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To cite this version:
Frédéric Prost. On the Heritage of Crypto Assets - Tales From the Crypt Protocol. 2022. hal-03727994

HAL Id: hal-03727994
https://hal.science/hal-03727994
Preprint submitted on 19 Jul 2022

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On the Heritage of Crypto Assets –
Tales From the Crypt Protocol

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July 19, 2022

Abstract

We discuss some issues to the inheritance of crypto assets. We propose a distributed, privacy preserving, protocol to establish a consensus on the death of the owner of crypto assets: the Tales From the Crypt Protocol. Until the actual death of the owner no link can be made between public information and the corresponding crypto assets. This protocol is generic and could be incorporated into any arbitrary crypto platform.

1 Introduction

Cryptocurrencies, starting with Bitcoin [8], have shaken the world of finance in less than a decade. Moving from a pipe dream idea to an every day reality in the meantime. At the time of writing the total market capitalisation of BTC is around 10% of the market capitalisation of gold. There are many discussions on the nature of money, and assessing the relative merits of BTC vs gold as a store of value. One of the central feature for any store of value is seldom discussed though: the issue of inheritance. This is a proposal to discuss and address some technical problems linked to inheritance.

Among the mandatory properties that a store of value must have, the heritability property is a central one. On a long enough timeline the survival rate for everyone drops to zero. Transmitting wealth to the next generations is not a peripheral issue, nor one that you can dodge. The body of laws, stories and traditions about inheritance is immense. In fundamental texts like the Bible [1] or the Odyssey [7], the question of who inherits what from whom, and more generally all kinds of problems linked with succession, are major preoccupations.

The issue of inheritance is orthogonal to the actual implementation of the store of value. Society, in a very broad sense, is the tool traditionally used to transfer titles and to settle questions like: ”Who is the new king?”. Regarding material wealth, objects do not disappear when you die. These remarks no longer hold with cryptocurrencies. Indeed, one fundamental feature of crypto assets
is that no one but the owner of the appropriate keys can transfer wealth. The ownership of crypto assets amounts to the knowledge of the keys and vice versa: everyone that knows the keys is deemed to be the rightful owner of the associated assets. But by definition, and under these circumstances, one cannot actually implement his/her own succession because the knowledge of the keys disapear with their death. It appears that we are finding ourselves painted into a corner: a good crypto asset platform can only allow transfers initiated by the legitimate owner; and the owner cannot transfer anything once dead, making the succession of crypto assets seemingly impossible.

In this paper we discuss various issues linked to the inheritance of crypto assets. We propose a solution to the specific issue of acknowledging the death by the network. This acknowledgment can later be used as a trigger for succession transactions and contracts. This is the "Tales From the Crypt Protocol". This protocol respects privacy and is distributed, in the original spirit of cryptocurrencies. Many unresolved issues remain to be solved to cope with all the intricacies linked to the practice of heritage. We hope that this work will open a fruitful research activity and will inspire others to progress on this subject.

2 The issues of the inheritance of cryptocurrencies

2.1 Inheritance and crypto assets, a short review of problems to be solved

Let’s examine some issues, as well as some workarounds, raised by the issue of crypto assets inheritance. A one liner frame of the question to be addressed goes something like this: "How can my seven years old daughter inherits the content of my crypto wallet?". This is a starting point, there are many subtler subproblems. Actually the general problem of inheritance becomes more and more complex the more you consider it seriously. Let’s examine a sample of those issues, together with some tentative solutions, by increased level of complexity.

1. The first idea to solve the basic "seven years old daughter inheritance" problem is: (a) - to set up a meeting with a lawyer. (b) - To write down the wills on a document, including the appropriate private keys. (c) - To seal off the enveloppe. (d) - To hope for the best.

This natural solution presents many challenges. The more salient being that Bitcoin has been built precisely to provide trustless agreements. There is maybe nothing as opposed to this aim than having to go to see a lawyer, and having to rely on the professional integrity and competence of this lawyer. This is a poster child of all the issues linked with centralization. I am not even touching on the additional issues of anonymity, risks (for lawyers that will be targeted by wrongdoers if this practice become mainstream, for your wallets...) etc. The saying "not your keys not your
coins” sums it all. Essentially this solution reintroduces the single point of failure.

