University of Stuttgart
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Language Composition Operators

A Literature Review

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Motivation

Uncovering the current state of language composition

- Efficiently engineering software languages demands their reuse through composition
- Composition operators emerged acting on different
  - constituents of languages,
  - technological spaces,
  - and purposes.
- Ten years ago, Erdweg et. al. classified language composition into 5 categories.
- Innovations in software language engineering question the validity of these categories

→ Uncovering the current state of language composition and drawing a detailed map of language composition operators to guide SLE researchers and practitioners

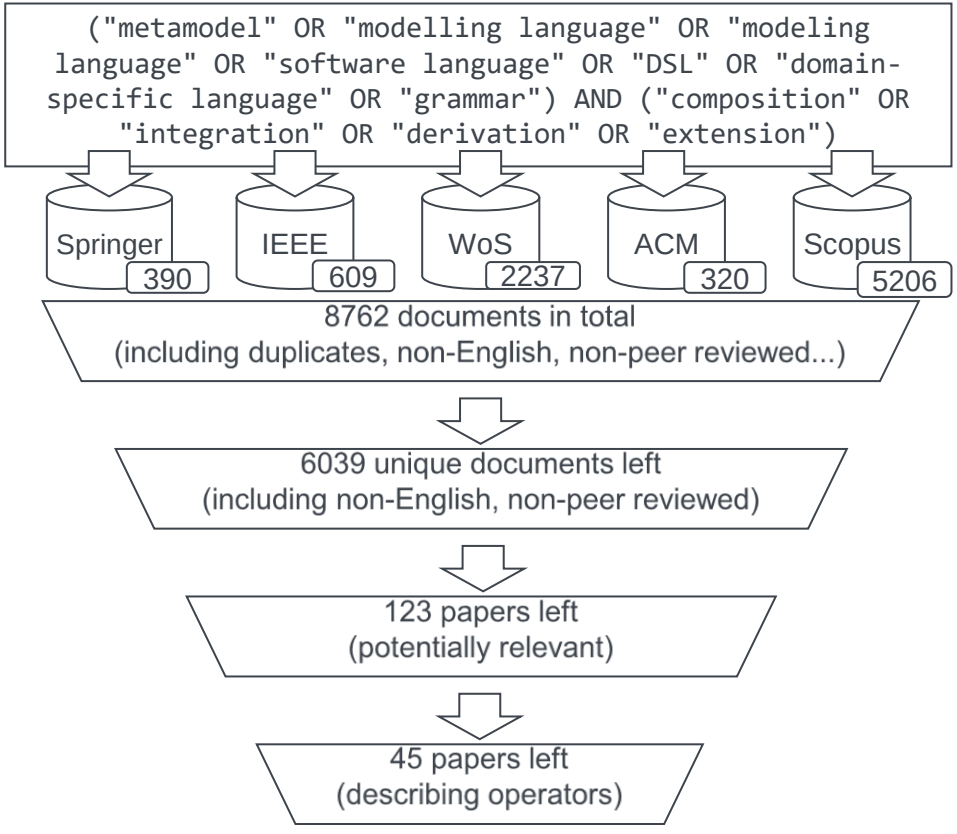
Language Composition Untangled [1]

Classifying composition operators for software languages

- Language Extension:
  - Extend a base language definition with rules.
  - Example: Adding rules to an inherited grammar
- Language Restriction:
  - Language extension restricts the language.
  - Example: Use context condition to prevent usage of certain modeling elements.
- Language Unification:
  - Composition on equal terms, i.e., without direction, using glue code.
  - Example: Names on transitions of statecharts refer to names of properties in a classdiagram
- Self-extension:
  - Embedding of languages into a host language by providing a host language model that encapsulates the embedded language's concept
  - Example: A class library in a GPL
- Extension Composition:
  - Language extensions can work together

Research Method

Conducting a systematic literature review on software language composition



- Classified the studies along the classification of LCU
- Developed a questionnaire for detailed analyses and comparability of extracted information
- Classified the first 20 studies in parallel among authors to avoid misunderstandings

Research Question 1

Which language composition operators exist?

