Tardigrade:

An atomic broadcast protocol for arbitrary network conditions

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What is atomic broadcast?

Atomic broadcast:

- Parties receive input values over time
- Want to agree on a growing, ordered *sequence* of values
- Some parties are **Byzantine** (faulty)

Our setting:

- Point-to-point authenticated channels
- Messages sent by an honest party eventually arrive (i.e., messages cannot be dropped)
- Assume trusted dealer performs setup for public key infrastructure (PKI), threshold signatures, threshold encryption

Network models

Synchronous model

- Messages arrive within fixed delay $\leq \Delta$
- Optimal fault tolerance*: $t < n/2$

Asynchronous model

- No upper bound on message delay
- Optimal fault tolerance*: $t < n/3$

*assuming PKI

How do I know which one to choose?
What happens if I'm wrong?

	Delay $\leq \Delta$, $t < n/2$	Unbounded delay, $t < n/3$
Async. Protocol	**Not secure for $t \geq n/3$ faults**	Secure
Sync. Protocol	Secure	**Not secure if delay exceeds Δ**

Prior work

Other settings:

- Network may be synchronous or partially synchronous [MNR19, MR21]
- Temporary partitions/“sluggish” faults [e.g. GPS17, AMNRY20]
- Tolerating $t < n/2$ *crash* faults if network is asynchronous [LVCQV16]

Most closely related:

- Network-agnostic Byzantine agreement [BKL19] and secure multiparty computation [BLL20]

Research question

Can we design a “network-agnostic” protocol that is

- Secure for $t_s > n/3$ faults if network is synchronous
- Secure for $0 \leq t_a \leq t_s$ faults otherwise?

Our contributions

1. **Lower bound**: if $t_a + 2t_s \geq n$, then there is no atomic broadcast protocol secure against t_s faults in a sync. network and t_a faults in an async. network.

2. **Tardigrade**: a network-agnostic atomic broadcast protocol
   - Optimal fault tolerance (any t_a, t_s such that $t_a + 2t_s < n$)
   - Can be made adaptively secure

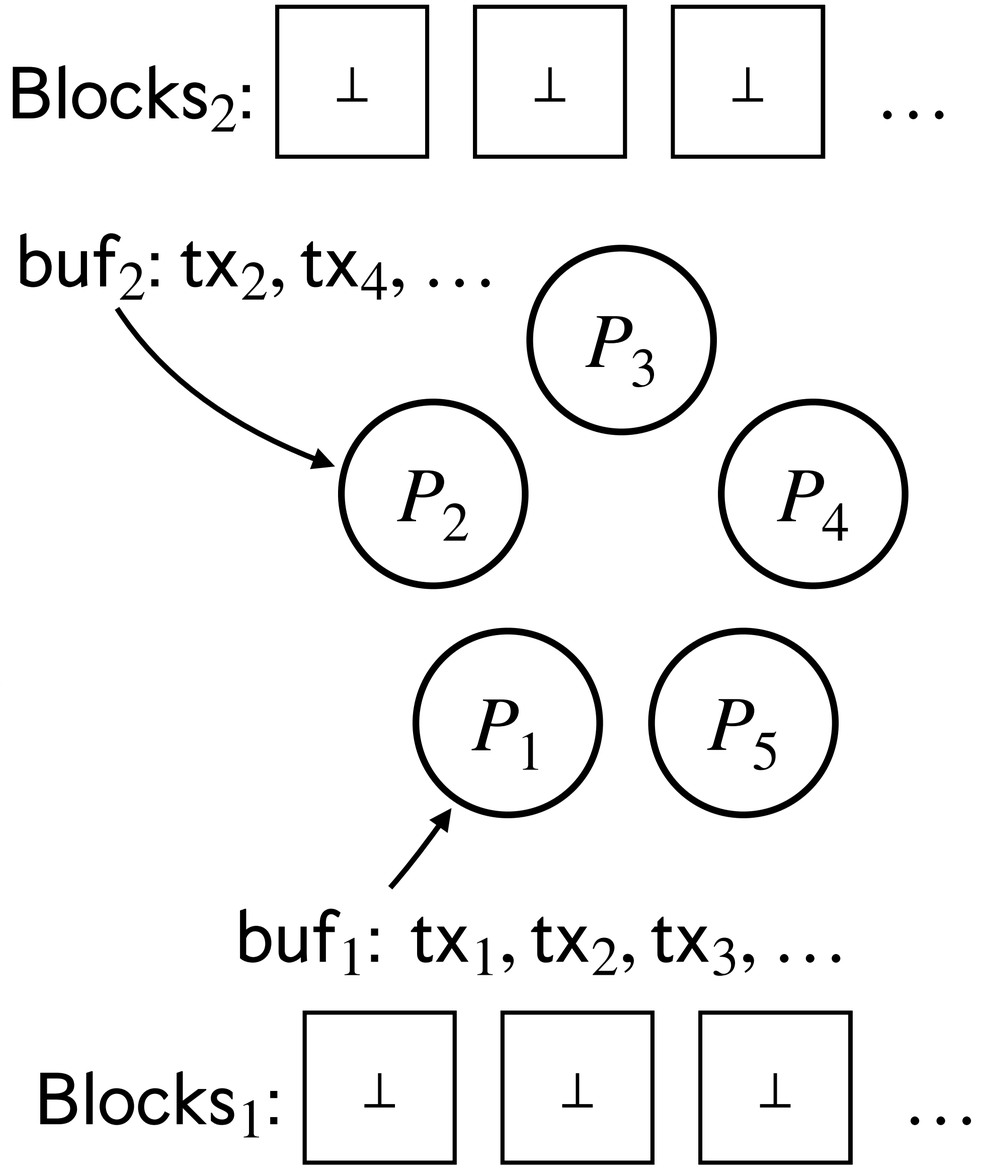
3. **Upgrade**: network-agnostic atomic broadcast with asymptotic communication complexity matching state of the art async. protocols, at the cost of tolerating $O(\epsilon)$ fraction fewer faults. (Only statically secure)