2. The second idea that may come to mind is to put all the keys on a thumbdrive, or write them down on a piece of paper, and lock them into a safe at home. It marginally improves on the previous point if you have more trust in your family. Besides the hazards that such a practice would produce if it were widely adopted, it has the following drawback: Actually my seven years old daughter is not my only heir. Let’s say I have four kids and seven nephews between whom the inheritance is to be divided. It is not as if dramas about succession, struggles within families, and communities, are a literary genre in their own right. Moreover, how can you be sure that the one opening the safe will behave correctly? It is harder to cheat with a pile of physical gold because there may be witnesses, the material has to be moved etc. With crypto assets you just have to remember a passphrase. No one can stop you from using it later. No one can delete this passphrase from your memory.

3. It is possible to be smarter and to write a smart contract that implements the succession wills. It solves the "four kids, seven nephews” problem. But it raises a new problem: how will the blockchain be aware of the death of the owner of the smart contract? This is a variant on the famous oracle problem [5]. Moreover, the heirs may not be of age to understand the technology, nor to have the legal rights to access such kind of funds. Some of the heirs may also not have wallets in the first place. If so the mechanisms by which the proper credentials could be transmitted to them, without being compromised, remain mysterious.

4. There is another issue: what if the four kids and the seven nephews die with the one they are supposed to inherit from? Let’s say, for instance, that they all disappear simultaneously in a plane crash. It is not possible to re-write the smart contract. The heritage disappears (more precisely it becomes inaccessible) in such a scenario. In real life there are specific laws and legal practices to deal with such kind of situation.

5. A rather simple solution is to set up an equivalent of a time capsule. If a date is chosen sufficiently far enough in the future, then the death of the capsule owner becomes a certain event. It can be done via smart contracts that just have to wait until some block number is reached in the blockchain before being executed. The drawbacks lie in the lack of flexibility and the necessary approximation of the time of death. A middle-aged victim of a traffic accident could potentially lead to a succession process stalled for more than half a century. Moreover, the probability that the potential beneficiaries of the inheritance may have died too in the meantime increases.

6. An improvement over the previous idea is to use a dead man’s switch. Instead of using the maximum age plus a safety margin for the time capsule
deadline, it is possible to use a shorter frame. If necessary one has just to edit the time capsule deadline before it is executed. Of course the death of the time capsule owner stops this process of reprogramming, and the time capsule is eventually delivered. It, partially, solves the issue of the lag between death and succession. On the other hand it requires a constant vigilance and work.

7. Everyone is going to die but we hope it will be as last as possible. Life expectancy has improved a lot lately. From a practical point of view it is a very challenging aspect of succession to manage. It is very difficult to anticipate the technological environment in a few decades. However, a credible proposal for succession must be resistant to the future. It suggests that any solution should be integrated within the crypto platform itself rather than relying on outsourced processes.

2.2 Existing solutions review

- Sarcophagus [2] is a dead man switch implementation that is blockchain-enabled. It is resistant to censorship and immutable. It is done by the combination of Arweave [10] for a permanent storage of data, and Ethereum to support the ERC20 Sarco Token. This token is used to pay so called archeologists which are in charge of releasing the data (essentially an encrypted file) to the person of interest. The user have to select one or more existing archeologists. The archeologist public key is used as an outer layer of encryption. This outer layer has to be rewrapped at predefined dates in the future. If one date expires then the archeologist decrypts the outer layer. The inner layer is the data encrypted with the public key of the final receiver that can decrypt it.

- Ternoa [4] is a french start-up that proposes a "death protocol" which is basically a smart contract triggered by the API’s of local authorities registering deaths. It presents the problem of being a centralised solution. One issue is that it is easier to hack the local authorities database (or to bribe agents working for this agency) than to break a distributed solution relying on crypto technologies. Another issue is that there is no standard API to deal with this issue that is shared amongst countries. Each solution is limited to one nation-state at best. Finally there is no warantee that the API are not going to change in the future.

- Casa [3] is a company that proposes solutions based on mutli-signature schemes. Their primary service is to provide better resiliency for crypto wallets. They also have an inheritance product that is basically a technological implementation of the second bullet point examined in section 2.1.
3 The Tales From the Crypt Protocol

The Tales From the Crypt Protocol (TFCP in the rest of this document) is a distributed, privacy preserving, uncensorable, open protocol designed to produce a consensus mechanism linked to the death of a physical person. The TFCP could be incorporated into arbitrary blockchains, modulo the governance peculiarities of the considered blockchains.

We propose to introduce new kind of transactions that follow specific rules. This proposition is justified by the following motivations and interests:

- Everyone is going to die eventually. Therefore, it makes sense to consider a special case for such an event. Maybe you are never going to make crypto transactions, but what is clear is that one day you are going to die.

- The death happens only once.

- There is no universally standardized service or norms for death registration. Every country has its own administrative processes.