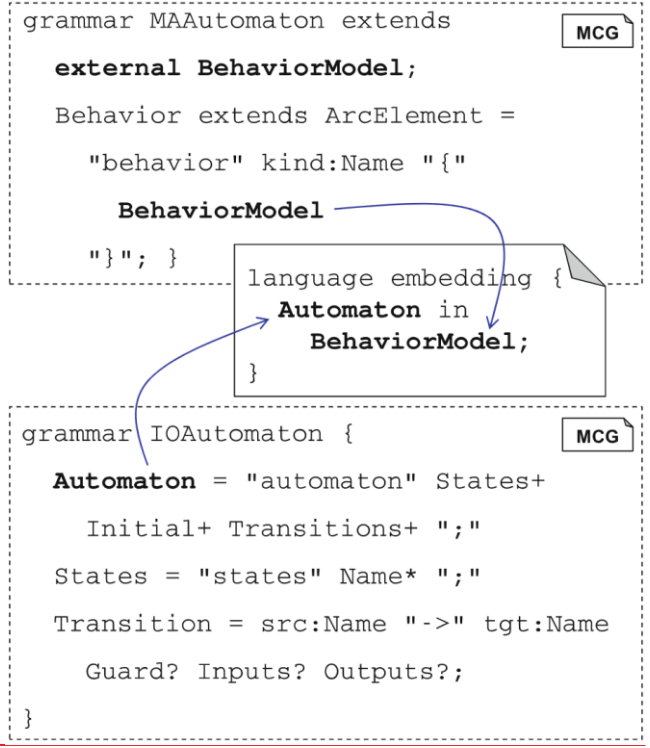
Which language composition operators exist?

Operators on Syntax

Grammar Embedding [14,22,25,32]

Language extension operator on syntax

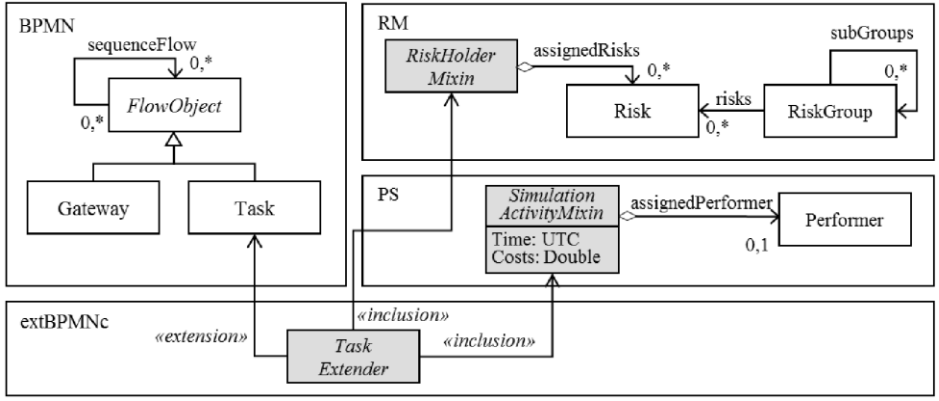
- Parameters: A production of a base grammar and a production of a client grammar
- Result: A new grammar in which the production of the base grammar is extended with an alternative containing the client grammar's production
- Effect on language instances (models): Models of the new grammar may use base and client grammar production instances in the same model.
- Additional: Explicit extensions (e.g., keyword `interface` in MontiCore)
- Technological space: MontiCore, SugarJ



Metamodel Mixins [71]

