A Generator Composition Approach for Aspect-Oriented DSLs

ICMT 2016

Reiner Jung Robert Heinrich
Wilhelm Hasselbring

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Motivation

Software development and evolution

- Domain, technology and environment changes
- Addition and changes to requirements

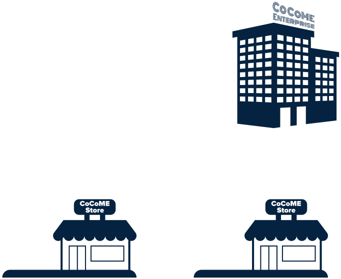
➡ Continuously growing complexity

Model-driven software development

- Provides: Specific views and models of software systems
- Requires: Model editors, evaluation tools, and code generators

➡ Evolution provoke generator alterations

Common Component Modeling Example



(Rausch et al. 2011; Heinrich et al. 2015)

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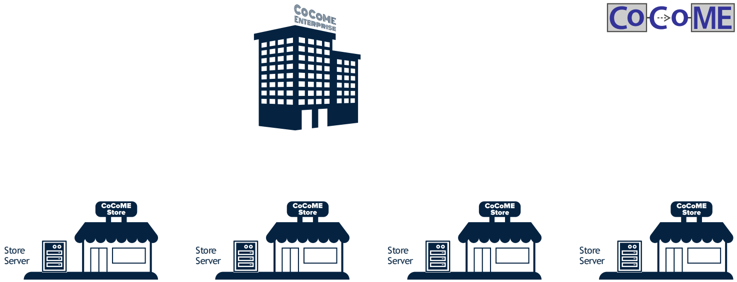

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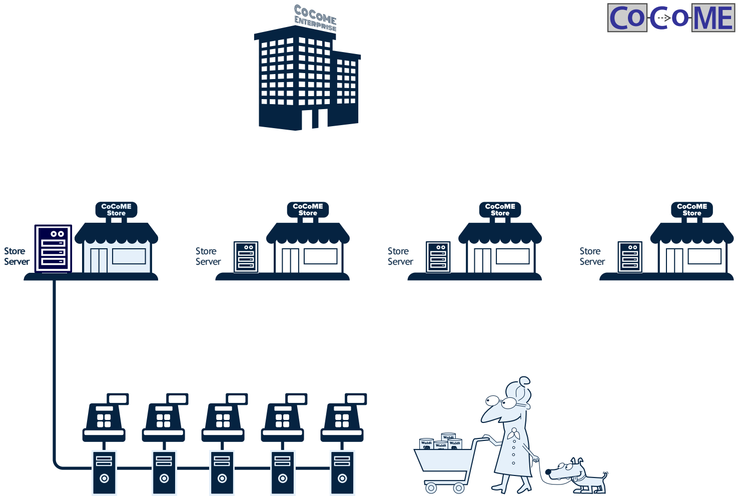

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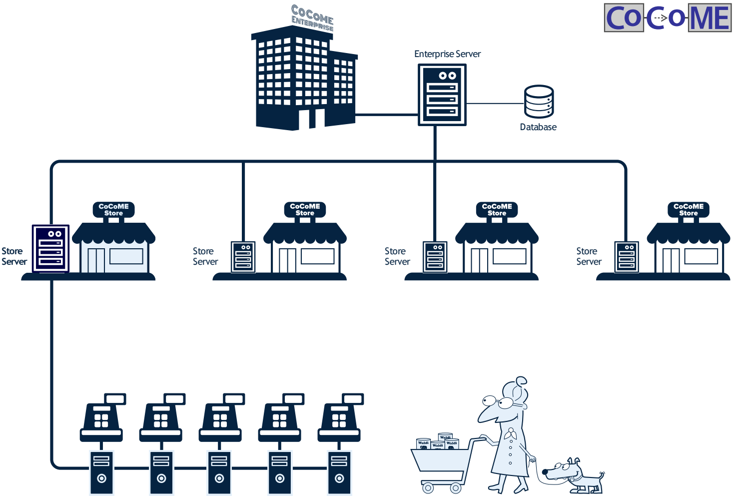

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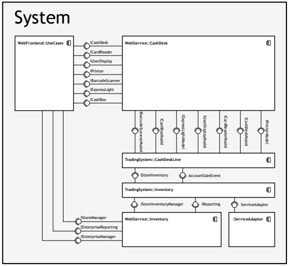
Modeling CoCoME

Source Model



Target Code

Modeling CoCoME

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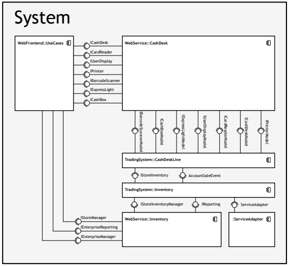

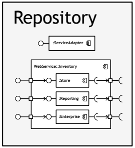

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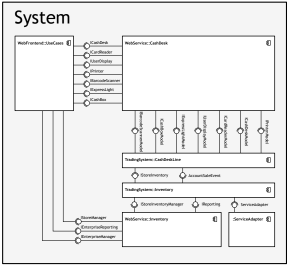

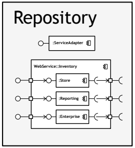

Data Types

```
package data

entity TradingEnterprise {
    long id
    string name
    Store[] stores
    ProductSupplier[] productSuppliers
}

entity ProductSupplier {
    long id
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    Product[] offers
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```

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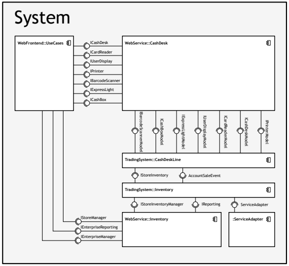

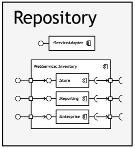

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Behavior

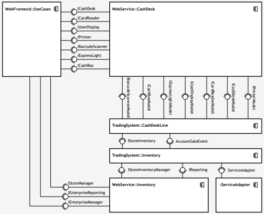
```
package cocome

import data.TradingEnterprise

repository "cocome/model/cocome.repository"

realize stateless TradingSystem.Inventory.Data.Enterprise {
    iface EnterpriseQueryIf
        operation queryEnterpriseById {
            return query TradingEnterprise
                "SELECT t FROM TradingEnterprise WHERE id=" + enterpriseId
        }
}
```

Target Code

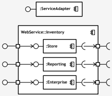
Modeling CoCoME

Source Model

System



Repository



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Kieker - Monitoring

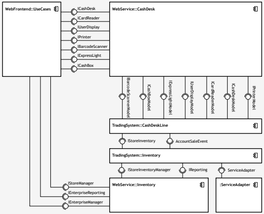
```
use pcm on cocome "irl-examples/src/cocome.repository"

advice TraceLogger () {
    before OperationBeforeEvent(time, signature, classname, signature)
    after OperationAfterEvent(time, signature, classname)
}

pointcut point class cocome.TradingSystem.Inventory.Data.Persistence

aspect point : EntryLogger
```

Target Code

Modeling CoCoME

Source Model

System



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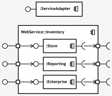

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aspect point : EntryLogger
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Target Code

AspectJ

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<aspectj>
    <weaver options=""/>
    <aspects>
        <aspect name="AbstractEntryLoggerAdvice0"/>
        <aspect name="AbstractEntryLoggerAdvice1"/>
        <concrete−aspect extends="AbstractEntryLoggerAdvice0" name="EntryLoggerAdvice0">
        <pointcut expression="TradingSystem.Inventory.Data.Persistence" name="point"/>
    </concrete−aspect>
    </aspects>
</aspectj>
```

JavaEE

```
package org.cocome.tradingsystem.inventory.data.enterprise;

...

public final class EnterpriseQueryProvider implements IEnterpriseQuery {

    @Override
    public TradingEnterprise queryEnterpriseById(final long enterpriseId, final IPersistenceContext pctx) {
        final EntityManager em = __getEntityManager(pctx);
        return em.createQuery("SELECT te FROM TradingEnterprise te WHERE te.id" + enterpriseID,
            TradingEnterprise.class).getResultList();
    }
```

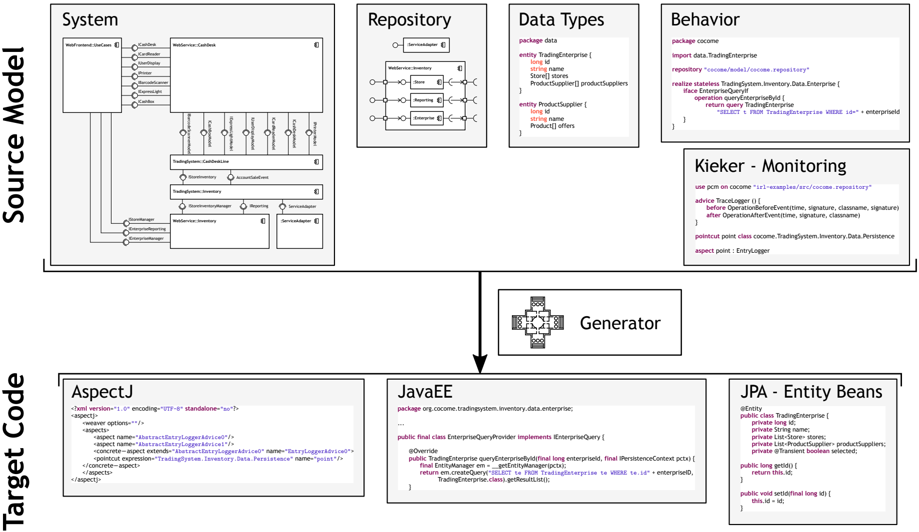
JPA - Entity Beans

```
@Entity
public class TradingEnterprise {
    private long id;
    private String name;
    private List<Store> stores;
    private List<ProductSupplier> productSuppliers;
    private @Transient boolean selected;

public long getId() {
    return this.id;
}

public void setId(final long id) {
    this.id = id;
}
```

Modeling CoCoME



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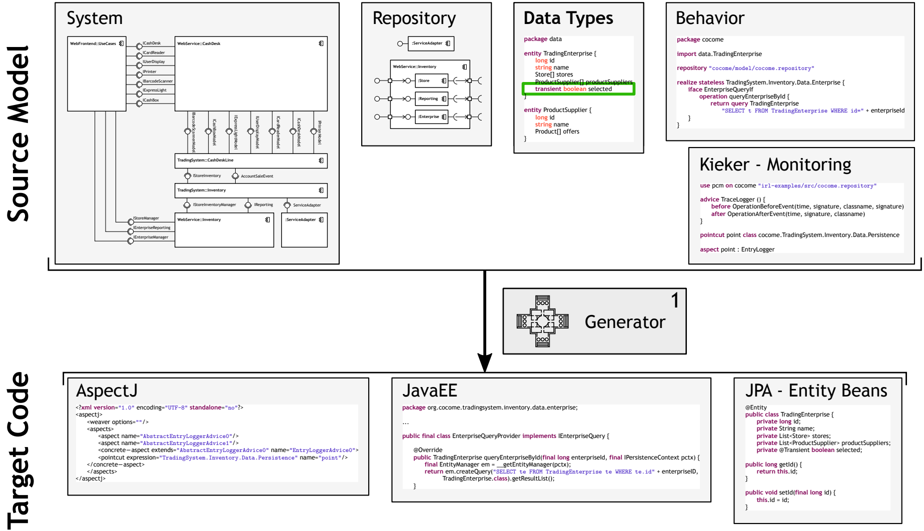

