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CryptoCurrency mining on mobile as an alternative monetization approach

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ABSTRACT

Can cryptocurrency mining (crypto-mining) be a practical ad-free monetization approach for mobile app developers? We conducted a lab experiment and a user study with 228 real Android users to investigate different aspects of mobile crypto-mining. In particular, we show that mobile devices have computational resources to spare and that these can be utilized for crypto-mining with minimal impact on the mobile user experience. We also examined the profitability of mobile crypto-mining and its stability as compared to mobile advertising. In many cases, the profit of mining can exceed mobile advertising's. Most importantly, our study shows that the majority (72%) of the participants are willing to allow crypto-mining as means to replace ads to trade-off for benefits such as a better user experience.

CCS CONCEPTS

• Applied computing → Digital cash; **• Human-centered computing → Empirical studies in ubiquitous and mobile computing**;

KEYWORDS

CryptoCurrency Mining, Mobile Monetization; Distributed Mobile Computing

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1 INTRODUCTION

As of the first quarter of 2018, 94% of all Android apps on Google Play and 88% of iOS apps on App Store were available for free [11]. The free-to-play pricing model with in-app advertising has remained the most popular and profitable monetization model for mobile app developers [2, 7].

However, many mobile users prefer an ad-free experience if given a choice because advertising has a negative impact on user experience. The mobile ad is usually in the form of a banner or full-screen image/video which obscures the phone screen. The appearance of ads could also disrupt user engagement. More importantly, mobile advertising is raising a privacy concern where user behavioral data in mobile contexts can be exploited for targeted advertising.

In this work, we explore the potential of an ad-free monetization model based on crypto-mining. The key idea is to leverage the opportunistic computing resources from smartphones to perform mining and distribute the reward to mobile developers. Mobile users can decide to pay for the mobile content by contributing either their computing resources (mining) or their time and attention (watching ads) depending on their personal preferences.

One interesting argument that motivated us to carry out this study is that a mobile device has limited computational resources, and is hence not suitable for energy-consuming and computation-intensive tasks. In fact, due to its compact physical size, the mobile device inherently has constrained resources, especially its limited battery capacity. However, mobile users do not run resource-hungry apps/games continually throughout the day. The mobile computing resources stay idle most of the time. Users have also adapted their phone usage behaviors to fit their devices' capability. For instance, people charge their mobile devices more frequently than before–multiple times a day and whenever a power source is available [5]. We argue that the resources of mobile devices can be leveraged to perform crypto-mining without noticeable interference with the user experience.

To evaluate our idea, we conducted a study with 228 Android users with their devices running crypto-mining under various conditions. We collected their CPU utilization, battery levels, and charging instances to examine the availability of mobile resources for mining and to see how mining may affect user experience. We also analyzed the profitability of mobile crypto-mining in comparison with advertising. Lastly, we surveyed users' *awareness* of the resource utilization for mining and their opinions on allowing the mining in exchange of being able to skip the ads in app/game. Our findings from the study are as follows:

- Mobile mining is as profitable as advertising under certain conditions. For example, average daily revenue from one mobile device performing mining only when it is plugged-in

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is equivalent to 3 to more than 50 full-screen ad impressions in some countries.

- Mining in the background at a low-intensity setting, would not cause any noticeable negative impact on battery life, charging speed or app performance.
- Users are open to crypto-mining on their mobile devices as an alternate means for developers to monetize. In our user study, 72% of participants are willing to allow (or would not mind) the mining if they can skip the ads and be well informed of the mining.

Our contributions are as follows:

- We empirically evaluated the crypto-mining on mobile as an ad-free monetization model for mobile app/game. In particular, we investigated the availability of mobile resources for mining, effects of mining on the resources and user experience, and the profitability of mining compared with advertising.
- We examined the feasibility of different strategies to use the opportunistic computing resources of mobile devices and minimize the negative effects of mining on the user experience.
- We studied the perceptions and attitudes of mobile users towards allowing mining in the background in exchange for an ad-free mobile experience.

