A Decentralized Blockchain with High Throughput and Fast Confirmation

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An Ideal Blockchain System

- **Robustness**
  - *Safety* against double spending attacks
  - *Liveness* against denial of service attacks

- **Performance**
  - High *throughput*
  - Fast *confirmation*

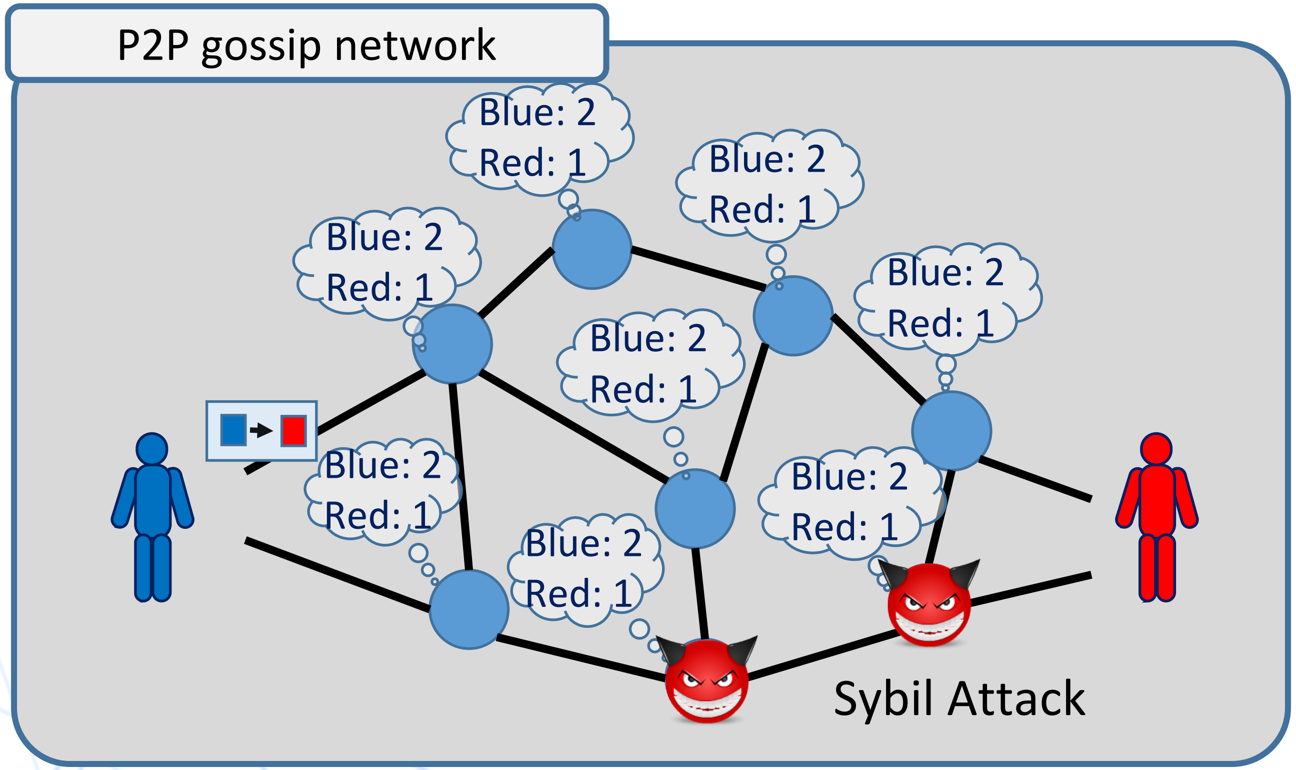
- **Decentralization**
  - *Scale* to large amount of participants
  - *Permissionless* to join and leave

Blockchain Performance Problem

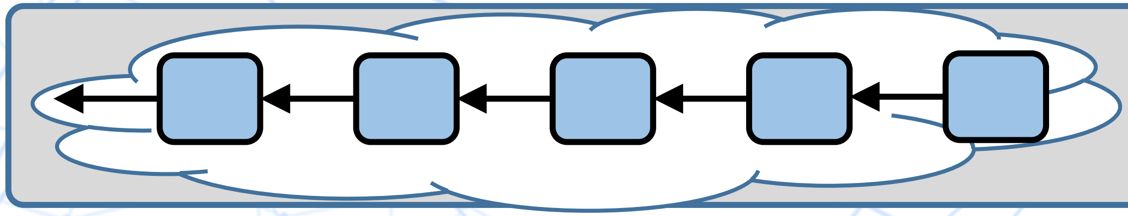
Transactions per Second:	~7	~30	~200	~3000
Confirmation Latency:	1 hour	7~10 minutes	Few seconds	Few seconds

Undesirable user experience, long processing delay, and skyrocketing transaction fees!

Bitcoin and Ethereum Background



Secured by
“Proof-of-Work”

