CHAINSPACE

The Blockmania Consensus Protocol & Scaling Distributed Ledgers with Chainspace

A Research Talk

(zero marketing = zero liability)

Who is George Danezis?

A brief introduction

Passion: **Decentralization & Privacy**

Co-Founder & Head of Research at **chainspace.io**

Prof. of Security and Privacy Engineering at University College London, London.

Before: **Microsoft Research, KU Leuven**, **Cambridge** (academic dad: Ross Anderson)

UCL is actively recruiting faculty, post-docs and PhD students in security. Apply!

Where to go find out more

Our research papers

George Danezis, Dave Hrycyszyn:

Blockmania: from Block DAGs to Consensus.

CoRR abs/1809.01620 (2018)

Mustafa Al-Bassam, Alberto Sonnino, Shehar Bano, Dave Hrycyszyn, George Danezis:

Chainspace: A Sharded Smart Contracts Platform. NDSS 2018

And some sneak previews of unpublished material.

Outline

How to build reliable distributed systems?

What is consensus, and what is it good for?

What is ‘the simplest’ practical form of Byzantine consensus?

How to implement it as efficiently as possible?

How can we scale ‘blockchains’ beyond faster consensus?

Why care about Consensus?

Smart contracts, distributed ledgers and Blockchains

Consensus as a primitive has been studied since the 1980s.

Bitcoin proposed “Nakamoto Consensus”. **Ethereum** uses it.

Pro: open membership through PoW.
Con: Weak finality, and energy hungry.

Renewal of interest in “traditional” consensus protocols.

What is consensus?

Building block of reliable distributed systems.

Set of **network nodes**, that may be subject to **failures**.

Consensus is a joint network protocol to make a **joint decision**.

Agreement (safety) – they want to all take the same decision.

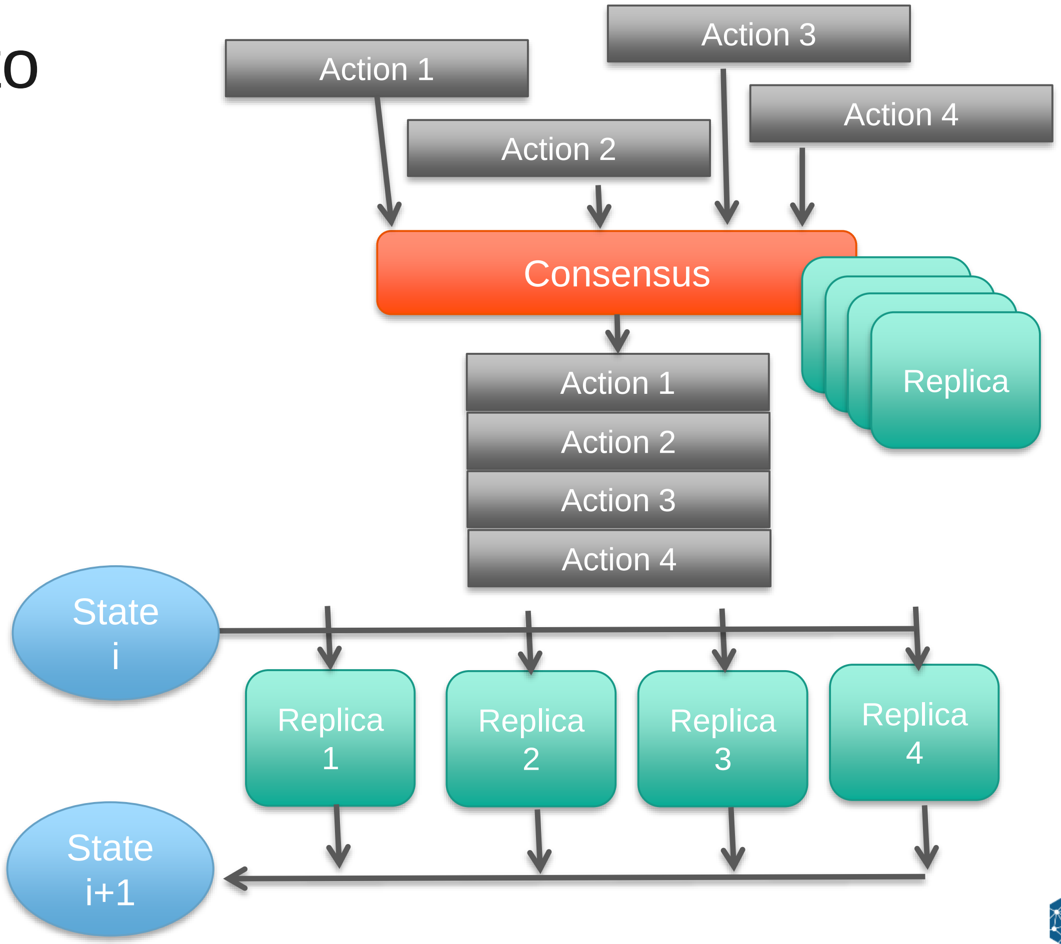
Liveness & finality – they all eventually take a decision, and it is final.

Single decision or **sequence** of decisions (optimization)

Consensus is key to reliable distributed systems

State machine replication paradigm for secure distributed computing (Fred Schneider, 1990)

All replicas start at State 0 and execute the same sequence of operation resulting in the same state i+1.



Flavors of consensus.

- **Network model**: Synchronous, asynchronous, **partial synchrony**.
- **Failure model**: crash-fail, crash-recovery, **byzantine**.
- **Initiator**: Honest or byzantine.

Blockmania: asynchronous safety, partial synchrony for liveness.

Core: simplification of PBFT protocol (Liskov & Castro, 1999)

Hard Limits

Limits to asynchronous Byzantine consensus

- **FLP theorem:** byzantine consensus is impossible, even with a single faulty node, under full asynchrony for a deterministic protocol.

- Solution: **partial synchrony.**
  After some period of asynchrony, the system becomes synchronous.

- **Synchrony**: messages from honest nodes are received within a known delay by other honest nodes.

