A Language for Feedback Loops in Self-Adaptive Systems: Executable Runtime Megamodels

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Engineering Self-Adaptive Software

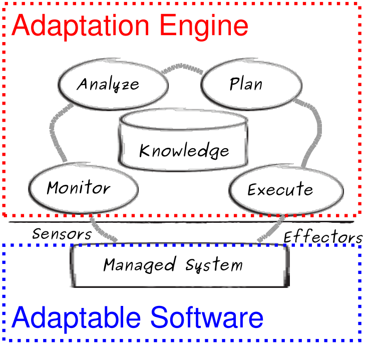
- Internal vs. **external** approach

  [Salehie and Tahvildari, 2009]
- Feedback Loop (MAPE-K)

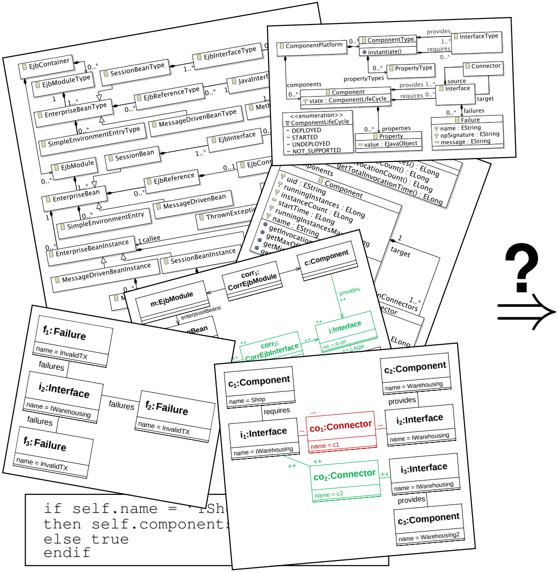
  [Kephart and Chess, 2003]
- **Multiple, flexible** feedback loops
  - Different concerns

    [Vogel et al., 2010a, Vogel and Giese, 2010]
  - Hierarchical structures

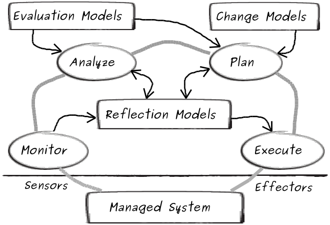
    [Hestermeyer et al., 2004,
    Kramer and Magee, 2007]
  - Uncertainty [Esfahani and Malek, 2012]
- **Models@run.time** for K and MAPE



Interplay of Runtime Models?



```
if self.name = 'iSh
then self.component
else true
endif
```



Specifying and Executing Feedback Loops

Specification — Modeling language

- Capturing the interplay of multiple runtime models [Vogel et al., 2010b, Vogel et al., 2011]
- Making feedback loops **explicit** in the design of self-adaptive systems [Müller et al., 2008, Brun et al., 2009]

Execution — Model interpreter

- Coordinated execution/usage of multiple runtime models
- **Flexible** solutions and structures for feedback loops
  - ⇝ Adaptable feedback loops

Specifying and Executing Feedback Loops

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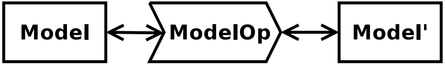
Executable Runtime Megamodels

Megamodels

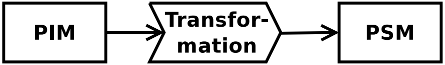
Definition (Megamodel)

A *megamodel* is a model that contains models and relations by means of model operations between those models.

In general:

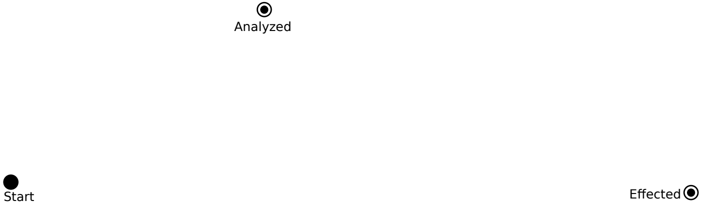


Model-Driven Architecture (MDA) example:



- Research on model-driven software development (MDA, MDE)
  [Favre, 2005, Bézivin et al., 2003, Bézivin et al., 2004, Barbero et al., 2007]
- “Toward Megamodels at Runtime” [Vogel et al., 2010b]

