

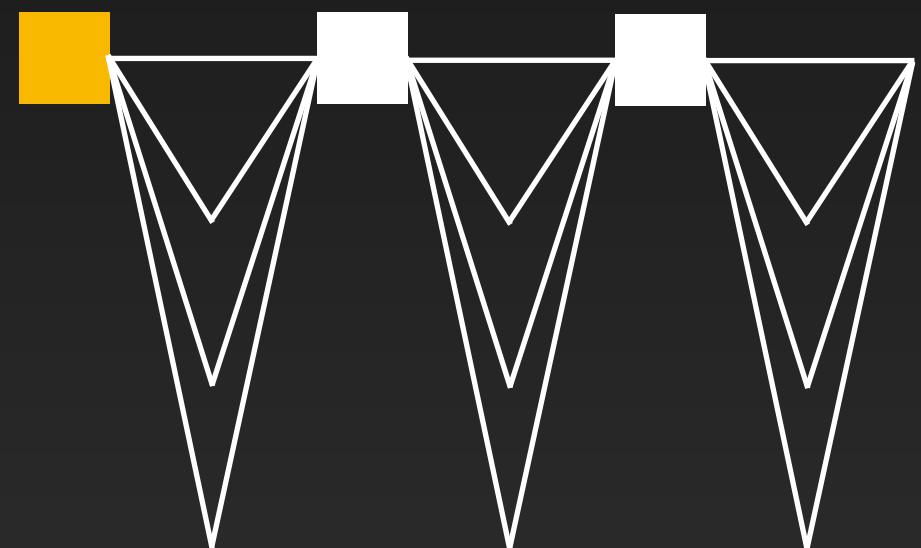
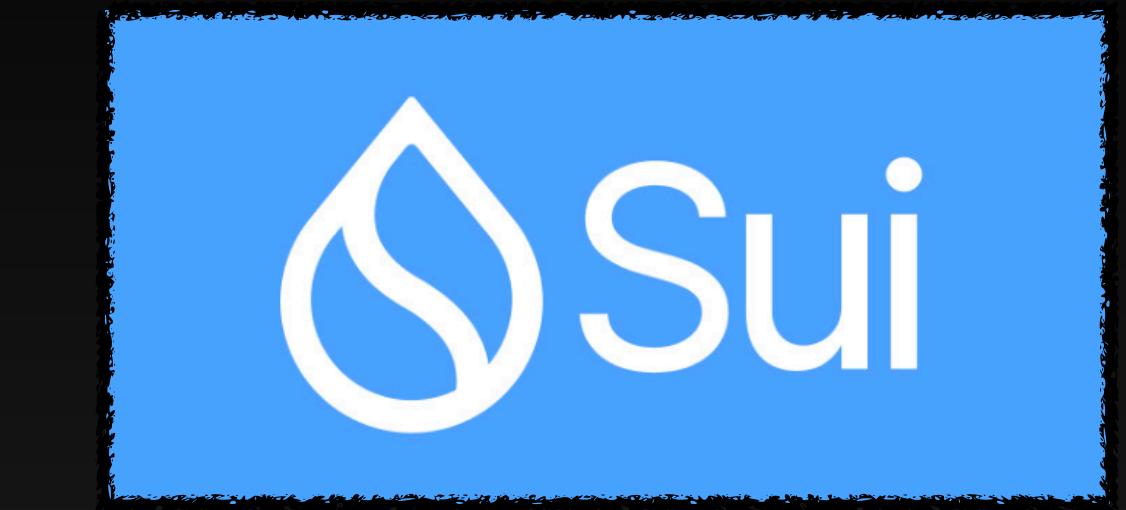
The Evolution of Sui

From Academic Paper to Mainnet

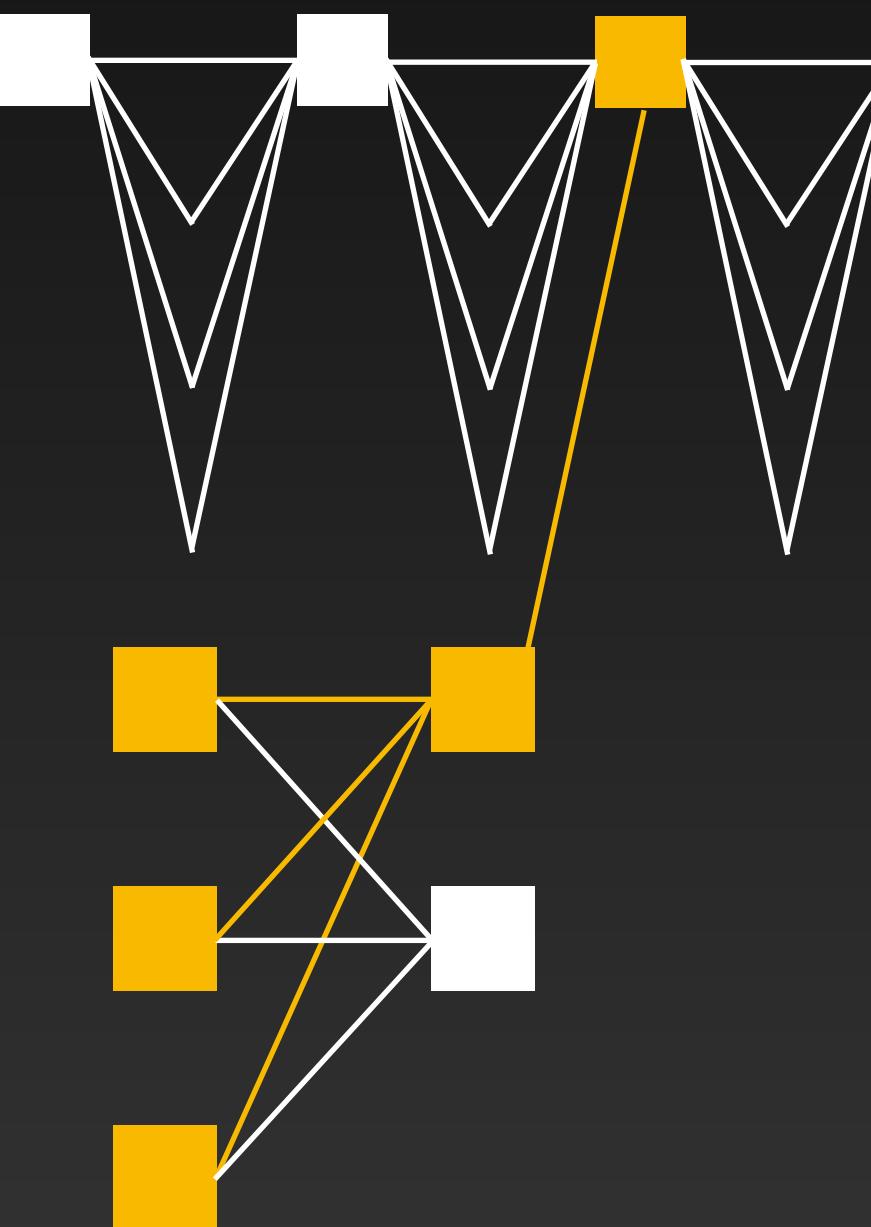
2019



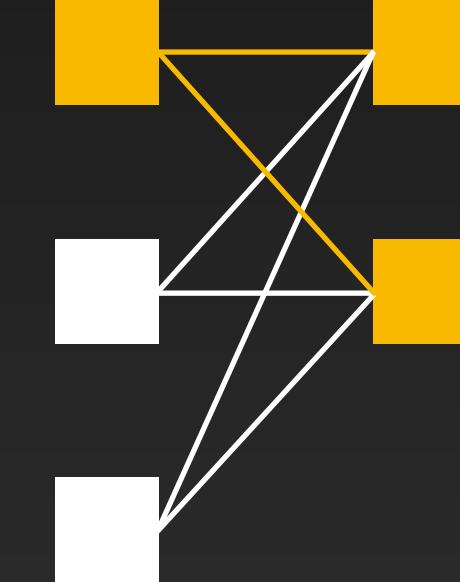
2024



HotStuff



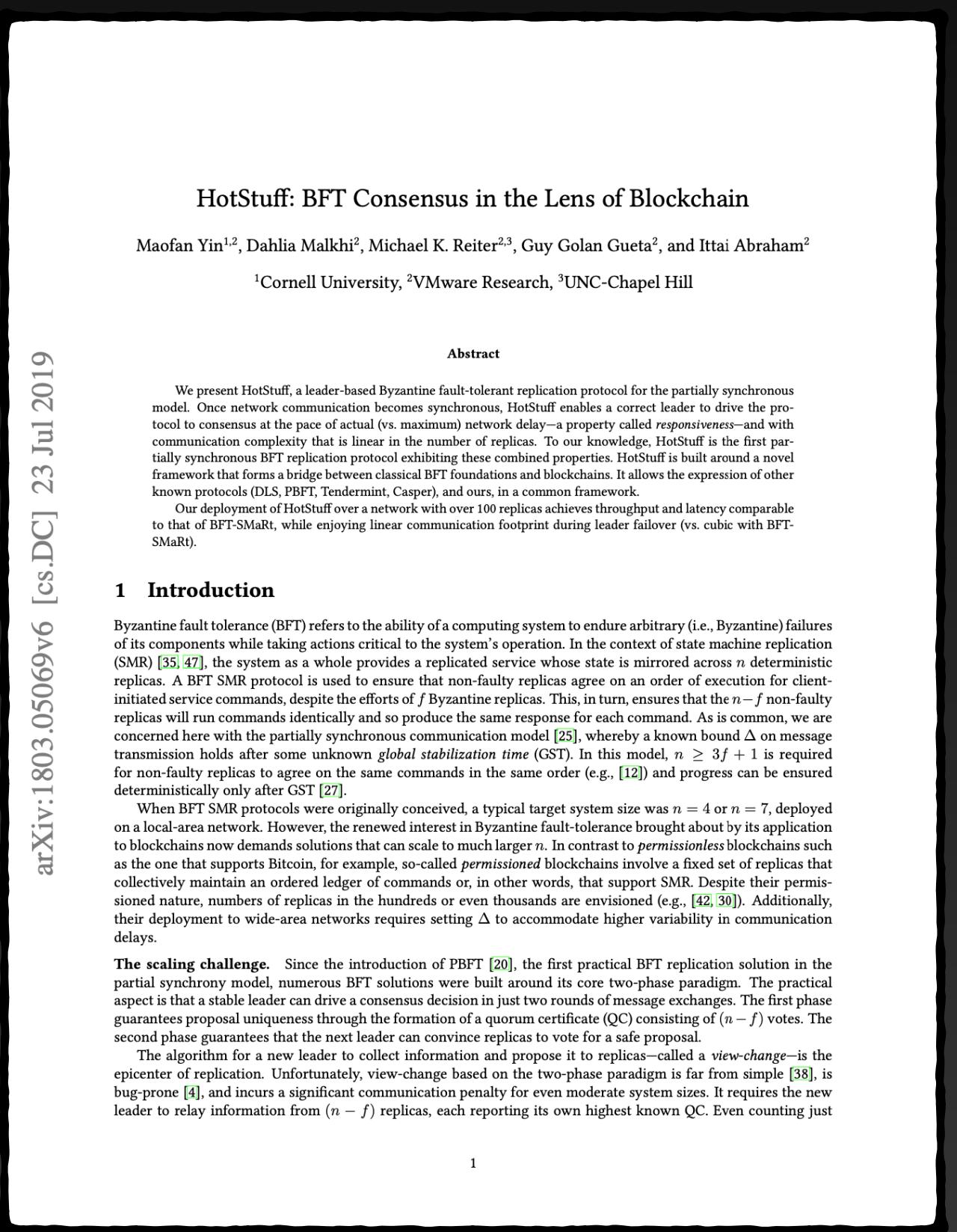
HotStuff + Mempool



**Bullshark,
Mysticeti**

Libra, 2019

HotStuff



arXiv:1803.05069v6 [cs.DC] 23 Jul 2019

HotStuff: BFT Consensus in the Lens of Blockchain

Maofan Yin^{1,2}, Dahlia Malkhi², Michael K. Reiter^{2,3}, Guy Golan Gueta², and Ittai Abraham²

¹Cornell University, ²VMware Research, ³UNC-Chapel Hill

Abstract

We present HotStuff, a leader-based Byzantine fault-tolerant replication protocol for the partially synchronous model. Once network communication becomes synchronous, HotStuff enables a correct leader to drive the protocol to consensus at the pace of actual (vs. maximum) network delay—a property called *responsiveness*—and with communication complexity that is linear in the number of replicas. To our knowledge, HotStuff is the first partially synchronous BFT replication protocol exhibiting these combined properties. HotStuff is built around a novel framework that forms a bridge between classical BFT foundations and blockchains. It allows the expression of other known protocols (DLS, PBFT, Tendermint, Casper), and ours, in a common framework.

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1



HashGraph



arXiv:2102.01167v1 [cs.LO] 1 Feb 2021

Verifying the Hashgraph Consensus Algorithm

Karl Crary
Carnegie Mellon University

Abstract

The Hashgraph consensus algorithm is an algorithm for asynchronous Byzantine fault tolerance intended for distributed shared ledgers. Its main distinguishing characteristic is it achieves consensus without exchanging any extra messages; each participant's votes can be determined from public information, so votes need not be transmitted.

In this paper, we discuss our experience formalizing the Hashgraph algorithm and its correctness proof using the Coq proof assistant. The paper is self-contained; it includes a complete discussion of the algorithm and its correctness argument in English.

1 Introduction

Byzantine fault-tolerance is the problem of coordinating a distributed system while some participants may maliciously break the rules. Often other challenges are also present, such as a lack of communication. The challenge is the creation of a variety of new applications, such as cryptocurrencies. Such applications rely on *distributed shared ledgers*, a form of Byzantine fault-tolerance in which a set of transactions are placed in a globally-agreed total order that is *immutable*. The latter means that once a transaction enters the order, no new transaction can enter at an earlier position.

A distributed shared ledger makes it possible for all participants to agree, at any point in the order, on the current owner of a digital commodity such as a unit of cryptocurrency. A transaction transferring ownership is valid if the commodity's current owner authorizes the transaction. (The authorization mechanism—presumably using a digital signature—is beyond the scope of the ledger itself.) Because the order is total, one transaction out of any pair has priority. Thus we can show that a commodity's chain of ownership is uniquely determined. Finally, because the order is immutable, the chain of ownership cannot change except by adding new transactions at the end.

Algorithmic Byzantine consensus (under various assumptions) have existed for some time, indeed longer than the protocol has been named [12, 9]. Practical algorithms are more recent; in 1999, Castro and Liskov [6] gave an algorithm that when installed into the NFS file system slowed it only 3%. As Byzantine consensus algorithms have become more practical, they have been tailored to specific applications. Castro and Liskov's algorithm was designed for fault-tolerant state machine replication [13] and probably would not perform well under the workload of a distributed shared ledger.

However, in the last few years there have arisen Byzantine fault-tolerance algorithms suitable for distributed shared ledgers, notably HoneyBadgerBFT [10], BEAT [7], and—the subject of this paper—Hashgraph [2]. Moreover, the former two each claim to be the first practical *asynchronous* BFT algorithm (with different standards of practicality). Hashgraph does not claim to be first, but is also practical and asynchronous.

In parallel with that line of work has been the development of distributed shared ledgers based on *proof of work*, beginning with Bitcoin [11]. The idea behind proof of work is to maintain agreement on the ledger by maintaining a list of blocks of transactions, and to ensure that the list does not become a tree. To ensure this, the rules state that (1) the longest branch defines the list, and (2) to create a new block, one must solve a difficult computational problem that takes the last old header as part of its input. The problem's solution is much easier to verify than to obtain, so when one learns of a new block, one's incentive is to restart work from the new head rather than continue work from the old head.

Bitcoin and some of its cousins are widely used, so in a certain sense they are indisputably practical. They are truly permissionless, in a way that the BFT algorithms, including Hashgraph, cannot quite claim. Nevertheless, they offer severely limited throughput. Bitcoin is limited to seven transactions per second and has a latency of one hour, while its BFT competitors all do several orders of magnitude better. Proof-of-work systems are also criticized for being wasteful: an enormous amount of electricity is expended on block-creation efforts that nearly always fail. Finally—more to the point of this paper—the theoretical properties of proof of work are not well understood.

The Hashgraph consensus algorithm is designed to support high-performance applications of a distributed shared ledger. Like the other BFT systems, it is several orders of magnitude faster than proof of work. Actual performance depends very much on configuration choices (e.g., how many peers, geographic distribution, tradeoff between latency and throughput, etc.), but in all configurations published in Miller, et. al [10] (for HoneyBadgerBFT) and Duan, et al. [7] (for BEAT), the Hashgraph algorithm equals or exceeds the published performance figures [4]. A frequently cited throughput goal is to equal the Visa credit-card network. According to Visa's published figures, Hashgraph can

Libra, 2019

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When BFT SMR protocols were originally conceived, a typical target system size was $n = 4$ or $n = 7$, deployed on a local-area network. However, the renewed interest in Byzantine fault-tolerance brought about by its application to blockchains now demands solutions that can scale to much larger n . In contrast to *permissionless* blockchains such as the one that supports Bitcoin, for example, so-called *permissioned* blockchains involve a fixed set of replicas that collectively maintain an ordered ledger of commands or, in other words, that support SMR. Despite their permissioned nature, numbers of replicas in the hundreds or even thousands are envisioned (e.g., [42, 30]). Additionally, their deployment to wide-area networks requires setting Δ to accommodate higher variability in communication delays.

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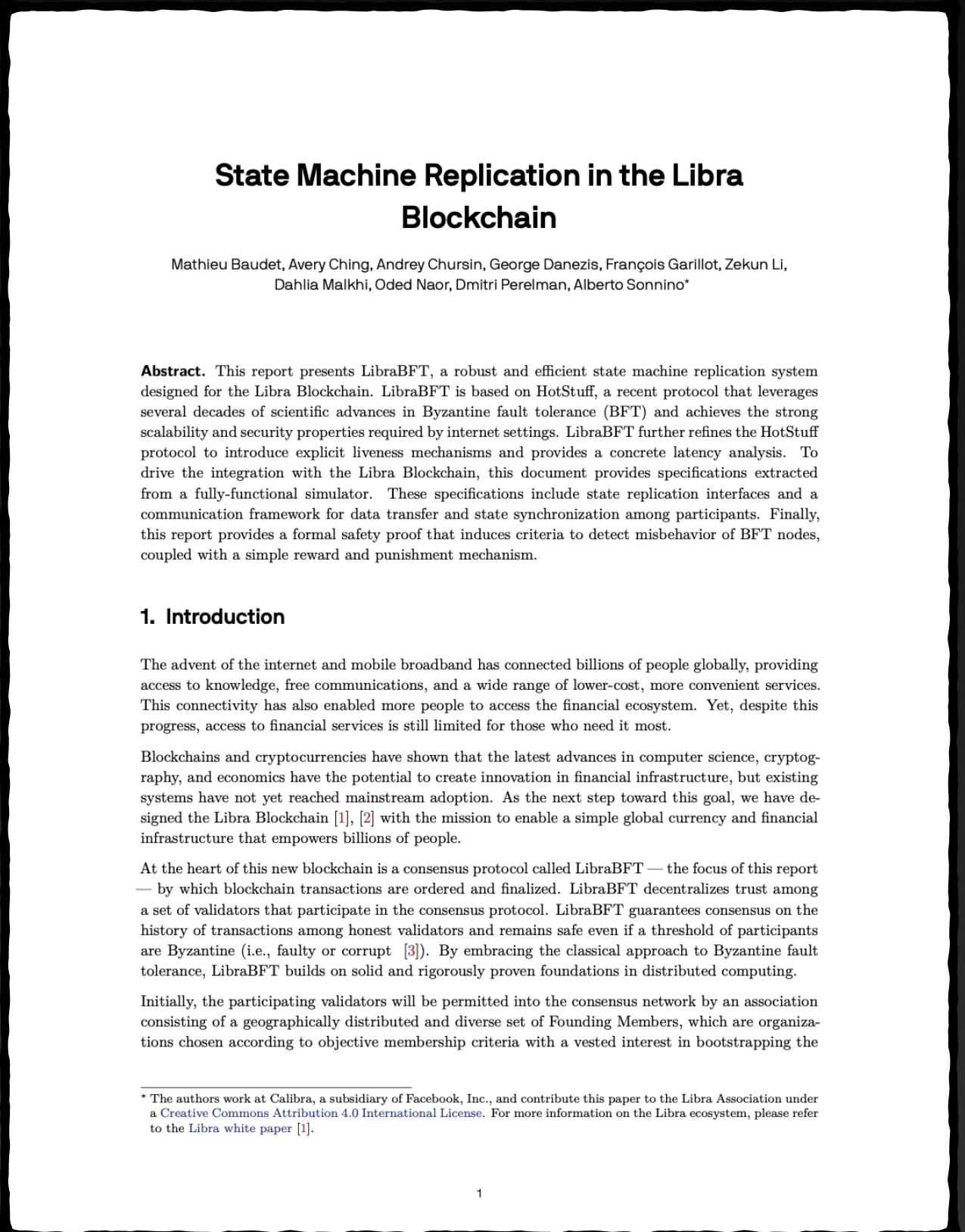
HotStuff

- ✓ Linear
- ✓ Clearly isolated components

HashGraph

- ✗ Hard to garbage collect
- ✗ Unclear block synchroniser

The first 6 months...



SMR in the Libra Blockchain

- The LibraBFT/DiemBFT pacemaker
- Codesign the pacemaker with the rest

State Machine Replication in the Libra Blockchain

Mathieu Baudet, Avery Ching, Andrey Chursin, George Danezis, François Garillot, Zekun Li, Dahlia Malkhi, Oded Naor, Dmitri Perelman, Alberto Sonnino*

Abstract. This report presents LibraBFT, a robust and efficient state machine replication system designed for the Libra Blockchain. LibraBFT is based on HotStuff, a recent protocol that leverages several decades of scientific advances in Byzantine fault tolerance (BFT) and achieves the strong scalability and security properties required by internet settings. LibraBFT further refines the HotStuff protocol to introduce explicit liveness mechanisms and provides a concrete latency analysis. To drive the integration with the Libra Blockchain, this document provides specifications extracted from a fully-functional simulator. These specifications include state replication interfaces and a communication framework for data transfer and state synchronization among participants. Finally, this report provides a formal safety proof that induces criteria to detect misbehavior of BFT nodes, coupled with a simple reward and punishment mechanism.