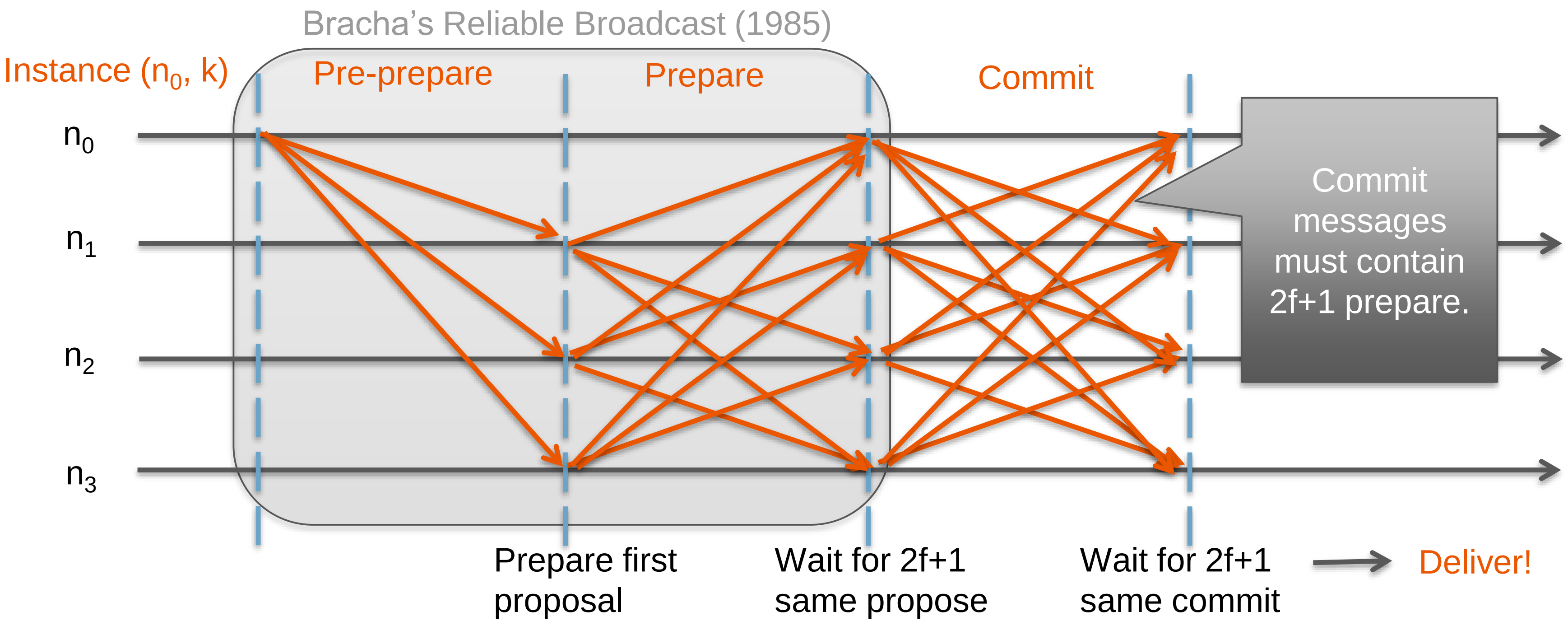
- **Tolerance to faulty nodes:** 3f+1 participants are required to tolerate up to f faulty nodes.

BLOCKMANIA

The Blocmania Core Consensus Algorithm

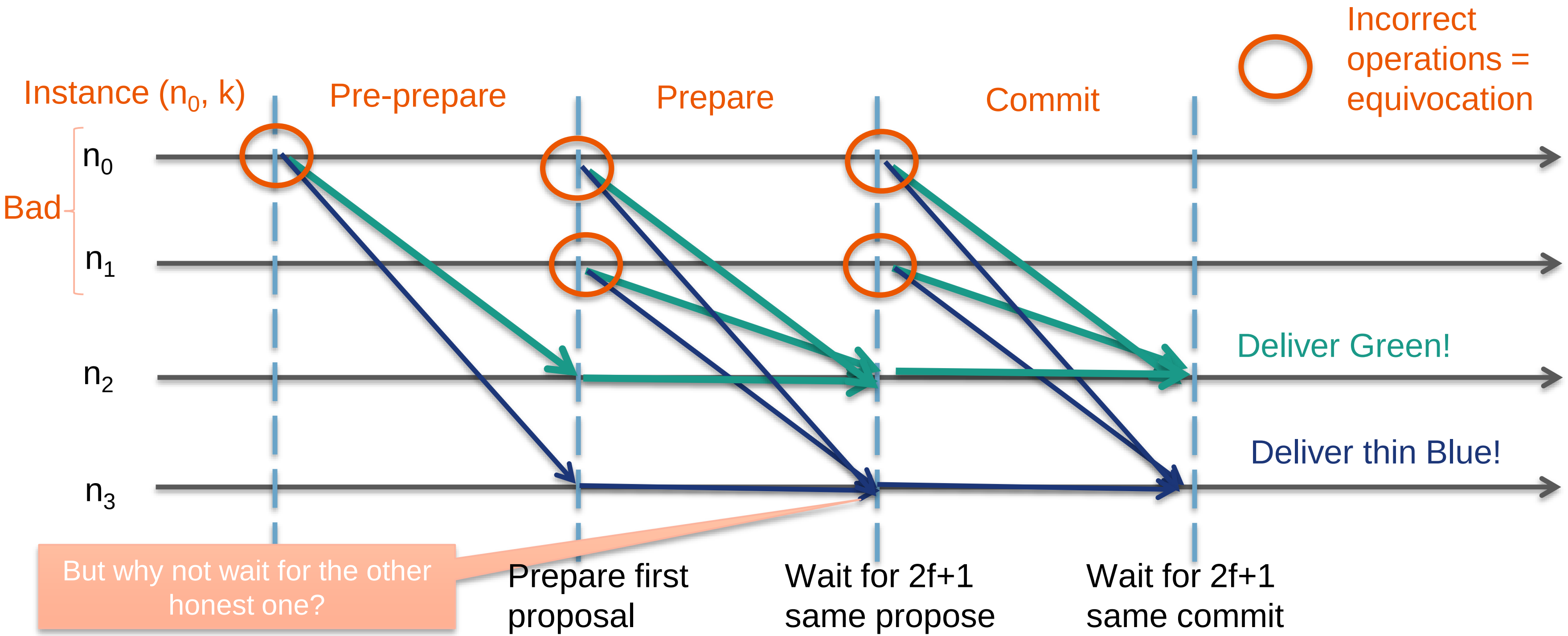
Blockmania / PBFT core consensus (happy path, view 0)

- A **participant n_0 proposes a block for slot k**. All need to agree on it, or agree on 'no block'.
- **Why**: A byzantine participant n_0 may propose **conflicting blocks, or no blocks.**



Insight: why do we need 2f+1 good nodes?

- Consider **both n_0 and n_1 are byzantine** – N < 3f+1. Example attack: **failed agreement.**



Insight: why have a Commit Phase & View Change.

Why not simply use Bracha's Broadcast (pre-propose & propose Phases)?