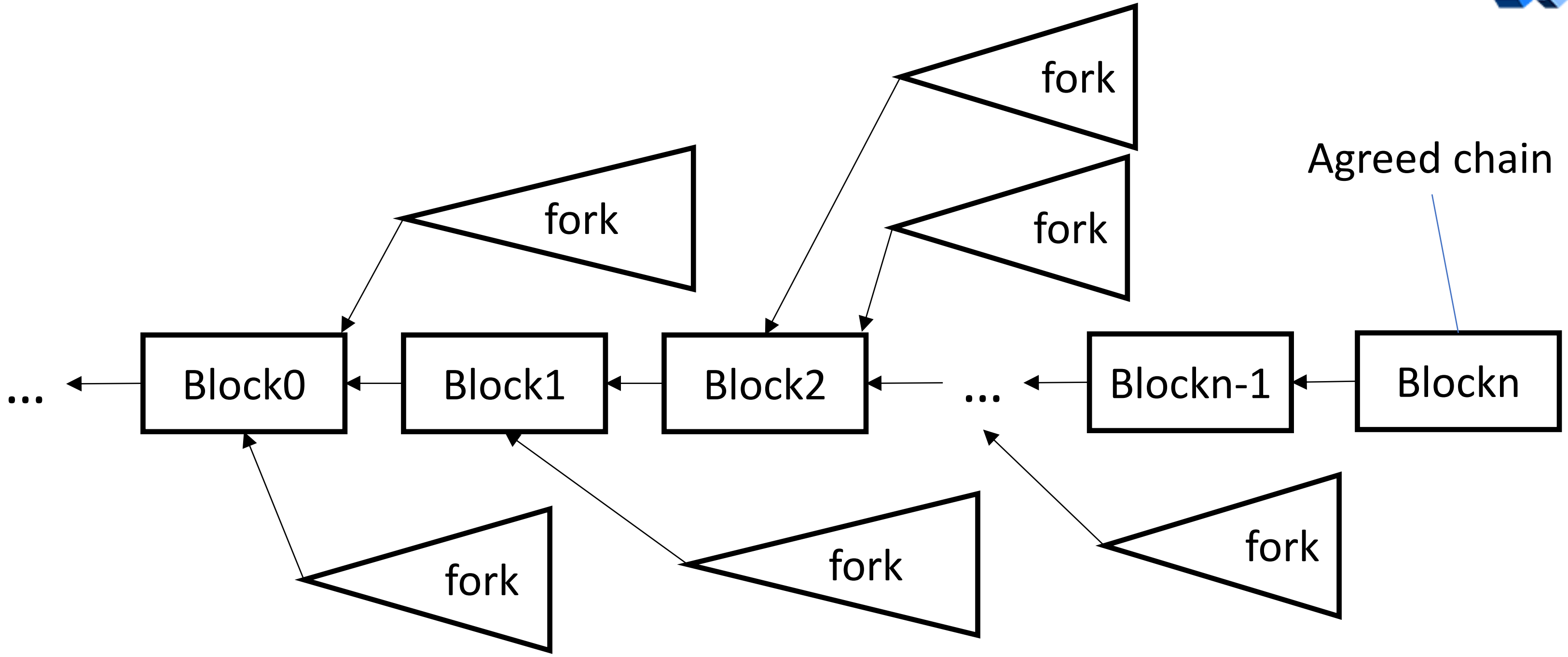


The Blockchain:
A record of transactions

Standard Nakamoto Consensus

- **Longest-chain**: all participants agree on the longest chain as the valid transaction history
  - Security assumption is >50% computation power owned by honest nodes.
- **Slow/small** block generation
  - Bitcoin: 1MB block per 10 minutes
  - Ethereum: ~100KB block per 15 seconds

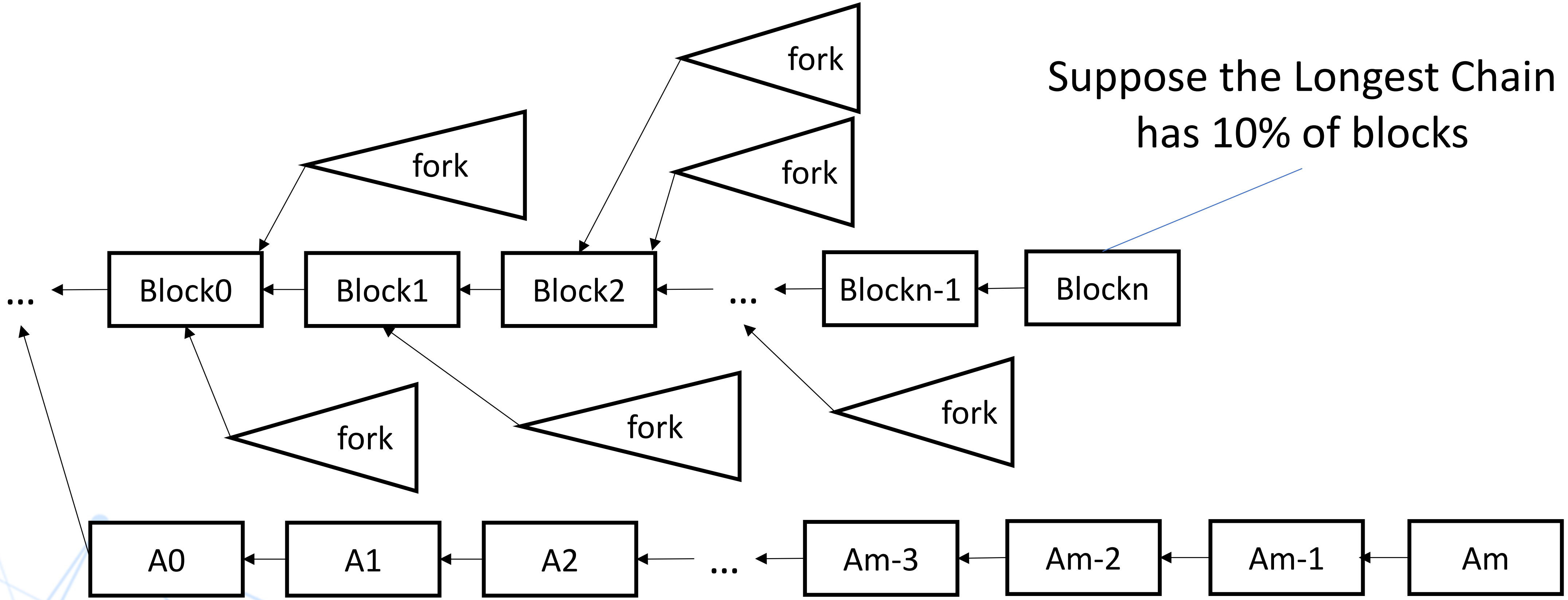
What if we run Nakamoto Consensus with **large** blocks or **fast** generation?



- Mining are concurrent and block broadcast has delay
- Larger block size/faster block-gen rate -> more forks

- Forks waste network/processing resources
- Downgrade safety

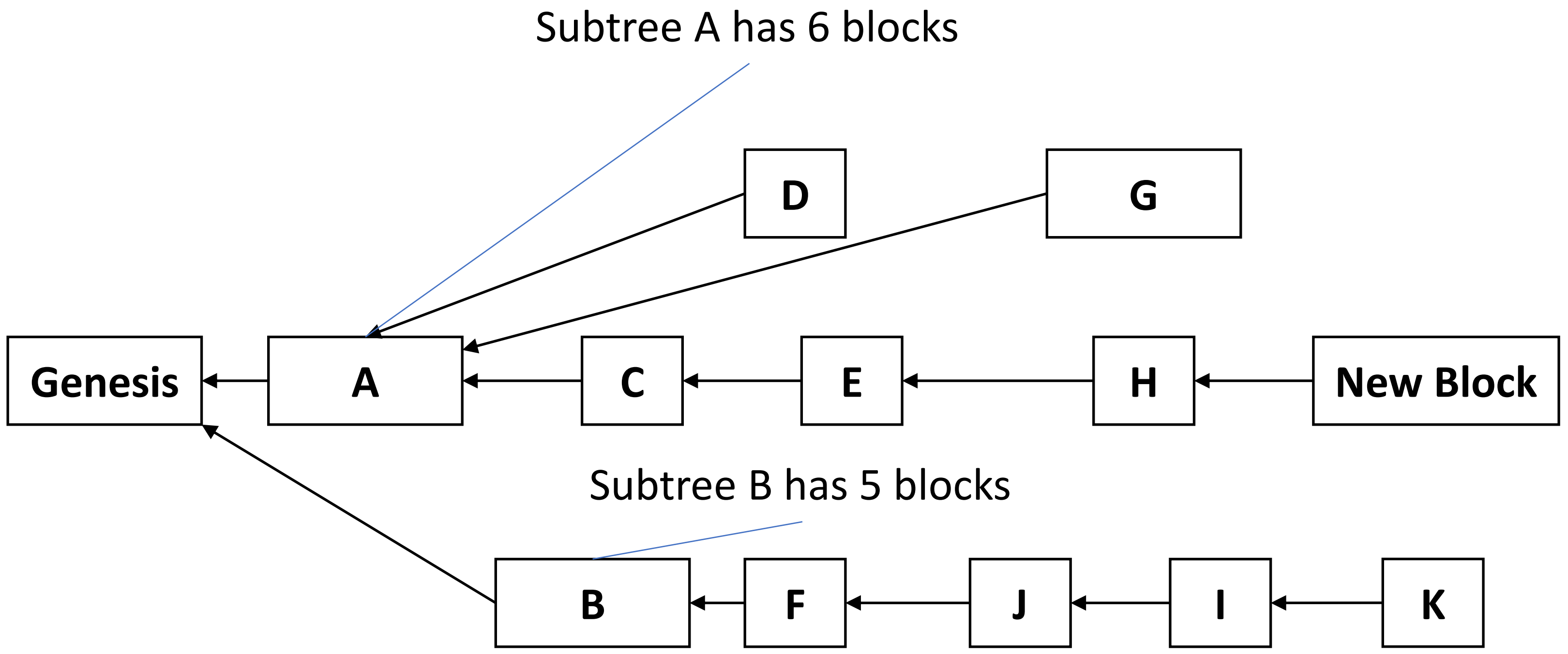
Longest Chain is **Not Safe** with Fast Generation



