before iOS 14 and one from after. This number of apps is comparatively small because many apps had not yet been updated since the new rules, while some other apps had been removed from the store (2,713 out of 12,000 apps were not available on the App Store anymore). We additionally scraped the Privacy Nutrition Labels for the newly downloaded apps.

3.2 App Analysis

For our further analysis of apps, we executed every app on a real device – one iPhone SE 1st Gen with iOS 14.2, and one with iOS 14.8 – for 30 seconds without user interaction, and captured apps’ network traffic using the tool *mitmdump*. We disabled certificate validation using *SSL Kill Switch 2*, after gaining system-level access on both iPhone (known as ‘jailbreak’). On the iPhone with iOS 14.2, we did not opt-out from ad personalisation from the system settings, thereby assuming user opt-in to use the IDFA (reflecting the assumption that many users, who would reject tracking, do

not do so because the option is in the less prominent settings on the OS [32]). On the iPhone with iOS 14.8, we asked all apps not to track from the system settings. Although in Android privacy research real user behaviour is simulated via various automation tools [6, 23, 42, 43, 45, 47, 53], Apple’s restrictions on debugging and instrumentation have prevented the development of such tools for iOS. However, tracking libraries are usually initialised at the first app start and without user consent [30, 32, 39, 45], and they can thus be detected without user interaction in the network traffic, as done in our analysis. To identify the presence of tracking libraries, we extracted the names of all classes loaded by each app using the tool *Frida* and checked them against a list of known tracker class names, curated by Kollnig et al. [32].

Many tracking libraries allow developers to restrict data collection using settings in the app manifest, e.g. to disable the collection of unique identifiers or the automatic SDK initialisation at the first app start. This can help set up tracking libraries in a legally compliant manner. For example, ‘Data minimisation’ is one of the key principles of GDPR (Article 5), and user opt-in is required prior to app tracking in the EU and UK [30]. We analysed the privacy settings provided by some of the most prominent tracking libraries: Google AdMob, Facebook, and Google Firebase.

Beyond analysing tracking in apps, we also obtained a list of permissions that apps can request. Permissions form an important part of the security model of iOS as they protect sensitive information on the device, such as apps’ access to the camera or address book. As such, permissions are different to the new privacy labels, which do not affect the runtime behaviour of apps. We extracted apps’ permissions by automatically inspecting the manifest file that every iOS app must provide.

4 RESULTS

In this section, we present our findings from analysing two versions – one from before and one from after the release of iOS 14 and the ATT – of 1,759 iOS apps (step 5 in Figure 2). We analysed 199.6 GB of downloaded apps, extracted 3.2 GB in information about