Liveness under faulty (or slow) **initiator**:

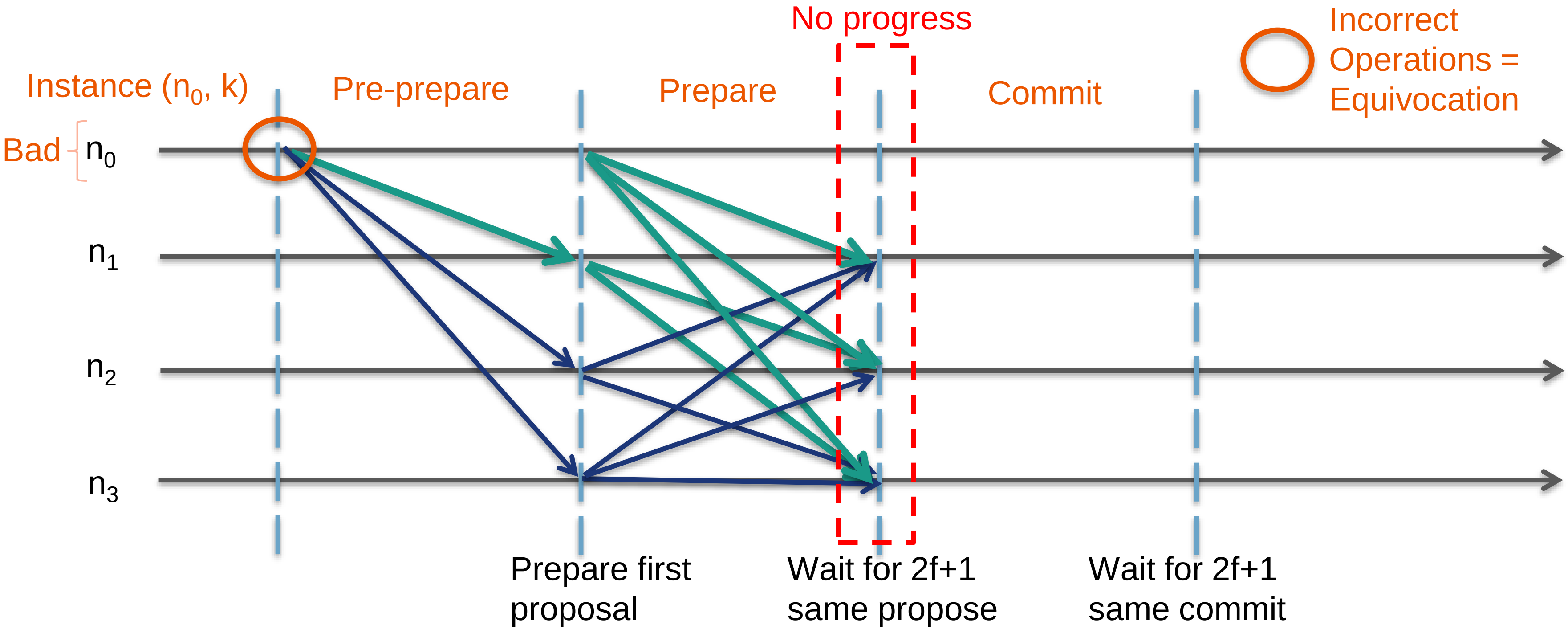
- Initiator does not sent a value for (n, k)?
- Initiator sends contradictory values for (n, k)?
- Initiator or network is too slow, and no delivery happens within some timeout?

Solution: **view change & new view protocols:**

- Nodes time out & broadcast "ViewChange": 2f+1 messages, new view for the same decision.
- Must not rely on the same initiator -> might be faulty!
- Commit phase: safety across views. Must propose the same value if one was committed.
- How to tune timeouts?

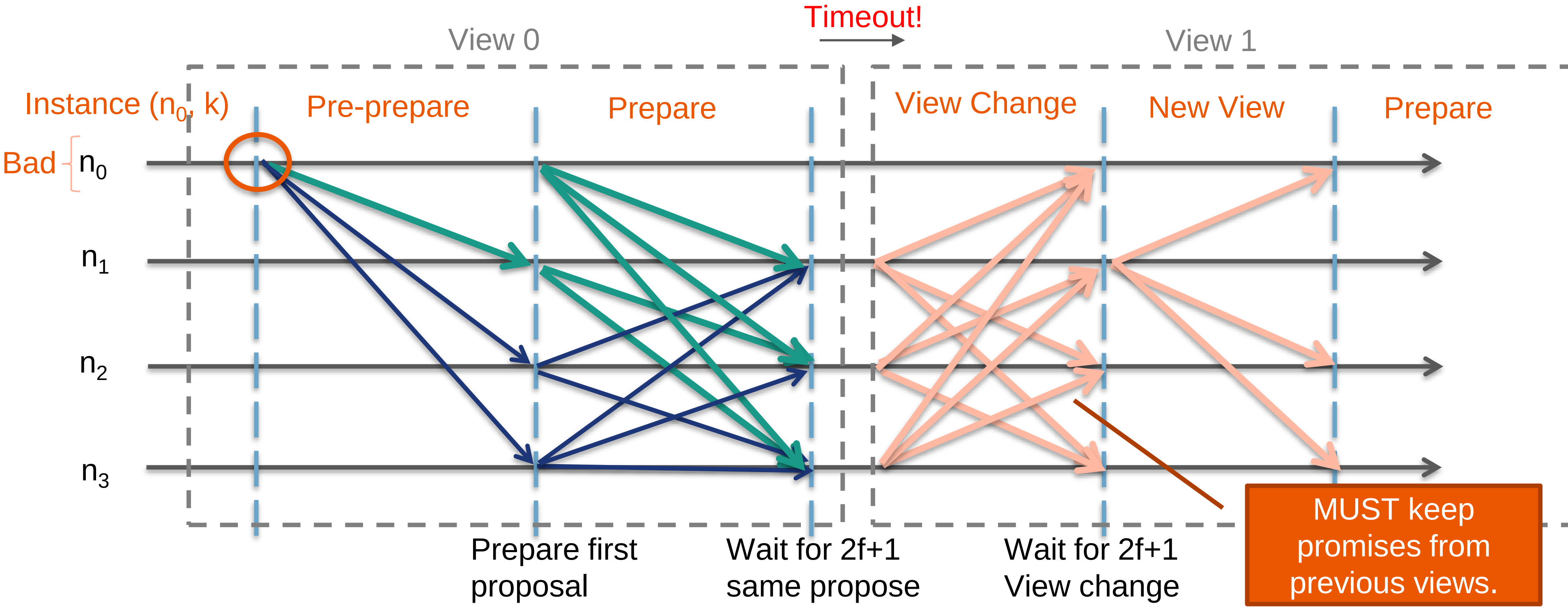
View Change & New View Preserves Liveness (1)

- Consider n_0 **is byzantine** – N = 3f+1. Example attack: **failed termination for view 0.**



View Change & New View Preserves Liveness (2)

- Consider **n_0 is byzantine** – N = 3f+1.



Blockmania vs PBFT View Change Simplifications

Traditional PBFT is complex:

- Rotate leader.
- Decide on a sequence of decisions/transactions.
- New leader must propose a value for all previous positions.

