האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

DAGlabs
A novel BlockDAG platform

BlockDAG protocols
SPECTRE, PHANTOM

BPASE’18, Stanford

Yonatan Sompolinsky
Joint work with Aviv Zohar

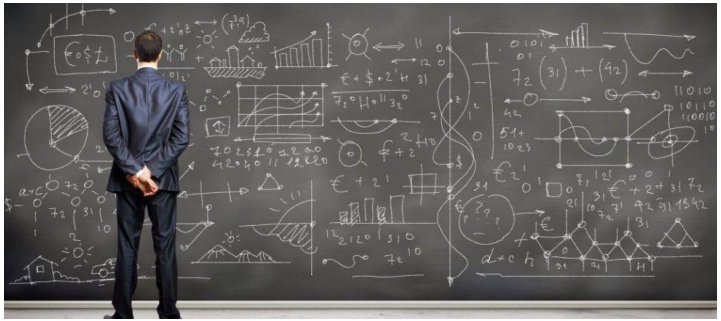
Motivation

– – –

- Algorithms on graphs are fun
- Blockchain does not scale
- BlockDAG - generlization of Satoshi’s paradigm
- 144 blocks per day → 1 million blocks per day

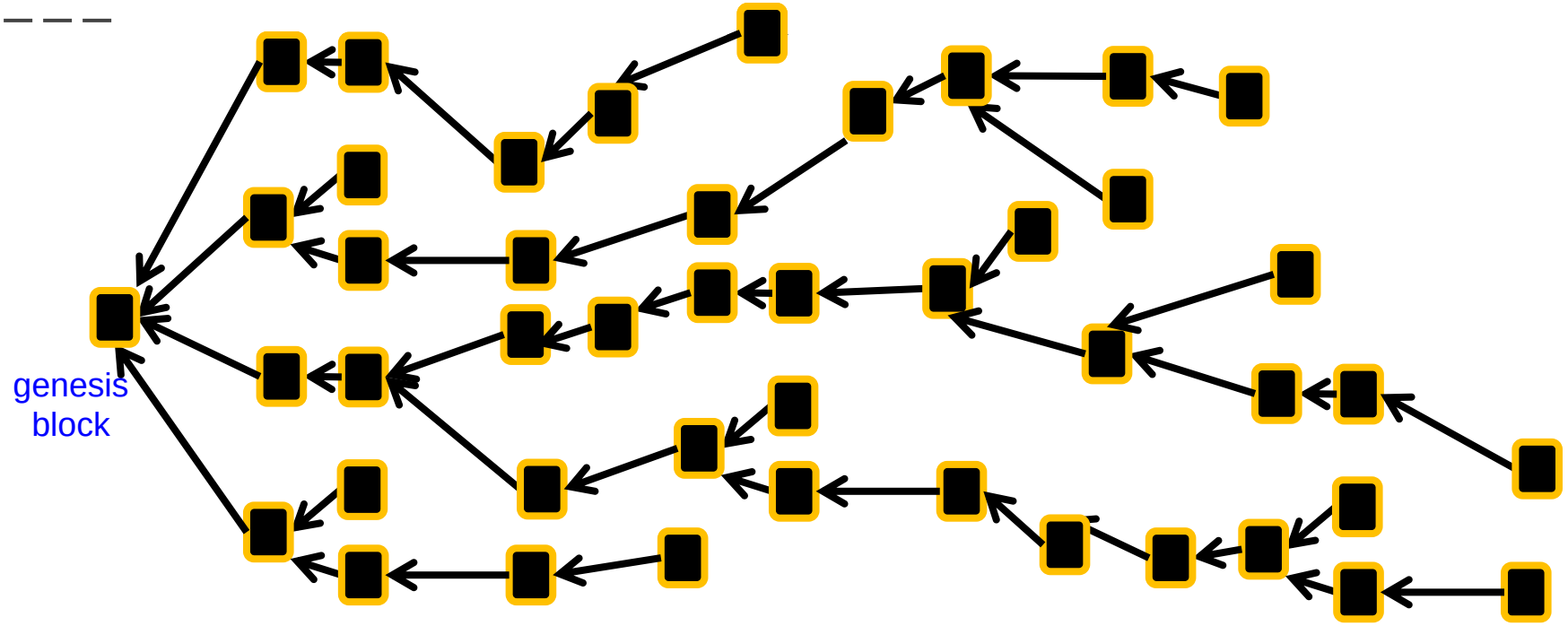
- Proof-of-work
- Miners
- Blocks
- Block rewards
- Transactions
- Transcation fees
- Activity on-chain
- …

- Proof-of-stake
- ByzCoin [Kogias *et al*.], Hybrid Consensus/Thunderella [Shi, Pass]
- Lightning Network [Poon and Dryja]
- Sharding protocols
- Blockchain project X



BlockDAG paradigm

BlockDAG with 10 blocks per second



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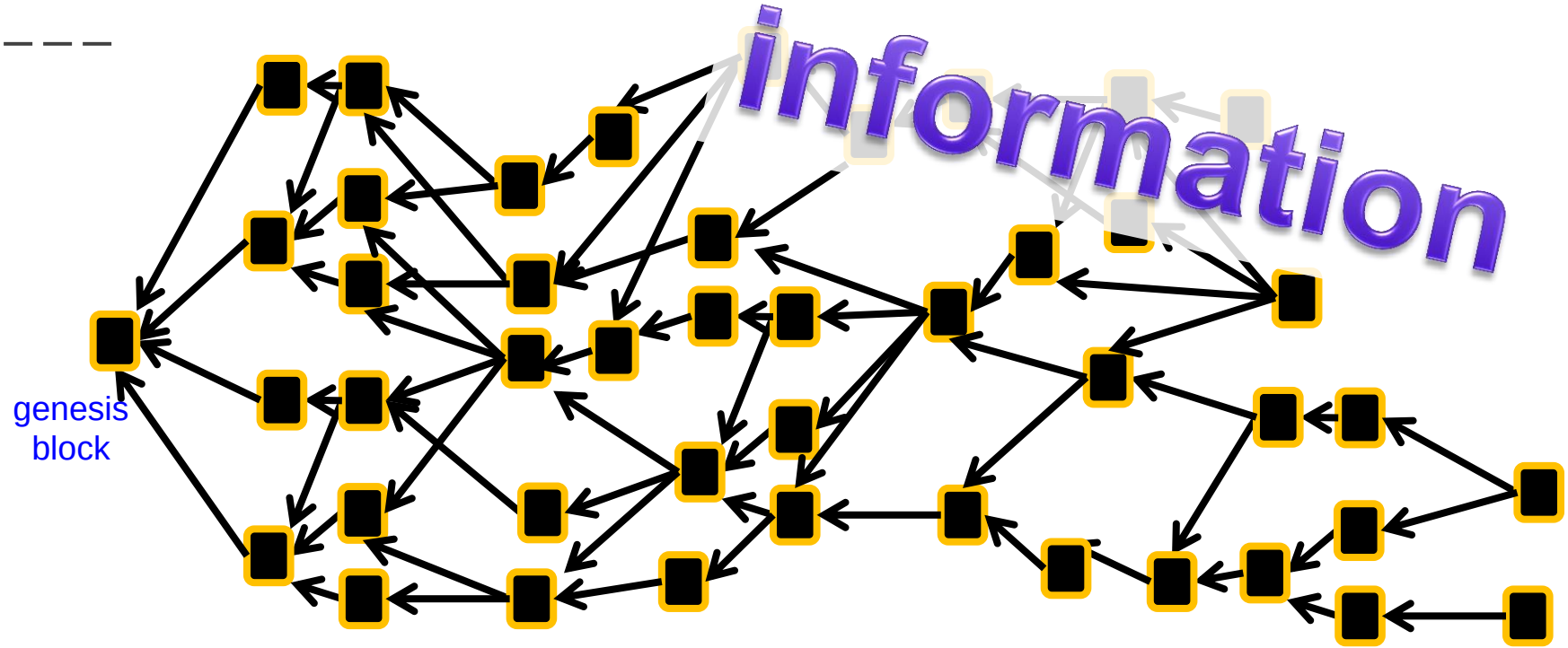