Atomic broadcast

- Each party P_i has a local buffer buf_i and array of blocks Blocks_i
- Values are added to buffers over time

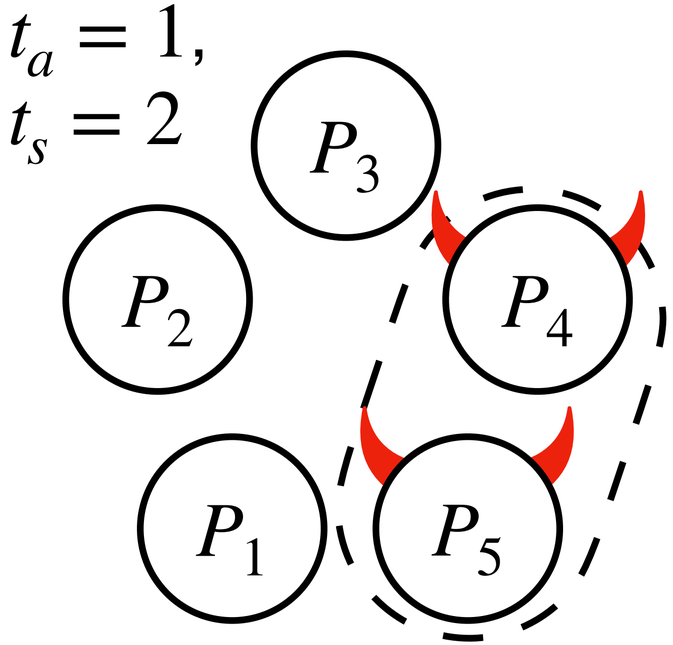
Security properties:

- <u>Consistency:</u> if P_i, P_j have both output block k, then $\mathsf{Blocks}_i[k] = \mathsf{Blocks}_j[k]$
- <u>Completeness:</u> each party eventually outputs a block at index k (for all k)
- <u>Liveness:</u> if tx is in all honest parties' buffers, then each party eventually outputs a block that contains tx



Technical overview: lower bound

Theorem: There is no atomic broadcast protocol secure against t_s faults in a sync. network and t_a faults in an async. network for $t_a + 2t_s \geq n$.



Honest P_1 has not heard from P_4, P_5.

Explanation 1: Network is asynchronous and P_4, P_5 are honest

Explanation 2: Network is synchronous and P_4, P_5 are malicious

Interlude: What is a tardigrade?

