TECHNISCHE UNIVERSITÄT WIEN
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Institut für Computertechnik
Institute of Computer Technology

Consistency Verification of Processes: From Businesses to Cyber-physical Systems

Keynote

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Based on
R. Hoch, C. Luckeneder, R. Popp and H. Kaindl, "Verification of Consistency between Process Models, Object Life Cycles, and Context-dependent Semantic Specifications," in *IEEE Transactions on Software Engineering*, doi: 10.1109/TSE.2021.3110191.

Agenda

- Introduction
- Background
- V&V Mismatch
- Context-dependent Action Specifications
- Extended Object Life Cycles
- Grounding of Action Specifications in Life Cycles
- Verification Through Model Checking
- V&V of a Cyber-physical Process
- Conclusion

Introduction

- Verification: building the system right
- Validation: building the right system
- Formal verification can provide certain guarantees.
- Business process model (BPM)
- Connection of control-flow models and object life cycles
- Semantic task / action specification (declarative)
- Formal verification of processes based on model checking
- Application to a cyber-physical (CPS) process — e-charging

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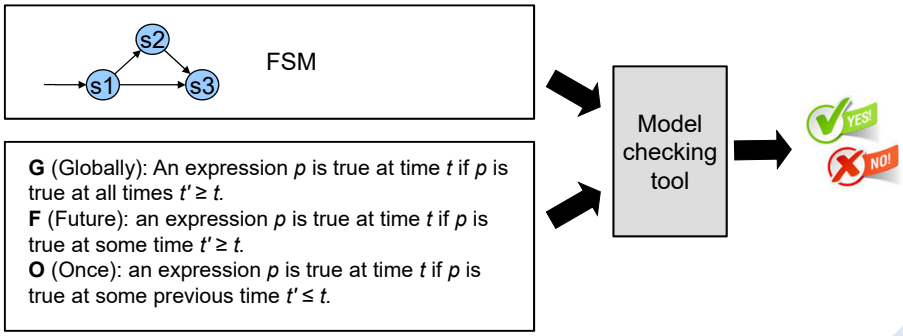
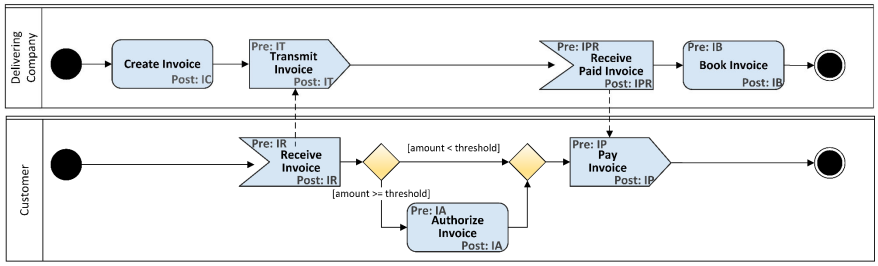
Background — Model Checking

- Model represented as *Finite State Machine* (FSM)
- Property formulas given in *Linear Temporal Logic* (LTL), more precisely PLTL (LTL with past).



Background — BPM as Activity Diagram

- Running example as an Activity Diagram (with annotations)

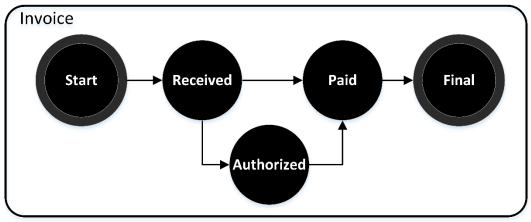


Post: IC = created(Invoice); Pre: IT = created(Invoice); Post: IT = transmitted(Invoice); Pre: IT = created(Invoice); Post: IT = transmitted(Invoice); Pre: IPR = transmitted(Invoice); Post: IPR = paymentReceived(Invoice); Pre: IB = paymentReceived(Invoice); Post: IB = booked(Invoice); Pre: IR = –; Post: IR = received(Invoice); Pre: IA = received(Invoice); Post: IA = authorized(Invoice); Pre: IP = received(Invoice); Post: IP = paid(Invoice);

- (Business) process model as control-flow (procedural)

Background — Object Life Cycle

- States (of an Invoice object) and transitions among them



- Transition conditions still to be defined here

Background — Semantic Action Specification

- Cf. semantic specification of (Web) services
- Pre- and postconditions

Receive Invoice:
Pre: —
Post: received(Invoice)

- Declarative representation

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V&V Mismatch — No problem first

- Formal verification of composed action against the specifications of its atomic actions

$< Receive\ Invoice,\ Pay\ Invoice >$

Sequence <Receive Invoice, Pay Invoice>:
Pre: —
Post: paid(Invoice)