1. Introduction

The advent of the internet and mobile broadband has connected billions of people globally, providing access to knowledge, free communications, and a wide range of lower-cost, more convenient services. This connectivity has also enabled more people to access the financial ecosystem. Yet, despite this progress, access to financial services is still limited for those who need it most.

Blockchains and cryptocurrencies have shown that the latest advances in computer science, cryptography, and economics have the potential to create innovation in financial infrastructure, but existing systems have not yet reached mainstream adoption. As the next step toward this goal, we have designed the Libra Blockchain [1], [2] with the mission to enable a simple global currency and financial infrastructure that empowers billions of people.

At the heart of this new blockchain is a consensus protocol called LibraBFT — the focus of this report — by which blockchain transactions are ordered and finalized. LibraBFT decentralizes trust among a set of validators that participate in the consensus protocol. LibraBFT guarantees consensus on the history of transactions among honest validators and remains safe even if a threshold of participants are Byzantine (i.e., faulty or corrupt [3]). By embracing the classical approach to Byzantine fault tolerance, LibraBFT builds on solid and rigorously proven foundations in distributed computing.

Initially, the participating validators will be permitted into the consensus network by an association consisting of a geographically distributed and diverse set of Founding Members, which are organizations chosen according to objective membership criteria with a vested interest in bootstrapping the

* The authors work at Calibra, a subsidiary of Facebook, Inc., and contribute this paper to the Libra Association under a Creative Commons Attribution 4.0 International License. For more information on the Libra ecosystem, please refer to the Libra white paper [1].

Research Questions

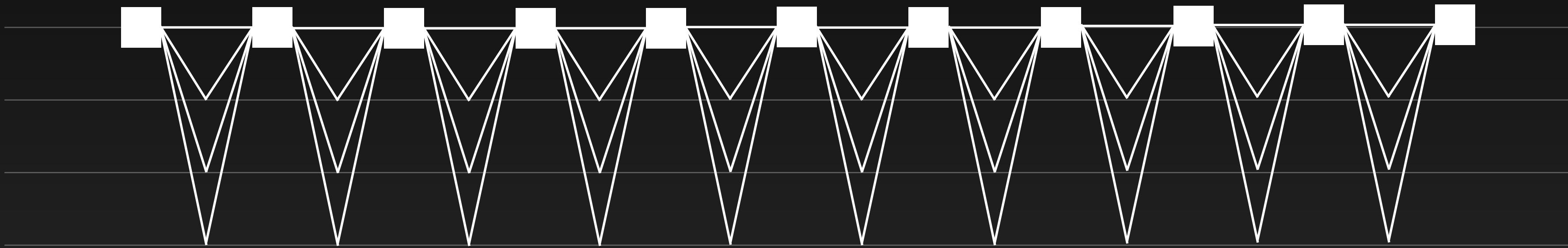
1. Network model?

Lessons Learned

1. Modularisation is a design strategy

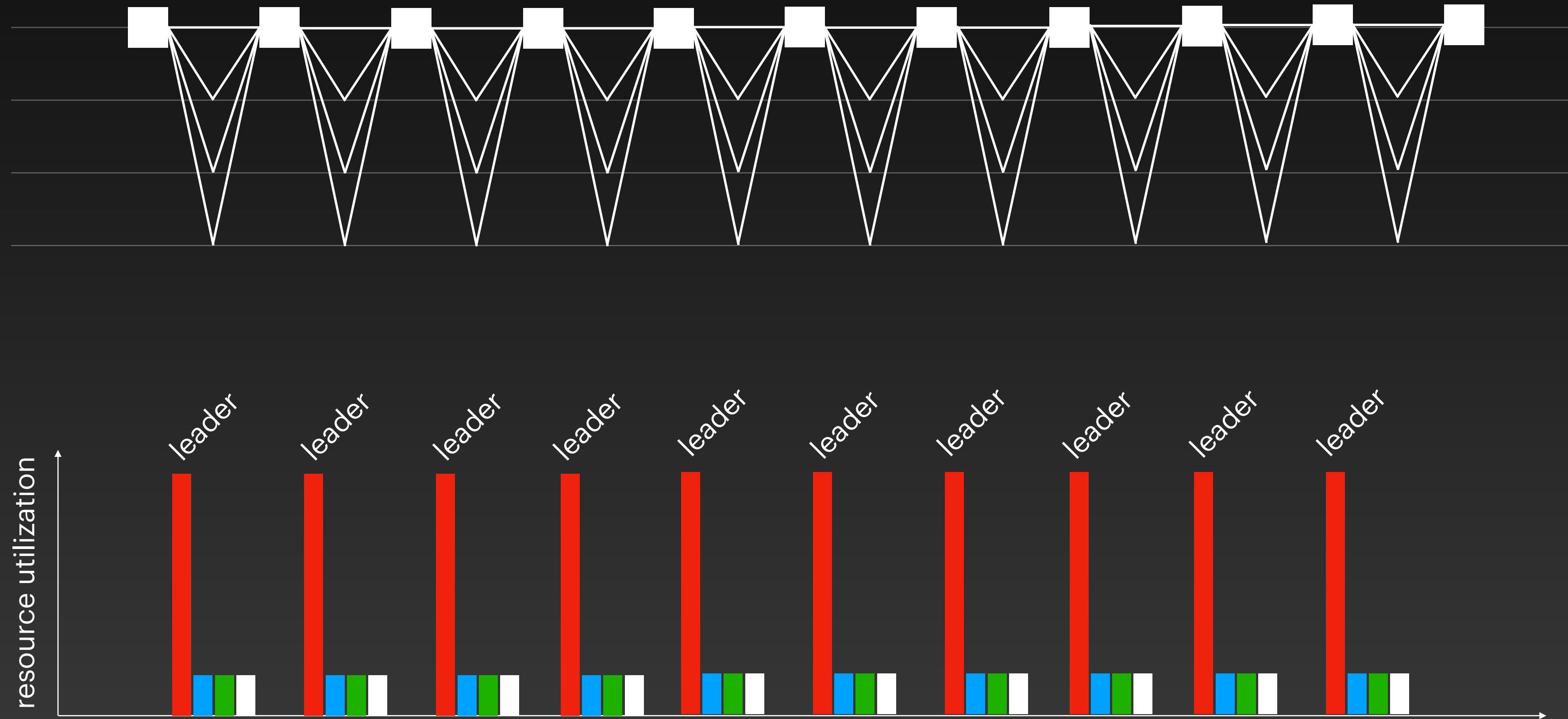
HotStuff

Typical leader-based protocols



Naive Implementation

Uneven resource utilisation



Research Questions

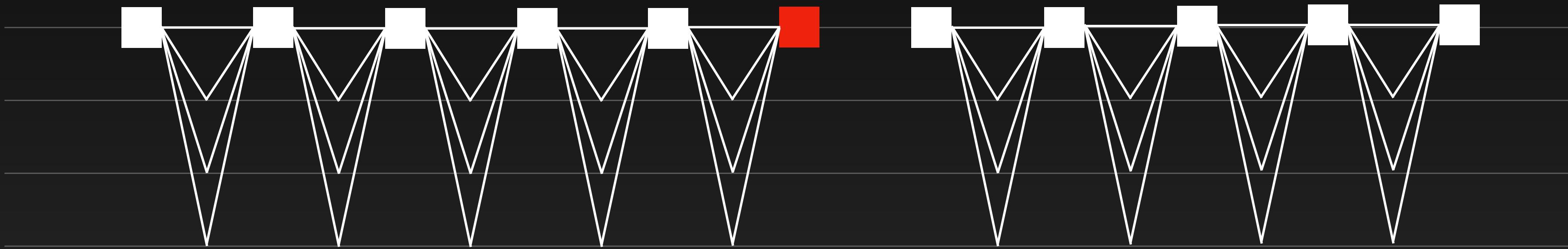
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Lessons Learned

1. Modularisation is a design strategy
2. Tasks-threads allocation

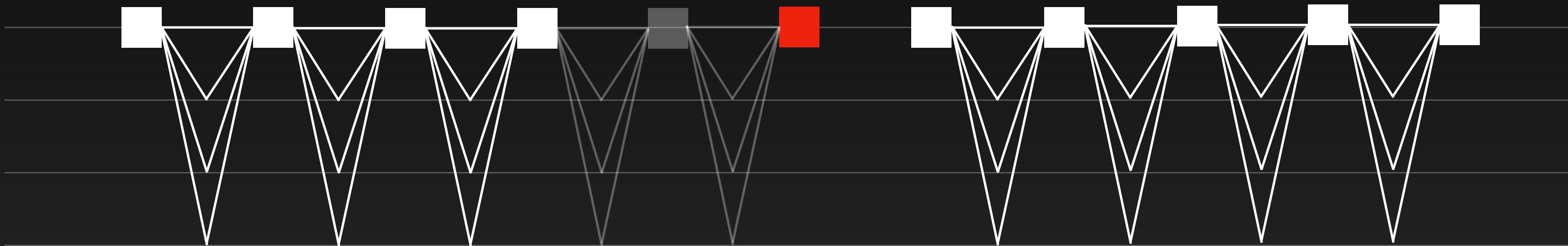
Leader-Driven Consensus

Fragility to faults and asynchrony

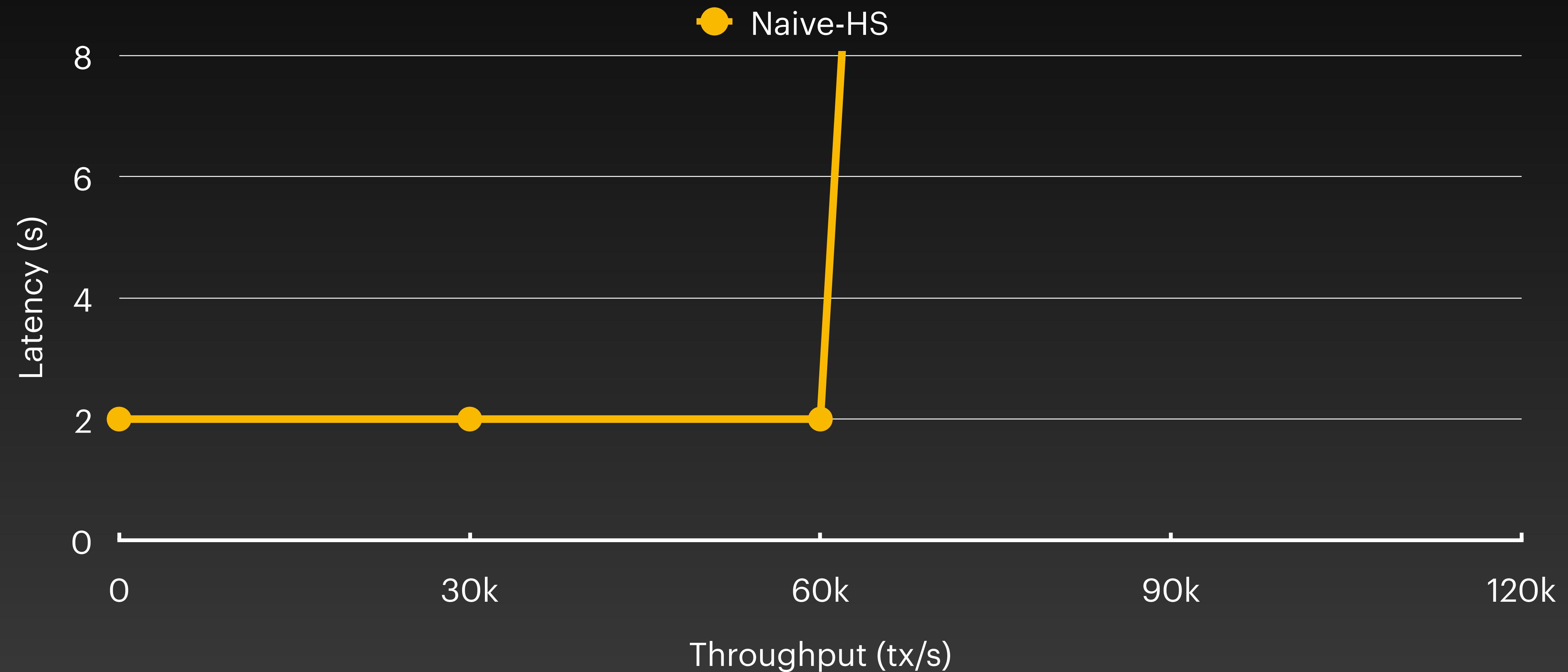


Leader-Driven Consensus

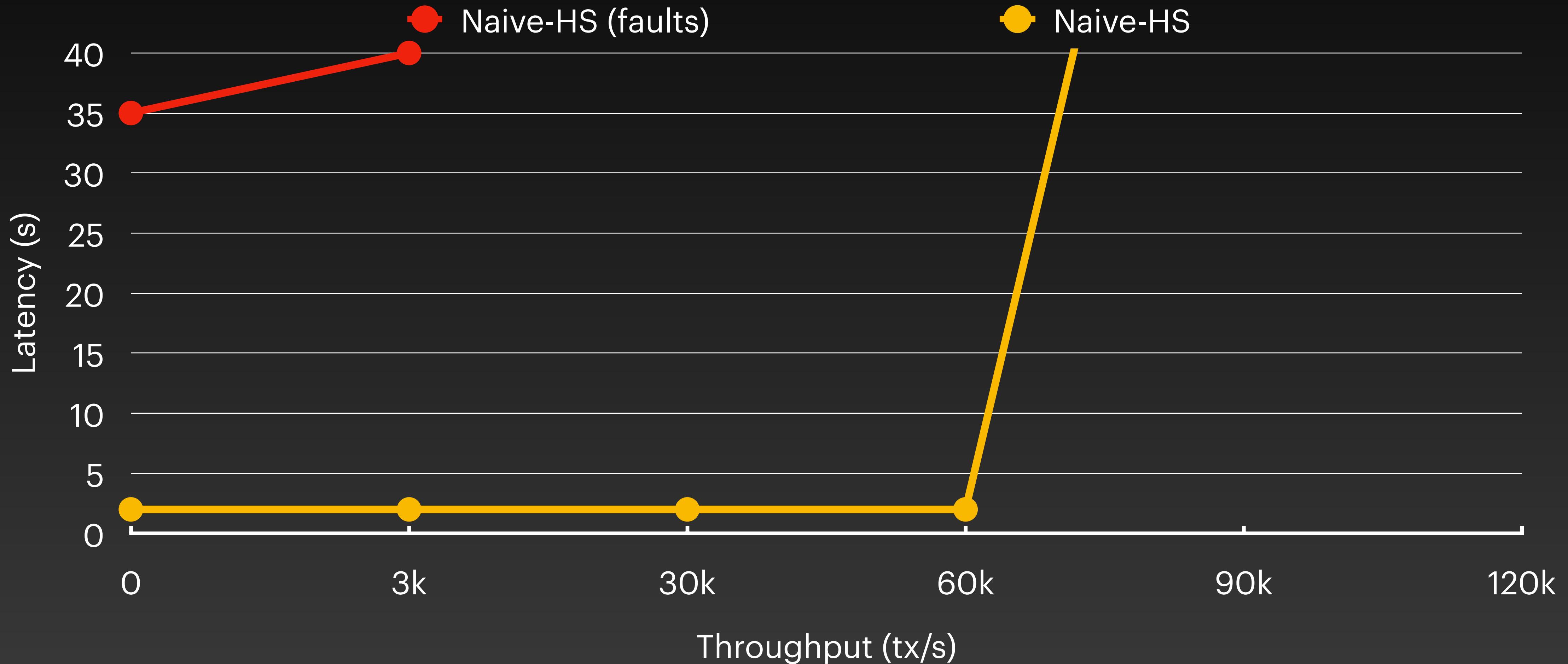
Fragility to faults and asynchrony



Performance



Performance



Research Questions

1. Network model?

Lessons Learned

1. Modularisation is a design strategy
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3. Benchmark early

Libra, 2019

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arXiv:1803.05069v6 [cs.DC] 23 Jul 2019

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HotStuff (naive mempool)

- Linear
- Clearly isolated components
- Uneven resource utilisation
- Fragile to faults and asynchrony
- Unspecified components (pacemaker)

Libra, 2021

Narwhal and Tusk: A DAG-based Mempool and Efficient BFT Consensus

George Danezis
Mysten Labs & UCL

Alberto Sonnino
Mysten Labs

Abstract
We propose separating the task of reliable transaction dissemination from transaction ordering, to enable high-performance Byzantine fault-tolerant quorum-based consensus. We design and evaluate a mempool protocol, Narwhal, specializing in high-throughput reliable dissemination and storage of causal histories of transactions. Narwhal tolerates an asynchronous network and maintains high performance despite failures. Narwhal is designed to easily scale-out using multiple workers at each validator, and we demonstrate that there is no foreseeable limit to the throughput we can achieve.

Composing Narwhal with a partially synchronous consensus protocol (Narwhal-HotStuff) yields significantly better throughput even in the presence of faults or intermittent loss of liveness due to asynchrony. However, loss of liveness can result in higher latency. To achieve overall good performance when faults occur we design Tusk, a zero-message overhead asynchronous consensus protocol, to work with Narwhal. We demonstrate its high performance under a variety of configurations and faults.

As a summary of results, on a WAN, Narwhal-HotStuff achieves over 130,000 tx/sec at less than 2-sec latency compared with 1,800 tx/sec at 1-sec latency for HotStuff. Additional workers increase throughput linearly to 600,000 tx/sec without any latency increase. Tusk achieves 160,000 tx/sec with about 3 seconds latency. Under faults, both protocols maintain high throughput, but Narwhal-HotStuff suffers from increased latency.

CCS Concepts: Security and privacy → Distributed systems security.

Keywords: Consensus protocol, Byzantine Fault Tolerant

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<https://doi.org/10.1145/3492321.3519594>

ACM Reference Format:
George Danezis, Lefteris Kokoris-Kogias, Alberto Sonnino, and Alexander Spiegelman. 2022. Narwhal and Tusk: A DAG-based Mempool and Efficient BFT Consensus . In *Seventeenth European Conference on Computer Systems (EuroSys '22), April 5–8, 2022, Rennes, France*. ACM, New York, NY, USA, 17 pages. <https://doi.org/10.1145/3492321.3519594>

1 Introduction
Byzantine consensus protocols [15, 19, 21] and the state machine replication paradigm [13] for building reliable distributed systems have been studied for over 40 years. However, with the rise in popularity of blockchains there has been a renewed interest in engineering high-performance consensus protocols. Specifically, to improve on Bitcoin's [33] throughput of only 4 tx/sec early works [29] suggested committee based consensus protocols. For higher throughput and lower latency committee-based protocols are required, and are now becoming the norm in proof-of-stake designs.

Existing approaches to increasing the performance of distributed ledgers focus on creating lower-cost consensus algorithms culminating with HotStuff [38], which achieves linear message complexity in the partially synchronous setting. To achieve this, HotStuff leverages a leader who collects, aggregates, and broadcasts the messages of other validators. However, theoretical message complexity should not be the only optimization target. More specifically:

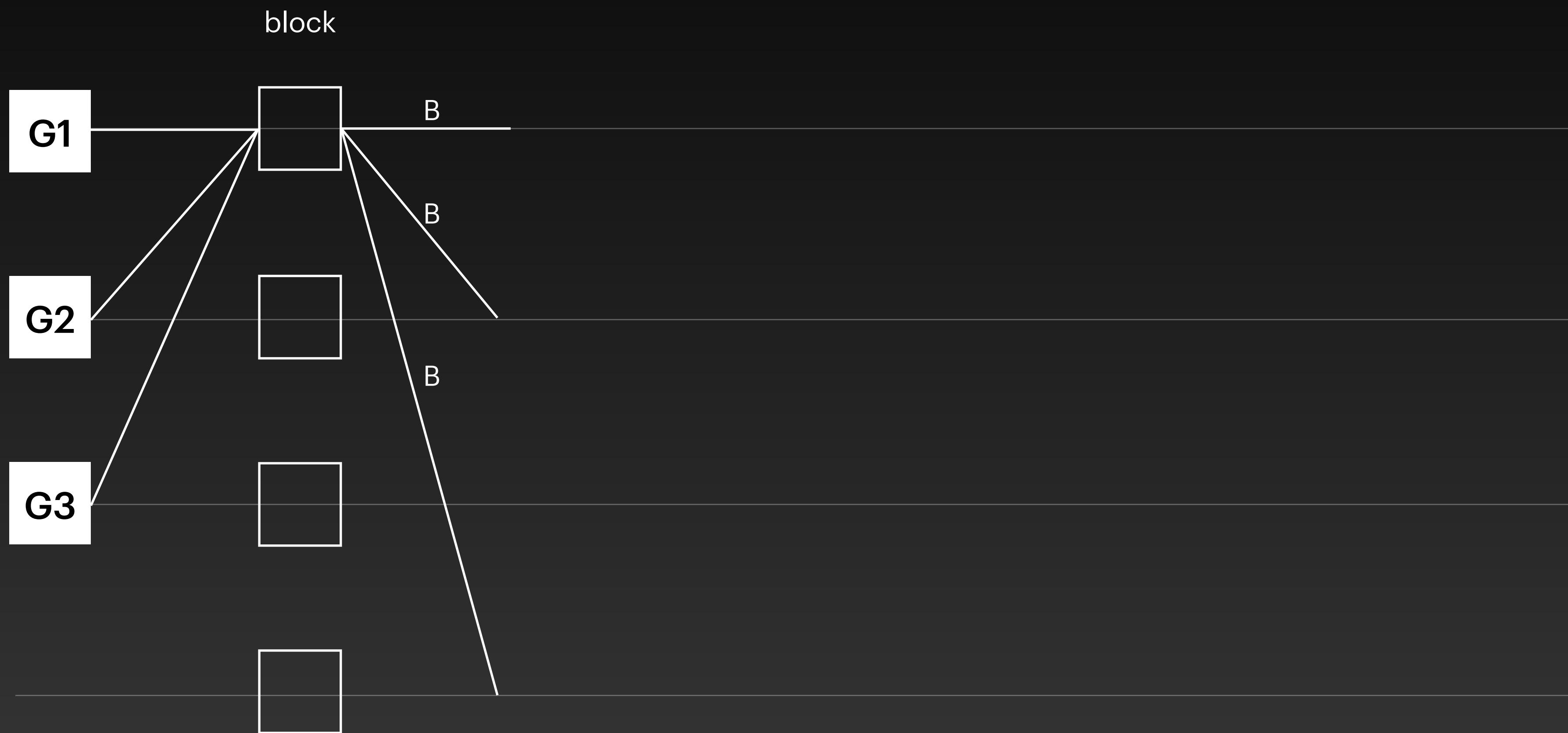
- Any (partially-synchronous) protocol that minimizes overall message number, but relies on a leader to produce proposals and coordinate consensus, fails to capture the high load this imposes on the leader who inevitably becomes a bottleneck.
- Message complexity counts the number of *metadata* messages (e.g., votes, signatures, hashes) which take minimal bandwidth compared to the dissemination of bulk transaction data (blocks). Since blocks are orders of magnitude larger (10MB) than a typical consensus message (100B), the asymptotic message complexity is practically amortized for fixed mid-size committees (up to ~ 50 nodes).

