Verification of Data-Aware Processes

Exploiting DCDSs: models, methods, concrete systems

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Outline

1. The story so far
2. Checking/ensuring state boundedness
3. Boundedness and resources
4. Unbounded systems
5. Towards concrete systems

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The story so far, with main references

- The need of **combining (business) processes and data**.
  [Calvanese, De Giacomo, and Montali 2013]
- A pristine formalism for data-aware business processes: **DCDS**.
  [Bagheri Hariri, Calvanese, De Giacomo, et al. 2013; Montali and Calvanese 2016]
- Suitable **verification logics** for data-aware processes.
  [Bagheri Hariri, Calvanese, De Giacomo, et al. 2013; Calvanese, De Giacomo, Montali, and Patrizi 2017]
- Corresponding **characterization theorems**.
  [Calvanese, De Giacomo, Montali, and Patrizi 2017]
- A **decidability map**, with an unexpected dichotomy between $\mu\mathcal{L}_A$ and LTL-FO$_A$.
  [Bagheri Hariri, Calvanese, De Giacomo, et al. 2013; Calvanese, De Giacomo, Montali, and Patrizi 2017]

Note: Incorrect results in [Bagheri Hariri, Calvanese, De Giacomo, et al. 2013; Okamoto 2010] fixed in [Calvanese, De Giacomo, Montali, and Patrizi 2017].

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How to check/ensure state boundedness?

Theorem

Checking whether a DCDS is **state-/run-bounded** is:

- **Decidable** for a **given** bound.
- **Undecidable** for an **unknown** bound.

Three possible strategies:

- Single out **classes of DCDSs** for which checking state-/run-boundedness is decidable.
- Identify **sufficient syntactic conditions** that are decidable to check, and that guarantee state-/run-boundedness
  - cf. syntactic conditions for chase termination in data exchange.
- Devise **modeling methodologies** that guarantee state boundedness.

DCDSs with decidable state-boundedness

Fact

DCDSs using only unary relations correspond to variants of Petri nets.

- The specific variant depends on the features used in the DCDS.

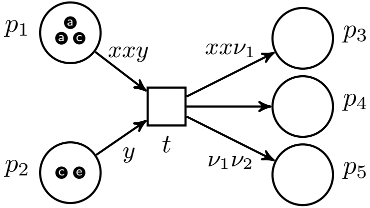
Note: State-boundedness relate to boundedness in Petri nets.

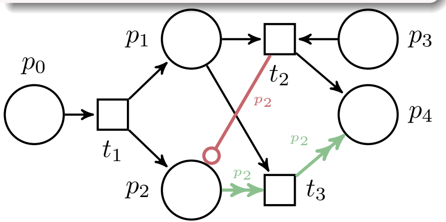
Petri nets with **name management**

Decidable boundedness.
[Rosa-Velardo and Frutos-Escrig 2011]

Reset-Transfer Nets

Undecidable boundedness.
[Dufourd, Jancar, and Schnoebelen 1999]





[Montali and Rivkin 2016]

Translation to DCDSs and $\mu\mathcal{L}_P$ verification.

[Bagheri Hariri, Calvanese, Deutsch, et al. 2014]

"Lossy" correspondence with DCDSs.

Attacking state-boundedness

The class of DCDSs with decidable state-boundedness very restrictive

These variants of Petri nets corresponds to DCDSs with only unary relations, limited use of negation, no or limited joins, ...

How to **check**/**guarantee** that a DCDS is state-bounded?

Sufficient, syntactic conditions:

- Extract a data flow graph from the DCDS.
- Check sources of unboundedness through this graph.

See [Bagheri Hariri, Calvanese, De Giacomo, et al. 2013] and [Bagheri Hariri, Calvanese, Deutsch, et al. 2014].

State-boundedness by design:

Design methods for state-bounded DCDSs. In [Solomakhin et al. 2013]:

- Processes are bound to evolving business objects (artifacts).
- Each business object manipulate boundedly many data.
- (New) business objects pick their names from a fixed pool of ids.