Blockmania takes a simpler view:

- No special leader (but initiator for each instance).
- Each instance of the consensus protocol to decide one block per node / position. (n_i, k) -> B.
- On new view either any node propose: (1) “no block” if none of the 2t+1 have committed or (2) the one value committed (there can only be one).
- Finality: either decide a block for a position, or “no block”.

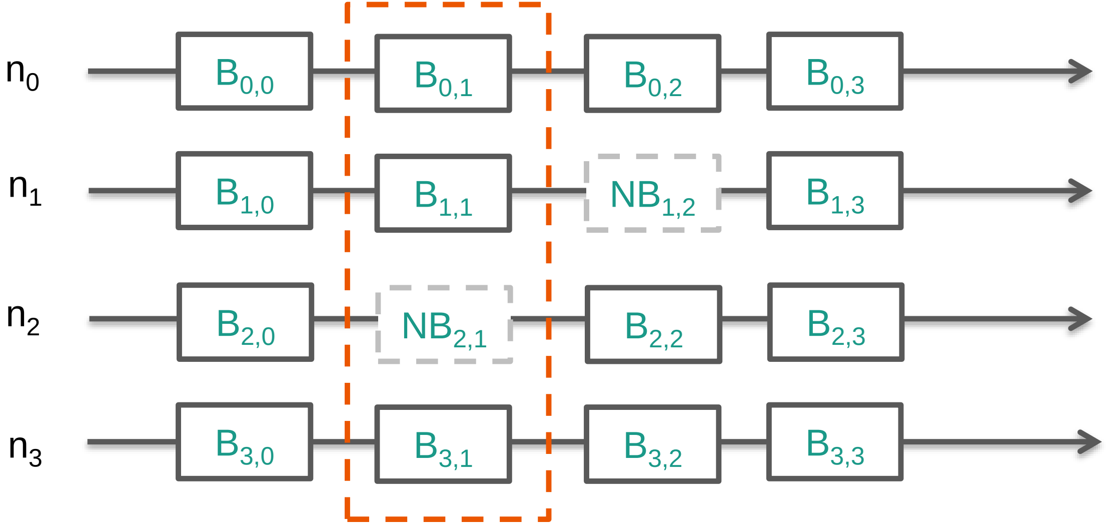
From block agreement to full consensus

Order all transaction in decisions (n_i, k)

- Agree on a block, or ‘no block’ for all nodes in round k.
- Apply a deterministic function to all transactions to get a total order.
- Hash of transaction = PoW.
- Order by fee.
- Commit then reveal + shared randomness for unbiasable order.

From Blockmania Instances to Full Consensus

- Run blockmania instance for each node and position
- Determine block $B_{i,k}$ or no block $NB_{i,k}$



Once all blocks in a round are determine, apply any deterministic ordering function to get a total order.

(1) By Hash = PoW
(2) By fee is what we do.

BLOCKMANIA

Efficient Network Instantiation

Problems with naïve implementations

Costs & complexities

Sending **explicit messages for all decisions** is Naive.

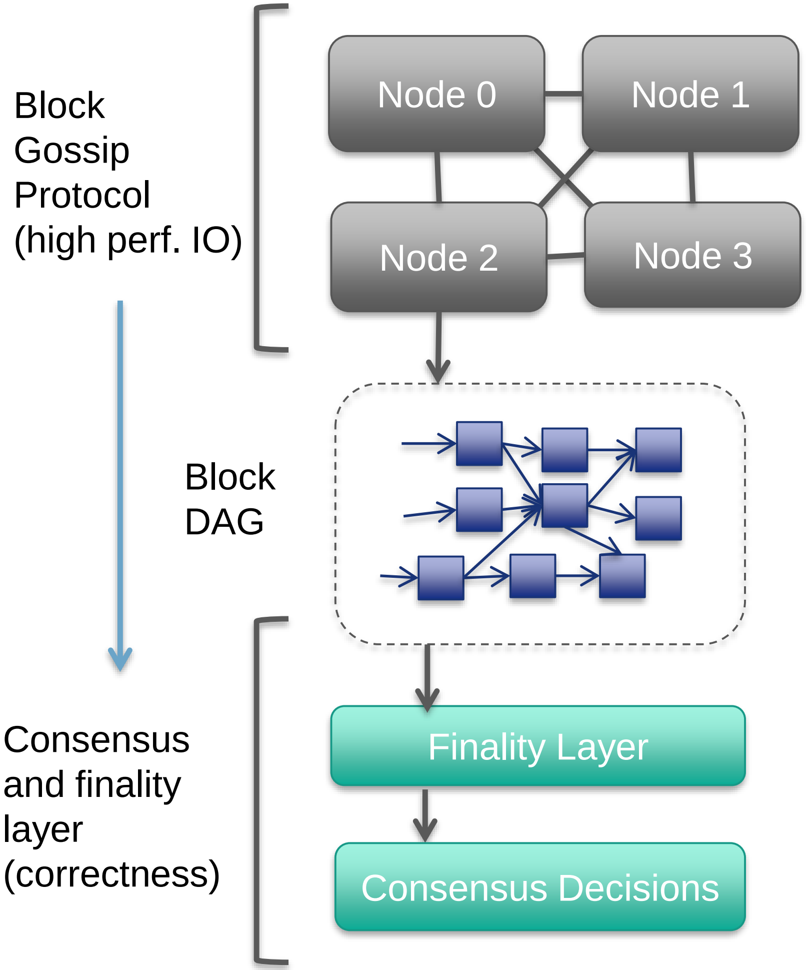
Inefficiencies and complexities:

- **Mixing code** for networking (efficient asynchronous IO) & protocol logic are intermixed (correctness).
- **Explicit evidence** for all Commit, View Change, New View messages. Increase in size $O(N^3)$ to $O(N^4)$.
- **Full separate 3-rounds** for each decision.