Additionally, consensus protocols have grouped a lot of functions into a monolithic protocol. In a typical distributed

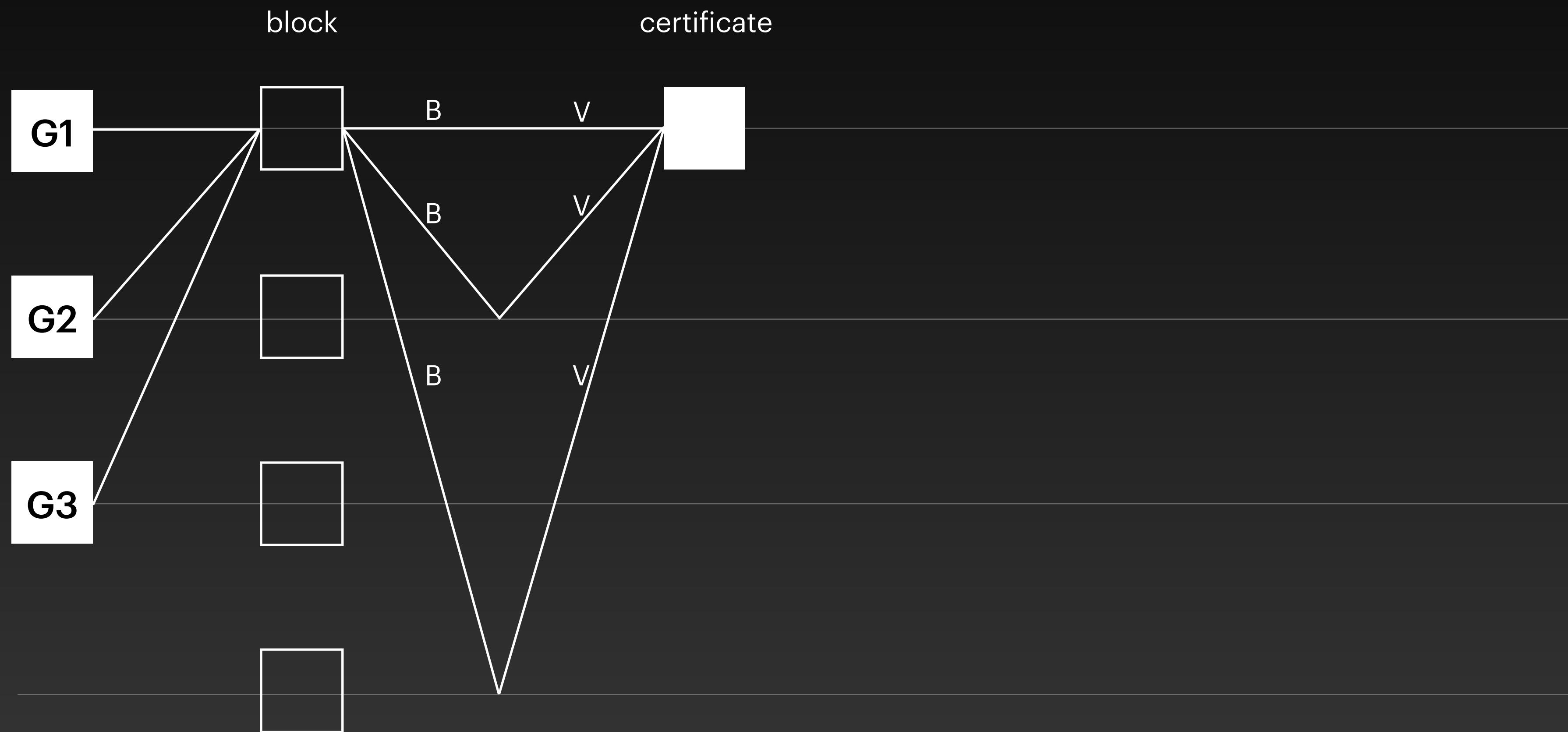
Narwhal

- Quadratic but even resource utilisation
- Separation between consensus and data dissemination

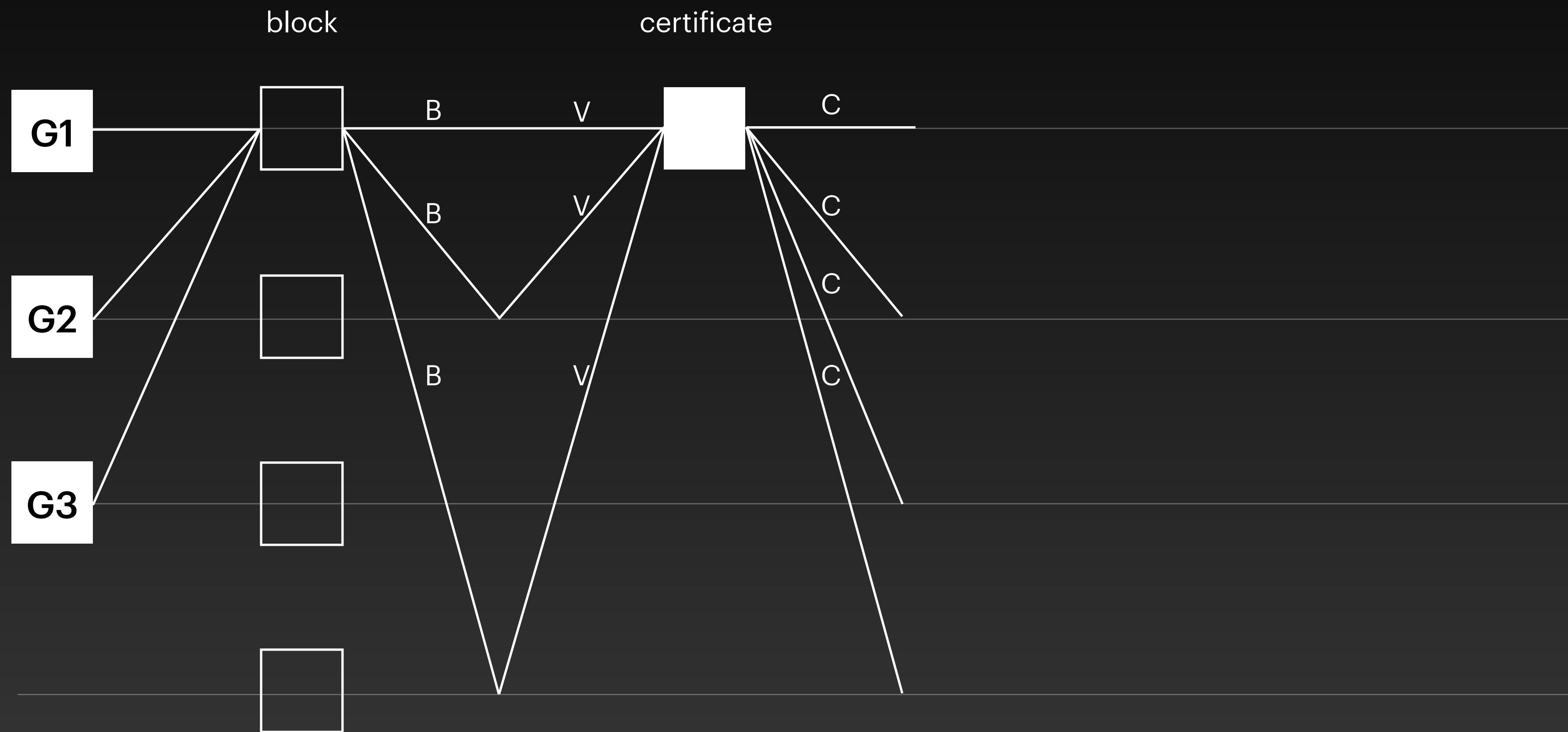
Narwhal



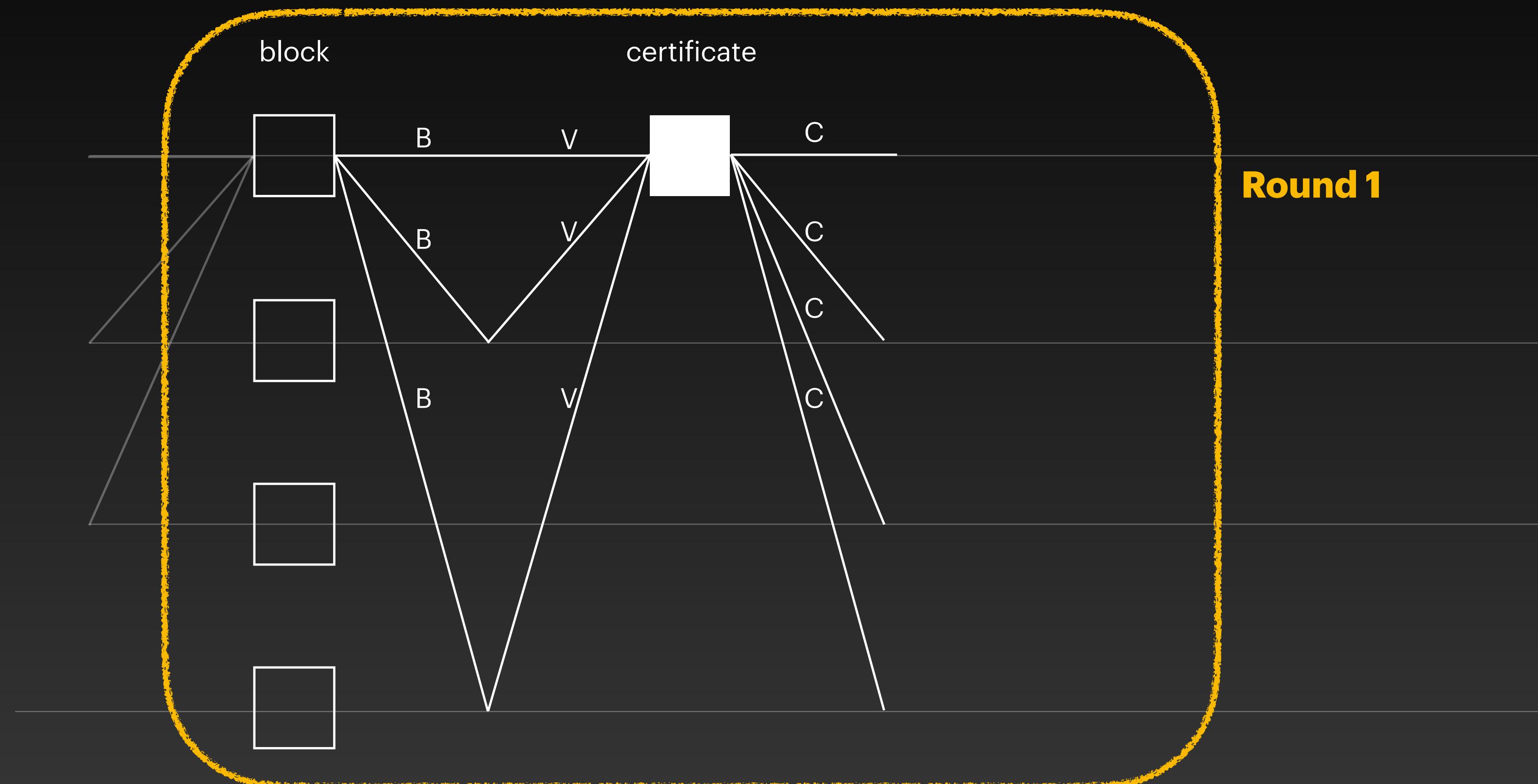
Narwhal



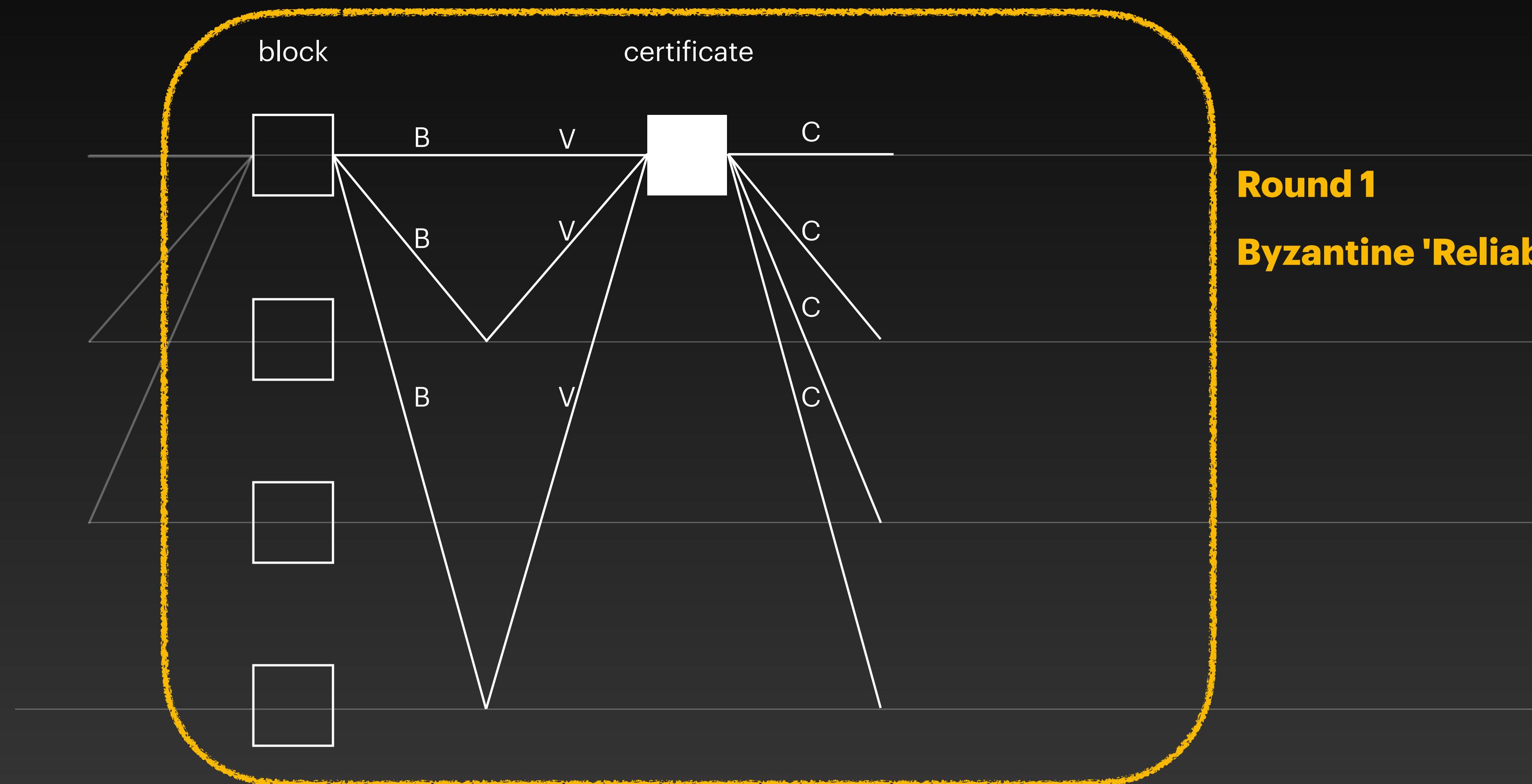
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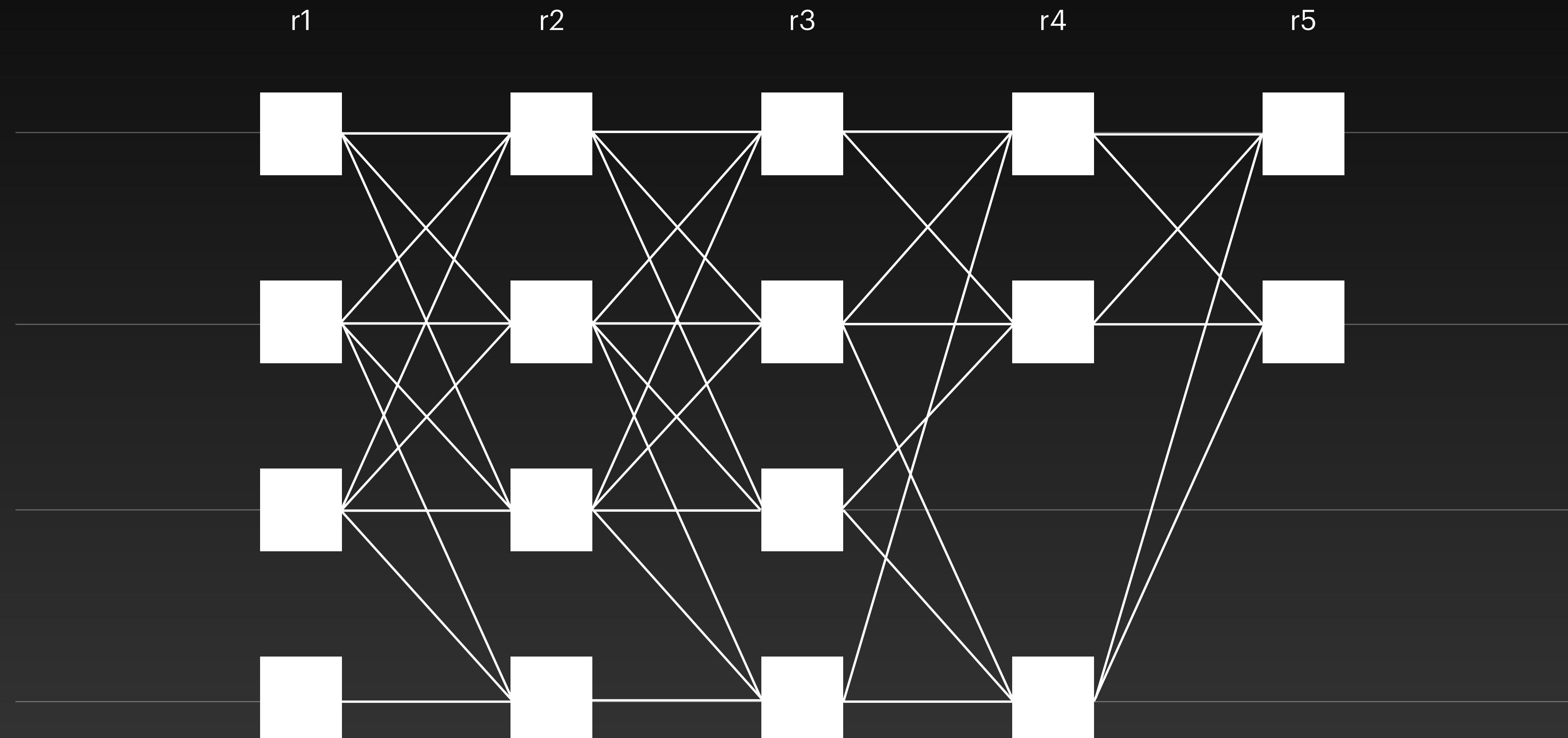
Narwhal



Narwhal



Narwhal



Research Questions

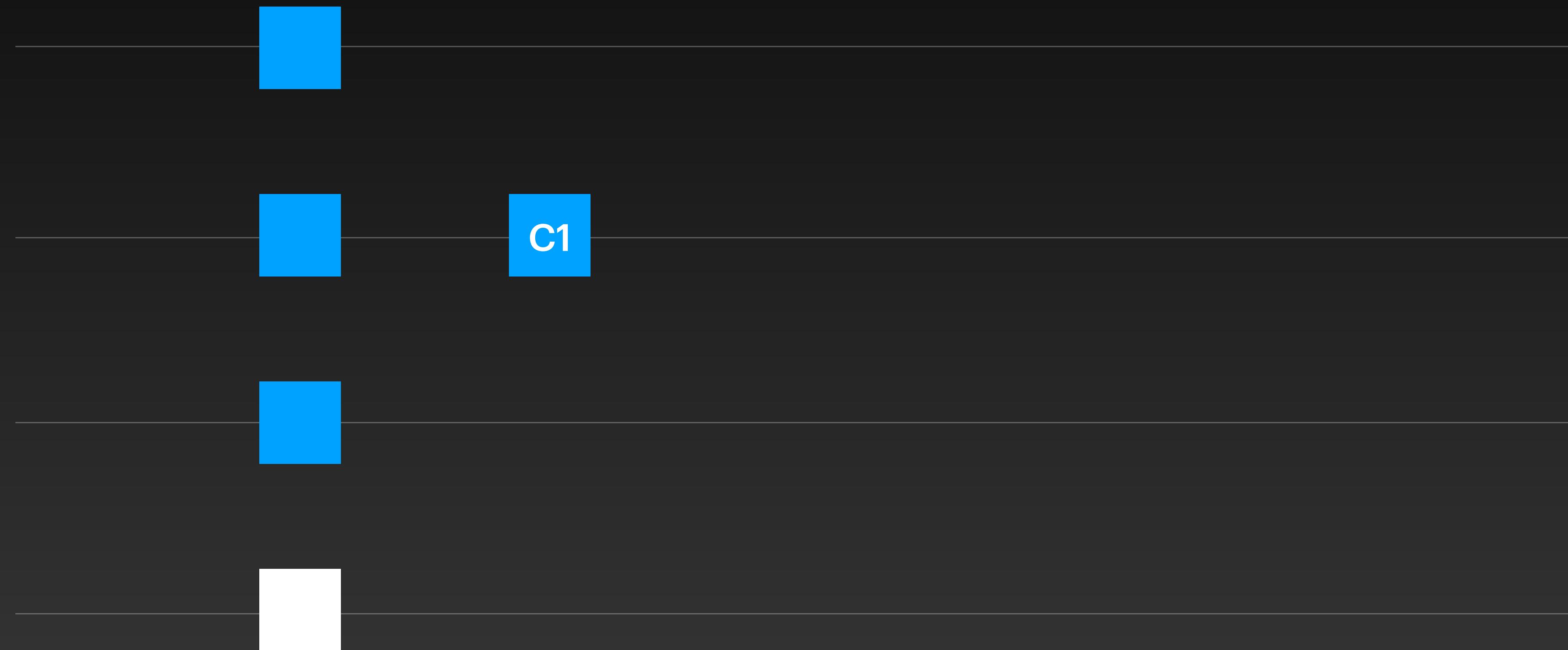
1. Network model?

