Peeking Into the Future

MPC Resilient to Super-Rushing Adversaries

Gilad Asharov

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BACK TO THE FUTURE
He was never in time for his classes...
He wasn't in time for his dinner...
Then one day... he wasn't in his time at all.
erik

“Well, hey, Doc, what’s the harm in bringing back a little info on the future? You know, maybe we could place a couple bets”

Biff's Attack on the Timeline

Biff's Attack on the Timeline

2015

Biff steals the almanac

Biff's Attack on the Timeline

1955

2015

Gives it to his past self

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Biff gets rich!

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Biff's Attack on the Tim[illegible]ne

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Biff gets rich!

Biff

The Weather

Hill Valley Telegraph

Index

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BIFF TANNEN

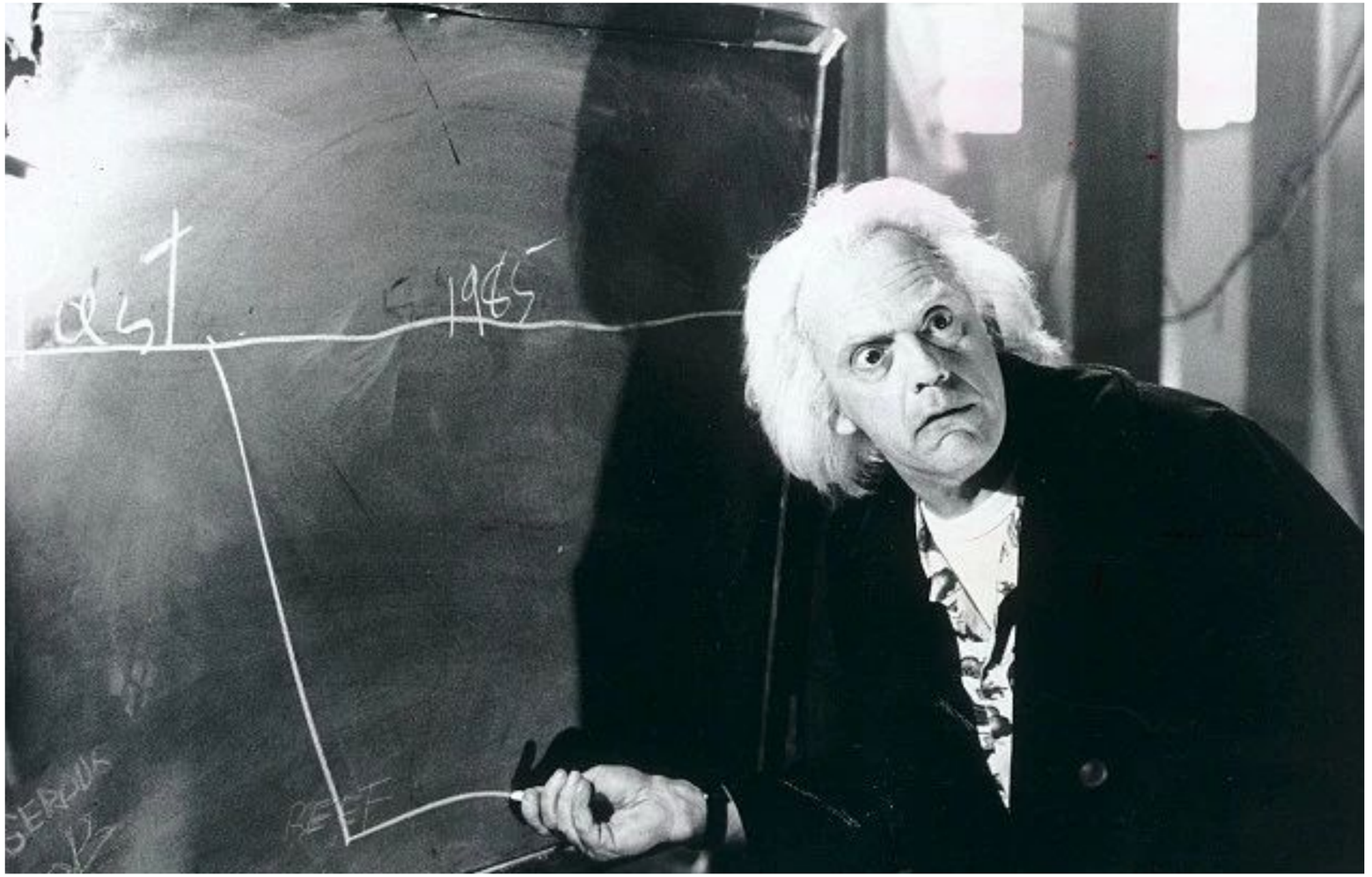
Luckiest Man On Earth

BIFF TANNEN

Nasser Accuses Reds of Plotting His Overthrow

State Likely to Start Payroll Tax in 1960

“No, Marty, we’ve already agreed that having information about the future could be extremely dangerous!”



Our Work

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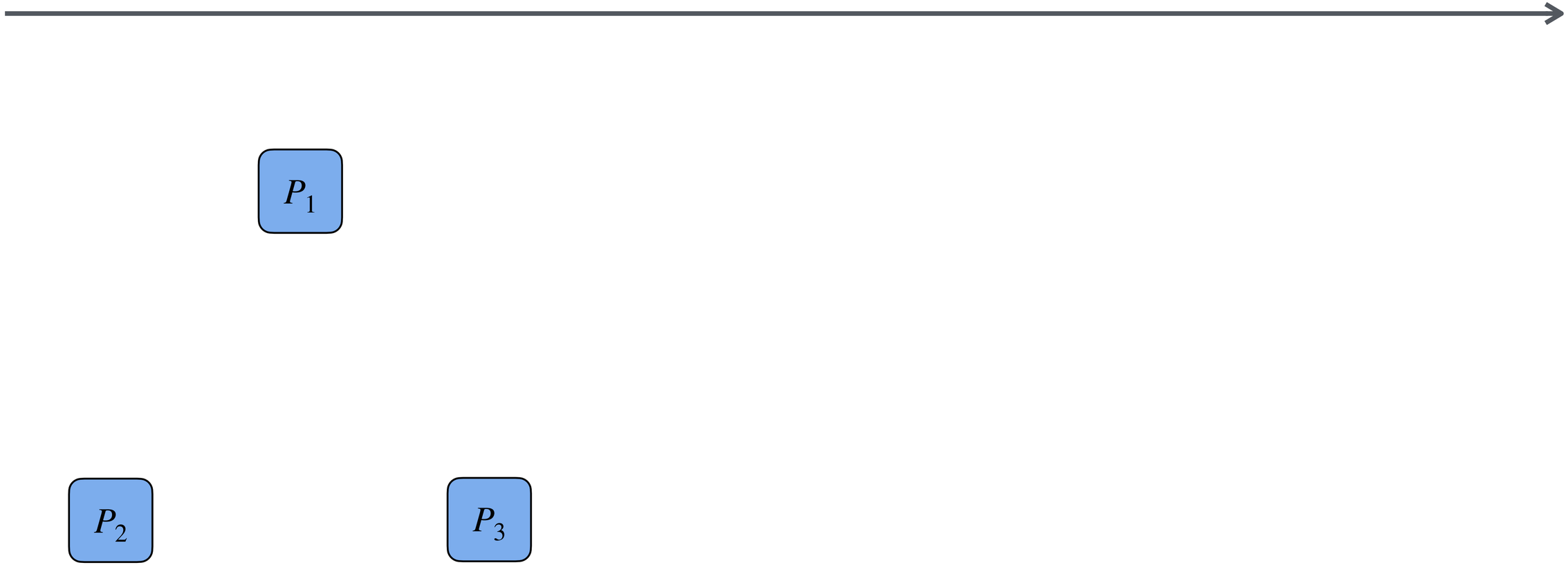
   - Some implementations of synchronous protocols are vulnerable
2. **Our Aim:** To understand which protocols are vulnerable to such an attack

Synchronous Protocols

Let there be rounds!



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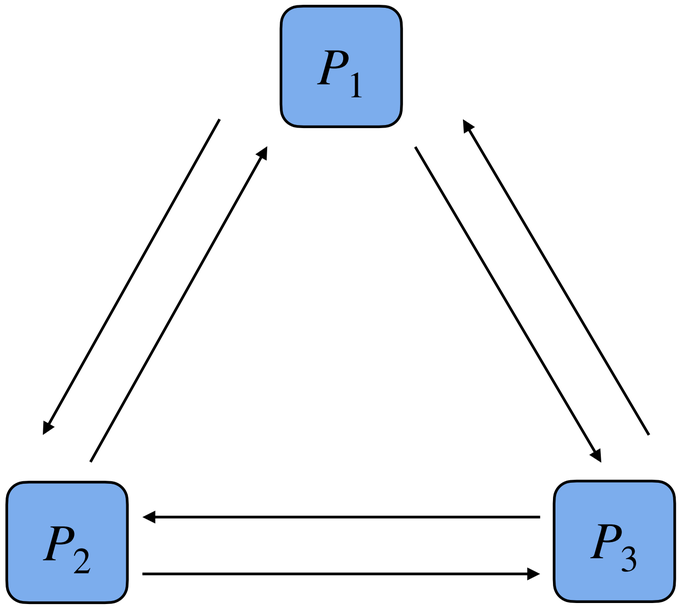
Round 1



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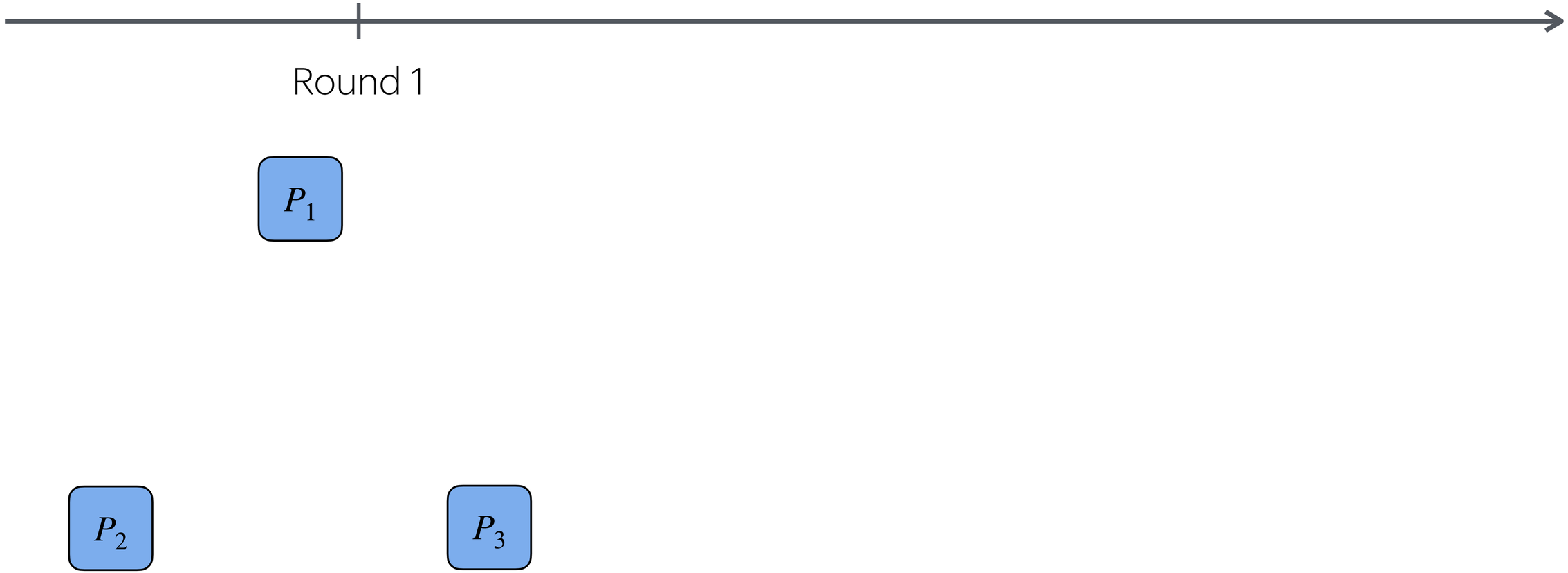

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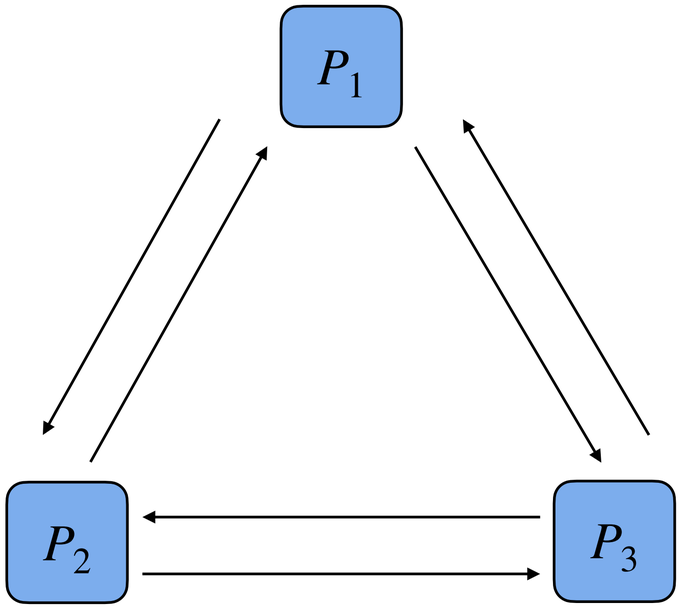

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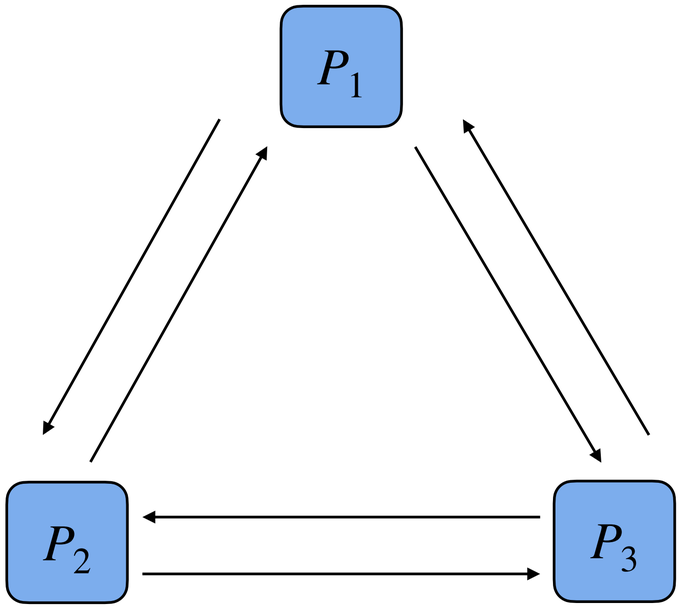