Language extension operator on syntax

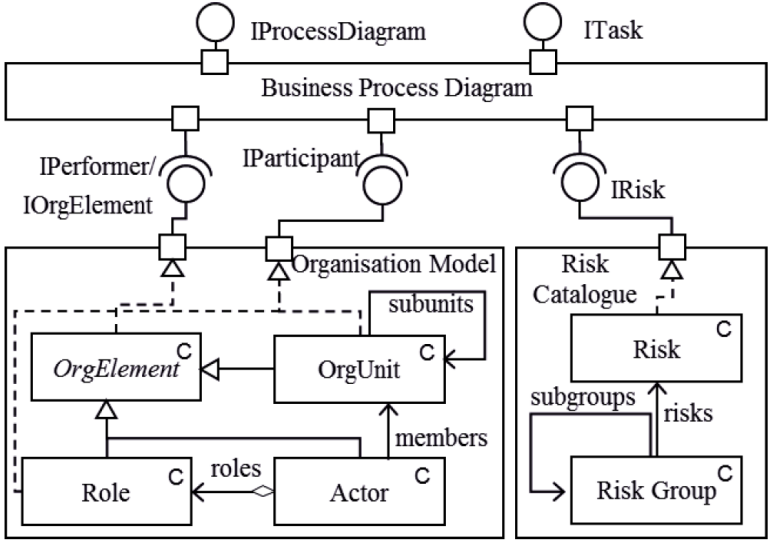
- Parameters: A parent metamodel, a mixin metamodel (abstract), concepts of the mixin metamodel that should be added to the parent metamodel
- Result: A metamodel featuring concepts from the parent metamodel including the mixin element
- Additional: The result of a mixin cannot be used as a mixin element
- Technological space: ADOxx



Metamodel Fragment Composition [70]

Language extension operator on syntax

- Metamodel Fragment is a container for a metamodel exposing provided and required interfaces
  - Provided interface exposes metaclasses
  - Required interface demands implementation by another metamodel fragment
- Parameter: Mapping of client's provided interface class to base fragment's required interface
- Result: Extended metamodel with realized required interface
- Technological space: n.a.



Annotation-Based Language Unification [53]

Language unification operator on syntax

- Parameters: Two textual syntax definition
- Result: Unified syntax by using annotations in the base language realizing concepts of the client language
- Base language must support annotations
- Technological space: n.a.

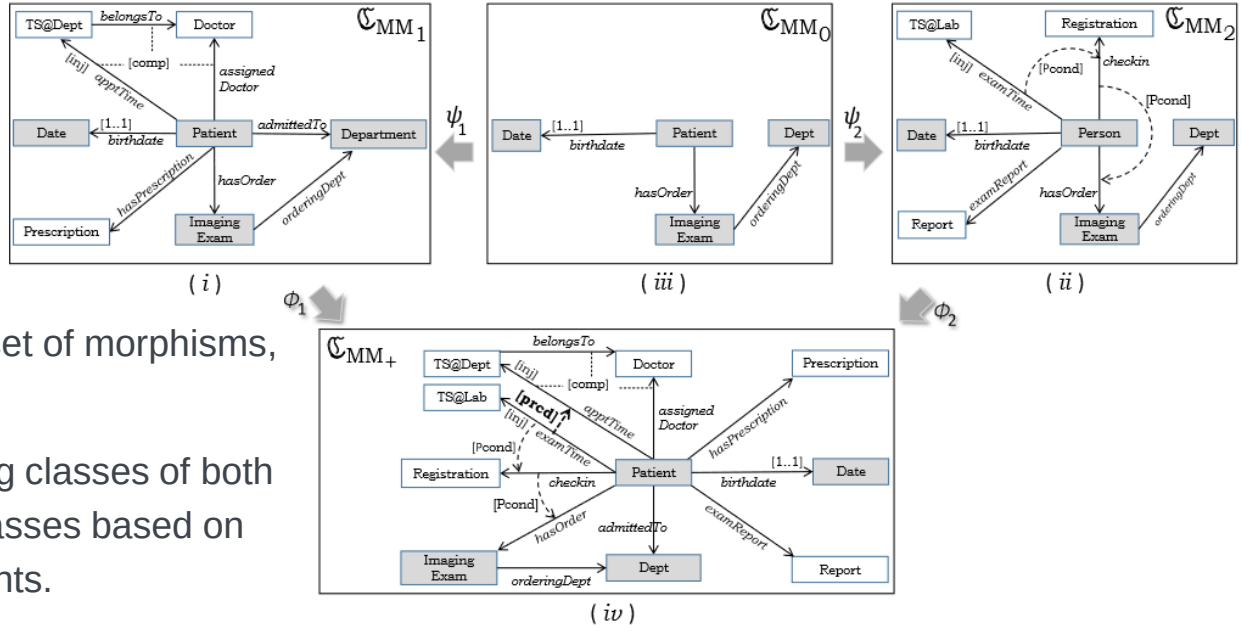
```
public class Person {
  private int id; //…
}
```

```
<entity class="model.Person" name="Person">
<table name="PERSON"/>
<attributes>
 <id name="id">
  <column name="IDENTIFIER"/>
 </id>
...
</entity>
```

```
@Entity(name = "Person")
@Table(name = "PERSON")
public class Person {
@Id
@Column(name = "IDENTIFIER")
private int id;
//…
}
```