DAG mining protocol

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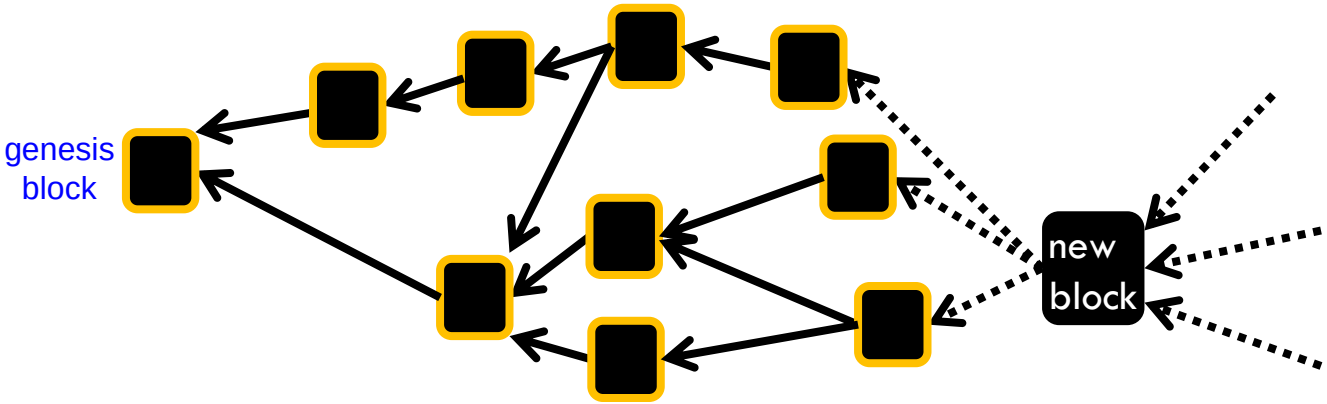
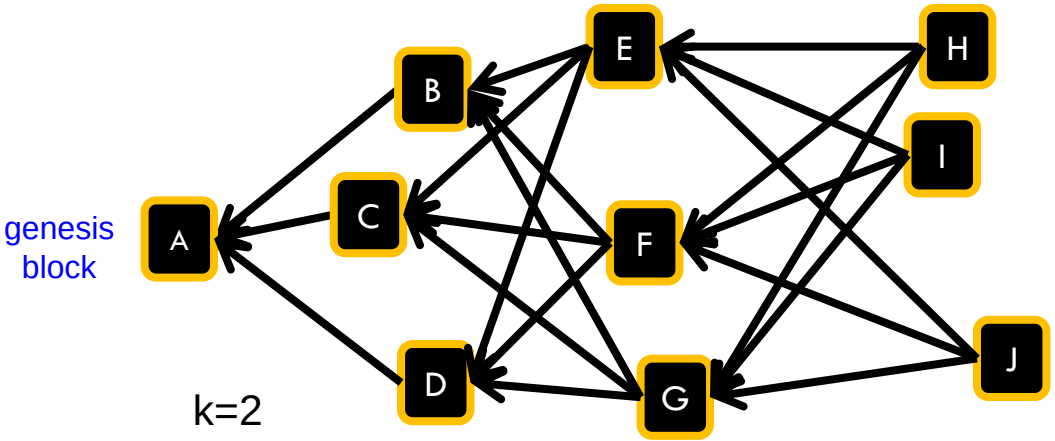
rule #1: reference ~~tip of longest chain~~ all tips of DAG