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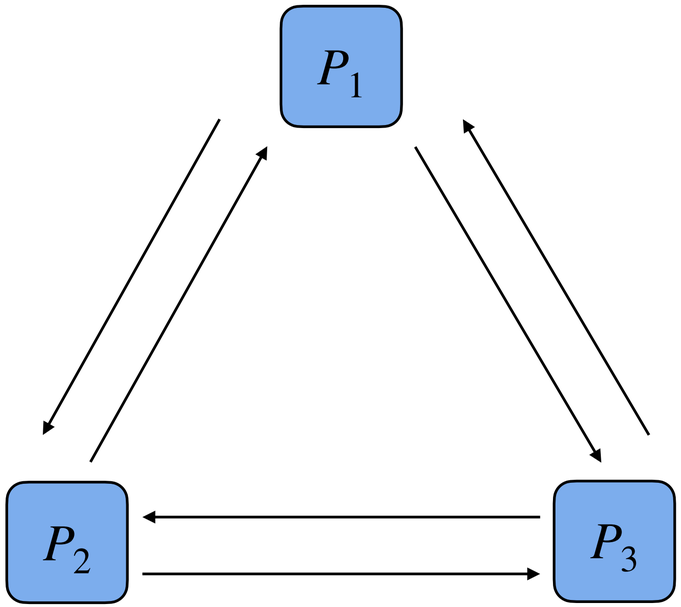

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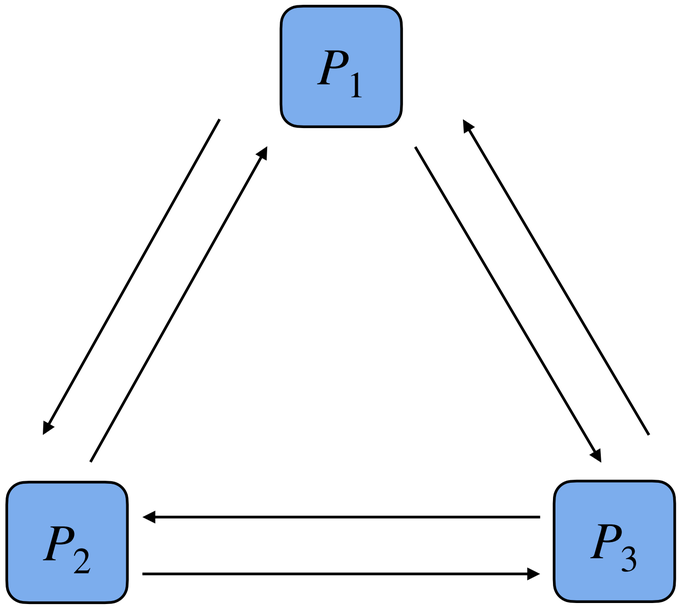

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- Majority of the literature

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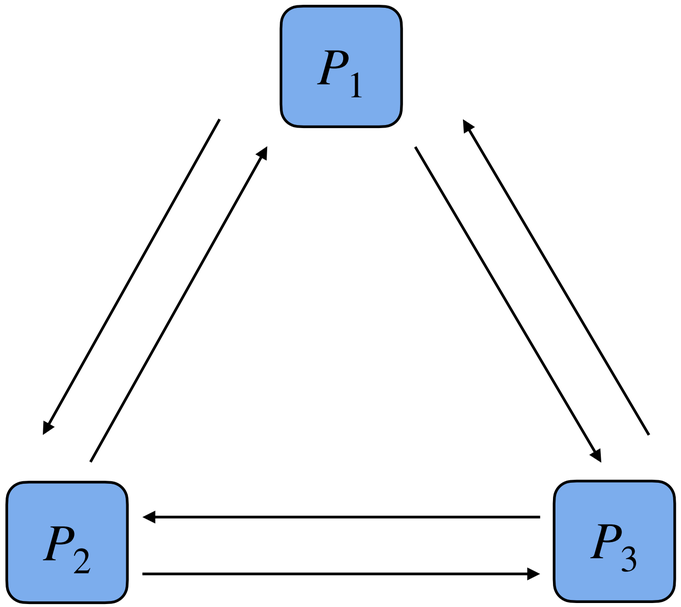

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- How to decide the delay?

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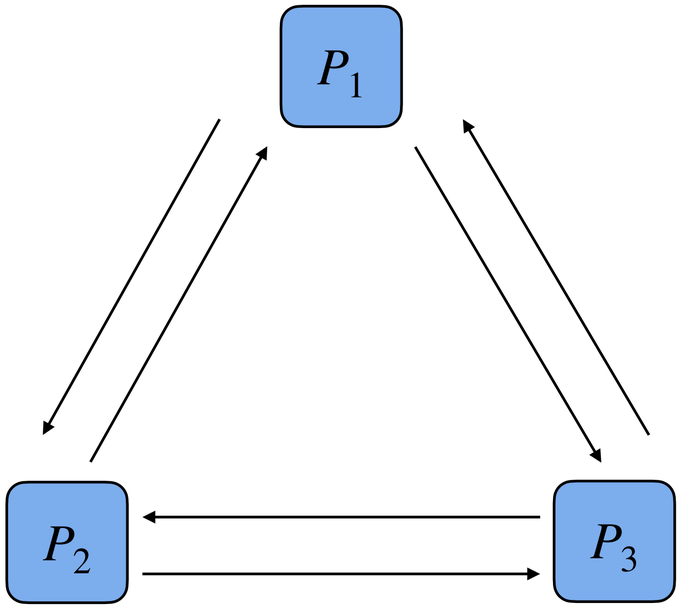

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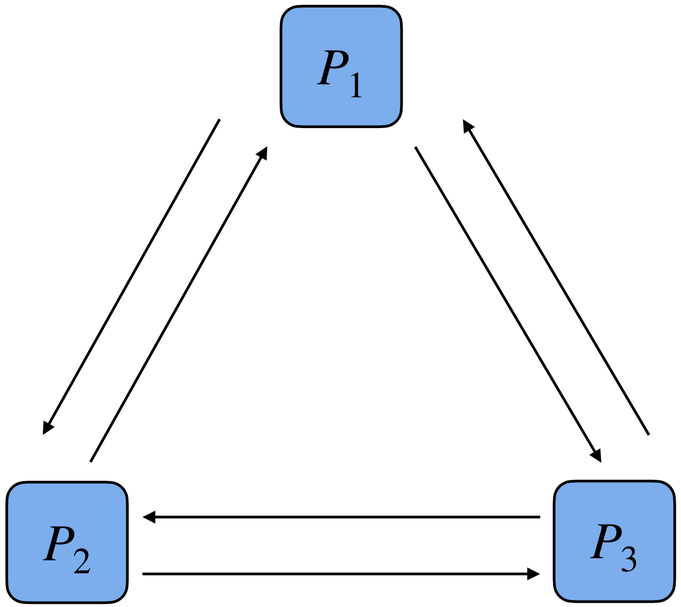

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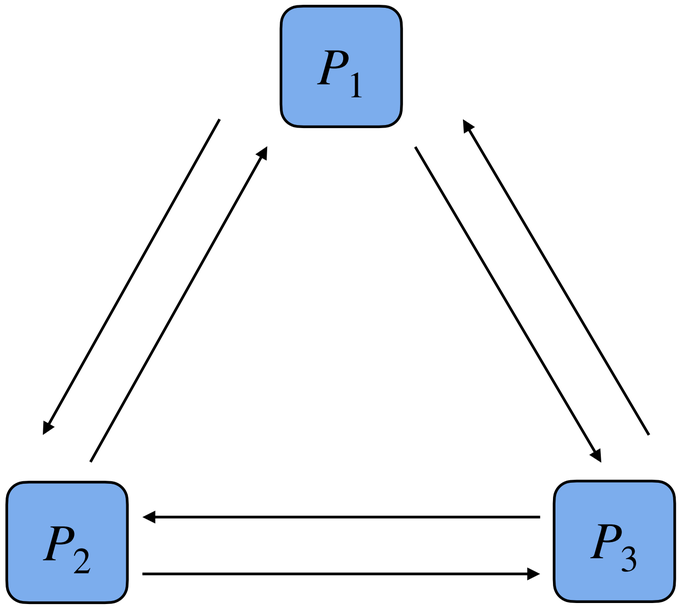

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Protocol Implementations

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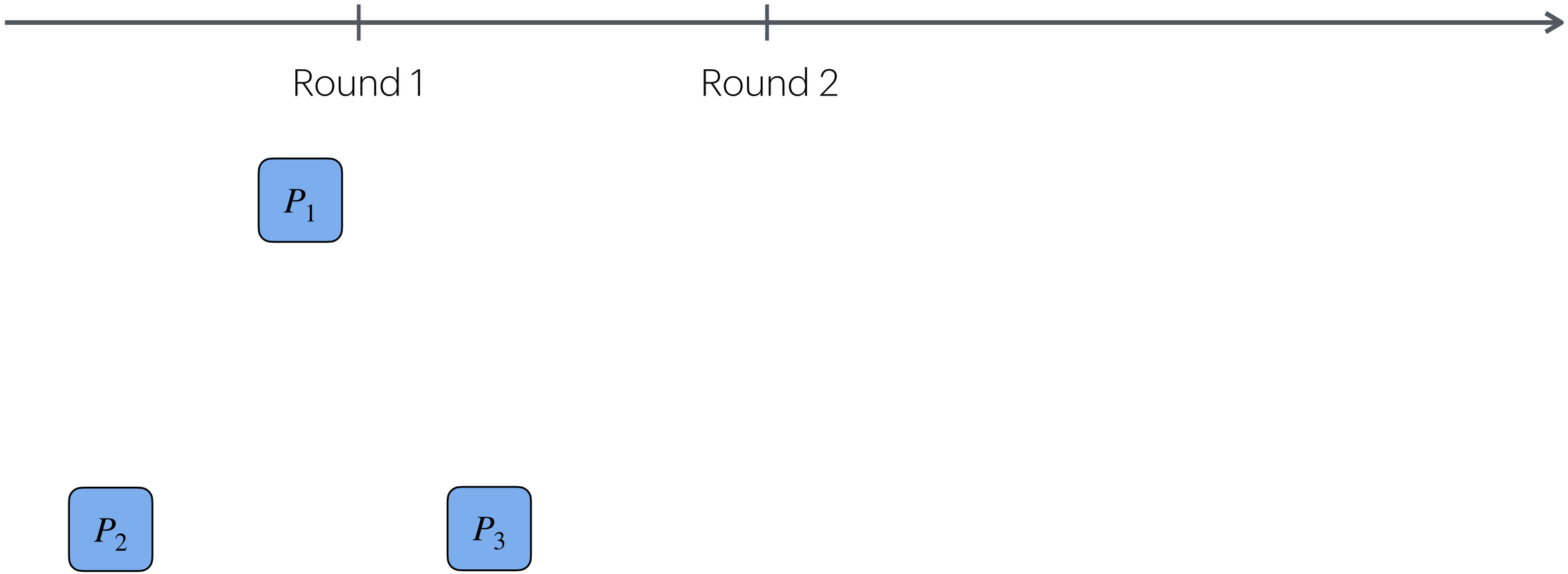

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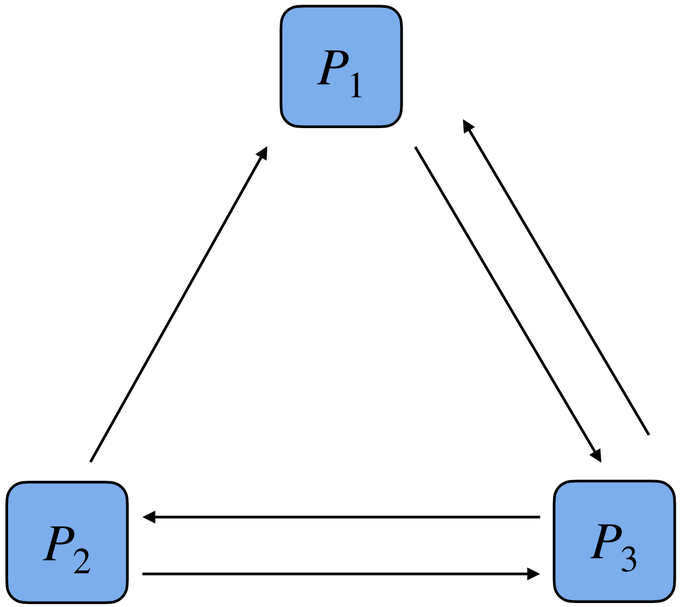

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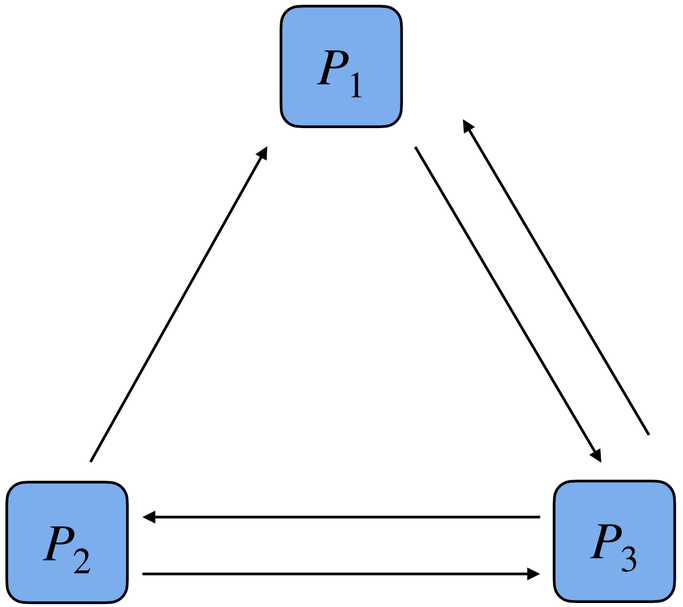