Pay Invoice:
Pre: received(Invoice)
Post: paid(Invoice)

- Verification and validation (V&V) straight-forward
- In a "larger" (hypothetical) company, an additional action for authorization:

Authorize Invoice:
Pre: received(Invoice)
Post: authorized(Invoice)

V&V Mismatch — The Problem

- Business process with additional authorization:

  $< Receive\ Invoice,\ Authorize\ Invoice,\ Pay\ Invoice >$

- Formal verification succeeds again.
- This is also a valid business process.
- Verification also succeeds for

  $< Receive\ Invoice,\ Pay\ Invoice,\ Authorize\ Invoice >$

- but not validation!
- Same for many other processes including authorization in the action composition

V&V Mismatch — Extending the semantic action specification

- Additional precondition (about the invoice being authorized)
- Avoids the successful verification of these invalid processes
- Original process *cannot* be verified anymore!

  $< Receive\ Invoice,\ Pay\ Invoice >$

- Mismatch of semantic specification and implementation, more precisely an overspecification
- Additional knowledge encoded not directly related to these implementations per se

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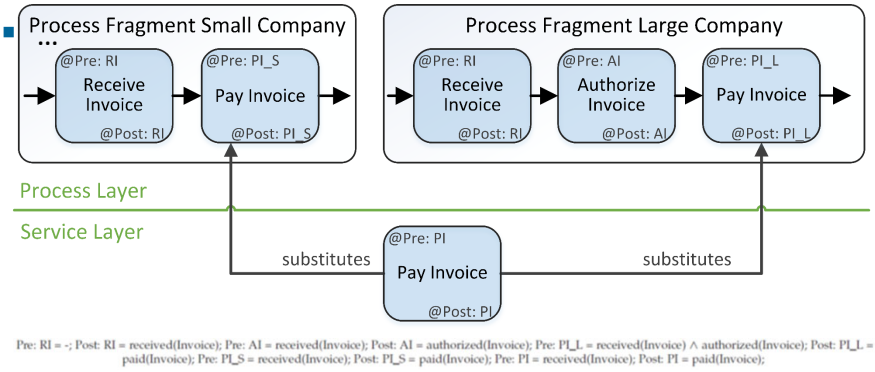
Context-dependent Semantic Action Specification



- The *Pay Invoice* action in the context of the large company has an additional precondition, *authorized(Invoice)*.
- The subtype relationship guarantees substitutability.

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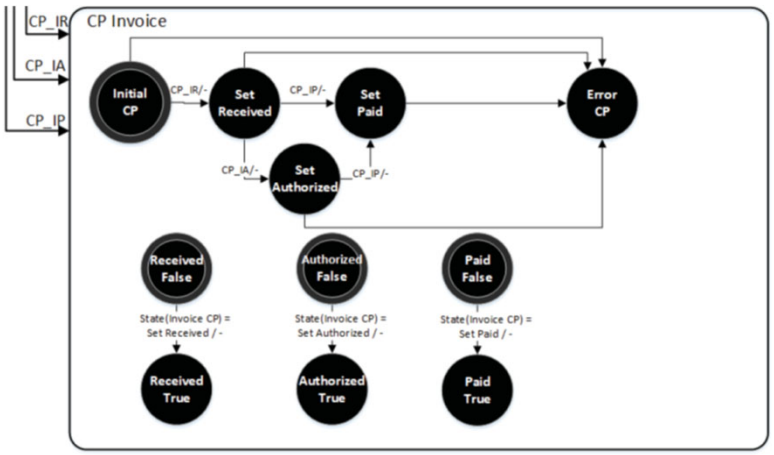
Extended Object Life Cycles — Attributes

- Extending with attributes for memorizing previous states



Extended Object Life Cycles — CPS

- Both software and physical parts
- Possible interaction between physical objects solely based on some physical law
- A physical property of one object modeled as an attribute in its extended life cycle
- Can be changed from a life cycle model of another physical object
- May lead to asynchronous communication between the extended object life cycles that model physical objects
- Another way of communication in addition to the software communication

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Grounding of Action Specifications in Life Cycles

- To define the real meaning of the semantic action specifications in the process models
- Predicates formulated in terms of the attributes
- Pay Invoice Action formalized using grounded predicates:

Pay Invoice:
Pre: attributeIsSet(InvoiceCPReceived, ReceivedTrue)
Post: attributeIsSet(InvoiceCPPaid, PaidTrue)