Attacker with more than 10% computation power
will be able to revert the longest chain

GHOST Consensus

- Proposed by Sompolinsky et. al., ICFCDS’15, adopted partially by Ethereum
- Heaviest subtree rule
- Start from the Genesis block
- Iteratively advance to the child block with the largest subtree



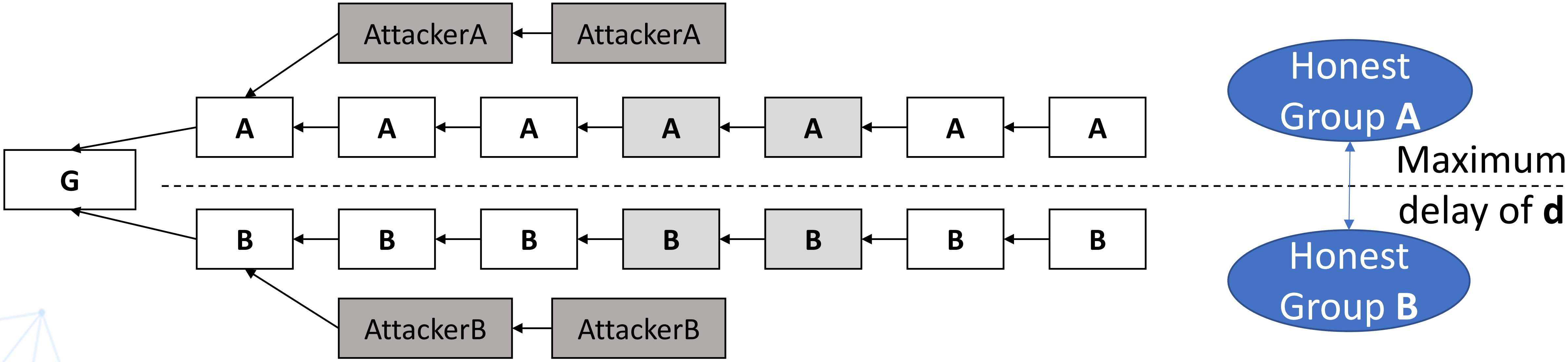
GHOST Rule:

1. Start from the Genesis block

2. Iteratively advance to the child block with the largest subtree

All the blocks including forked blocks contribute to the chain selection

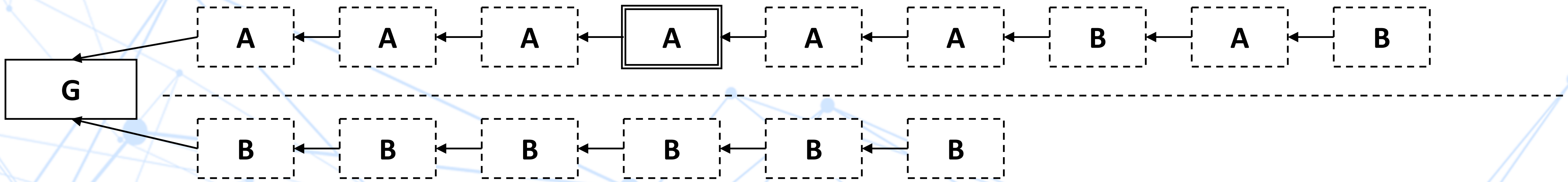
GHOST is Weak to Liveness Attacks



- When the block generation is much faster than **d**, an attacker with little computation power can stall the consensus forever!

One Fix: Structured GHOST Approach

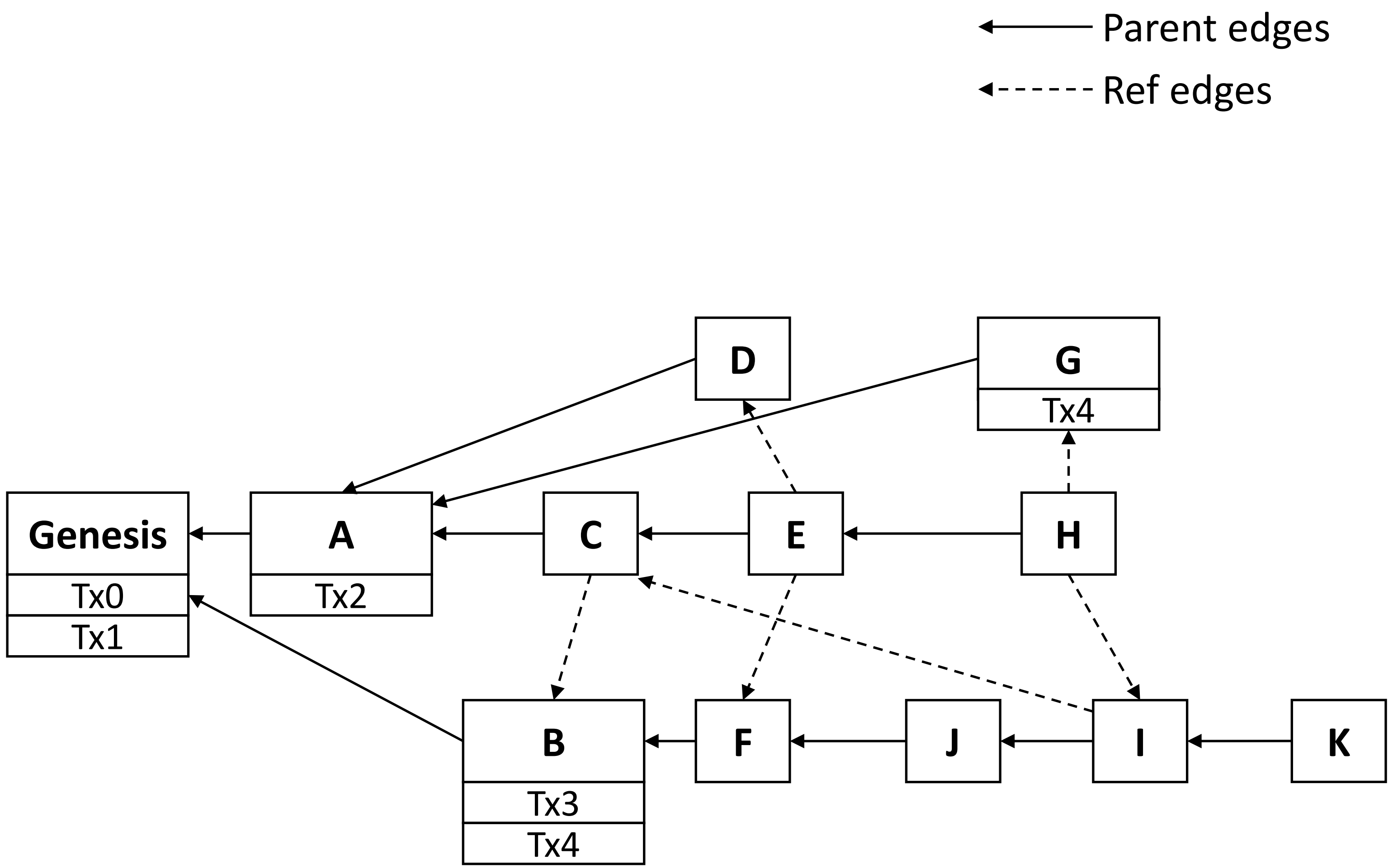
- Only **1/h** of blocks have weights for chain selection
  - Remaining blocks only contribute transactions
- Secure against liveness attacks if **h is large enough**
  - Because concurrent generation of weighted blocks is rare
- Cons: Slow confirmation!
  - Need to wait for enough weighted blocks being generated to confirm