More sophisticated techniques in [Montali and Calvanese 2016; Calvanese, Montali, et al. 2014].

State-boundedness in concrete process modeling languages

Classical BPM languages/suites

- Central notion of **case** representing a process instance.
- Each case carries its own case data, in isolation to the other cases (e.g., order details, customer address, ...).
- Cases interact by accessing a central, persistent data storage.

Artifact-centric approaches:

- Central notion of **business object** gluing data and behaviour together.
- All data relevant to a business object are attached to it.
- Processes may query multiple business objects at once, to determine the possible next steps.

External and internal stakeholders...

- New cases/business objects are created upon **events** issued by external stakeholders (e.g., new order request).
- But then they are bound to internal resources, responsible for progressing the corresponding process instances.

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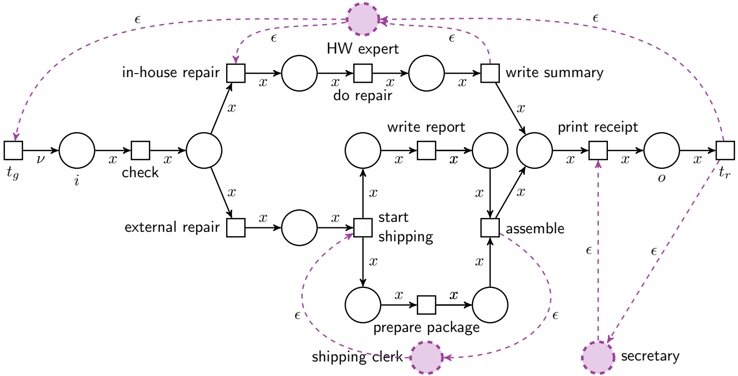
RIAW-nets [Montali and Rivkin 2016]



RIAW-nets = ν-PNs + workflow nets

- Emitter transition generating a **new process id** when fired.
- Control-flow name matching to **selectively spawn/synch** tokens using their id.
- Resource places to **bound the number of simultaneously coexisting active process instances**! (but **unboundedly many over time**).

Decidability of model checking via translation to state-bounded DCDSs.

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Data isolation and case unboundedness

What if the number of simultaneously active cases cannot be bounded?

In [Montali and Calvanese 2016; Calvanese, Montali, et al. 2014], we show that **decidability** of model checking can be retained, if the system obeys to:

- **relative boundedness** (each case manipulates boundedly many data);
- **data isolation** (cases interact very weakly).

State	
group	state
12	out
4	in
431	running

Group
id
12
4
431
...

MarryM		
id	combatLevel	group
76	pro	null
19	basic	4
56	ok	431
3	basic	431
98	ok	431

Modeling guidelines to guarantee data isolation and relative boundedness:

1. Queries must be navigational (no arbitrary access to relations).
2. 1-to-many relations require a number restriction on the "many" side.
3. Each case cannot create a chain of tuples of unbounded lenght.
4. Cases can share tuples only in a controlled way (no construction of chains).

Beyond State-Boundedness

Question

Are there classes of DCDSs that are **unbounded**, but still **amenable to verification**?

Key result in [Abdulla et al. 2016].

Recency-bounded data-aware processes

Unbounded DB, but only the latest inserted/accessed values can bound to parameters.

Verification via under-approximation

Decidability by focusing only on runs that are k-recency-bounded for an explicitly given key.

Open problem

Investigate the relationships between all such results and those where the initial DB is **not fixed**, and verification is studied **for every possible** initial DB.

Incorporation of datatypes

Databases have **datatypes**

Numeric domains, domain-specific predicates, arithmetic.

- Many coordination algorithms and auctions require dense orders.
- Processes with costs and payment policies require integers and arithmetic.

Dense orders combine well with state-boundedness

Data-aware, state-bounded distributed systems with reals [Calvanese, Delzanno, and Montali 2015]:

- **OK** to include **dense linear orders**: minor extension to the standard DCDS abstraction technique. Intuition...