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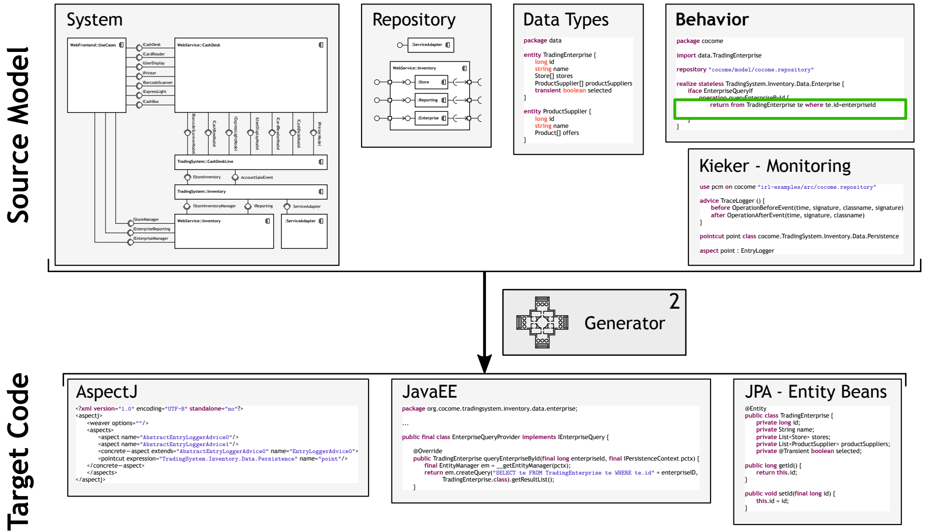

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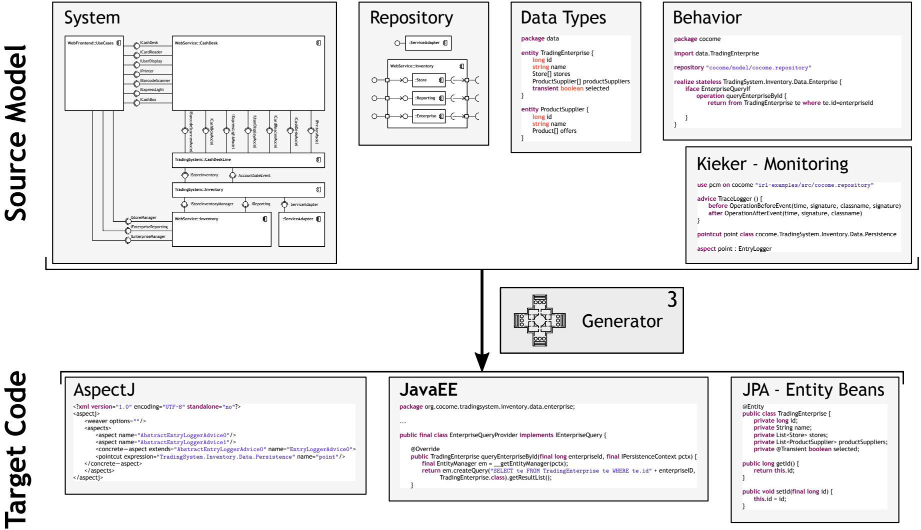

Challenges

Key challenges in generator development

- Domain and technology **evolution**
- Increasing **complexity** of generators
- **Reusability** of metamodels and generators

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- Domain and technology **evolution**
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- **Reusability** of metamodels and generators

Experts Generator and DSL reuse are not applied by industry

Contributions

GECO Approach

- Generator megamodel patterns (Jung et al. 2016)
- Generator fragment design

GECO Artifacts

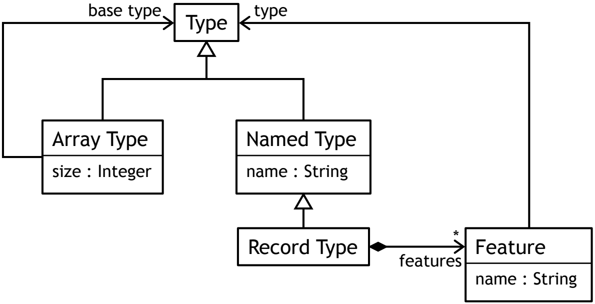
- Instrumentation aspect and record languages (Jung et al. 2013)
- Generator composition language
- Software architecture evaluation (Jung et al. 2015)

Foundations

Metamodel Partitions

Metamodel Structures

- Structure and typing



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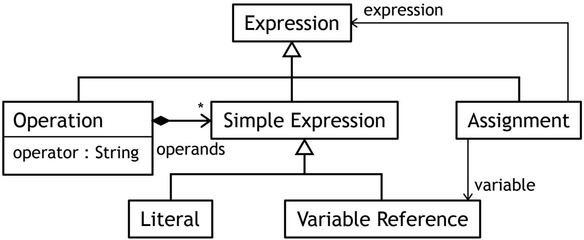
Metamodel Partitions

Metamodel Structures

- Structure and typing
- Expressions



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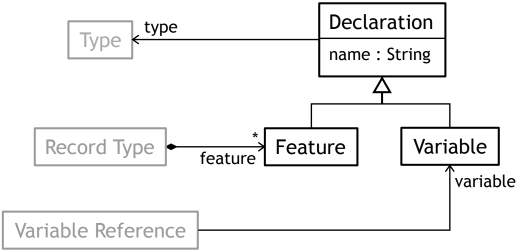
Metamodel Partitions

Metamodel Structures

- Structure and typing
- Expressions
- Declaration



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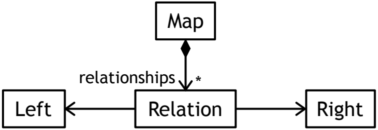
Metamodel Partitions

Metamodel Structures

- Structure and typing
- Expressions
- Declaration
- Maps, e.g., Traces, Pointcuts



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Metamodel Roles

Aspect-Oriented Modeling

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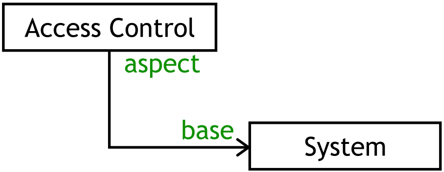

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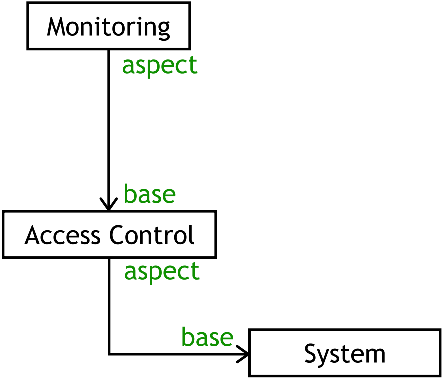

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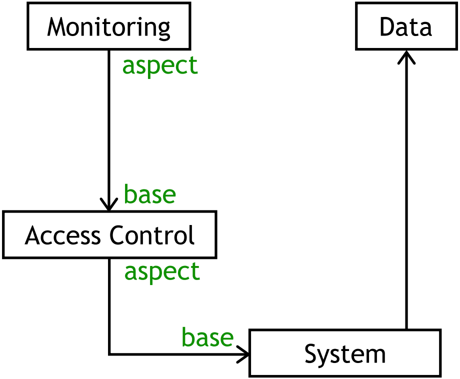
Metamodel Roles

Aspect-Oriented Modeling

View-Based Modeling



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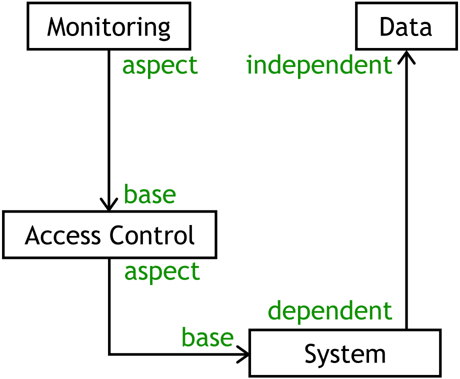

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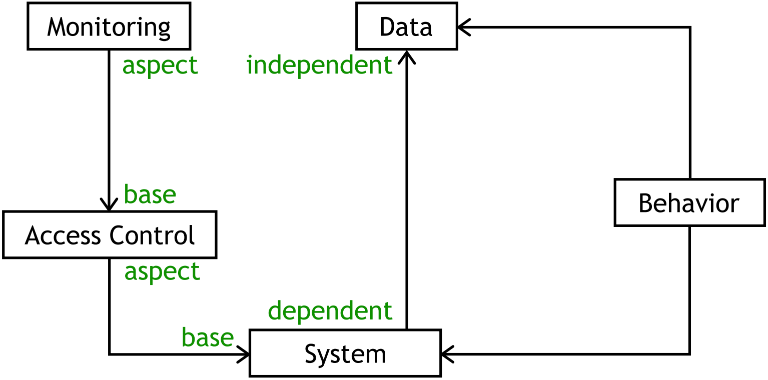

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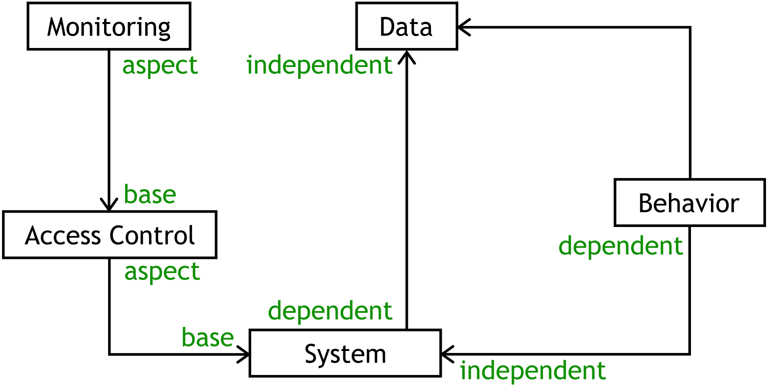

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Megamodel Notation

Example Megamodel based on CoCoME Szenario

(Bézivin et al. 2004; Favre 2004)

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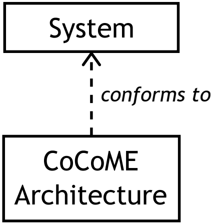

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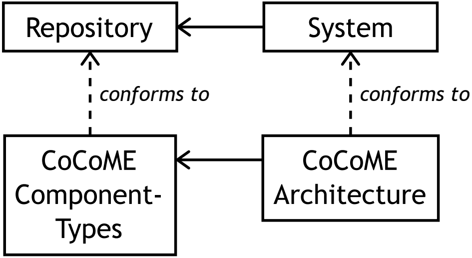