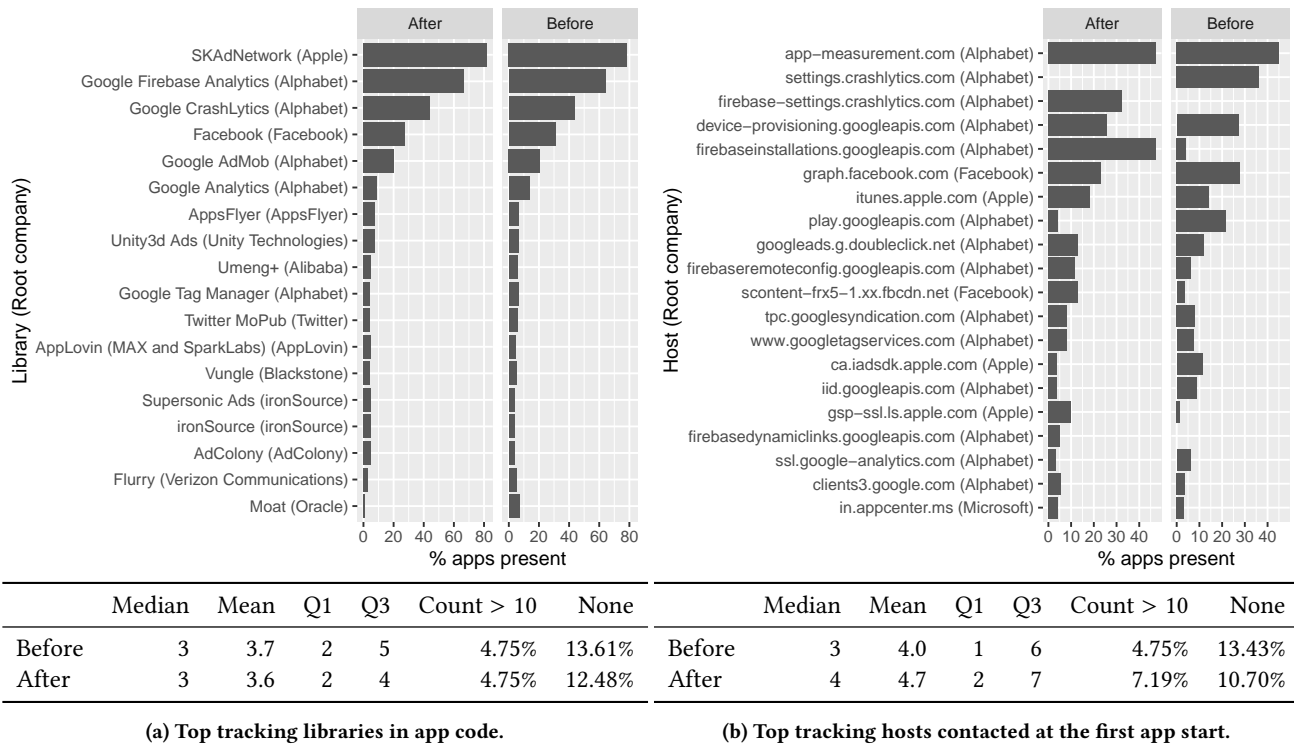


Figure 3: Third-party libraries and contacted tracking domains of apps, as well as the companies owning them (in brackets). Shown are the top 15 tracking libraries and domains for before and after the new privacy changes under iOS 14.

classes in apps' code, and collected 3.9 GB of data in apps' network traffic. Installing and instrumentation failed for 74 iOS apps; we have excluded these apps from our subsequent analysis and focus on the remaining 1,685 apps.

First, we focus on the tracking libraries found in the code analysis (Section 4.1) and whether or not they were configured for data minimisation (Section 4.1.1). Next, in Section 4.2, we analyse apps' access to the IDFA (which is now protected by the ATT) and also their permissions. Following up, in Section 4.3, we report on the data sharing of apps before consent is provided, with a particular focus on whether apps that are instructed not to track actually do so in practice. Lastly, in Section 4.4, we check whether and to what extent apps disclose their tracking practices in their Privacy Nutrition Labels.

4.1 Tracking Libraries

Apps from both before the ATT and after widely used tracking libraries (see Figure 3a). The median number of tracking libraries included in an app was 3 in both datasets. The mean before was 3.7, the mean after was 3.6. 4.75% of apps from before ATT contained more than 10 tracking libraries, compared to 4.75% after. 86.39% contained at least one before ATT, and 87.52% after.

The most prominent libraries have not changed since the introduction of ATT. The top one is the SKAdNetwork library (in 78.4% of apps before, and 81.8% after). While part of Apple's privacy-preserving advertising attribution system, this library discloses

information about what ads a user clicked on to Apple, from which Apple could (theoretically) build user profiles for its own advertising system. Following up with Apple about this potential issue (exercising the GDPR's *right to be informed* under Article 13 of the law), they did not deny the fact that this data might be used for advertising, but assured us that any targeted ads would only be served to segments of users (of at least 5,000 individuals with similar interests). Google Firebase Analytics ranks second (64.3% of apps from before ATT, and 67.0% after), and Google Crashlytics third (43.6% before, 44.4% after).

Overall, Apple's privacy measures seem not to have affected the integration of tracker libraries into *existing* apps.

4.1.1 Configuration for Data Minimisation. Among the apps that used Google AdMob, 2.9% of apps from before and 4.5% from after chose to delay data collection. Among the apps using the Facebook SDK, there was an increase in those which delayed the sending of app events (6.7% before, and 12.5% after); an increase in those which delayed the SDK initialisation (1.0% before ATT, 2.2% after), and an increase in those which had disabled the collection of the IDFA (5.0% before, 8.6% after). Among apps using Google Firebase, 0.6% had permanently deactivated analytics before ATT and 0.8% after, 0.6% had disabled the collection of the IDFA before and 0.6% after, and 0.6% had delayed the Firebase data collection before ATT and 1.0% after.

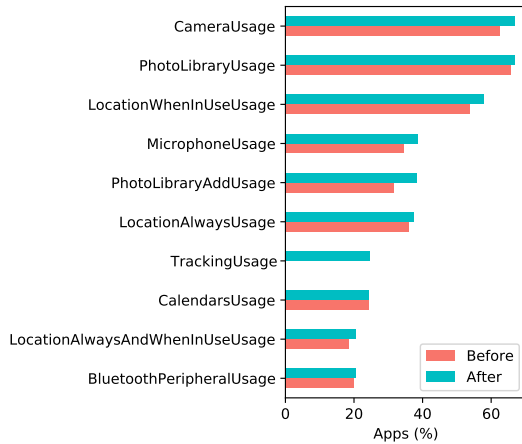


Figure 4: Top permissions.

Overall, we found that only a small fraction of apps made use of data-minimising SDK settings in their manifest files. This fraction has subtly increased since the introduction of the ATT.

4.2 Data Access and Permissions

Most prevalent permissions. Figure 4 shows the most prevalent permissions before and after the introduction of the ATT. On average, there was an increase in permission use (4.3 permission before, 4.7 after – excluding the new *Tracking* permission). *CameraUsage* (for camera access) was the most common permission (62.6% before ATT, 66.9% after), closely followed by *PhotoLibraryUsage* (65.8% before ATT, 66.9% after), and *LocationWhenInUseUsage* (53.8% before ATT, 58.0% after).