- It is relatively easy to hack hospitals or morgues IT systems. There are many entry points, and many levels at which the system can be compromised. To have a truly decentralized mechanism to acknowledge the death makes the system more resilient to fraud. The aim is to build a consensus mechanism for this specific event akin the distributed consensus on a public ledger.

- Inheritance transactions fundamentally differ from usual transactions because, by definition, they cannot be performed by the owner of the account since they are performed after his/her death. In most cases this event cannot be forecasted precisely.

- Adding a special case for inheritance transactions opens the possibility to make existing cryptocurrencies able to evolve and integrate them. How this integration can take place depends on the specifics of the governance of the considered crypto platform.

3.1 TFCP scheme

In this section we describe the TFCP without going into technical details. We focus on the general ideas and rationale behind the protocol. The TFCP involves two sets of actors, Registrars and Witnesses. This is a fundamental mechanism to provide privacy properties. The TFCP also relies on adversarial incentives (rewards and penalties) to prevent bad actors from interfering with the desired behavior of the protocol. Heritage details are not considered in TFCP. The sole purpose of the TFCP is to provide a signal that is equivalent to the recognition of the death of the Donor by the network. We say that the Acknowledgment has been enacted by the network.
3.1.1 Definition of terms and concepts used in the TFCP

Let’s start by introducing the actors considered. Here we identify persons with the secret key of an account, and with the account itself. We are using the term ”account” to denote both the physical person, the private keys, and the associated wallet. When necessary, the distinction between the physical person, the private keys and an the associated wallet is explicitly stated.

- The **Donor** is the account of the physical person for which the network has to enact the death **Acknowledgment**.

- The **Security Deposit** is the account used to signal the death of the **Donor**. The **Donor** has the key of this account.

- The **Witnesses** is the set of accounts that testify on the death of the **Donor**.

- The **Registrars** is the set of accounts that provide public keys and are operative to share secrets.

Let’s follow by the definition of values and terms that play a special role in TFCP.

- The **Threshold** is the amount of coins that has to be stacked on the **Security Deposit** account by the **Witnesses** to signal the death of the **Donor**.

- The **Wills** is a document that contains the link between the **Donor**, the **Announcement** and the **Security Deposit**. Those links are not public, they are encrypted using a shared key between **Registrars**. It is signed by the **Security Deposit**.

- The **pre-Wills** is very similar to the **Wills** document. Both can be considered equivalent at this level of abstraction. **pre-Wills** are published to recruit **Registrars**. Once the recruitment, and some checks, are done **pre-Wills** are transformed into **Wills** (mainly by stripping away technical informations), and published. Both the **pre-Wills** and the **Wills** are signed by the **Security Deposit**.

- The **Announcement** is a public document that contains the social security name of the **Donor**, the **Fees** to be distributed to the **Witnesses**, the **Threshold**, the **Deliberation Time** and the address of the **Security Deposit** account.

- The **Ante** is the amount of coins that a **Witness** has transferred to the **Security Deposit** to signal the death of a **Donor**.

- The **Shares** are the share of a secret share scheme that is used by the **Donor** to multi-encrypt the **Wills**.
• The Fees are the rewards for the participation of both the Registrars (specified in the Wills) and the Witnesses (specified in the Announcement).

• The Bail is the amount of coins that Registrars have to stake on a special account. They are there to insure that Registrars are executing the protocol in a fair way.

• The Deliberation Time is the amount of time during which the Wills account remains locked after the Threshold has been reached.

• The Acknowledgment is the reckoning of the death of the Donor by the network.

The schematical use case, if everything goes as planned, unfolds as follows:

1. The Donor selects a set of Registrars.
2. The Donor publishes the pre-Wills under the identity of the Security Deposit.
3. The interested Registrars check the validity of the published documents. They can accept the Donor’s request by publishing their acceptance or decline (by doing nothing).
4. Once enough Registrars have accepted, the Donor sends a Share of a secret key to each interested Registrar.
5. The Donor encrypts the Wills with the shared key of step (4). The Wills are published under the Security Deposit identity.
6. The Donor publishes the Announcement under the Security Deposit identity.
7. When the Donor dies, the Witnesses transfer coins to the Security Deposit account.
8. When the Threshold is reached on the Security Deposit account, the process of acting the death Acknowledgment by the network is initiated. Two cases: either there is a move from the Donor’s account before the Deliberation Time has elapsed or not.
(a) If there is no move.
   i. The Registrars decrypt the Wills. A public version of the Wills is published by the Registrars.
   ii. The Donor’s death Acknowledgment is acted by the network.
   iii. The Fees are transferred to the Registrars and Witnesses following what has been specified both in the Announcement and the Wills. Then, the heritage transfers are done (typically via the execution of smartcontracts), details of which are not in the scope of this paper.
(b) If there is a move. Then, the **Donor** is alive and the **Acknowledgment** cannot be acted by the network. It becomes possible to make moves from the **Security deposit**. The **Donor** may initiate a new instance of TFCP.

