Judge, Jury & Encryptioner:
Exceptional Access with a Fixed Social Cost

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Abstract
We present Judge, Jury and Encryptioner (JJE) an exceptional access scheme for unlocking devices that does not give unilateral power to any single authority and places final approval to unlock in the hands of peer devices. Our scheme, JJE, distributes maintenance of the protocol across a network of “custodians” such as courts, government agencies, civil rights watchdogs and academic institutions. Unlock requests, however, can only be approved by a randomly selected set of unlock delegates, consisting of other peer devices that must be physically located to gain access. This requires that law enforcement expend both human and monetary resources and pay a “fixed social cost” in order to find and request the participation of law abiding citizens in the unlock process.

Compared to other proposed exceptional access schemes, we believe that JJE mitigates the risk of mass surveillance, law enforcement abuse, and vulnerability to unlawful attackers. We aim to raise the bar set by government sponsored “backdoors” which can be used to covertly unlock any device deemed suspicious by law enforcement. While we propose a concrete construction, our primary goal with JJE is to spur discussion on ethical exceptional access schemes that balance privacy of individuals and law enforcement desires.

Our scheme transparently reveals the use of exceptional access to device owners—and to the public—in a way that is clear what are the trade offs in security and privacy. In order to unlock devices, governments must pay a fixed social cost that, we believe, can be an effective deterrent to mass surveillance and abuse.

1 Introduction
On December 7th, 2018, Australia passed a series of controversial and contested laws designed to compel technology companies to provide law enforcement and government agencies access to all encrypted communications [44, 45]. On September of 2019, the U.K. government ruled that Facebook and WhatsApp are required to share private messages with the police to assist in criminal investigations [16].

These laws raise important security, political, and ethical questions for both the cryptography and technology policy communities. This recent legislation in both Australia and the U.K. is of great interest to the Five Eyes intelligence compact (U.S., U.K., Australia, Canada & New Zealand). In 2018, the Five Eyes issued a joint statement advocating for lawful electronic interception [1]. These recent developments raise the fear that other countries, specifically the United States, will enact similar laws to that of Australia and the U.K. [30].

The advent of encryption-by-default for many smartphones and instant messaging applications has left law enforcement and intelligence agencies worried that many of their surveillance tools, purportedly used for national security, could “go dark” [1]. As several recent events have demonstrated, law enforcement and government officials firmly believe that they are entitled to “exceptional access” to encrypted data and devices, sparking significant pushback by both the private sector and the academic cryptography community [1, 57].

There is an understanding among the security and privacy experts that building “backdoors” into devices fundamentally compromises security [2, 14]. Unfortunately, the technical nuances of this reasoning is often lost in the policy making process. Moreover, the vocal opposition to giving law enforcement access to devices has not been successful in stopping countries from pushing for more legislation surrounding intercept technologies [30, 44, 45]. It is therefore imperative to understand the consequences and discuss practical solutions to this problem. Our goal is not to advocate for the deployment of exceptional access, but rather to instigate discussion into the trade offs needed to build ethical exceptional access schemes.

As recently pointed out by Ray Ozzie [46], it is the responsibility of the cryptography community to ensure that backdoors are not implemented in a manner which could have serious long-term security implications. Our goal is to address the concerns of law enforcement at face value while still constructing a system which mitigates the concerns of
abuses posed by the cryptographic and policy community. We do not expect our proposal will be preferable to law enforcement compared to existing methods of “backdoors” or key escrow. Rather, we hope to show that a middle ground is feasible and to provide a counter argument to the reasoning that carte blanche government backdoors are necessary to maintain effective national security.

In this work, we present an exceptional access scheme, JJE, that decentralizes the trust and unlock process without placing unilateral power in the government’s hands. From a high level, our scheme works as follows: At set up, each device secretly and blindly chooses a number of other anonymous devices to act as its “access delegates.” Crucially, the device chooses these delegates at random with no knowledge of who they are selecting and this selection does not leave the device. It then builds a unique exceptional access challenge which can be turned into an unlock token by a subset of the chosen delegates.

To use the exceptional access scheme, law enforcement needs approval from a set of “custodians” in order to identify and physically locate the delegates. Each delegate device provides a necessary signature through a secure hardware protocol that does not compromise the security or privacy of the delegate. Once a sufficient number of signatures are obtained, they can be used to unlock the specified device. Finding and accessing all of the needed delegate devices requires broad manpower and access to intelligence that only the government has. This aspect of JJE is intangible and difficult to steal even by a determined adversary, making JJE robust against malicious foreign state actors or other well funded attackers.

1.1 Ethical Implications

The strong opinion of the cryptography community is that building backdoor technology is inherently misguided as it cannot be done while maintaining the security of cryptography [33]. However, the vocal opposition of the community has not caused the problem to go away [30, 44, 45]. It is apparent that there is a disconnect between researchers who deeply understand the problem and legal experts who seek a solution that simply works. What governments want is a slight weakening in individual privacy for the gain of security as a nation [22, 57]. On the other hand, many researchers believe that any such “slight” weakening exposes the real possibility of massive security vulnerabilities and provides governments with yet another tool for mass surveillance.

It is tempting for members of the academic cryptography community to answer questions seeking secure backdoors with an unequivocal, “not possible.” In fact, the technical argument for why this is impossible is a tautology: If you provide access to someone else, then your system is insecure because someone else, possibly less trustworthy, now has access too. History has shown that this is not just a problem in theory. In fact, any centralized database, no matter how practically secure, is susceptible to attack [43]. While this fact is likely obvious to the technically savvy reader, it is not so inherently obvious to a lay person or to a politician [57] making the privacy community come across as recalcitrant on the subject.

The situation is complicated by the fact that the political playbook used to argue for the existence of exceptional access plays to fears and emotions. A common and manipulative argument envisioned by policy makers advocating against encryption goes as follows: Imagine there is a terrorist who will imminently attack unless we can unlock this phone, on the spot, and discover their plan [32]. By focusing on such an extreme scenario, advocates against strong encryption argue it is reasonable to weaken security for all devices.

However, currently deployed and proposed systems allow governments to use the same access system for mass surveillance, or to weaken the legal rights of individuals simply accused of low level crimes [57]. Ultimately, the legal line between security and privacy will be determined not by cryptographers, but by policy experts, the industry, and consumers. However, we believe that it is of crucial importance that the research community engages in a discussion regarding potential solutions in order to attempt to bridge a gap, and that it does so judiciously. Our goal is to instigate research of ethical exceptional access that is fully transparent to the public and incurs high social costs making it impractical as a tool for mass surveillance. We believe that any proposed exceptional access scheme should be designed, from the start, to be truly exceptional, i.e., they should only be useful in the most extreme of cases.

1.2 Our Contributions

To the best of our knowledge, JJE is the first exceptional access proposal which is fully decentralized, ensures legal authorities are engaged in the unlock process, and incurs a high operational cost per device when used by law enforcement. In addition, using JJE requires a fixed, unavoidable social cost. Our technical contributions are twofold.