Tracking permission and access to IDFA. As part of ATT, apps that want to access the IDFA or conduct tracking must declare the *TrackingUsage* permission in their manifest. 24.7% of apps from our dataset choose to declare this permission, and might ask users for tracking. At the same time, the share of apps that contain the *AdSupport* library, necessary to access the IDFA in the app code, has stayed unchanged at 50.8% of apps. This means that 50.8% of apps from after the ATT can access the IDFA on earlier versions of iOS than 14.5, but only 24.7% can on iOS 14.5 or higher.

Tracking permission and integration of tracking SDKs. The share of apps that both contain a tracking library and can request tracking varies somewhat between the used tracking library. 69.3% of the 350 apps that integrate Google AdMob declare the *TrackingUsage* permission; 78.7% of the 110 apps that integrate Unity3d Ads; 50.0% of the 116 apps that integrate Moat; and 77.3% of the 54 apps that integrate Inmobi. Whether the app is from before or after the ATT, the vast majority of apps (between 97 and 100%) that integrate any of these tracking libraries also integrate the *AdSupport* library, and can therefore access the IDFA if running on iOS versions before 14.5.

4.3 Data Sharing

4.3.1 Before Consent. This section analyses how many tracking domains apps contacted before any user interaction has taken place;

Information	Example	Before	After
iPhone Name	MyPhone	2.5%	4.2%
iPhone Model	iPhone8,4 iPhone SE	60.2%	74.5%
Carrier	Three	20.2%	20.2%
Locale	en_GB en-gb	85.7%	90.1%
CPU Architecture	ARM64 16777228	13.7%	16.1%
Board Config	N69uAP	3.1%	4.5%
OS Version	14.8 18H17	79.9%	86.9%
Timezone	Europe/London	3.9%	3.4%

Figure 5: Potential fingerprinting and cohort tracking, even after ATT: Proportion of *all* apps that shared device information, which can potentially be used for fingerprinting or cohort tracking.

the next Section 4.3.2 then analyses what data was shared with trackers. Since tracking libraries usually start sending data right at the first app start [30, 32, 39, 45], this approach provides additional evidence as to the nature of tracking in apps – and without consent. Our results are shown in Figure 3b.

The average number of tracking domains contacted was somewhat higher for apps from after the introduction of the ATT (4.0 before, 4.7 after). The most popular domains are related to Google’s analytics services: `firebaseinstallations.googleapis.com` (4.1% of apps before the ATT, 47.4% after) and `app-measurement.com` (45.2% before, 47.2%).

Our data reflects the acquisition of the crash reporting software Crashlytics by Google from Twitter in January 2017. Over time, Google integrated Crashlytics ever more into its analytics suite Firebase, and deprecated the old API endpoints (from `settings.crashlytics.com` to `firebase-settings.crashlytics.com`) in November 2020. This has the direct effect that all Crashlytics users must now also use Google Firebase. The domain `settings.crashlytics.com` was contacted by 36.4% for apps from before the ATT, and `firebase-settings.crashlytics.com` by 32.3% after the ATT. While this might point to a small difference in the adoption of Google Crashlytics, the exact same number of apps (734, 43.6%) integrated the Crashlytics library into their code, before and after the ATT. Similarly, the exact same number of apps integrate the Facebook SDK (523, 31.1%); the share of apps that contacted the associated API endpoint `graph.facebook.com` at the first start has fallen from 27.7% to 23.1%. The Google Admob SDK, too, is integrated in the same number of apps (350, 20.8%), and has not seen a decline in apps that contact the associated API endpoint `googleads.g.doubleclick.net` (12.1% before, 12.9% after).

Overall, data sharing with tracker companies before any user interaction remains common, even after the introduction of the ATT. This is in potential violation with applicable data protection laws in the EU and UK, which require prior consent [30].

4.3.2 Exposure of Personal Data. We found that 26.0% of apps from before the ATT shared the IDFA over the Internet, but none from after the ATT. In this sense, the ATT effectively prevents apps from accessing the IDFA. Despite Apple’s promises, closer inspection of the network traffic showed that both Apple and other third parties are still able to engage in user tracking.

```

{
  "sdk_version": "1.2.0",
  "bundle_id": "[Redacted]",
  "hw_model": "N69uAP",
  "kid": "[Redacted]",
  "total_storage": "30745123781",
  "country": "GB",
  "zdata": "[Redacted]",
  "app_version": "[Redacted]",
  "app_name": "[Redacted]",
  "sdk_type": "IOS",
  "storage": "14078912372",
  "zdata_ver": "1.1.0",
  "source_id": "umeng",
  "idfV": "7EBDAFC8-97BB-4FDB-B4D3-E2F4EA040B8C",
  "timezone": "1",
  "os_version": "14.8",
  "model": "iPhone8,4",
  "hostname": "MyPhone",
  "appkey": "[Redacted]",
  "idfa": "00000000-0000-0000-0000-000000000000"
}

```

(a) Request: Sending a range of device information to Umeng at <https://aaid.umeng.com/api/postZdata>.

```

{
  "aaid": "BAEC362C-49FC-494B-B0A7-175D990B059D",
  ...
}

```

(b) Response: Umeng returns an identifier that is shared by multiple apps, and can be used for cross-app tracking.