Some remarks regarding this protocol:

- The **pre-Wills** contain enough information so that only the **Donor** can produce the **Wills**. It is a bit tricky because at the publishing time of the **pre-Wills** it is not possible to check this link. It becomes possible once enough **Registrars** have accepted and were given a share of the secret key.

- There is nothing preventing the **Donor** to set up as many instances of TFCP’s as desired. Since any TFCP has public partis, the **Announcement** and the **Wills**, it is easy to find the most recent one. It will be the only one considered valid. It makes possible to have several versions of the **Wills**. It implies that a fixed fraction of the **Fees** for the **Registrars** has to be payed immediately, in order to deter useless TFCP instances and unpaid work for the **Registrars** (since all but one TFCP is going to be completed). It could be done via the **Security Deposit** account of the appropriate TFCP instance.

### 3.2 Expected Properties of TFCP

The TFCP does not solve all the issues discussed in section 2. Though, it is expected to have the following good properties:

1. Distributed Oracle: the only requirement for **Witnesses** is the amount of **Ante** they are going to transfer to the **Security Deposit**. It ensures a maximally distributed system. There is no special person or organisation. It is a completely open process. Likewise there are no special requirements for **Registrars**, apart from the **Bail** they have to provide and stack. It is essentially the same kind of requirements than the ones required for the **Witnesses**. Though it is more significant in volume, and unlike **Witnesses** there is less/no freedom in the volume chosen. It is also supposedly for longer time period. **Witnesses** are refunded after the completion of the TFCP instance they are participating in while **Registrars** are not refunded immediately.

2. Anonymity: If all actors are honest but curious they can’t link the **Security Deposit** to the corresponding **Donor**’s account before the **Acknowledgment** is enacted by the network: the **pre-Wills** doesn’t contain enough information. **Registrars** can make this link if they cooperate after the publication of the **Wills**. It is possible to add an extra layer to build an equivalent of a mix network to jam this track. Basically **Registrars** can act as mixes in a mix-network so that it is not possible
to directly trace back the path between the Donor and the Announcement. Something like the Monero can also be considered. Such a kind of solutions introduce costs and complexities at many levels: trade-offs have to be considered on a case by case basis.

3. Blockchain agnostism: in principle the TFCP can be adapted to any crypto platform. As discussed at the beginning of section 3, death is an exception that eventually occurs exactly once for every human. It is not unreasonable to integrate such kind of exceptions in every crypto platform.

3.3 Discussion on the incentive structure

The basic incentive structure of TFCP relies on the following pair of adversarial incentives:

- Positive incentives: the Fees for Registrars and Witnesses.
- Negative incentives: the Ante and the Bails respectively stacked by the Witnesses and the Registrars. The difference between the two being that the Ante are a one-time thing. Moreover, the time horizon for the staking of the Ante is much shorter than the one for the Bails. Typically the Deliberation Time gives an idea of how long the Ante will be freezed on the Security Deposit. The duration of the Bails could be chosen by the market: when the Donor is chosing a set of Registrars he can choose the Registrars with a sufficiently remote published date on their Bails.

The delay and precise circumstances to adjudicate the enforcement of the negative incentives have to be tested in order to discover the best trade-offs. Here are some ideas related to these issues:

- Alice could create an essentially empty wallet, be minimally active, and transmit the secret key this shallow account to Bob. Then Alice can behave as a Donor and set up a TFCP instance. When Alice dies, Bob can make a move on Alice’s Security Deposit account. The TFCP protocol is halted and Bob can take control of the Security Deposit account. Notice that Alice has to actually die for this attack to work because no one can force any Witnesses to transfer any Ante to the Security Deposit.

As the name of the Donor will be made public it will tarnish his reputation. Another factor that may limit this type of attack is to consider the Ante as a bet on honesty: the appropriate odds will be ultimately set by the market. A null Deliberation Time would render this attack impossible, but at the cost of losing the adjudication period.

