Consistency vs. Scalability in Blockchain Systems

Goals: Determine the trade-offs between consistency and performance in permissionless and permissioned blockchains.

Tools: Logic, algorithmic reasoning, programming

Prerequisites: basic knowledge of distributed algorithms (with a focus on state-machine replication, Byzantine Fault-Tolerance, storage systems), basic concurrent programming skills, curiosity and persistence

Summary

The prominent *blockchain* technology aims at implementing a public "ledger": a decentralized consistent history of transactions proposed by an *open* set of participating processes, with no static membership. This problem can be seen as an instance of fault-tolerant *state-machine replication* [14], prominent examples of which are the *crash-tolerant* Paxos protocol by Lamport [11] and the BFT (*Byzantine* fault-tolerant) system by Castro and Liskov [3]. These systems use instances of *consensus* protocols in order to ensure that users get consistent views of the system evolution.

Principal downside of classical consensus protocols are lack of scalability and the need for a fixed or properly reconfigurable set of participants out of which only a bounded fraction (up to one third) can be faulty. This can be hard to ensure in an open system, where an arbitrary fraction of participants can be controlled by the adversary [5]. Prominent blockchain protocols [13,15] achieve (nondeterministic) consistency by assuming that (1) the system is synchronous, (2) participants can use asymmetric cryptography, and (3) the adversary can control at most a minority (in practice, a minor fraction) of computing power.

Intuitively, these assumptions are used to overcome the folklore CAP theorem [2, 8] stating that no system can combine Consistency, Availability, and Partition-Tolerance. In particular, these protocols avoid partitioning by enforcing the *proof of work* (PoW) mechanism requiring that a participant must solve a time-consuming cryptographic puzzle before updating the ledger. The resulting protocols are notoriously slow and energy-demanding. More recent blockchain prototypes propose to obviate the energy demands via using *proof-of-stake* [1, 10], *proof-of-space* [6], or *proof of space-time* [12]. However, the proposals still resort to synchronous networks and/or impose restrictions on the fraction of honest players to ensure proper security levels. An immediate question is whether these costs and assumptions are unavoidable.

The goals of this project are twofold. On the one hand, we intend to characterize the model assumptions that enable strong ledger consistency in an open system. This will involve determining precise bounds on the amount of synchrony [4, 7] and energy/space/time consumption for implementing a generic distributed transaction ledger. This might lead to improving the conventional "proof" mechanisms, used, e.g., in Tezos [9] and Cardano [10] platforms.

On the other hand, we plan to explore the space of consistency definitions that enable solving the *digital currency* problem addressed by the original Bitcoin protocol [13]. Maintaining a total order on all currency transfers may not be necessary: intuitively, nonconflicting transactions may be accepted in parallel without requiring consensus. In the permissionless context, this may allow us to completely get rid of costly and slow "proofs". In conventional ("permissioned") models, we expect this to bring considerable performance gains.

Theoretical in its nature, the project is motivated by viable practical concerns. Besides provable complexity and computability bounds, it intends to develop system prototypes that are not only formally proved correct but also studied experimentally.

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