rule #2: publish block immediately

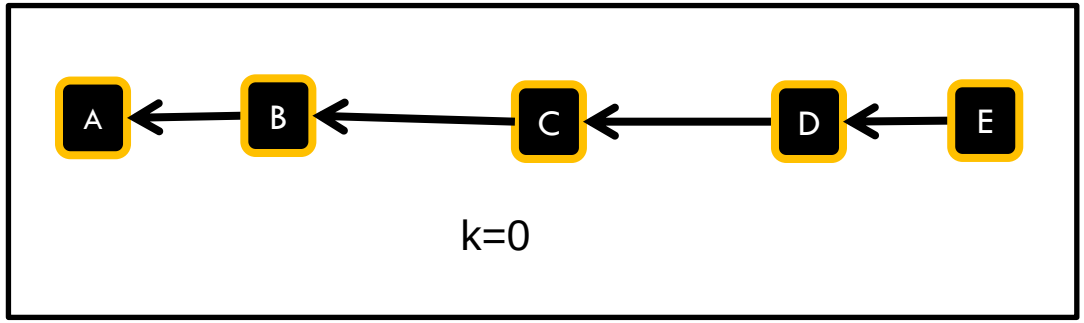


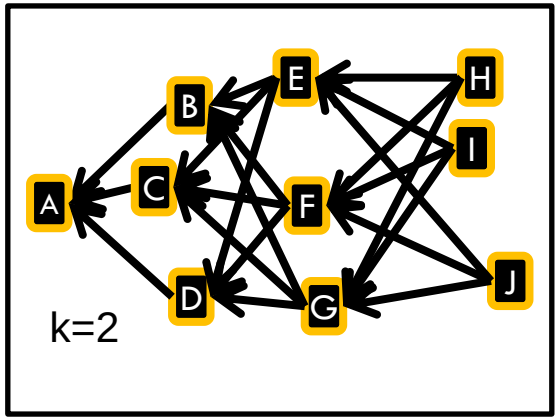
Key observations

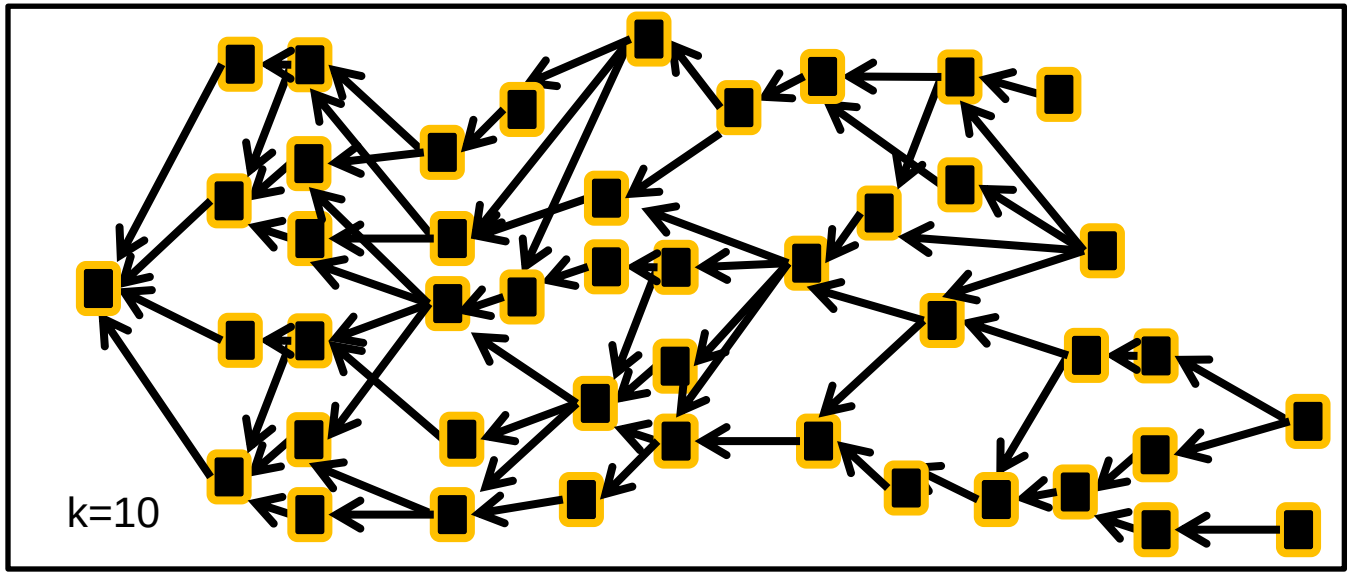
1. Two honest blocks unconnected in the DAG only if created at approx same time
2. Rarely more than k honest blocks created at approx same time
3. Attacker can create arbitrary structures, but <50%



$$k = k(D \cdot \lambda)$$
$$\lambda = block\ rate$$
$$D = propagation\ delay$$







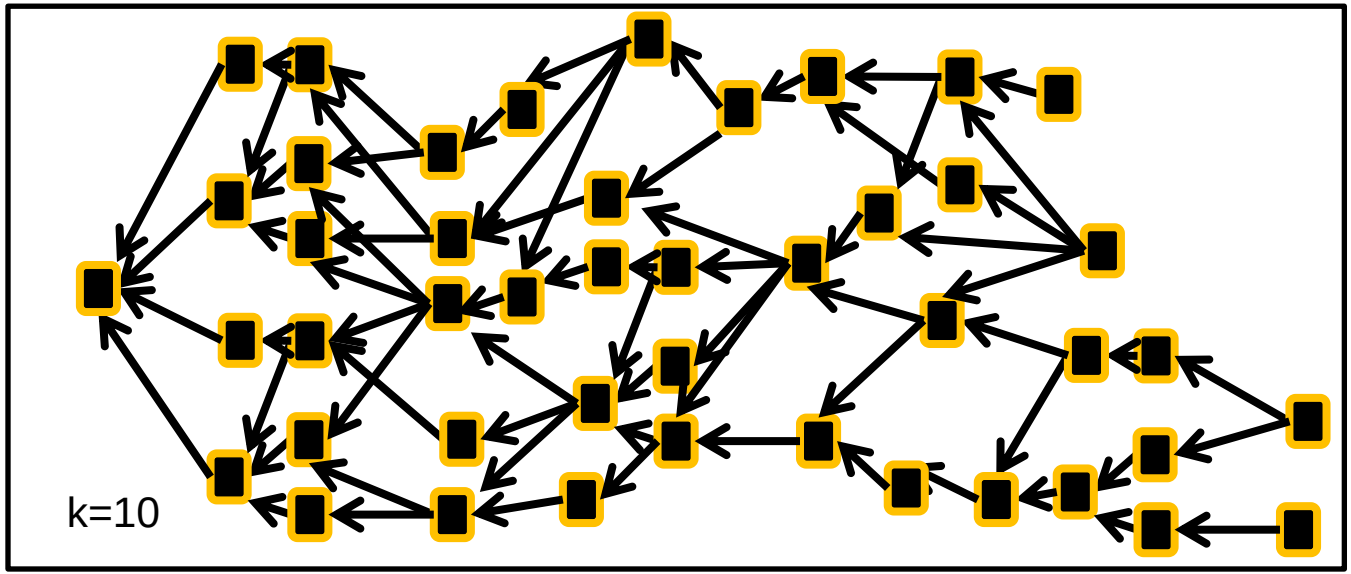
$$k \leq 2 \cdot D \cdot \lambda$$

$$D = prop\ delay$$

$$\lambda = block\ rate$$

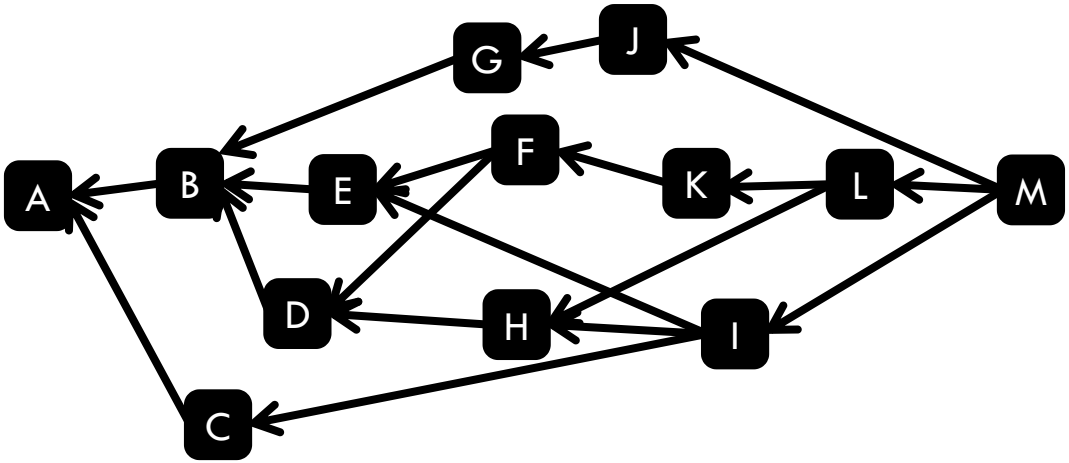
BlockDAG paradigm

- It’s a paradigm, not a solution
- Still need to resolve conflicts, aka double-spends



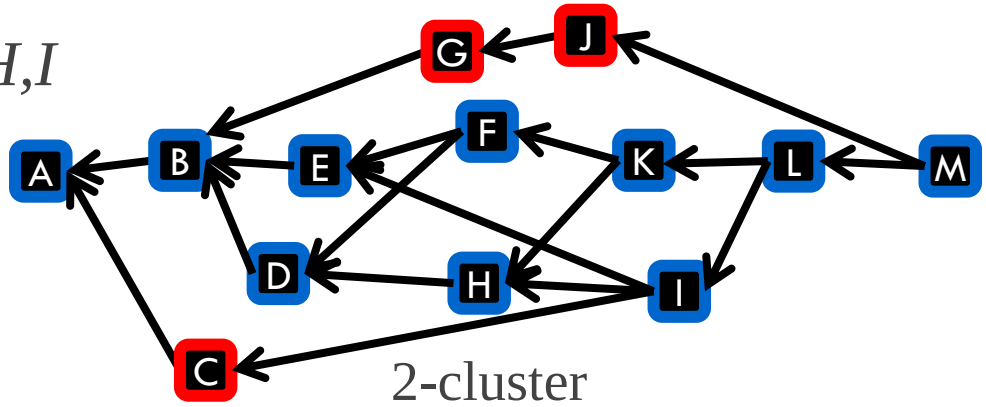
The PHANTOM protocol

PHANTOM's goal: recognize cluster of honest blocks, discard (or penalize) the rest