2 BACKGROUND & RELATED WORK

Cryptocurrency mining: Blockchain systems often involve a cryptocurrency like Bitcoin that is created in exchange for the computational processing work performed by users in the distributed network. This distributed computational processing is known as *mining* and serves two purposes: (1) to verify the legitimacy of a transaction and to prevent double-spending; (2) to create more of the cryptocurrency to reward miners for performing the computational task. The cryptocurrency incentivizes transaction verifiers (miners) to use their computing power to verify the ledger.

The difficulty of mining also scales to keep the rate of block discovery (creating more of the currency) steady. The more computing power added to the network, the more computations required to create a new block. Conversely, if computational power is taken off the network, the difficulty adjusts downward to make mining easier. This adjustment of difficulty makes the mining outcome less volatile than the cryptocurrency itself.

Choosing a suitable algorithm for mobile mining: To evaluate mobile mining as a monetization model for developers, we chose the *CryptoNight* algorithm because it is specifically designed and maintained for mining using commodity CPUs. CryptoNight was originally developed in 2013, as the hash function of CryptoNote [3] and is designed to be inefficient on GPU, FPGA, and ASIC architectures, and mitigates *mining centralization*. This is opposed to other popular mining algorithms such as SHA-256 (Bitcoin) or Scrypt (Litecoin) [10] that can be mined using ASICs, which renders mining using normal PCs or mobile devices comparatively incompetent.

The resource utilization (main memory, CPU, and network) of CryptoNight on the desktop has been empirically studied [9], with the CPU being the most power-consuming component. In the same manner, mining on mobile devices could result in some negative effects such as reduced battery life and app performance (e.g., lower frame rates). In this work, we proposed and evaluated suitable strategies to minimize these effects.

Cryptocurrency Mining on Mobile: Since the release of a JavaScript CryptoNight miner named CoinHive in September 2017 [4], an increasing number of Internet content providers have been trying to monetize their content using browser-based mining fully or along with ads. We adopt this approach into the mobile domain in which developers will be rewarded with cryptocurrency mined by users' mobile devices. As crypto-mining is a computation-intensive activity, the biggest problem facing mobile mining is that it could negatively affect user experience such as draining the battery and reducing app performance. However, by implementing the miner as a mobile background service, the mining process is independent of the app or game that users are playing. This is different from the traditional use case of a browser-based miner in which the mining process can only be triggered when users visit the website with the embedded miner. In other words, the duration and timing to run mobile mining process is independent and not limited to the running app. As a result, the mobile mining task can be *scheduled* to minimize the mining effects on user experience and optimize profit for developers. This enables crypto-mining to be a feasible monetization approach even in the resource-constrained condition of mobile devices.

3 PERFORMANCE CHARACTERISTICS OF MINING ON MOBILE DEVICES

We first conducted a micro lab experiment to understand how the CryptoNight miner performs on Android devices with different CPU specifications (Galaxy Note 4, Galaxy Tab S2, Galaxy S7, Galaxy S8). We measured the mining hash rate, CPU temperature, battery temperature and power consumption (battery discharge rate) corresponding to each mining intensity level.

We ran the Javascript CoinHive miner in the background with mining intensity levels from 10% to 50%. The intensity level indicates the percentage of time the CPU will be used to run the task. The number of mining threads was set equal to the device's number of CPU cores. For each intensity level, the mining task was performed for 20 minutes continuously. No other application ran during mining. The devices were unplugged and their screens were off. The room temperature was 26°C. At the beginning of each session, the battery temperature was approximately 27°C and the CPU temperature was around 30°C. We used Batterystats, a tool included in the Android framework, to collect the battery data. The CPU and battery temperature were logged every 5 seconds.

Table 1: Hash rate (hash/second) / Battery Discharge Rate (mAh) at different mining intensity levels.

	Mining Intensity Level		
Device	10%	30%	50%
Note 4	2.74 / 267.5	5.46 / 445.4	7.06 / 564.8
Tab S2	5.54 / 297.0	7.78 / 520.7	11.16 / 697.9
S7	6.52 / 326.7	13.38 / 523.5	16.08 / 780.9
S8	6.22 / 309.3	13.50 / 517.8	16.10 / 775.5

Table 1 shows the mining hash rate and battery discharge rate corresponding to each device and mining intensity level. More powerful devices with higher CPU clocks (Galaxy S7 and S8) can mine with higher hash rates. The mining task consumed more power and drained the battery more quickly at the higher intensity. For example, the discharge rate on Galaxy S7 is from 326.7 mAh (10.89%/hour) to 780.9 mAh (26.03%/hour) when the mining intensity increase from 10% to 50%. Android devices are also getting more energy-efficient. In particular, running the mining at the hash rate of 6 H/s, the discharge rate on Note 4 and Tablet S2 are around 400 mAh, while the corresponding discharge rate on Galaxy S7 and S8 is less than 300 mAh.