Figure 6: Fingerprinting in apps, even after the ATT, and in potential violation of Apple’s new policies and the expectations of many end-users (personal data redacted).

We found that iPhones continue to share a range of information with third-parties, that can potentially be used for device fingerprinting or cohort tracking, see Table 5. Only *timezone* has seen a subtle decrease in the number of apps that share this information. It is not clear why apps need to access or share some of this information, e.g. the carrier name (shared by 20.2% of apps) or the iPhone name (shared by 3% of apps). Meanwhile, some types of information, particularly the iPhone name, might allow the identification of individuals, especially when combined with other information.

In our analysis, we found 9 apps that were able to generate a mutual user identifier that can be used for cross-app tracking, through the use of server-side code. These 9 apps used an “AAID” (potentially leaning on the term Android Advertising Identifier) implemented and generated by Umeng, a subsidiary of the Chinese tech company Alibaba. The flow to obtain an AAID is visualised in Figures 6a and 6b. As expected, the IDFA is only zeros because we used the opt-out provided by iOS 14.8; we observe, however, that the IDfV (ID for Vendors), a non-resettable, app-specific identifier is shared over the Internet, see Figure 6a. The sharing of device information for purposes of fingerprinting would be in violation of the Apple’s policies, which do not allow developers to “derive data from a device for the purpose of uniquely identifying it” [3]. Other experts and researchers have also voiced concerns that tracking might continue [17, 34, 38, 59].

We reported our observations to Apple on 17 November 2021, who said that they would investigate the problem. We conducted a follow-up investigation on 1 February 2022, and re-downloaded and analysed a range of iOS apps. Some of the apps still continued to retrieve a unique identifier from the URL <https://aaid.umeng.com/api/postZdata>. Other apps now contact the URL <https://utoken.umeng.com/api/postZdata/v2>, and now use a custom encryption for both requests and responses. This encrypted data has roughly the same size (750 bytes for the request, 350 bytes for the response); the mimetype, too, is the same (`application/json` for the request, `application/json; charset=UTF-8` for the response). The issue seems to persist still, but has now been hidden away from the public through the use of encryption. We have tried to reproduce these experiments for a few apps on iOS 15 and higher, but did not observe the same behaviour; there currently exists no public jailbreak for these iOS versions, and therefore does not (yet) allow similar investigations on these iOS versions. There is a possibility that the issue has been fixed on iOS 15 or higher, or that we did not pick up the same behaviour in our small-scale testing (about 10 apps instead of more than 1000).

Analysing the top 20 most commonly contacted domains, we could confirm that installation-specific identifiers (see column “User ID”) are commonly collected alongside further device-specific information, see Table 1. While these installation-specific identifiers are usually randomly generated at the first app start, large tracking companies can likely still use these identifiers to build profiles of an app user’s journey across apps, using their server-side code to link different identifiers together (e.g. through the user’s IP address, other device information and first-party data). Companies also receive information about a user’s locale (i.e. the display language), the device model, and the OS version. Such information can be used to disambiguate different users connecting from the same IP address (e.g. households sharing the same Wi-Fi router) – and even across different IP addresses through the use of additional, first-party data that large tracking companies hold.

Table 1 does not include all the different kinds of information that we observed being sent to tracking domains because the kinds of information varied a lot between companies. For example, Google assigned an `android_id` to an app upon first contact with the company that was then used for all subsequent communication with Google’s API endpoints. This identifier differed between apps, and did not seem to be used for cross-app tracking on-device (it might be on Google’s servers). When contacting the domain `googleads.g.doubleclick.net`, Google collected the current system volume and the status of the silencing button. As already described above, `ca.iad.sdk.apple.com` collected a `purchaseTimestamp`, that can be used to identify the user, and is something that is not accessible for other app developers. The domain `gsp64-ssl.ls.apple.com`, which is linked to Apple’s location services, even collected the IP address and port that we used for proxying the network traffic through `mi_tmdump` as part of our analysis. We did not observe any other domains that had access to this information, underlining Apple’s privileged data access. Crucially, for many of the observed transmissions between apps and servers, we could not even determine what data was sent, due to use of encryption [34] and closed-source communication protocols.