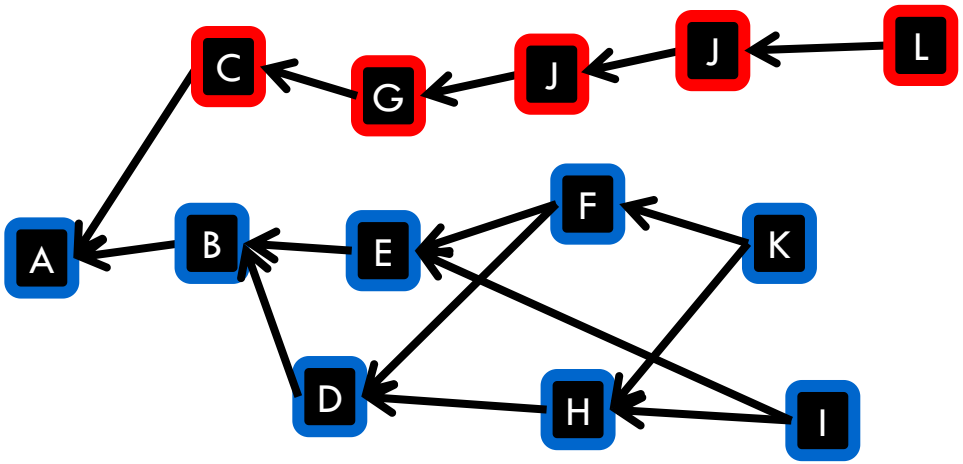
Definition: A ***k-cluster*** is a subset of blocks such that each block in it is connected to every block in it, apart from at most *k* blocks

E not connected to D,H
F not connected to H,I
J not connected to E,F,K,L,D,H,I



2-cluster

Good news #1: honest blocks form a k-cluster



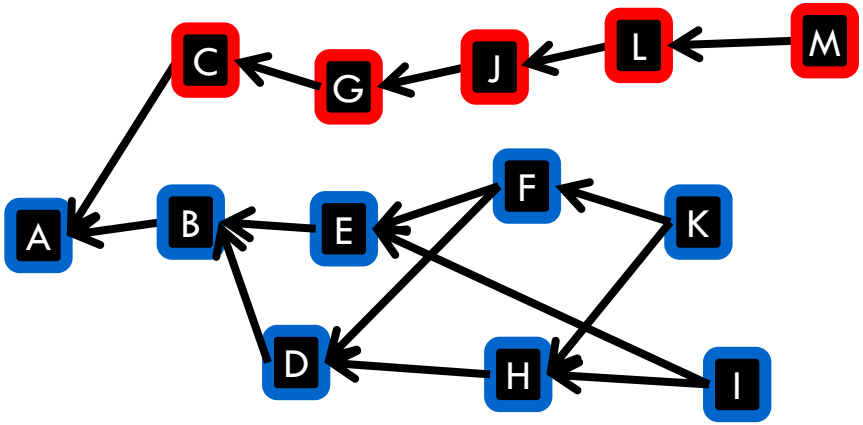
honest large k-cluster

Key observations:

1. Two honest blocks are unconnected in the DAG only if created at approx same time

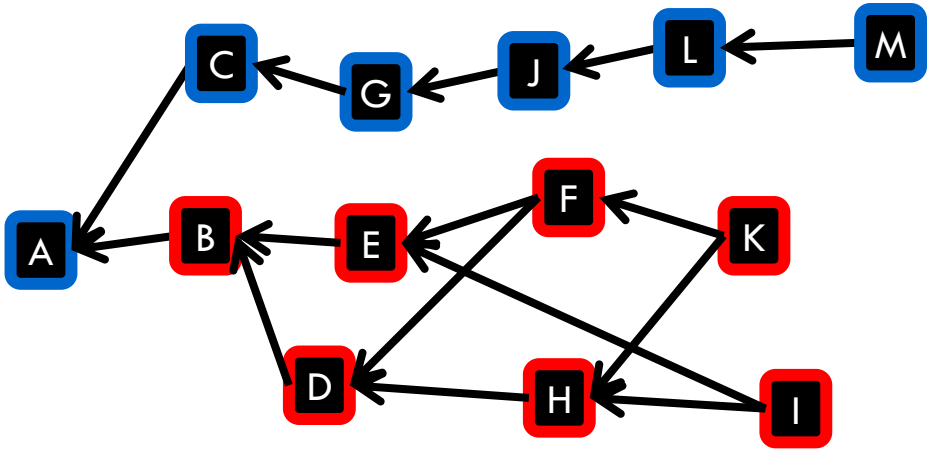
2. At most k blocks created at approx same time

Good news #1: honest blocks form a k-cluster
Bad news: attacker forms a k-cluster as well

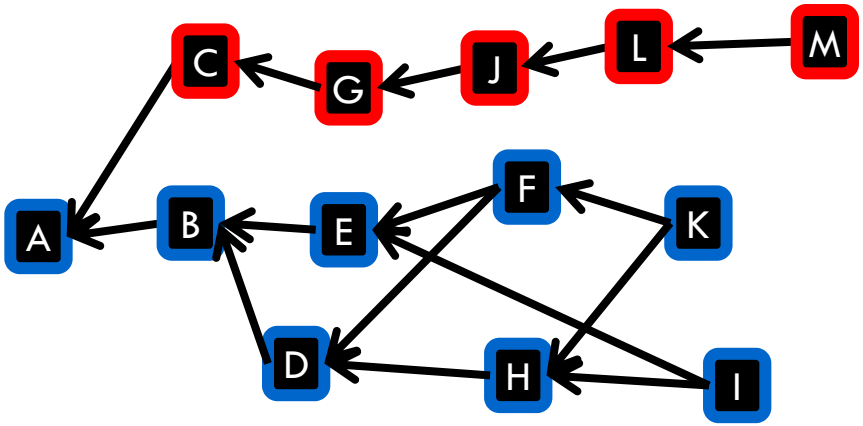


honest k-cluster

attacker k-cluster

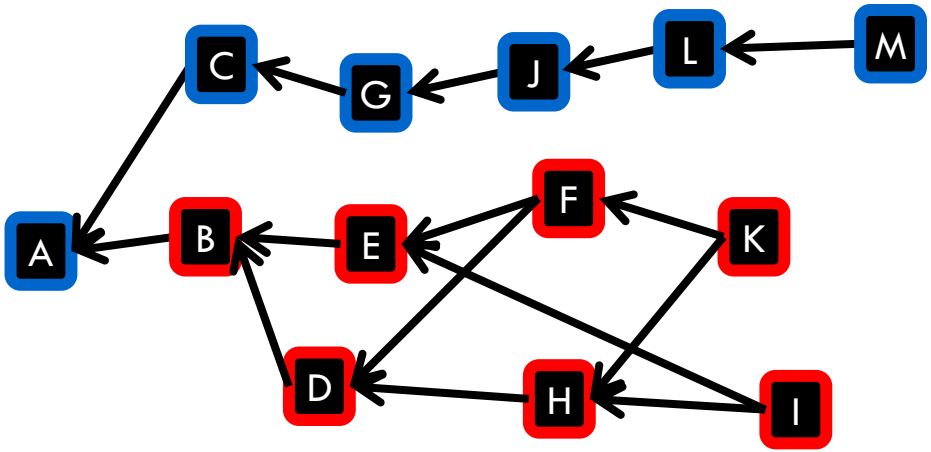


Good news #1: honest blocks form a k-cluster
Bad news: attacker forms a k-cluster as well
Good news #2: honest blocks form a larger one!