Lessons Learned

1. Modularisation is a design strategy
2. Tasks-threads allocation
3. Benchmark early
4. Codesign with mem. and storage

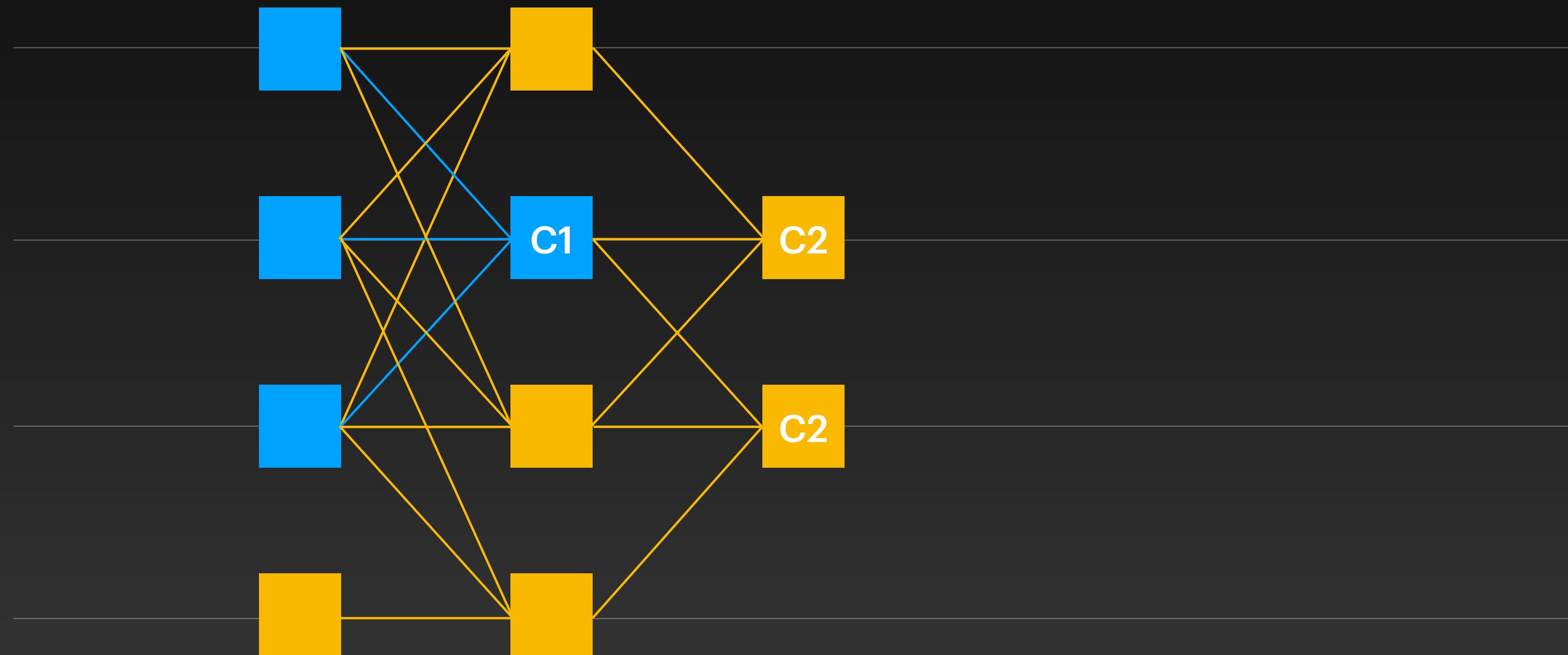
HotStuff on Narwhal

Enhanced commit rule



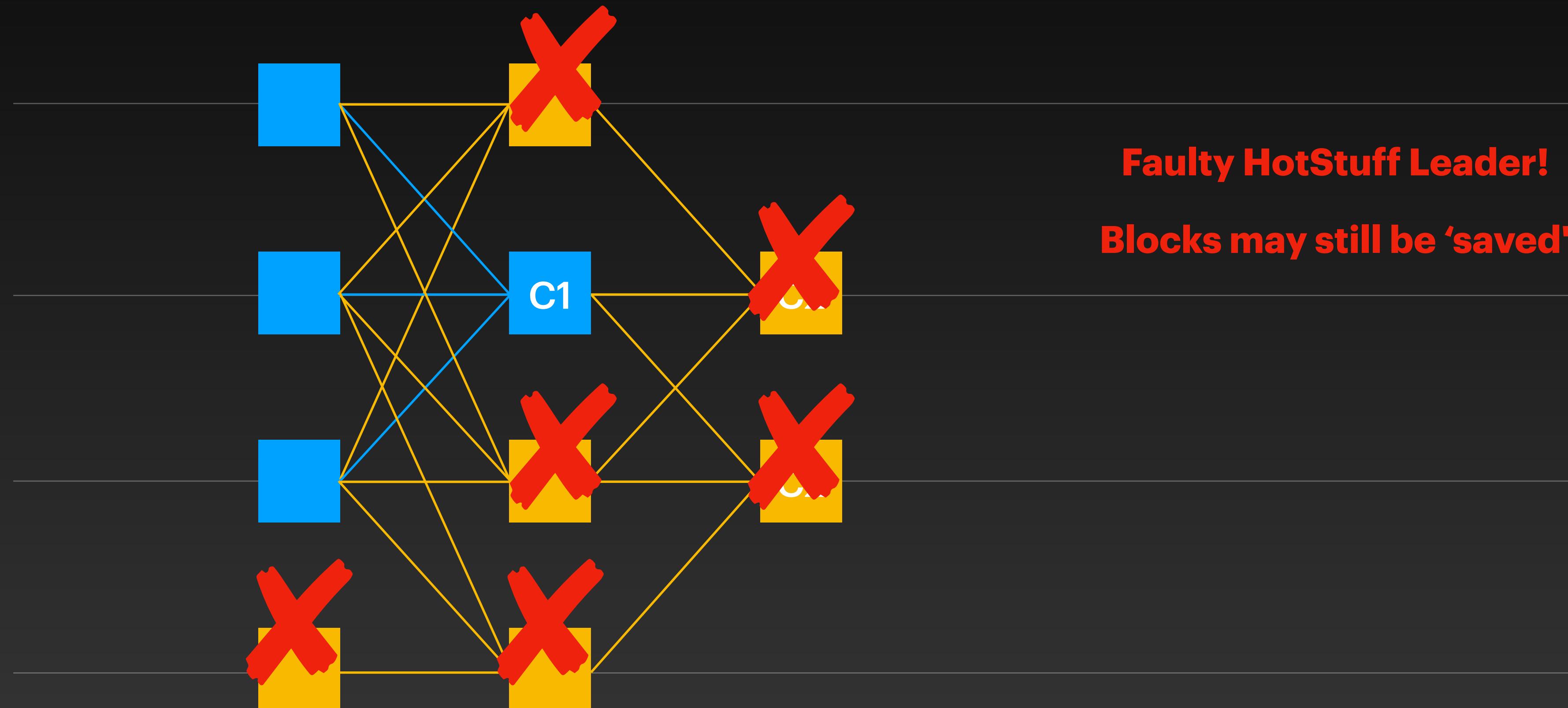
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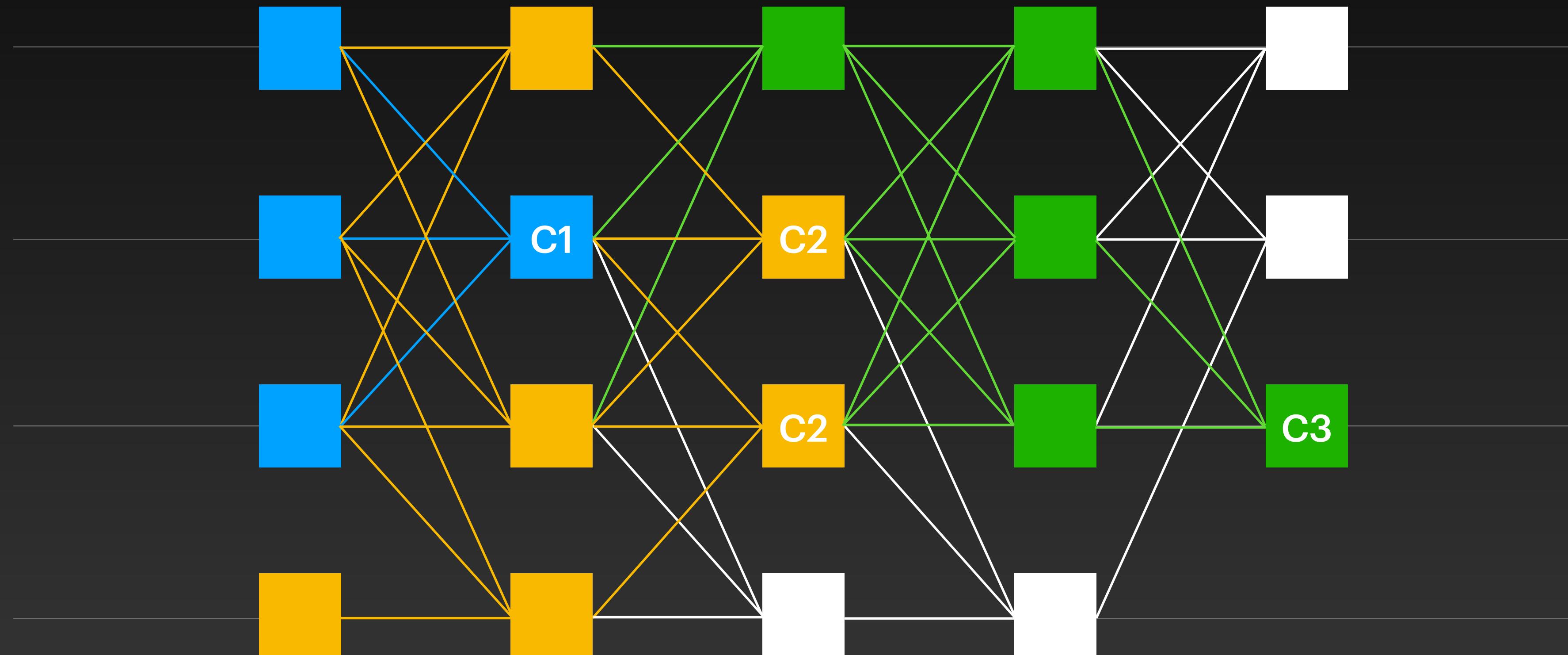
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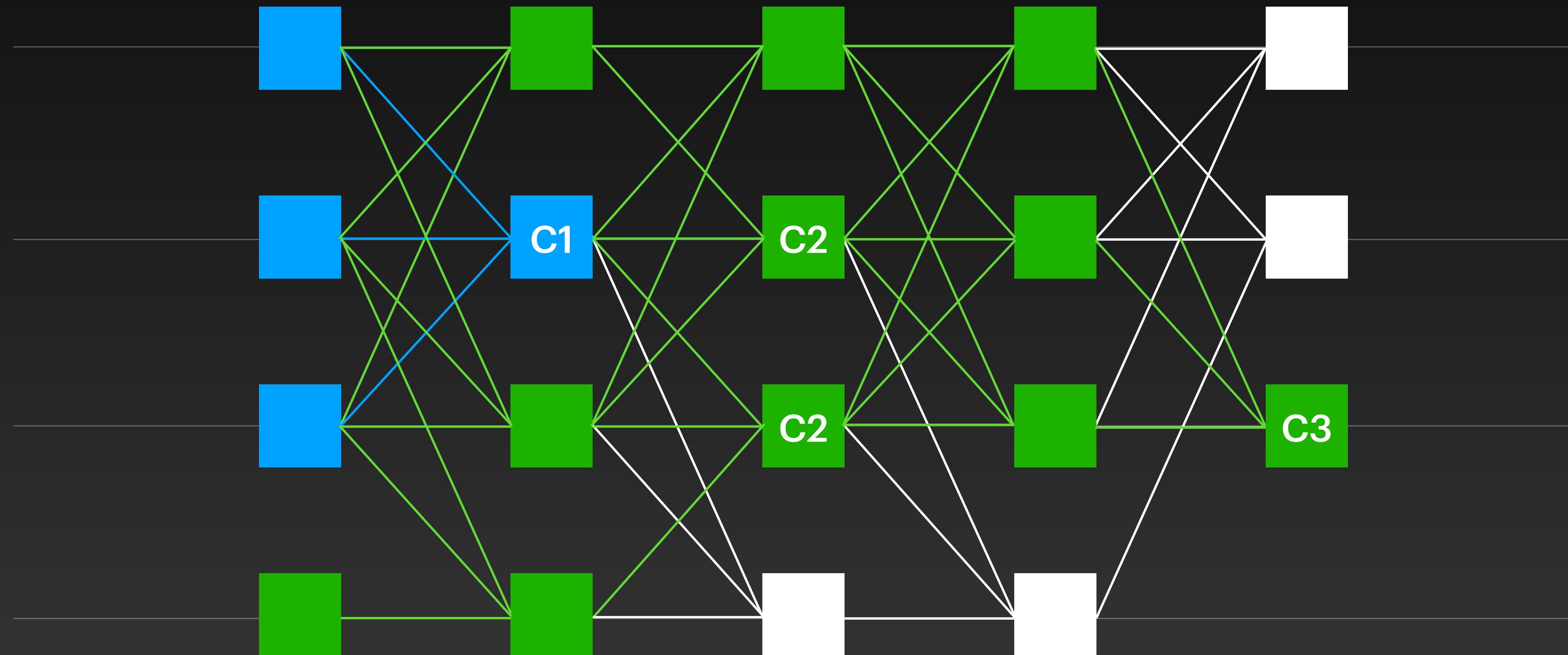
HotStuff on Narwhal

Enhanced commit rule

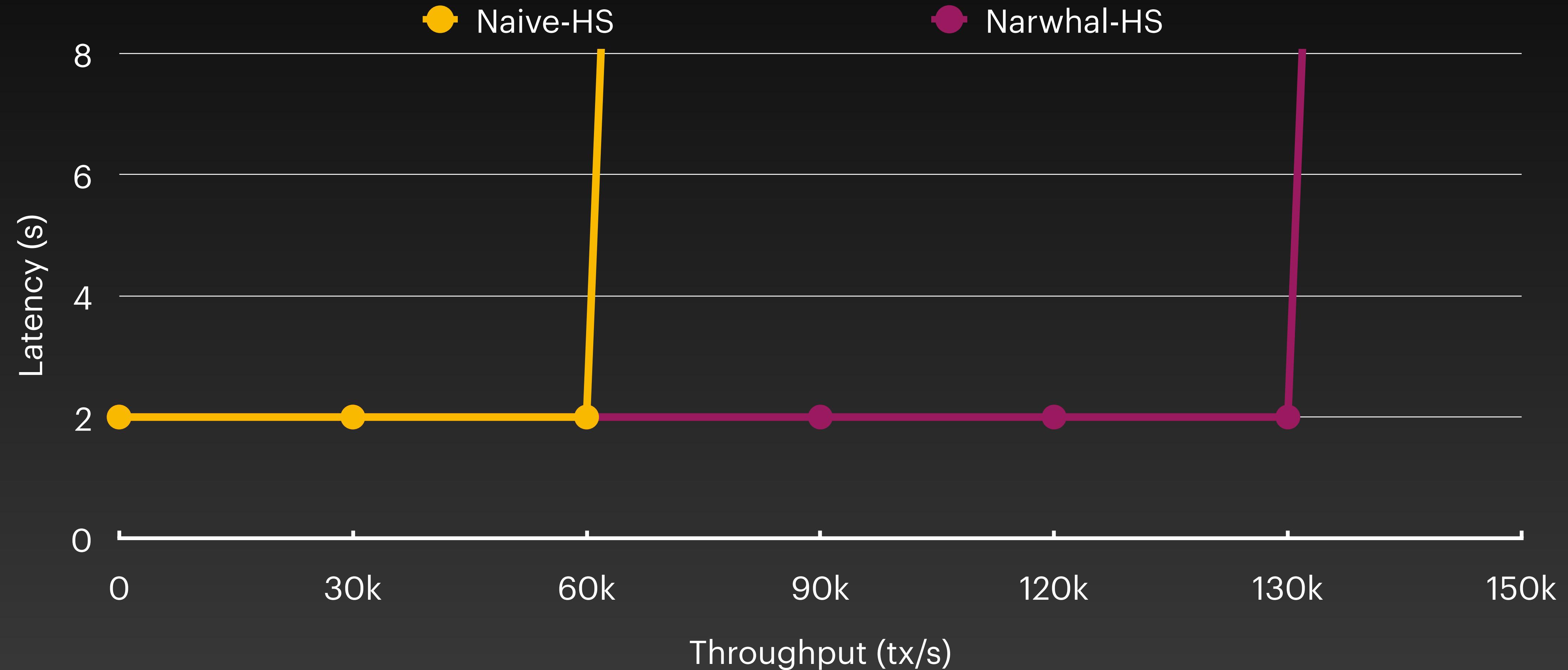


HotStuff on Narwhal

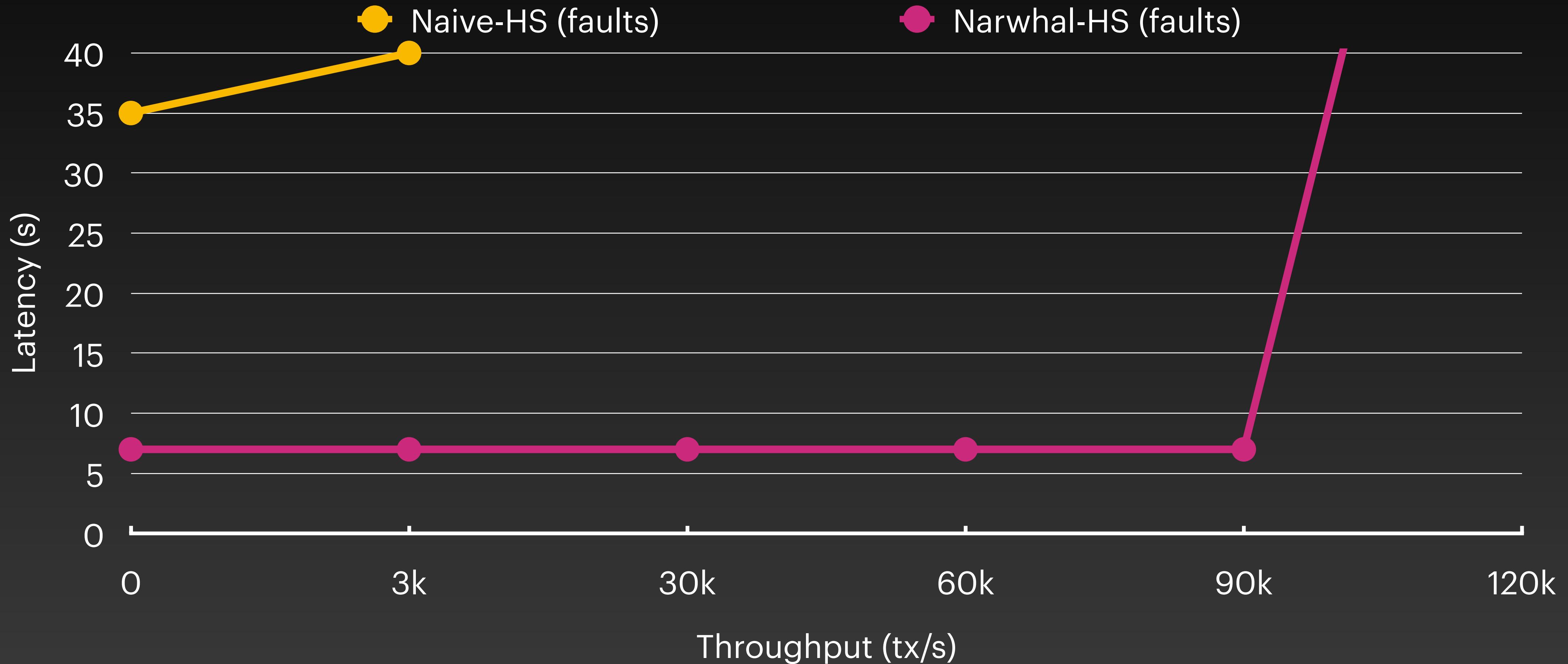
Enhanced commit rule



Performance

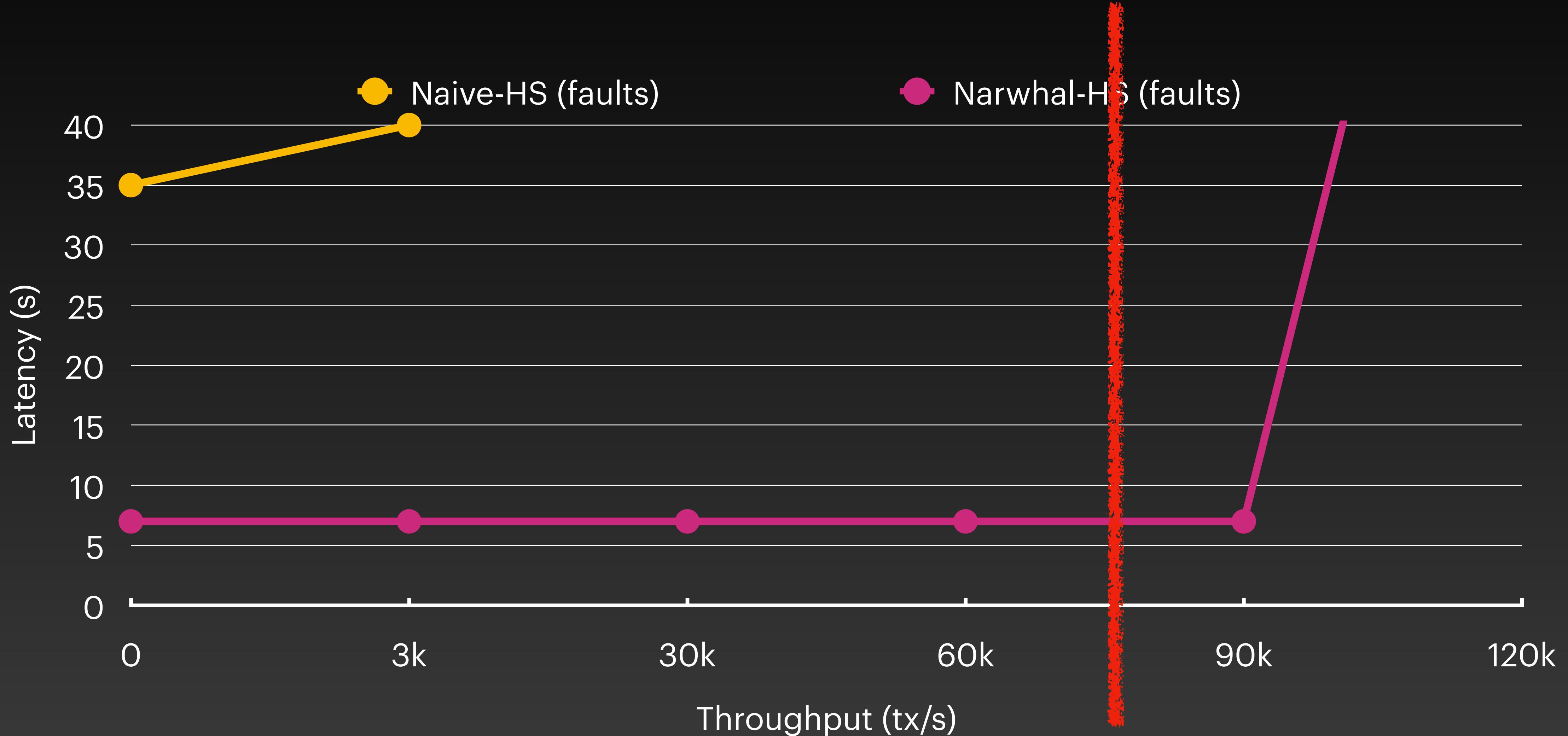


Performance



Performance

visa+mastercard



Libra, 2021

Narwhal and Tusk: A DAG-based Mempool and Efficient BFT Consensus

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Mysten Labs & UCL

Alberto Sonnino
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Abstract
We propose separating the task of reliable transaction dissemination from transaction ordering, to enable high-performance Byzantine fault-tolerant quorum-based consensus. We design and evaluate a mempool protocol, Narwhal, specializing in high-throughput reliable dissemination and storage of causal histories of transactions. Narwhal tolerates an asynchronous network and maintains high performance despite failures. Narwhal is designed to easily scale-out using multiple workers at each validator, and we demonstrate that there is no foreseeable limit to the throughput we can achieve.