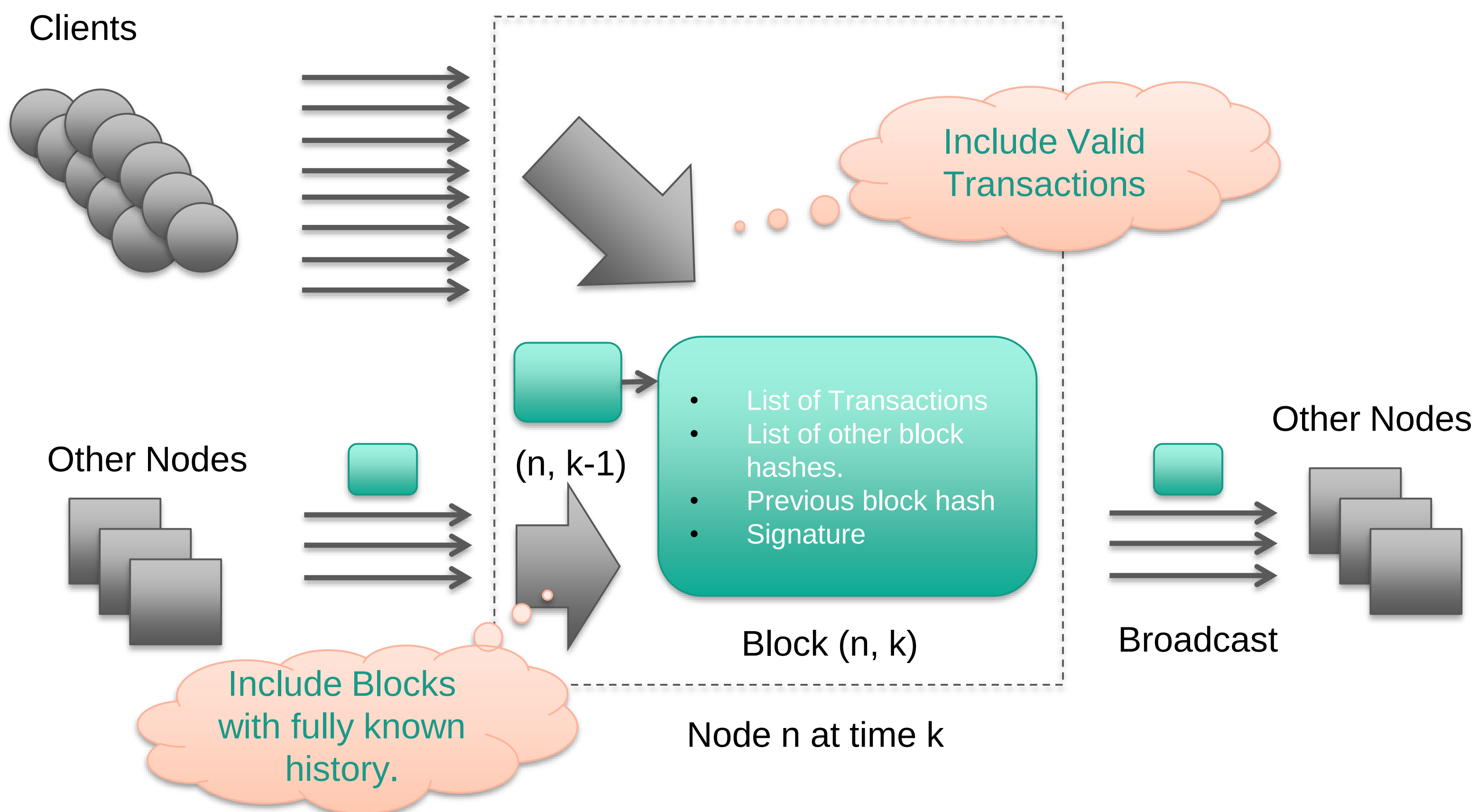
Result: few PBFT quality implementations.

Blockmania Architecture

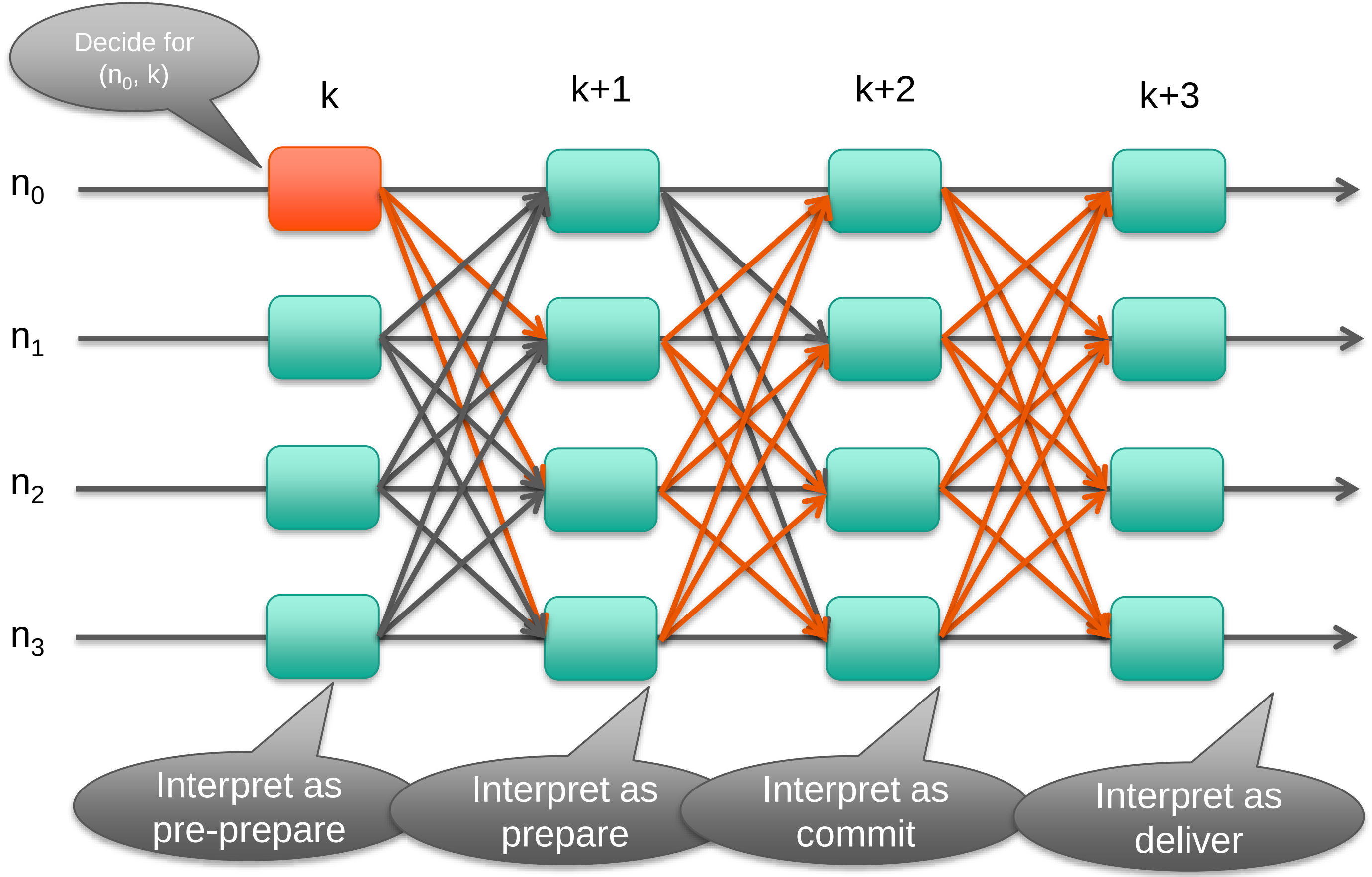
Block DAG + Finalization



The Block DAG networking layer



The finalization layer (interpreting core consensus)



Insight:

Since core protocol is deterministic can “simulate” the state of others through messages received and sent.