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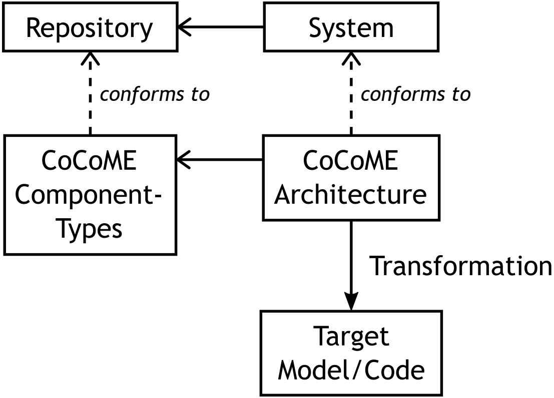

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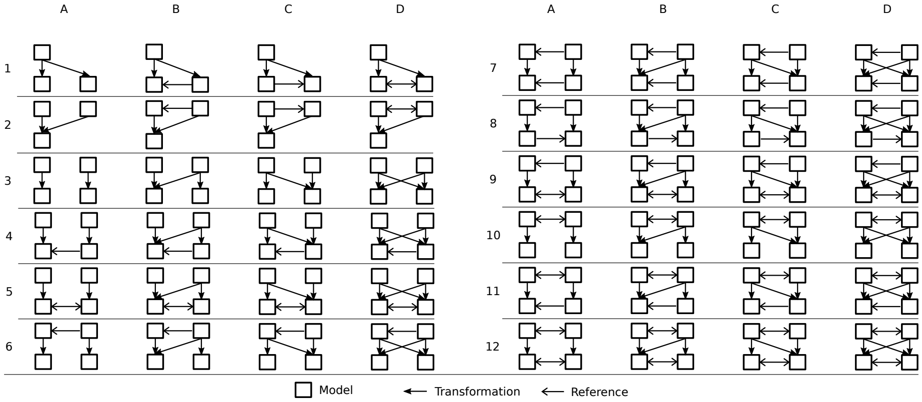
The GECO Approach

Generator Composition Pattern Candiates



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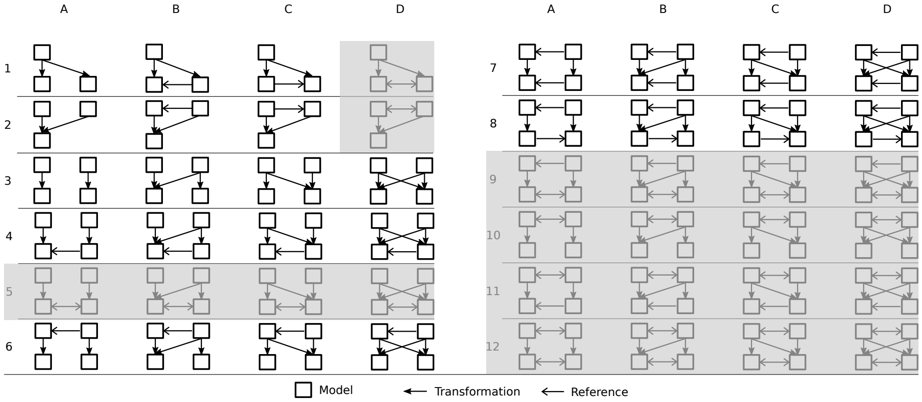

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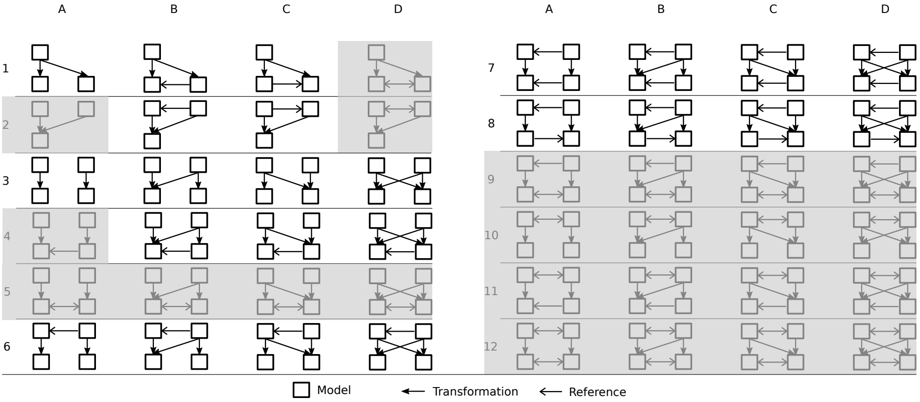

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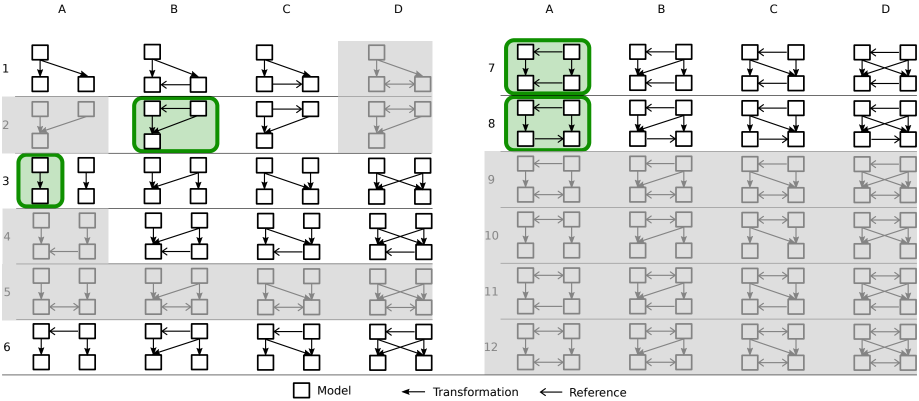
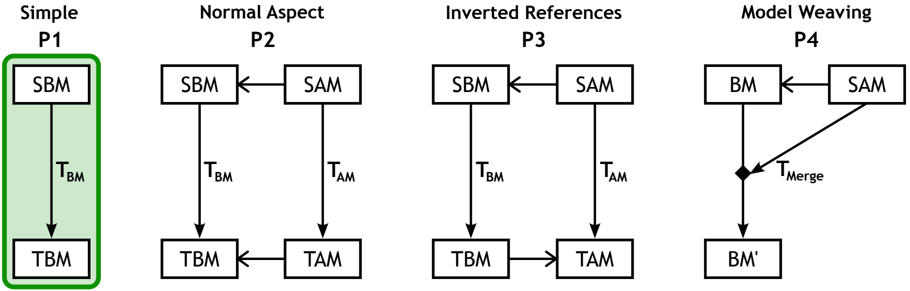


Generator Composition Megamodel Patterns



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TBM	Target Base Model	TAM	Target Aspect Model	←	Reference

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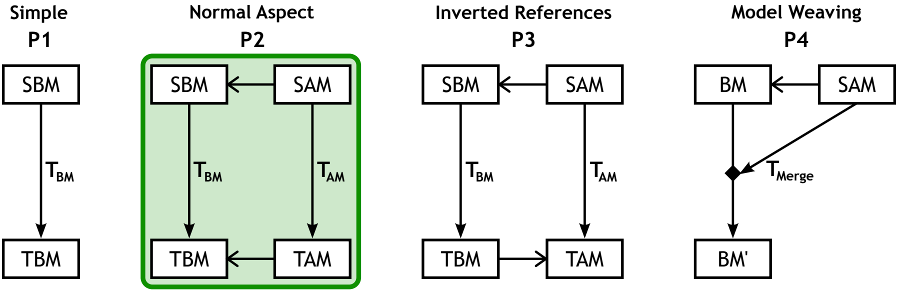

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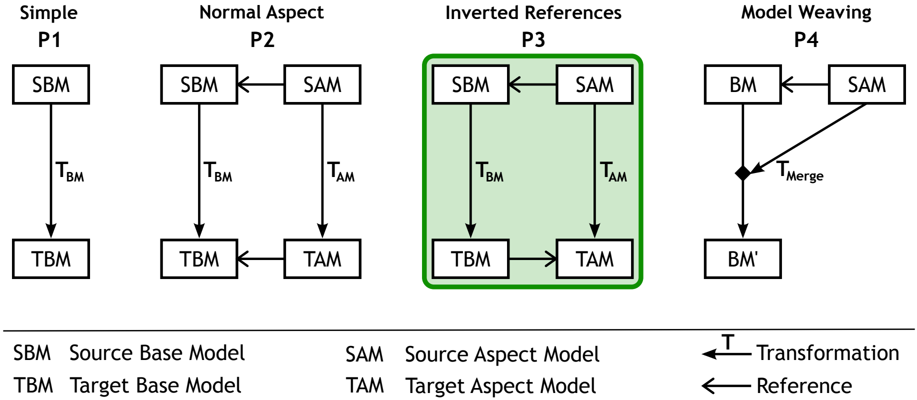

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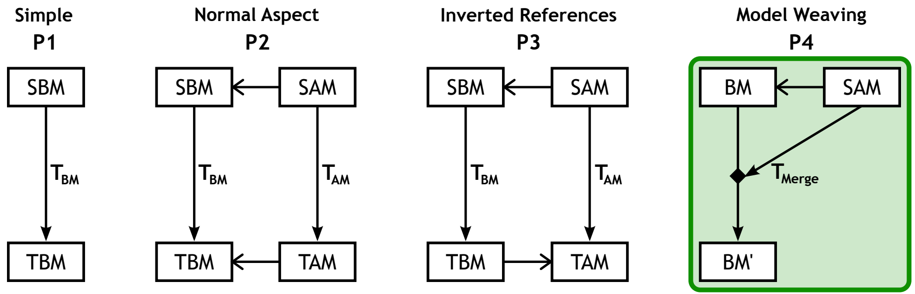

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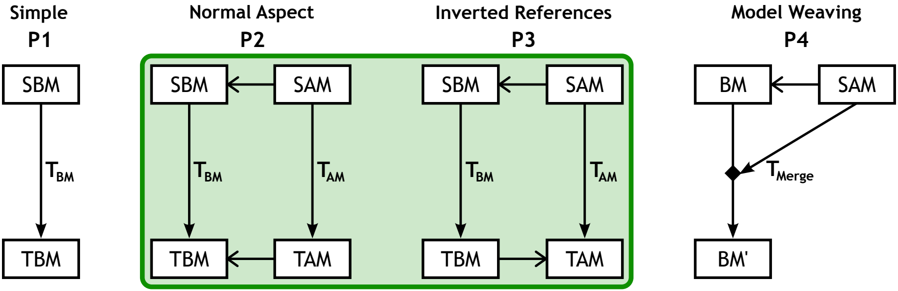

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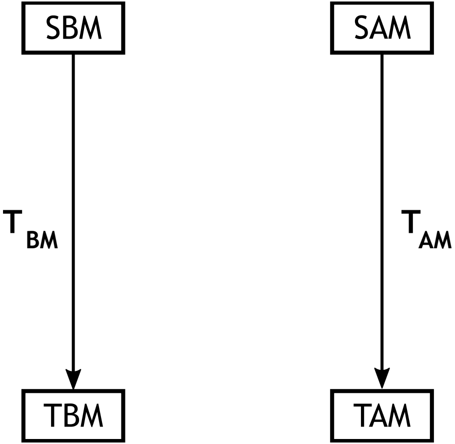

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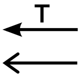