Metamodel Merging [51,56]

Language unification operator on syntax



- Parameters: Two metamodels, set of morphisms, set of constraints
- Result: One metamodel featuring classes of both metamodel including merged classes based on name similarity fulfilling constraints.
- Technological space: n.a.

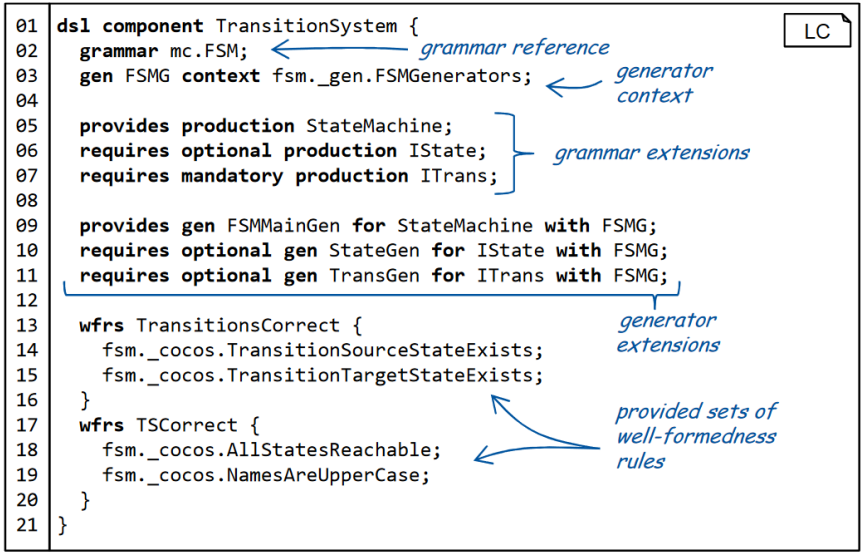
Which language composition operators exist?

Operators on Syntax and Semantics

Language Component Embedding [12, 15]

Language extension operator on syntax and semantics

- Language Component:
  - Comprises a grammar, well-formedness rules and a code generator
  - The interface consists of provided and required extensions making constituents explicit
- Parameters: Required interface point of a base language component, provided interface point of a client language component
- Result: A new language component and a new language embedding client provided extensions into base languages required extensions
- Technological space: MontiCore



Object-Oriented Language Unification [50]

