Resolve-impossibility for a contract signing protocol

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July 6, 2006

Outline

1. Multi-party contract signing
2. A protocol by Garay and MacKenzie
3. A revised protocol by Chadha, Kremer and Scedrov
4. A flaw in the revised protocol
5. Impossible to "resolve"

Digital Contract Signing

- Use digital signatures to sign a pre-agreed contract over a computer network
- Potentially useful for e-commerce
- Why it is not simple:

$$\begin{array}{lcll} A & \longrightarrow & B & : \ Sign_A(contract) \\ B & \longrightarrow & A & : \ Sign_B(contract) \end{array}$$

Someone has to start first.

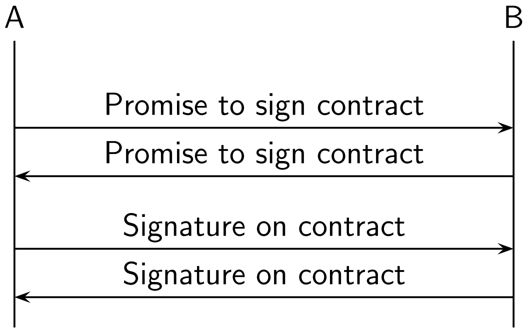
Contract Signing protocol

- Main property: fairness
  - 2-party: if A gets B's signature, then B can get A's signature, and vice-versa
  - *n*-party: if any agent gets a signature from any other agent, then all agents can get signatures from every other agent.
- Must not fail in the presence of a Dolev-Yao attacker on the network
- ... controlling a coalition of up to $n - 1$ dishonest agents

Solutions

- Use trusted party T to collect and distribute the signed contracts
  - Problem: T may become a bottleneck.
- Optimistic protocols:
  - The agents can complete the contract signing without T (optimistic case)
  - T will be invoked and will take decisions iff something goes amiss.
  - Channels between parties and T are resilient.

"Optimistic" protocols: 2-party



- T will enforce the contract if presented with both promises
- More involved for n-party

"Optimistic" protocols: T

- T can enforce the contract by converting promises to signatures
  - it will do so if it has proof that all parties have issued a promise
- T can issue an abort token
  - 2-party: means that it will not enforce contract
  - n-party: means that it will not enforce contract; but it may overturn this abort decision if presented with evidence of cheating by the signer that got the abort
- T acts only when requested by an agent
  - decides whether to abort or resolve based on the evidence in the complaint

“Optimistic” protocols

- Optimistic synchronous multi-party contract signing:
  - Asokan, Baum-Waidner, Schunter, Waidner, 1998
- Optimistic asynchronous multi-party contract signing:
  - Baum-Waidner, Waidner, ICALP 2000 and 2001
  - Garay, MacKenzie, DISC 1999;
    Revised version Chadha, Kremer, Scedrov, CSFW 2004.

Garay-MacKenzie protocol

- Two parts:
  - Main protocol: defines actions for signers
  - Resolve protocol: defines actions for a T
- Signers' promises are private contract signatures (Garay, et al [CRYPTO'99]):
  - $PCS_A(m, B, T)$ is a promise from A to B on m
  - Only B and T can verify its validity
  - T can convert it into a conventional digital signature that binds A on m

GM: main protocol

- Signers: $P_1, \ldots, P_n$
- The protocol is divided into n levels:
  - Promises are level-specific, i.e. they are of the form $PCS_A((m, i), B, T)$, where $i = 0, \ldots, n+1$
  - The ith-level is triggered when P_i receives 1st-level promises from P_{i+1} through P_n
  - In the ith-level signers P_i through P_1 exchange ith-level promises
  - P_i through P_1 close higher levels
- After the nth-level actual signatures are exchanged

GM: main protocol

P_i P_{i-1} $\ldots$ P_1

Distribute 1-level promises to $P_{<i}$

$i-1$-level protocol

Collect $i-1$-level promises

Exchange i-level promises

GM: main protocol

- Depending on the level of the protocol execution a signer P_i may:
  - Quit the protocol P_i if did not send any promises
  - Request T to intervene
- Each signer may contact T only once
- T replies with a resolved contract or an abort token
- T may overturn its abort decision, but never resolve