- We present the first decentralized system for providing exceptional access where accountability is enforced and social costs are imposed on a per device basis;
- We extensively analyze our system under a realistic threat model to ensure it does not lend itself as a tool for mass-surveillance or other forms of abuse;

2 Related Work

Exceptional Access & Key Escrow There have been several recent works related to exceptional access targeting both encryption and devices. This prior body of work has either focused on providing law enforcement with access to encrypted
communications or proposing systems for lawful device unlocking under certain assumptions.

Bellare and Goldwasser [7, 8, 26] describe several different techniques for “key escrow” systems, where the trust placed in law enforcement is limited. At a high level, they propose different means of providing a partial secret key to a trusted 3rd party such that after the partial key is recovered, obtaining the full secret key requires computational (and monetary) resources with the hope that such cost would limit mass surveillance.

In a similar vein, Wright and Varia [58] propose a scheme for giving law enforcement access to encrypted data using time-lock puzzles. Their approach, in theory, requires law enforcement to expend significant monetary resources to break encryption by requiring abundant computing power and up-front costs for pre-computation. These costs, they claim, can be tuned so that each intercepted message costs between $1000 and $1M to crack.

Ozzie [46] proposes a system for unlocking devices by placing full trust in the device manufacturer. While the proposal lacks much technical detail and analysis, the high-level idea is to place full trust in the device manufacturer which then acts as an arbiter for the unlock process. In the proposed scheme, each device encrypts its own “master key” with the manufacturer’s public key which can then be decrypted by the manufacturer in cooperation with law enforcement to provide access to the device.

Savage [52] expands and formalizes several of Ozzie’s ideas to propose a similar system for lawful device unlocking by placing power and trust in the manufacturer’s hands. The scheme also sets in place several safeguards for preventing mass unlock capabilities by law enforcement, ensuring post unlock transparency, and time vaulting.

Surveillance & Cryptography Using cryptography for creating accountability in surveillance has been studied in several prior works. Kroll et al. [34] propose a mechanism for providing accountability in the court system using secure multi-party computations to execute warrant requests in a private yet auditable manner.

In a similar vein, Bates et al. [6] propose a system for accountable wiretapping technology with the goal of keeping law enforcement activity in the public record. This line of work was followed up more recently by Frankle et al. [24] where the authors discuss ways in which secret processes can be made publicly auditable without compromising secrecy of investigations. The system uses a combination of zero-knowledge proofs, a tamper-proof ledger, and multi-party computation to achieve that goal.

Goldwasser et al. [27] describe a cryptographic system for allowing accountability of secret laws related to the Foreign Intelligence Surveillance Act (FISA). Their solution uses zero-knowledge proofs to provide public auditing of (secret) data collection and surveillance procedures.

While orthogonal to our work, [6, 24, 27, 34] provide interesting avenues for exploring extensions to our system, especially in regards to providing different levels of accountability and privacy in exceptional access mechanisms.

3 Overview

3.1 Goals

The primary goal of any system designed to give legal access to a third party is to avoid abuse and ensure transparent legal compliance. The primary concern of backdoors is their potential for fueling mass surveillance practices by a malicious government agency, rogue employees, and hackers. Hence, the foremost priority of designing a lawful access scheme is to bake in limits on the scheme’s usage at the design level. Ozzie’s proposal [46] fails to identify this particular risk, instead relying on the private sector to act as a restrainer.

Stefan Savage, in his technical discussion [52], identifies the crucial need for imposing clear technical barriers to government mass surveillance. However, the proposed system still requires the private sector to keep the government in check, albeit to a lesser extent by imposing time-lock mechanisms to limit covert unlocking.

Following Savage’s outline of goals (Section 3.2 of [52]), we establish the following desirable properties which we require a lawful device access scheme to achieve. A summary of the desired properties is listed in Table 1.

Authorization Law enforcement must provide proof-of-authorization to unlock a device (e.g., a warrant). This is an imperative first step to avoiding abuse of power; however, it is not sufficient on its own as seen from numerous historical examples [22, 23].

Non-scalability We desire that individual device access is infeasible to scale to mass surveillance operations. We can do this by requiring law enforcement to expend a finite resource (e.g., physical or monetary) to obtain access. The access mechanism should incur a certain physical cost to law enforcement. This could take the form of officers on the ground and task force organization on a per device basis. Other forms of physical costs could include computational or monetary costs, as proposed in [58].

Social Costs While non-scalability via physical costs is important, it is not sufficient on its own. A well funded adversary (e.g., a government agency) can adapt by increasing its budget or creating specialized task forces. Thus, we additionally require fixed social costs — social and political costs levied through transparency which act as deterrent to mass surveillance. With both physical and social costs imposed on the unlock mechanism, the barriers to mass surveillance can be
Table 1: Summary of desiderata for JJE.

| Authorization | Non-scalability | Physical Access | Transparency | Social Cost |
|---------------|-----------------|-----------------|--------------|-------------|
| Identity of the selected delegation can only be revealed by the custodians. | Finite resources must be expended by law enforcement to unlock a device. | Physical possession is required to initiate the unlock scheme. | All unlock request require participation of multiple custodians and peer devices. | Device access must incur a high social cost. |

fine-tuned such that governments are unable to orchestrate device access operations *en masse*.

**Physical Access** A related goal which serves the purpose of guaranteeing non-scalability is ensuring that no device unlock procedure can be instigated remotely. In other words, physical possession of the device is required in order to unlock it. We therefore desire that law enforcement possesses the device prior to being able to issue *any aspect* of the unlock request. To this end, we propose cryptographic methods that are used in conjunction with existing hardware to achieve this requirement.

**Transparency** Finally, it is crucial to maintain transparency of the unlock procedure. There must be some level of public awareness to the use of the exceptional access scheme in order to avoid covert spying. This also serves as a deterrent to covert mass surveillance since government agencies can be held accountable for their actions without whistle blowers jeopardizing sensitive information in the process.

3.2 Why Devices and not Encryption

A crucial distinction is that JJE does not affect security of *encryption* itself. Much work has been dedicated to arguing why building backdoors into encryption schemes is simply not feasible without compromising security at some level \[2, 57\]. This work does not attempt to refute those claims. Indeed, having to redesign every encryption scheme from Transport Layer Security to Symmetric Key Encryption would introduce a host of vulnerabilities simply due to increased complexity, let alone the inherent risk associated by backdoors to begin with.

This paper addresses the more reasonable demand of accessing *personal devices* that are encrypted by default. We do not make any attempt to weaken encryption or give law enforcement access to encrypted communication. However, it is important to note that, in many cases, the information stored on personal devices contains most of the data law enforcement may wish to gather on an individual. Encrypted and secure communication applications such as Signal, WhatsApp, and iMessage, by default are *secure solely on the premise that the device on which they are installed is encrypted and locked*. Hence, it is reasonable to assume that with access to personal devices, law enforcement can obtain access to otherwise encrypted data as well.

4 Framework

We are now ready to describe the JJE framework. We begin by delineating roles and establishing the assumptions we make in the security model.

**Roles & Threat Model**

JJE has four entities which interact together while following a specified unlock protocol. The entities are Manufacturer, Custodians, Law Enforcement and Delegates. In this subsection, we describe the role of each entity and the trust model we assume for each role.