Table 2: Lab experiment: battery temperature / CPU temperature (°C) per mining intensity level.

	Mining Intensity Level				
Device	10%	20%	30%	40%	50%
Note 4	32/50	34/53	36/58	36/61	36/61
Tab S2	34/70	36/73	36/75	36/77	38/79
S7	33/51	35/63	36/71	37/74	38/77
S8	32/NA	34/NA	36/NA	36/NA	37/NA

Table 2 shows the temperature of battery and CPU after 20 minutes of mining per each intensity level. The mining has a significant heating effect on mobile devices. For instance, at an intensity level of 40%, the battery temperature across four devices all increased from 26°C to 36°C after the mining duration. We do not run the mining intensity level higher than 50% to avoid damaging the devices as the CPUs get close to 80°C at the intensity level 40% and 50%, and the mining hash rate is not stable after 10-15 minutes of mining. Overall, mining at higher intensity generates the same amount of profit faster, but it could cause significant negative impact on mobile devices such as heating and battery draining.

4 MOBILE MINING USER STUDY

We conducted an IRB-approved study with 228 Android users recruited from Amazon Mechanical Turk (ages from 18 to 62, M = 32.34, SD = 8.57; 85 females). 79% of the participants had used their current mobile device for less than 2 years. As for the gaming frequency on mobile, 49% of participants reported spending more than 3 hours each week playing.

4.1 Study Procedure

We first detail the study procedure and acquire consent from participants to take part in our study. The participants are then asked to install our experiment Android app. The app has two tasks that run in Android background service for 24 hours starting from the moment that the app is first opened:

- Crypto-mining using CPU: CryptoNight algorithm, Monero (XMR) coin [13], Coinhive JavaScript implementation. The number of threads of the mining task is set to the number of CPU cores on the device. Our intent is to run the mining task at low intensity for longer periods to prevent the battery from draining too quickly and moderate the device temperature. The mining intensity is set at 20%.
- Collecting mobile usage data: we register Broadcast Receivers to get updates of the device battery level, charging state and connectivity. We also collect the CPU utilization and CPU temperature every 10 seconds. The CPU utilization is averaged across threads.

After 24 hours, participants are asked to answer a survey. The survey includes questions on user awareness of the effects of mining on battery life, charging speed, and processing speed (e.g., app responding, frame rate) for the past 24 hours. Additionally, we ask participants if they would allow their phone to run the background crypto-mining: '*Considering the background mining may cause some negative effects like you have experienced in the last 24 hours, would you allow it in exchange for the ability to skip ads? Please explain?*'.

4.2 Mining Modes

In the study, we included various experiment modes where the mining is triggered by different conditions. This is to study the mining performance and effects on user experience under different phone usage conditions. Each participating device was randomly assigned one of six modes in Table 3. Participants were not aware of their assigned mining modes.

Table 3: Experiment modes and mining conditions.

		Mining Conditions			
Mode	n	Network	Screen	Battery	Plug
Baseline	85				
Always	31	On		> 15%	
Plug	30	On		> 15%	In
Plug_FChar	31	On		100%	In
Unplug_ScrOff	28	On	Off	> 15%	Out
Unplug_ScrOn	23	On	On	> 15%	Out

In the Always mode, the app runs the mining as long as the Internet connection is available and the battery level is higher than 15%. These two conditions apply to all the mining modes. An Internet connection is required for all mining modes as a miner needs to periodically exchanges blockchain data and hash to avoid getting stale shares. We also set the minimal battery level as 15% to run mining to prevent the battery from getting entirely drained by the mining task. Plug_FChar is the least obtrusive mode in which the app only mines when the device is fully charged and still plugged in. We also include a baseline mode as the control group in this study.