GM: resolve protocol

- The resolve protocol defines what T replies to signers' requests
- Found to be flawed by Chadha, Kremer and Scedrov (CSFW 2004): attacks on fairness involving four (and more) signers
- Proposed a revised resolve protocol:
  - Abort is overturned iff T infers that each signer that contacted it in the past has been dishonest
- Verified with model-checker MOCHA for protocol runs involving three and four signers

CKS: resolve protocol

- P_i requests recovery with:

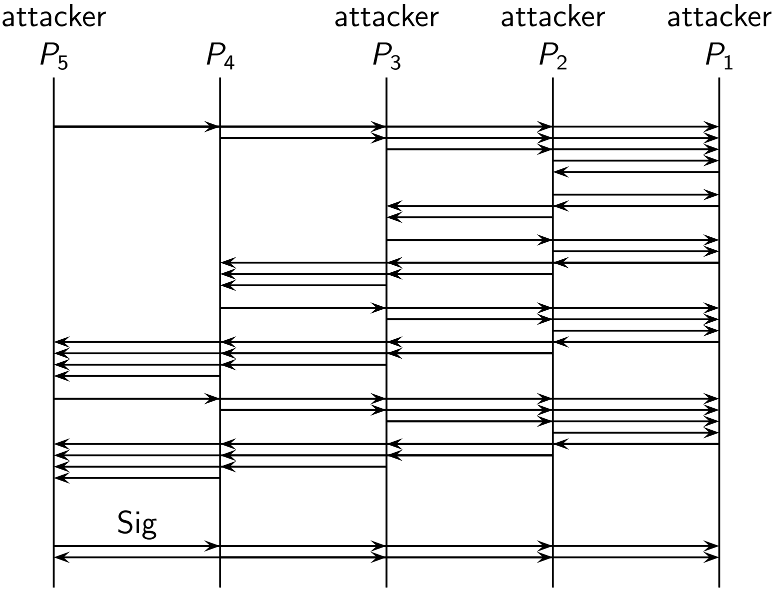
$$S_{P_i}(\{PCS_{P_j}((m, \tau_j), P_i, T)\}_{j \in \{1,\ldots,n\} \setminus \{i\}}, S_{P_i}((m, 1)))$$

  where τ_j is the (appropriate) level of promise from P_j to P_i.
- T stores names of agents in a set $S(m)$ to whom it has replied with abort
- For each P_i in $S(m)$, T deduces the highest level promises P_i could have sent to higher and lower indexed agents:
  - T infers P_i's dishonest iff it is later presented with a higher level promise issued by P_i

Our analysis

- The revised protocol is still flawed – attacks on fairness involving five signers:
  - $P_1, \ldots, P_5$ optimistically execute the protocol until P_4 sends out its signature on a contract m.
  - P_1, P_2 and P_3 do not send their singatures to P_4.
  - P_5 requests abort and P_3, P_2, P_1 request resolve from T.
  - P_4 requests resolve from T, but gets abort.

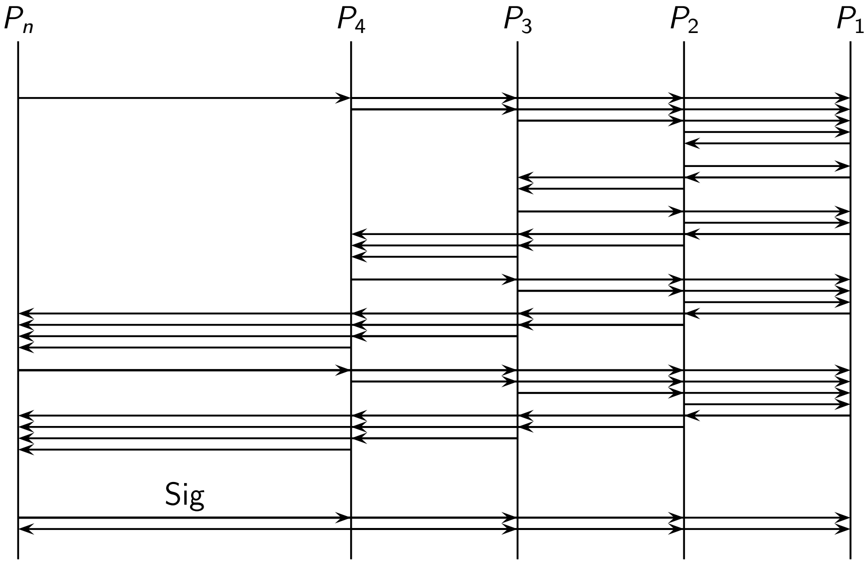
Our analysis: five signers



Our analysis: more signers

- The attack applies to runs with any $n > 4$ signers:
  - $P_1, \ldots, P_n$ optimistically execute the protocol until P_4 sends out its signature on a contract m.
  - P_1 and P_3 do not send their signatures to P_4.
  - P_n requests abort and P_3, P_2, P_1 request resolve from T.
  - P_4 requests resolve from T, but gets abort.
- Idea of the attacks: a coalition of dishonest signers propagates T's abort decision