**Manufacturer** A device manufacturer is responsible for ensuring each device produced is designed with hardware that supports JJE and isn’t compromised by law enforcement at manufacture time. In the most basic terms, a manufacturer must be trusted to make devices that have a secure processor that isn’t tampered or vulnerable to attack.

**Custodians** A custodian in our model corresponds to an entity in possession of a (partial) secret key and is fixed at system set up time. We imagine custodians as servers belonging and operated by the government itself (e.g., district courts), nonprofit groups, corporations, and/or academic institutions. We require a group of custodians in our system to approve unlock requests issued by government agencies and law enforcement.

Specifically, custodians are tasked with the role of recognizing legitimate unlock requests issued by law enforcement. We imagine that organizations acting as custodians have the legal knowledge and funding to validate court issued subpoenas,
and for them to not be easily pressured into cooperation. Importantly, custodians have the power to approve device access requests, but not the power to unlock devices.

**Threat Model:** We model individual custodians as fully-malicious (i.e., deviating from protocol by collaborating with law enforcement) but assume that at least some threshold \( r \) of custodians are honest and follow protocol. Again, this model captures a real-world expectation of trust placed in many legal systems and public institutions such as universities and civil rights groups. It is important to note, JJE may be less practical in countries without some institutions capable of standing up to government abuse. We discuss this limitation in Section 9.

**Delegates** Delegates are peer devices that collectively have the power to unlock a single device at a time. A “delegation” consists of a randomly chosen set peer devices that act as a type of key escrow. A sufficient coalition of devices from a delegation can unlock a device. Though we describe the full technical details in subsequent sections, we stress here the fact that each device has a random, anonymous and independent delegation consisting of other devices participating in JJE. Conceptually, a delegation can be seen as a “jury” though we do not require delegates to act as “jurors” in the legal sense. Importantly, we do not expect the owners of delegate devices to decide what is a lawful or unlawful request. The purpose of delegate involvement is to ensure a fixed social cost and enforce transparency of exceptional access.

**Threat Model:** We assume that any device in a selected delegation could be actively malicious. In addition, we expect some devices to have limited connectivity, others to be lost, broken, or otherwise not able to cooperate with the protocol. Our only requirement is that most devices are not physically compromised by an adversary. Since we assume that the delegation consists of devices produced by the honest-but-curious manufacturer. We will show that, under a reasonable parameter selection, as long as no more than some percentage of all devices (e.g. 25%) are corrupted, the system is secure from law enforcement abuse with high probability. We elaborate on the details of this requirement in Section 6.

**Law Enforcement** Law enforcement wish to obtain access to a locked device. To achieve this, law enforcement interacts with custodians to obtain approval and subsequently with delegates within the selected delegation to obtain an unlock token used for unlocking the device. In the process, law enforcement will need physical access to all of the devices in the delegation in order to use the exceptional access mechanism.

**Threat Model:** We model law enforcement as fully malicious. Indeed, a large part of the reason for implementing JJE is to protect law-abiding citizens from corrupted law-enforcement organizations or rogue officers within an agency. Moreover, any malicious adversary such as state sponsored hackers would be equivalent under JJE to rogue law enforcement attempting to (unlawfully) access the device.

### 4.1 Assumptions

With the roles and threat model established, we now turn to the assumptions made by JJE. We make three assumptions which serve as a foundation for constructing the framework. We are careful to justify our trust model based on current real-world security assumptions made in practice. Moreover, these assumptions would be required by any practical unlock system, not just JJE.

**Assumption 1.** We assume that tamper-resistant, secure enclaves exists and are free of vulnerabilities.

*Justification:* A device is only as secure as its password. While it is possible to encrypt a device directly, it is impractical for most users to memorize a full encryption key. Some modern devices maintain state of the art security against physical attack by using secure enclave co-processors which run only software cryptographically signed by its manufacturer in order to gate access to the true decryption key of the device [3, 5]. In fact without some sort of dedicated tamper resistant hardware, an adversary can be reasonability assumed to be able to unlock a device if they have physical access to it [3, 5, 19]. Because of this, we believe that any secure access scheme would be trivially insecure without this requirement.

It is important to note that the term “secure enclave” has a somewhat overloaded definition. There have been a number of works describing creative attacks on secure processors which allow execution of arbitrary user code, specifically the recent SGX processor developed by Intel [37, 54, 55]. However, in JJE it is sufficient for devices to run dedicated software designed by the manufacturer at device creation time such as a TPM [3, 13]. This is the model used by iPhones, Macs and some Android phones [3, 5] and is suspected to be difficult to break [32]. Furthermore, recent work has developed formal guarantees for enclave processors [19], making them more resilient to attacks.

**Assumption 2.** We assume that the only two ways to unlock a device is through the intended mechanism (i.e., by providing a password) and the JJE exceptional access protocol.

*Justification:* In other words, we do not claim that JJE fixes other methods of breaking into a device. Therefore for our security analysis we exclude the possibility of breaking into the device via side-channels and zero-day vulnerabilities. While in the real world this is certainly not assured, such methods for accessing devices are tangential to the usefulness of JJE.

**Assumption 3.** We assume that only devices honestly following the protocol can be unlocked using the JJE exceptional access protocol.
With the necessary context and assumptions in place, we are about to describe an initial attempt at a solution which addresses the aforementioned design goals. The JJE framework is divided into four stages which we outline below.

**Initial Setup**  
For simplicity of presentation, assume a set of custodians $C_1, C_2, \ldots, C_n$ have among them shares of a secret key $sk_C$ such that any subset of $t$ custodians can decrypt a ciphertext encrypted under the corresponding public key $pk_C$.

**Device Setup**  
Each manufactured device $D_j$ uses its secure processor to run a key generation protocol and generates a public verification key $vk_{D_j}$ and secret key $sk_{D_j}$. The secret key $sk_{D_j}$ is stored on the device using secure sealed storage\(^1\), managed by the device’s secure processor, and the public verification key is published to a public list $L$ maintained by the manufacturer or some other trusted entity.

\(^1\)See https://developer.apple.com/documentation/security/certificate_key_and_trust_services/keys/storing_keys_in_the_secure_enclave for details.

**Device Protocol**  
Each device $D_j$ selects a randomly chosen subset $S$ of $m$ verification keys from $L$. To ensure that custodians are required to approve exceptional access requests, $D_j$ encrypts the entire set of verification keys it selected using the public key $pk_C$. Recall that custodians hold the corresponding shares of the secret key $sk_C$. This process results in a challenge ciphertext $[\text{chal}] = \text{Enc}_{pk_C}(\text{chal})$.

When prompted, $D_j$’s secure processor writes $[\text{chal}]$ to the write-only “mailbox” which supports read-only queries. Currently, existing secure processors only have one mailbox interface, used for communicating with the device’s CPU. For simplicity, we assume an additional read-only mailbox interface accessible via hardware pins [3].