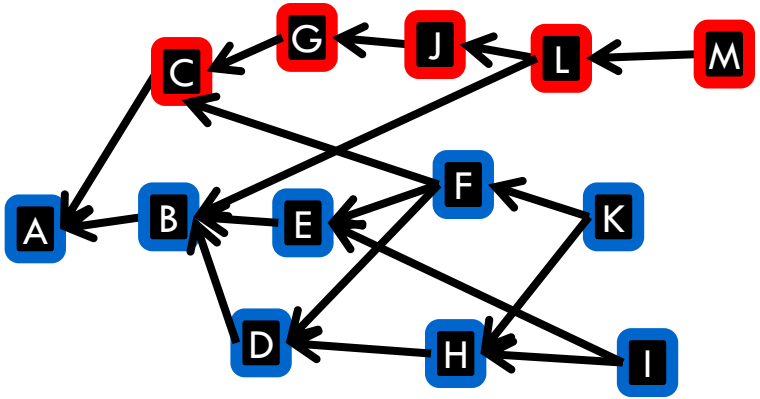


honest large k-cluster

attacker small k-cluster



The PHANTOM protocol



<u>Algorithm</u> (NP hard version):

1. Search for **largest *k*-cluster**
2. Order its blocks via some topological ordering
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The PHANTOM protocol

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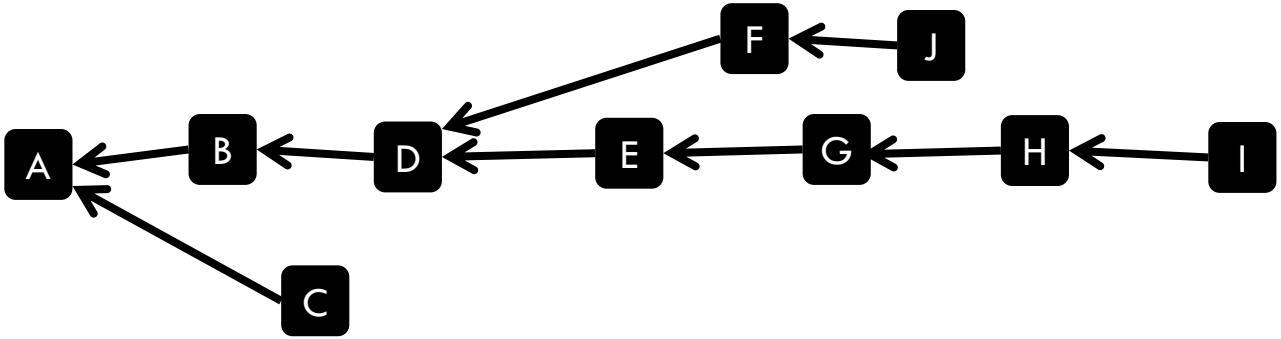
why is this secure?

Generalization of Satoshi’s paradigm

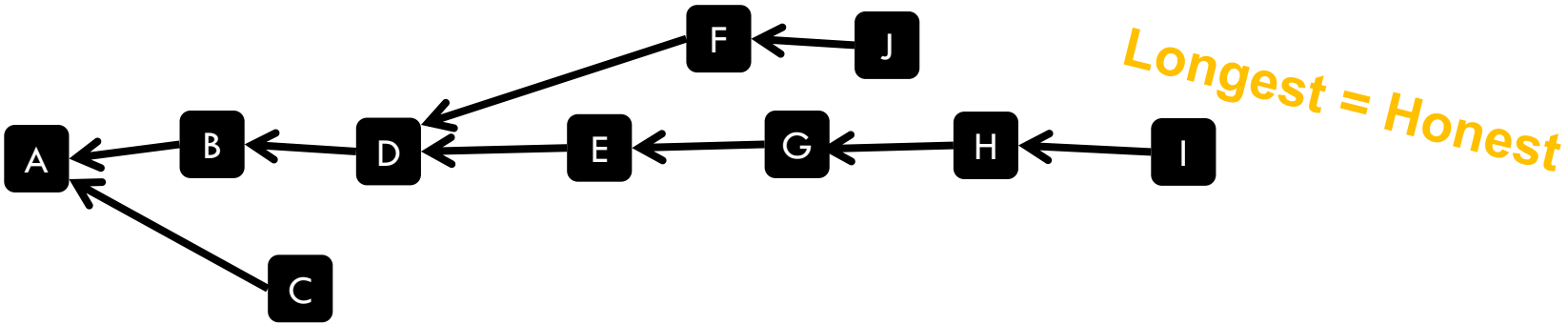
Forks in the blockchain



deliberate attack? miner of C ignored B
propagation delay? miner of C didn’t receive B yet

What happened here? Who is honest???

Recognizing honest chain of blocks



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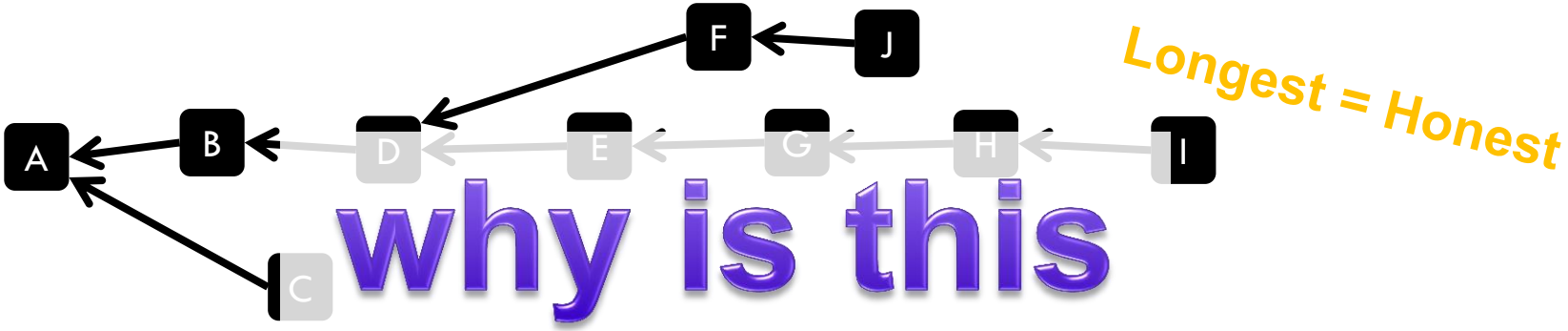
Recognizing honest chain of blocks