- A very wealthy Witness, or a flash loan attacker [9], could, all alone, trigger the Heritage by transferring an Ante as large as the Threshold to
the **Security Deposit**. The attacker would like to obtain the **Fees**. One way to circumvent this attack is to require that \( x > 1 \) separate transactions have to be done over a sufficiently long span of time (otherwise the wealthy attacker could set up multiple accounts) in order for the TFCP to be valid. Typically something to the order of the **Deliberation Time**. Having a non 0 **Deliberation Time** introduces the risk (from the attacker point of view) of losing the **Ante**. One circumstance where it could be dangerous is if the **Donor** cannot access to his/her account (because of illness or whatever peculiar situation) during the **Deliberation Time**.

### 4 TFCP technical specifications

As a first approximation all public documents are published on the blockchain (or a commitment mechanism has to be set up). Every public document is signed with the keys of the publishing account. This account pays the fees of publication.

#### 4.1 Registrars

To be registered as a **Registrar**, an account has to commit itself to stack a given amount of coin on a **Bail** account. Moreover, the **Registrar** has to declare for how long the **Bail** is due. Precise amount and minimal bailing time are determined through the governance of the considered blockchain. Typically **Registrars** will be institutions since their life expectancy can be longer than human’s one. There is a kind of chicken and egg situation: **Registrars** may be forced to bequeath their portfolio. This is a special case of inheritance (because **Registrars** are not required to die), and each crypto platform have to adopt the suitable policies to implement solution to this issue.

#### 4.2 Wills

The **pre-Wills** are published by the **Security Deposit** and contain at least:

- The **Donor**’s account address encrypted using a shared secret \( s \) a key.
- The **Security Deposit**’s account address.
- The number \( n \) of **Shares** needed to compute the shared key \( s \).
- A list \( \{R_i\} \) \( 1 \leq i \leq m \), with \( n > m \), of acceptable **Registrars**. This is optional. If there is no list specified, then any **Registrar** can apply to certify the **Wills**.
- The **Fee** for the **Registrars**.
- The **Donor**’s signature of the hash of the **Wills**.
Notice that the Donor’s signature cannot be checked by the Registrars when they receive the pre-Wills. Only the signature of the pre-Wills by the Security Deposit account can be checked. The validity of the Donor’s signature can be checked once the Acknowledgment has been acted by the network.

The difference between the pre-Wills and the Wills is that the list of acceptable Registrars is not part of the Wills.

4.3 Announcement

The Announcement is a public document. It is signed by the Security Deposit. The Announcement contains:

- The civil name of the Donnee and enough additional information to be identified in the real life. It may include, but is not restricted to: birth date, birth place, middle names, social security number etc.

- The reference to the Wills. Typically the bloc number on which the Wills have been published.

- The Security Deposit address on the blockchain.

- The Fees for the Witnesses.

- The Deliberation Time.

5 Conclusion

In this paper are presented some ideas to tackle with the issue of inheritance. It is focussed on a distributed way to initiate the heritage process. The TFCP is agnostic with relation to the crypto platform considered. How to integrate it and technical details are issues of governance of interest. THCP introduces special kind of transactions and procedures. THCP doesn’t require any kind off rollback, the Security Deposit is playing the role of a backup account if there were problems (misinformation or hacking attempts). The TFCP respects privacy until the death of the Donor. Unless Witnesses conspire there is no way to link the publicly known information, ie the name of a Donor, to the actual Donor account. This link will appear after the death has been acknowledged by the network. It is possible, using a Mix-net kind of idea [4], to reach some type of anonymity at the expense of simplicity.

5.1 Open questions

There remains many unsolved challenges with relation to the inheritance of crypto assets. We list a few of them hoping that they will be tackled by some of the readers.
• Can Registrars resell/transfer their accepted tasks? Hopefully the inheritance is set to be triggered a long time ahead. What happens if Registrars have died (filed for bankruptcy) in the meantime?

• Shall a market for Registrars actions be made? For instance we could decide that the first ones to decrypt the Wills get more rewards than the remaining ones in order to accelerate the process.

• Transferring credentials to the next generations: heirs can be too young to understand how crypto assets work. What happens before they come of age? How are the credentials stored and safely delivered when majority (or the suitable time) has come? Many real life scenarios have to deal with such considerations.

• The heirs are not precisely known in advance. Think at the holiday travel accident scenario during which a whole family is victim for instance. Is it possible to delay the triggering of the heritage until some form of resolution has been settled?

The right tuning of the incentive structure (importance of the Fees, average acceptable Deliberation Time etc.) is going to be found via market mechanisms and progressively discovered through use. It can hardly be anticipated before being tested in real life and at large scale.

References