Greedy Heaviest Adaptive SubTree (GHAST)

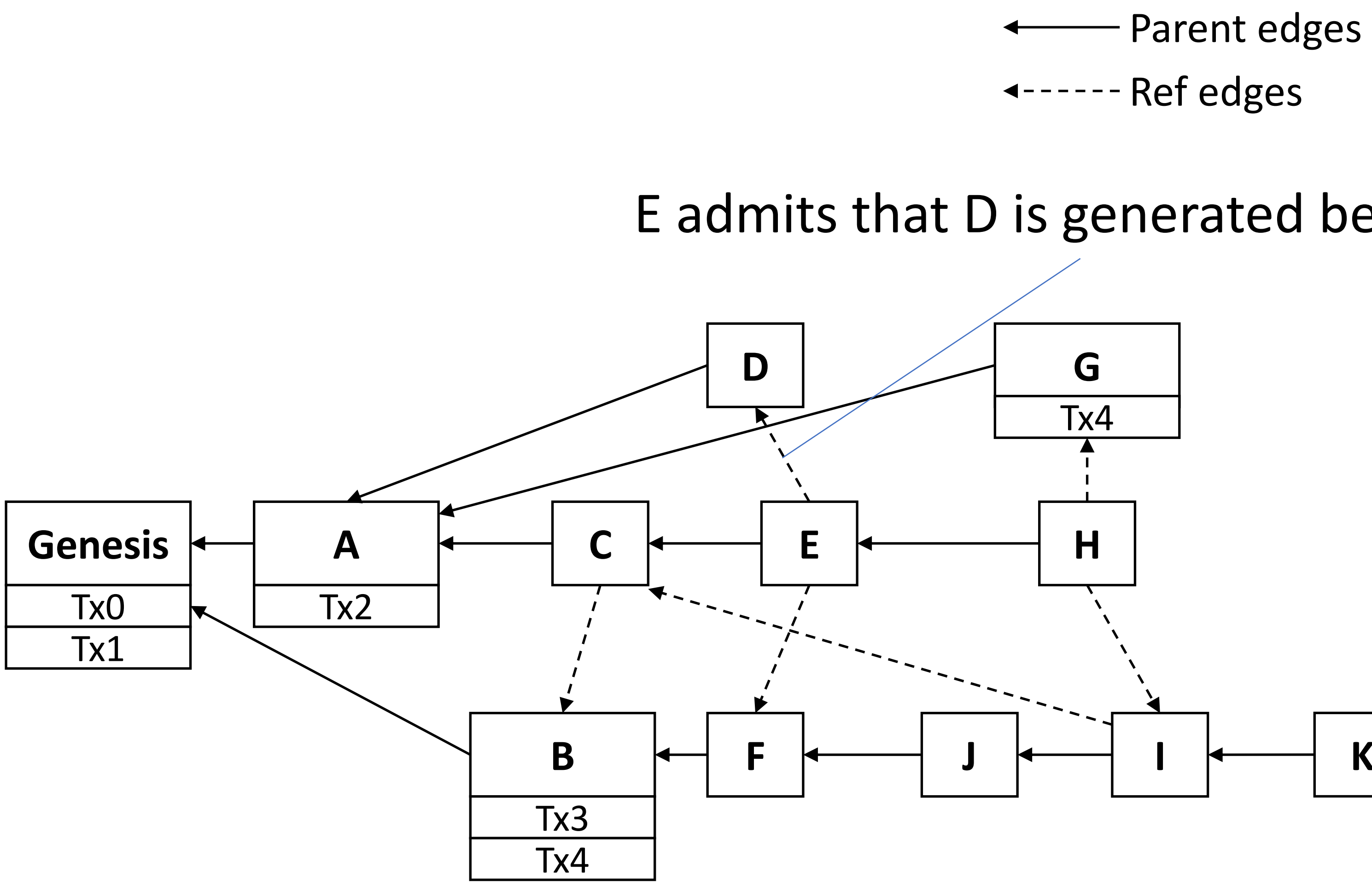
- Assign different weights to generated blocks
- Select **pivot chain** using heaviest subtree rule and decide total order of all blocks based on the pivot chain.
- In normal scenarios, assign **equal** weights to all blocks
  - Operate like GHOST
  - Achieve near optimal throughput and confirmation latency
- When attack happens, assign **high weights** to a **small subset** of blocks
  - Operate like structured GHOST
  - Slow confirmation to ensure consensus progress

How to make honest participants **automatically** switch between two scenarios?