Transformation
Reference

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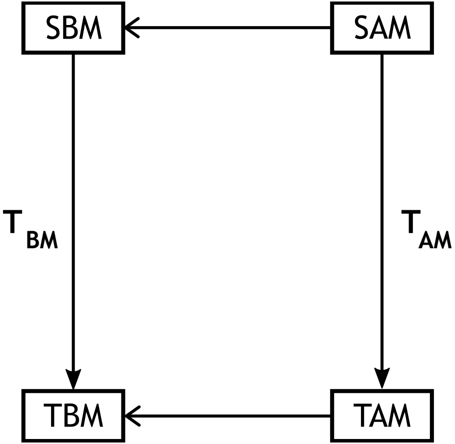

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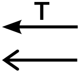

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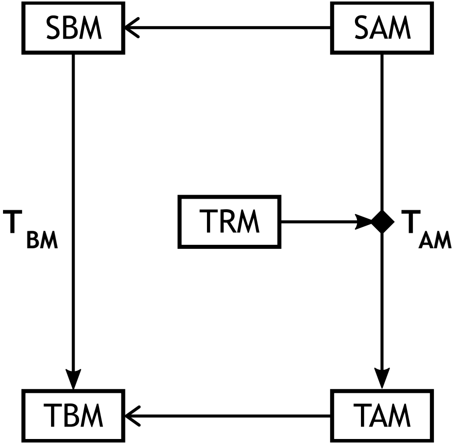

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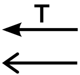

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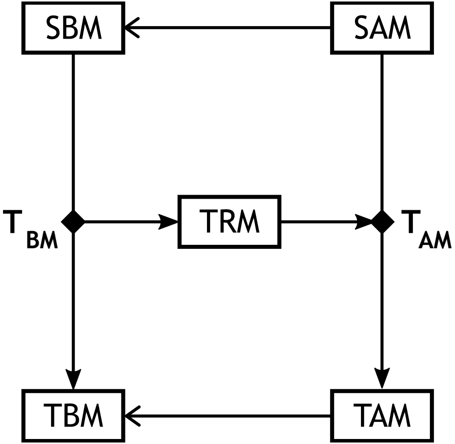

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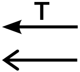
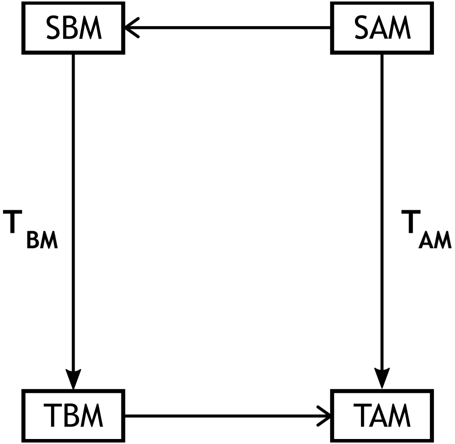


Transformation
Reference

Pattern P3 - Inverted References



SBM	Source Base Model
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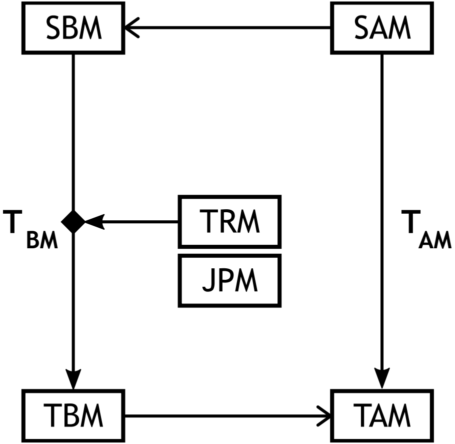
TRM	Trace Model
JPM	Join Point Model

T ← Transformation

← Reference

Pattern P3 - Inverted References



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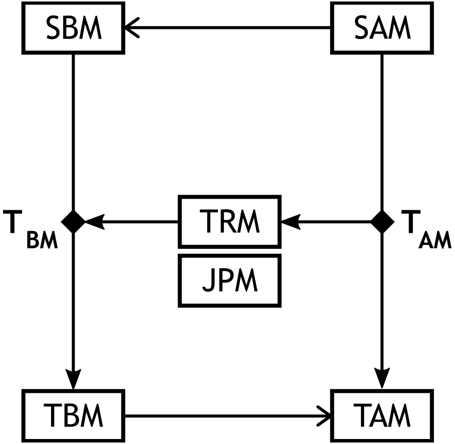
TAM Target Aspect Model
TRM Trace Model
JPM Join Point Model

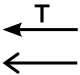
Transformation


Reference

Pattern P3 - Inverted References

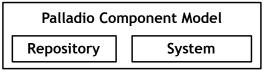


SBM	Source Base Model
SAM	Source Aspect Model
TBM	Target Base Model
TAM	Target Aspect Model
TRM	Trace Model
JPM	Join Point Model

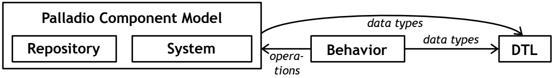


Transformation
Reference

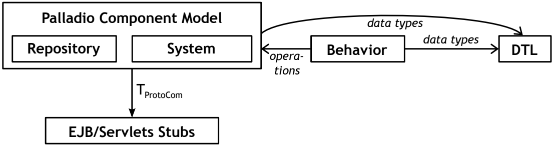
CoCoME Case Study - Generator Megamodel



CoCoME Case Study - Generator Megamodel

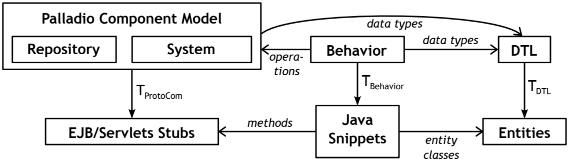


CoCoME Case Study - Generator Megamodel



iObserve CoCoME

CoCoME Case Study - Generator Megamodel



iObserve CoCoME

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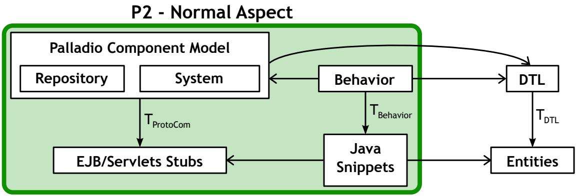

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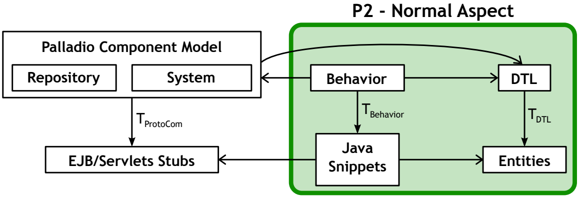
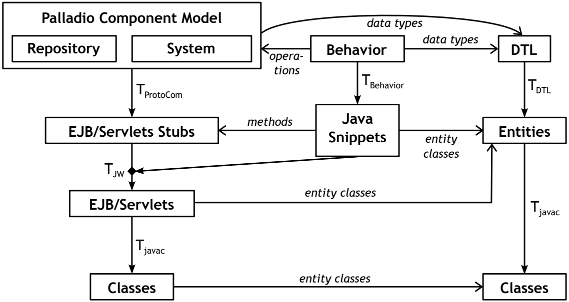


CoCoME Case Study - Generator Megamodel



iObserve CoCoME

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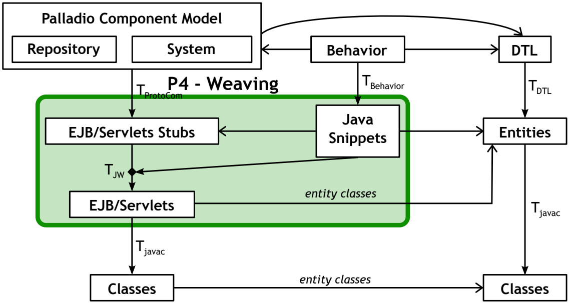

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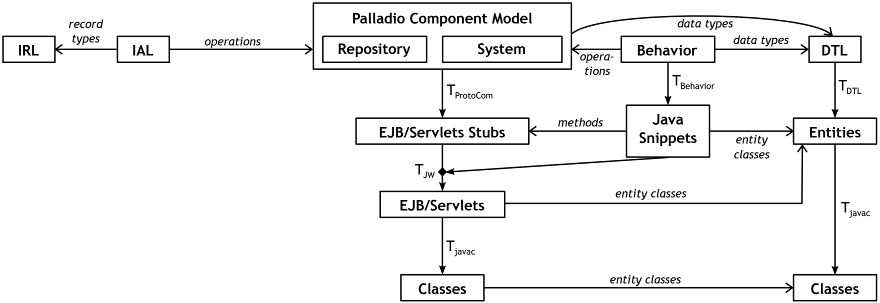

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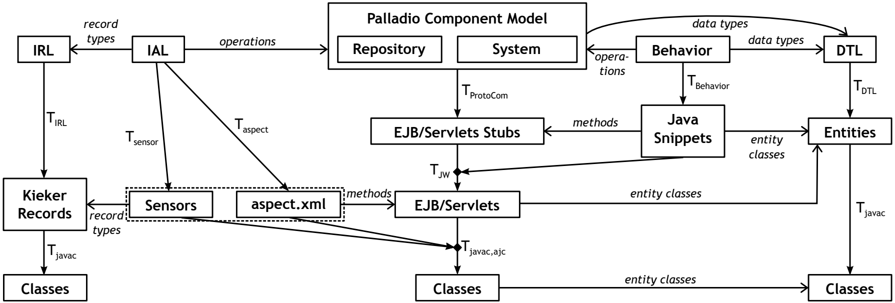

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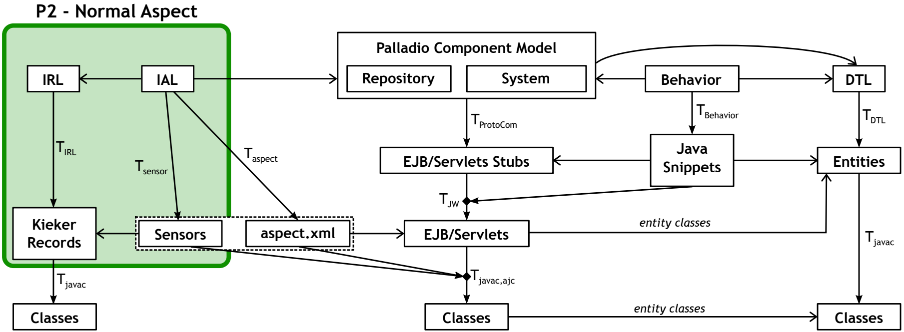