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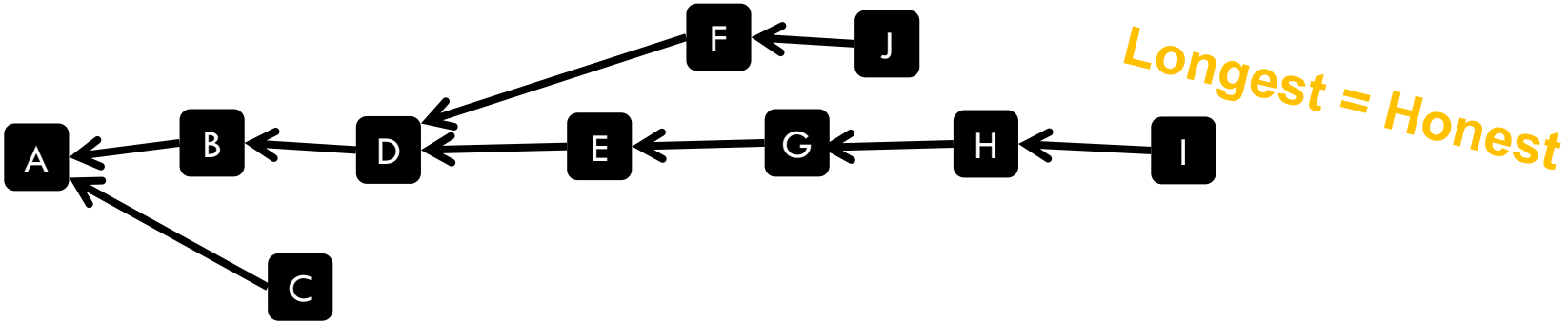
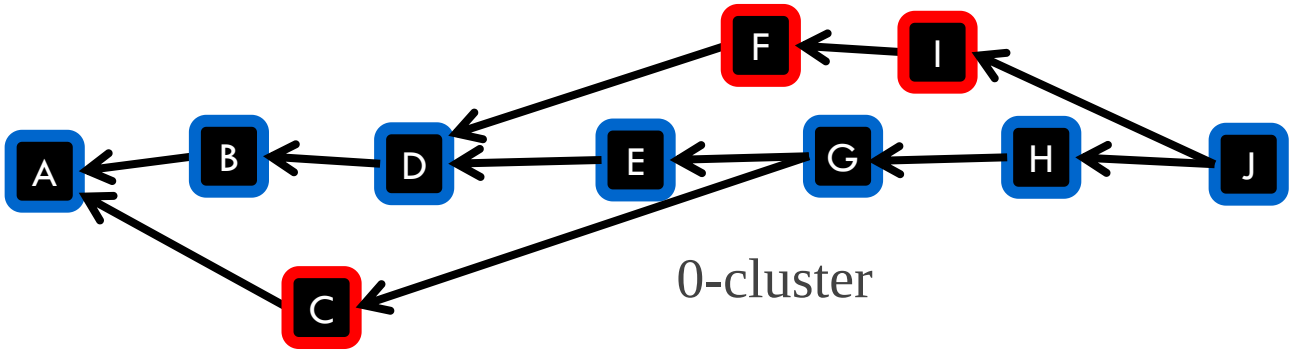
Recognizing honest chain of blocks



Key observations

1. Two honest blocks unconnected in the ~~DAG~~ chain only if created at approx same time
2. Rarely more than ~~k~~ 1 honest block created at approx same time
3. Attacker can create arbitrary structures, but <50%

Longest chain = Largest 0-cluster



Theorem (Bitcoin):
If attacker<50%, then under low throughput, the largest 0-cluster (aka longset chain) was created by honest nodes

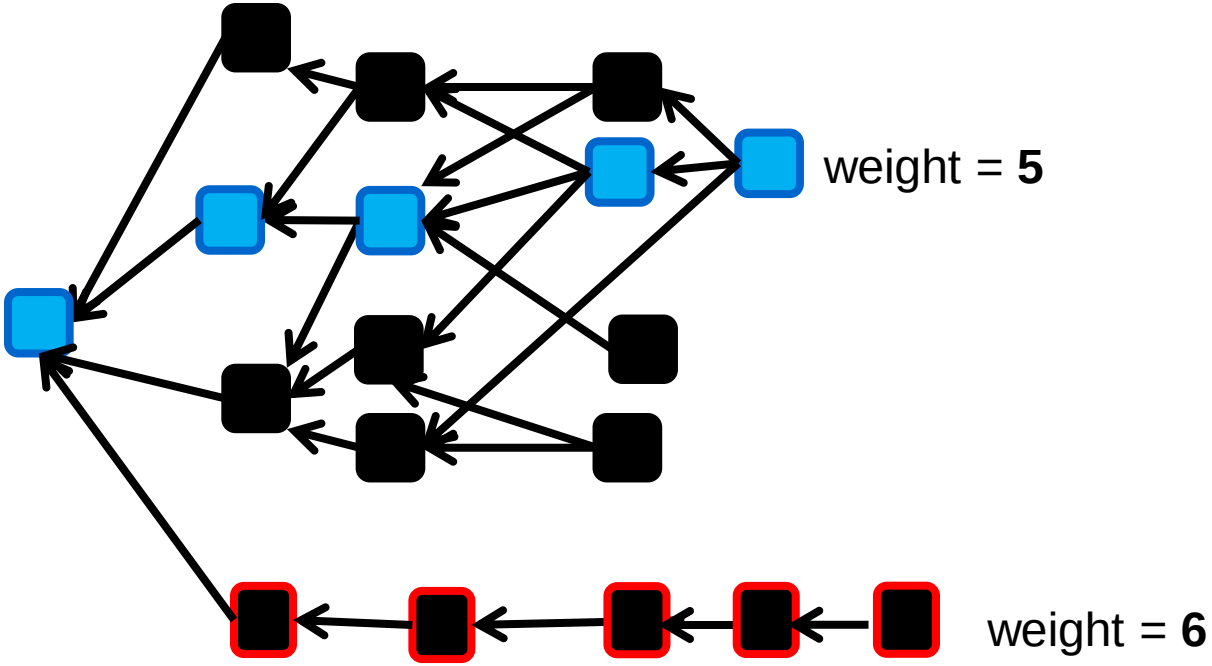
Theorem (PHANTOM):
If attacker<50%, then under *any* throughput, the largest k-cluster was created by honest nodes, for some suitable k

PHANTOM Greedy Algorithm

<u>Algorithm</u> (**NP hard** version):