BLOCKMANIA

PERFORMANCE

Concrete Performance & Theory

Small constants make a difference

Concrete WAN performance (Tx/sec) for different quorum sizes:

- 10 nodes (f=2) – 430K tx/sec
- 13 nodes (f=3) – 440K tx/sec
- 16 nodes (f=4) – 520K tx/sec

(not stat. different, Network bound).

Theory: $O(N^2)$ communication cost:

- Blocks are broadcast to all $O(N)$.
- Blocks are $O(N)$ (hashes)
- **However, low constants**:

  20 bytes * N^2 + transaction bytes * N

Questions so far?

And more topics for subsequent discussion

More **blockmania topics**:

- Byzantine clock sync.
- Encouraging partial synchrony.
- O(n) variant of Blockmania.
- Sequential variants.
- Reliable Broadcast variants.
- Statistical variants ('AvalanceMania').
- Integration with Proof of Stake.

SHARDING FOR BETTER SCALABILITY

Chainspace & SBAC

- The world needs more than 500K tx/second

How to build a scalable distributed system?

A generic primer

Scalability is not the same as a high number of tx/sec.

Scalability: the more resources you invest in the system the more tx/sec you can process.

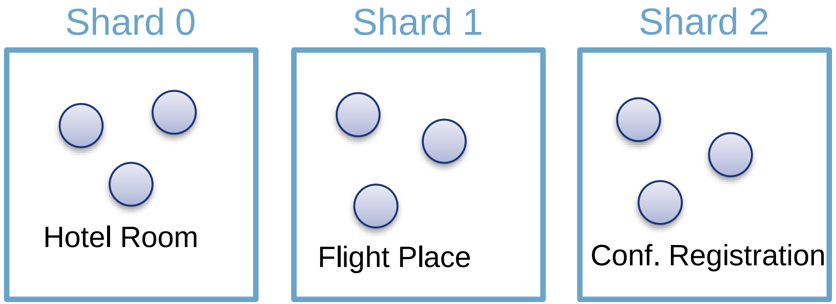
PBFT/Blockmania: not scalable by that definition (cost $O(N)$ / $O(N^2)$) in N resources.

Sharding is a generic solution.

Sharding: ensure that a transaction only uses $O(1)$ to $O(\log N)$ resources to be processed.

Sharding Challenges

Not easy even in theory



Naïve sharding: just partition all state, and have the many different shards not interact with each other.

Problem: How to ensure atomicity for opetations? Eg. I want a booking for a flight, hotel and conference to be “all-or-nothing”.

Naïve solution 2: No cross shard transactions (poor functionality); or super-shards deals with those (poor scalability).

Chainspace: Shards need to coordinate a little bit!

Chainspace execution model

Objects: Objects contain state within the system.

Object status: Objects may be active, inactive or locked. (Shard shared state!)

c.T(x,y) -> z

Procedures: Take one of more objects as inputs, and produce one or more object outputs.

Object status: to succeed a procedure should use “active” objects, and turns them inactive.

Transaction: A trace of execution of one or more transactions, including all the input and output objects for one or more procedures.

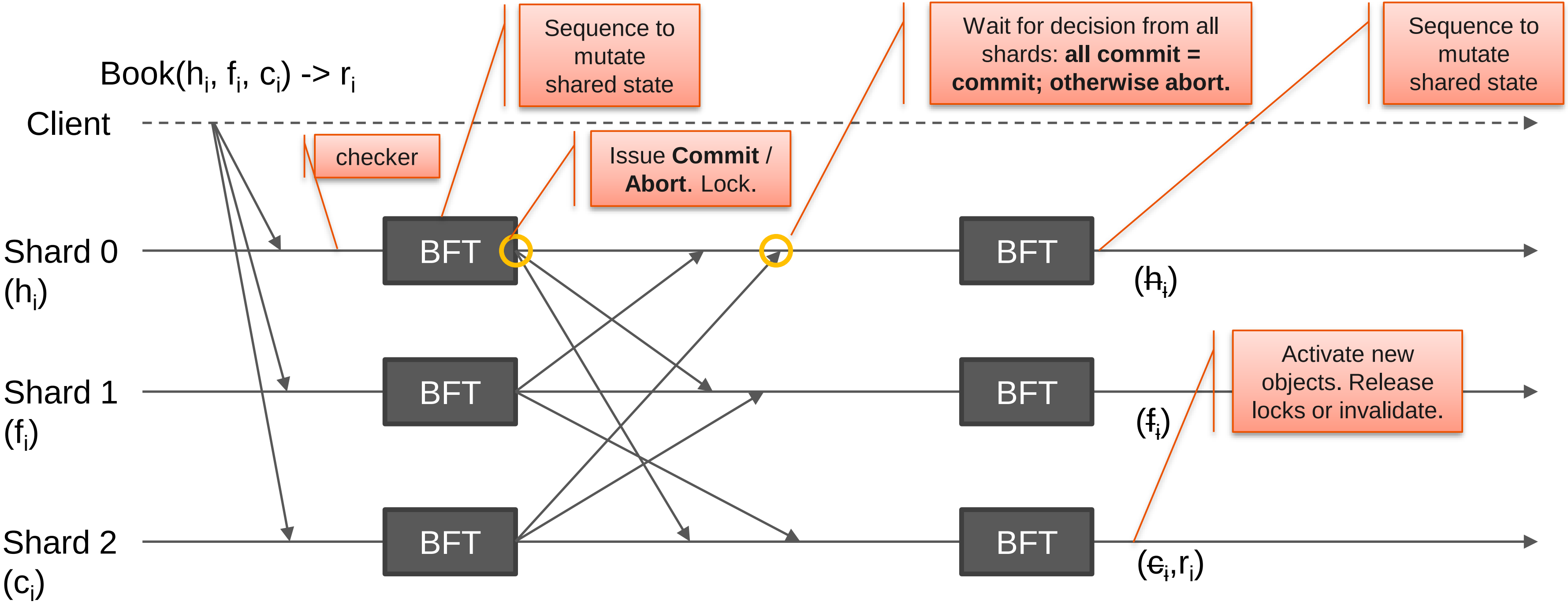
[c, T, (x,y), z]

Why many? To allow subroutine calls and cross contact calls.

Checkers: Code that takes the trace of execution of a single procedure and returns true if it conforms to the contract.