Milnesium tardigradum

- Type of microscopic animal also known as “water bears”
- Capable of surviving extreme heat, cold, radiation, and pressure by entering a state called *cryptobiosis*
- In one experiment, 68% of tardigrades survived exposure to hard vacuum of outer space

Technical overview: Tardigrade

Share inputs:

Send (buf_i, σ_i) to all

Wait to collect "pre-block" $B_i = \{(\text{buf}_j, \sigma_j)\}_{j \in P' \subseteq P}$ containing $n - t_s$ inputs

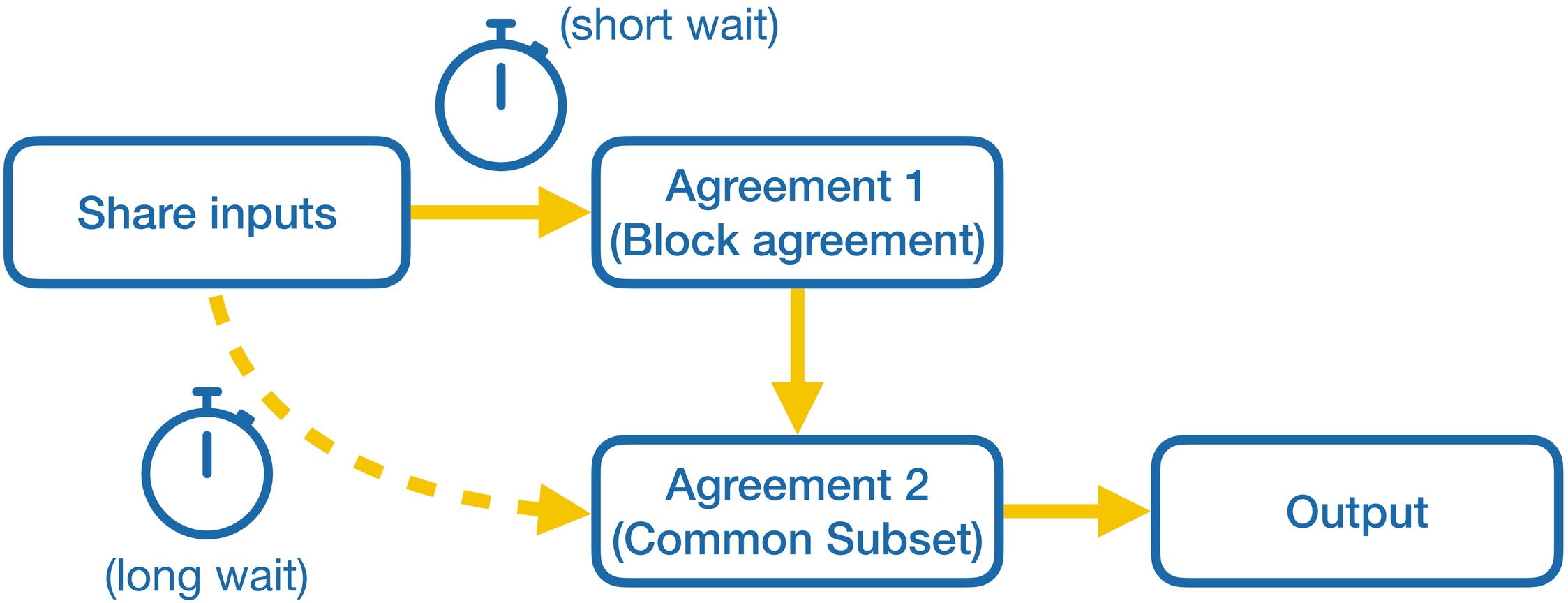
Agreement 1&2:

Agree on set of pre-blocks

Output:

Output new block

Technical overview: Tardigrade

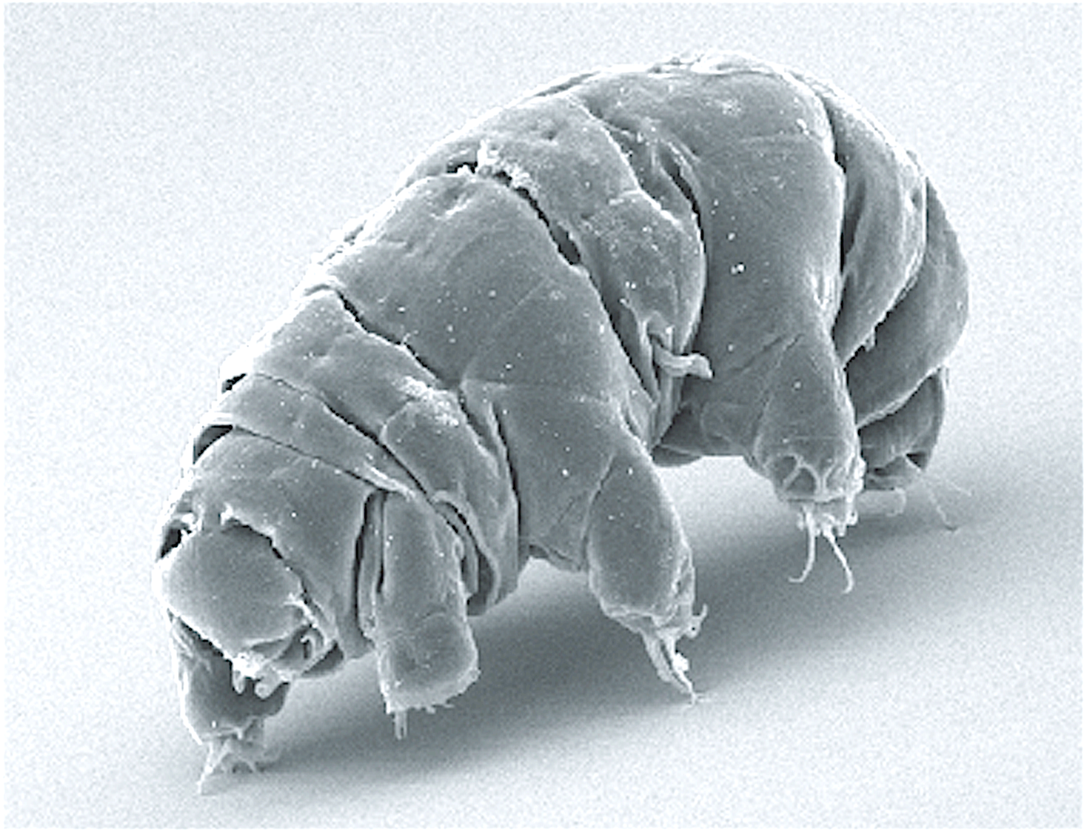


Technical overview: Tardigrade

Why it works

	Sync. network (t_s faults)	Async. network (t_a faults)
Agreement 1 (Block agreement)	**Terminates in time with consistent output**	If it terminates, then the output is valid
Agreement 2 (Common Subset)	If all honest parties input S, then all honest parties terminate with output S	**Terminates eventually with consistent output**

Recap



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Tardigrade facts: https://en.wikipedia.org/wiki/Tardigrade

Lower bound: if $t_a + 2t_s \geq n$, there is no atomic broadcast protocol secure against t_s faults in a sync. network and t_a faults in an async. network.

Tardigrade: network-agnostic atomic broadcast with optimal fault tolerance

Upgrade: better communication complexity for $O(\epsilon)$ fewer faults

Full paper: eprint.iacr.org/2020/142.pdf

References

E. Blum, J. Katz, and J. Loss. Synchronous consensus with optimal asynchronous fallback guarantees. In *17th Theory of Cryptography Conference—TCC 2019*. Springer, 2019.

E. Blum, C.-D. L. Zhang, and J. Loss. Always have a backup plan: Fully secure synchronous MPC with asynchronous fallback. In *Advances in Cryptology— Crypto 2020*. Springer, 2020.

I. Abraham, D. Malkhi, K. Nayak, L. Ren, and M. Yin. Sync HotStuff: Simple and practical synchronous state machine replication. In *2020 IEEE Symposium on Security and Privacy*. IEEE, 2020.

Y. Guo, R. Pass, and E. Shi. Synchronous, with a chance of partition tolerance. *In Advances in Cryptology —Crypto 2019.* Springer, 2019.

S. Liu, P. Viotti, C. Cachin, V. Quema, and M. Vukolic. XFT: Practical fault tolerance beyond crashes. In *12th USENIX Symposium on Operating Systems Design and Implementation (OSDI 16)*, USENIX, 2016.

D. Malkhi, K. Nayak, and L. Ren. Flexible byzantine fault tolerance. In *26th ACM Conf. on Computer and Communications Security (CCS).* ACM Press, 2019.

A. Momose and L. Ren. Multi-threshold Byzantine fault tolerance. In *28th Conference on Computer and Communications Security (CCS),* 2021. Available at https://eprint.iacr.org/2017/307.