Rigid $>$ relation over the entire domain	$\longrightarrow$	Non-rigid $GreaterThan$ relation over active domain elements.

- **No hope** to include the **successor** relation (or integers): 2 data slots are sufficient to encode two counters.

Discrete orders and arithmetic combine well with run-boundedness

Ongoing work...

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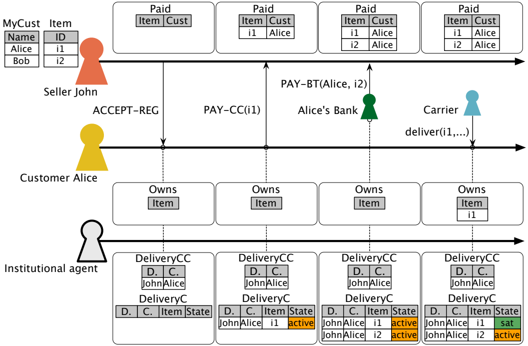
Relational multiagent systems and commitments

Relational MAS [Montali, Calvanese, and De Giacomo 2014]

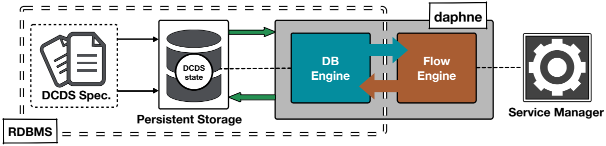
- Agents have names and hold/manipulate local, state-bounded DBs.
- Agents exchange data using their names for addressing.
- An institutional agent manages agent creation and deletion.
  - Due to state-boundedness: unboundedly many agents can dynamically enter into the system, but at each moment only boundedly many are active.



Relational commitments

In the same work: first proposal for modeling and verifying interaction protocols based on relational commitments, i.e., commitments with data payload and multiple instances.

daphne: implementing DCDSs with relational technology



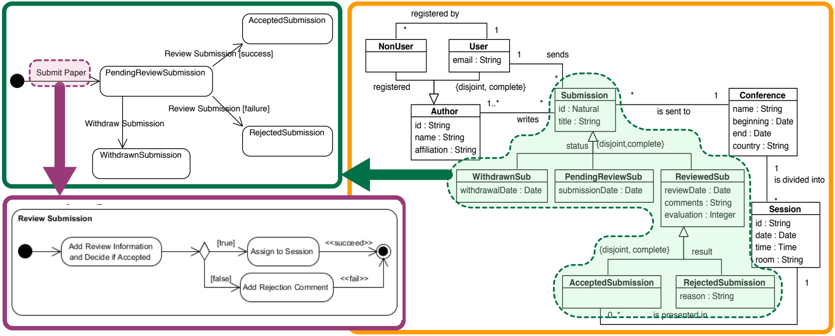
Native **modeling and execution** of DCDSs using relational DBMSs:

- **SQL-like syntax** for DCDSs with datatypes.
- Automated translation into **relational DBMSs**, as (temporal) tables, constraints, and stored procedures.
- **Java APIs** to support enactment and integration with concrete services.

Native **explicit model checking** of DCDSs using relational DBMSs:

- **Same model for execution and verification!**
- **Special tables** for storing the RTS induced by a DCDSs.
- **Factoring of tables** into temporal and atemporal parts.
- **Computation** of equality commitments and value recycling in services.
- **Java APIs** for RTS construction and search.

BAUML: artifact-centric processes with UML

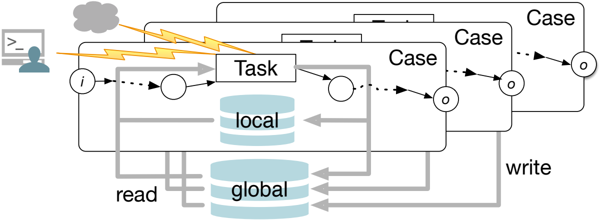


BAUML approach

- **Business objects**, states, associations and attributes: UML class diagrams.
- Business object **lifecycle**: UML statechart diagram.
- **Complex event** triggering a lifecycle transition: UML activity diagram.
  - **Tasks** modeled as OCL operation contracts.