**Exceptional Access Protocol**  
If law enforcement have physical access to a device, they can read the challenge $\text{chal}$ from the hardware mailbox. Law enforcement then requests $t$ custodians to decrypt $[\text{chal}]$, which, if they agree, allows law enforcement to recover the set of delegate verification keys selected by the device. Law enforcement then requests the manufacturer to provide the identity of each device on the delegation so as to locate them and obtain a signature of $\text{chal}$ from each device on the delegation. Call this set of signatures $\tilde{S}$.

When $D_j$ is presented with $\tilde{S}$, it locally verifies that the signatures are valid (and match its selection $S$). If the check verifies, $D_j$ outputs an access token $\phi$ which tells the operating system to unlock the device.

The high-level strawman solution satisfies the design goals outlined above. Specifically, 1) authorization is satisfied given

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**Figure 1:** Overview of JJE protocol and interaction steps necessary to unlock a device. (1) manufactured devices upload a public signature key and encrypted identifier to the delegate list. (2) When an unlock request is issued by law enforcement, the (locked) device selects a random set of indices from the list of delegates which becomes its unlock challenge. (3) Law enforcement signs the identities of the devices located at indices selected by the device. (4) Law enforcement locates the delegates and obtains a set of signatures which are the key to unlocking the device.

**Justification:** It is impossible to stop a device from furthering its own security given a savvy and determined user. For instance, a user can always encrypt important files using a second layer of encryption which JJE would not provide access to. Moreover, a user could trivially wipe the preinstalled operating system and use their own system which does not participate in JJE. We discuss in Section 8.2 practical means for incentivize non malicious users to participate in JJE.

**4.2 Strawman Proposal**

With the necessary context and assumptions in place, we are now ready to describe an initial attempt at a solution which addresses the aforementioned design goals. The JJE framework is divided into four stages which we outline below.
that custodians must agree to decrypt the challenge and reveal the identity of the selected delegation; 2) Non-scalability is achieved by the fact that each device that law enforcement needs unlocked requires a unique access token making the unlock protocol effective only on a per device basis; 3) the physical access requirement is achieved by writing the access challenge to a read-only hardware interface; 4) transparency is achieved by requiring the involvement of both custodians and randomly chosen delegate devices; 5) finally, social costs are incurred by the need for Law Enforcement to locate a randomly chosen delegation, on a per device basis.

**Problems with Strawman** While the strawman solution described above does achieve the desired properties of Section 3, there are a few technical questions that must be addressed and fleshed out. Specifically, how is the list \( L \) of peer device keys maintained? How do we prevent an adversary from inserting malicious delegate keys into the list? How do we ensure that devices chosen in the delegation are active (i.e., not lost or broken) and can be located? Finally, how do we prevent network or man-in-the-middle attacks when a device retrieves the list \( L \) to construct its unlock challenge?

5 The JJE Scheme

In this section, we describe the necessary protocols for realizing JJE and address the problems described in the strawman scheme. To do so, we must introduce some necessary security and cryptographic building blocks to use in our construction.

5.1 Cryptographic Building Blocks

**Secure Processors** Secure processors such as Apple’s T2 Chip [3] used in iPhones and MacBooks, and Google’s Titan M Chip for high end Android phones [5], are becoming increasingly prevalent in smartphones and computers alike. Such processors enable computations to run securely on the device, isolated from other device components. This enables secure computation even in the presence of adversarial software on the device [19, 20, 51]. What’s more, this family of processors are resilient to both hardware and software attacks and engineered to be tamper-resistant [19, 20, 51]. For ease of presentation, we describe our protocol using Apple’s T2 terminology, and we make use of Assumption 1 that the secure processor on the device is secure and tamper-resistant.

**Cryptographic Signatures** We require a cryptographic signature scheme [21, 31] for the purpose of verifying different entities in the system. We denote a signature issued by an entity \( E \) in the system by \( \sigma_{E}(m) \) where \( m \) is the message being signed. Anyone can verify the signature \( \sigma_{E}(m) \) using the public verification key \( vk_{E} \).

Figure 2: Merkle tree for a list \( L \) containing four verification keys. The root hash, in conjunction with the hashes highlighted in green, attest to the correctness of \( vk_{1} \).

**Merkle Trees** We use Merkle trees [40, 41] to efficiently validate entries in a list. A Merkle tree consists of three algorithms: \( \text{MerkHash} \), \( \text{MerkPath} \), and \( \text{MerkVer} \). A list of values is hashed using \( \text{MerkHash} \) which outputs a succinct “root hash” of the entire list. A proof that an element is contained in the list can be issued using \( \text{MerkPath} \) which takes as input an entry from the hashed list and outputs a list of hashes that form a path from the root hash to the entry. The proof can be verified efficiently using \( \text{MerkVer} \) which outputs 1 if it is given a valid path and 0 otherwise (i.e., if the element is not in the list). Importantly the size of the proof is logarithmic in the size of the list. Figure 2 provides an illustrative toy example of a Merkle tree for a list containing four verification keys.

5.2 International Mobile Equipment Identity

IMEI is a unique 15-digit identifier used to identify all mobile phones. The IMEI is device specific and independent of the operating system and cellular network. All devices in a cellular network share the IMEI number with the cellular network provider (e.g., AT&T) which links it to an International Mobile Subscriber Identity (IMSI). In practice, the network provider has the ability to blacklist devices based on the IMEI (e.g., if a device is stolen). We refer the reader to [47, 53] for more specifics.

In this work, we use the fact that network providers know the (IMEI, IMSI) pair for each device in their network and can therefore provide information about the subscriber (i.e., device owner) based on the IMEI. For simplicity, we assume that law enforcement already has efficient means to access these records.
5.3 Custodian Setup

Custodians $C_1, C_2, \ldots, C_n$ run a Distributed Key Generation protocol [12, 25] to obtain a public key $pk_c$ and where each $C_i \in C_1, C_2, \ldots, C_n$ holds a share of the decryption key $sk_c$.

We assume that the custodians collectively maintain an append-only list of keys $L$ to which devices can write to. Custodians initialize the time epoch $\tau = 0$. For each new epoch (e.g., on a weekly basis), $C_1, C_2, \ldots, C_n$ engage in a protocol to update the list $L_{\tau-1}$ to $L_{\tau}$. Each active device writes to a list $L_{\tau}$ for each epoch $\tau$ in order to ensure only operational devices are available for delegate selection.

Custodians then check that all entries in the list $L_{\tau}$ are valid and index the entries from $i = 1 \ldots N_{\tau}$, where $N_{\tau}$ is the number of valid entries in the list for the epoch $\tau$. We assume that the custodians run an integrity check and reach consensus as to the correctness of $L_{\tau}$. This indexed list, $L_{\tau}$, forms the public list of delegates, i.e., the delegate pool, for the time epoch $\tau$. For notational simplicity, we drop the $\tau$ subscript and denote the number of devices in the current epoch by $N$ and the list of keys by $L$.

5.4 Manufacturer Setup

We split manufacturer setup phase into two protocols: SystemSetup and DeviceSetup. The former is used to initialize the system once (i.e., when the manufacturer begins operations), the latter protocol is used to initialize each new manufactured device.