Language unification operator on syntax´and semantics

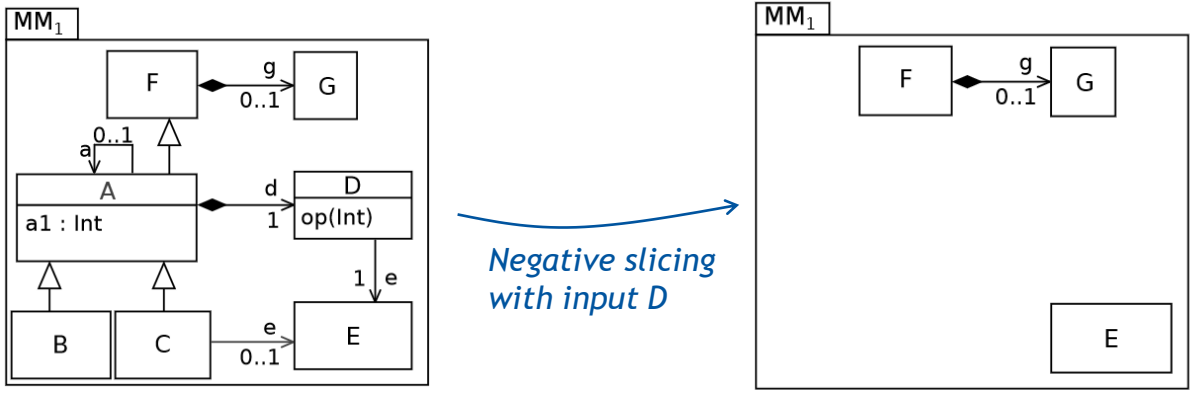
- Language module description
  - comprises definitions of CS, AS and computation rules (e.g. for semantics)
  - Computation rules are unambiguously related to a single AS element
- Parameters: Two language modules, a set of glue rules overriding rules of the input languages
- Result: A new language module extending from both modules and comprising overriding rules.
- Technological space: LISA

```
1   language RobotUnificationExprAdd extends Robot, ExprAdd {
2     rule extends start {
3       compute {}
4     }
5     rule overrides command {
6       COMMAND ::= left EXPR compute {
7         COMMAND.outx = COMMAND.inx – EXPR.val;
8         COMMAND.outy = COMMAND.iny; };
9       COMMAND ::= right EXPR compute {
10        COMMAND.outx = COMMAND.inx + EXPR.val;
11        COMMAND.outy = COMMAND.iny; };
12      COMMAND ::= up EXPR compute {
13        COMMAND.outx = COMMAND.inx;
14        COMMAND.outy = COMMAND.iny + EXPR.val; };
15      COMMAND ::= down EXPR compute {
16        COMMAND.outx = COMMAND.inx;
17        COMMAND.outy = COMMAND.iny – EXPR.val; };
18    }
19  }
```

Language Slicing [21]

Language restriction operator on syntax and semantics

- Parameters: Metamodel, elements to slice
- Result: New metamodel without the sliced elements
- Technological space: GEMOC / Melange

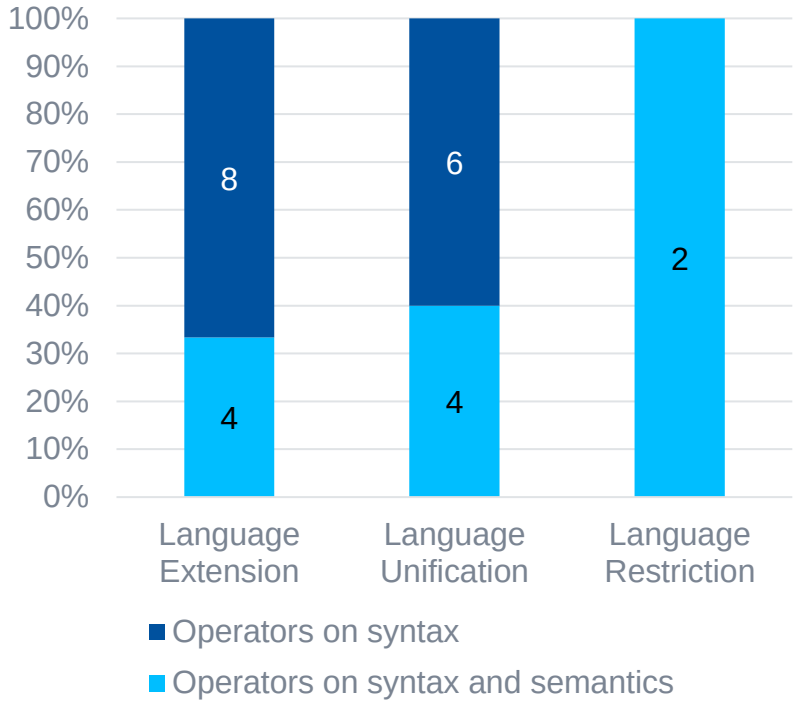


Research Question 2

Which language definition dimensions are supported?