Composing Narwhal with a partially synchronous consensus protocol (Narwhal-HotStuff) yields significantly better throughput even in the presence of faults or intermittent loss of liveness due to asynchrony. However, loss of liveness can result in higher latency. To achieve overall good performance when faults occur we design Tusk, a zero-message overhead asynchronous consensus protocol, to work with Narwhal. We demonstrate its high performance under a variety of configurations and faults.

As a summary of results, on a WAN, Narwhal-HotStuff achieves over 130,000 tx/sec at less than 2-sec latency compared with 1,800 tx/sec at 1-sec latency for HotStuff. Additional workers increase throughput linearly to 600,000 tx/sec without any latency increase. Tusk achieves 160,000 tx/sec with about 3 seconds latency. Under faults, both protocols maintain high throughput, but Narwhal-HotStuff suffers from increased latency.

CCS Concepts: Security and privacy → Distributed systems security.

Keywords: Consensus protocol, Byzantine Fault Tolerant

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1 Introduction
Byzantine consensus protocols [15, 19, 21] and the state machine replication paradigm [13] for building reliable distributed systems have been studied for over 40 years. However, with the rise in popularity of blockchains there has been a renewed interest in engineering high-performance consensus protocols. Specifically, to improve on Bitcoin's [33] throughput of only 4 tx/sec early works [29] suggested committee based consensus protocols. For higher throughput and lower latency committee-based protocols are required, and are now becoming the norm in proof-of-stake designs.

Existing approaches to increasing the performance of distributed ledgers focus on creating lower-cost consensus algorithms culminating with HotStuff [38], which achieves linear message complexity in the partially synchronous setting. To achieve this, HotStuff leverages a leader who collects, aggregates, and broadcasts the messages of other validators. However, theoretical message complexity should not be the only optimization target. More specifically:

- Any (partially-synchronous) protocol that minimizes overall message number, but relies on a leader to produce proposals and coordinate consensus, fails to capture the high load this imposes on the leader who inevitably becomes a bottleneck.
- Message complexity counts the number of *metadata* messages (e.g., votes, signatures, hashes) which take minimal bandwidth compared to the dissemination of bulk transaction data (blocks). Since blocks are orders of magnitude larger (10MB) than a typical consensus message (100B), the asymptotic message complexity is practically amortized for fixed mid-size committees (up to ~ 50 nodes).

Additionally, consensus protocols have grouped a lot of functions into a monolithic protocol. In a typical distributed

Narwhal

- Quadratic but even resource utilisation
- Separation between consensus and data dissemination
- High engineering complexity

Research Questions

1. Network model?
2. BFT testing?

Lessons Learned

1. Modularisation is a design strategy
2. Tasks-threads allocation
3. Benchmark early
4. Codesign with mem. and storage

DagRider

arXiv:2102.08325v2 [cs.DC] 4 Jun 2021

Tusk

Narwhal and Tusk: A DAG-based Mempool and Efficient BFT Consensus

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Abstract

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Additionally, consensus protocols have grouped a lot of functions into a monolithic protocol. In a typical distributed

Bullshark

Bullshark: DAG BFT Protocols Made Practical

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ABSTRACT

We present Bullshark, the first directed acyclic graph (DAG) based asynchronous Byzantine Atomic Broadcast protocol that is optimized for the common synchronous case. Like previous DAG-based BFT protocols [19, 25], Bullshark requires no extra communication to achieve consensus on top of building the DAG. That is, parties can totally order the vertices of the DAG by interpreting their local view of the DAG edges. Unlike other asynchronous DAG-based protocols, BullShark provides a practical low latency fast-path that exploits synchronous periods and deprecates the need for notoriously complex view-change mechanisms. BullShark achieves this while maintaining all the desired properties of its predecessor DAG-Rider [25]. Namely, it has optimal amortized communication complexity, it provides fairness and asynchronous liveness, and safety is guaranteed even under a quantum adversary.

In order to show the practicality and simplicity of our approach, we also introduce a standalone partially synchronous version of BullShark which we evaluate against the state of the art. The implemented protocol is embarrassingly simple (200 LOC on top of an existing DAG-based mempool implementation [19]). It is highly efficient, achieving for example, 125,000 transaction per second with a 2 seconds latency for a deployment of 50 parties. In the same setting the state of the art pays a steep 50% latency increase as it optimizes for asynchrony.

ACM Reference Format:

Alexander Spiegelman, Neil Giridharan, Alberto Sonnino, and Lefteris Kokoris-Kogias. 2022. Bullshark: DAG BFT Protocols Made Practical. In *Proceedings of ACM Conference, Los Angeles, CA, USA, November 2022 (Conference '22)*, 17 pages.

<https://doi.org/10.1145/nnnnnnnnnnnnnn>

1 INTRODUCTION

Ordering transactions in a distributed Byzantine environment via a consensus mechanism has become one of the most timely research areas in recent years due to the blooming Blockchain use-case. A recent line of work [8, 19, 21, 25, 33, 40] proposed an elegant way to handle the distribution of transactions and the

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<https://doi.org/10.1145/nnnnnnnnnnnnnn>

logic required to safely order them. The idea is simple. To propose transactions, parties send them in a way that forms a causal order among them. That is, messages contain blocks of transactions as well as references to previously received messages, which together form a *directed acyclic graph (DAG)*. Interestingly, the structure of the DAG encodes information that allow parties to totally order the DAG by locally interpreting their view of it without sending any extra messages. That is, once we build the DAG, implementing consensus on top of it requires *zero-overhead* of communication.

The pioneering work of Hashgraph [8] constructed an unstructured DAG, where each message refers to two previous ones, and used hashes of messages as local coin flips to totally order the DAG in asynchronous settings. Aleph [21] later introduced a structured round-based DAG and encoded a shared randomness in each round via a threshold signature scheme to achieve constant latency in expectation. The state of the art is DAG-Rider [25], which is built on previous ideas. Every round in the DAG has at most n vertices (one for each party), each of which contains a block of transactions as well as references (edges) to at least $2^j + 1$ vertices in the previous round. Blocks are disseminated via reliable broadcast [11] to avoid equivocation and an honest party advances to the next round once it reliably delivers $2^j + 1$ vertices in the current round. Note that building the DAG requires honest parties to broadcast vertices even if they have no transactions to propose. However, the edges of the DAG encodes the “voting” information that is sufficient to totally order all the DAG’s vertices. So in this sense it is not different from other BFT protocols in which parties send explicit vote messages, which contain no transactions as well. Remarkably, by using the DAG to abstract away the communication layer, the entire edges interpretation logic of DAG-Rider to totally order the DAG spans over less than 30 lines of pseudocode.

DAG-Rider is an asynchronous Byzantine atomic broadcast (BAB), which achieves optimal amortized communication complexity ($O(n)$ per transaction), post quantum safety, and some notion of fairness (called Validity) that guarantees that every transaction proposed by an honest party is eventually delivered (ordered). To achieve optimal amortized communication DAG-Rider combines batching techniques with an efficient asynchronous verifiable information dispersal protocol [14] for the reliable broadcast building block. The protocol is post quantum safe because it does not rely on primitives that a quantum computer can brake for the safety properties. That is, a quantum adversary can prevent the protocol progress, but it cannot violate safety guarantees.

However, although DAG-based protocols have a solid theoretical foundation, they have multiple gaps before being realistically deployable in practise. First, they all optimize for the worst case

Dumbo-NG

arXiv:2209.00750v3 [cs.CR] 1 Feb 2024

Dumbo-NG: Fast Asynchronous BFT Consensus with Throughput-Oblivious Latency

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ABSTRACT

Despite recent progresses of practical asynchronous Byzantine-fault tolerant (BFT) consensus, the state-of-the-art designs still suffer from suboptimal performance. Particularly, to obtain maximum throughput, most existing protocols with guaranteed linear amortized communication complexity require each participating node to broadcast a huge batch of transactions, which dramatically sacrifices latency. Worse still, the f slowest nodes' broadcasts might never be agreed to output and thus can be censored (where f is the number of faults). Implementable mitigation to the threat either uses computationally costly threshold encryption or incurs communication blow-up by letting the honest nodes to broadcast redundant transactions, thus causing further efficiency issues.

We present Dumbo-NG, a novel asynchronous BFT consensus (atomic broadcast) to solve the remaining practical issues. Its technical core is a non-trivial *direct reduction* from asynchronous atomic broadcast to multi-valued validated Byzantine agreement (MVBA) with *quality* property (which ensures the MVBA output is from honest nodes with $1/2$ probability). Most interestingly, the new protocol structure empowers completely concurrent execution of transaction dissemination and asynchronous agreement. This brings about two benefits: (i) the throughput-latency tension is resolved to approach peak throughput with minimal increase in latency; (ii) the transactions broadcasted by any honest node can be agreed to output, thus conquering the censorship threat with no extra cost.

We implement Dumbo-NG with using the current fastest GLL+22 MVBA with quality (NDSS'22) and compare it to the state-of-the-art asynchronous BFT with guaranteed censorship resilience including Dumbo (CCS'20) and Speeding-Dumbo (NDSS'22). Along the way, we apply the techniques from Speeding-Dumbo to DispersedLedger (NSDI'22) and obtain an improved variant of DispersedLedger called sDumbo-DL for comprehensive comparison. Extensive experiments (over up to 64 AWS EC2 nodes across 16 AWS regions) reveal: Dumbo-NG realizes a peak throughput 4-8x over Dumbo, 2-4x over Speeding-Dumbo, and 2-3x over sDumbo-DL (for varying scales); More importantly, Dumbo-NG's latency, which is lowest among all tested protocols, can almost remain stable when throughput grows.

CCS CONCEPTS

- Security and privacy → Systems security; Distributed systems security;
- Computer systems organization → Reliability.

*Authors are listed alphabetically. Yingzi, Yuan & Zhenliang made equal contributions. An abridged version of the paper will appear in ACM CCS 2022.

KEYWORDS

Asynchronous consensus, Byzantine-fault tolerance, blockchain

1 INTRODUCTION

The huge success of Bitcoin [63] and blockchain [19, 24] leads to an increasing tendency to lay down the infrastructure of distributed ledger for mission-critical applications. Such decentralized business is envisioned as critical global infrastructure maintained by a set of mutually distrustful and geographically distributed nodes [11], and thus calls for consensus protocols that are both secure and efficient for deployment over the Internet.

Asynchronous BFT for indispensable robustness. The consensus of decentralized infrastructure has to thrive in a highly adversarial environment. In particular, when the applications atop it are critical financial and banking services, some nodes can be well motivated to collude and launch malicious attacks. Even worse, the unstable Internet might become part of the attack surface due to network fluctuations, misconfigurations and even network attacks. To cope with the adversarial deployment environment, *asynchronous* Byzantine-fault tolerant (BFT) consensus [4, 20, 35, 47, 58, 60] are arguably the most suitable candidates. They can realize high security-assurance to ensure liveness (as well as safety) despite an asynchronous adversary that can arbitrarily delay messages. In contrast, many (partial) synchronous consensus protocols [5, 6, 8, 15, 27, 44, 45, 64, 73] such as PBFT [26] and HotStuff [75] might sustain the inherent *loss of liveness* (i.e., generate unbounded communications without making any progress) [36, 60] when unluckily encountering an asynchronous network adversary.

1.1 Practical obstacles of adopting asynchronous BFT consensus

Unfortunately, it is fundamentally challenging to realize practical asynchronous BFT consensus, and none of such protocols was widely adopted due to serious efficiency concerns. The seminal FLP “impossibility” [36] proves that *no deterministic* consensus exists in the asynchronous network. Since the 1980s, many attempts [1, 12, 13, 21, 25, 65, 67] aimed at to circumventing the “impossibility” by randomized protocols, but most of them focused on theoretical feasibility, and unsurprisingly, several attempts of implementations [22, 61] had inferior performance.

Until recently, the work of HoneyBadger BFT (HBFT) demonstrated the first asynchronous BFT consensus that is performant in the wide-area network [60]. As shown in Figure 1, HBFT was

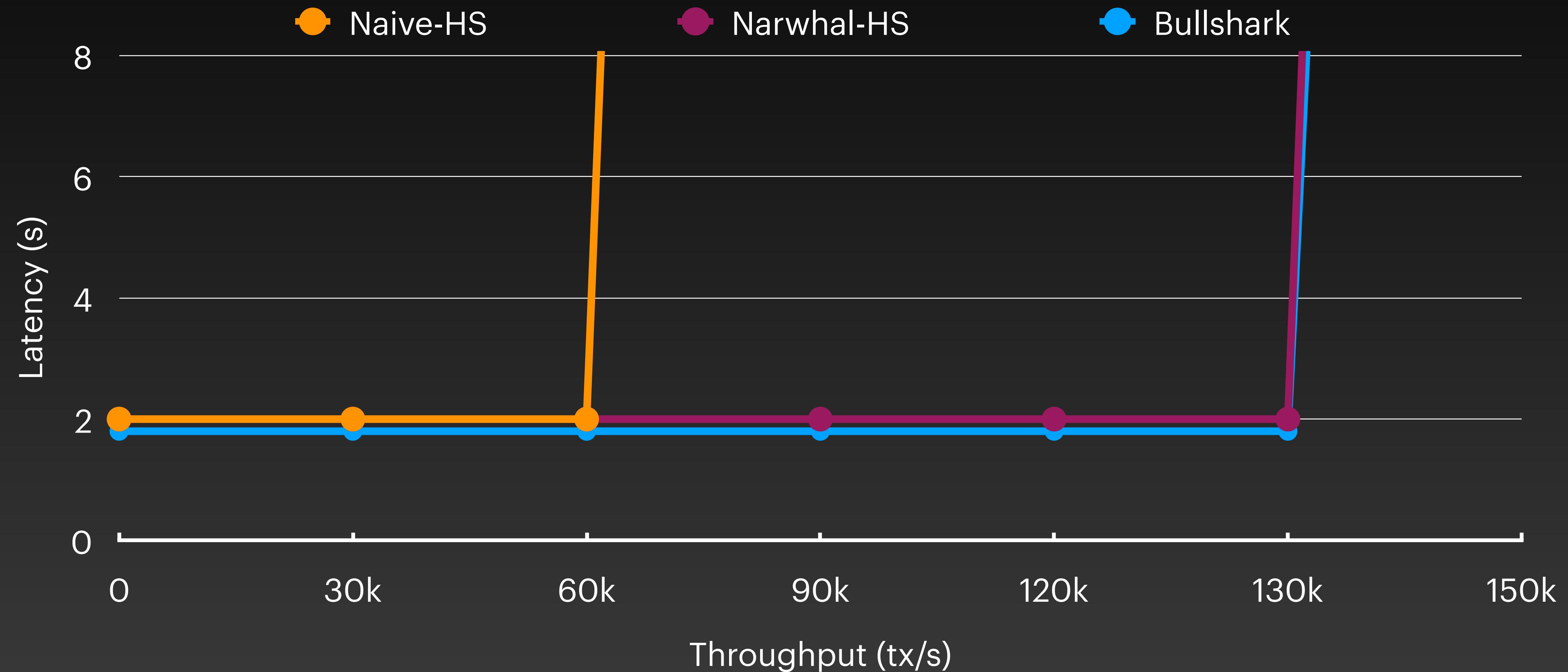
Data Dissemination

- Hard to make efficient
 - 99% of the code

Consensus

- Error prone
Isolated, easy to maintain

Performance



Research Questions

1. Network model?
2. BFT testing?
3. Consensus-exec interface?

Lessons Learned

1. Modularisation is a design strategy
2. Tasks-threads allocation
3. Benchmark early
4. Codesign with mem. and storage
5. Core is hard, consensus is easy

By that time...



← Post

Reply

Pinned



David Marcus

@davidmarcus



...

How Libra Was Killed.

I never shared this publicly before, but since [@pmarca](#) opened the floodgates on [@joerogan](#)'s pod, it feels appropriate to shed more light on this.

As a reminder, Libra (then Diem) was an advanced, high-performance, payments-centric blockchain paired with a stablecoin that we built with my team at [@Meta](#). It would've solved global payments at scale. Prior to announcing the project, we spent months briefing key regulators in DC and abroad. We then announced the project in June 2019 alongside 28 companies. Two weeks later, I was called to testify in front of both the Senate Banking Committee and the House Financial Services Committee, which was the starting point of two years of nonstop work and changes to appease lawmakers and regulators.

By spring of 2021 (yes they slow played us at every step), we had addressed every last possible regulatory concern across financial crime, money laundering, consumer protection, reserve management, buffers,

By that time...



Sui

Aptos

Linera

...

Sui, 2022

Over a year for mainnet

- Lack of checkpoints
- Lack of epoch-change
- Lack of crash-recovery

Research Questions

1. Network model?
2. BFT testing?
3. Consensus-exec interface?
4. Storage architecture?

Lessons Learned

1. Modularisation is a design strategy
2. Tasks-threads allocation
3. Benchmark early
4. Codesign with mem. and storage
5. Core is hard, consensus is easy
6. Epoch change is not an add-on

Sui, 2023

- Latency was too high
- Crash faults were the predominant faults
- Building Bullshark was still too complex

Shoal

arXiv:2306.03058v2 [cs.DC] 7 Jul 2023

Sailfish

Sailfish: Towards Improving the Latency of DAG-based BFT

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Abstract—Directed Acyclic Graph (DAG) based BFT protocols balance consensus efforts across different parties and maintain high throughput even when some designated parties fail. However, existing DAG-based BFT protocols exhibit long latency to commit decisions, primarily because they have a *leader* every 2 or more “rounds”. Recent works, such as Shoal (FC’23) and Mysticeti, have deemed supporting a leader vertex in each round particularly difficult, if not impossible. Consequently, even under honest leaders, these protocols require high latency (or communication complexity) to commit the proposal submitted by the leader (leader vertex) and additional latency to commit other proposals (non-leader vertices).

In this work, we present Sailfish, the first DAG-based BFT that supports a leader vertex in each round. Under honest leaders, Sailfish maintains a commit latency of one reliable broadcast (RBC) round plus δ to commit the leader vertex (where δ is the actual transmission latency of a message) and only an additional RBC round to commit non-leader vertices. We also extend Sailfish to Multi-leader Sailfish, which facilitates multiple leaders within a single round and commits all leader vertices in a round with a latency of one RBC round plus δ . Our experimental evaluation demonstrates that our protocols introduce significantly lower latency overhead compared to existing DAG-based protocols, with similar throughput.

1. Introduction

Byzantine fault-tolerant state machine replication (BFT-SMR) protocols form the core underpinning for blockchains. At a high level, a BFT-SMR enables a group of n parties to agree on a sequence of values, even if a bound of up to f of these parties is Byzantine (arbitrarily malicious). Owing to the need for efficient blockchains in practice, there has been a lot of recent progress in improving the key efficiency metrics namely, latency, communication complexity, and throughput under various network conditions. Assuming the network is partially synchronous, existing SMR protocols can commit with a latency overhead of 3δ (where δ represents the actual network delay) [11], [12], [22] and also achieve linear communication complexity [37], [51] under optimistic conditions (such as an honest leader).

Most of these protocol designs rely on a designated leader who is the party responsible for proposing transactions and driving the protocol forward while other parties

agree on the proposed values and ensure that the leader keeps making progress. From an efficiency standpoint, this approach results in two key drawbacks. First, there is an uneven scheduling of work among the parties. While the leader is sending a proposal, the other parties’ processors and their network are not used, leading to uneven resource usage across parties. Second, in typical leader-based protocols progress stops if the leader fails and until it is replaced. Several techniques proposed in the literature can potentially mitigate these concerns. These include the use of erasure coding techniques [2], [41] or the data availability committees [26], [27], [49] to disseminate the data more efficiently.