SystemSetup: The manufacturer $M$ generates a key pair $(vk_M, sk_M)$ for a cryptographic signature scheme. The public verification key $vk_M$ is made public. We note that, in many cases, this setup is already in place as it is needed for manufacturers to sign software updates [42].

DeviceSetup: For each manufactured device, $M$ interfaces with $D$’s secure enclave via a designated API to request the generation of a new signature key pair. The enclave generates and stores the secret key $sk_D$ in sealed storage and outputs the public verification key $vk_D$ via the secure processor interface. $M$ signs the device’s public key using its secret key $sk_M$ to generate a signature $\sigma_M(vk_D)$ which it sends back to the device’s enclave. This signature is subsequently used by the device to “prove” that it is real device and not a virtual “sock puppet” when participating as a delegate in the system. This is analogous to hardware attestation with a root of trust which is widely available at scale [3, 13, 19, 20]. In practice the root key $vk_D$ is not used directly, but can be used to validate other equivalent device keys [13, 20].

5.5 Device Protocols

As a delegate, each device in the system must do two things: (1) it must make itself “available” as a delegate and (2) it must be able to “approve” unlock requests for other devices that have selected it to be part of a delegation. To this end, we require a protocol by which each device $D$ can share some identifying information which can only be revealed by a coalition of custodians. Next, we require a protocol for securely selecting a set of delegates without risking man-in-the-middle attacks and without leaking the delegation identity in the process. Finally, we require an unlocking protocol by which the device reveals a unique access token $\phi$ used to unlock the device. We split these three separate functionalities into the following protocols: InitSetup, SelectDelegates and Unlock.

$D$.InitSetup(): To participate in the system as a delegate, the device must add itself to the list of participating devices. To this end, for each new time epoch, $D$ generates a fresh key pair $(vk_{del}, sk_{del})$ and encrypts its own IMEI number using the public key of the custodians to obtain $[IMEI_D] = Enc_{pk_c}(IMEI_D)$. $D$ then generates the tuple

$\text{DelegateID}_D = (vk_{del}, [IMEI_D])$

$D$ then proceeds to write DelegateID$_D$ to $L$ by interfacing with the custodians.

$D$.SelectDelegates($H$): Given the latest metadata about $L$, consisting of the custodian-signed header

$H = \langle \text{timestamp}, \text{MerkHash}(L), N \rangle$

$D$ verifies the signature using $pk_c$ upon which it selects indices $\ell_1, \ell_2, \ldots, \ell_m$ uniformly at random such that $1 \leq \ell_i \leq N$, where $N$ is the size of $L$. Let $S = \{\ell_1, \ldots, \ell_m\}$ which $D$ stores in secure memory. This delegate selection does not leave the device. Therefore, the selection of which other devices are on a given delegation is remains entirely private and thus not vulnerable to man-in-the-middle attacks.

$D$.SignUnlockReq($W$): Let $W$ be a token verifying that the current device is needed as a delegate in a specific valid unlock request. See Section 5.7 for the full definition of $W$. If $W$ is correctly verified as being signed by the custodians public key $pk_c$, the device signs the input and sends back

$\sigma_D(W)$

through the secure hardware mailbox interface. This process allows law enforcement to obtain the necessary signatures from delegate devices without compromising the security of delegates.

---

2Secure enclave encrypted storage – $sk_D$ never leaves the secure processor and remains unknown to the manufacturer.
\(D.\text{RevealChal}(\cdot)\): The device \(D\) encrypts its selection of
delegates under the custodian’s threshold encryption key
\[ [S] = \text{Enc}_{pk_c}(S) \]
and reveals it via the enclave’s secure mailbox interface. This
protocol is only used if a device is attempted to be unlocked
via JJE.

\(D.\text{Unlock}(\tilde{S}, W, M)\): When given the set \(\tilde{S} = \{\sigma_j(\text{vk}_{del}^j) \mid j \in S\}\) consisting of signatures obtained from a subset of delegate
devices in \(L\), indexed by the set \(S\), \(W\) a set of custodian-signed
verification keys, and \(M\) consisting of a set of Merkle proofs
for each delegate key, the device verifies the following:

1. \(|\tilde{S}| \geq t\) where \(t\) is the threshold of signatures required for
unlocking;
2. \(\text{MerkVer}(\text{vk}_{del}^j||\text{Enc}_{pk_c}(\text{IMEI}_j))|j| = 1 \forall j \in \tilde{S};\)
3. For each signature in \(W\), there is a verification key
\(\text{vk}_{del}^j \in \tilde{S}\) that is signed by the custodians and verifies
the signature of \(W\).

The verifications ensure that a sufficient coalition of devices
from the delegate selection signed the unlock request and, cru-
cially, that each signature obtained was from delegate device
indexed by the set \(S\) in \(L\). This latter step ensures that the
delegation selection was not “swapped out” for a selection
\(S' \neq S\).

If the three verification steps pass, \(D\) reveals the unlock
token \( \phi \) by writing it to the secure mailbox interface. The
token \( \phi \) can be as simple as the device’s password. Otherwise,
the unlock process fails.

5.6 Delegate Protocol

Devices can be called upon as delegates in order to verify the
unlock of other devices through the \(D.\text{SignUnlockReq}(W)\)
protocol. We stress that the process by which an owner of
a delegate devices signs a warrant should be non-invasive.
Specifically, there is no need for a device owner in a dele-
gation to unlock their device in order to sign a request. The
signature can be obtained by interfacing directly with the
device’s enclave through a physical pin connection, or, alter-
atively, wirelessly using RFID. Physical access by law
enforcement is needed both to incur a social cost and to re-
cude the risk of side channel attacks. However, participation
should not incur an invasion of privacy for the delegate device
owner.

5.7 Warranted Access Protocol

We will now describe how law enforcement proceed to unlock
a device through JJE. We denote the locked device by \(D^*\).

We assume that the law enforcement has physical access to
\(D^*\) so that they can interface with the secure processor over a
mailbox interface [19]. Law enforcement proceeds as follows:

Step 1: Law enforcement sends a request to the secure hard-
ware enclave. \(D^*\) sends back the challenge:

\[ \text{chal} = ([S], pk_d, \sigma_d([S]), \sigma_M(pk_d), \tau) \]

where \(S \subseteq \{1, 2, \ldots, N\}\) is a (random) choice of indices in \(L\),
\(\sigma_d(S)\) is a signature under the secret key \(sk_d\), \(\sigma_M(pk_d)\)
is a signature by the manufacturer attesting the \(pk_d\)
(which \(D^*\) obtains at setup time, see Section 5.4), and \(\tau\)
is the epoch number. Once a device receives an unlock
challenge it should not update to new epochs for some
fixed period to ensure reasonable time to complete the request.

Step 2: Law enforcement now presents \(\text{chal}\) to the custodi-
ans. The custodians validate that signature \(\sigma_d([S])\) and that
\(\text{vk}_{del}^j\) has been signed by a manufacture’s \(\text{vk}_M\). We presume
that at least \(r\) custodians are honest and will not participate if
the request is unlawful. Note, even if all custodians are mali-
cious, they cannot unlock the device, only reveal the identities
of the delegates.