An Example: Self-repair

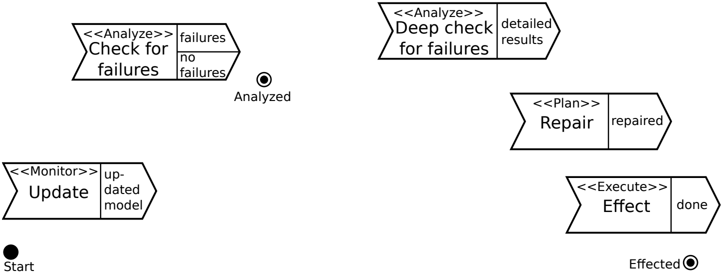


Legend
(concrete syntax)

● Initial state

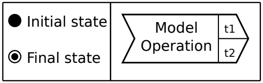
◉ Final state

An Example: Self-repair



Legend

(concrete syntax)



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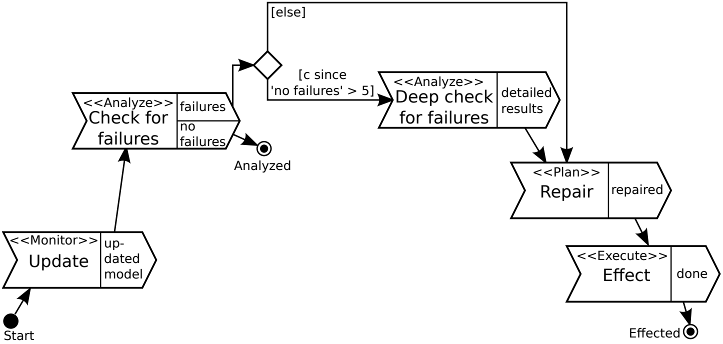

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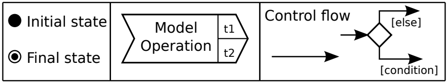

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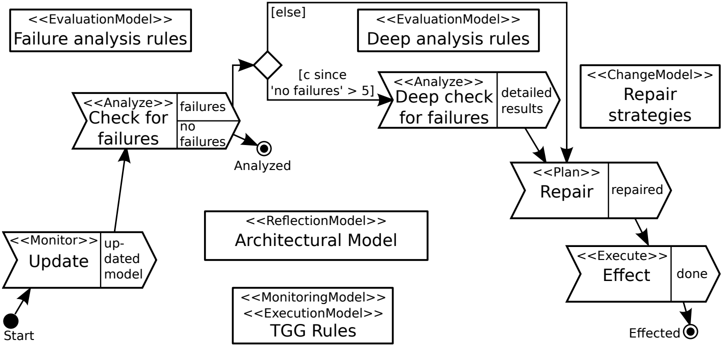

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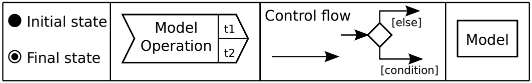

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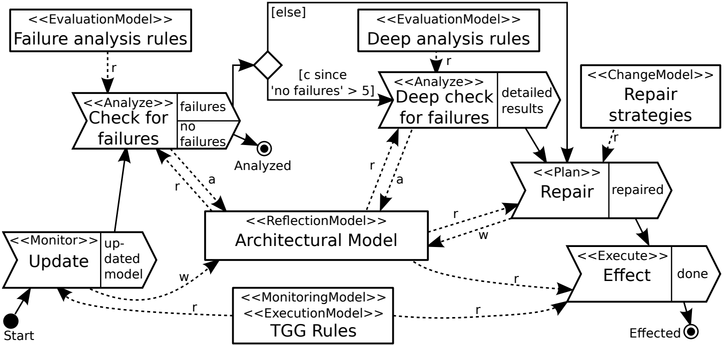

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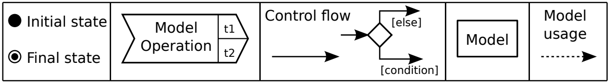
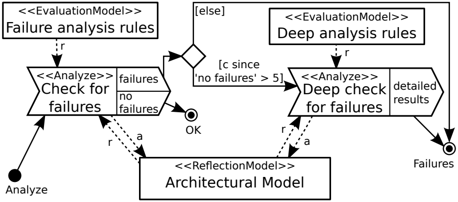
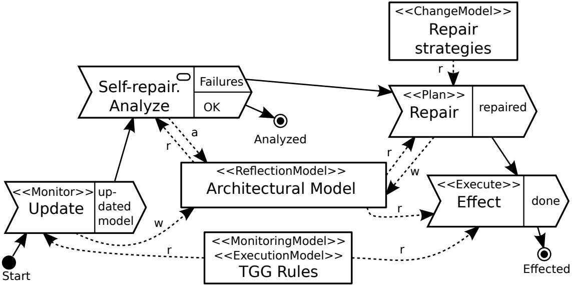


