Formal Tropos

Integrating Formal Methods and Software Engineering

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Outline

- Motivations
- The Formal Tropos Project
- Results so Far: Model Checking Early Requirements
- Conclusions and Future Works
A Software Development Process

- Early Requirements amounts to the definition of the domain.

- Late Requirements
- Architectural Design
- Detailed Design
- Implementation
A Software Development Process

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Late Requirements amounts to explicitly introduce the system and in refining and completing the system definition.
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Architectural Design amounts to describe how system components work together.

Detailed Design amounts to refine the architectural components of the system.

Implementation amounts to the effective coding.
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Formal Methods and Software Development Process

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System too big to be efficiently handled.
Possible bugs discovered too late.
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  - Smooth borders between the phases.
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Applying FM to Early Requirements

- Early Requirement Specification is a crucial phase in the development process.
- Formal Methods are commonly used in advanced stage of the development process.
- Formal Methods are difficult to apply in Early Requirements:
  - The typical approach that amounts to validate an implementation against requirements does not apply.
  - Formal Methods require a detailed description of the behavior of the system.
  - The concepts of Formal Methods are not appropriate for Early Requirements.
Applying FM to Early Requirements (II)

- Formal Methods in Early Requirements cannot be used to prove correctness of specifications.

- However they can . . .
  - show misunderstanding and omissions in the requirements that might not be evident in an informal setting.
  - assist the requirement elicitation by helping the interaction with stakeholders.
  - add expressive power to the requirement specification formalism.
The RBC case study in Tropos

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Strategic dependencies have a temporal evolution (they arise, they are fulfilled, . . . ).
The RBC case study in Tropos (II)
The RBC in Formal Tropos

**Actor Train**
- **Goal** AvoidCollision
- **Goal** RespectMA
- **Goal** ReachDestination

**Actor RBC**
- **Goal** GenerateMA

**Dependency Pos**
- **Type resource**
- **Depender** RBC
- **Dependee** Train

**Dependency SendMA**
- **Type Goal**
- **Depender** Train
- **Dependee** RBC
The RBC in Formal Tropos (II)

Adding the “class” layer . . .

**Entity** Track
**Entity** MovingAuthority
  **Attribute** tracks : set of Track
**Entity** Position
  **Attribute** track : Track
**Actor** Train
  **Goal** AvoidCollision
  **Goal** RespectMovingAuthority
  **Goal** ReachDestination
  **Attribute**
    pos : Position
    ma : MovingAuthority
    . . . . .
Modeling the temporal aspects

Formal Tropos places special emphasis in modeling the “strategic” aspects of the evolution of the dependencies.

The focus is on the two central moments in the life of dependencies and entities: creation and fulfillment.

Formal Tropos allows the designer:

- to specify different modalities for the fulfillment of the dependencies (e.g.: is it a maintain or an achieve goal?)
- to specify temporal constraints on the creation and fulfillment of dependencies and goals.
Adding goal modalities ...

**Actor** Train

**Goal** AvoidCollision

**Mode** maintain

...

**Goal** ReachDestination

**Mode** achieve

**Dependency** Pos

**Type** resource

**Mode** maintain

**Depender** RBC

**Dependee** Train

...
The RBC in Formal Tropos (IV)

Adding behavioral properties …

**Actor** Train

**Goal** AvoidCollision

**Mode** maintain

**Fulfillment condition**

\( \exists \) rma : RespectMA \((rma.\text{actor} = \text{self} \land \text{Fulfilled}(rma))\)

…

**Dependency** SendMA

**Type** goal

**Mode** maintain

**Depender** Train \quad **Dependee** RBC

**Creation condition**

\( \exists \) gma : GenerateMA

\((gma.\text{actor} = \text{dependee} \land \text{Fulfilled}(gma))\)

…
Constraint properties determine the possible evolutions of the objects in the specification.

Constraint properties are specified with formulas given in a first-order linear-time temporal logic with past operators.