In [Calvanese, Montali, et al. 2014]: **methodology to guarantee decidability of model checking** (see before). Estanol PhD thesis: BAUML to DCDS!

raw-sys: marrying workflow nets and databases



raw-sys **model** [De Masellis et al. 2017]:

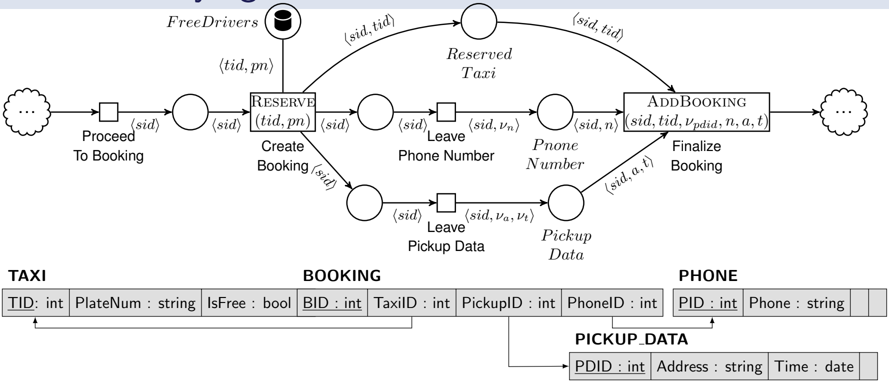
Data-aware processes using **well-known formalisms**:

- **Data**: global and local relational databases.
- **Process control-flow**: workflow nets, enriched with:
  - Guards (queries over the DBs).
  - STRIPS-like actions with external inputs from an infinite domain, invoked upon firing net transitions.

raw-sys **verification** [De Masellis et al. 2017]:

- Map of **(un)decidability**, exploiting **translation to DCDSs**.
- **Encoding into planning** systems to handle reachability problems.

db-nets: marrying colored Petri nets and databases

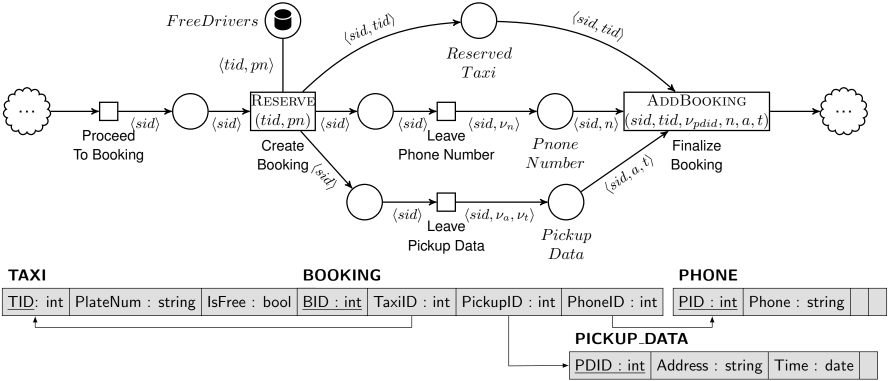


db-net **model** [Montali and Rivkin 2017], three layers:

1. **Persistence**: relational database with constraints.
2. **Data logic**: queries and actions over the persistence layer.
3. **Control**: colored Petri net with ν-variables, enriched with **view places** and **transition-action bindings** to inspect/update the persistence layer.

Note: Natural formalization of contemporary process modeling suites!

db-nets: marrying colored Petri nets and databases



db-nets **execution, simulation, verification** [Montali and Rivkin 2017]:

- Foundational results thanks to **translation to DCDSs**.
- Ongoing implementation effort inside `www.cpntools.org`.

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