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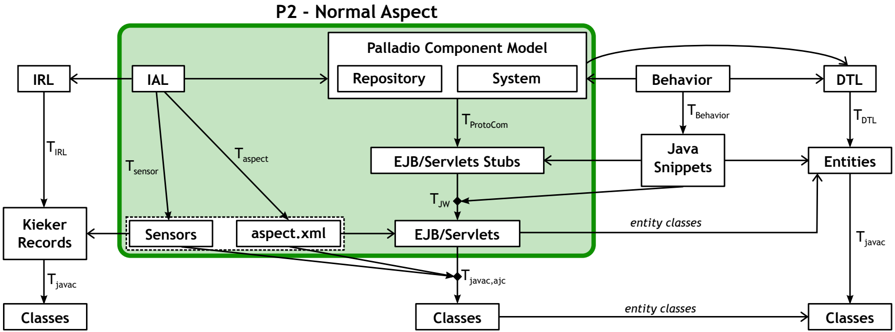
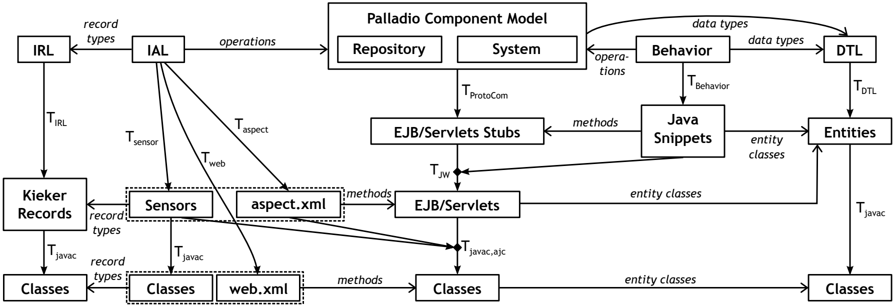


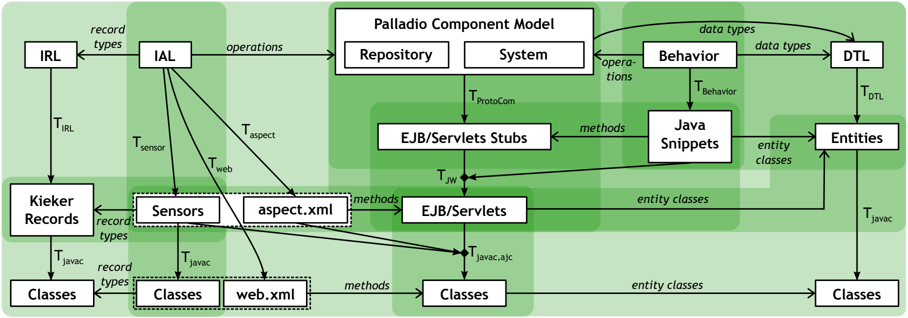
iObserve CoCoME

CoCoME Case Study - Generator Megamodel



iObserve CoCoME

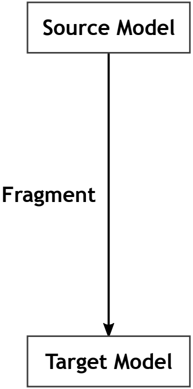
CoCoME Case Study - Generator Megamodel



7 **P2 - Normal Aspect**
2 **P4 - Weaving**

Internal Structure of Generator Fragments

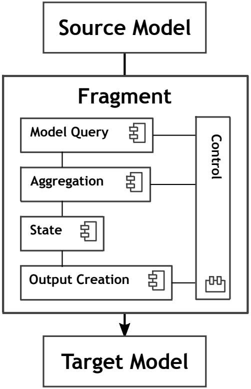
Technical Dimension



Semantic Dimension

Internal Structure of Generator Fragments

Technical Dimension



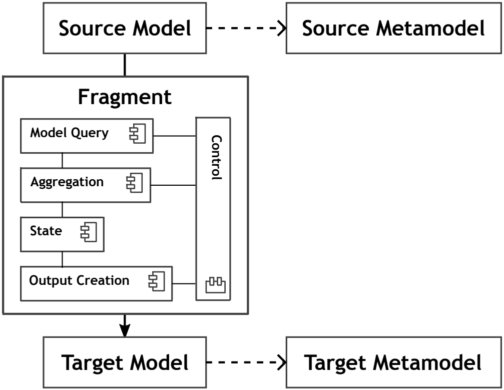
(Mens et al. 2006; Biehl 2010)

Semantic Dimension

Internal Structure of Generator Fragments

Technical Dimension

Semantic Dimension

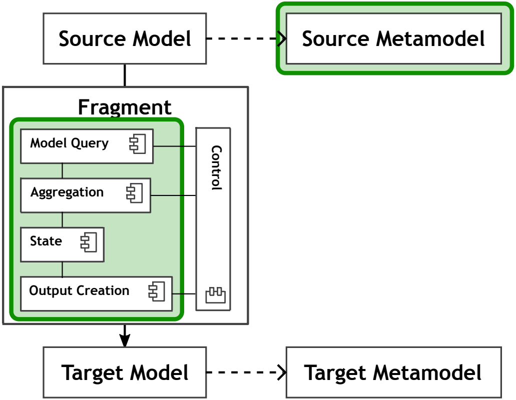


(Mens et al. 2006; Biehl 2010)

Internal Structure of Generator Fragments

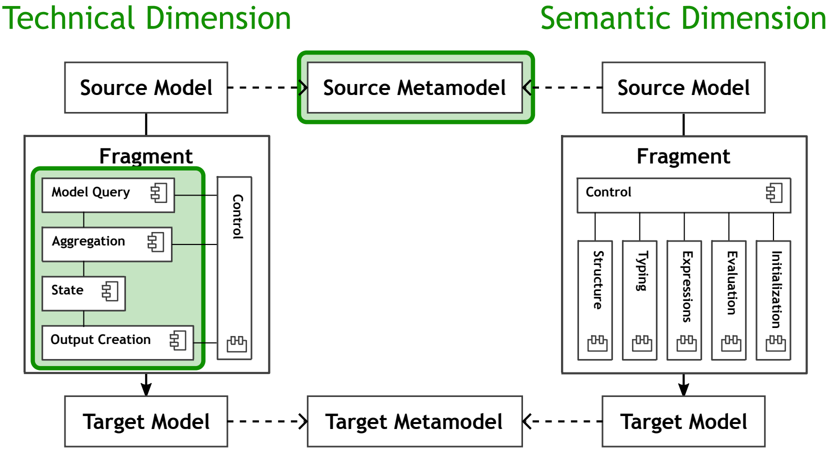
Technical Dimension

Semantic Dimension



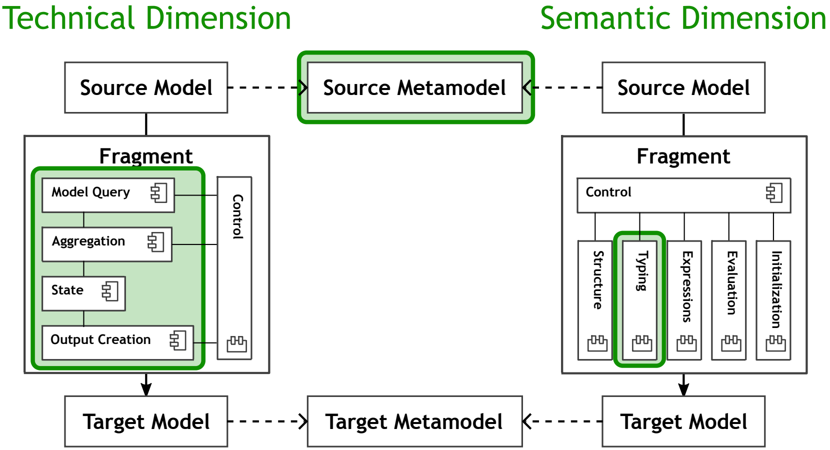
(Mens et al. 2006; Biehl 2010)

Internal Structure of Generator Fragments



(Mens et al. 2006; Biehl 2010)

Internal Structure of Generator Fragments



(Mens et al. 2006; Biehl 2010)

Evaluation

Evaluation Design

Qualitative Evaluation with two case studies (based on GQM)

Evaluate the effect of **GECO** on

- Goal G1 the utility and program quality
- Goal G2 the evolvability
- Goal G3 the reusability

Questions

Utility and program quality (ISO91; ISO11)

- **effort** spent on the development of features
- **modularity** of different generator implementations
- **understandability** of the implementations

Evolvability (Rowe et al. 1998; Koziolek 2011)

- Change in **modularity** during the evolution
- Change in **understandability** during the evolution
- Effects on the **changeability** during evolution
- Change in **stability** during evolution

Reusability (ISO91; ISO11)

- **modifiability** of the generator implementations
- **modularity** of the generator implementations
- **generality** of the generator implementations

Questions

Utility and program quality (ISO91; ISO11)

- **modularity** of different generator implementations

Evolvability (Rowe et al. 1998; Koziolek 2011)

- Change in **modularity** during the evolution

Reusability (ISO91; ISO11)

- **modularity** of the generator implementations

Metrics

Modularity

(Allen 2002; Allen et al. 2007)

- Low **complexity** of the system
- Low **coupling** of modules of a system
- High inner module **cohesion** of a system

CoCoME Case Study

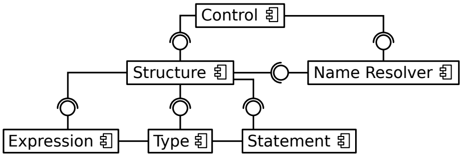
Common Component Modeling Example (Heinrich et al. 2015)

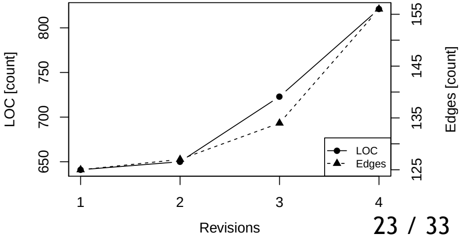
- **Domain**: Information system
- **Source**: PCM, data type, behavior and monitoring DSLs
- **Target**: Java EE and AspectJ
- **Evaluation**: Combination of existing and new generators
  - ProtoCom (Giacinto et al. 2013)
  - Data types, behavior and monitoring (Jung et al. 2013)
- **Evolution steps** ($F_{Behavior}$): 4