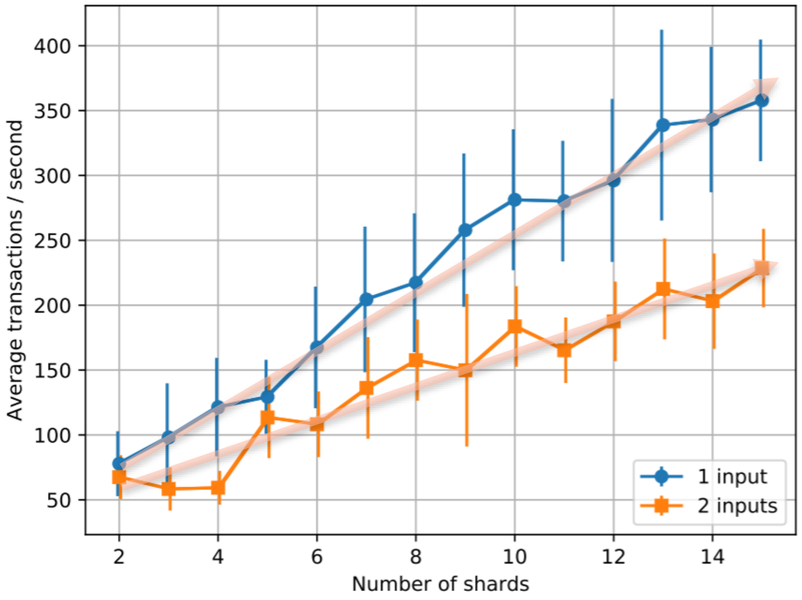
Note: clients execute procedures, and pack transactions for checkers to check in shards.

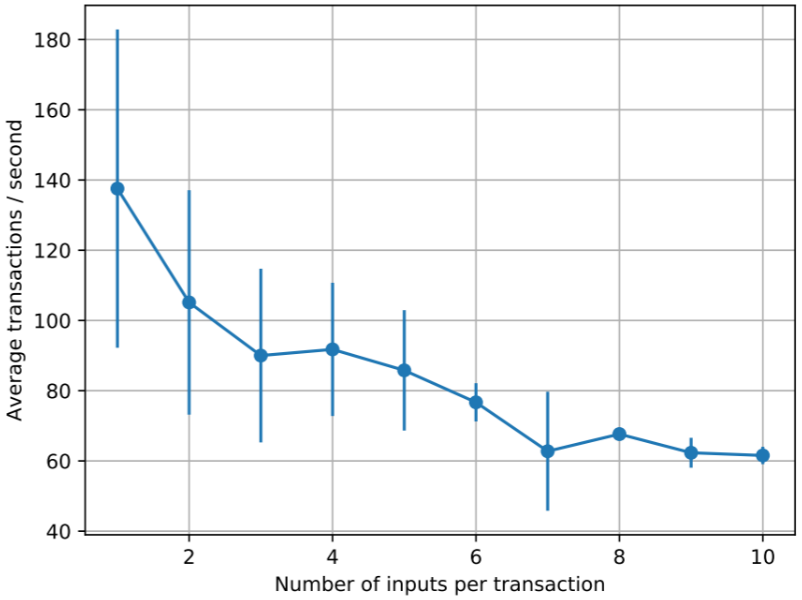
Sharded Byzantine Atomic Commit Protocol (SBAC)



SBAC guarantees either all process transaction (eventually) or none does. (Safety)
Liveness follows from the liveness of consensus within each shard.

Performance (Summer 2017)



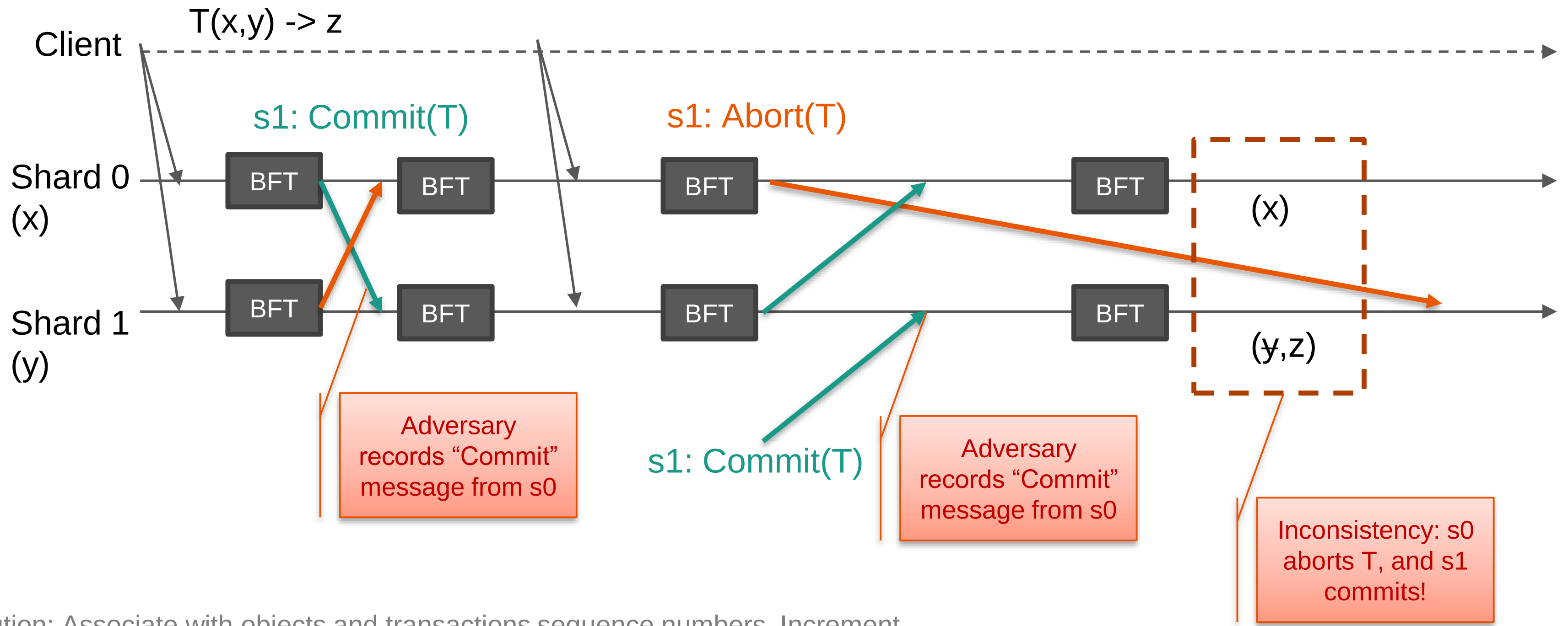


Validation: the more shards, the more transactions per second – linearly.