If a threshold of \(t \leq n - 1\), (fixed a priori), custodians agree
to the validity of the request, then, they decrypt \([S]\) and reveal
the IMEI numbers of the selected delegation by decrypting
the entries in \(L\) indexed by \(S\). Recall that \(i\)th entry in \(L\) is of the
form

\[ L_i = \text{vk}_{del}^j || [\text{IMEI}_{del}^j] || i \]

The custodians can then reveal each \(\text{IMEI}_{del}^j\) of the entries
indexed by \(S\) using threshold decryption. To this end, the
custodians output the set

\[ I = \{\text{IMEI}_{del}^j \mid j \in S\} \]

Custodians also produce a “warrant” consisting of a set of
signatures of each delegate’s verification key \(\text{vk}_{del}^j\) specific to
this unlock request

\[ W = \{\text{vk}_{del}^j||\sigma_c(\text{vk}_{del}^j) \mid j \in S\} \]

The signature \(W\) acts as validation to each delegate in the
delegation that the law enforcement has authority only for
this specific unlock request. The custodians send \((I, W)\) to
law enforcement.

Step 3: Law enforcement now has the IMEI numbers, which
uniquely identify each device. Law enforcement is now re-
ponsible for physically locating devices in \(I\) to obtain a signa-
ture. To prove that the selected delegate keys in \(W\) are correct
(i.e., are indeed the keys in \(L\) indexed by \(S\)), law enforcement
generates a set of Merkle proofs,

\[ M = \{\text{MerklePath}(L_i) \mid j \in S\} \]
where \(L_j\) is the element at the \(j\)th index of \(L\).

**Step 4:** Law enforcement needs to locate at least \(t\) devices. For each delegate device that law enforcement locates, they interface with the secure hardware mailbox interface and send \(W\). If the signature is correct, each delegate sends back a signature \(\sigma_{\tau_i}(W)\). Define the set of all \(i\) or more delegate signatures
\[
S = \{\sigma_{\tau_i}(W) \mid \text{for } i \in S\}
\]

**Step 5:** Law Enforcement sends \((S, W, M)\) to \(D^*\) in response to the challenge \(chal\). \(D^*\) verifies the correctness of the response according to \text{Unlock}(S, W, M) and, if the verification passes, outputs the unlock token \(\phi\).

### 5.8 Partial Epoch Participation

For simplicity of our analysis, we assume every device is capable of participating in each epoch. In practice devices may miss epochs due to having limited network access, no power or for any number of other reasons. As long as most devices participate in an epoch \(\tau\), the size of \(L\) will be sufficient. The list \(L\) for each epoch can be maintained by the custodians and each device can maintain its old verification keys. Devices which have not updated to new epochs can be unlocked using JJE and the root hash of the last valid epoch.

Additionally, writing to \(L\) can be structured so that devices can write their keys over a number of days or weeks [18] and does not require synchronization between devices in the process.

### 6 Security & Privacy

In this section we analyze the security properties of JJE in relation to our threat model. We then address several privacy concerns which are important to consider in a deployed system.

#### 6.1 Security Analysis

Let JJE be initialized with some threshold of \(r\) custodians as a security parameter. We will first show that as long as \(r\) custodians are honest for epoch \(\tau\), the list \(L\) for that epoch can be validated.

**Theorem 1.** Given \(r\) custodians are honest for epoch \(\tau\), the list \(L\) will contain entries from each active devices and only entries from devices signed by a manufacturer \(M\).

**Proof:** Each device must send its public key \(pk_d\) and a signature \(\sigma_M(pk_d)\). As long as at least one custodians is honest, every device entry in \(L\) will be validated by that honest custodian. \(\Box\)

**Theorem 2.** Let \(N\) be the number of devices participating in the epoch \(\tau\) and \(C > 0\) be some constant. Then, given an adversary can corrupt at most \(N/C\) devices and epoch \(\tau\) has been initialized correctly, there exists a security parameter \(0 < p < 1\) and a delegation size \(m\) for JJE such that with probability \(p\) the adversary must obtain at least one honest delegate to unlock the device.

**Proof.** We will begin by stating and proving a few lemmas.

**Lemma 1.** Let \(D\) be some device with delegate selection \(S\). Without both device access and cooperation of \(r\) custodians, \(S\) cannot be determined with better than negligible probability.

**Proof.** No witness to the selection of \(S\) leaves the device until the hardware protocol \(D, RevealChal()\) is initiated. Furthermore, only \(Enc_{pkc}(S)\) is returned. Given \(r\) honest custodians we assume \(S\) cannot be decrypted with better than negligible probability \(\Box\)

**Lemma 2.** Let \(D\) be some device with delegate selection \(S\). Without access to \(S\), no adversary can guess the identities of a device’s delegation with probability that is better than random guessing.

**Proof.** By construction, we assume each device selects its delegation uniformly at random from the set of all \(N\) devices in \(L\). The choice of \(S\) never leaves the secure enclave of \(D\). Therefore, without the direct witness of \(S\) an adversary can do no better than randomly guess. \(\Box\)

**Lemma 3.** Given the current epoch \(\tau\) is set up correctly, a device \(D\) cannot be unlocked through JJE without access to the verification secret keys \(\{sk_i \mid i \in S\}\) where \(S\) is the delegation selected by \(D\).

**Proof.** We assume device \(D\) has downloaded the Merkle hash of \(L\) for the current epoch \(\tau\). This header can be verified by \(D\) since it is signed by the custodians which we assume to have correctly initialized the epoch.

The only means to unlock \(D\) through JJE is through the \(D, Unlock(S, W, M)\) protocol. Recall
\[
\overline{S} = \{\sigma_j(vk_{del}) \mid j \in S\}
\]

and \(M\) is a set of Merkle proofs verifying that \(S\) is in the list \(L\). The proofs \(M\) can be verified via the Merkle hash \(D\) has downloaded for epoch \(\tau\).

This input is required by the secure enclave in order to unlock. Suppose the adversary could generate this input without access to the secret keys \(\{sk_i \mid i \in S\}\) of the signatures. It must therefore be either able to forge the signatures \(\sigma\) or fabricate the Merkle proofs \(M\). We assume this only happens with negligible probability [40]. \(\Box\)
Lemma 4. Let $(1/C) < 1$ be a static fraction of corrupt devices controlled by an adversary. Then, for any probability $0 < p < 1$, there exists a delegation size $m$ for JJE such that an adversary cannot recover the set of signatures $S$ when given $\text{chal}$ with probability greater than $p$.

Proof. We assume devices select its delegation keys $S$ with $|S| = m$ uniformly at random and independently from all other $N-1$ devices in $L$. Since the keys are chosen uniformly at random the probability that the adversary possess all devices on $D$’s delegation is bounded by

$$\binom{m}{t} \left( \frac{1}{C} \right)^m \quad (1)$$

We can trivially select $t = m$ and select $m$ such that $(1/C)^m < p$. In practice, this probability is exponentially small with reasonable choices for $m$ and $t$. See 7 for analysis of practical choices of parameters.