Recently, a novel approach known as DAG-based BFT has emerged [5], [18], [28], [33], [34], [46], [47]. These protocols enable all participating parties to progress in parallel, maximizing bandwidth utilization and ensuring equitable distribution of workload. Additionally, because each party is responsible for disseminating its own transactions, the protocol continues to progress in constructing the DAG even if a party fails during a round. Consequently, these protocols have demonstrated improved throughput compared to their leader-based counterparts under moderate network sizes [19], [46]. However, existing DAG-based protocols incur a high latency compared to their “leader-heavy” counterparts [12], [22], [30], [37], [51]. Is high latency inherent for such DAG-based protocols? Addressing this question is the key goal of this paper.

All existing DAG-based protocols progress in *rounds*. In each round, every party can create a potential DAG vertex containing transactions, with edges pointing to vertices from previous rounds. These protocols rely on committing a designated “leader vertex” and order other non-leader vertices in the DAG. Therefore, the frequency with which leaders are designated and how fast the leader vertices are committed directly influences the commit latency.

Supporting a leader vertex in each round. State-of-the-art protocols designate leaders once every two or more rounds, and in fact, deem supporting a leader vertex in each round particularly difficult. In their words, Shoal [45] writes, “Our attempts to solve the problem by delving into the inner workings of the protocol and exploring complex quorum intersection ordering rules have not been fruitful. Intuitively, this is because ...”. Similarly, Mysticeti [4]

CM

arXiv:2205.09174v6 [cs.DC] 22 Sep 2023

Cordial Miners: Fast and Efficient Consensus for Every Eventuality

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Technion

Oded Naor

Technion and StarkWare

Ouri Poupko

Ben-Gurion University

Ehud Shapiro

Weizmann Institute of Science

Abstract

Cordial Miners are a family of efficient Byzantine Atomic Broadcast protocols, with instances for asynchrony and eventual synchrony. They improve the latency of state-of-the-art DAG-based protocols by almost 2x and achieve optimal good-case complexity of $O(n)$ by forgoing Reliable Broadcast as a building block. Rather, Cordial Miners use the *blockface*—a partially-ordered counterpart of the totally-ordered blockchain data structure—to implement the three algorithmic components of consensus: Dissemination, equivocation-exclusion, and ordering.

2012 ACM Subject Classification Computing methodologies → Distributed algorithms

Keywords and phrases Byzantine Fault Tolerance, State Machine Replication, DAG, Consensus, Blockchain, Blockface, Cordial Dissemination

Related Version Cordial Miners: Fast and Efficient Consensus for Every Eventuality

Full Version <https://arxiv.org/abs/2205.09174>

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1 Introduction

The problem of ordering transactions in a permissioned Byzantine distributed system, also known as *Byzantine Atomic Broadcast (BAB)*, has been investigated for four decades [30], and in the last decade, has attracted renewed attention due to the emergence of cryptocurrencies.

Recently, a line of works [4, 14, 20, 33, 21, 27] suggests ordering transactions using a distributed Directed Acyclic Graph (DAG) structure, in which each vertex contains a block of transactions as well as references to previously sent vertices. The DAG is distributively constructed from messages of *miners* running the consensus protocol. While building the DAG structure, each miner also totally orders the vertices in its DAG locally. That is, as the DAG is being constructed, a consensus on its ordering emerges without additional communication among the miners.

The two state-of-the-art protocols in this context are DAG-Rider [21] and Bullshark [33]. DAG-Rider works in the asynchronous setting, in which the adversary controls the finite delay on message delivery between miners, and Bullshark works in the Eventual Synchrony (ES) model, in which eventually all messages between correct miners are delivered within a known time-bound.

Mysticeti

MYSTICETI: Reaching the Latency Limits with Uncertified DAGs

Techniques

- Many leaders per round
 - Leaders every round
 - Uncertified DAG

Discussion

Certified DAG

Uncertified DAG



Shoal/shoal++

- Low latency
- Easier synchroniser
- Leverage existing code

Sailfish/BBCA

- Lower latency
- Easy synchroniser
- Flexible

CM/Mysticeti

- Lowest latency
- Graceful crash faults
- Simpler, less CPU

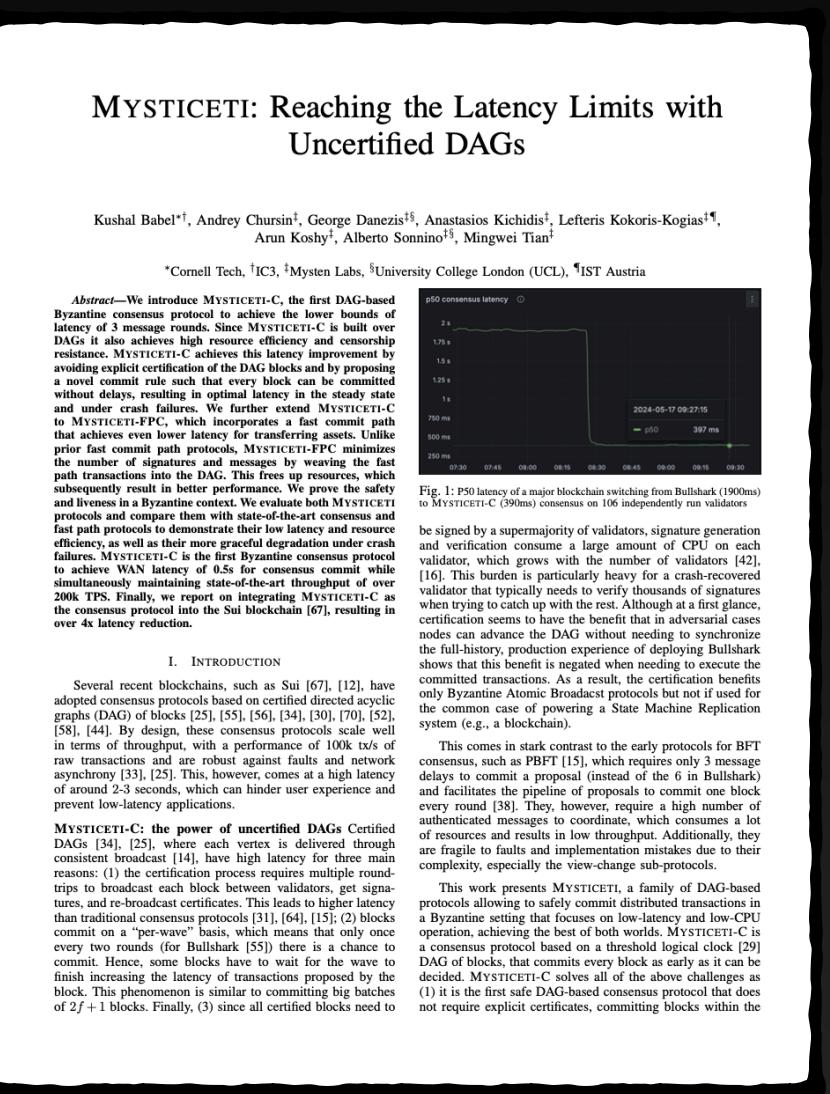
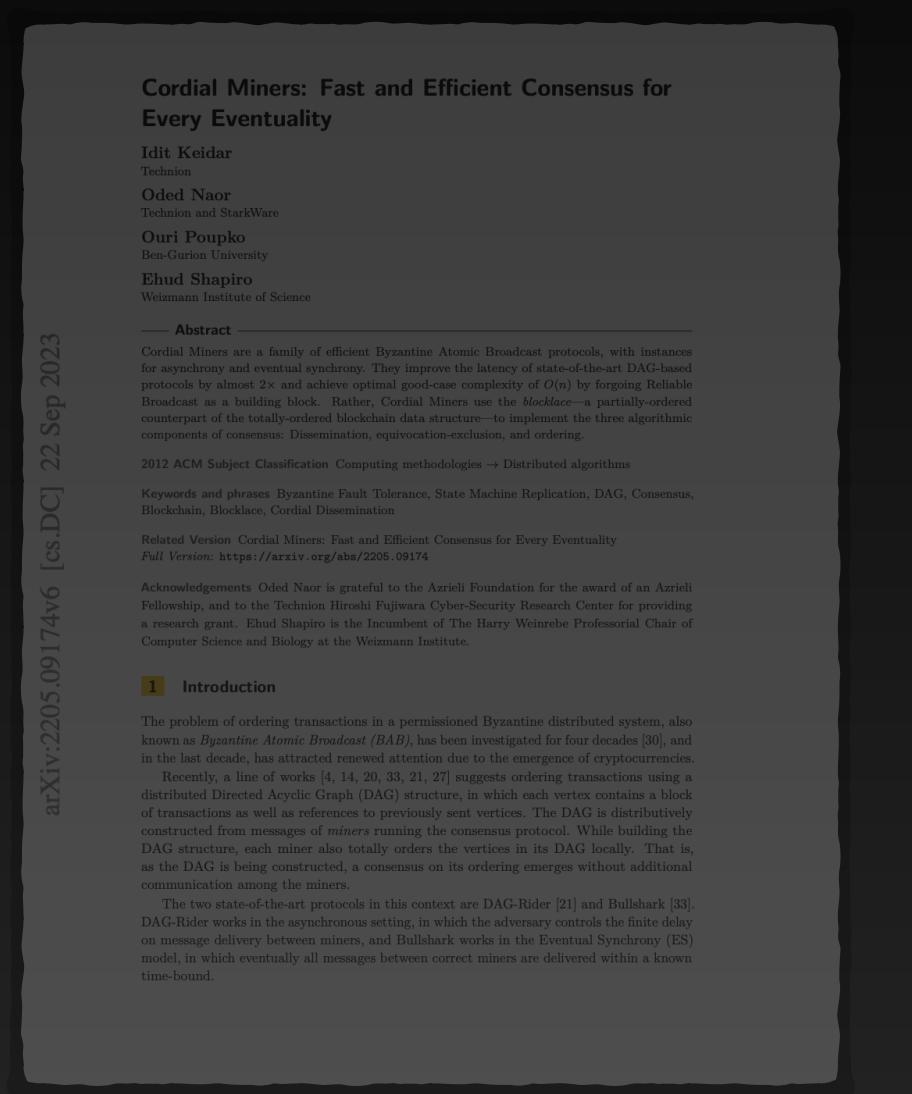
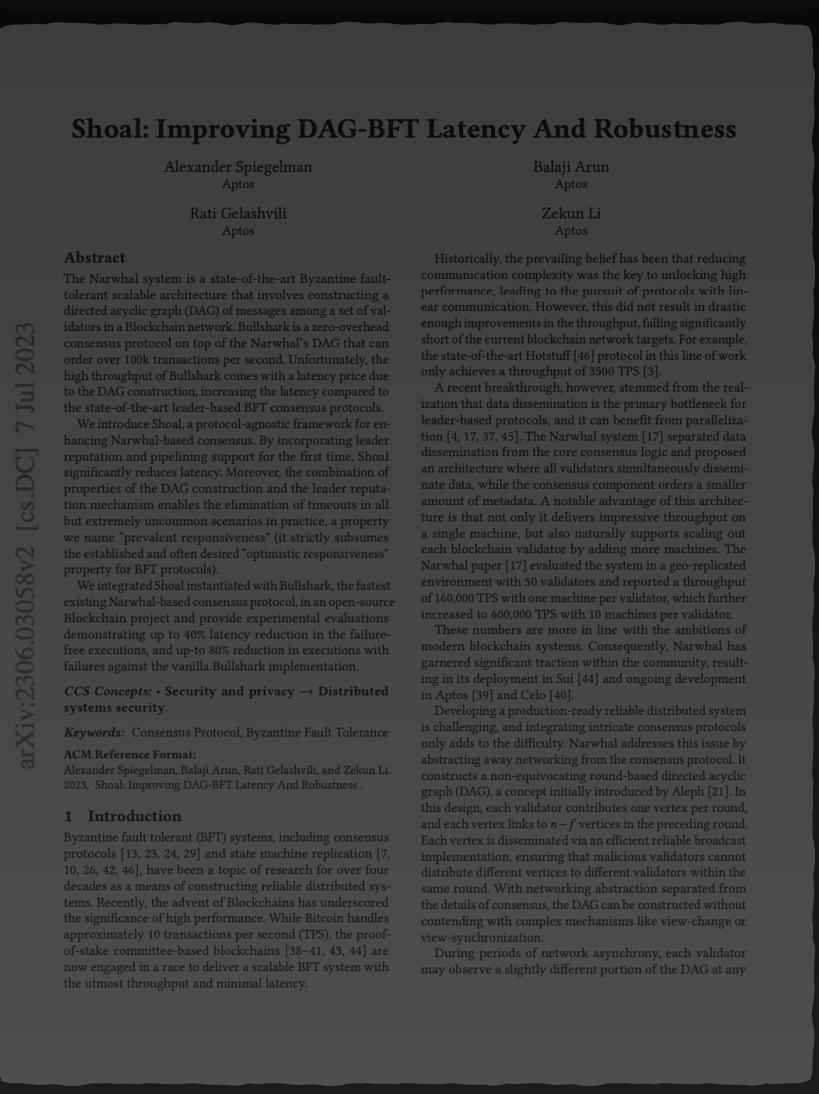
Research Questions

1. Network model?
2. BFT testing?
3. Consensus-exec interface?
4. Storage architecture?
5. Block synchroniser?

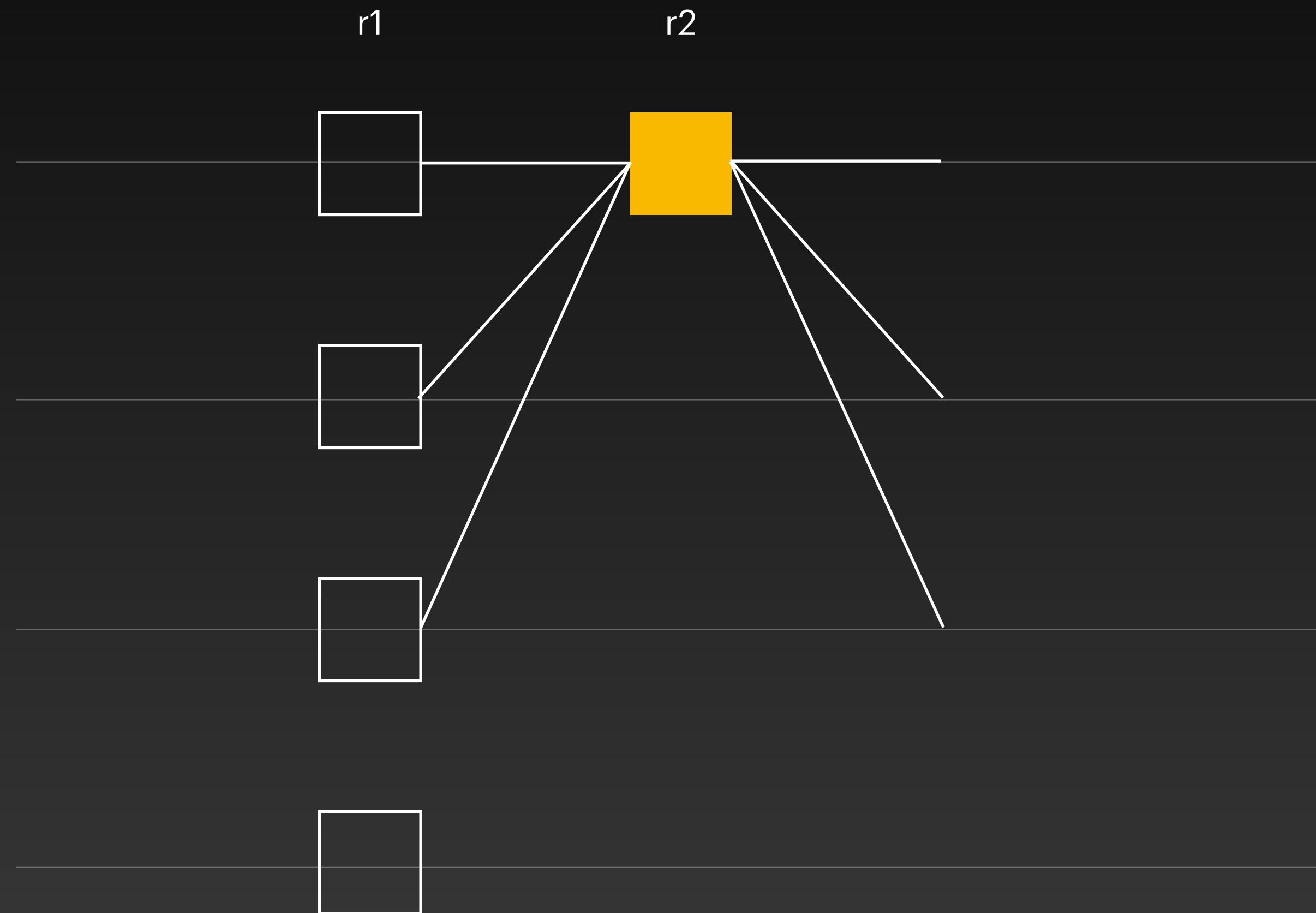
Lessons Learned

1. Modularisation is a design strategy
2. Tasks-threads allocation
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6. Epoch change is not an add-on