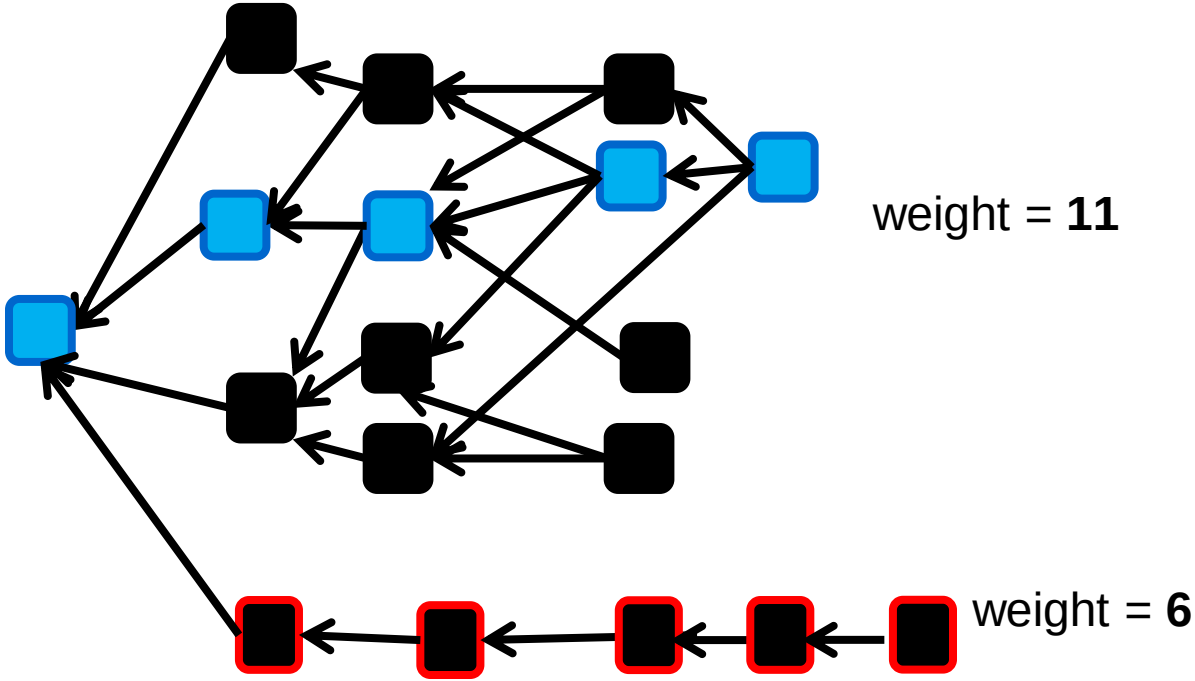
1. Search for **largest *k*-cluster**
2. Order its blocks via some topological ordering
3. Iterate over blocks in the prescribed order, and accept transactions consistent with history

Why not longest-chain of DAG??



b/c orphans do not contribute to honest chain

Why not count all orphans??



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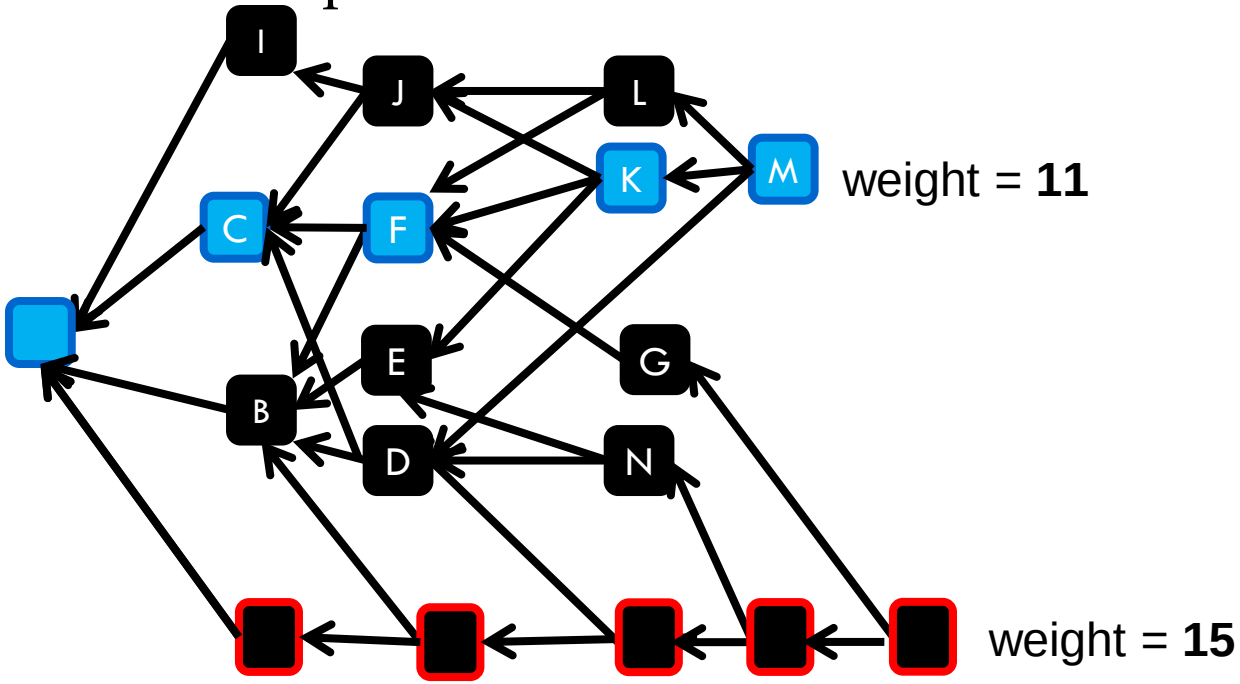
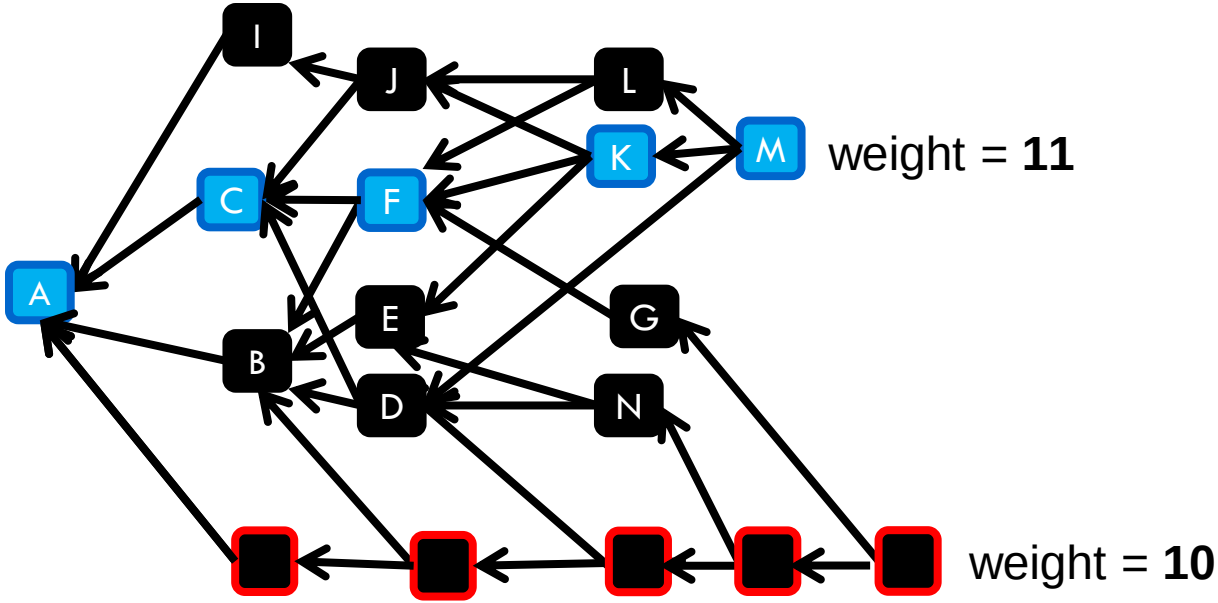