Modularity and Composition

Analysis step for self-repair



Self-repair

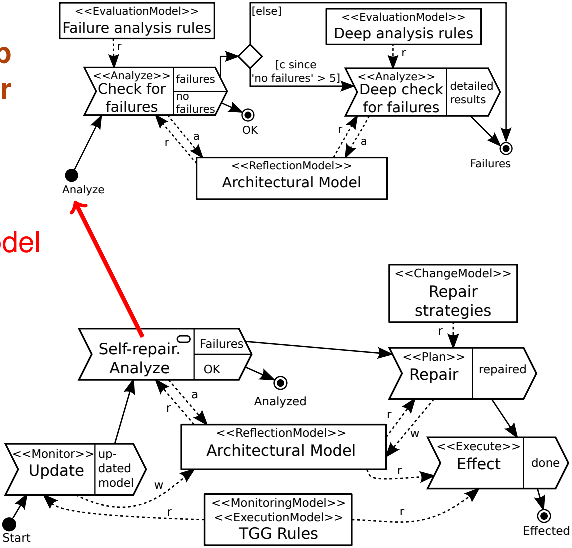


Modularity and Composition

Analysis step for self-repair

Complex model operations

Self-repair



<<EvaluationModel>>
Failure analysis rules

r

<<Analyze>>
Check for failures

failures

no failures

OK

[else]

[c since 'no failures' > 5]