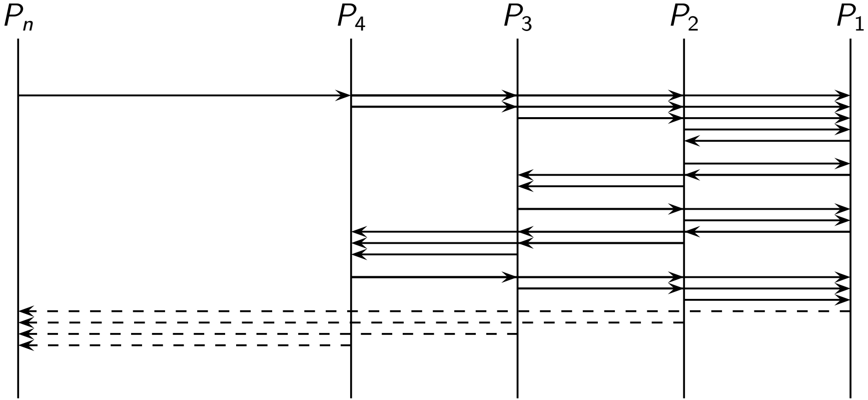
Our analysis: more signers



Our analysis: resolve impossibility

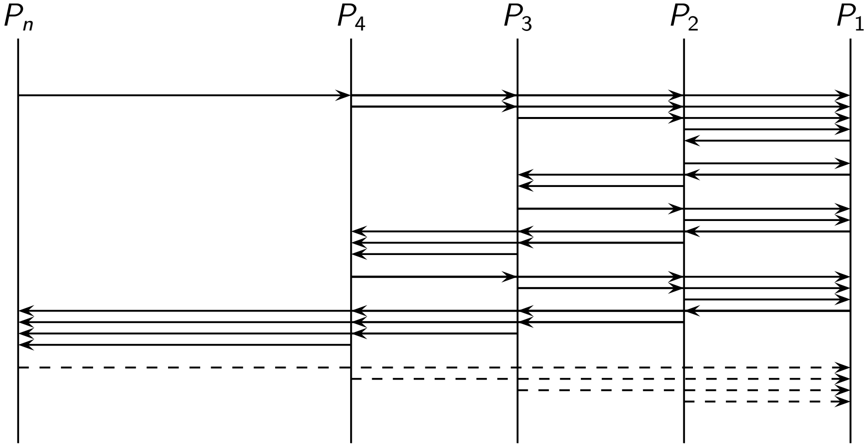
- Attacks do not depend on the resolve protocol:
  - for any resolve protocol, the main protocol is subject to attacks on fairness
- Resolve impossibility follows from case-by-case analisys of T's actions in the previous attack:
  - no matter what T does, it is unfair to someone, who could be honest.

Our analysis: resolve impossibility



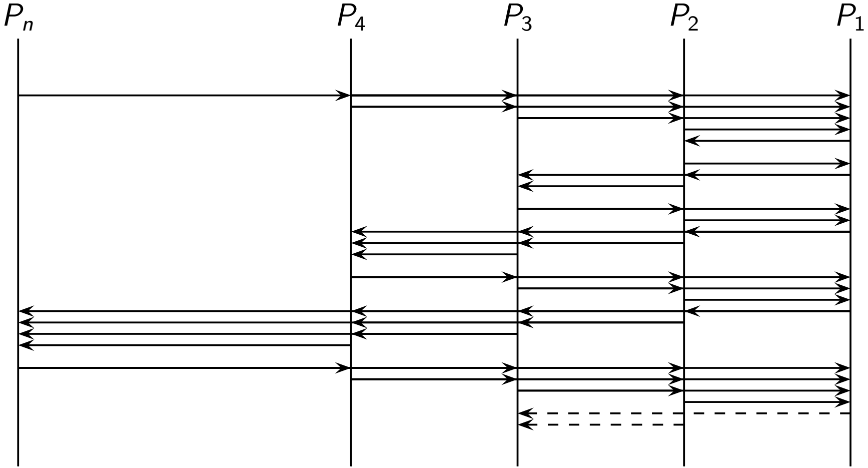
If P_n requests abort claiming not to have received dotted messages, T must grant it.