b/c orphans will contribute to attacker chain

PHANTOM's solution: Count all orphans that are well connected to the chain

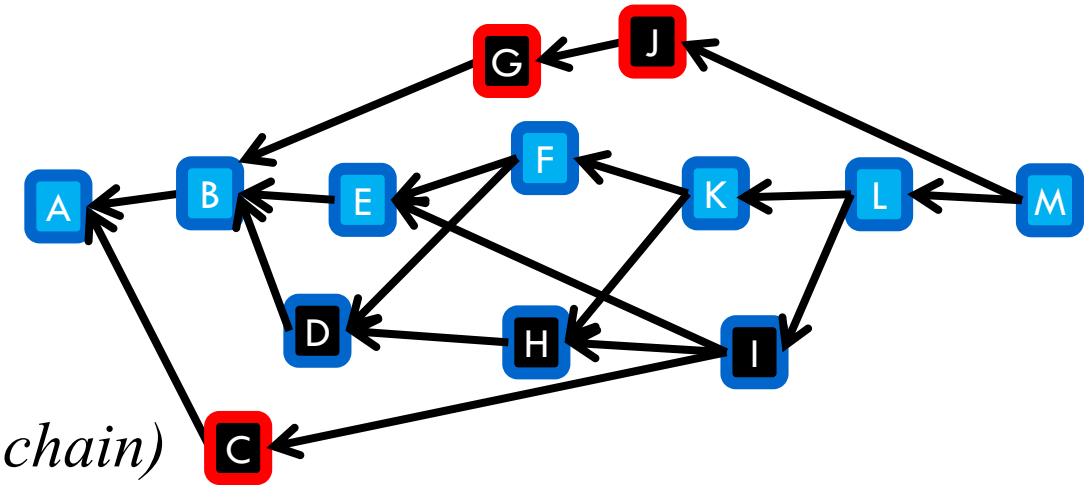


weight = **11**

weight = **10**

Longest chain: count no orphans (attackable)
Previous suggestion: count all orphans (attackable)
PHANTOM: count some orphans (secure)

Definition: A ***k***-uncle of a chain is a block which is unconnected to at most *k* blocks in it



Examples:

B - 0-uncle (it's inside the chain)

D - 1-uncle (unconnected to E)

H - 2-uncle (unconnected to E,F)

C - 4-uncle (unconnected to B,E,F,K)

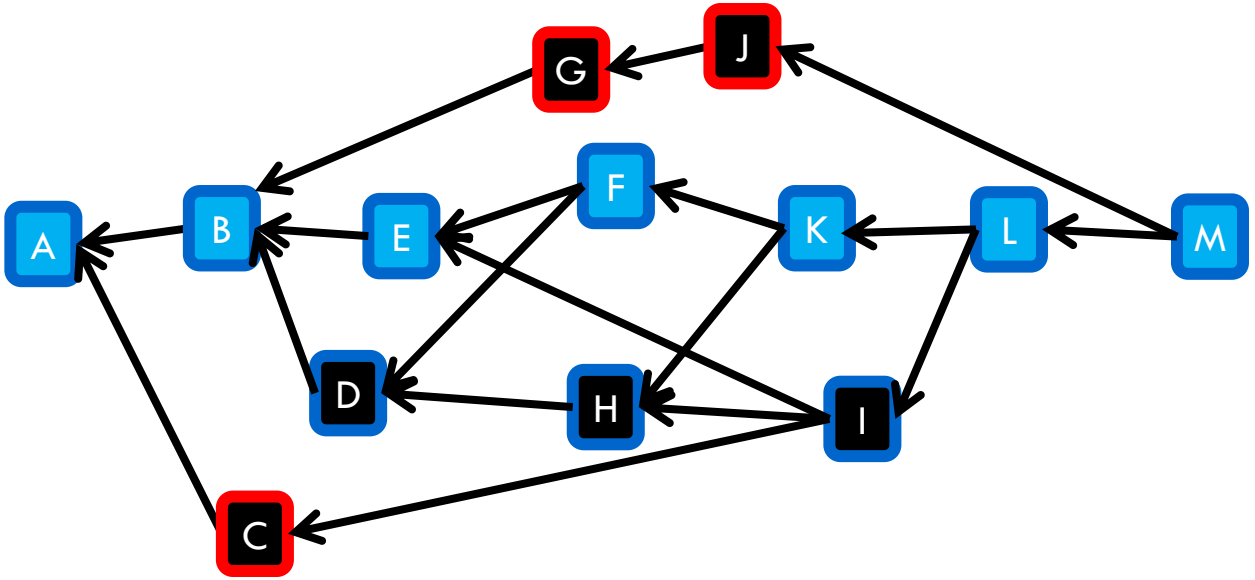
PHANTOM (greedy version):

1. Search for **chain** with largest # of uncles of degree $\leq k$; the chain + uncles are honest
2. Order its blocks via some topological ordering
3. Iterate over blocks in the prescribed order, and accept transactions consistent with history

PHANTOM (NP hard version):

1. Search for **largest *k*-cluster**; the cluster is honest
2. Order its blocks via some topological ordering
3. Iterate over blocks in the prescribed order, and accept transactions consistent with history

The chain with largest number of 2-uncles:

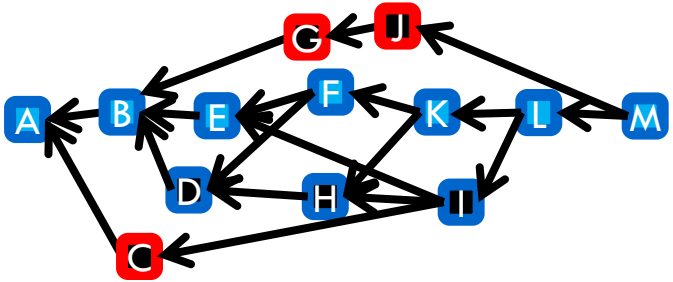


Security guarantee: For properly chosen k,

1. (almost) all honest block are uncles of degree $\leq k$ of heaviest chain

2. (almost) no attacker blocks are uncles of degree $\leq k$ of heaviest chain

3. any topological order over honest blocks will converge



PHANTOM pros and cons

- throughput unlimited by the protocol
- easy to implement efficiently
- poor waiting times when conflicts are visible

Throughput

Desired throughput	**Required bandwidth**	**Required storage**	Block size	Block creation rate
1,000 txns per sec	0.5 MB per sec	~100 GB per day	50 KB	10 blocks per sec
10,000 txns per sec	5 MB per sec	~1 TB per day	100 KB	50 blocks per sec
1,000,000 txns per sec	500 MB per sec	~0.1 PB per day	0.5 GB	1 block per sec

Scalability, SPECTRE vs PHANTOM

Protocol	Throughput limited by	Confirmation times		Ordering
		w/o conflicts	w/ conflicts	
Bitcoin	latency	slow	slow	linear
SPECTRE	capacity	very fast	not guaranteed*	pairwise
PHANTOM	capacity	slow	very slow	linear
SPECTRE + PHANTOM	capacity	very fast	very slow	pairwise

*under active balancing attack; Weak Liveness

More stuff in the paper…

– – –

- Other greedy variants
- How to incorporate “red” blocks as well
- Formal proof of convergence
- Waiting times in PHANTOM
- Combining SPECTRE and PHANTOM