Domain	Company	Apps	User ID	Locale	Model	OS Version
firebaseinstallations.googleapis.com	Google	47.4%	✓	✓		
app-measurement.com	Google	47.2%	✓	✓		
firebase-settings.crashlytics.com	Google	32.3%	✓	✓	✓	✓
device-provisioning.googleapis.com	Google	25.8%	✓	✓	✓	✓
graph.facebook.com	Facebook	23.1%	✓	✓	✓	✓
itunes.apple.com	Apple	18.3%	✓	✓	✓	✓
fbcdn.net	Facebook	13.0%		✓		
googleads.g.doubleclick.net	Google	12.9%	✓	✓	✓	✓
firebase-remoteconfig.firebaseio.com	Google	11.8%	✓	✓		
gsp-ssl.ls.apple.com	Apple	9.9%	✓	✓	✓	✓
tpc.googlesyndication.com	Google	8.3%		✓		✓
www.googletagmanager.com	Google	8.1%		✓		✓
clients3.google.com	Google	5.3%		✓		
firebase-dynamiclinks.firebaseio.com	Google	5.2%	✓	✓		✓
in-appcenter.ms	Microsoft	4.3%		✓	✓	✓
play.googleapis.com	Google	4.2%	✓	✓	✓	✓
skadsdk.appsflyer.com	AppsFlyer	4.0%	✓	✓		
gsp64-ssl.ls.apple.com	Apple	3.9%		✓	✓	✓
api.onesignal.com	OneSignal	3.7%		✓		
ca.iadsk.apple.com	Apple	3.7%	✓	✓	✓	✓

Table 1: 20 most common tracking domains after ATT: sharing of unique user identifiers with third-parties, alongside device information. Empty cells mean that we did not observe the sharing of a certain type of information, although this might still take place.

```
<plist version="1.0">
<dict>
...
<key>dsid</key>
<string>[Apple ID]</string>
<key>guid</key>
<string>[UDID]</string>
<key>serialNumber</key>
<string>[serial number]</string>
...
</dict>
</plist>
```

(a) Request of Apple App Store to [https://buy.itunes.apple.com/WebObjects/MZFinance.woa/wa/renewVppReceipt?guid=\[UDID\]](https://buy.itunes.apple.com/WebObjects/MZFinance.woa/wa/renewVppReceipt?guid=[UDID]).

```
{
  "attributionMetadataExistsOnDevice": false,
  "toroId": "[Redacted]",
  "purchaseTimestamp": "2021-11-01T15:15:05Z",
  "adamId": 477718890,
  "attributionDownloadType": 0,
  "developmentApp": false,
  "anonymousDemandId": "[Redacted]",
  "bundleId": "ru.kinopoisk",
  "attributionKey": "[Redacted]"
}
```

(b) Request (shortened) of Apple's advertising framework to <https://ca.iadsk.apple.com/adserver/attribution/v2>.

Figure 7: Sharing of unique user identifiers with Apple (personal data redacted).

System-Level Tracking by Apple. We found that iPhones exchange a range of unique user identifiers directly with Apple, see Figure 7. We observed that network requests, which included various unique user identifiers and other personal data, were issued following the interaction with apps and connected to Apple's App

Store and advertising technologies. While this does not allow user-level apps to gain access to these user identifiers, Apple itself can use these identifiers to enrich its own advertising services. Indeed, Apple claims in its privacy policy that it may use users' interactions with its advertising platform and with the App Store to group users into segments (of at least 5,000 individuals), and show adverts to these groups [2]. Specifically, we found that the App Store collected the UDID, the serial number of the device, the DSID (an identifier linked to a user's Apple account), and a purchaseTimestamp. All of these identifiers can be used by Apple to single out individual users. Crucially, the UDID has been inaccessible to app developers other than Apple since 2013 [50], but Apple continues to have access to this identifier. Moreover, Apple collects the serial number, which cannot be changed and is linked to a user's iPhone. This might be unexpected for some users. These findings are in-line with previous reports that both Google and Apple collect detailed information about their users as part of regular device usage [33].

4.4 Disclosure of Tracking in Privacy Nutrition Labels

We now consider whether and to what extent apps (from after the introduction of iOS 14) disclose their tracking activities in their Privacy Nutrition Labels.

Among the studied apps, 22.2% claimed that they would not collect any data from the user. This was often not true: as shown in Figure 8, 80.2% of these apps actually contained at least one tracker library (compared to 93.1% for apps that did disclose some data sharing), and 68.6% sent data to at least one known tracking domain right at the first app start (compared to 91.4%). On average, apps that claimed not to collect data contained 1.8 tracking libraries (compared to 4.3), and contacted 2.5 tracking companies (compared to 4.2).

As noticed above (see Table 1), tracking libraries usually create a unique user identifier. Among the apps that use the SKAdNetwork,

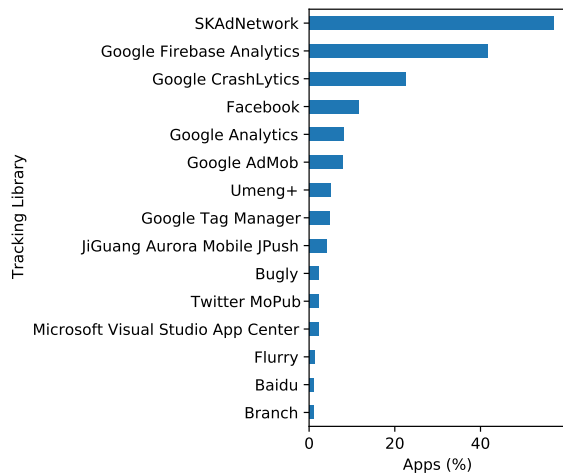


Figure 8: Top tracking libraries in apps that claim in their Privacy Nutrition Labels not to collect any data.