➨ Test **GECO**'s feasibility for generator construction

CoCoME Case Study – Behavior Evolution

Behavior Generator

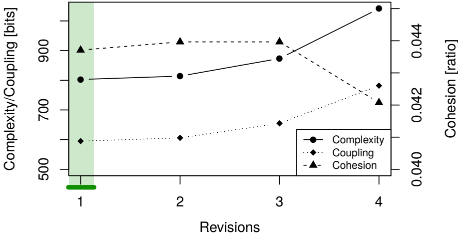


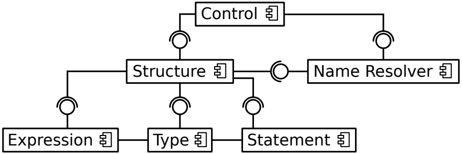


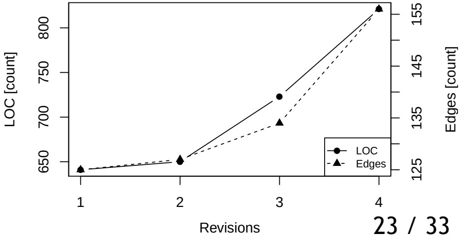
CoCoME Case Study – Behavior Evolution

Behavior Generator

1. Basic functionality



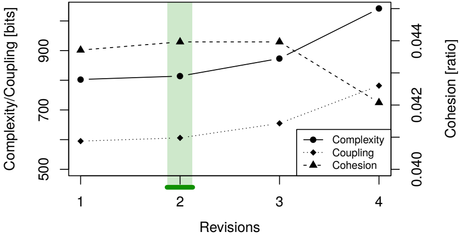


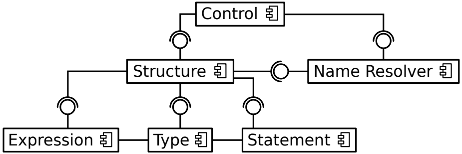


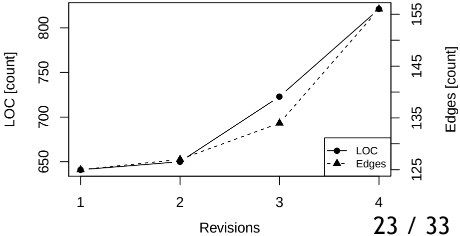
CoCoME Case Study – Behavior Evolution

Behavior Generator

1. Basic functionality
2. Stateless/-full components



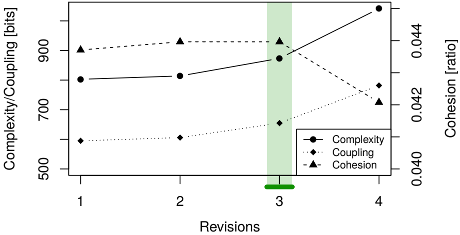


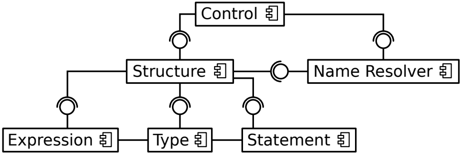


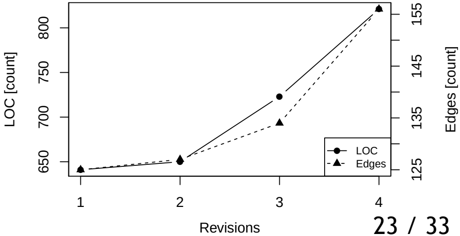
CoCoME Case Study – Behavior Evolution

Behavior Generator

1. Basic functionality
2. Stateless/-full components
3. Java EE lifecycle functions



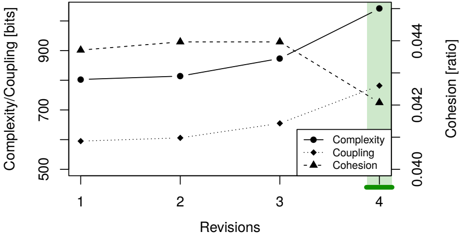


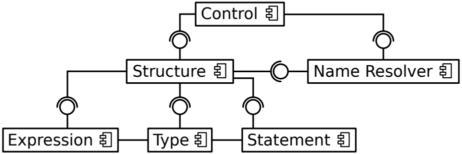


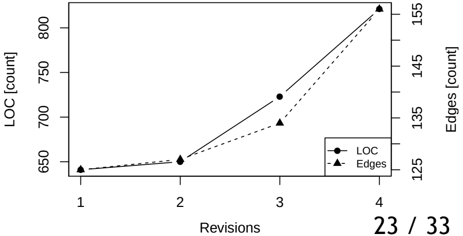
CoCoME Case Study – Behavior Evolution

Behavior Generator

1. Basic functionality
2. Stateless/-full components
3. Java EE lifecycle functions
4. Persistence support







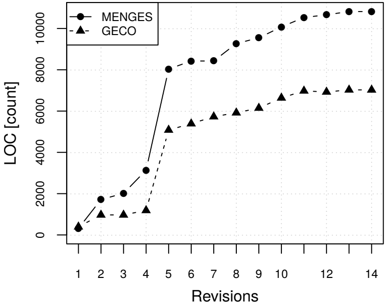
MENGES Case Study

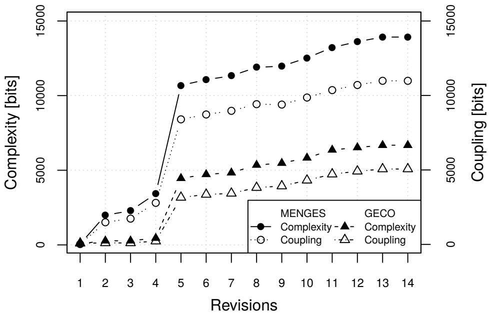
New Generator for MENGES (Goerigk et al. 2012)

- **Domain**: Embedded system for railway control centers
- **Source**: Nine DSLs covering different aspects and views
- **Target**: Single output model in PLCOpenXML for IEC61131-3 (IEC03)
- **Evaluation**: Comparison of generator implementations
  - Original MENGES generator
  - GECO-based generator
- **Evolution steps**: 14

➨ Test evolution effects of using **GECO**

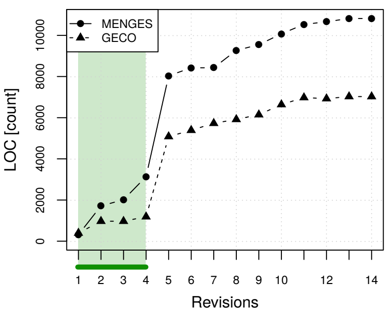
MENGES Case Study – Generator Comparison

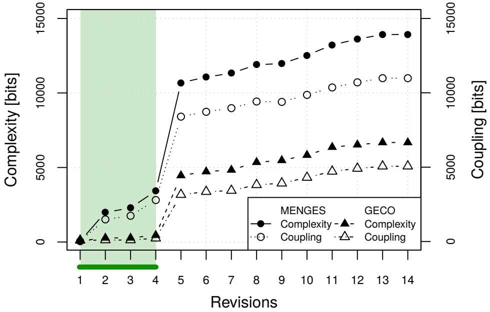




MENGES Case Study – Generator Comparison

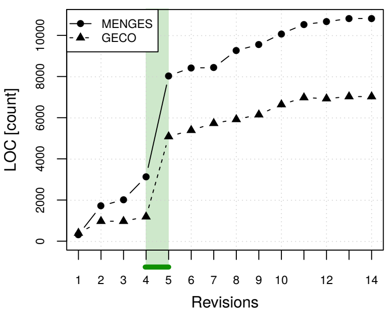
Structure and Typing

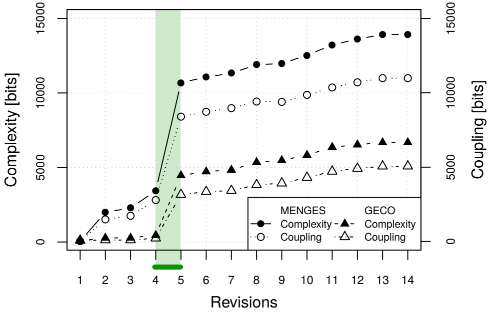




MENGES Case Study – Generator Comparison

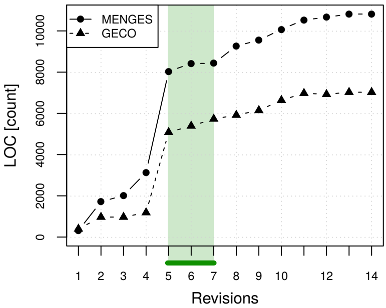
Expressions and Statements

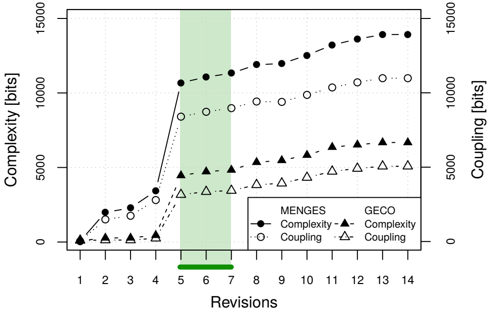




MENGES Case Study – Generator Comparison

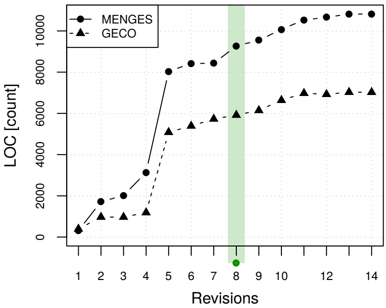
Refactoring and Communications

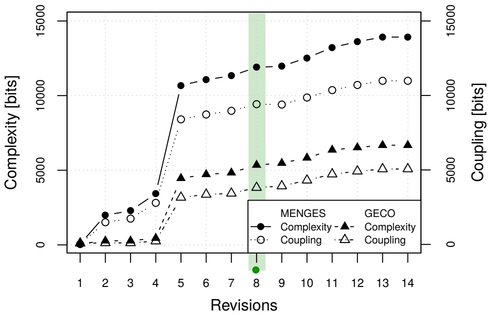




MENGES Case Study – Generator Comparison

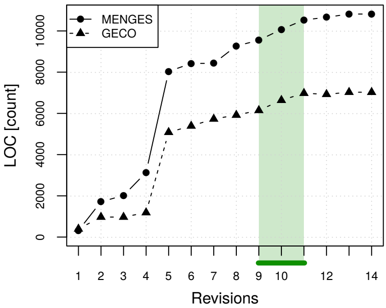
Improvment of Polymorphism

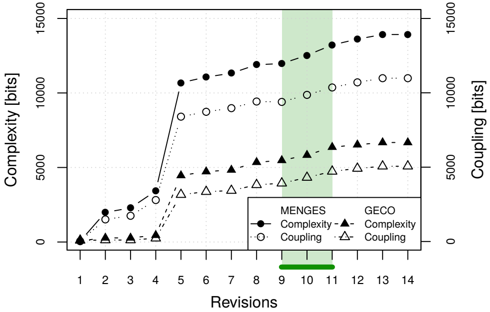




MENGES Case Study – Generator Comparison

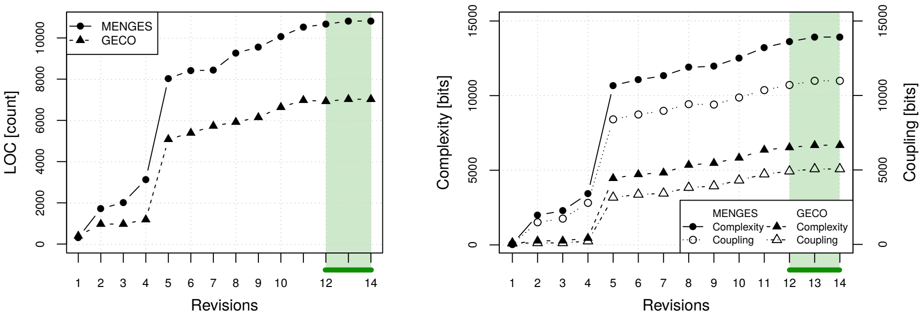
Timers and Template Improvements





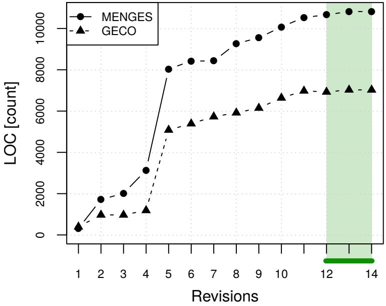
MENGES Case Study – Generator Comparison