<<EvaluationModel>>
Deep analysis rules

r

<<Analyze>>
Deep check for failures

detailed results

Failures

Analyze

r

a

r

a

<<ReflectionModel>>
Architectural Model

<<ChangeModel>>
Repair strategies

r

Self-repair. Analyze

Failures

OK

Analyzed

<<Plan>>
Repair

repaired

a

r

r

w

<<ReflectionModel>>
Architectural Model

<<Monitor>>
Update

up-dated model

<<Execute>>
Effect

done

w

r

r

r

Start

<<MonitoringModel>>
<<ExecutionModel>>
TGG Rules

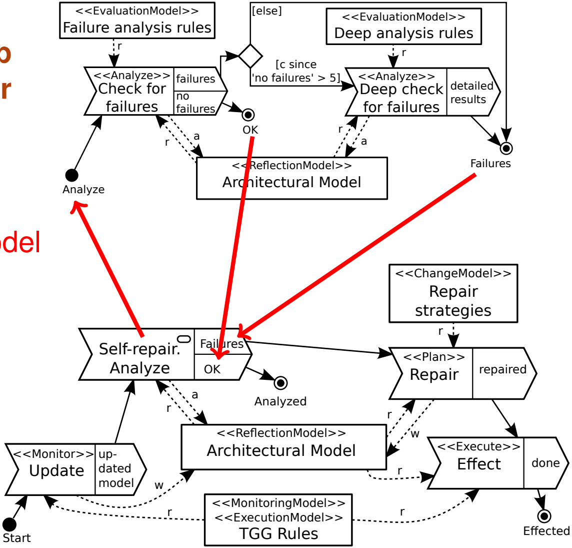
Effected

Modularity and Composition

Analysis step for self-repair

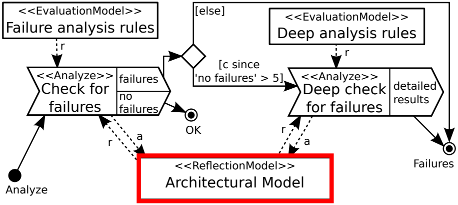
Complex model operations

Self-repair



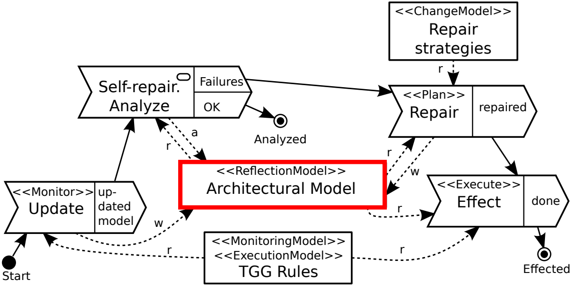
Modularity and Composition

Analysis step for self-repair



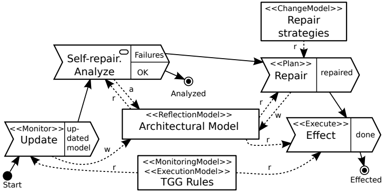
Shared runtime models

Self-repair

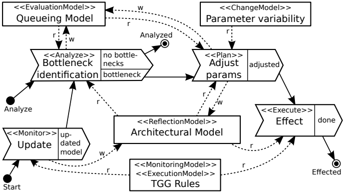


Modeling Interacting Feedback Loops

Self-repair



Self-optimization



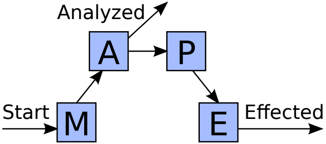
Two example solutions:

1. Linearizing Complete Feedback Loops
2. Linearizing Analysis and Planning Steps of Feedback Loops

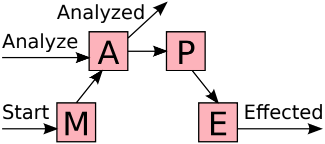
by using **complex model operations** and shared **runtime models**

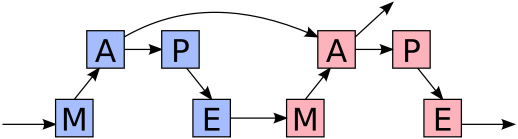
(1) Linearizing Complete Feedback Loops

Self-repair



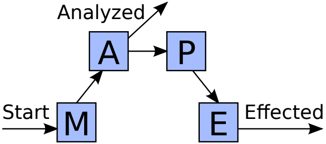
Self-optimization



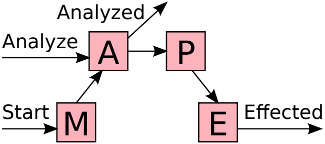


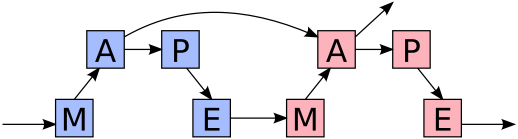
(1) Linearizing Complete Feedback Loops

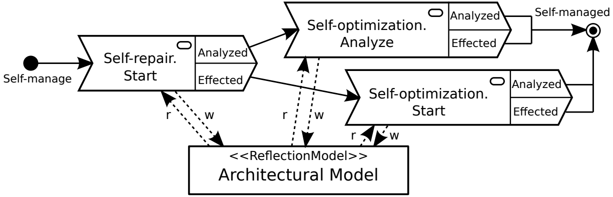
Self-repair



Self-optimization

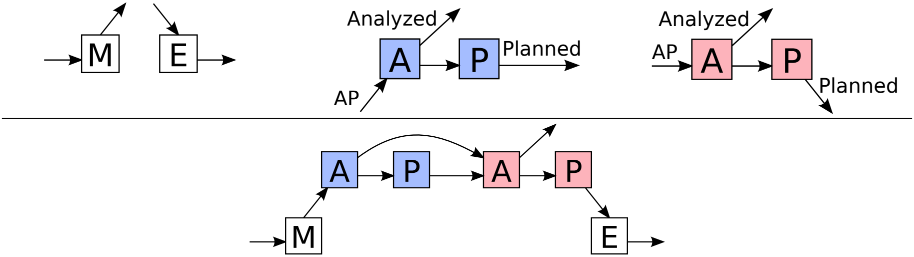






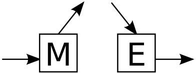
(2) Linearizing Analysis and Planning Steps