P_1 has not yet sent round-1 message to P_2

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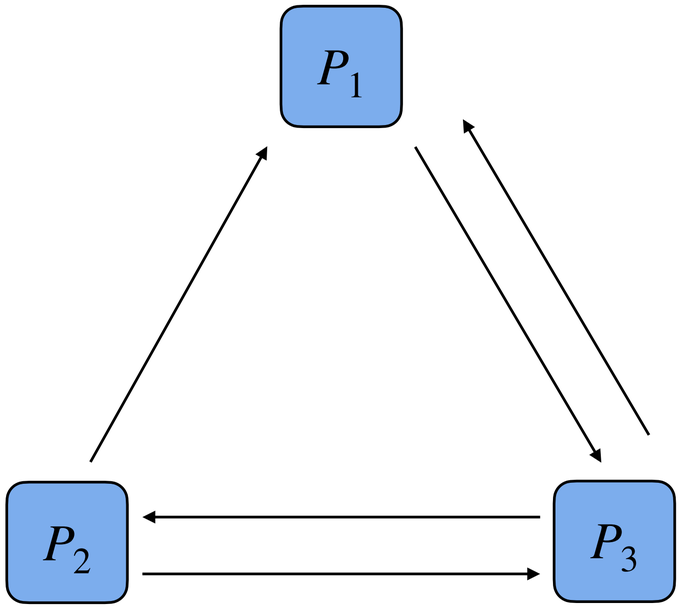

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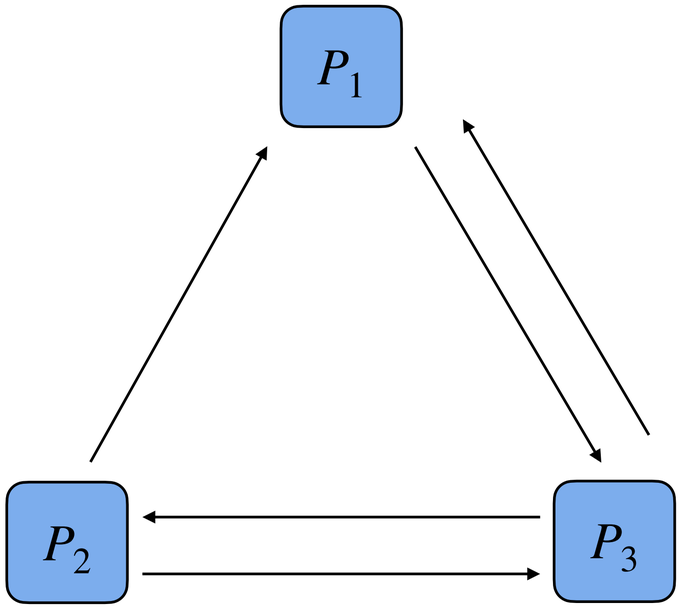

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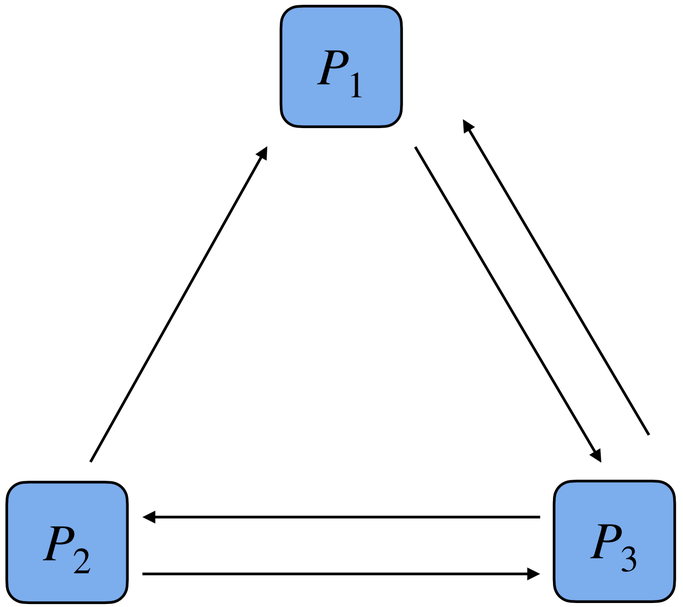

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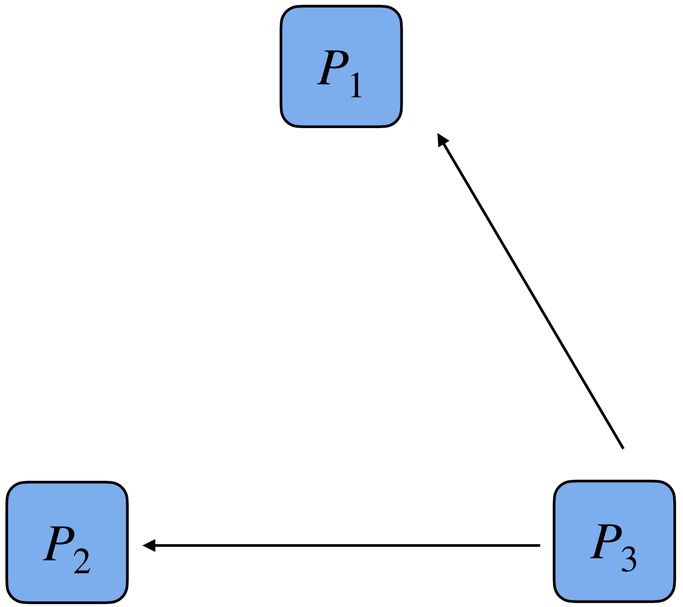

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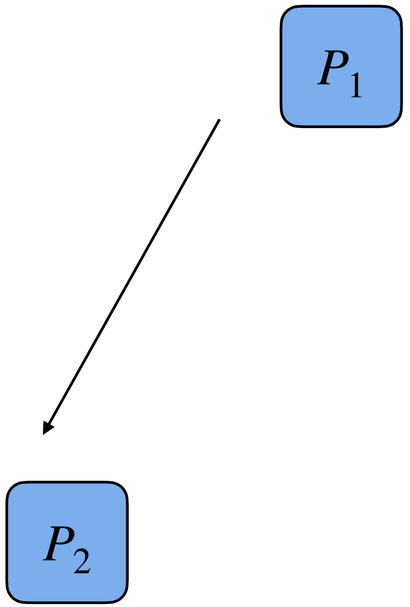

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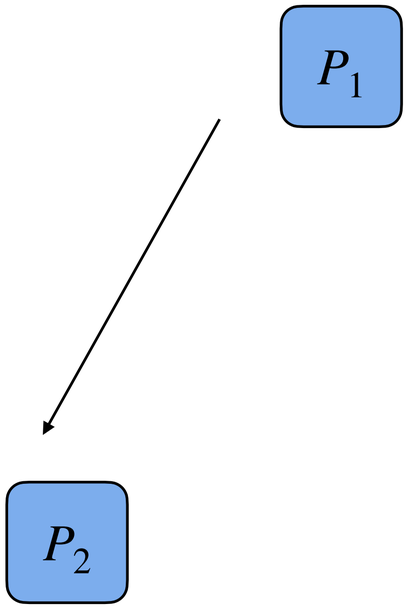

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P_3 has finished round-1

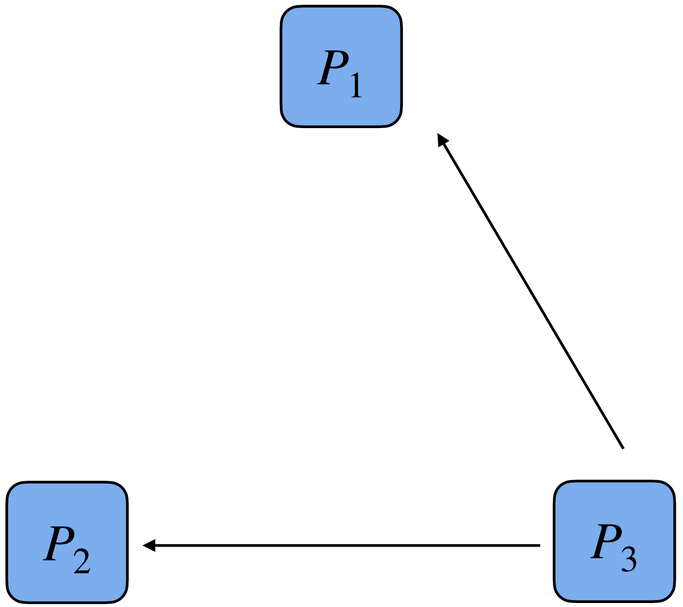
P_3 sends round-2 messages

P_1 sends round-1 message to P_2

P_1 gets a message from the future (from P_3)

“Wait a minute. Wait a minute Doc, uh, are you tellin’ me you built a time machine ... out of a synchronous network?”

No!



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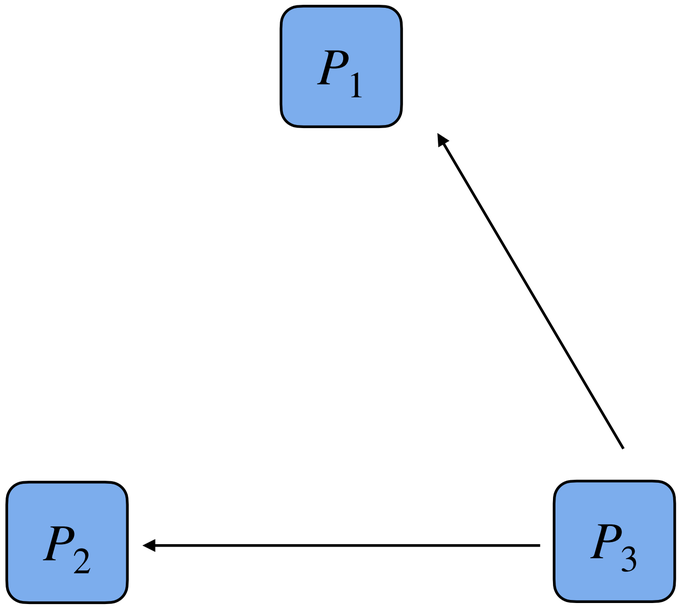
P_1 can "peek" into the future one round



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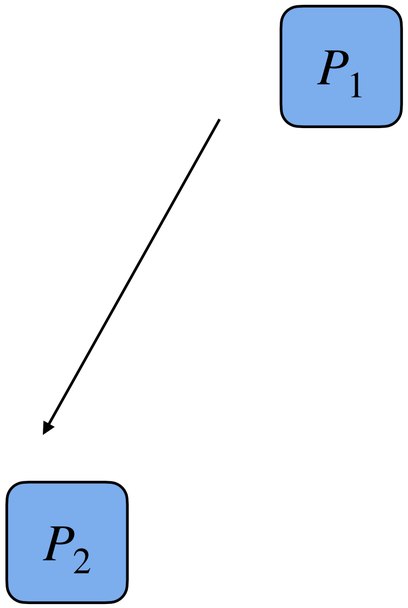

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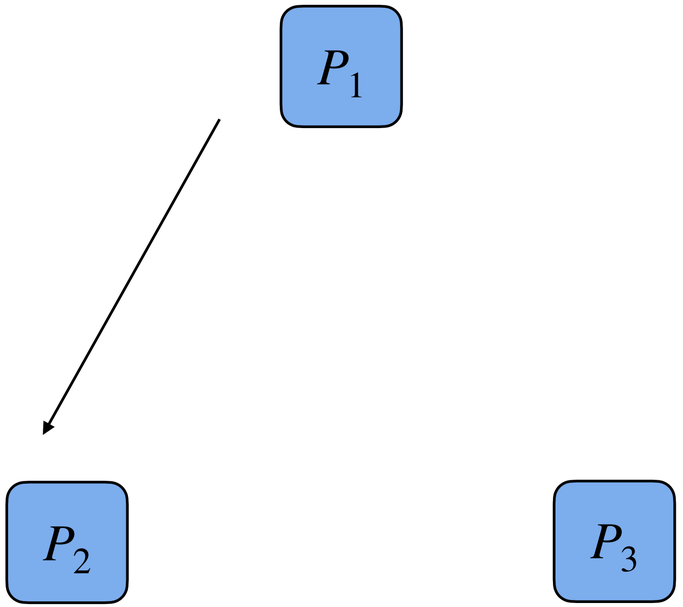

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P_3 sends round-2 messages

P_1 sends round-1 message to P_2

Note: All-to-all communication $\Longrightarrow$ Peeking at most 1 round

Peeking → Super-Rushing

Non-Rushing

Adversary sends round-r messages **before** receiving the honest parties' round-r messages

Non-Rushing

Adversary sends round-r messages **before** receiving the honest parties' round-r messages

Rushing

Adversary can send round-r messages **after** receiving the honest parties' round-r messages

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Adversary sends round-r messages **before** receiving the honest parties' round-r messages

Rushing

Adversary can send round-r messages **after** receiving the honest parties' round-r messages

Super-Rushing

Adversary can send round-r messages **after** receiving the honest parties' round-$r' > r$ messages

A Gap in the Security Analysis

Theory

Practice

A Gap in the Security Analysis

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Practice

Rushing

A Gap in the Security Analysis

Theory

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Practice

Super-Rushing

A Gap in the Security Analysis

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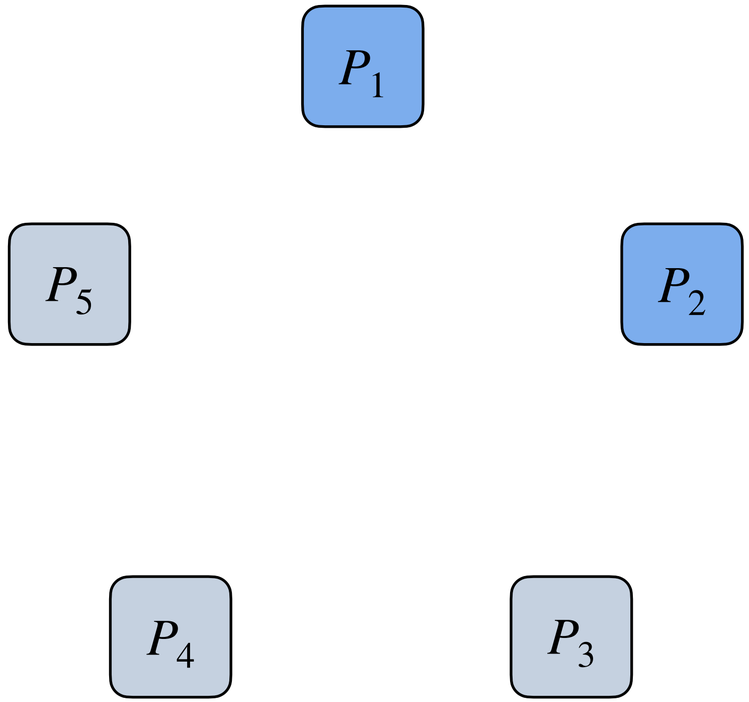
Super-Rushing

Question: Are existing synchronous protocols vulnerable to super-rushing attacks?