Mysticeti

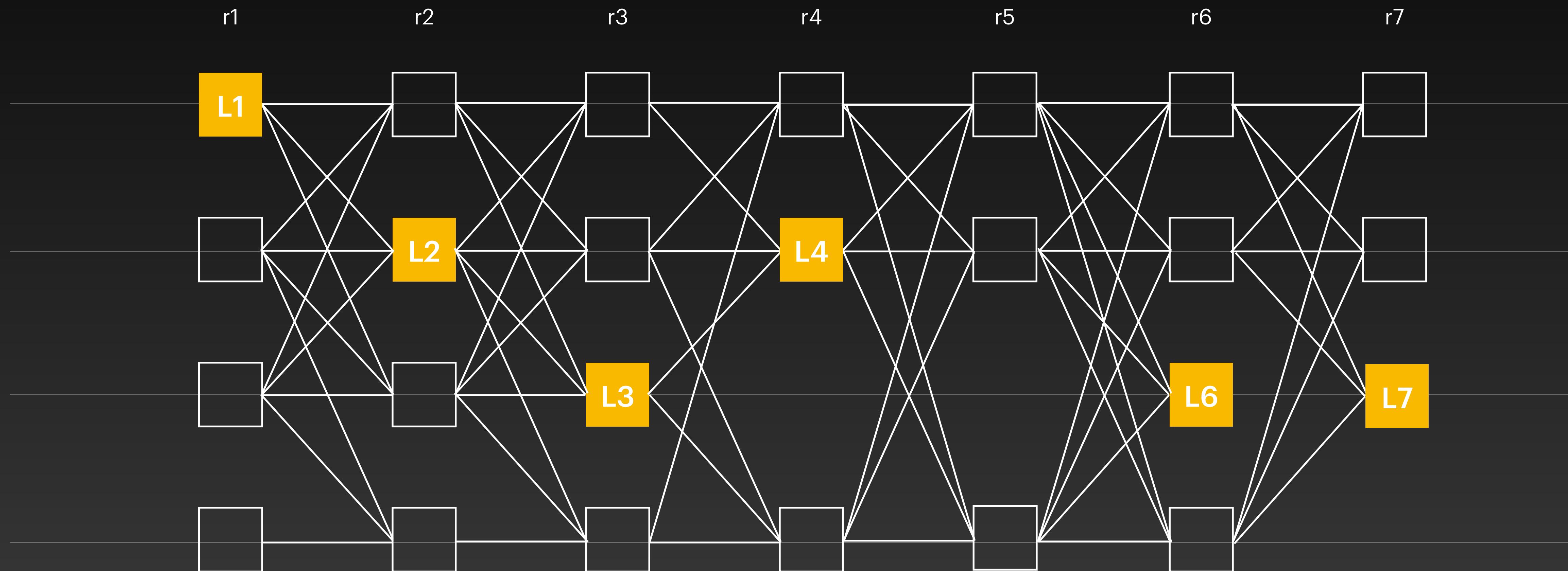


Uncertified DAG

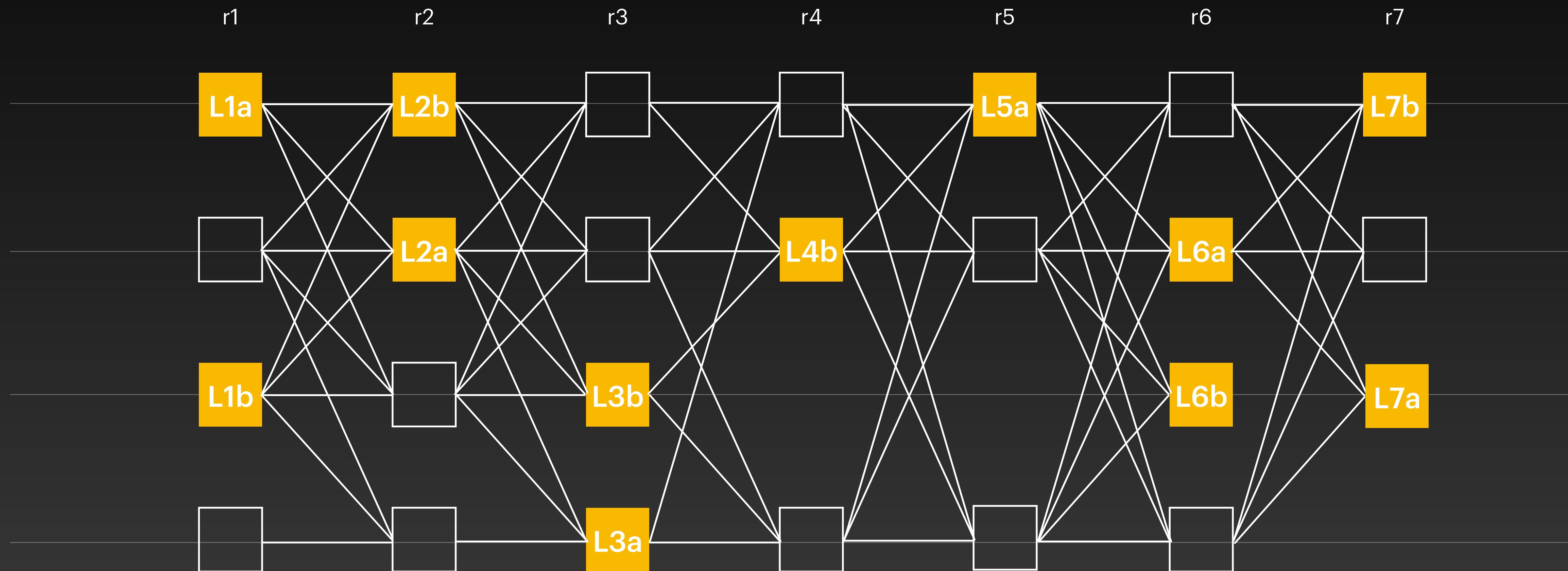


- Round number
- Author
- Payload (transactions)
- Signature

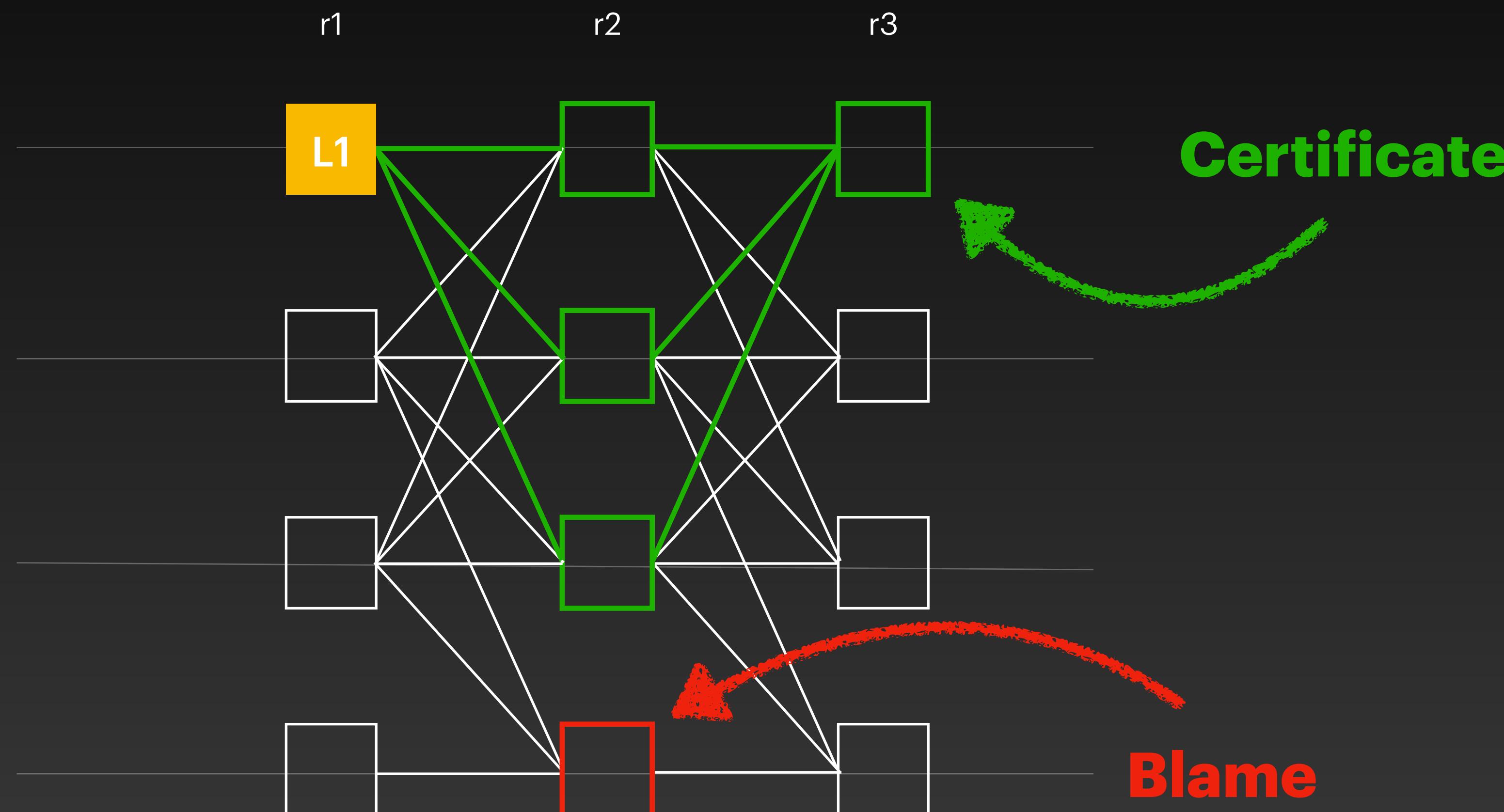
Uncertified DAG



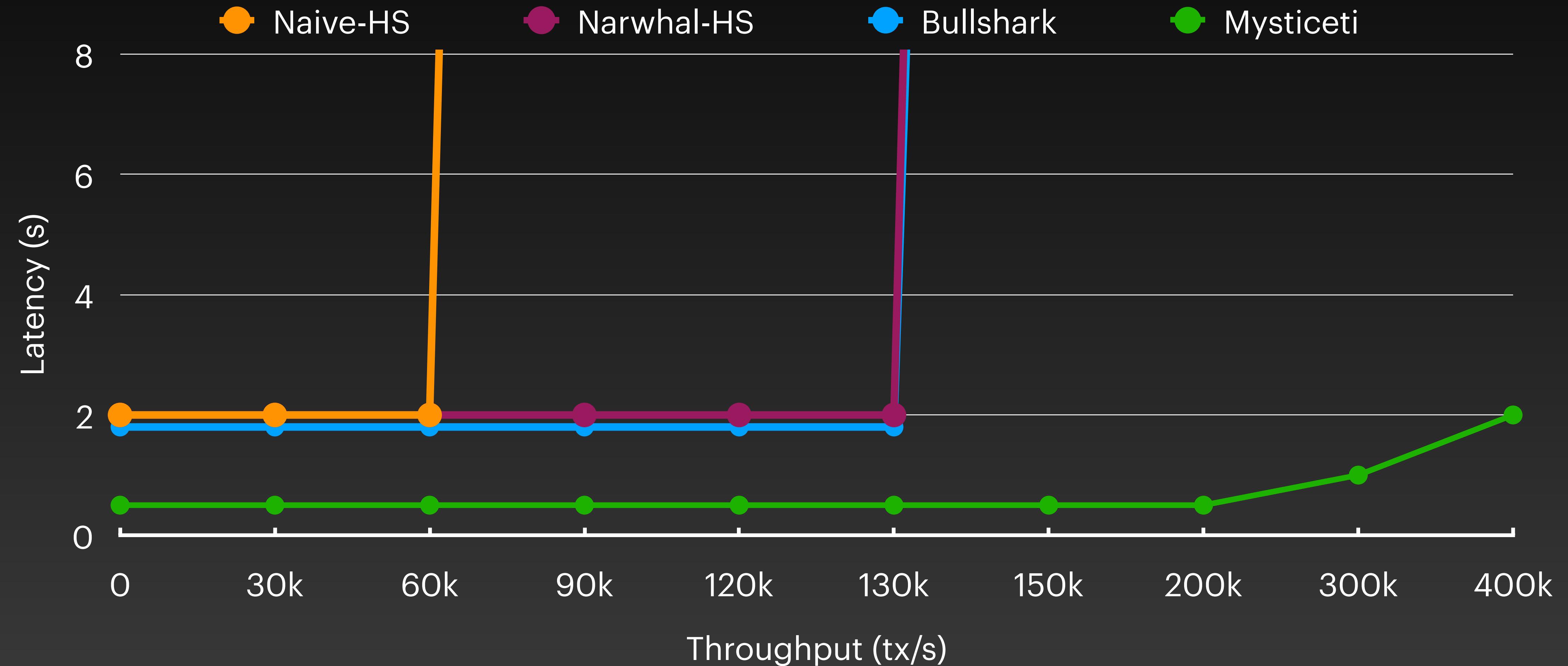
Uncertified DAG



Interpreting DAG Patterns



Performance



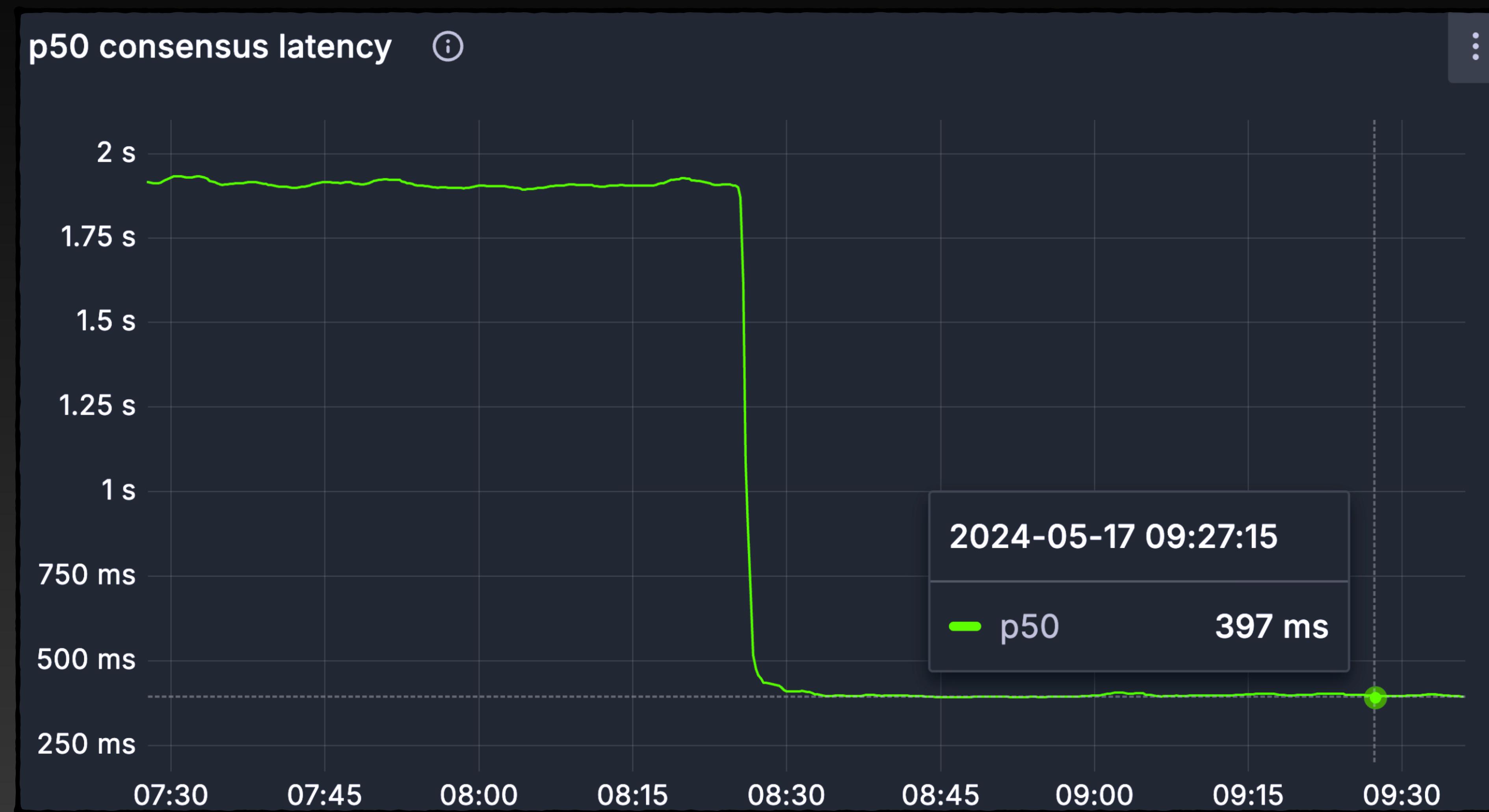
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7. Efficient reads?

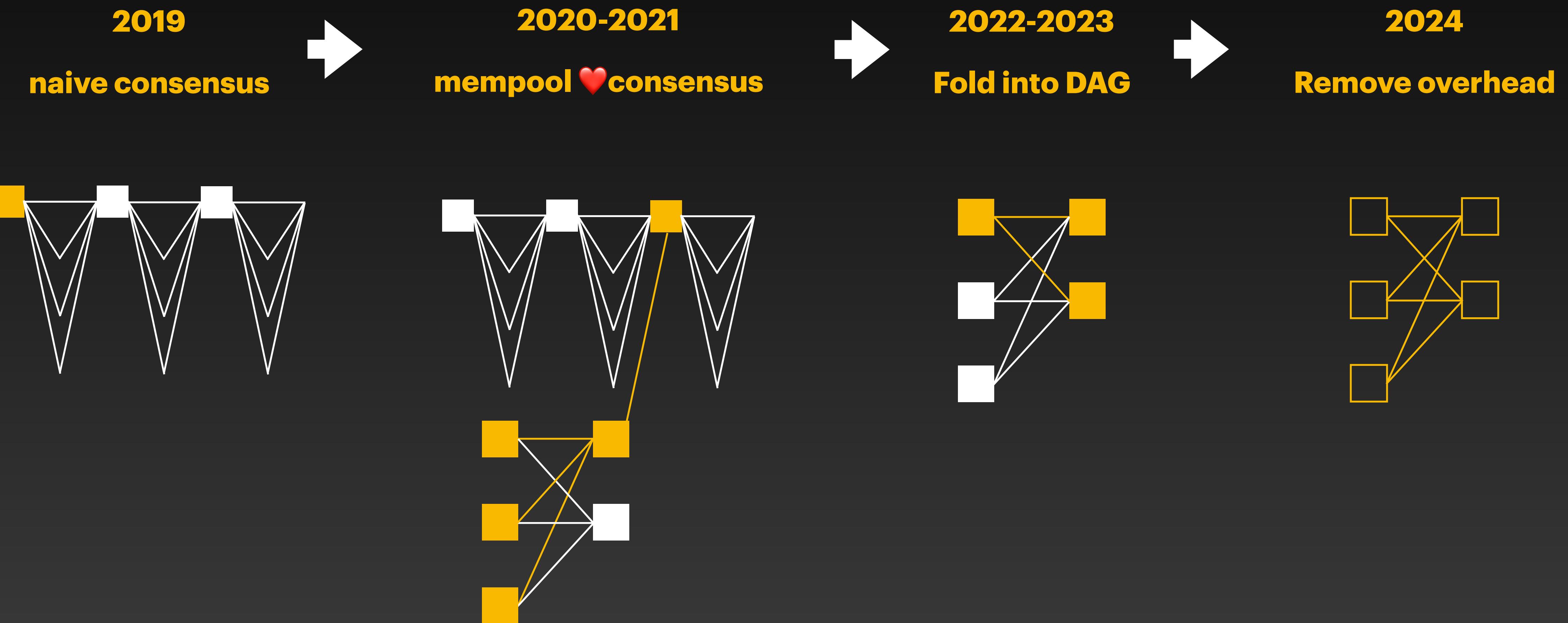
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The Sui Mainnet



The Roadmap



EXTRA:

Research in Industry

Projects Roadmap



Dmitri Perelman Oct 18th at 5:55 AM

In tomorrow's Research <> Core Eng syncup, [@Mark Logan](#) is going to share top of mind of Core Eng pain points and current struggles. See you 



2



Projects Roadmap

 **Dmitri Perelman** Oct 18th at 5
In tomorrow's Research <> C
going to share top of mind of
struggles. See you 

 2 

< **Thread** # sui-core-internal

 **Dmitri Perelman** Oct 18th at 5:55 AM
In tomorrow's Research <> Core Eng syncup, [@Mark Logan](#) is
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struggles. See you 

 2 

2 replies

 **John Martin** Oct 18th at 6:16 AM
Can I get an invite to this 

 2 

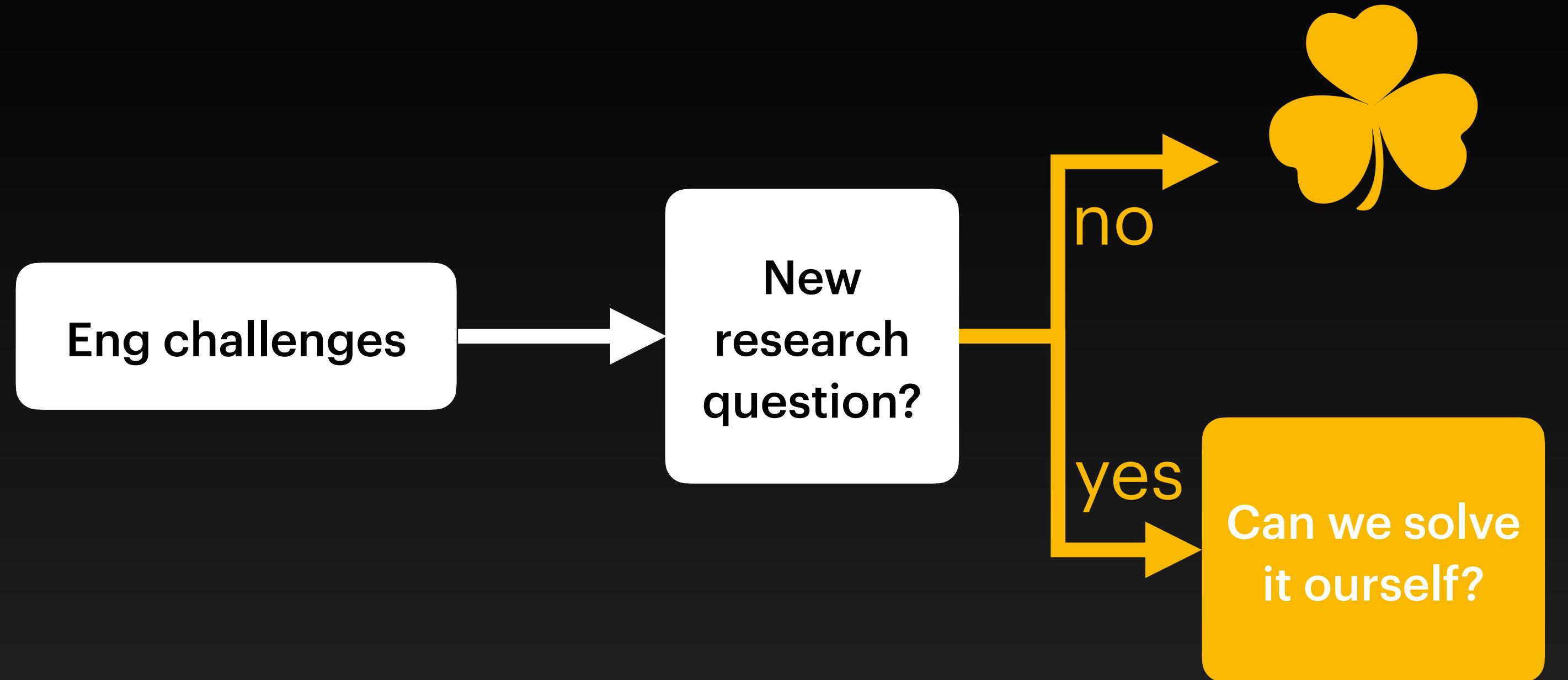
 **Dmitri Perelman** Oct 18th at 7:36 AM
You're in the invite list!

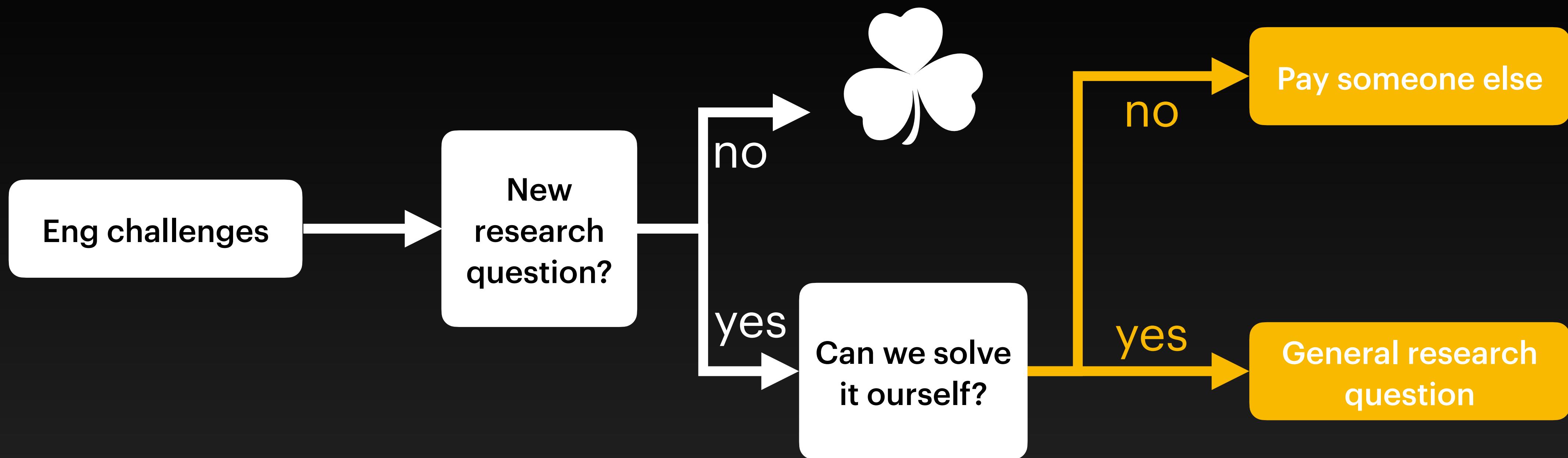
 1 

Eng challenges



New
research
question?