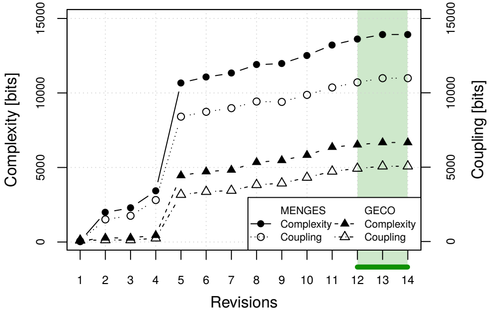
Maintenance



MENGES Case Study – Generator Comparison

Maintenance





	MENGES	GECO	Ratio
Lines of code	10816	7025	1.5396
Complexity	13921.88	6675.88	2.0854
Coupling	10983.81	5060.83	2.1704

Related Work

Modeling and Code Generation

Aspect-oriented and view-based modeling

- Reusable aspect models (RAM) (Klein et al. 2007)
- Orthographic software modeling (OSM) (Atkinson et al. 2010)

Aspect-oriented code generation (Mehmood et al. 2013)

- Theme/UML (Clarke et al. 2005)
- FDAF (Bennett et al. 2010)
- RAM-based (Kienzle et al. 2009; Kramer et al. 2011)

Transformation Modularization

Reuse and product lines

- Template-based transformations (Kapova et al. 2010)
- Genesys approach (Jörges 2013)

Modularization

- Genericity for model management operations (Wimmer et al. 2011)
- Factorization and composition of transformation (Sánchez Cuadrado et al. 2008)
- Chaining of transformations (Vanhooff et al. 2006)
- Localized transformations (Etien et al. 2015)

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- **Localized transformations** (Etien et al. 2015)

Conclusion

Contributions

Approach

- Generator composition megamodel patterns
- Internal modularization of generator fragments

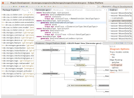
Replication Package

- Sources and datasets
  http://dx.doi.org/10.5281/zenodo.46552
- Software snapshots
  http://dx.doi.org/10.5281/zenodo.47129
- MENGES sources can be accessed via *b+m informatik AG*

Contributions

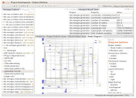
Generator framework and composition tooling

https://github.com/rju/geco-composition-language.git



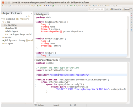
Architecture analysis tool

https://github.com/rju/architecture-evaluation-tool.git



Generators used in CoCoME case study

https://github.com/research-iobserve/



Future Work

Evaluation

- **GECO** used for modernization, e.g., ProtoCom
- Evaluating technology impact on megamodel patterns

Tool Development

- Integration of **GECO** generators in build systems
- Instrumentation aspect and record language
  - IAL integration in Kieker
  - IRL evolution, e.g., trace support

Summary

GECO Approach http://www.oiloftrop.de/geco-approach/

- Generator composition megamodel patterns
- Internal modularization of generator fragments

Replication Package

- Sources and datasets
  http://dx.doi.org/10.5281/zenodo.46552
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- MENGES sources can be accessed via *b+m informatik AG*

Resources https://github.com/

- Framework and tool rju/geco-composition-language.git
- Architecture analysis rju/architecture-evaluation-tool.git
- CoCoME DSLs research-iobserve
- Monitoring DSLs kieker-monitoring/instrumentation-languages

References

Bibliography I

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Foundations

Metamodel Partitioning

Identifying Metamodel Partitions

Metamodel Partitioning

Identifying Metamodel Partitions

1. Find all root classes $R \subseteq N_T$

$$R = \{\forall n_t \in N_T | \forall e_T \in E_T, ((e_t, n_T) \in s_T \wedge (e_T, n_T) \in t_T) \vee (e_T, n_T) \notin t_T\}$$

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2. Form parts for all $r_i \in R$: $P_i = contains_{TG}(r_i) \cup \{r_i\}$
3. Detect overlapping parts O_k with $n = |R|$

$$O = \{P_i \cap P_j | \forall i, j \in [1 \ldots n] \wedge i \neq j \wedge P_i \cap P_j \neq \emptyset\}$$

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$$\forall i \in [1 \ldots n] \;\; P_i^{'} = P_i \cap (\bigcup_{j=0}^{m} O_k)$$

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5. Remove identified partitions $P_i^{'}$ from graph
6. Reiterate process with remaining graph

Model Traceability

Model Traces

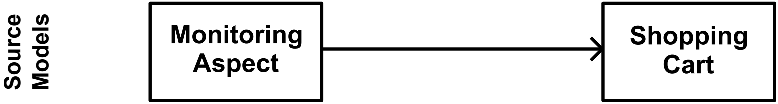
Model traces are a set of source and target nodes with a relation between them. (Aizenbud-Reshef et al. 2005)

Approaches (Galvão et al. 2007)

- Constructive
  - TraceAddr adds trace model support to ATL (Jouault 2005)
- Reconstructive
  - Heuristic (Grammel et al. 2010; Saada et al. 2013)
  - Probabilistic (Antoniol et al. 2002)
  - Property matching

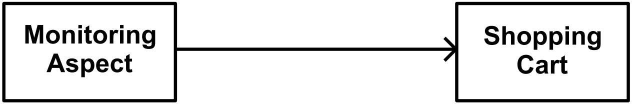
Approach

Join-Point Computation



Join-Point Computation

Source Models



Target Models

```
call(void init (...)) ||
call(void service(...))
```

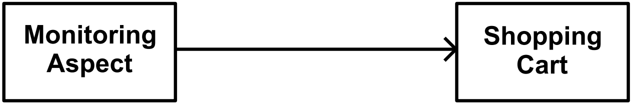
AspectJ Pointcuts

```
class Cart extends HTTPServlet {
      public void init (...) {
            ...
      }
      public void service (...) {
            ...
      }
      ...
}
```

Java Servlet

Join-Point Computation

Source Models



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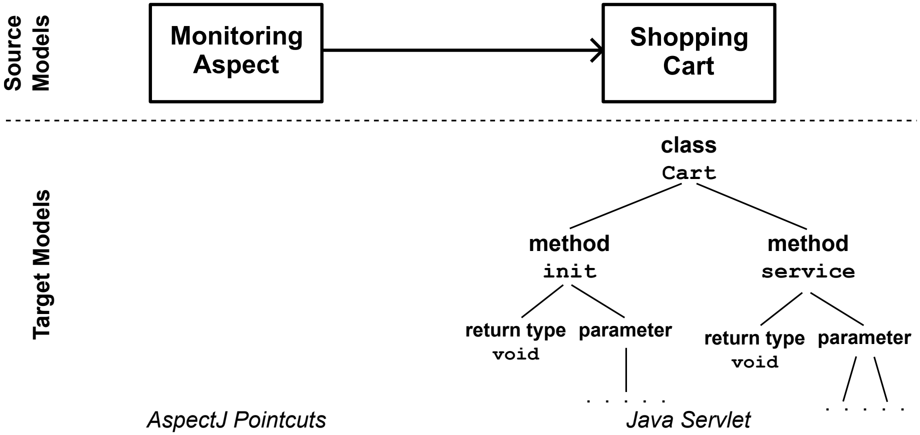

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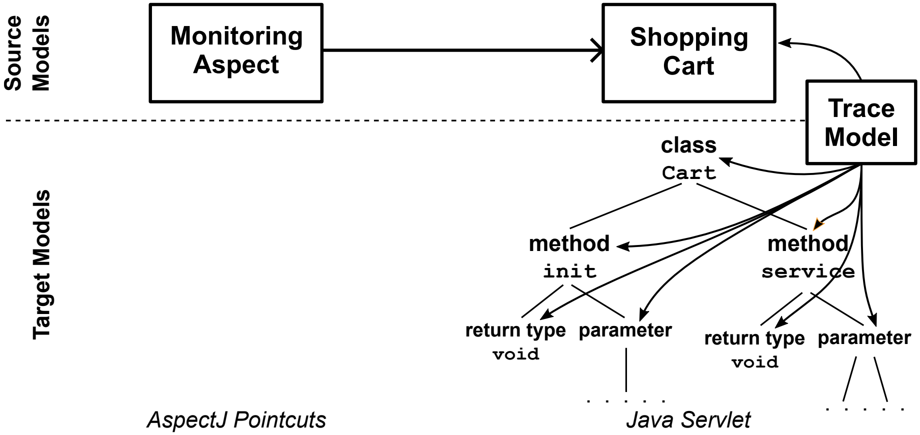

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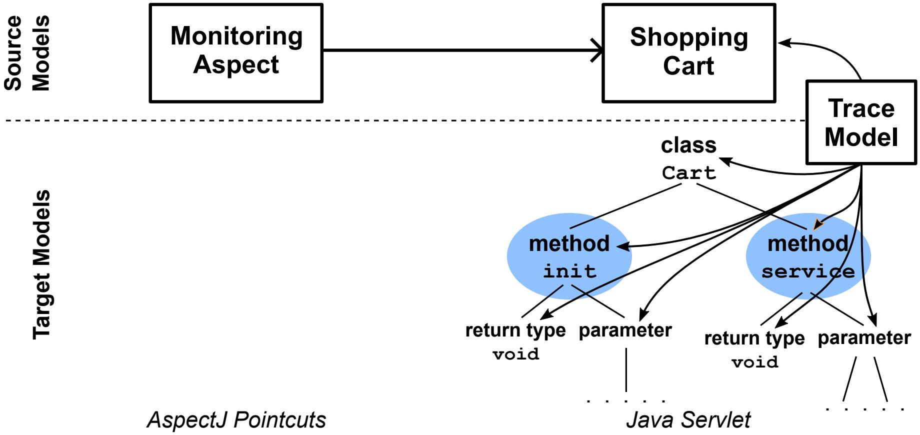

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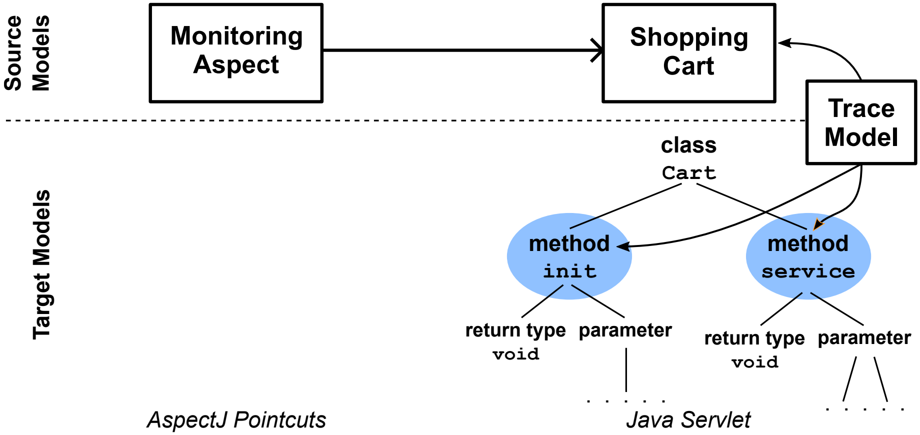
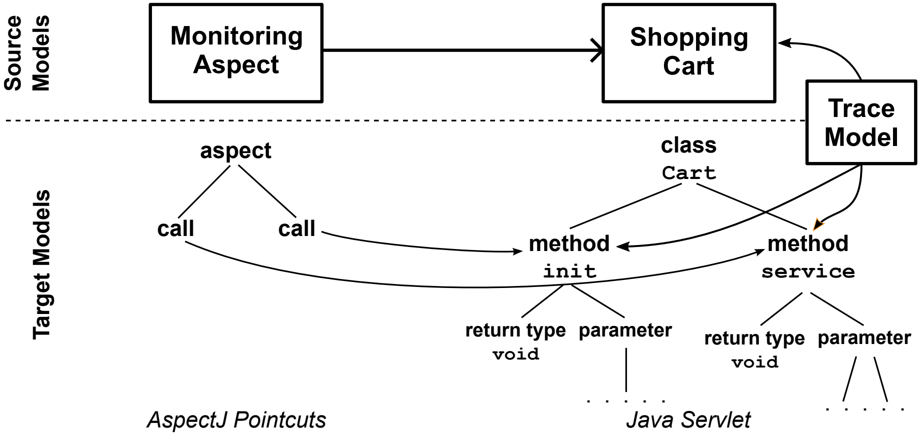