Yes! Some protocols are insecure against super-rushing adversaries

Simultaneous Broadcast [CGMA85]

1 corruption, 2 senders, 5 parties



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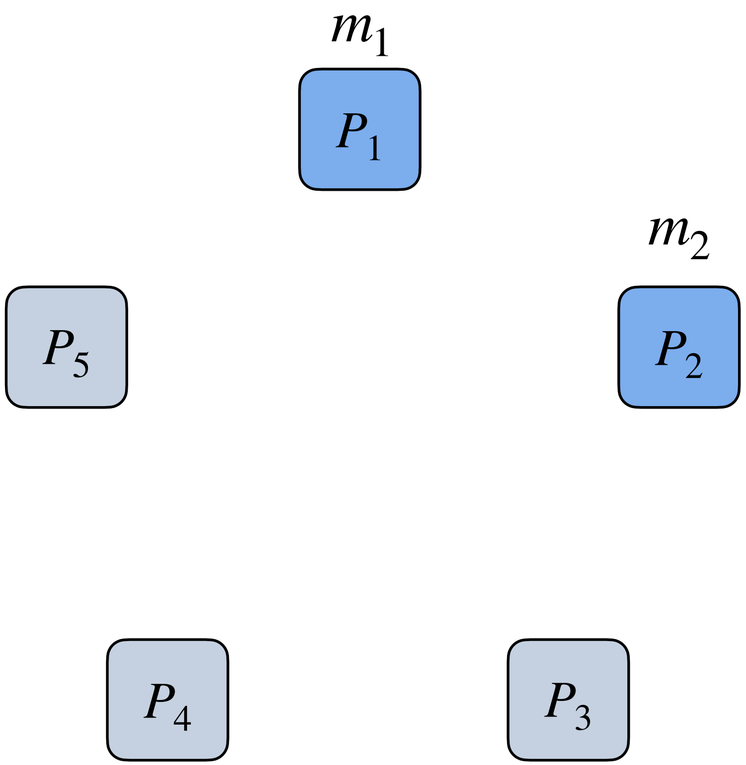

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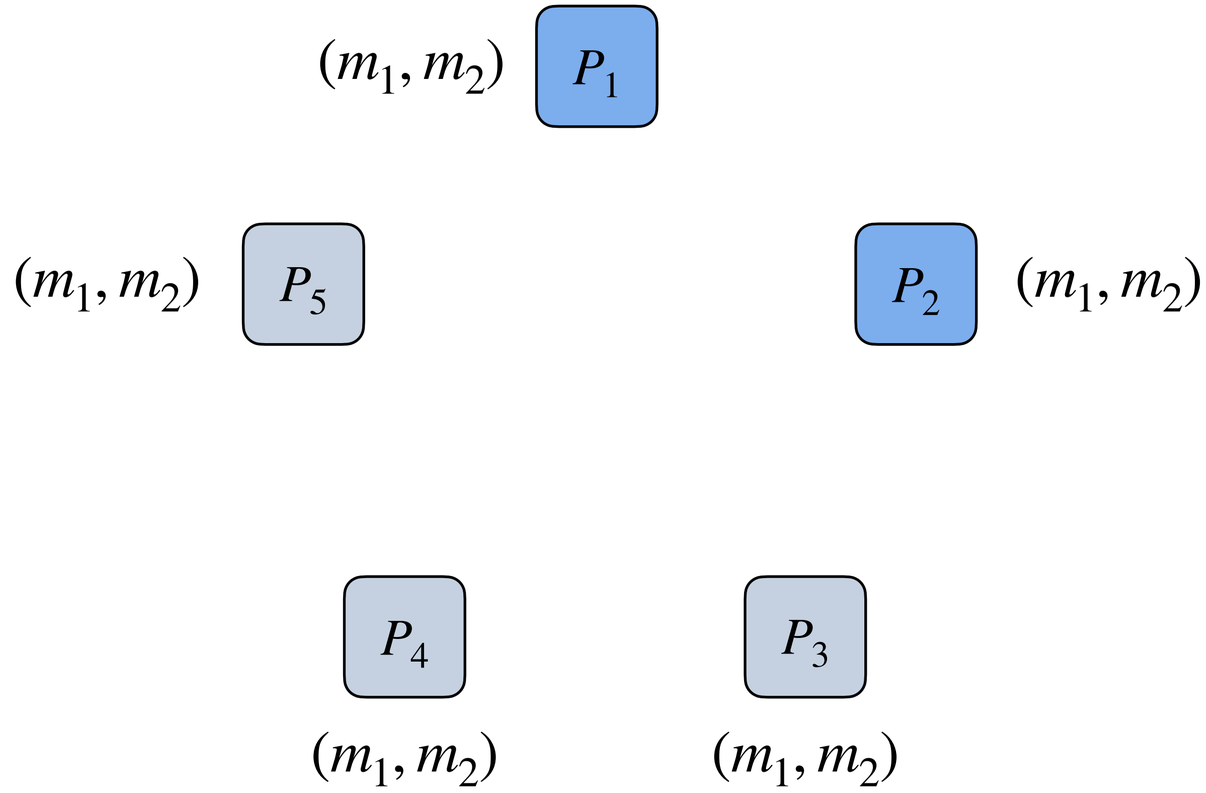

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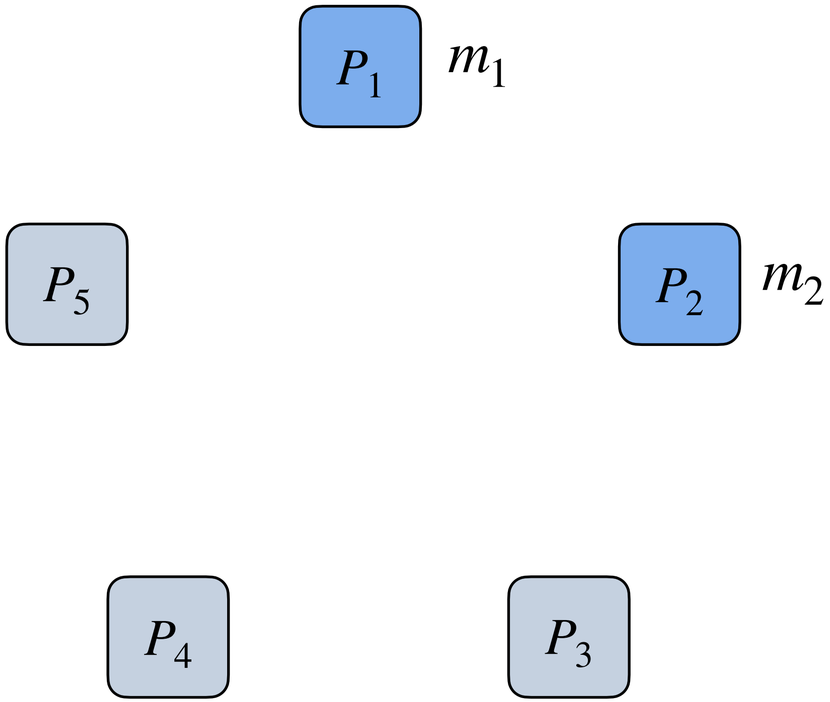

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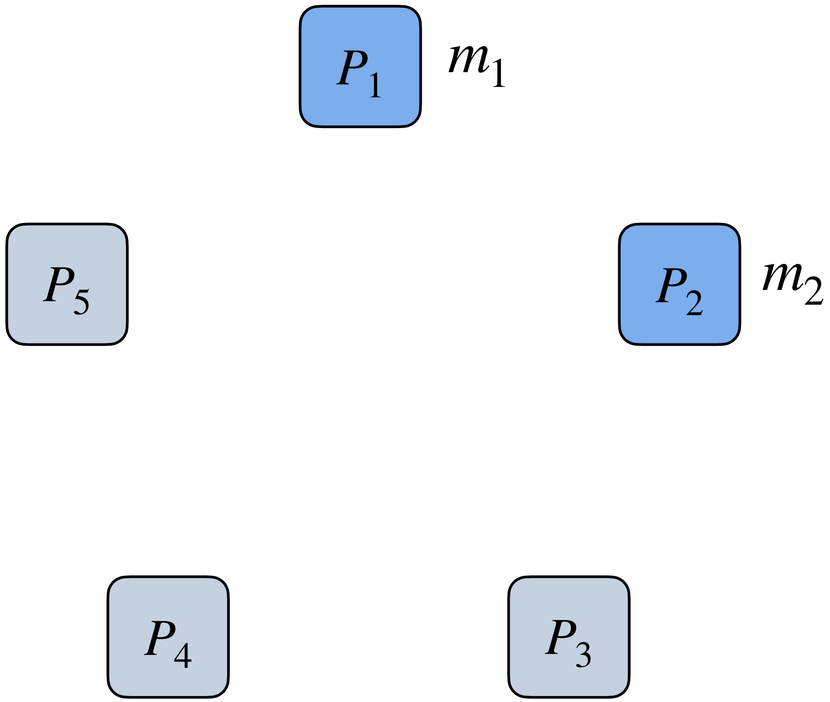

- Round 1: P_1, P_2 send input message to P_3, P_4, P_5

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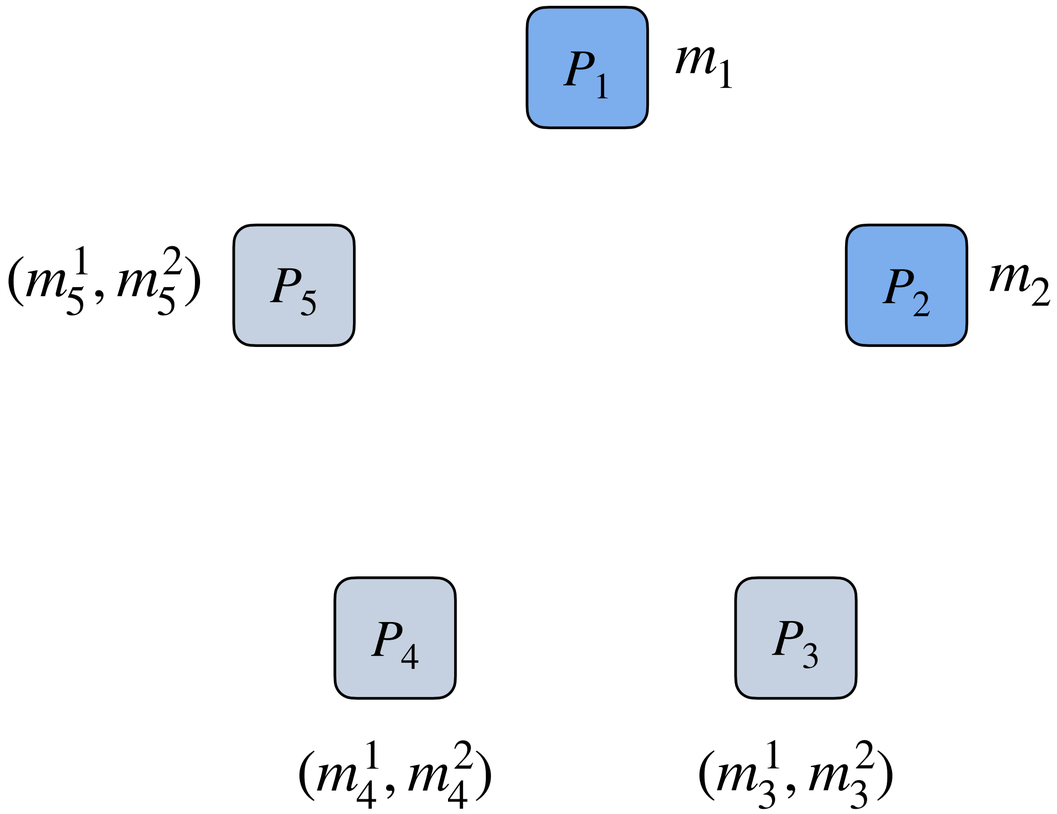

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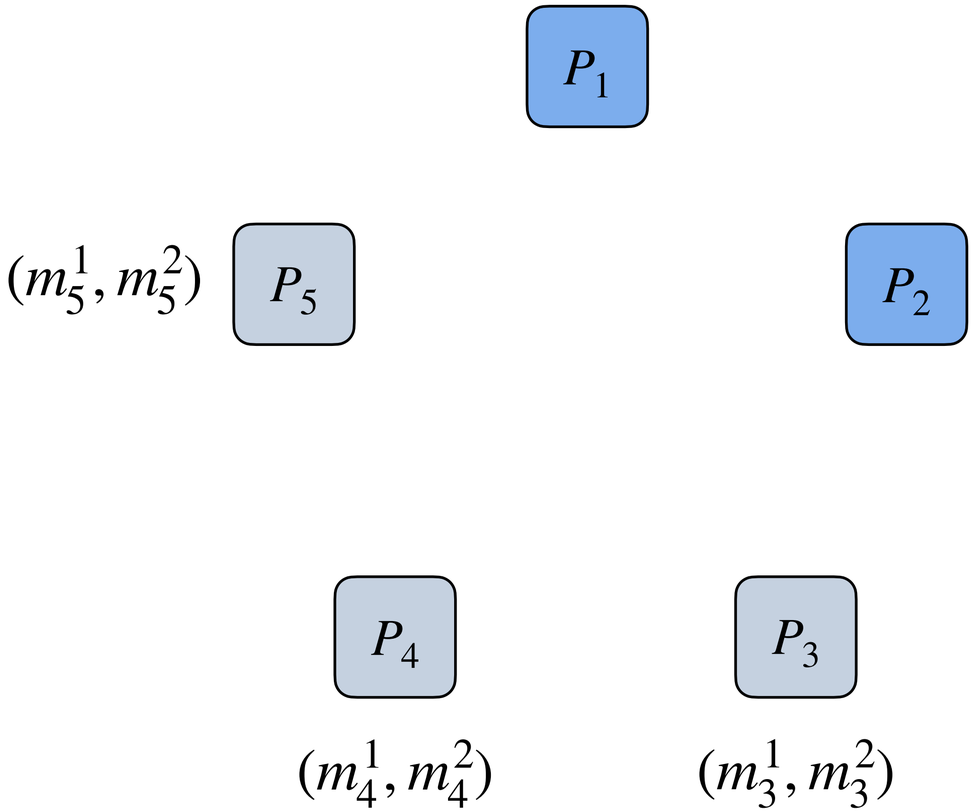