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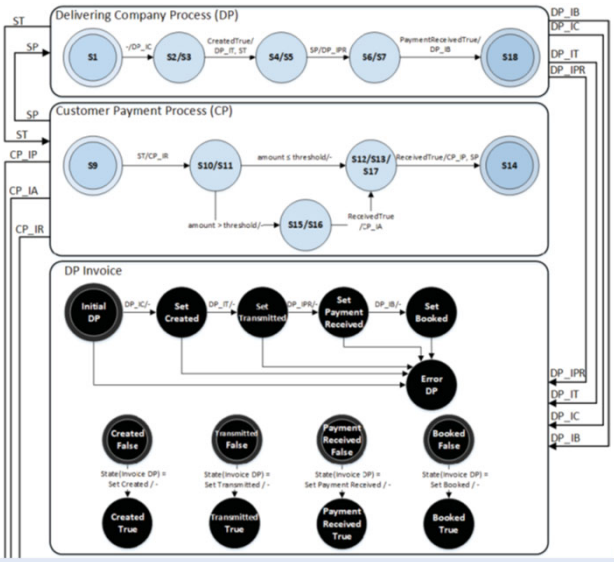
Verification Through Model Checking — FSMs

- Model-checker tool nuXmv
- Verification of consistency



Verification Through Model Checking — Consistency

- Consistency verification
- All the involved specifications 'fit together', both procedurally and logically.
- The process model (or a defined part of it) can continue with an action based on the given state of the object life cycle: *F*(*DefStates*), and
- The object life cycle can handle a given action in a given state: *G*(¬*Error*)
- nuXmv takes a few seconds on a laptop computer for verifying this running example.

Verification Through Model Checking — Context-dependent Semantic Specifications

- The role of context-dependent semantic specifications for verification
- They constrain the possible transitions in the models, which makes the verification stricter.

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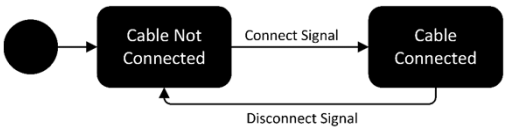
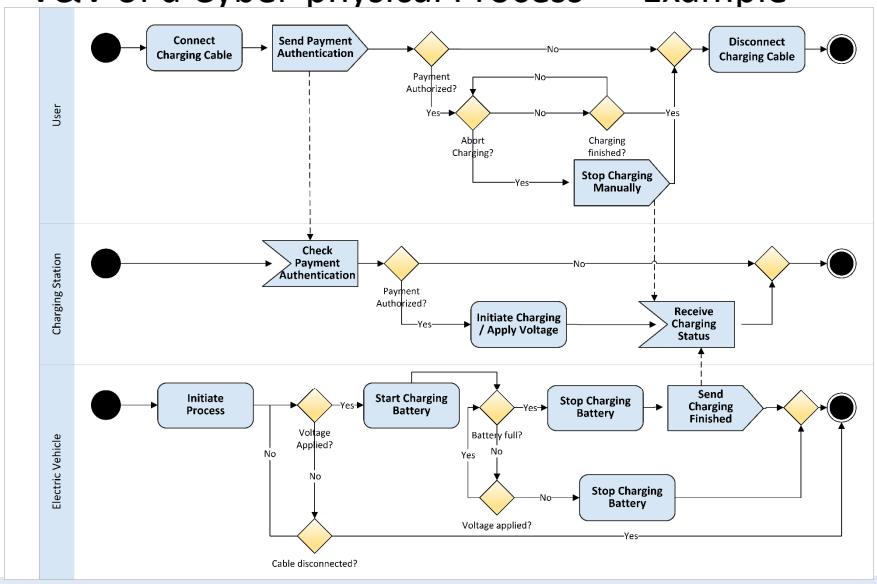
V&V of a Cyber-physical Process

- Case study of a real-world cyber-physical process for charging an electric vehicle at a charging station
- Several iterations of verification and validation
- Physical interaction in CPS:
  establishing a physical connection via cable between two physical devices
- Non-monotonicity



V&V of a Cyber-physical Process — Example



V&V of a Cyber-physical Process — Lessons Learned

- Automated consistency verification of such a process helps finding related problems in the models, of course.
- Complementary to validation of the process, which requires knowledge of domain experts and their precious time
- Even skilled modelers are struggling to create formally correct processes.
- The interpretation of the counterexamples as listed by the nuXmv tool is difficult, as they are very verbose.
- The successful verification run (for checking our two consistency properties) on the final model took about 11 seconds on a laptop computer.

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Conclusion

- New major contributions:
- Grounding of semantic action specifications in (extended) object life cycles
- Extending object life cycles with attributes
- Supporting processes including non-monotonicity
- Modeling communication based on physical interaction in cyber-physical systems
- Our integration of procedural and declarative specifications facilitates a comprehensive verification approach for consistency.

Acknowledgments

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