Language Constituents Supported by Composition Operators

- 10/24 (41.6%) operators support composition of syntax **and** semantics
- Syntax mainly defined in grammars and metamodels
- Semantics realized via code generators, internal and external interpreters, and aspects
- No operators composing
  - Grammars and metamodels
  - Semantics in different realizations



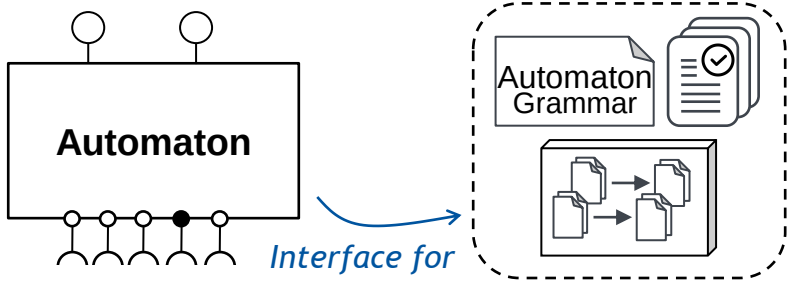
Research Question 3

Which properties do language composition operators have?

Blackbox Language Composition Operators

How much knowledge about language internals is necessary for composition?

- Language Component Embedding [12,15] and Unification [55]
  - Language components representing language fragments including syntax and semantics
  - Provided and required extensions expose the language's concepts
  - Composition via mapping between interfaces enables black-box language composition
- Metamodel Fragment Composition [70]
  - Fragments encapsulate metamodels
  - Expose metamodel elements via provided and required interfaces
  - Composition by binding interfaces



Traceability and Modularity of Composition

The original languages stay independent origins after composition

Modular

- Grammar Embedding [14, 22, 25, 32]:
  - Creates a new grammar where the base production is extended with the client production as an alternative
  - The original grammars are referenced in the resulting grammar
  - No information is lost

Non-modular

- Metamodel Merging [51, 56]:
  - Merges two metamodels into one
  - After the composition the concept's origins are not visible in the result anymore
- Metamodel Mixins [71]:
  - Takes a metamodel and a mixin model as input
  - Creates a new metamodel comprising metamodel classes and mixin classes
  - It is not clear which concepts origin from mixin

Closed Under Composition

Can the result of composition again be used as input for the operator?

- Metamodel Mixins [71]
  - Parameters: metamodel, mixin element
  - The resulting metamodel is not usable as mixin
- Language Union [18]
  - Merge new rules into an existing language
  - Rules do not need to be part of another language
  - Resulting language definition cannot be merged into an existing language
- Language Module Restriction [18, 63]
  - Extend a language without inheriting concepts
  - E.g., selecting concepts not to be reused

Challenges

Our observations lead to challenges for future investigations

1 Heterogeneous composition

- Composing languages across different technological spaces
- E.g., embedding a Neverlang language into a Xtext language

2 Black-box composition

- Hiding implementation details of languages
- Only three operators supported currently

3 Automated composition

- Minimizing the manual effort and white-box knowledge after the composition
- Relevant for black-box approaches

4 Alignment of operators

- Do we need this many composition operators?
- How similar are the operators?
- Which are the ones most frequently used?

Summary

- **Motivation:** Uncovering the current state of language composition ten years after the classification of “Language Composition Untangled”

- **Research Questions:**
  1. Which composition operators exist?
  2. Which language dimension are supported?
  3. Which properties do the operators have?

→ 8762 papers in initial search → 45 relevant

- **Results:**
  - We found 24 operators
    - Extension of syntax (8) and semantics (4)
    - Unification of syntax (6) and semantics (4)
    - Restriction on syntax and semantics (2)
  - 2/3 of the operators are technology-specific

a) Black-box

b) Traceability and modularity

c) Closed under composition

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