LocalChains:
A Decentralized Ledger with a tiny global state

Orfeas Stefanos Thyfronitis Litos and Aggelos Kiayias

University of Edinburgh
o.thyfronitis@ed.ac.uk, akiayias@inf.ed.ac.uk

Abstract.

1 Introduction

2 Transaction DAGs

There exists a genesis transaction that contains all coins to ever exist. This transaction is hardcoded in the protocol and is by definition *valid* and *trustworthy* for all nodes.

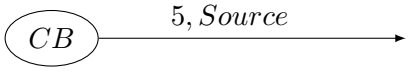

Fig. 1: Coinbase transaction

All other transactions must have the following attributes to be valid:

- Inputs that correspond to valid unspent outputs (UTXOs) of previous transactions.
- Outputs that have a total value that is less than or equal to the total value of the inputs, with a public key corresponding to each output. Each public key can exist only once in the valid and trustworthy DAG of a node[1].
- One signature for each input, made with the private key that corresponds to the public key of the corresponding previous output.

At any point in time, *Alice* considers a DAG X of transactions as *valid* and *trustworthy*. She may be informed by Charlie about the existence of another DAG of transactions, Y. To consider this DAG valid, *Alice* must verify that

[1] This is to ensure that a transaction input cannot be connected with two different transaction outputs. It is not entirely clear that this limitation is necessary though.

– all the transactions in Y are valid and
– all root transactions of Y are connected to UTXOs in X.

We will later see what course of action she is expected to take in case the second requirement does not hold.

For example, let X be:

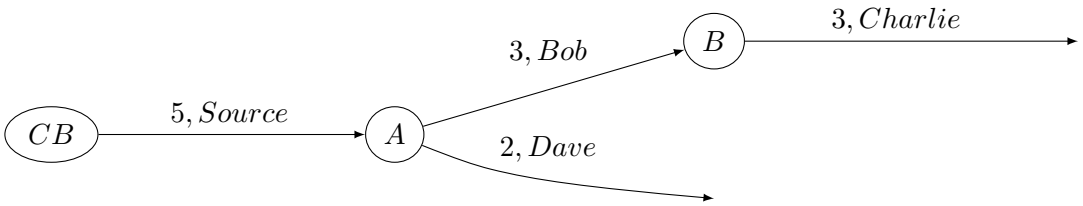

Fig. 2: Base DAG X

Then *Alice* would consider Y_1 valid, but Y_2 invalid:

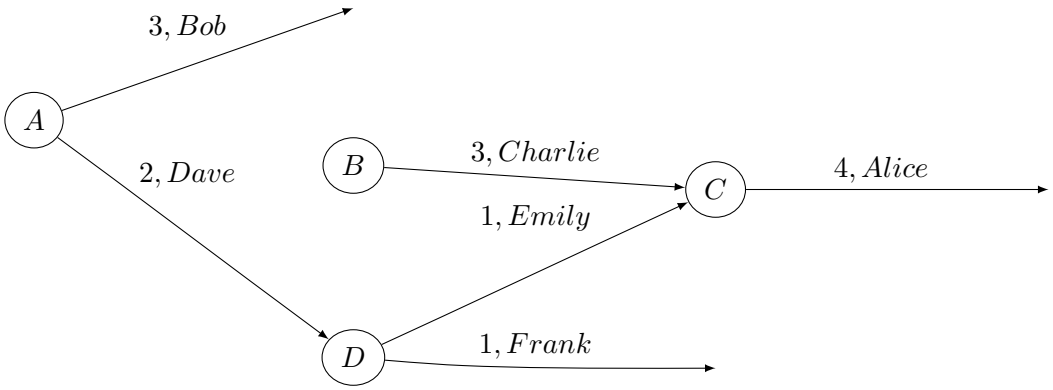

Fig. 3: Good DAG Y_1

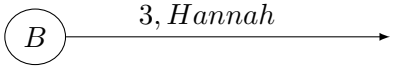

Fig. 4: Bad DAG Y_2

X and Y_2 cannot be valid at the same time because there is a conflict regarding which private key can spend the output of the transaction B.