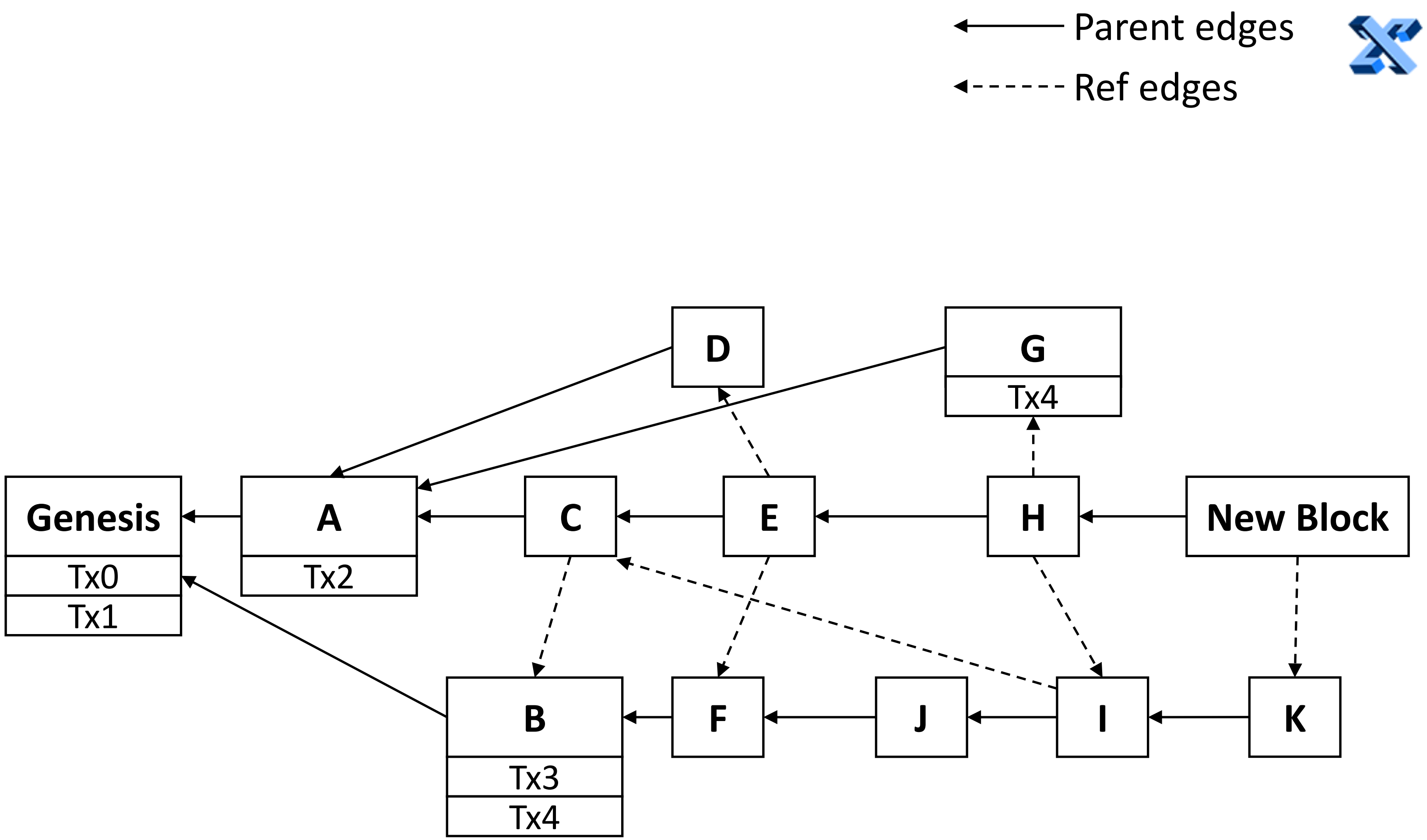
Conflux operates with a **Tree-Graph** structure.

Each block has one **parent edge.**



Each block may have multiple **reference edges**

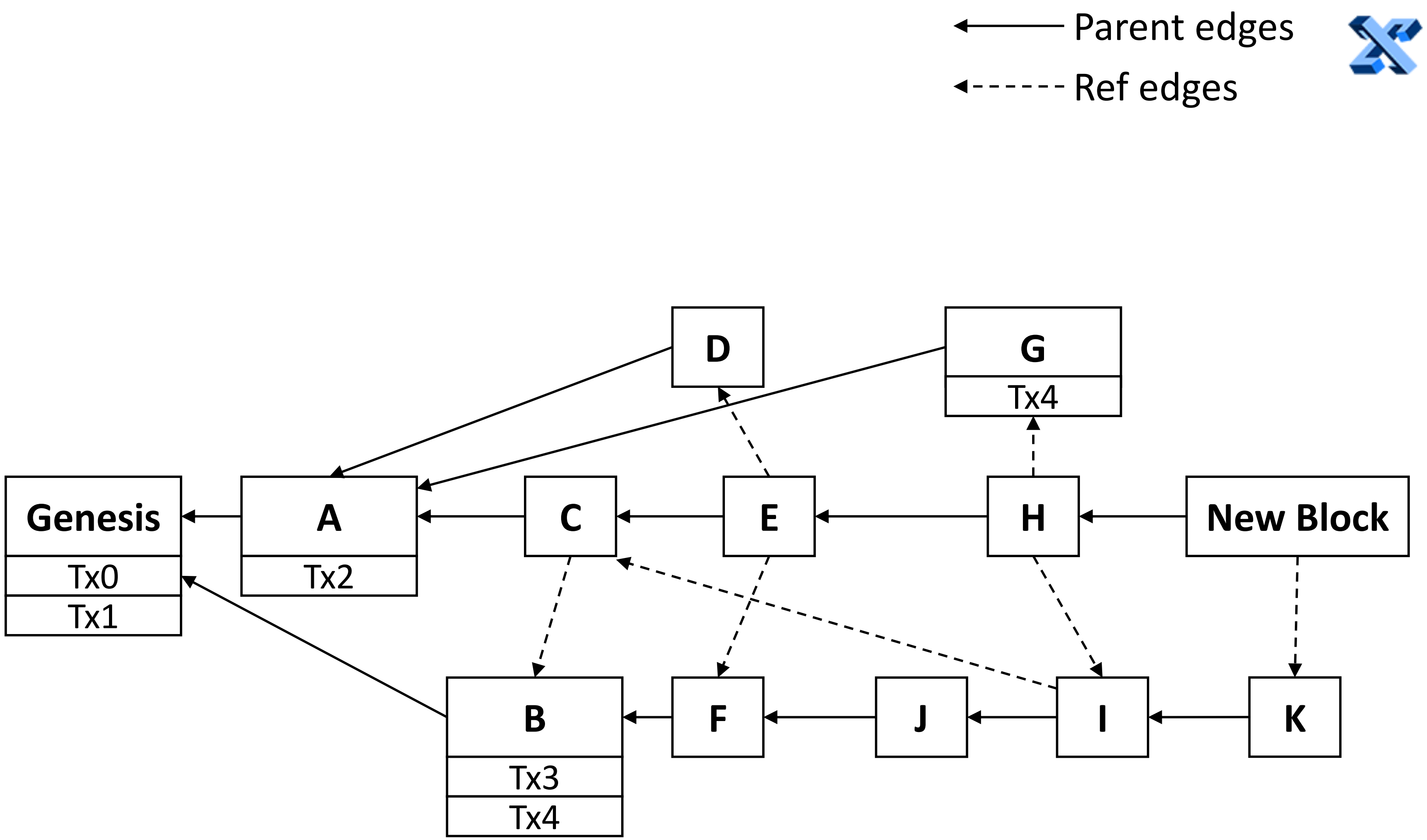
Reference edges simply denote happens-before relationships