Join-Point Computation



Evaluation

Interviews

Results

- Reuse not applied by practitioners
- **GECO** patterns and modularization
  - Supportive for generator development
  - Applicable to own generator development/evolution

Industry

- Interviewees 17
- Experience range first year to senior engineer
- Agile/iterative development
- Evolution induced by customers and framework evolution

Research

- Interviewees 6
- PhD candidates and postdoc researchers
- Agile/iterative development, limited maintenance
- Evolution induced by personal/project needs

Metrics

Effort developer days per feature

Modularity (Allen 2002; Allen et al. 2007)

- Low **complexity** of the system
- Low **coupling** of modules of a system
- High inner module **cohesion** of a system

Understandability inverse of **complexity** (Laitinen 1996)

Changeability (ISO11)

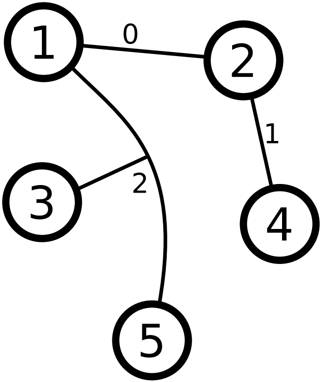
- Low **coupling** of modules of a system
- High inner module **cohesion** of a system

Stability of the code base (ISO11)

- Low **coupling** of modules of a system

Evaluation Measure properties for each revision

Metric: Amount of Information in the System



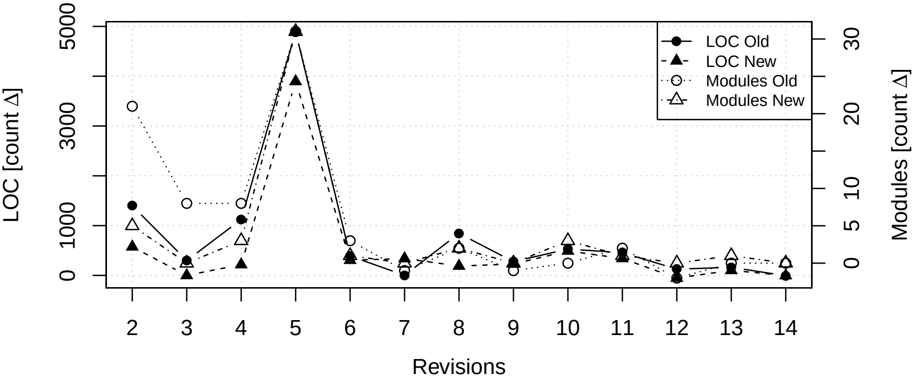
Nodes	Hyperedges	Probability $\hat{p}_l$
1	101	1/5
2	110	1/5
3,5	001	2/5
4	010	1/5

$$Size(\mathbf{S}) = \sum_{i=1}^{n} (-\log_2 \hat{p}_{L(i)})$$

$$Size(S) = 3 * 2.322 + 2 * 1.322 = 9.610 bit$$

Metric by Edward B. Allen Allen et al. 2007

MENGES LOC and Modules



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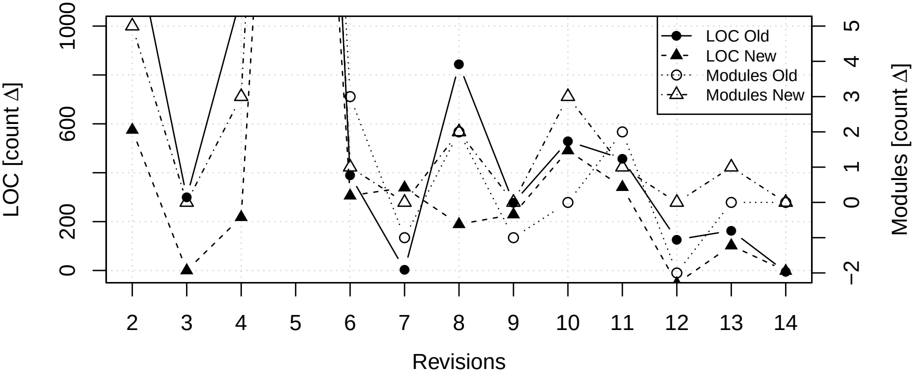
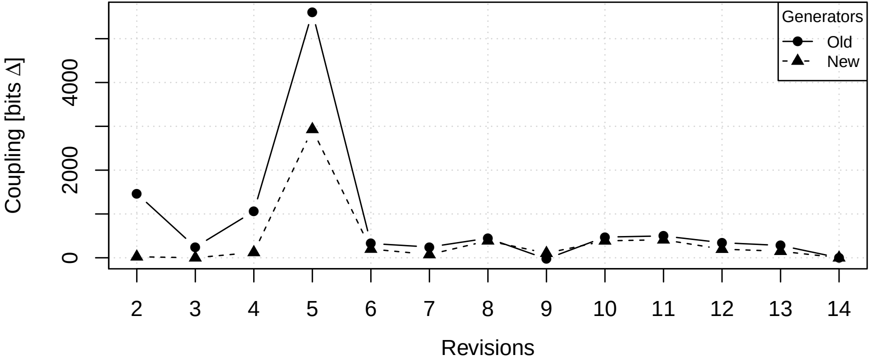
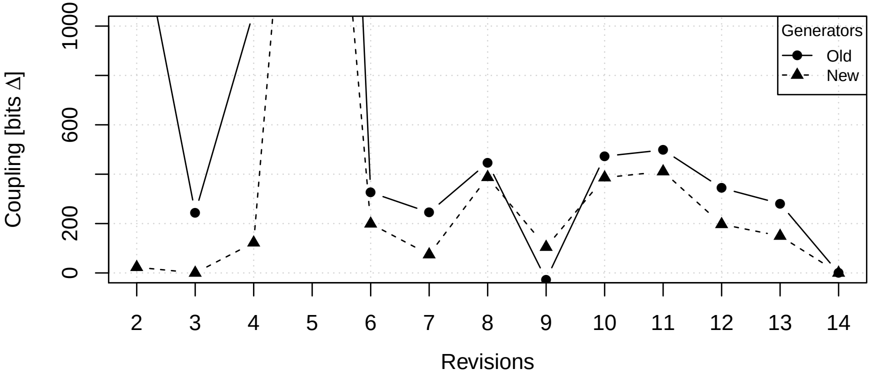


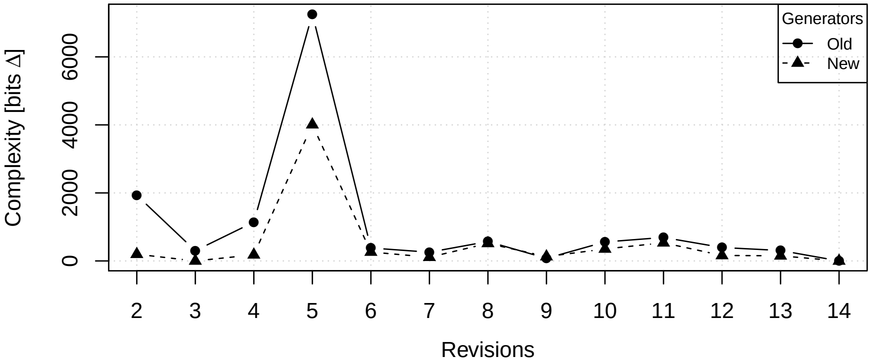
MENGES Coupling Delta



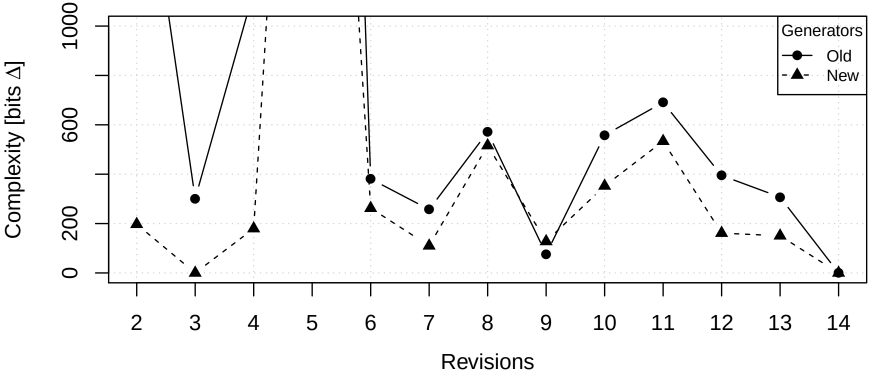
MENGES Coupling Delta



MENGES Complexity Delta



MENGES Complexity Delta



Tooling

Architecture Analysis Tool

Java Graph Mapping

- Modules represent classes
- Nodes represent methods
- Edges represent
  - method calls
  - access to class features
- Java interfaces (modules)
- Framework classes (only when used)
- Ignore data type classes

Software Complexity Analysis

`https://github.com/rju/architecture-evaluation-tool`

Instrumentation Aspect Language

```
package demo

import demo.EntryEvent
import demo.ExtendedEntryEvent
import demo.ExitEvent

use pcm on cocome "irl-examples/src/cocome.repository"

advice EntryLogger () {
	before EntryEvent(time, $signature) ExtendedEntryEvent(time, $signature, $classname)
	after ExitEvent(time, $signature)
}

pointcut point class cocome.TradingSystem.Inventory.Data.Persistence

pointcut complex class cocome.TradingSystem.Inventory {
	Data.**
	exclude Data.Persistence.**
}

aspect point : EntryLogger

aspect complex : EntryLogger
```

Instrumentation Record Language

```
package demo

@author 'Reiner Jung' @since '1.5'
entity ArrayExample {
	int [10] staticArray
	int [] dynamicArray
	int [10][5][][9] mixed
	string [][][6] stringMixed
}

template Event {
	long timestamp
}

template OperationSignature {
	string signature
}

entity EntryEvent : Event, OperationSignature
entity ExitEvent : Event, OperationSignature

entity ExtendedEntryEvent extends ExitEvent {
	string classSig
}
```