5 RESULTS

In this section, we will first examine the profitability and stability of cryptocurrency mining on mobile to demonstrate its potential as a monetization model. We will also analyze the availability of mobile resources for mining, how the mining affects user experience and how users perceive it. Lastly, we discuss preference and opinions on allowing the background mining as a way to pay mobile developers.

5.1 Mining Profit

5.1.1 Profitability of mining as a mobile monetization model. Table 4 shows the average mining profit on one device estimated with the XMR price, the block reward and difficulty at the time we conducted our study (May 2018). For instance, Plug_FChar averaged 205.9 mins of mining in the 24 hours study duration and a hash rate of 5.15, giving an estimated profit of 0.11 cents.

Table 4: Average mining duration, hash rate and estimated profit of each mining mode .

Mining Mode	Duration (minute/day)	HashRate (hash/s)	Profit (cent/day)
Always	551.7	5.04	0.28
Plug	251.4	5.21	0.13
Plug_FChar	205.9	5.15	0.11
Unplug_ScrOff	326.3	5.80	0.19
Unplug_ScrOn	236.2	3.21	0.08

To give a perspective of how profitable mobile mining is as a monetization model for developers, we compare it with mobile advertising. In January 2017, the average full-screen ads eCPM (earnings per 1000 ad impressions) of Google Admob is $0.75, or 0.075 cent per one ad impression [1]. However, at the range lower than the first quartile of eCPM distribution, there were more than 40 countries with the eCPM ranging only from $0.02 to $0.4. In comparison with the mining profit shown in Table 4, it means that if user device performs mining at Plug mode, the daily mining reward is equivalent to the revenue from 3 to over 50 full-screen ad impressions in those countries.

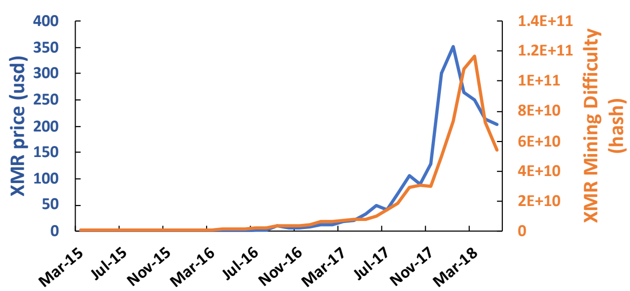

Figure 1: Monero (XMR) price and mining difficulty from May 2015 to May 2018.

5.1.2 *Stability of mining as a mobile monetization model.* Figure 1 shows the price and mining difficulty of Monero coin (XMR) in the last three years. As the difficulty level indicates the total computing power contributed to the network, we can see the miner responds quickly and accordingly to price changes. For instance, the mining difficulty started to increase significantly in November 2017 almost at the same time as the rise in price and then went down after the price decreased steeply in February and March 2018. This relationship between the price and the total computing power contributed to the XMR network results in the stability of the mining profit.

Figure 2 shows the comparison of average advertising and mining daily profit in the last three years. Note that the Admob eCPM data after January 2017 is not available. At the time of Oct 2016, the mining profit with our Plug configuration was equal to the average global eCPM ($0.75). In other words, daily mining profit per device at that time equaled the profit generated by one full-screen ad. However, mobile advertising revenue has a wide-spread distribution. The eCPM in many countries, especially in Asia, is much lower than the average (ranging from $0.02 to $0.4). For instance, Figure 2 shows the eCPM in China, India, and Russia are all approximately $0.3 in January 2017. The mining profit of Plug mode then was $1.50 per 1000 devices, meaning users in those countries can skip 5 ad impression daily by running the Plug mode. More importantly,

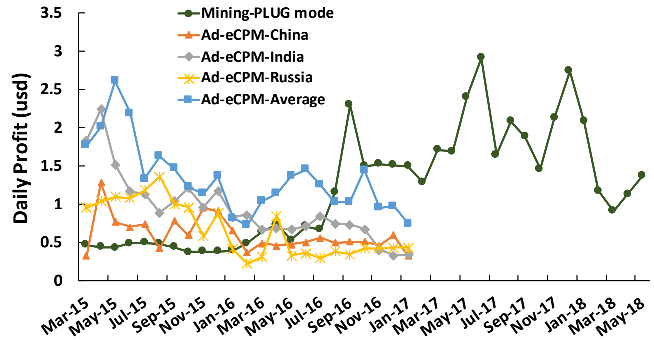

Figure 2: Average daily profit of mobile advertising (Google Admob, 1000 impressions of full-screen ad) and mining (XMR mining, 1000 devices, PLUG mode).

despite the fact the cryptocurrency has been very volatile with the price changing very fast (Figure 1), the mining profit is much more stable as a result of the adaptive mining difficulty level.