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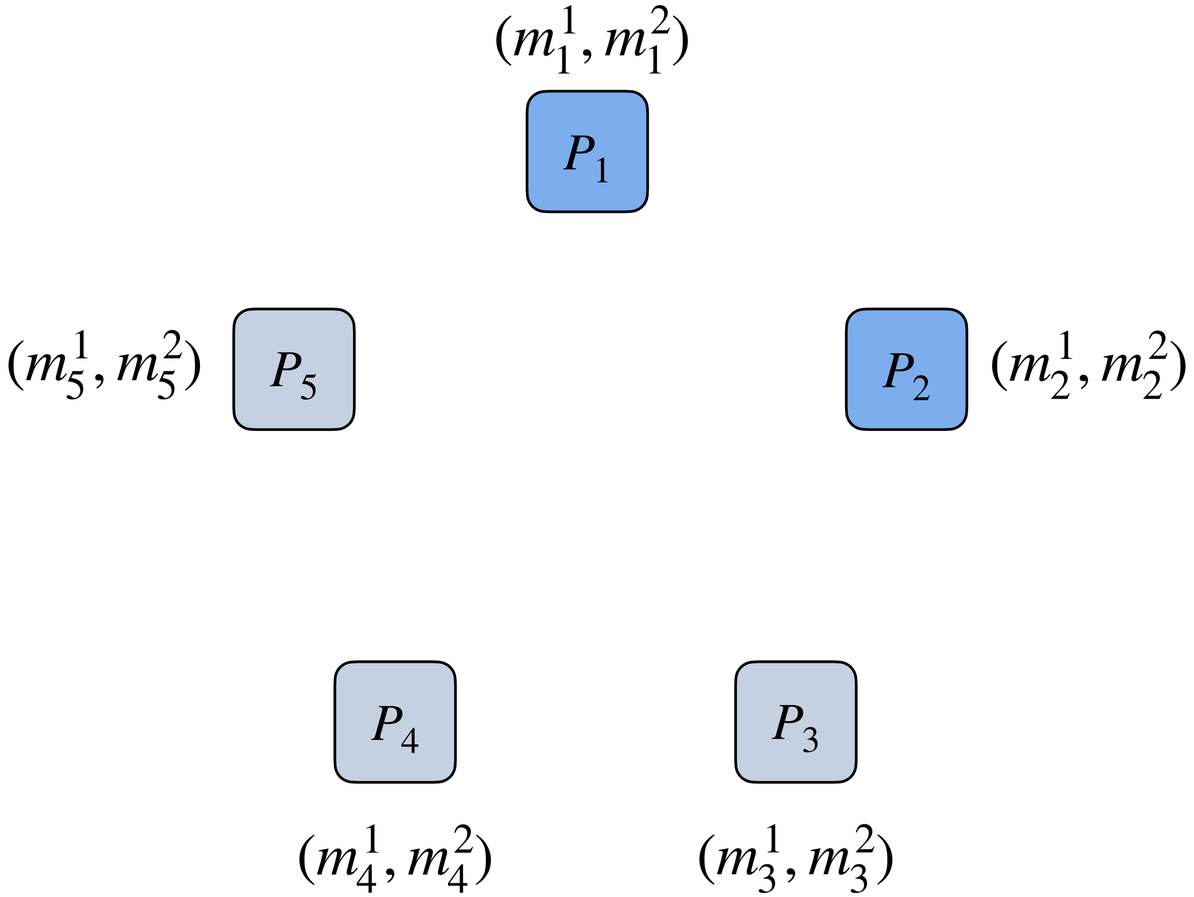

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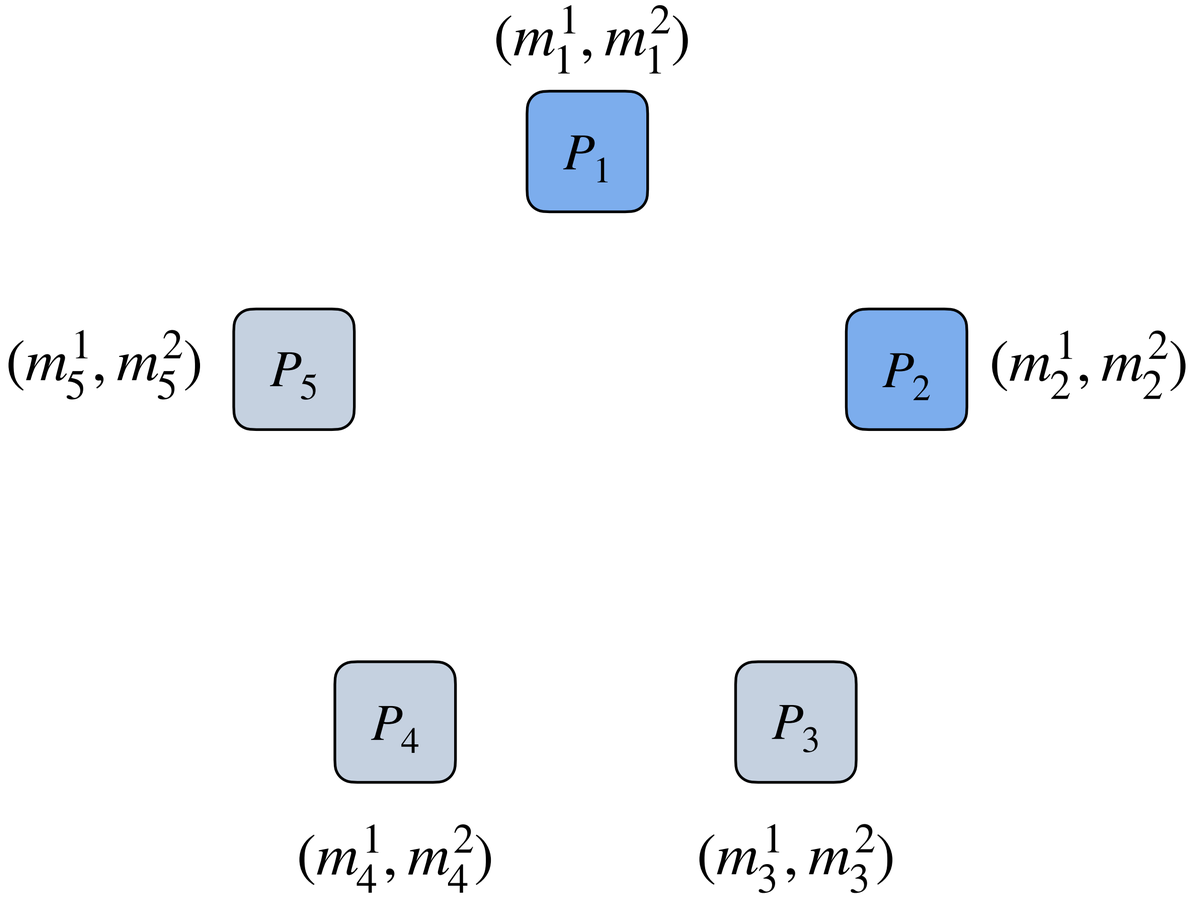

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- Output: (m_1', m_2') such that at least 2 parties echoed (m_1', m_2')

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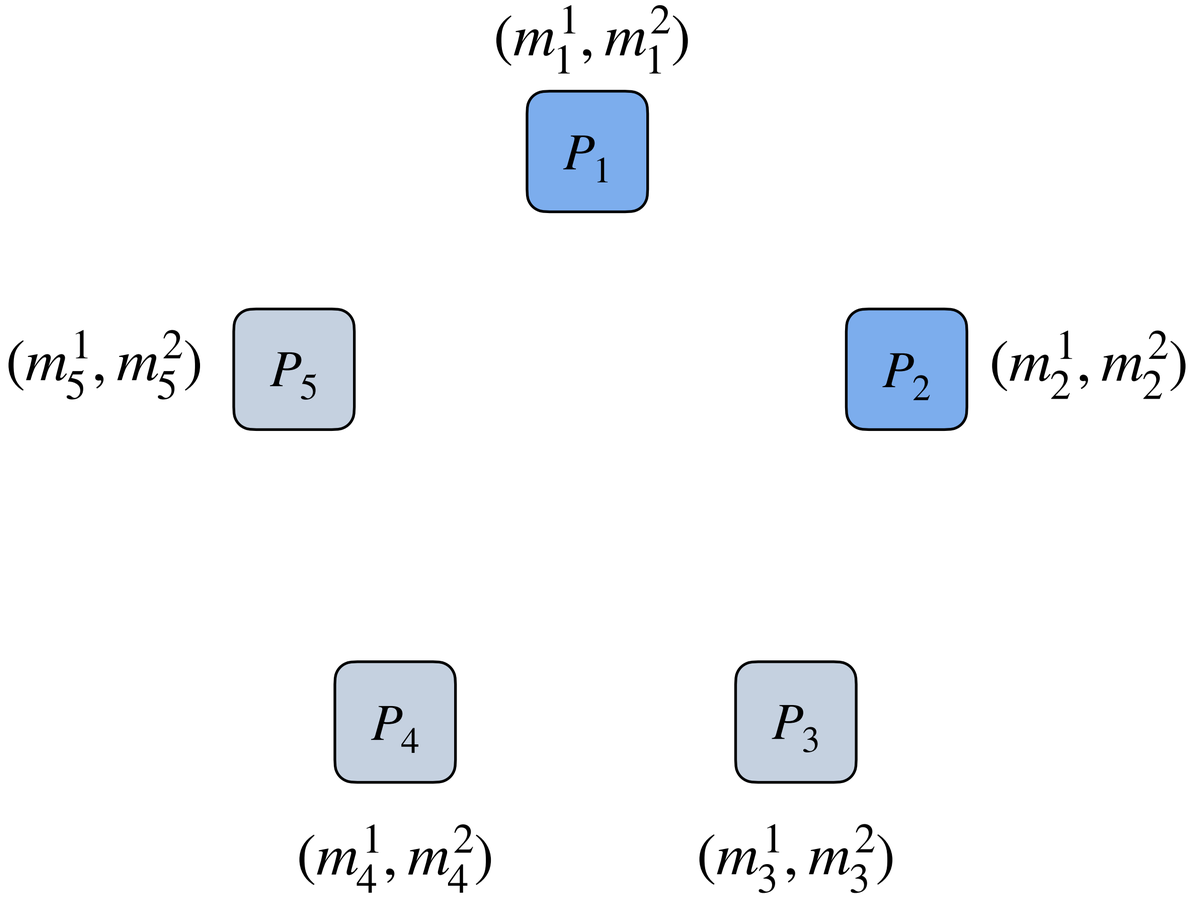

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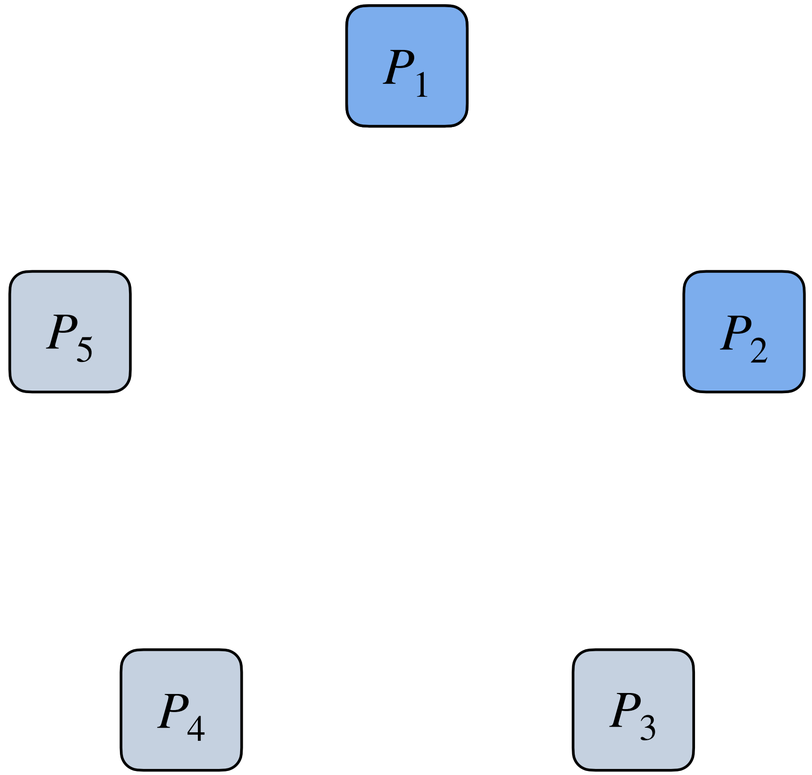
Rushing adversary cannot affect majority decision **and** cannot bias output

A Super-Rushing Attack



A Super-Rushing Attack

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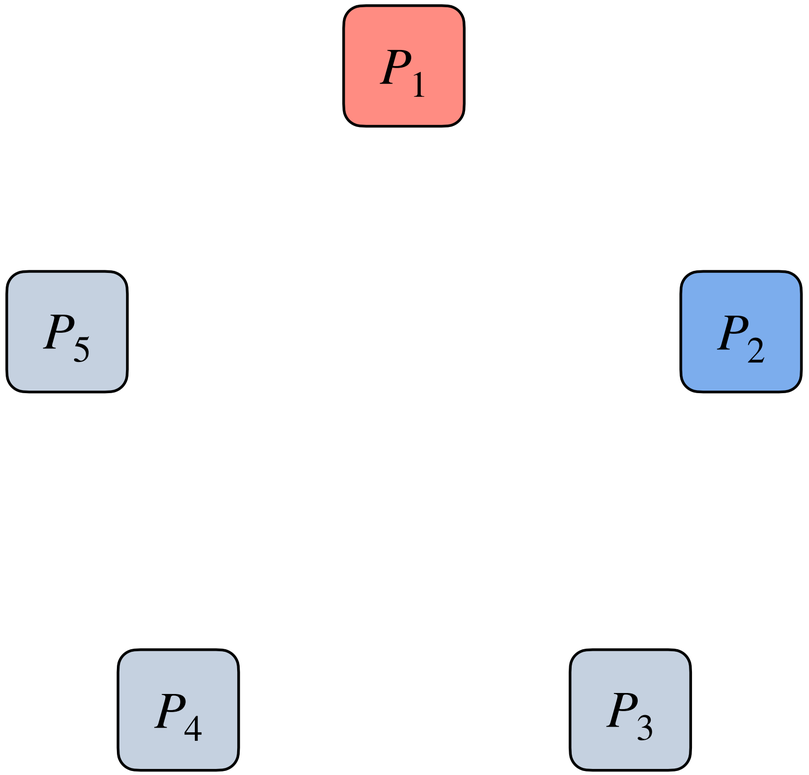