When generating a new block:

1. Select the last block in the pivot chain as the parent

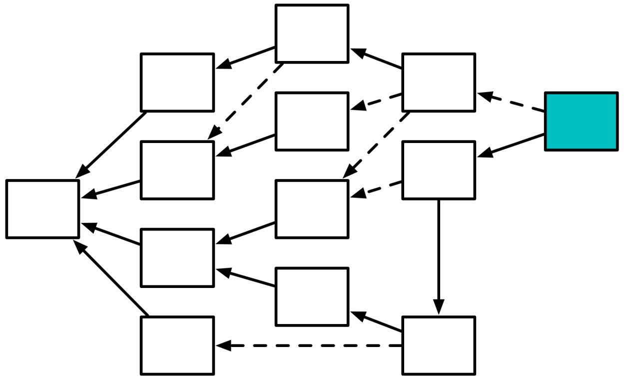
2. Create reference edges to all other blocks without incoming edges



Edges in the Tree-Graph capture the history blockchain state for each generated block

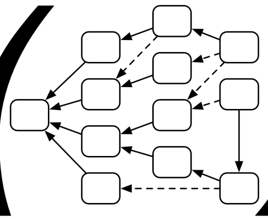
The past-subgraph of a block → All blocks that the block generator saw

Determine Weights from Past Sub-graphs



Is the past sub-graph stable enough?

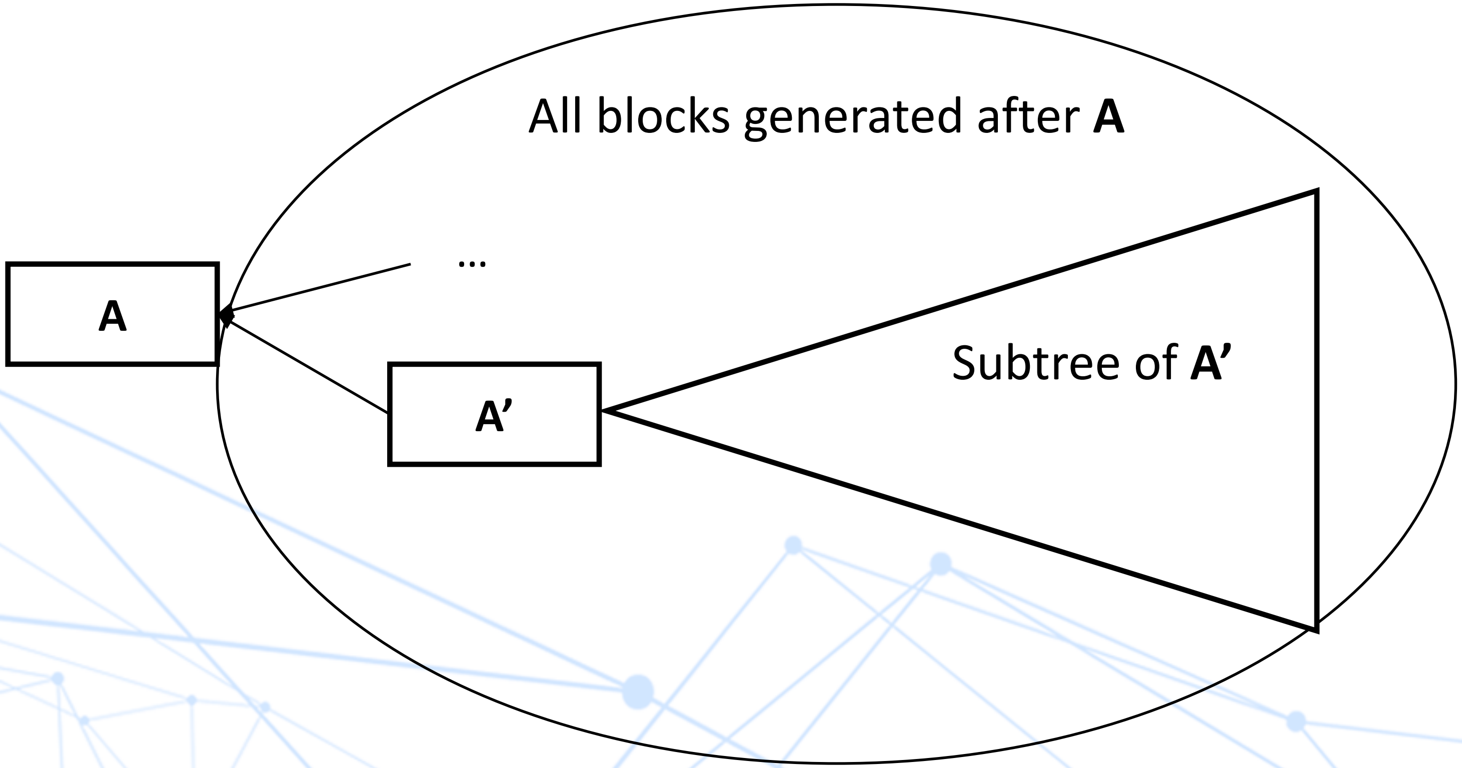
Yes: Assign weight 1
No: Assign weight h for 1/h blocks, 0 for other blocks

f() = Weight of the generated block

- All honest participants will agree on the weights
- Even with the presence of attackers!