42.0% disclosed their access to a “User ID”, 42.2% of apps using Google Firebase Analytics, 48.2% of apps using Google Crashlytics, and 53.2% of apps using the Facebook SDK. 63.2% of apps using Google Firebase Analytics disclosed that they collected any data about “Product Interaction” or “Other Usage Data”, and about 70% of apps using the Facebook SDK, Google Analytics, or Google Tag Manager. Additionally, apps can disclose their use of “Advertising Data”: 27.5% of apps with the SKAdNetwork did so, 66.0% of apps with Google AdMob, 80.9% of apps with Unity3d Ads, and 45.4% apps with AppsFlyer.

All of this points to notable discrepancies between apps’ disclosed and actual data practices.

5 DISCUSSION

Tracking continues, and reinforces power of gatekeepers and opacity of mobile data ecosystem. Our findings suggest that tracking companies, especially larger ones with access to large troves of first party, still track users behind the scenes. They can do this through a range of methods, including using IP addresses to link installation-specific IDs across apps and through the sign-in functionality provided by individual apps (e.g. Google or Facebook sign-in, or email address). Especially in combination with further user and device characteristics, which our data confirmed are still widely collected by tracking companies, it would be possible to analyse user behaviour across apps and websites (i.e. fingerprinting and cohort tracking). A direct result of the ATT could therefore be that existing power imbalances in the digital tracking ecosystem get reinforced.

We even found a real-world example of Umeng, a subsidiary of the Chinese tech company Alibaba, using their server-side code to provide apps with a fingerprinting-derived cross-app identifier, see Figure 6. The use of fingerprinting is in violation of Apple’s policies [3], and raises questions around to what extent the company is able to enforce its policies. ATT might ultimately encourage a shift of tracking technologies behind the scenes, so that they are

outside of Apple’s reach. In other words, Apple’s new rules might lead to even less transparency around tracking than we currently have, including for academic researchers.

Privacy Nutrition Labels can be inaccurate and misleading, and have so far not changed data practices. Our results suggest that there is a notable discrepancy between apps’ disclosed (in their Privacy Nutrition Labels) and actual data practices. We observed many apps that gave incomplete information or falsely declared not to collect any data at all. This is not necessarily to blame on app developers, who often have no idea of how third-party libraries handle users’ personal data [11, 30, 36]. As reported in Section 4.1.1, the proportion of app developers that make use of data-minimising settings of popular tracker libraries has roughly doubled, but these developers still remain a small minority. The Privacy Nutrition Labels have not (yet) had an impact on developers’ actual practices at large, but might do so in the long run.

Despite being potentially able to increase transparency and enhance consumer choice, the Privacy Nutrition Labels on iOS are currently often inaccurate, and thus misleading and create a false sense of security for consumers. As long as the labels stay inaccurate, they mainly seem to serve the advertising and marketing strategy of Apple around privacy. In response to Apple’s changes, Google has announced to introduce a similar feature in its Android app store, Google Play, also relying on self-reporting and with no apparent systematic enforcement strategy [20].

Are the most egregious and opaque trackers tamed now? The reduced access to permanent user identifiers through ATT could substantially improve app privacy. While in the short run, some companies might try to replace the IDFA with statistical identifiers, the reduced access to non-probabilistic cross-app identifiers might make it very hard for data brokers and other smaller tracker companies to compete. Techniques like fingerprinting and cohort tracking may end up not being competitive enough compared to more privacy-preserving, on-device solutions. We are already seeing a shift of the advertising industry towards the adoption of such solutions, driven by decisions of platform gatekeepers (e.g. Google’s FloC / Topics API and Android Privacy Sandbox, Apple’s ATT and Privacy Nutrition Labels) [15, 31], though more discussion is needed if these new technologies protect privacy meaningfully.

The net result, however, of this shift towards more privacy-preserving methods is likely going to be more concentration with the existing platform gatekeepers, as the early reports on the tripled marketing share of Apple [14], the planned overhaul of advertising technologies by Facebook/Meta and others [15], and the shifting spending patterns of advertisers suggest [16]. At the end of the day, advertising to iOS users – being some of the wealthiest individuals – will be an opportunity that many advertisers cannot miss out on, and so they will rely on the advertising technologies of the larger tech companies to continue targeting the right audiences with their ads.

Failure of GDPR enforcement, and power of platforms. Apple’s new rules should not have a dramatic effect on the tracking of users in the EU and UK, given that existing data protection laws in these jurisdictions already ban most forms of third-party tracking without user consent [30, 40]. While there was vocal outcry over the Apple’s new privacy measures by advertisers, the adtech industry was aware of tightened EU and UK data protection rules since

April 2016, and had plenty of time to work out a way to ensure compliance with basic provisions of the GDPR, until May 2018, including the need to seek consent from users before engaging in tracking [30]. Broad empirical evidence, from this and other pieces of research [29, 30, 32, 42, 45, 60], suggests that apps' compliance with the GDPR is somewhat limited.