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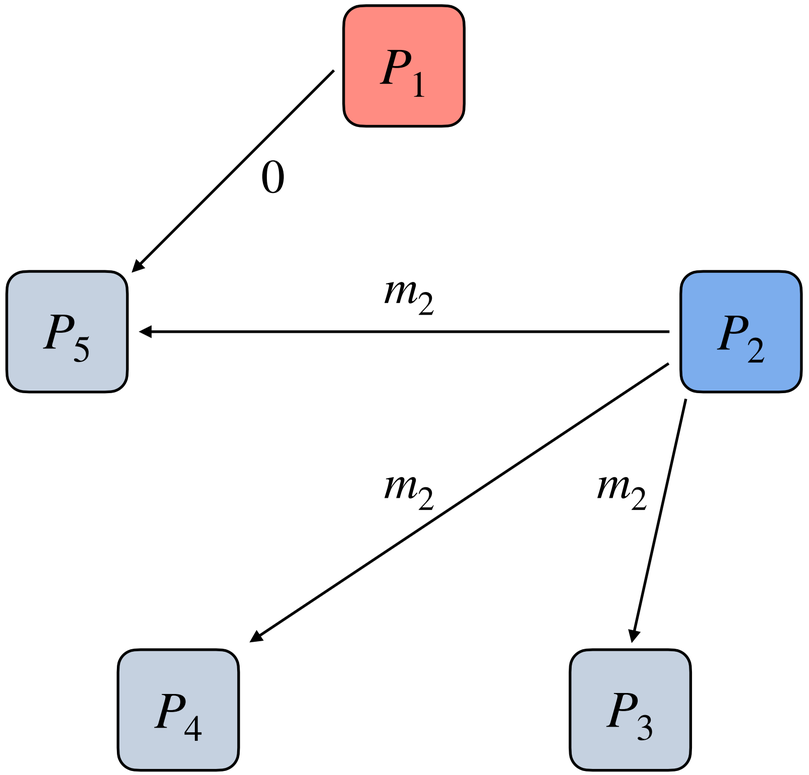

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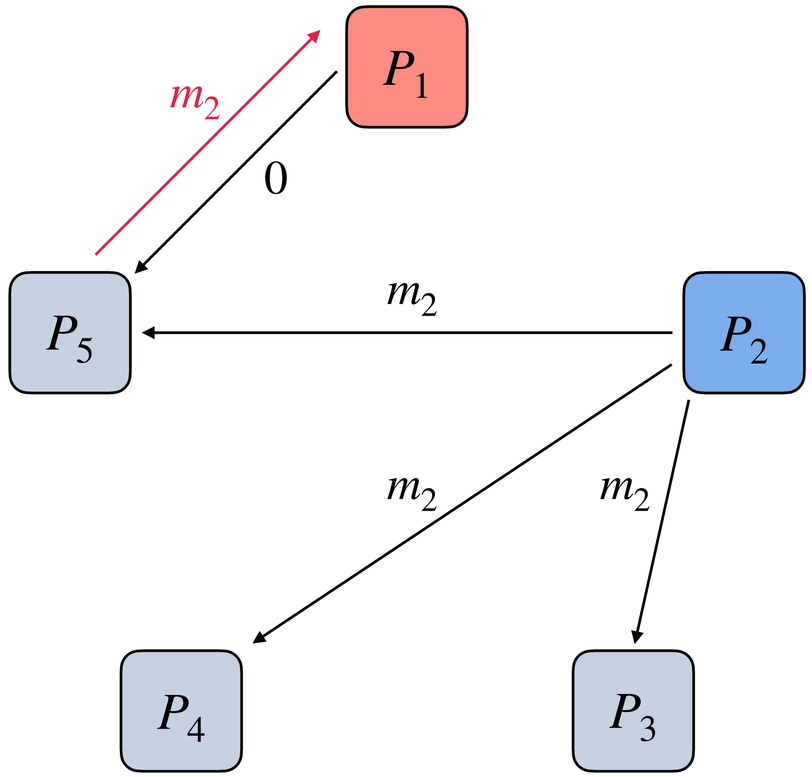

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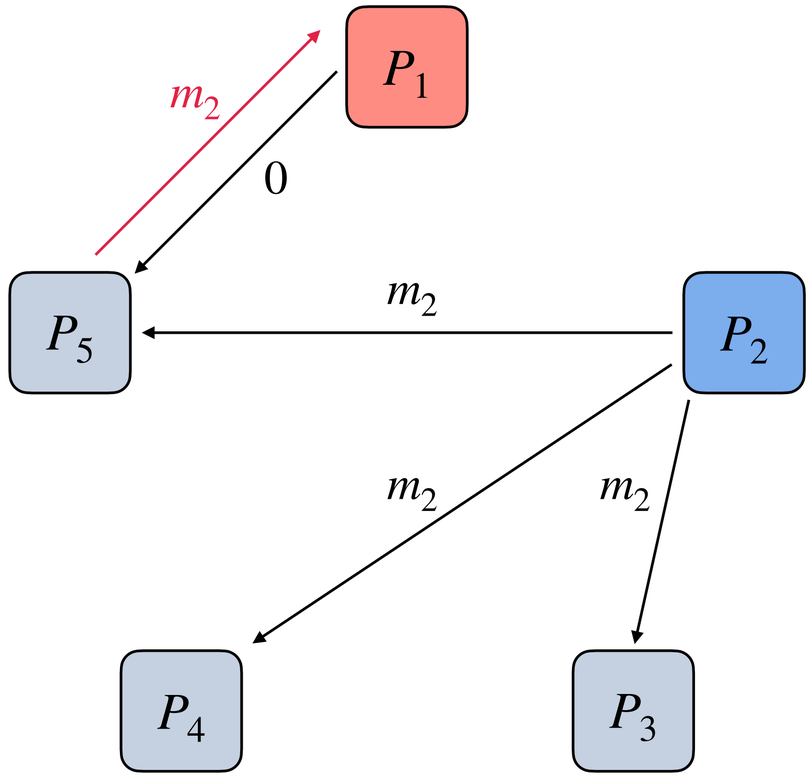
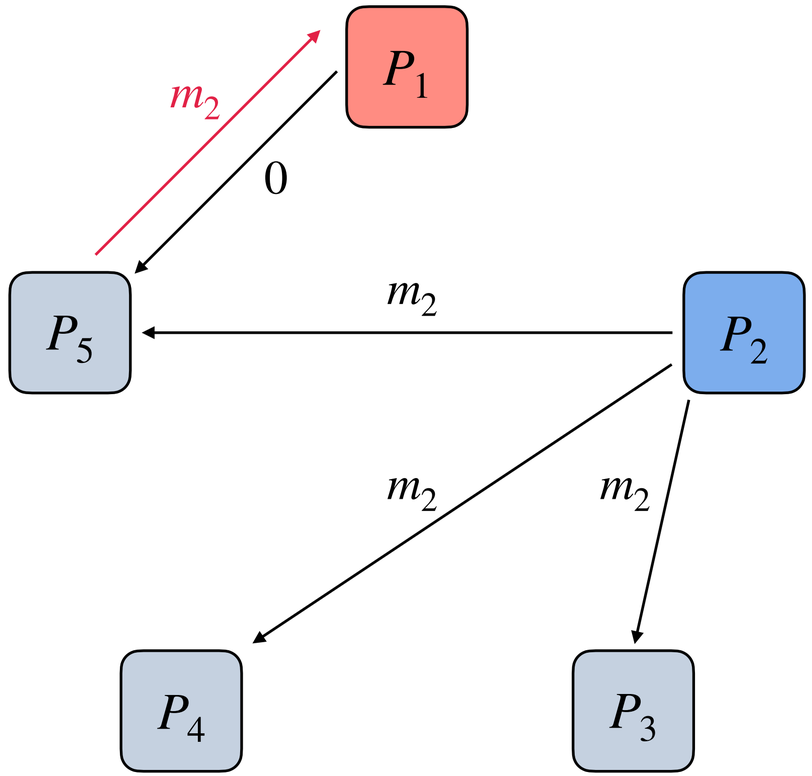


Attack: Corrupted P_1

- Round 1: P_1 sends 0 to only P_5
- Round 2: (only for P_5) Sends $(0, m_2)$ to P_1
- Round 1: P_1 sends $m_1 = m_2$ to P_4, P_5
- Round 2: (everyone) echos the remaining messages
- Output: Everyone outputs (m_2, m_2)

A Super-Rushing Attack



Attack: Corrupted P_1

- Round 1: P_1 sends 0 to only P_5
- Round 2: (only for P_5) Sends $(0, m_2)$ to P_1
- Round 1: P_1 sends $m_1 = m_2$ to P_4, P_5
- Round 2: (everyone) echos the remaining messages
- Output: Everyone outputs (m_2, m_2)

P_3, P_4: Looks like P_5 is cheating

Our Results #1

[CGMA85] (2,5) Simultaneous Broadcast

Theorem: There exists a protocol (with two input providers) that is secure against rushing adversaries but is insecure against super-rushing adversaries

Which synchronous protocols remain secure against super-rushing adversaries?

Modeling Super-Rushing

Extension of Rushing

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Extension of Rushing

Rushing

Adversary can schedule messages within a round

Modeling Super-Rushing

Extension of Rushing

Rushing

Adversary can schedule messages within a round

Super-Rushing

+ Can “pull” future messages from honest parties (these parties must have finished all previous rounds!)

Back to the Future: Simultaneous Broadcast

1 corruption, 2 senders, 5 parties

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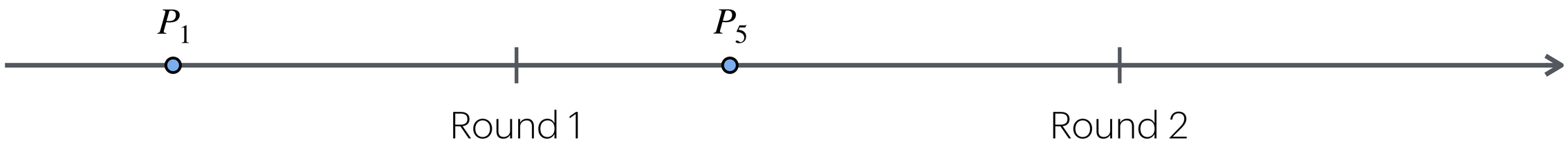

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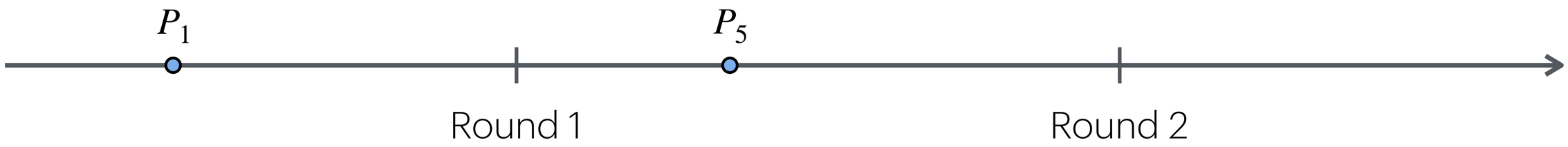

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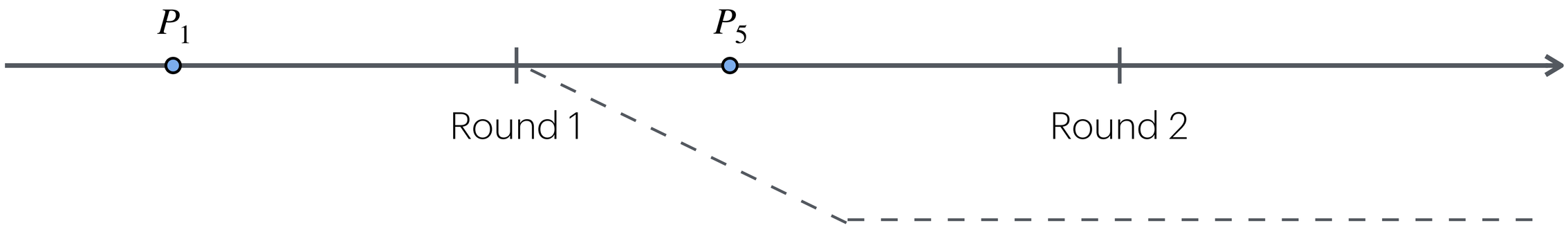

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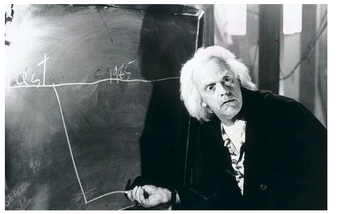

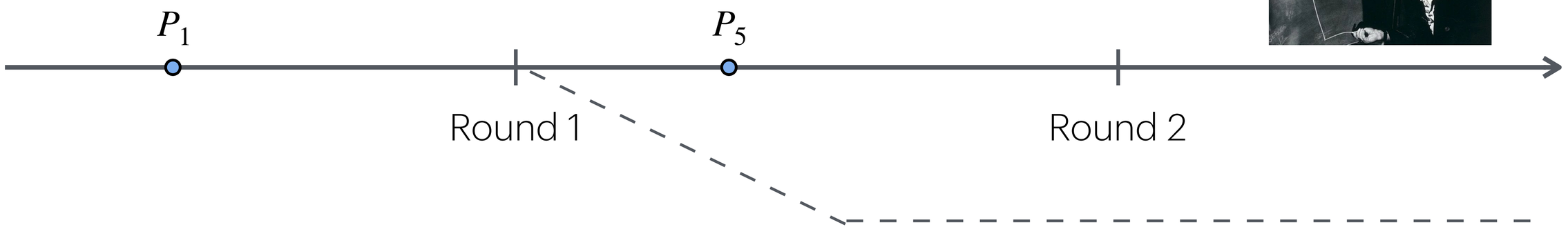

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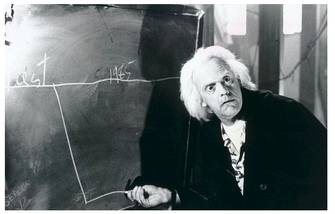

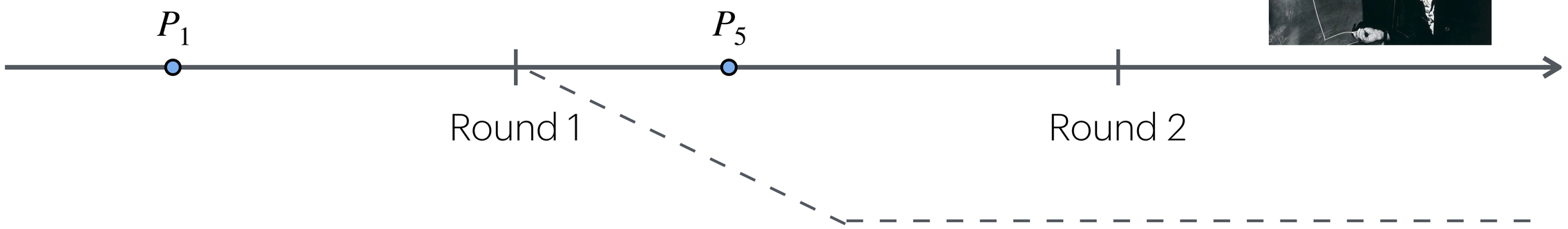

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Super-rushing breaks input independence

What if only one party provides input?

