FORMALIZING THE HASHGRAPH GOSSIP PROTOCOL

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Distributed shared ledger

- Consensus total order on “transactions”
  - No central authority
  - No reversal of transactions
- Applications:
  - Cryptocurrencies
  - Smart contracts
  - Digital property
  - Gaming

Scaling problem

- Bitcoin can handle ≈ 7 transactions/second.
- Ethereum can handle ≈ 15 tps.
- Paypal can handle ≈ 450 tps
- Visa can handle 56k tps (claimed)

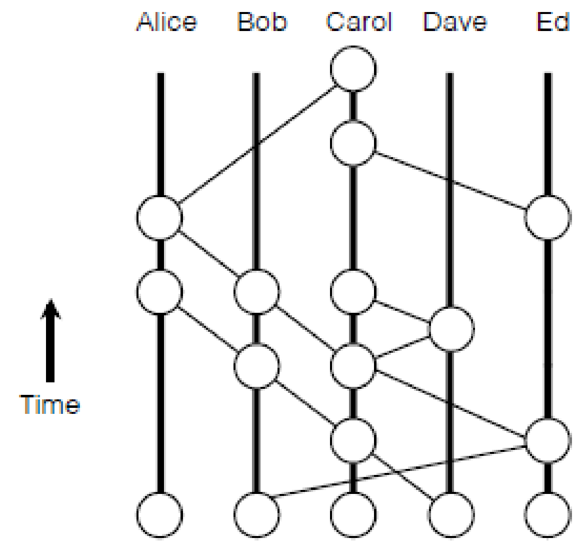
- Proof-of-work is secure **because** it is slow.
  - To serve as a general currency, we need a completely different technology.

Byzantine consensus

- Get participants to agree on something
- Up to 1/3 can break the rules
- Solved in theory in 1982 [Lamport, *et al.*]
  - Impractical: voting rounds require lots of messages

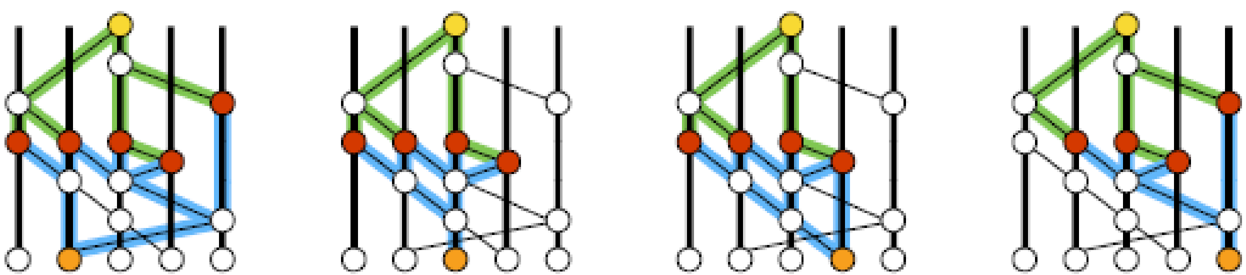
Hashgraph [Baird 2016]

- First practical algorithm
  - No proof-of-work
  - No voting messages
- Based on a gossip protocol:
  - Create *event* when receiving a message
    - Attach a payload of transactions
  - Track who talks to whom, in what order
  - Conduct a *virtual election*
    - Each event's vote is determined by its ancestry
    - Gossip allows each participant can carry out the election independently
  - Agree on a total order on network events



Hedera Hashgraph

- A distributed leger / cryptocurrency based on Hashgraph
- Gossip protocol's overhead is very low:
  - Don't send any messages you wouldn't send anyway
  - Add a gossip payload to each message
- Throughput ≈ 10k-500k tps (in experiments)



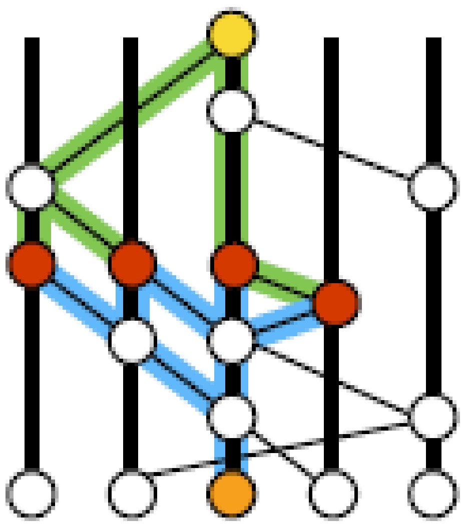
(a) (b) (c) (d)

Honest peers

- Never create a fork
  - X and Y are a *fork* if they have the same creator, and neither is an ancestor of the other
- An honest peer’s events are linearly ordered
- Over 2/3 are honest

Strongly seeing

- X *sees* Y if:
  - (1) X is a descendant of Y
  - (2) a technical condition holds, such that no event can see both sides of a fork
- X *strongly sees* Y if:
  - there exists a set of peers P such that:
    - (1) P contains over 2/3 of the peers
    - (2) for every Z in P
      - X is a descendant of Z
      - Z sees Y



Strongly-seeing lemma

- If X and X' are a fork, they cannot both be strongly seen, even by different events
- Proof
  - Suppose Y strongly-sees X, and Z strongly-sees X'
  - Let P and P' be the corresponding sets of peers
    - Then there exists at least one honest peer in P ∩ P'
  - Let V and W be the mediating events on that honest peer
    - Then V and W are linearly ordered
    - Without loss of generality, assume V is an ancestor of W
  - Thus W sees X' (directly) and X (through V)
  - That can't happen

Witnesses

- Break events into *rounds*
- Each peer's first inhabitant in a round is called a *witness*
- Advance to a new round when you can strongly-see 2/3 of the previous round's witnesses

- Cheaters can have multiple witnesses per round
  - But – by the lemma – at most one can be strongly seen
  - The extra witnesses are irrelevant

Famous witnesses

- An event enters the consensus order when “most” peers can see it
  - Can’t say *all* peers, because some might not be talking
  - You can’t know if silent peers have seen it or not
- Use *famous witnesses*
- A witness is *famous* if most later witnesses can see it
  - Use virtual voting to determine
- Since it’s famous, nearly everyone knows about it
  - (In particular, what it can see)
- An event enters the consensus order the first round in which every famous witness is a descendent

Verification

- Formalized correctness proof using Coq.
  - (Popular proof assistant developed in France.)
- 13k lines of Coq
- Gives 100% confidence that the algorithm works, barring some flaw in the model or in Coq.
  - (Extremely unlikely.)

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(* Lemma 5.12 *)
Lemma strongly_seeing :
  forall W x y v w,
    member W v
    -> member W w
    -> fork x y
    -> stsees x v
    -> stsees y w
    -> False.
Proof.
intros W x y v w Wv Ww Hfork Hssx Hssy.
destruct Hssx as (v' & Hv & Hmajx).
destruct Hssy as (w' & Hw & Hmajy).
so (supermajority_intersect_3 _#5 eq_peer_decide supermajority_honest Hmajx Hmajy) as (a & Hhonest &
 Hseesx & Hseesy).
destruct Hseesx as (q & Hcrq & Hxq & Hqv').
```

Ongoing and future work

- Verify the algorithm that is actually implemented.
- Verify the Hashgraph software.
  - First, develop the machinery to make it possible.

Thank you