At the same time, it is worrying that a few changes by a private company (Apple) seem to have changed data protection in apps more than many years of high-level discussion and efforts by regulators, policymakers and others. This highlights the relative power of these gatekeeper companies, and the failure of regulators thus far to enforce the GDPR adequately. An effective approach to increase compliance with data protection law and privacy protections in practice might be more targeted regulation of the gatekeepers of the app ecosystem; so far, there exists no targeted regulation in the US, UK and EU (see Section 2.2).

Apple's Double Standards: Making and Enforcing App Store Policies. Our analysis shows that Apple has a competitive advantage within the iOS ecosystem in various ways. First, it both makes the rules for the App Store and interprets them in practice. This is particularly reflected in Apple's definition of tracking, which ostensibly exempts its own advertising technology [2]: "Tracking refers to the act of linking user or device *data collected from your app* with user or device data collected from *other companies' apps, websites, or offline properties* for *targeted advertising or advertising measurement purposes*. Tracking also refers to sharing user or device data with *data brokers*." (emphasis added) [3] In other words, for tracking to fall under Apple's definition, it must fulfil three conditions, or be done by a data broker.

Apple's definition hinges on a distinction between first-party and third-party data collection, when this is not usually the root of privacy problems. This is why the W3C defines tracking as "the collection of data regarding a particular user's activity across multiple distinct contexts and the retention, use, or sharing of data derived from that activity outside the context in which it occurred." [56]. Rather than *companies*, this definition is centred around different *contexts*, as is commonly sought to be protected in privacy theory (e.g. contextual integrity [41]) and in privacy and data protection law (e.g. purpose limitation under the Article 5 GDPR). Apple's definition of tracking might both betray the expectation of consumers who expect that tracking would stop (when first-party tracking, notably by Apple itself, continues to be allowed), and motivate other companies to consolidate and join forces leading to increased market concentration.

Apple additionally foresees a list of exempt practices [3] (see Figure 9 for an excerpt). These include "fraud detection, fraud prevention, or security purposes", which might be interpreted extremely broadly by tracking companies. The exempt practices further allow tracking by a "consumer reporting agency". The term "consumer reporting agency" is defined in the US Fair Credit Reporting Act (FCRA), regulating the relationship between these agencies and other "furnishers of information" relating to consumers. By explicitly exempting credit scoring, Apple might try to avoid liability, and it might not have much choice under current US law. The exemption of credit scoring is nonetheless problematic because the use of personal data for credit scoring can have disproportionate impacts on individuals, and might be protected by other data protection

App Store

The following use cases are not considered tracking, and do not require user permission through the AppTrackingTransparency framework:

- When user or device data from your app is linked to third-party data solely on the user's device and is not sent off the device in a way that can identify the user or device.
- When the data broker with whom you share data uses the data solely for fraud detection, fraud prevention, or security purposes. For example, using a data broker solely to prevent credit card fraud.
- When the data broker is a consumer reporting agency and the data is shared with them for purposes of (1) reporting on a consumer's creditworthiness, or (2) obtaining information on a consumer's creditworthiness for the specific purpose of making a credit determination.

Figure 9: Tracking Transparency: Excerpt from Apple's exempt data practices, including credit scoring, from requiring user opt-in under ATT (emphasis added) [3].

and privacy laws. This might create the (false) impression for some app developers that other legal conditions do not apply, and a *false sense of security* for many consumers.

Apple's Double Standards: Access to Data. Being the maker of the iOS ecosystem, Apple has a competitive advantage, by being able to collect device and user data, including hardware identifiers, that other app developers do not have access to, and use this for its business purposes. For example, by collecting the device's serial number regularly, Apple can accurately tie the point-of-sale of its devices to activities on the device itself, and track the device lifecycle in great detail. Some of Apple's own apps, including the App Store itself, have access to this information because they are not distributed via the App Store and hence do not fall under the rules governing the App Store, including those that relate to tracking of users.

These observations raise concerns around fair competition in the App Store, similar to those related to Apple's payment system that have been before courts for many years. Even if Apple might lose access to the 30% fee of sales through its platform as a result of the ongoing legal cases, the promotion of its own advertising platform over its competitors through the recent app store changes will help Apple offset some of the lost revenues, if not increase them. Since any regulatory enforcement or judicial proceedings will take time, the company will likely not see meaningful challenges to its changed conduct anytime soon.

5.1 Limitations

A few limitations of our study are worth noting. First, for practical reasons, we were not able to analyse all the apps in the App Store, only a reasonably large subset of free apps in the App Store's UK region. Furthermore, for the purposes of examining the effect of ATT, we restricted this sample to include only those apps that were available before the introduction of the ATT and were updated since. Crucially, we only focused on apps that already existed on the App Store before iOS 14 – newly released apps may adopt different strategies. Finally, the sampling method to select the original dataset

of apps relied on the App Store’s search functionality, which is opaque and likely to be biased in various ways.