Shared M+E **Self-repair** **Self-optimization**

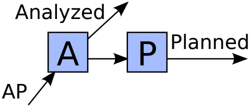


(2) Linearizing Analysis and Planning Steps

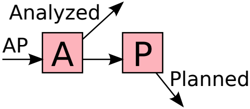
Shared M+E

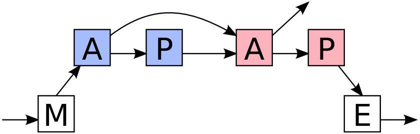


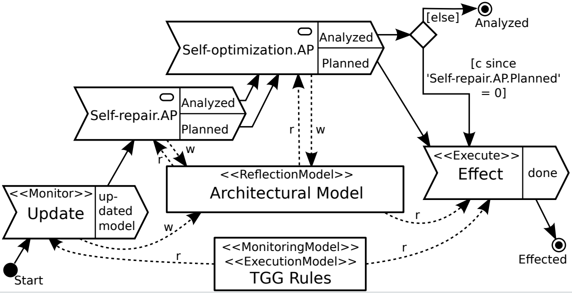
Self-repair



Self-optimization

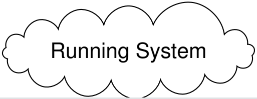






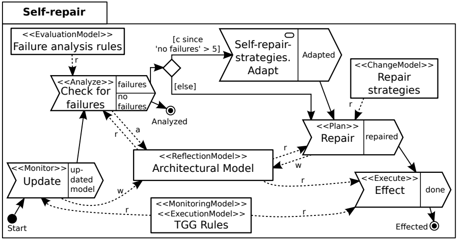
Hierarchy of Feedback Loops

Layer$_0$

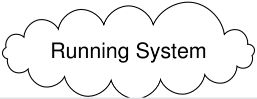


Hierarchy of Feedback Loops

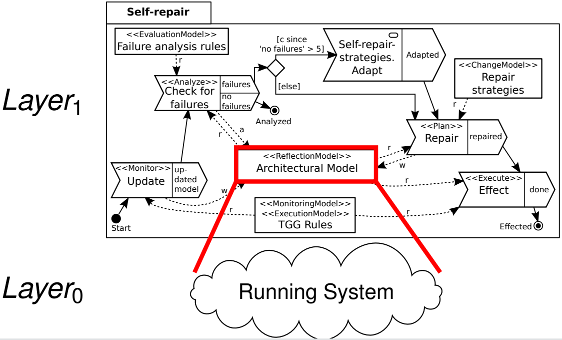
Layer$_1$



Layer$_0$



Hierarchy of Feedback Loops



Causal connection

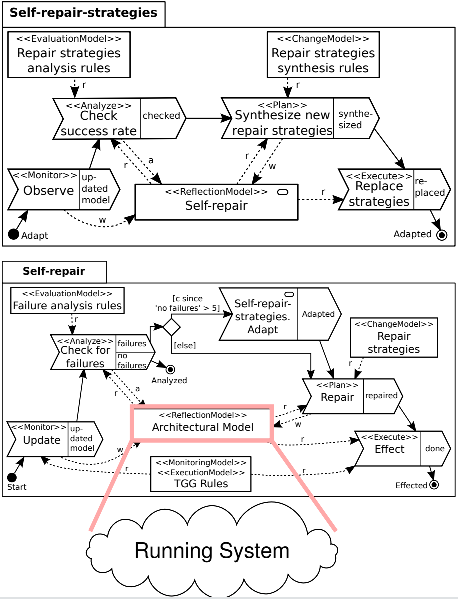
- sensors + effectors required
- implementation efforts!