VSS, Broadcast, ...

Our Results #2

Super-Rushing ≡ Non-Rushing with a single input provider

Theorem: Every protocol for a single input provider that is secure against non-rushing adversaries is also secure against super-rushing adversaries

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We worked too hard to show too little!

The Story So Far

Security of protocols against super-rushing

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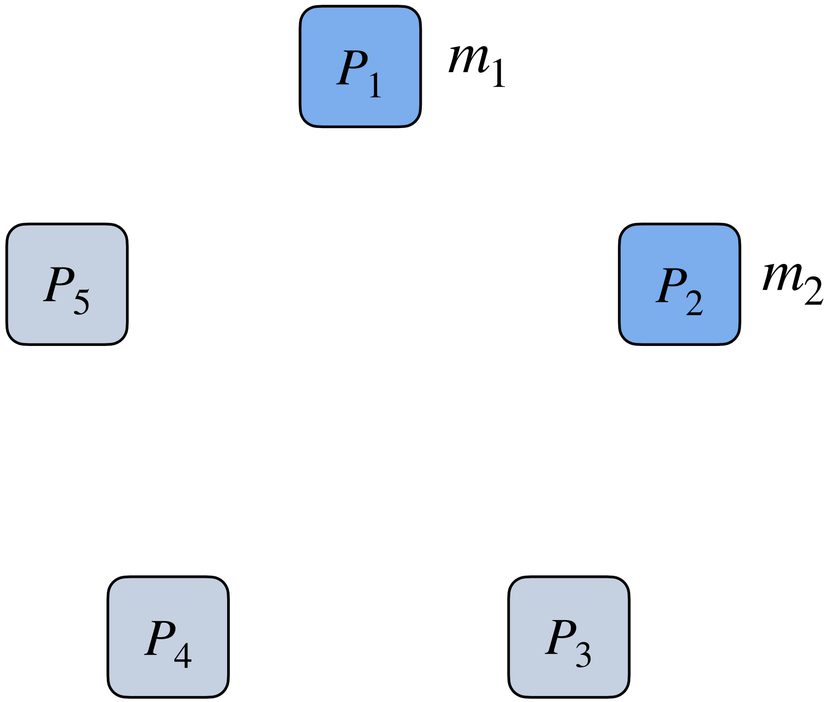

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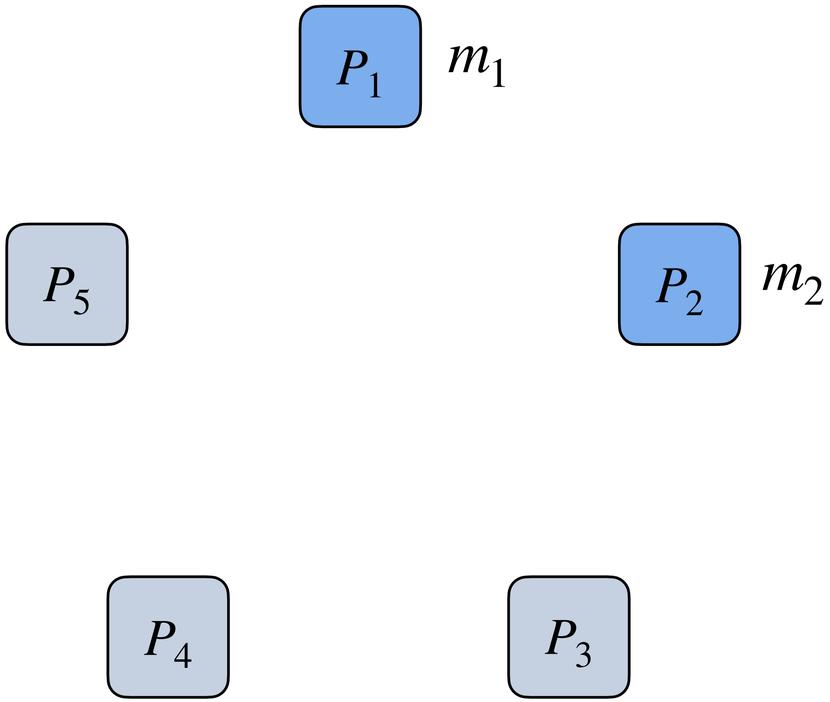

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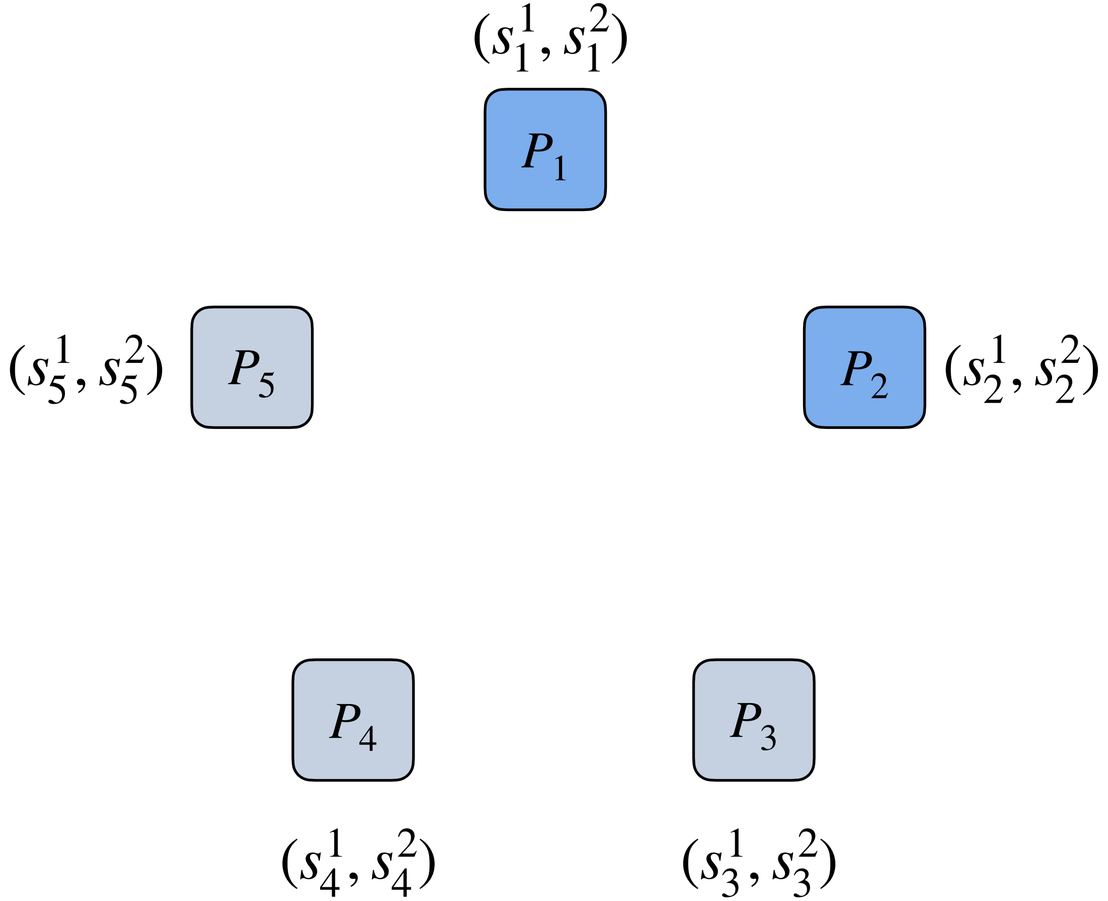

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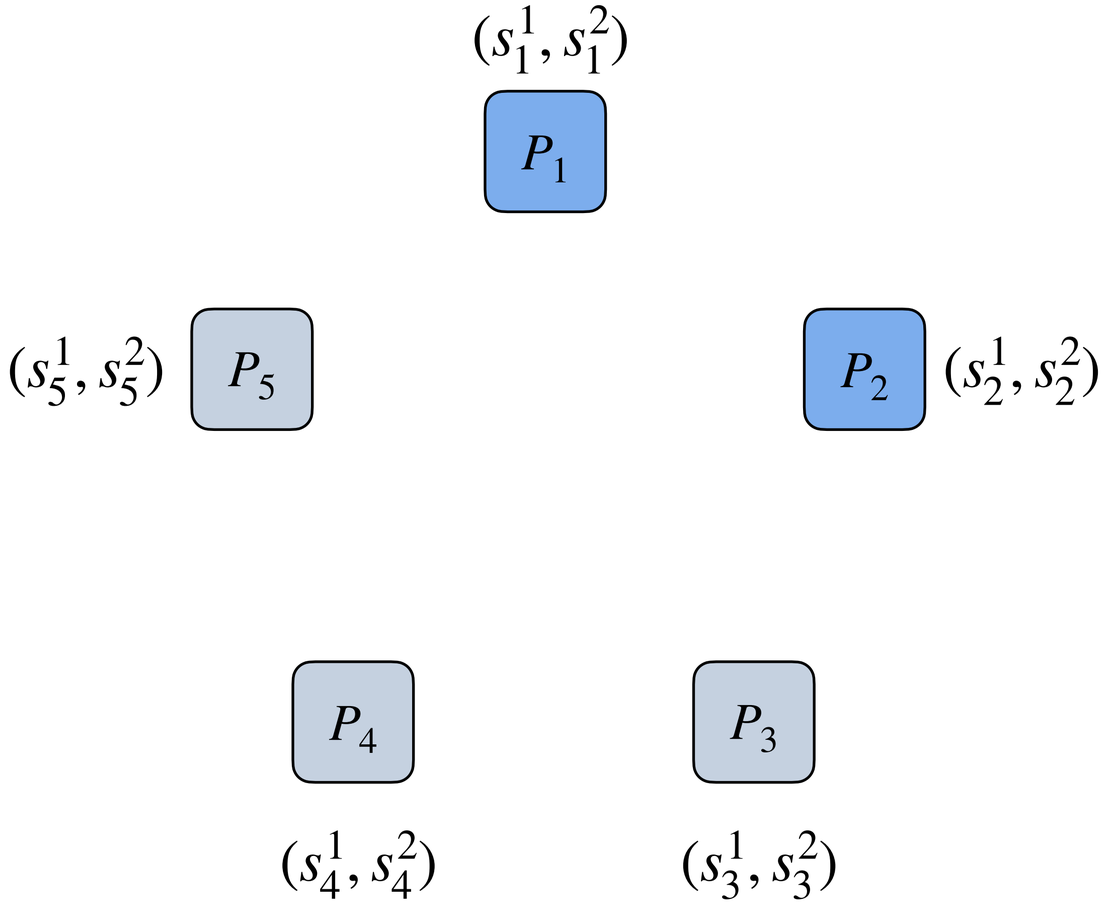

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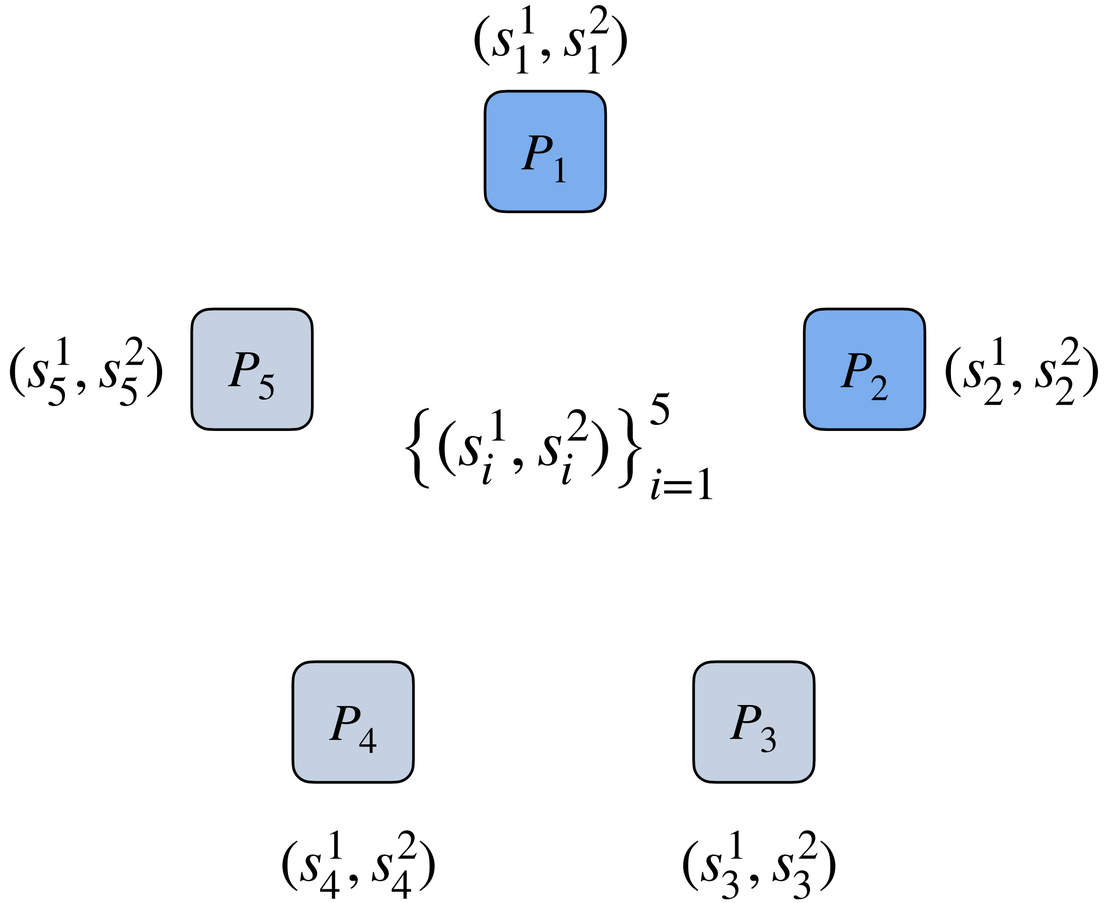