5.2 Mining Resources

5.2.1 *Battery.* Mobile users usually do not unplug the device right after it is fully charged (especially during the night) as there is no harm in keeping it plugged in. Figure 3 shows the distribution of time until participants in our study unplugged their phones after the battery was fully charged. 71% of the charging instances were of participants keeping the device plugged in for more than 30 minutes after the battery was fully charged. On average, each device was kept plugged in for 207 minutes after the charging has been completed for the 24 hours duration of the experiment. These are opportunistic time slots where we can run computation-intensive tasks like mining with minimal effect on the device's battery life.

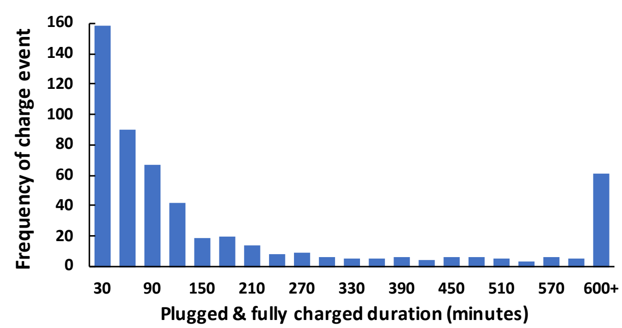

Figure 3: Distribution of duration when mobile device is fully charged and plugged in.

5.2.2 *CPU.* Our study shows that, in regular daily use (the baseline group), the CPU utilization is less than 20% more than half of the time. The CPU utilization is higher when the screen is on as the devices were in use. The CPU utilization when performing mining is 10-12% higher than the baseline. Although users' mobile CPUs still perform far below its full capacity, pushing the CPU utilization higher could drain the battery quickly and disrupt the user experience.

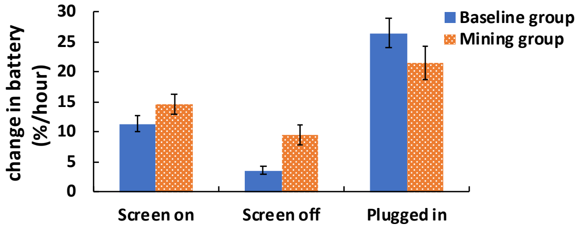

Figure 4: Mining effects on battery life.

5.3 Mining Effects and User Awareness

Figure 4 shows the effect of mining on the battery drain and charging speed. As expected, mining makes the battery drain faster. Running mining when the phone is not in use or not plugged in (Screen off), results in a battery drain of 0.16% per minute or around 9.5% per hour. This is significant as compared with the baseline–when the screen is off, the battery only drops 3-4% per hour. The average charging speed also decreased from 26.4% down to 21.5% per hour because of the mining. However, users may be unable to notice this effect on battery life.

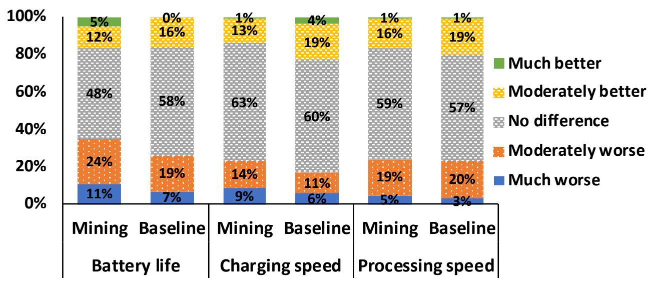

Figure 5: Survey: user perception of mining effects.

Figure 5 summarizes participants' perception regarding changes of battery charging speed, draining rate and CPU processing speed caused by the mining. We give a comparison of the perception between the baseline group and the mining group. Overall, 76% of the participants have not noticed any negative effects caused by the mining. There is no significant difference in the participants' perception of changes in processing speed and charging speed between the mining and baseline groups.