Hierarchy of Feedback Loops

Layer$_2$

Layer$_1$

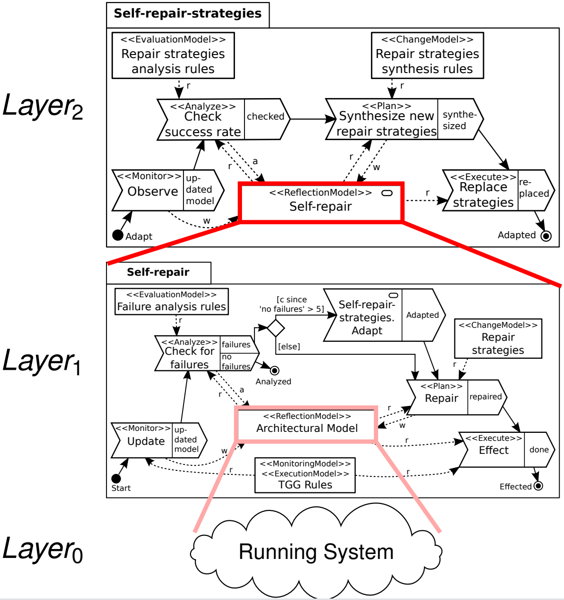
Layer$_0$


Self-repair-strategies
<<EvaluationModel>> Repair strategies analysis rules
<<ChangeModel>> Repair strategies synthesis rules
r
r
<<Analyze>> Check success rate
checked
<<Plan>> Synthesize new repair strategies
synthe-sized
a
r
r
w
<<Monitor>> Observe
up-dated model
<<ReflectionModel>> Self-repair
r
<<Execute>> Replace strategies
re-placed
w
Adapt
Adapted
Self-repair
<<EvaluationModel>> Failure analysis rules
r
[c since 'no failures' > 5]
Self-repair-strategies. Adapt
Adapted
<<ChangeModel>> Repair strategies
<<Analyze>> Check for failures
failures
no failures
[else]
Analyzed
a
r
r
<<Plan>> Repair
repaired
r
w
<<ReflectionModel>> Architectural Model
<<Monitor>> Update
up-dated model
w
r
<<Execute>> Effect
done
<<MonitoringModel>> <<ExecutionModel>> TGG Rules
r
r
Start
Effected
Running System

Causal connection

- sensors + effectors required
- implementation efforts!

Hierarchy of Feedback Loops



Layer$_2$ directly uses the megamodel of *Layer*$_1$

- no specific sensors and effectors required
- adapts the models or control flow of the *Layer*$_1$ megamodel
- interpreter (flexibility)!

Causal connection

- sensors + effectors required
- implementation efforts!

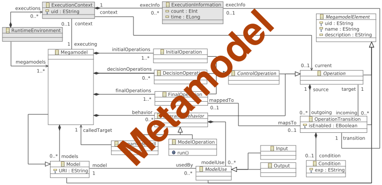
Execution Semantics and Interpreter

Focus

- Coordinated execution of operations (adaptation steps)
- Handling input/output models for these operations

Simple approach

- A megamodel as a singleton
- Execution information
  - `count` and `time`
- Expression language for conditions
- Synchronous, single-threaded execution

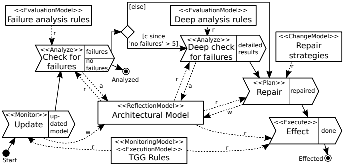

Metamodel

Implementation

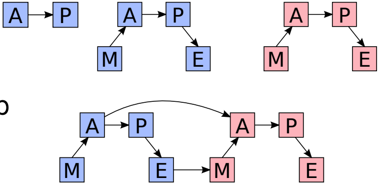
- EMF, JavaCC

Discussion: Executable Megamodels (I)

- **Explicit** specification of feedback loops by megamodels



- **Modularity**: individual adaptation steps and feedback loops
  - Composing steps to a feedback loop
  - Composing multiple feedback loops



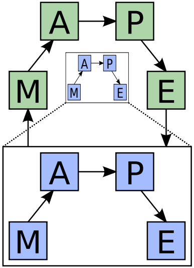
- Abstraction level similar to software architectures
  - Reusing implementations of adaptation steps
  - Coordinated interplay and execution of such steps

Discussion: Executable Megamodels (II)

- Executable specifications kept **explicit** and **alive** at runtime

  → Runtime megamodels

- **Interpreter**: flexibility to cope with megamodel changes at runtime
- Megamodels as reflection models for feedback loops
  - Hierarchical control/structures
  - No specific sensors and effectors required



⇝ **Supports the design/engineering of self-adaptive systems**

⇝ **Eases development/implementation efforts**

Related Work

Frameworks [Garlan et al., 2004, Schmidt et al., 2008]

- Focus on reducing development efforts for single feedback loops
- Rather prescribe static solutions for feedback loops

Explicit Feedback Loops

- Abstraction level of controllers, no runtime support [Hebig et al., 2010]
- Formal modeling and analysis of design alternatives for self-adaptive systems, no runtime support [Weyns et al., 2010]

Multiple, Interacting Feedback Loops

- Implementation framework for distributed self-adaptive systems [Vromant et al., 2011]

Modeling Languages

- Flowcharts and dataflow diagrams, like *UML Activities*

Conclusion and Future Work

Conclusion

- Modeling language for feedback loops based on runtime models (Adaptation steps, single and multiple feedback loops)
- Executable megamodels kept alive at runtime
- Flexibility to dynamically change megamodels (interpreter)
- Leverages advanced solutions, like layered feedback loops

Future Work

- Elaborate the modeling language
  - Formal interface definitions for models and model operations
  - Analysis of megamodels
- Discuss restrictions on the execution semantics (concurrency)

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