We will now complete the proof of Theorem 2. By Lemma 1 and Lemma 2 no matter which devices the adversary choses to corrupt, they cannot select a device on $D$’s choice of delegation with better than random chance. By Lemma 3, the adversary must obtain access to all delegate devices in $S$. By Lemma 4 there exists some $m$ such that adversary cannot obtain all of $S$ with probability less than $p$. Therefore with the security parameter choice of $m$ the adversary needs to obtain at least one honest device with high probability. □

6.1.1 Privacy Analysis

It is also important to show that reasonable privacy for devices is maintained by JJE. Recall that the $i$th entry of the list $L$

$$L^{(i)} = \text{vk}_{\text{del}}^{(i)} || \text{Enc}_{\text{pk}}^{\text{iMEI}}_{\text{del}}(i)$$

corresponds to some $i$th device $D_i$. Each $\text{vk}_{\text{del}}^{(i)}$ is generated anew for each new epoch and the publicly identifiable information (the $\text{iMEI}_{\text{del}}$ value) is encrypted under the custodians threshold scheme. It is reasonable, however, to assume that a sophisticated adversary could link device identities to $L$ entries through network traffic analysis. This, however, does not compromise the security of the scheme for honest devices by Lemma 1 and only leaks that a particular device is participating in JJE.

7 Discussion

7.1 Practical Security and Concerns

While our proofs of security provide necessary guarantees, there are practical concerns and side channel attacks that need to be addressed.
7.2 Auditing

An advantage of JJE is that both the manufacturer and custodians can be audited by one another and the public. This helps ensure that JJE is being correctly carried out in practice by quickly revealing anomalous behavior.

Auditing Manufacturers Under our threat model we assume that a device’s manufacture needs to be trusted otherwise the device itself could be built in a compromised manner via a supply chain attack. It’s possible, however, that the manufacture could be coerced into malicious participate with an adversary after building a device.

A malicious manufacturer could perform a sybil attack by flooding the system with “sock puppet” devices under an adversary’s control. Since manufacturers validate the device keys they could take over an arbitrary percentage of all devices.

However, the number of devices in JJE is public knowledge and collectively the custodians have the power approve of $L$. Any public auditor observing the resulting $L$ for each epoch would be able to discover a huge spike in new devices. Since an adversary must control a large number of all devices we believe it would be difficult for such an attack to succeed without notice. As long as at least $r$ custodians are honest, they could then remove suspected malicious devices from new epochs.

Additionally, it is not the device manufacture who needs to be trusted per-se, but the manufacture of the secure enclave. Some modern android phones use a standardized Titan M secure enclave which could be build independently of the device [5]. Due to the nature of secure enclaves, in practice they already require rigorous hardware auditing and validation in order to provide trusted attestation [3, 4, 28].

Auditing Custodians Likewise, devices and the public can verify that the custodians are correctly carrying out JJE. The Merkle hash of $L$ guarantees that the correct public keys are used during unlocking. However, its possible that if every custodian conspired they could purposefully exclude devices from $L$. Since $L$ is public, however, any device which wishes can verify that its key has been added to $L$.

7.3 Privacy and Transparency

There are two crucial sides to consider when analyzing the privacy properties of JJE: privacy of delegation devices (and the people that own the devices) and the transparency of the exceptional access use.

Delegation Privacy The privacy of delegates is maintained by only having public keys stored in $L$ while all other uniquely identifying information (such as the IMEI number) remains encrypted and only accessible via consensus of the custodians. Delegate obtains no information about the identity of the device being unlocked only that they were selected as one of its delegates.

However, JJE does require law enforcement to contact delegates in order unlock a device. We argue that this very real inconvenience is a feature and not a bug. Using JJE requires law enforcement to pay this social cost. Every use of JJE fundamentally must leak the use of exceptional access to ordinary citizens. If use of the exceptional access scheme were to be frequent, then it is perhaps good that citizens would be aware and discomforted by this abuse of power.

Moreover, being called to serve on traditional jury is already an accepted social responsibility in many democracies. One can view participation in JJE as an extension of jury duty in the digital sphere. Additionally, the device of a delegate can easily be requested to provide a digital signature without unlocking or exposing personal information to law enforcement, as explained in Section 4.

Law Enforcement Secrecy Public information pertaining to on-going cases could severely impede investigation for law enforcement [24]. JJE reveals nothing more than the fact that some device is being unlocked meaning that law enforcement secrecy is maintained.

8 Extensions

8.1 Incorporating Time-lock Mechanisms

One of the goals outlined of the exceptional access mechanism described in [52] is to impose a time-lock mechanism to require a certain amount of time (e.g., 3 days [52]) before giving law enforcement the ability to proceed with the unlock protocol. In theory, such a mechanism would mitigate the effectiveness of a “device swap” attack (e.g., where the target is away from the phone for a weekend). However, upon careful consideration, we do not believe such a mechanism would be an effective deterrent for a dedicated adversary and would likely only be a cause of frustration to law enforcement in an urgent situation (e.g., terrorist attack). However, we note that a time-lock mechanism can be added to JJE as a modular extension. For example, using recent developments in verifiable delay function [10, 11], law enforcement can provide a proof-of-time-elapse to the device when issuing the unlock token. Taking a different approach, we can use the ideas presented in [58], to create time-lock puzzles which law enforcement must break to recover a part of the access token. Such an approach would both incur a monetary cost and a time-lock cost (as described in [58]).

8.2 Incentivizing JJE Participation

As mentioned in Assumption 3, it is impossible to force a device to cooperate with any exceptional access scheme. For
instance, a user could always use a second layer of strong encryption. In practice, however, the secure processor is the only means to pair strong physical security with ease of use [3, 19, 55, 56]. Directly encrypting the device requires the user to memorize or store a full encryption key which is often impractical.

Modern devices using a secure hardware enclave often use a mechanism such as a pin code or biometric to decrypt the device while maintaining state-of-the-art security [3]. JJE can therefore tie the use of the secure processor with participation. Every part of JJE that happens on a device happens in its secure enclave. As long as the enclave verifies that it continues to receive valid headers for lists $\mathcal{L}_\tau$, for each new epoch $\tau$, it can be unlocked using JJE. Likewise, the enclave can verify that its writes are received by the custodians and that it is successfully contributing its delegate verification keys. If the enclave fails to update to a new epoch, it can continue to provide JJE exceptional access on the last valid epoch.

If too much time passes since the last updated epoch and the device’s password has been correctly used during that time, then the secure enclave can provide a failsafe where any valid unlock request signed by the custodians will unlock the device. This timeout period can be set to be a reasonably long period of time (such as six months) to incentivize devices to participate.

8.3 Write-anonymous Append-only List

It may be desirable in certain scenarios to prevent a network adversary or the custodians themselves from knowing the mapping from a device to an entry in $\mathcal{L}$. For example, certain deployments may desire that a device makes itself available as a delegate without custodians knowing which entry (key) in $\mathcal{L}$ corresponds to that device to diminish the power a network adversary, or malicious custodians, can have. This can be achieved using a write-anonymous list. At a high level, using a system such as Riposte [18], it becomes possible to have device write to an index in a list in a completely anonymous way (i.e., the servers maintaining the list do not learn the index). Coupled with cryptographic signatures, this construction is secure against a malicious client attempting to submit multiple entries in an effort to spam the system by inserting multiple keys. We refer the reader to [18] for technical details of such an instantiation.