As regards our analysis methods, our instruments are also potentially limited in several ways. The results of our static analysis must be interpreted with care, since not all code shipped in an app will necessarily be invoked in practice. We may have overestimated tracking in certain contexts, e.g., if tracking code was included but not used. This is an inherent limitation of this type of analysis, but relatively uncommon because modern build pipelines typically eliminate unused libraries or dead code to reduce application bundle size.

We used off-device network analysis, in which all device traffic is analysed in aggregate. The risk here is that we may wrongly attribute some communications to an app that in fact was generated by some other app or subsystem on the device. To minimise this risk, we uninstalled all pre-installed apps, and ensured no apps were running in the background. We also used jailbreaking to circumvent certificate validation, which might make some apps alter their behaviour. For instance, some apps have jailbreak detection code which disables certain functionality when jailbreak is detected. In all parts of our analysis, we consider all apps equally, regardless of popularity [6] and usage time [53], both of which can impact user privacy. Likewise, we treat all tracking domains, libraries and companies equally, though they might pose different risks to users.

6 CONCLUSIONS & FUTURE WORK

Overall, we find that Apple’s new policies live largely up to its promises in making tracking more difficult. Tracking libraries cannot access the IDFA anymore, and this directly impacts the business of data brokers. These data brokers can pose immense risks to individuals, since they try to amass data about individuals from a wide range of contexts and sell this information to third-parties. At the same time, apps still widely use tracking technology of large companies, and send a range of user and device characteristics over the Internet for the purposes of cohort tracking and user fingerprinting. We found real-world evidence of apps computing a mutual fingerprinting-derived identifier through the use of server-side code (see Figure 6) – a violation of Apple’s new policies [3], highlighting the limits of Apple’s enforcement power as a privately-owned data protection regulator [21, 52]. Indeed, Apple itself engages in some forms of user tracking (see Figure 7) and exempts invasive data practices like first-party tracking and credit scoring from its new privacy rules. Apps’ Privacy Nutrition Labels were often inaccurate and are currently misleading for consumers. These observations are in conflict with the company’s marketing claims and the resulting expectations of many iOS users.

Despite positive developments over the recent months and years, especially through initiatives by Apple, there is still some way to go for app privacy. Violations of various aspects of data protection and privacy laws remain widespread in apps [29, 30, 32, 42, 45, 60], while enforcement of existing data protection laws against such practices stays sporadic. Apple’s privacy efforts are hampered by its closed-source philosophy on iOS and the opacity around its enforcement of its App Store review policies. These decisions by Apple remain an important driver behind limited transparency around iOS privacy.

To strengthen iOS privacy, Apple has already started to prevent IP-based tracking through routing traffic to trackers via its own servers when using the iOS browser (“Privacy Relay”). As a direct response to our findings, Apple could consider extending the Privacy Relay to tracking within apps, thereby making the tracking of users through their IP address more difficult [38]. However, this would also further extend Apple’s reach over the iOS ecosystem and potentially allow the company to track users even more accurately.

More generally, the key decision makers with regards to privacy technologies must establish robust transparency and accountability measures that allow for independent assessment of any privacy guarantees and promises. This is especially true, given the current lack of targeted regulations for app platforms like Google Play and the Apple App Store (see Section 2.2). In the case of Apple, improved transparency measures must necessarily involve the phasing out of encryption of free iOS apps by default, which currently forces independent privacy researchers into legal grey areas and severely hampers such research efforts (see Section 2.1). This is why most previous privacy research focused on Android and the last large-scale privacy study into iOS apps had been conducted in 2013 [1], until the recent release of the method used in this study [32].

We conclude that the new changes by Apple have traded more privacy for more concentration of data collection with fewer tech companies. Stricter privacy rules may encourage even less transparency around app tracking, by shifting tracking code onto the servers of dominant tracking companies. Despite the new rules, large companies, like Google/Alphabet and Facebook/Meta, are still able to track users across apps, because these companies have access to unique amounts of data about users. Apple is now able to track its customers even more accurately, by taking a larger share in advertising technologies and getting unique access to user identifiers, including the device serial number. This underlines that privacy and competition problems can be highly intertwined in digital markets and need holistic study.

Future work. In this work, we only analysed apps that were already present on the App Store before iOS 14 and the ATT; it would be interesting to analyse how the ATT has impacted the privacy properties of *newly released* apps on the App Store, and how it might impact app privacy in the long run. It also would be helpful to develop a new automation tool for iOS apps to observe apps’ data practices automatically, even beyond the first app start – as studied in this present paper – and thereby generate richer insights into these data practices. Furthermore, it would be pertinent to study user tracking by platforms in more detail, and also how the new Apple’s Privacy Nutrition Labels inform the decision-making and education process of individuals around app privacy.

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