The existence of the two versions of the transaction B is proof that *Bob* attempted to double spend his output from transaction A. *Alice* and *Charlie* just discovered a proof of fraud commited by *Bob* and can use this proof of fraud so that one of the two can keep the coins in the transaction DAG and the other can get a refund from the network. Here is where the global part of the infrastructure comes into play.

3 Global Trust Ledger

Observe that in the previous example, it was never said that *Alice* thinks that Y_1 is *trustworthy*; *Alice* only perceives Y_1 as *valid*. The lack of a global transaction ledger makes it possible that *Charlie*, *Dave* or *Emily* have double spent the new transactions *Alice* learned about, thus *Alice* has no reason to assume that she exclusively owns the coins at the output of transaction C. In order to be insured in case a previous transaction has been double spent, there has to be some kind of global, public commitment from each of the players in question (or someone vouching for them) that a refund will be given in case fraud is committed.

The global ledger consists of a directed graph of refund promises between players in case fraud is committed. In order for *Alice* to be insured against the double spend of a transaction that lies before a UTXO she can spend, there must be a sufficiently heavy chain of insurances between her and each of the players that spent these preceding transactions. The following examples clarify the concept with regards to the trustworthiness of Y_1:

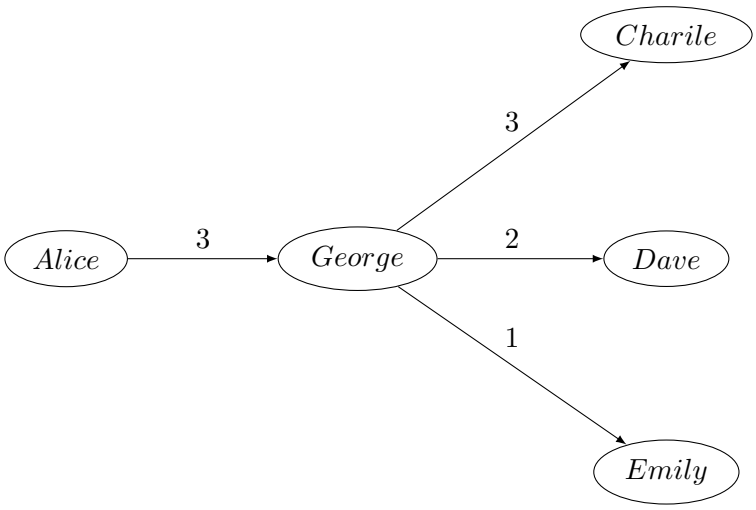

Fig. 5: Trust graph that insures *Alice* from Y_1

In this example, if any of *Charlie*, *Dave* or *Emily* double spend their money and *Alice* finds out, then she will post the proof of fraud to the global ledger and *George* will automatically refund her with the money that he is insuring the fraudster. Observe that there is enough insurance to cover for any individual fraud.

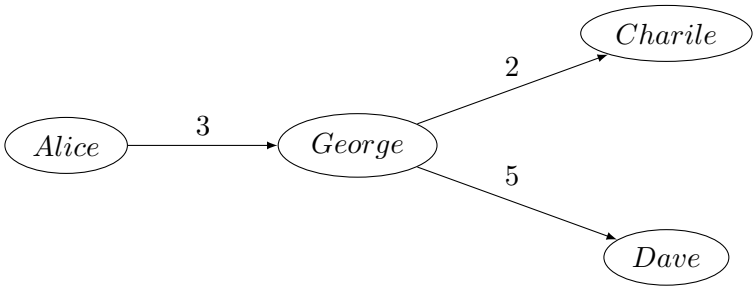

Fig. 6: Trust graph that does not insure *Alice* from Y_1

In this case however, *Alice* stands entirely uninsured against fraud by *Emily* and only partly against fraud by *Charlie*. She is well insured against fraud by *Dave*.

4 Formal Definitions

Definition 1 (Trustworthy Transaction). *Assume a transaction A spent by Bob is accepted by Alice as valid and she includes it in her transaction DAG. This transaction precedes a transaction B that pays to Alice's address. Let v be the value that Alice can lose from B if A is double spent. Alice deems A trustworthy if $maxFlow\,(Alice, Bob) \geq v$ on the global trust ledger.*