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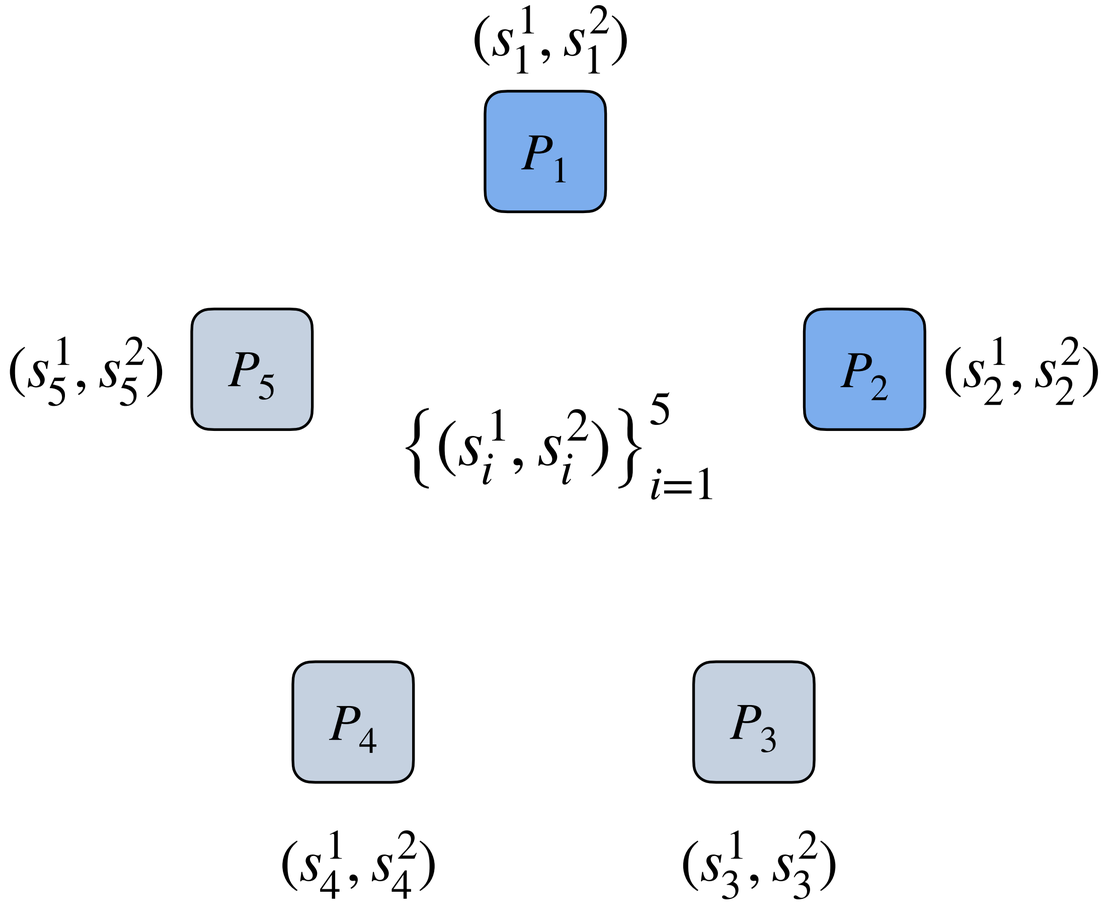

- Round 1: P_1, P_2 perform 1-round VSS of their inputs
- Round 2: Parties perform VSS reconstruction
- Output: (m_1', m_2') from VSS reconstruction.

Super-rushing still breaks independence of inputs

What are the sufficient conditions for security against super-rushing adversaries?

Our Sufficient Conditions

All-to-all communication $\Longrightarrow$ Peeking up to 1 round

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Round CR

Inputs are committed

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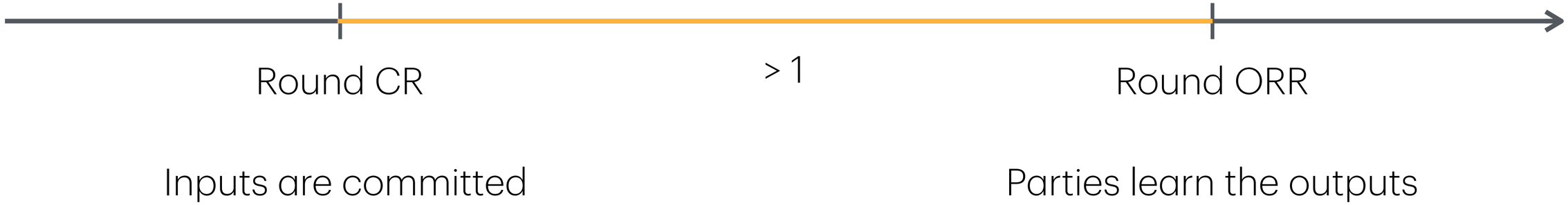

Mitigates Super-Rushing

Peeking into round ORR only possible after all parties complete round CR

Our Results #3

General Sufficient Conditions

Theorem: Every protocol that is

1. secure against rushing adversaries*
2. has all-to-all communication
3. ORR > CR+1

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Extensions

What if ORR = CR + 1

Theorem: Every protocol that is

1. secure against rushing adversaries*
2. has all-to-all communication
3. CR is over broadcast or is a synchronization round

is also secure against super-rushing adversaries

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Our Results #4

Sequential Composition

Theorem: There exists a protocol (with one input provider) that is secure against rushing adversaries but is insecure against super-rushing adversaries when sequentially composed even once

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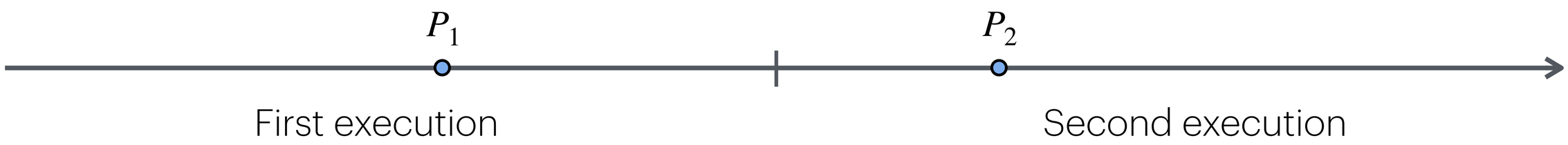

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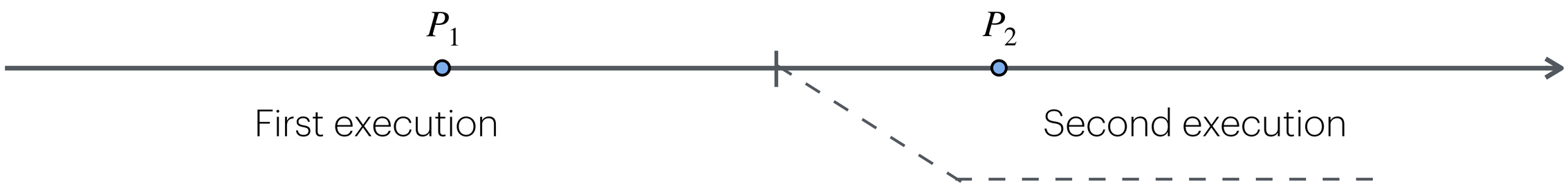

Our Results

Perfect Security

✔ Single Input: Super-Rushing ≡ Non-Rushing

- Two Input Providers:
  - ✘ secure against rushing but not against super-rushing
  - ✘ committal round does not help

✘ Sequential composition of single input protocols is not secure

✔ Main Result: Rushing $\Longrightarrow$ Super-Rushing for protocols with all-to-all communication and ORR > CR + 1

✔ Extensions when ORR = CR + 1

BGW is secure against super-rushing attacks

No need to reprove security

An Alternate Strategy

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Asynchrony admits Super-Rushing Attacks

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- Asynchronous MPC with guaranteed output delivery inevitably ignores some honest parties' inputs

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Asynchrony admits Super-Rushing Attacks

- Asynchronous MPC with guaranteed output delivery inevitably ignores some honest parties' inputs
- Universally composable protocols [Canetti01] typically settle for security with abort

Alternate Sufficient Conditions

Kushilevitz, Lindell, Rabin, STOC '06

Theorem: Every protocol that is

1. secure against rushing adversaries; and
2. has synchronization steps,

is also UC-secure [Canetti01]

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$\times 2$ round complexity and $+O(n^2)$ communication complexity

Statistical Security

We require different sufficient conditions

Theorem: There exists a protocol that is

1. secure against rushing adversaries (with statistical security)
2. has all-to-all communication
3. ORR > CR+1

but is insecure against super-rushing adversaries

Conclusion

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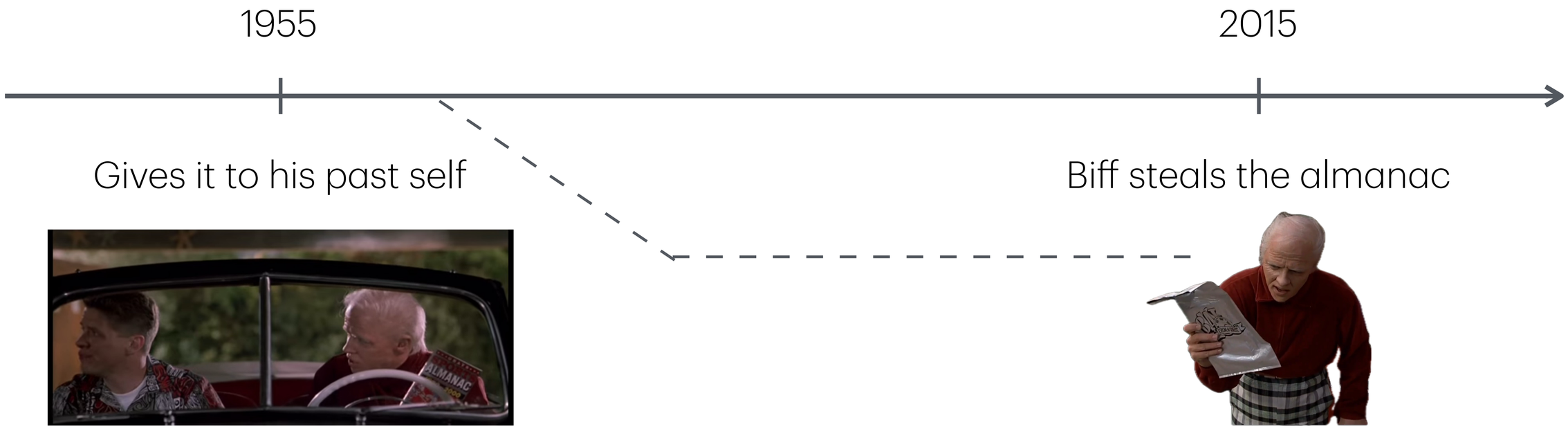

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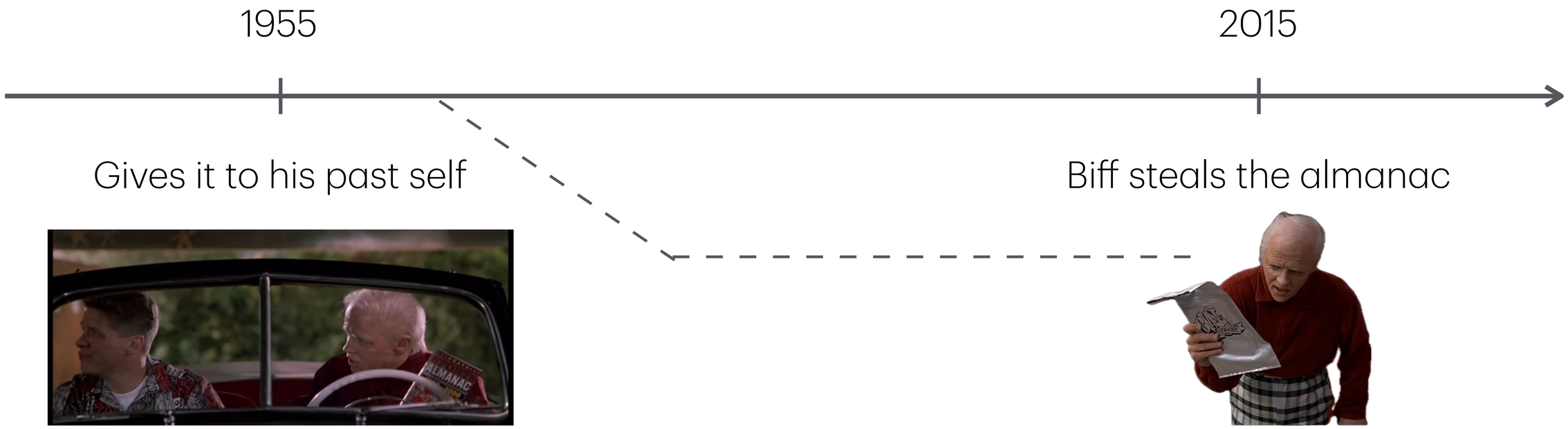

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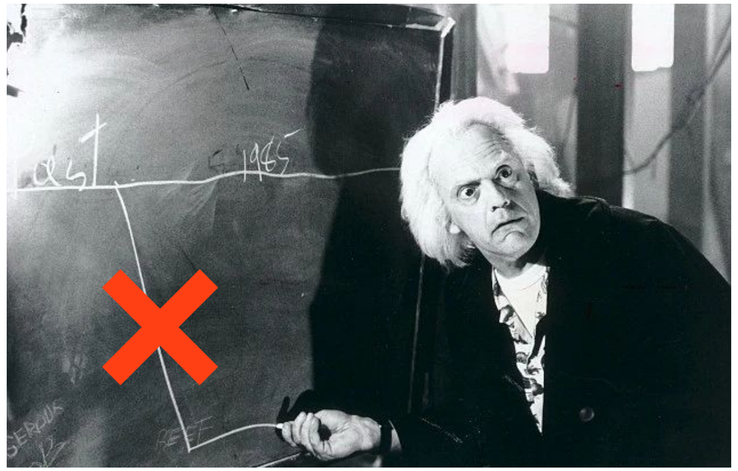

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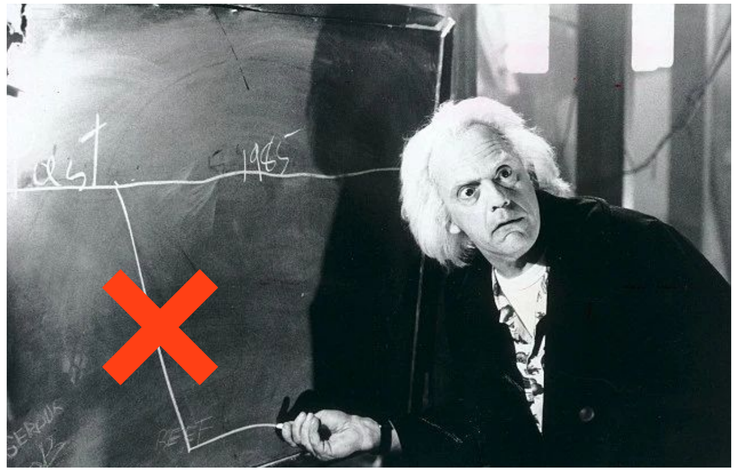

Thank you