Our analysis: resolve impossibility



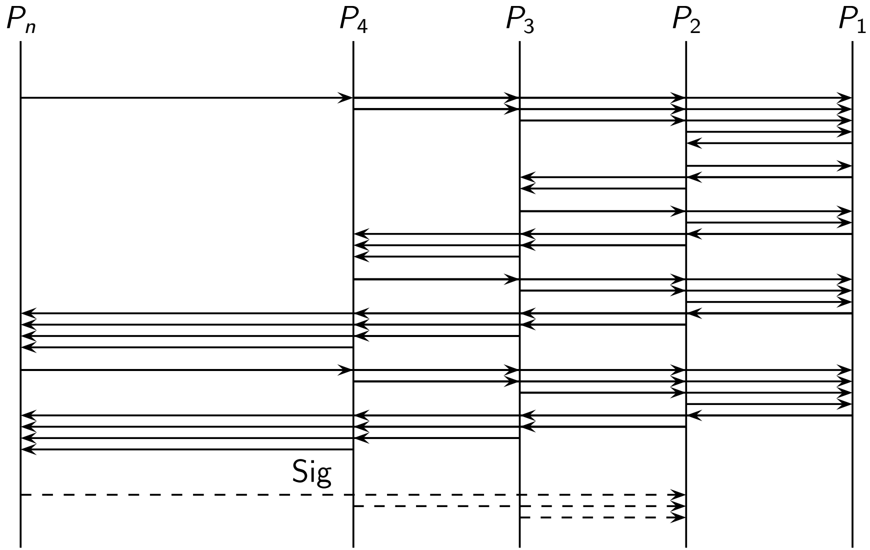
If P_1 requests resolve, T must confirm previous abort.

Our analysis: resolve impossibility



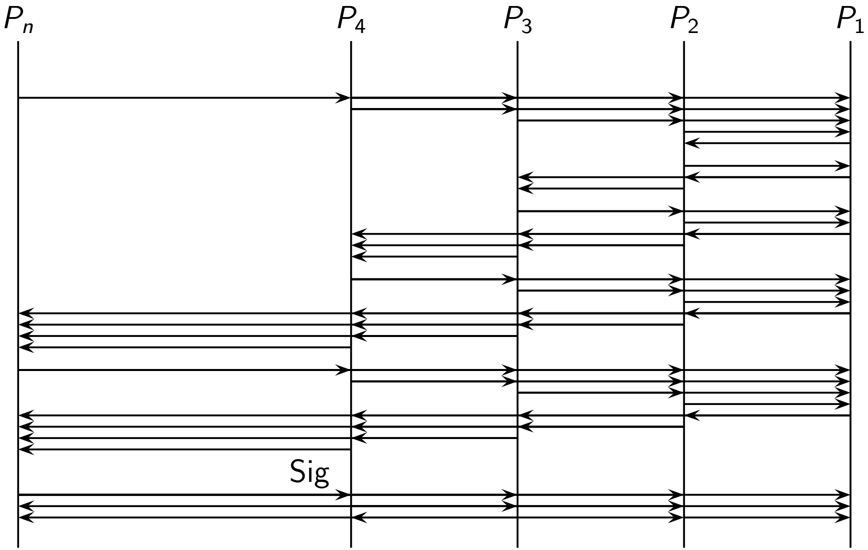
If P_3 requests resolve, T must still confirm previous abort

Our analysis: resolve impossibility



If P_2 requests resolve, T must still confirm previous abort

Our analysis: resolve impossibility



Conclusion

- Garay and MacKenzie protocol broken and fixed by Chadha, Kremer and Scedrov: the new protocol was verified for runs with three and four signers
- New attack on the fixed protocol involving $n > 4$ signers
- Our attack also shows that the idea behind the main protocol does not work – no resolve protocol will fix it.

Future work

- New protocol preserving the ideas of Garay/Mackenzie and Chadha/Kremer/Scedrov:
  - Private contract signatures (abuse-freeness for free)
  - Cascading promises
  - Elegant procedure for resolve protocol