Three kinds of properties:
- **creation** properties.
- **invariants**.
- **fulfillment** properties.

Creation and fulfillment properties may express:
- necessary **conditions** (for creation, fulfillment...).
- sufficient conditions, or **triggers**.
- necessary and sufficient conditions, or **definitions**.
Formal analysis in Formal Tropos

Formal Tropos allows for the following kinds of formal analysis:

- **Consistency check**: "The specification admits valid scenarios".
- **Possibility check**: "There is some scenario for the system that respects certain possibility properties".
- **Assertion validation**: "All scenarios for the system respect certain assertion properties".
- **Animation**: The user interactively explores valid scenarios for the system. Provides immediate feedback on the effects of the constraints. Makes it possible to catch trivial errors. Is an effective way of communicating with the stakeholder."
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A possibility:

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**Example:** “It is always possible for a train to achieve \( P_1 \) and then \( P_2 \).”

**Global possibility**
\[
\text{exists } t : \text{Train } \quad F \ ((t.\text{pos} = P_1) \land F \ (t.\text{pos} = P_2))
\]
An assertion:

- describes *expected* conditions for all the valid scenarios;
- is used to guarantee that the specification does not allow for unwanted scenarios.
Assertion Validation in Formal Tropos

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- describes *expected* conditions for all the valid scenarios;
- is used to guarantee that the specification does not allow for unwanted scenarios.

**Example**: “It is never the case that two different trains occupy the same position if they respect their moving authority.”

Global assertion

\[
\text{forall } t_1 : \text{Train} \ (\text{forall } t_2 : \text{Train} \\
(t_1 \neq t_2) \land \text{respectma}(t_1, t_1.\text{ma}) \land \text{respectma}(t_2, t_2.\text{ma})) \\
\rightarrow (t_1.\text{pos} \neq t_2.\text{pos}))
\]
The technical details

Our approach consists of the following 3 steps:

1. The analyst writes a **Formal Tropos** specification.
2. **T-Tool** automatically translates the specification into an **Intermediate Language**.
3. **NuSMV** performs the formal analysis on the Intermediate Language specification.

The Intermediate Language is:
- a small core language with a clean semantics.
- independent from **Formal Tropos** (the Intermediate Language may be applied to other requirements languages).
- independent from any particular analysis technique (model checking, LTL satisfiability, theorem proving).
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- a **methodology** to extend the requirements with assertions on expected behaviors of the system.
- a **prototype tool** (based on NuSMV) to support the proposed approach.
So far we have...

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The approach is

- **feasible**: we obtained feedback from the formal analysis even when dealing with just a few instances.
- **useful**: we were able to identify ambiguities and problems in the informal requirements (e.g. insurance company).
- **heavy**: it is difficult to write LTL specifications.
Ongoing Works
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  - ... stress the scalability.
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- Extension of the scope of the approach by...
  - ... formalizing goal decomposition.

- Enhancement of the tool by...
  - ... improving the interaction with the user.
  - ... enhancing the animation techniques.
  - ... developing specifically tailored verification algorithms.
Future Works

- Extend the scope of the approach by allowing for the use of different specification languages (e.g., KAOS, UML, ...).
- Extend to later phases of the Tropos development process with the same concepts, different interpretations, and different V&V techniques.
- Automatic generation from the requirements.
- Integration of the informal and formal layer with graph transformations.
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- **Integration of the informal and formal layer**
  - graph transformations.
In Late Requirements the system component is explicitly added and it is refined by introducing new actors, goals and dependencies.

In this phase the focus is in the refinement of the system to be.
The specification approach is similar to the approach used in early requirements, but here more details are added.

Provided the system shows a “certain behavior at the interface” (*Assume*), then the environment works “correctly” (*Guarantee*).

Verification/Validation can be performed using Assume/Guarantee reasoning.

The process can be iterated within the system, thus allowing for a compositional approach.