However, participants are more concerned about the battery life than the other two metrics. 35% of the participants in the mining group think that the battery drained faster during the study, the proportion is 12% higher compared to the baseline group. In other words, participants would notice that their user experience is negatively affected if the mining task runs constantly or runs when the device is unplugged (Always, Unplug_ScrOn and Unplug_ScrOff modes). On the other hand, mining when the device is plugged in (Plug or Plug_FChar) is less intrusive and would not cause any noticeable effects (with the configuration in our study).

5.4 User Preference

In the last part of the post-mining survey and after experiencing the background mining for 24 hours, we asked users if they consider mining to be a practical alternative to pay for the mobile content instead of watching ads.

Participants were open to the idea of their mobile computing resources being used to mine cryptocurrency in exchange for the ability to skip the ads in apps/games. 47% of the participants indicated that they would allow the mining and 25% with a neutral opinion (i.e., choosing 'do not mind' option). Only 26% would not allow the background mining because of various reasons including privacy concern, negative impacts on phone usage, or not familiar with the concept of cryptocurrency. We also noticed that the acceptance rates of baseline modes are not better than those of the other mining modes, which is reasonable because most of the participants did not notice any different effects caused by the mining.

6 DISCUSSION

Privacy Concerns: The CryptoNight mining operation, itself, is highly anonymous as it just exchanges blockchain data with a cryptocurrency network or a mining pool – it does not collect any personal data at all. On the contrary, mobile ads, to improve their relevance, frequently collect user behavioral, location, and other contextual data [6]. Overall, we believe that cryptomining is fundamentally more privacy-preserving compared to mobile advertising.

User Consent: However, using computing resources without user knowledge and permission can be considered a malicious action on the part of developers. Unlike advertising which is usually easily identifiable, it is much harder for users to notice if a mining task is running in the background of their devices. Therefore, providing *user transparent* mining, with full user permission and understanding, is crucial before these types of techniques can be widely used by developers for monetization for developers.

User Preference: Both Mobile advertising and mining can be used as sources of income for developers; with each one "paid for" by users differently. For mining, the users "pay" by providing computing power that consumes both energy and and could lower the performance of users' devices. While smart scheduling can minimize the effects of mining on the user experience, the mining still incurs energy costs. On the other hand, users "pay" for mobile advertising by giving up their attention and privacy to various app-overlying frequently targeted ads. An opportunity this work provides is the feasibility for developers to inform users about the costs of each option and let them choose their preferred monetization approach.

Scaling for multiple apps: Our study was limited to only one app running a crypto miner in the background. In a full deployment, additional tooling would be required to handle the case of multiple apps competing with each other for the mining resources. In particular, we anticipate these functions to be: (1) monitoring the usage of all apps using a mining reward model, (2) scheduling the mining task with multiple competing processes, and (3) distributing the mined rewards to different app developers using a fair and efficient scheme.

Future of Crypto-mining: Despite the recent popularity of crypto mining, it has been criticized for being economically inefficient and / or consuming too much energy when running the miners. In addition, the legality of crypto mining is unclear in many countries. As such, it's possible that various markets and / or cell phone providers may block background mining. Those are major challenges that make the future of a crypto-mining monetization approach uncertain. However, even if crypto mining does not pan out, there are other cases where the spare resources of mobile devices can be leveraged for distributed applications with the goal of earning rewards. For example, mobile users can participate in a distributed cloud storage network like Filecoin[8] or Storj[12] in which their storage is used to host encrypted content for other clients in return for rewards. These potential distributed applications could be more economically productive and environmentally friendly.

7 CONCLUSION

In this study, we investigated the potential of crypto-mining as an ad-free monetization approach for mobile app developers. With the data collected from a lab experiment and a user study with 228 Android users, we demonstrate (1) the availability of opportunistic mobile resource that can be used for computation-intensive tasks such as crypto-mining; (2) the mining profit on mobile device is comparable to mobile advertising; (3) the mining task can be scheduled to minimize its negative effects on the mobile user experience; and (4) if being well informed, the majority of mobile users are willing to allow the crypto-mining in exchange for an ad-free experience. Hence, crypto-mining can indeed become a viable alternative source of income for mobile app developers.

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