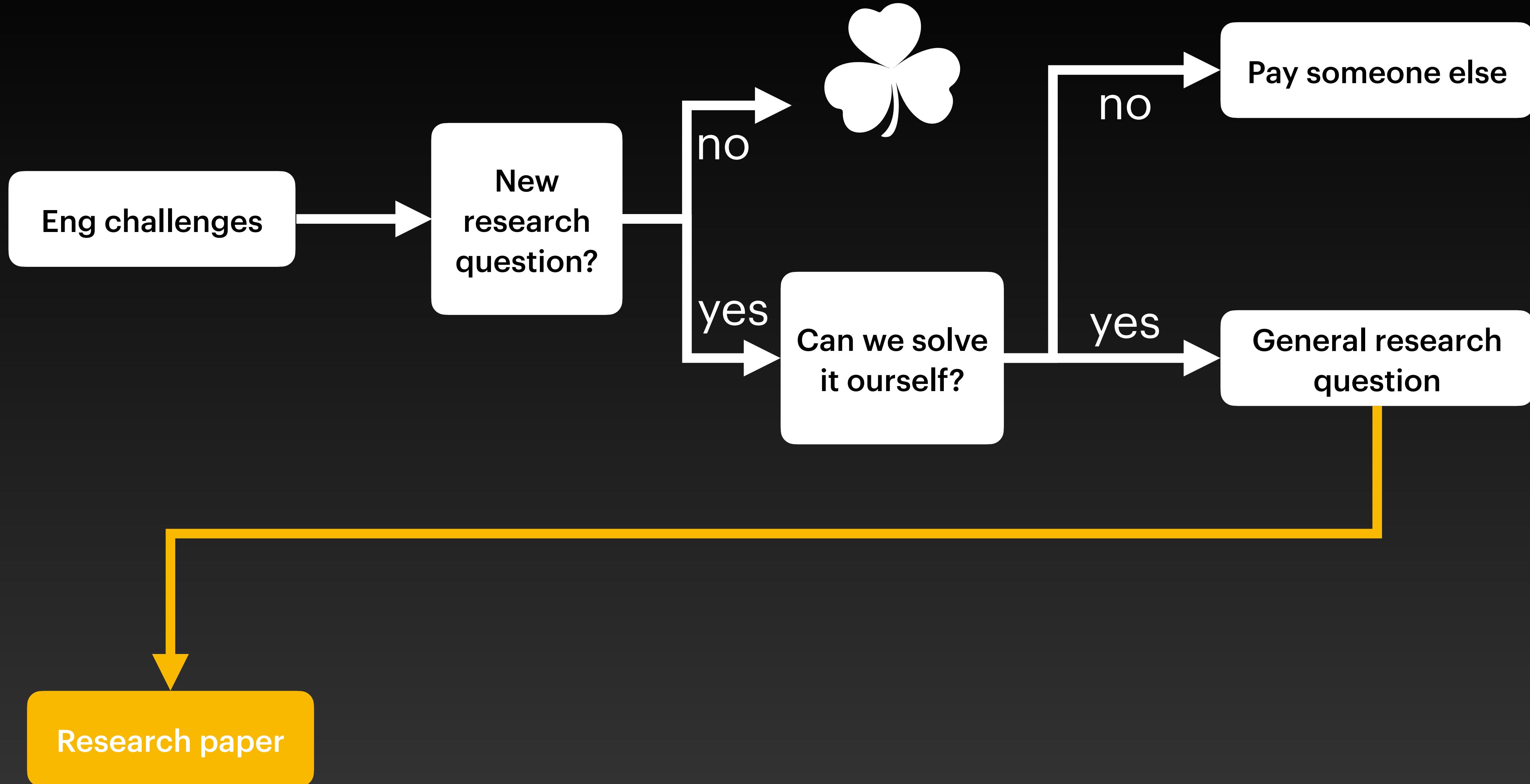


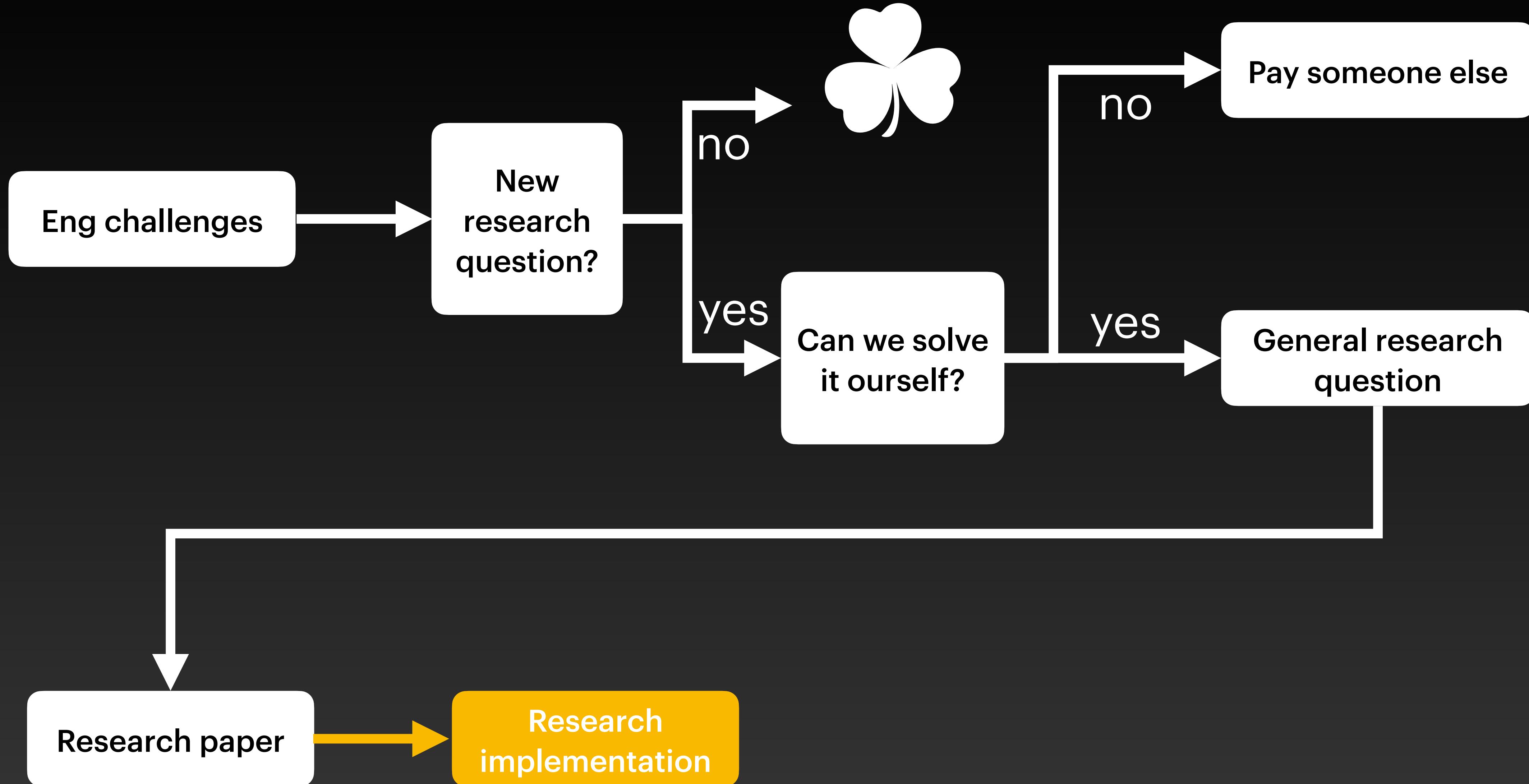


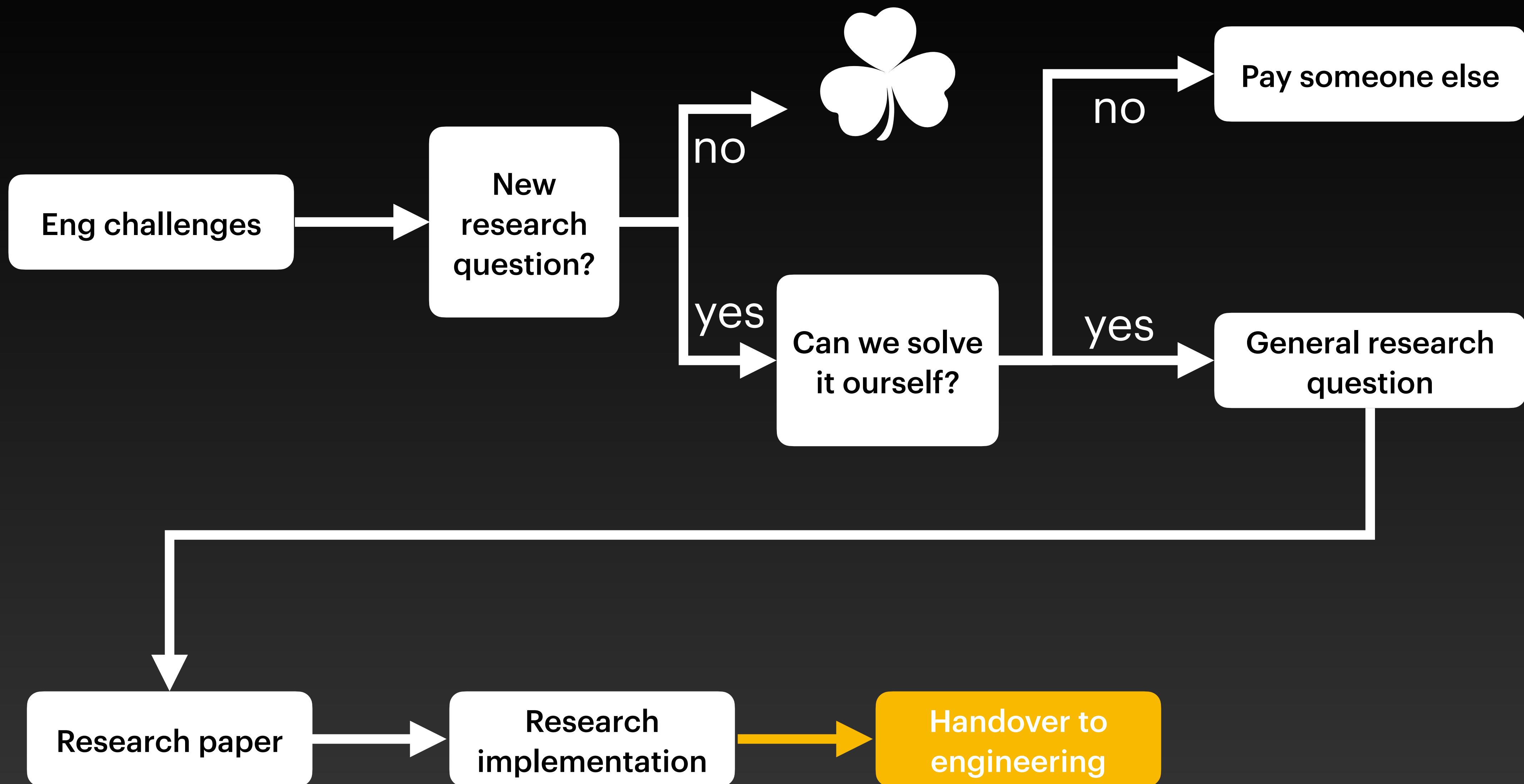
Research Gifts

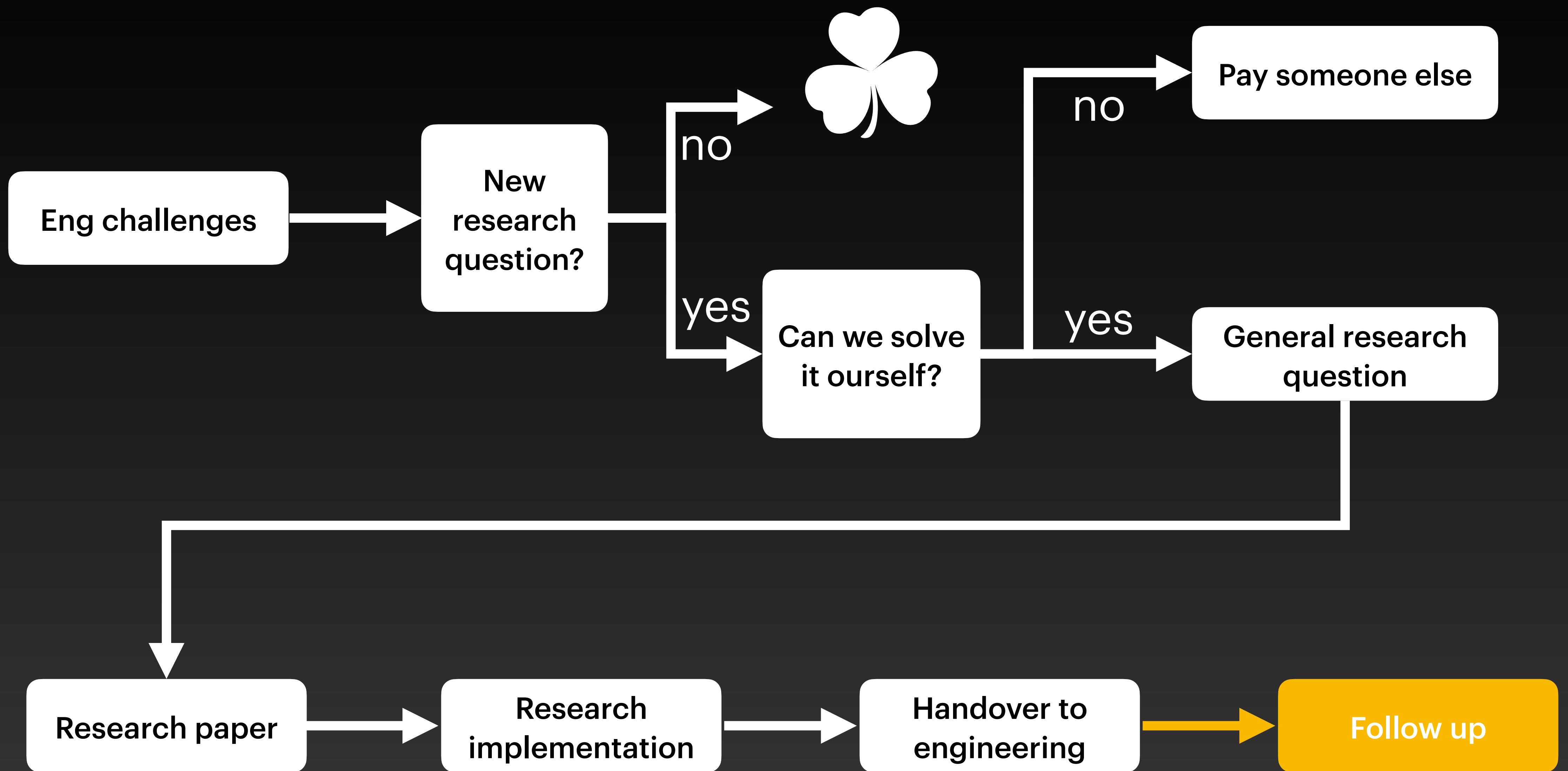


(please keep it short)









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6. Epoch change is not an add-on
7. Writing papers to explore designs

EXTRA:

Benchmarks

Implementation

- Written in Rust
- Networking: Tokio (TCP)
- Storage: custom WAL
- Cryptography: ed25519-consensus

<https://github.com/mystenlabs/mysticeti>

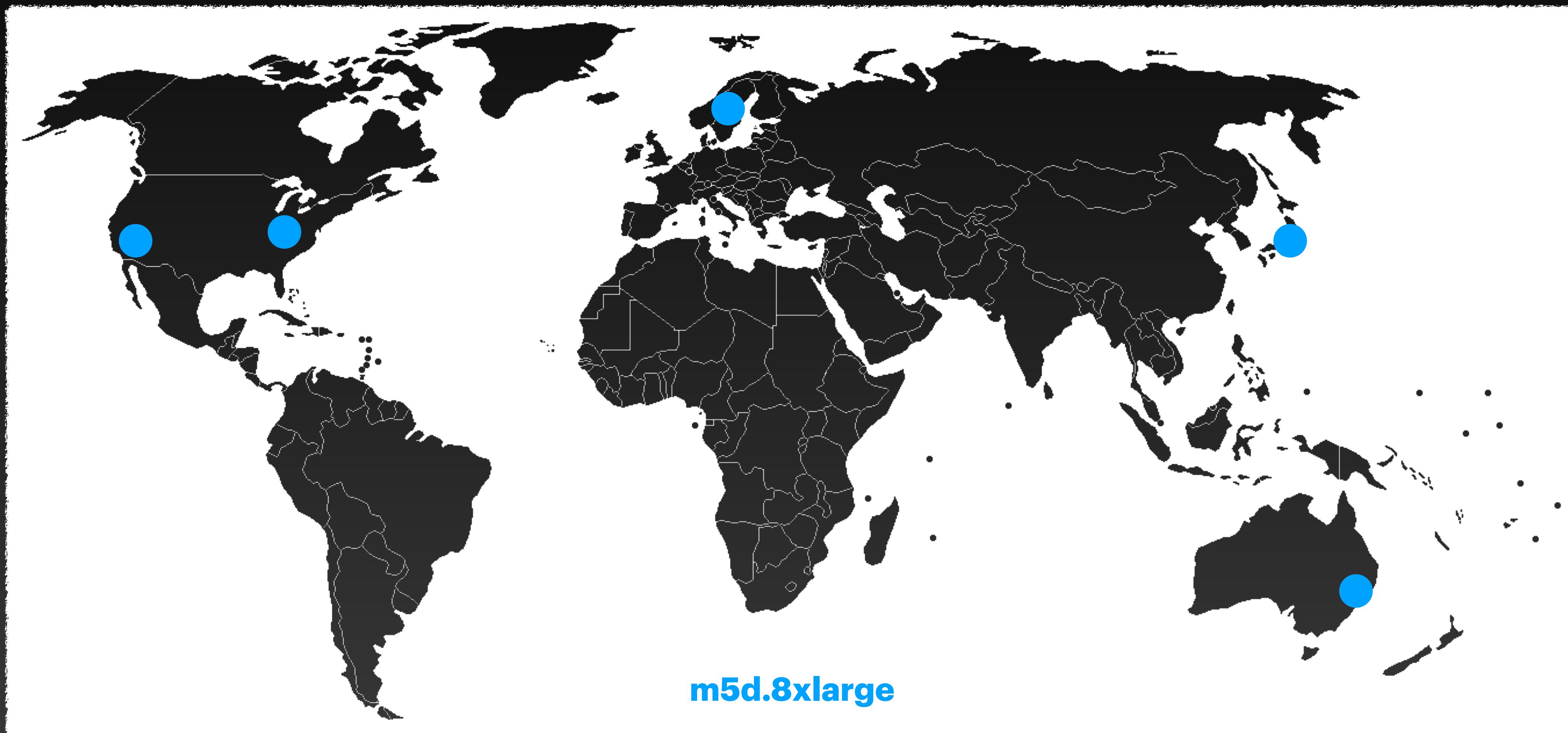
Implementation

- Synchronous core
- One Tokio task per peer (limiting resource usage)
- DTE simulator

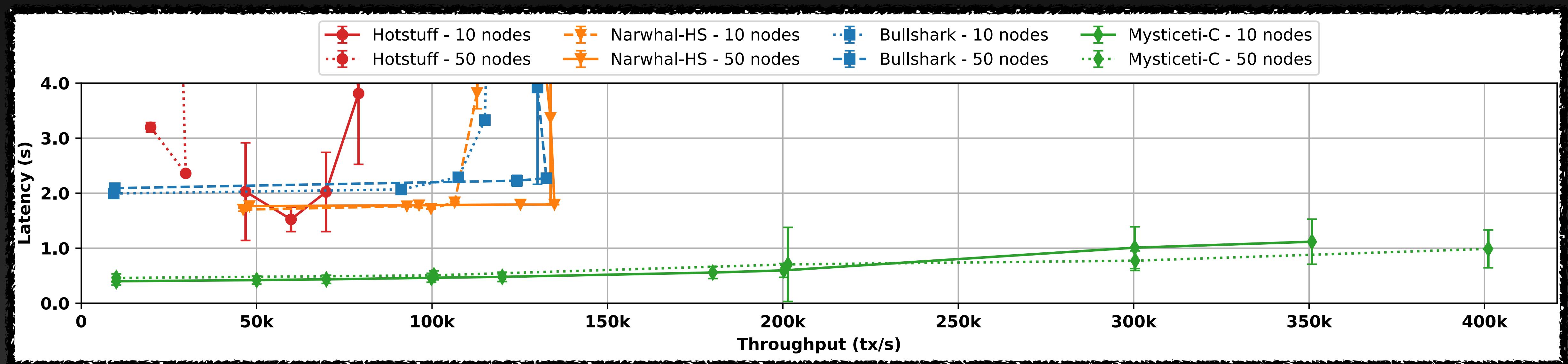
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Evaluation

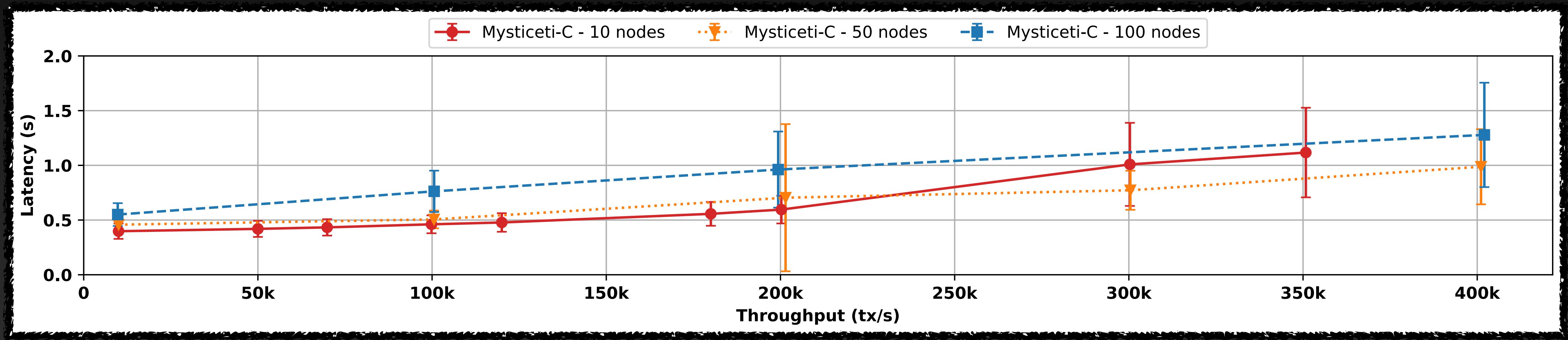
Experimental setup on AWS



Prototype Benchmarks



Prototype Benchmarks



Mysticeti

Key Limitations

- Block Synchroniser
- Parallelise block creation and synchronisation
- Rigid DAG structure?