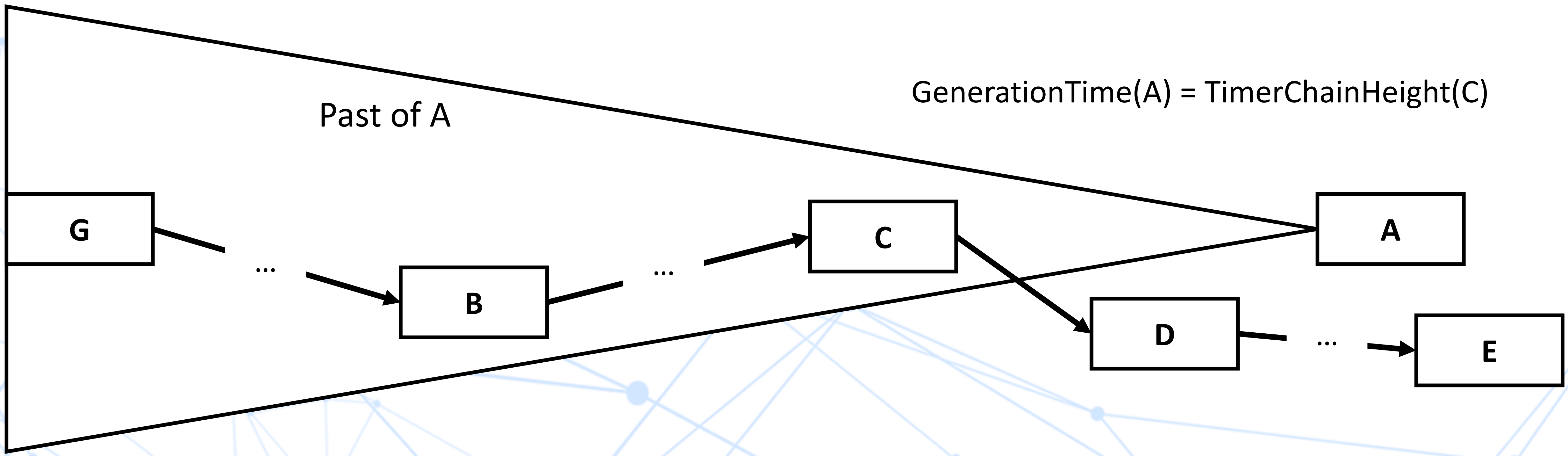
Determine Sub-graph Stability

- **Rationale**: For any pivot chain block **A** that is generated long enough, one of its child **A'** must become **dominant**
- Most future blocks after **A** should accumulate under the subtree of **A'**



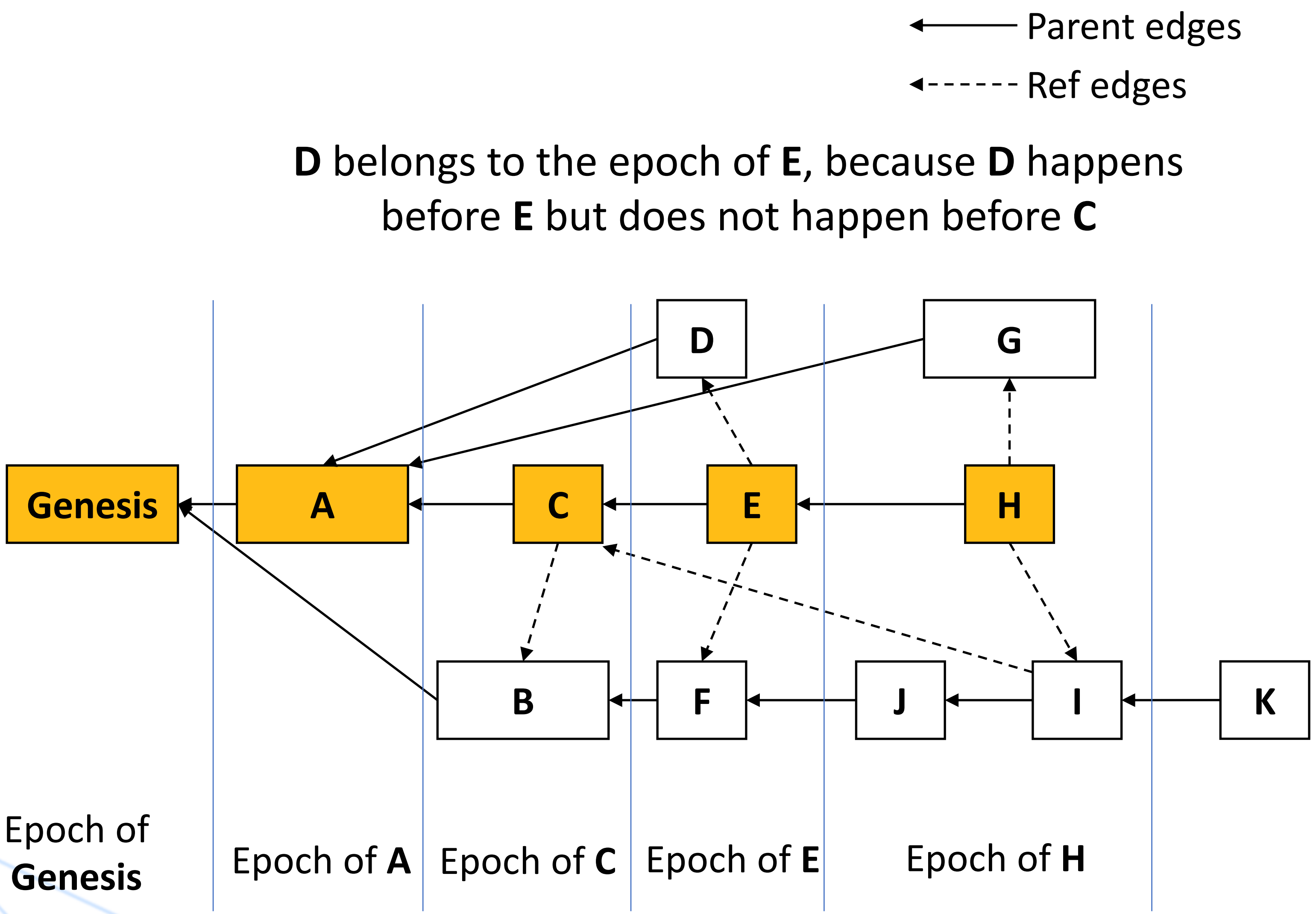
Trusted Block Generation Time: TimerChain

- TimerChain: a blockchain embedded in TreeGraph with longest-chain rule and low generation rate.
  - A small subset of blocks (Timer Blocks) have weights, like structured GHOST
- Block generation time: the height of the latest Timer Block in its past.