9 Limitations

We believe that JJE is a significant advancement compared to previously proposed exceptional access schemes, especially when it comes to reducing trust in any single authority and mitigating the risk of abuse. However, we are under no illusion that JJE is capable or solving all security, practical or ethical problems resulting from deploying exceptional access. We discuss a few important, but by no means exhaustive, limitations to JJE and other similar systems.

Necessary Political Infrastructure In order for JJE to operate, there needs to be reasonable trust in public institutions selected as custodians and public accountability of the government. JJE rests on the assumption that it would be difficult for abusive law enforcement to secretly coerce all custodians or to routinely silence citizens selected as delegates. This is certainly not true in all countries especially countries with authoritarian or unstable governments. In these situations implementing JJE is likely unsuitable.

Jurisdiction of JJE Today, most devices are designed and assembled in supply chains that cross international borders [15]. Additionally, a handful of large corporations under the jurisdiction of a few powerful countries build and sell devices across the entire world [38]. Consider a device which participates in JJE, but the custodians and most other peer devices resided in another country. Attempting to unlock a device using JJE could result in complicated legal questions of international sovereignty. This could be mitigated by requiring correct geolocation for epoch participation.

Normalization of Exceptional Access If a country were to adopt an ethically designed exceptional access scheme such as JJE, it could provide cover for less judicious countries to employ insidious backdoors with claims of false equivalence. Additionally, if citizens objected to participating as delegates in JJE, dishonest actors might call to remove the delegate requirement (thereby undermining the system), rather than be pressured into reducing the use of exceptional access.

10 Conclusion

As far as we are aware, JJE is the first exceptional access scheme which does not place approval for unlocks in a single trusted authority, but rather in the hands of devices participating in the scheme. We show that JJE provides strong security and is resistant to abuse for mass surveillance by tying unlocks to a fixed social cost. We present a feasible outline of how JJE could be implemented in practice and rigorously analyze the security of the protocol. We hope that the ideas presented in this paper will spur discussion on what exceptional access schemes are possible and deemed appropriate by society.

Acknowledgments

We thank Seny Kamara for introducing us to this research topic in his phenomenal seminar, Danny Weitzner for a helpful discussion on the topic, Ben Murphy, Ilia Lebedev, and Kyle...
Hogan for reading an early draft of this paper and providing us with many valuable suggestions.

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A History & Background

Since the Edward Snowden leaks in 2013 [23], tech companies have put significant work into building devices and software that is secure from both hackers and government surveillance. Today, devices manufactured by Apple and many Android devices use full disk encryption by default [3, 28]. Moreover, some popular messaging services like iMessage, Signal, and WhatsApp use end-to-end encryption [17]. The U.S. Government and the FBI have vocally objected to such technology, arguing that such levels of privacy present a national security threat [35].

Indeed, in 2015, the FBI filed suit against Apple, Inc. in an attempt to force the company to unlock an iPhone owned by the terrorist responsible for the San Bernardino shooting [32]. Apple claimed they had no way of unlocking the phone without actively building a new way to break their own encryption and argued, in court, that being forced to do so would be a violation of the first amendment and the right to free speech [32, 49]. The case was ultimately dropped by the FBI after they found a 3rd party company willing to break into the phone, without Apple’s help, using a zero-day vulnerability that has since been patched [36]. The highly publicized case has sparked academic interest in this problem. Recently, there have been a handful of proposed ideas for enabling exceptional access to locked smartphones and encrypted communications while limiting the risk mass surveillance and under-funded hackers gaining access [46, 52, 58]. On the law and policy side, there has been renewed interest in encryption technology and its impacts [50].

The technical discussion so far has focused on placing full trust on the private sector to handle everything from complying with warrants to managing the secret keys used to unlock devices. Roughly speaking, the argument for proposing such as solution is the belief that the private sector will hold their ground when it comes to protecting users, mostly because of monetary incentive structures that are currently in place [49]. While such arguments may have merit, they place undue burden on the private sector to manage the entire infrastructure [49]. Not to mention the burden imposed from the legal overhead of meeting the demands of law enforcement. Moreover, excessive trust in a manufacturer creates a flaring target for foreign hackers and other well-funded and determined adversaries. Perhaps the most illustrative example of this occurred in 2010 when Chinese hackers breached a Google surveillance database used by the U.S. government to track suspects’ activities [43] which allowed the perpetrators to gain a full list of Google users currently under surveillance by the U.S. government.

These problems, and proposed solutions, are not entirely a new phenomenon. In fact much of this debate can be traced to the so called “Crypto Wars” of the 90’s. With the advent of practical encryption available to consumers, the U.S. Government, and specifically the NSA, realized that phone calls and other forms of electronic communication would be impossible to wiretap should encryption become used by the general public [50]. In order to preserve electronic surveillance, the government proposed that cryptographic backdoors should be implemented in all consumer devices that use encryption [50]. Their solution relied on an electronic chip called “Clipper Chip” which held a special “backdoor key” that could be used by law enforcement to decrypt communications [33]. This way, the hope was, only the government would be able to use the key, and then only with a wiretap warrant [33]. This plan was short lived, however, and resulted in a complete public-relation disaster after the Clipper Chip was shown to be vulnerable to attack [9, 33].

In the early days of the internet, the government also sought to weaken the perceived damage of strong encryption by placing restrictions on the sale and distribution of cryptographic technology and software, classifying cryptographic tools as
military weapons [33]. Moreover, the U.S government aggressively took action against the PGP protocol used for encrypting emails [33]. However, PGP and other encryption standards flourished, despite the crackdown and legal restrictions, which ultimately caused the government to relent [33]. However, even though encryption technology became widespread, subpoenas for information from ISPs, email providers and social networks have amply satiated law enforcement [33, 49]. Additionally, since at least the early 2000’s the U.S. government has been monitoring wide spread network traffic under the name of “Total Information Awareness” with the goal to preemptively predicting terrorist activity at the expense of civil liberties [29, 48].

However, after the Edward Snowden leaks in 2013, coupled with the rise of modern device encryption that use secure hardware enclaves, the U.S. government has placed renewed interest in its quest to force technology companies to provide exceptional access [49]. The topic of unlocking terrorist’s phones went as far as to show up in the 2016 presidential election debate and will likely continue to be a contested topic [39].

B Authors’ Opinions

Considering the controversy surrounding this area of research, we believe it is important to stress that we, the authors, are not advocating legislation mandating exceptional access schemes. We firmly believe that attempts to outlaw strong encryption are misguided and dangerous. However, we also believe that the cryptographic research community needs to take this problem seriously in order to avoid rushed legislation that gives government unilateral power to unlock devices. While we are aware that credible exceptional access research could be used as a fig leaf to justify backdoors that are secure “in name only,” we believe that recent events show governments are willing to mandate them regardless [30, 44, 45]. We hope JJE can help facilitate a discussion into ethical exceptional access and to show that there are more secure and more ethical alternatives to secretive “backdoors”.

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