THE TRICKS THAT NEVER MAKE IT TO THE PAPER

SBAC in the real-world

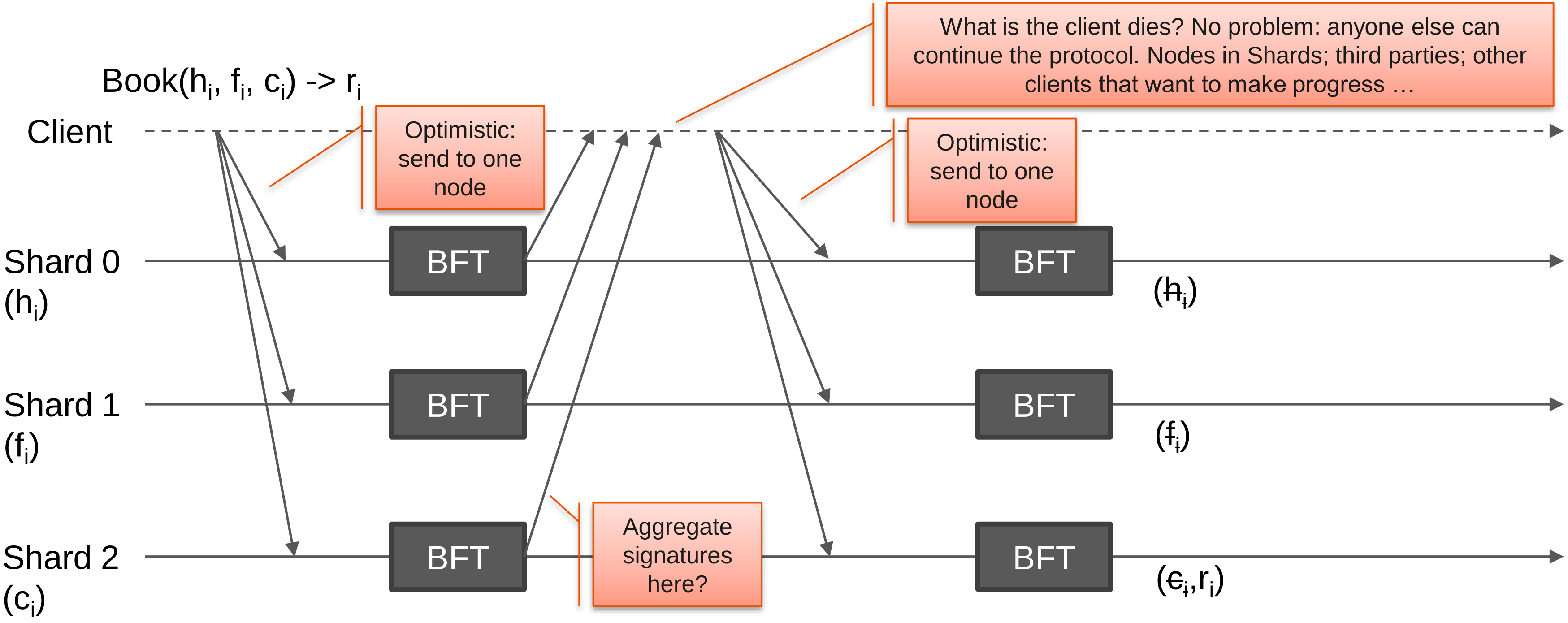
Security Under Composition: an attack



Solution: Associate with objects and transactions sequence numbers. Increment Those wisely. And use them to discard replays. (See manuscript soon).

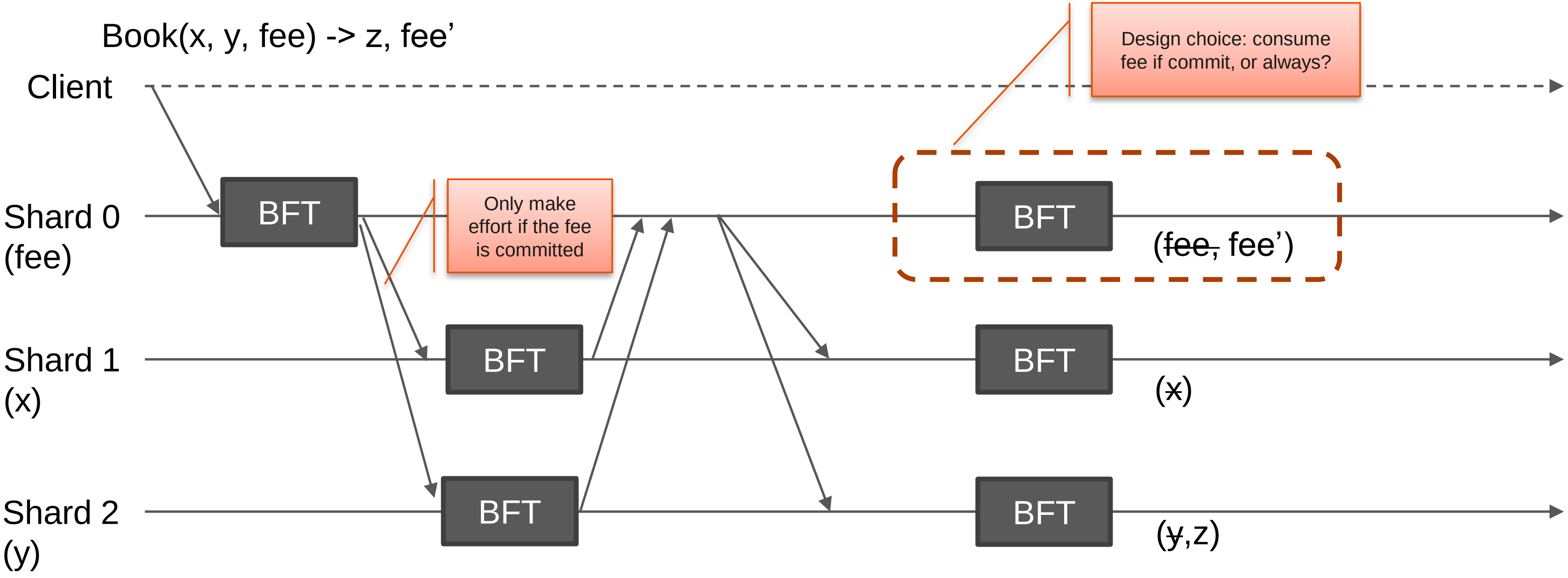
Performance improvements.

Problem: opening a lot of sockets is expensive. $O(S^2)$ in the number of shards per transaction.
Solution: Anyone can “drive this protocol” (thanks to Omniledger crew for this!)



SBAC for fun, but mostly for profit.

Problem: SBAC is an expensive protocol. Only execute for a fee!
Solution: make SBAC steps conditional on commit for fee shard.



The missing details

The joys of building real systems …

Why procedures vs checkers?

Privacy?

How to support light clients?

What if one or more shards do not have an honest supermajority?

How to shard audit and verification?

How to assign nodes to shards?

Smart contract lifetime management?

Separate checkers from nodes?

Updating smart contracts?

Non-deterministic contracts?

Sybil attack resistant open system?

Proof of stake economics?

Dynamic fees according to congestion?

…

Thanks for listening

george@chainspace.io