Soundness in negotiations.

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Automata, Logic, and Games
Communicating, Distributed and Parameterized Systems
Singapore 22/08/2016

Introduction

Negotiations [Desel, Esparza '13]

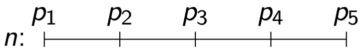
- model multiparty distributed cooperation,
- better complexity than alternative models (Petri Nets),
- embeds natural concepts: soundness, race properties,...

This paper:

- study of different restrictions on the model,
- complexity of deciding soundness, concurrency relationships
- application to workflow analysis for programs

The negotiation model

Negotiations involve a set of processes, which must decide on outcomes according to a fixed structure.
The model builds on the notion of atomic negotiation or node.



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If all five are ready to engage, the node can be *fired*: the processes agree on an outcome and move on.

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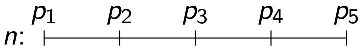

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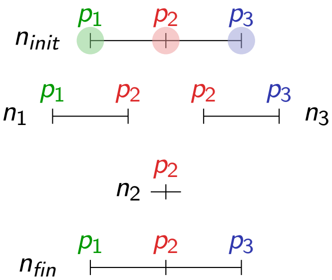
A negotiation $\mathcal{N}$ consists of

- a set of processes $Proc$,
- a set of nodes N,
- a domain function $dom : N \to \mathcal{P}(Proc)$,
- a set of outcomes R,
- a transition table $\delta : N \times R \times Proc \to \mathcal{P}(N)$.

Run of a negotiation

n_{init} initial node, n_{fin} final node.
Here: 3 processes p_1, p_2, p_3 and only one action a.



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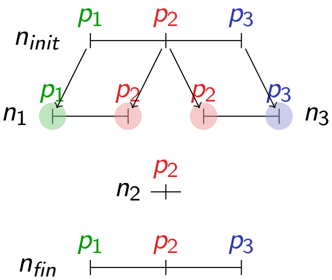

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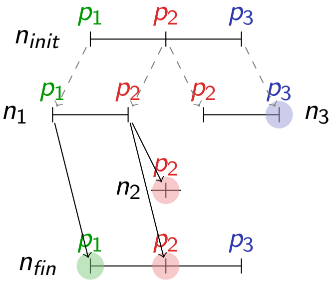

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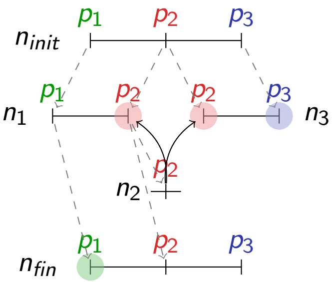

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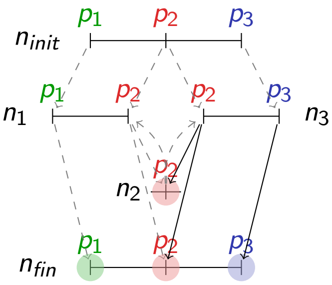

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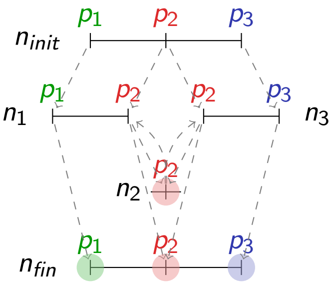

p_2 is non-deterministic, while p_1 and p_3 are deterministic.

The Soundness problem

Soundness property

Soundness:
Every partial run can be completed into an accepting run.
Non-blocking property, witnessing good design.

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Problem:
Configuration: $Proc \to \mathcal{P}(N)$
$\to$ Number of configurations exponential in $|\mathcal{N}|$
$\to$ Runs can have exponential length.

Subclasses of negotiations

Soundness problem PSPACE-complete in general [DE '13].

Complexity of the soundness problem for *classes of negotiations*?

Natural Restrictions on negotiations:

- **Deterministic**: All processes are deterministic.
- **Weakly non-deterministic**: All nodes involve at least one deterministic process.
- **Acyclic**: No cycle in the transition graph between nodes.

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Theorem (DE '14)

Deciding soundness is in PTIME for deterministic negotiations.

Results on the complexity of the soundness problem

Theorem (EKMW '16)

Deciding soundness is in PTIME for acyclic weakly non-deterministic negotiations.

Main tool used in the proof: the Omitting Theorem.

Theorem (EKMW '16)

It can be decided in PTIME if for a given deterministic, acyclic, and sound negotiation $\mathcal{N}$ and two sets $P \subseteq N \times R$ and $B \subseteq N$, there is a successful run of $\mathcal{N}$ containing P and omitting B.

Proof: Via a game argument.

General interest: characterize the important parts of a negotiation.

Soundness problem for bigger classes

What happens if we drop restrictions in the previous results ?
Dropping weak non-determinism:

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Dropping acyclicity for a milder constraint:

Theorem (EKMW '16)

The soundness problem for det-acyclic (very) weakly non-deterministic negotiations is coNP-complete.

Det-acyclicity: deterministic processes are acyclic.
In this context, it is enough to prevent cycles in actual runs.

Applications of sound negotations

Race Property

Race Problem:
INPUT: a sound negotiation $\mathcal{N}$, and two nodes n, m of $\mathcal{N}$.
OUTPUT: can n and m be concurrently enabled ?

- standard question for concurrent systems
- used for guaranteeing predictable behaviours
- inherently parallel property, hard to work with linearizations

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Theorem (EKMW '16)

The race problem is

- *NLOGSPACE-complete for deterministic acyclic negotiations,*
- *in PTIME for deterministic negotiations.*

Workflow Analysis

Application of negotiations: analyze the workflow of programs. We add global variables that can be affected by nodes via operations: $\mathit{alloc}(x)$, $\mathit{read}(x)$, $\mathit{write}(x)$, $\mathit{dealloc}(x)$.

Acyclic deterministic negotiations with variables $\rightsquigarrow$ formalize data-flow problems from the literature [van der Aalst et al, '09]:

- **Well-defined behaviour**: no concurrent operations on the same variable,
- **No redundancy**: allocated variables are used,
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Theorem (EKMW '16)

All these properties can be checked in PTIME on data-flows.

Exponential improvement on [van der Aalst et al, '09]. Proof using the Omitting Theorem.

Conclusion

Soundness problem for negotiations:

- PTIME for acyclic weakly non-deterministic
- coNP-complete for mild relaxations

Race problem for sound negotiations:

- NLOGSPACE-complete for deterministic acyclic,
- PTIME for deterministic.

Data-flow analysis:

- modelisation with deterministic acyclic negotiations,
- PTIME algorithms for standard problems on data-flows.

Omitting problem for sound negotiations

- PTIME for deterministic acylic negotiations
- used for Soundness problem and Data-flow analysis.