Conflux Ordering Algorithm

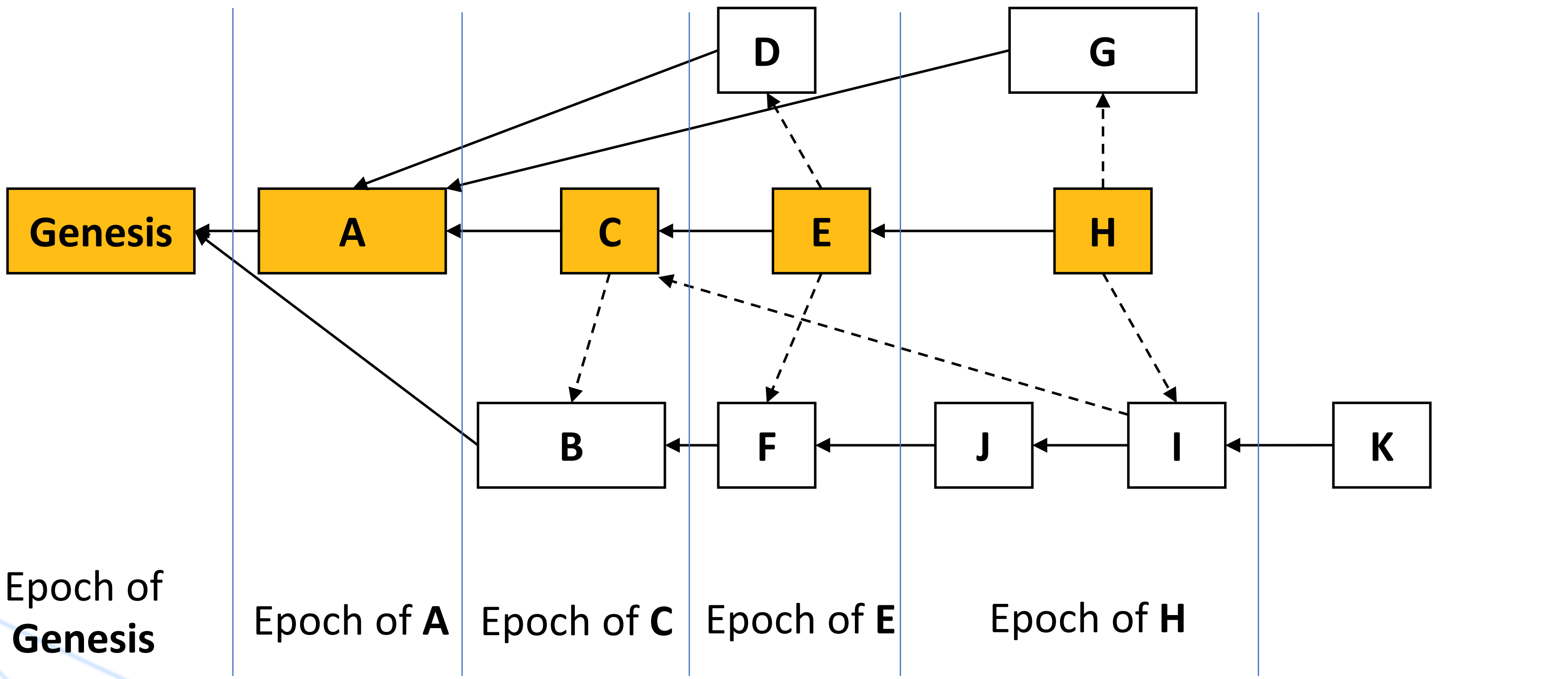
- **Key Idea:** deterministically define a block total order of a Tree-Graph based on a chain
- First use GHAST to agree on **a pivot chain** of blocks
- Then extend the agreed pivot chain into a total order of all blocks in the Tree-Graph



1. Each pivot chain block forms one **epoch**

2. An off-chain block belongs to the first epoch whose corresponding pivot chain block happens after it.

1. Order based on epoch first
2. Topologically sort blocks in each epoch
3. Break ties based on block id



Block Total Order: Genesis, A, B, C, D, F, E, G, J, I, H, K

Implementation & Optimizations

- Implemented in Rust with a modified EVM to handle smart contract transactions.
- Several key optimizations:
- *Link-cut tree* and *lazy validation*
  - Efficiently maintain weights in Tree-Graph
- *Deferred execution*
  - Avoid redundant execution rollbacks

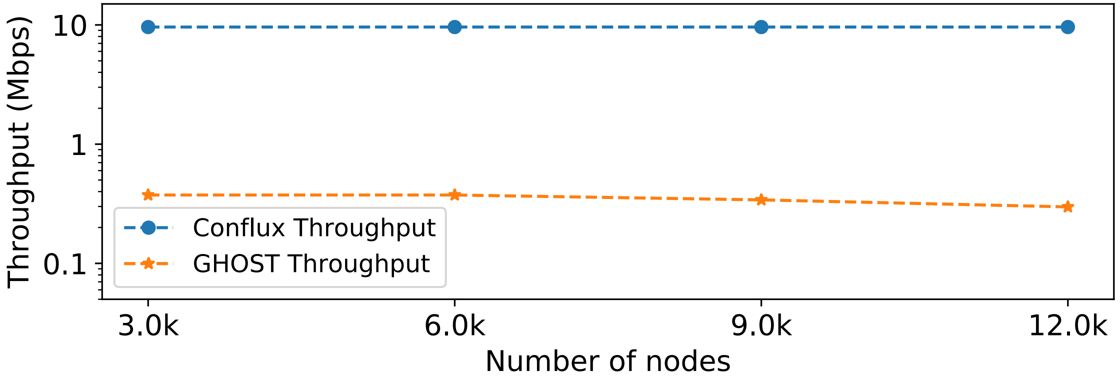
Evaluation

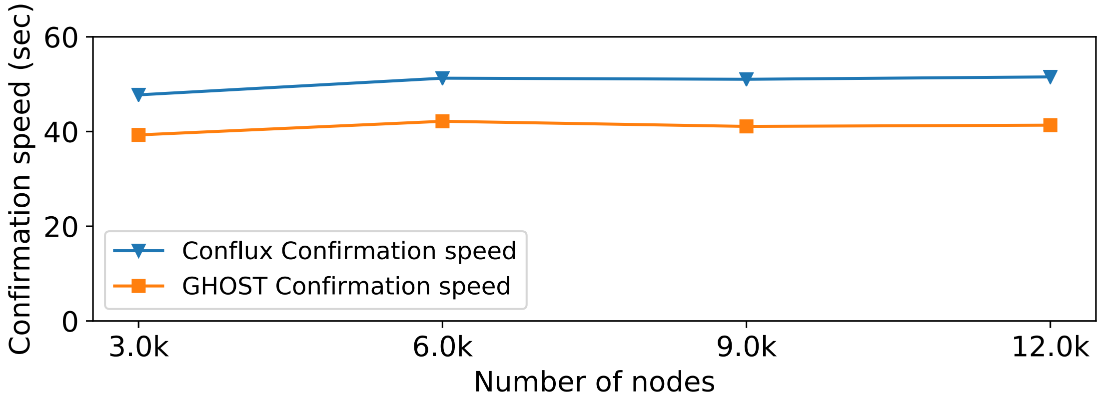
Experimental Environment

- Run up to 12k Conflux full nodes on Amazon EC2 m5.2xlarge VMs
- Limit the bandwidth of each full node to 20Mbps
- Simulate network latency between full nodes

- Measure the achieved throughput and confirmation latency
  - Consider a block confirmed if its confidence is the same as waiting for 6 Bitcoin blocks

Throughput, Latency, and Scalability





Run up to 15 full nodes per EC2 VM and disabled transaction executions

- 300K block size and 4 block per second.
- Conflux achieves 9.6Mbps throughput
- Up to 32X GHOST throughput.
- Confirm transactions on avg. **51.5 seconds.**
- Scales to 12k full nodes

Conclusion

- Conflux achieves both high throughput and fast confirmation.
- Conflux is safe against both double spending and liveness attacks.
- Conflux achieves this with a novel consensus protocol GHAST, which assigns different weights to blocks adaptively and automatically.
- With 12K nodes, Conflux can reach 9.6Mbps throughput and confirm blocks within one minute.

Thanks!

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Conflux Website: https://www.conflux-chain.org/