Data Validation Constraints in MDE

Alessandro Rossini\textsuperscript{1}, Adrian Rutle\textsuperscript{2}, Federico Mancini\textsuperscript{1}, Dag Hovland\textsuperscript{1}, Khalid A. Mughal\textsuperscript{1}, Yngve Lamo\textsuperscript{2}, Uwe Wolter\textsuperscript{1}

\textsuperscript{1}\textsuperscript{1}Department of Informatics, University of Bergen, Norway

\textsuperscript{2}\textsuperscript{2}Faculty of Engineering, Bergen University College, Norway

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Outline

1. Introduction and Motivation
   - Security
   - MDE

2. Diagram Predicate Framework (DPF)
   - Example
   - Syntax

3. DPF and Data Validation
   - Example
   - Syntax

4. Summary and Future Work
Software Security

- Society relies on software systems
- Violating systems threaten economy, politics and health
- Software security:
  - confidentiality, integrity and availability of systems
Software Security in Software Development

- Present-day software development
  - security neglected: budget constraints and lack of skills
  - security concerns considered too late

- Ideal software development
  - security from the early phases of the development
  - potential security flaws revealed before a software system is implemented
Model-Driven Engineering (MDE)

- Software models as abstract representations of software systems
  - reasoning at a high level of abstraction
- Model-Driven Engineering (MDE)
  - models as primary artefacts of the software development process
  - generation of systems by means of model transformations
MDE Standards: State-of-the-art

- Modelling languages
  - Unified Modeling Language (UML)
  - Eclipse Modeling Framework (EMF)
  Usually graph-based languages

- Constraint languages
  - Object Constraint Language (OCL)
  Usually text-based languages
Challenge

- Specification of security constraints within software models
- Constraints for data validation:
  - process of ensuring that a system operates on correct and meaningful data
  - most common web application security weakness
Our contribution

- Specification of data validation constraints on multiple, interdependent structural features of models
  - Diagram Predicate Framework (DPF) as the formal underpinning of our approach to modelling
- Data validation constraints at the model level mapped to corresponding tests at the code level
  - SHIP Validator as a Java based framework for the validation of properties of Java objects
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Project management example

UML class diagram

Requirements

1. An employee must work for at least one department.
2. A department may have none or many employees.
Project management example

UML class diagram

Requirements

3. An employee may be enrolled in none or many projects.
4. A department may control none or many projects.
Project management example

UML class diagram

Requirements

5 An employee enrolled in a project must work in the controlling department.

6 A set of employees working for a controlling department must not be enrolled in the same controlled project more than once.
5. An employee enrolled in a project must work in the controlling department.

6. A set of employees working for a controlling department must not be enrolled in the same controlled project more than once.
Project management example

**Requirements**

5. An employee enrolled in a project must work in the controlling department.

6. A set of employees working for a controlling department must not be enrolled in the same controlled project more than once.
Proposed solution: constraints integrated
Formalisation approach

- **Diagram Predicate Framework (DPF)**
- Based on category theory and generalized sketches formalism
  - models: graphs
  - constraints: user-defined diagrammatic predicate signatures
Data Validation Constraints in MDE

Diagram Predicate Framework (DPF)

Syntax

\[ \sum_{\text{struct-specification}} \]

\[ S = (G^S, C^S) \]
Data Validation Constraints in MDE

Diagram Predicate Framework (DPF)

Syntax

\[ \Sigma_{\text{struct-specification}} \]

\[ S = (G^S, C^S) \]

\[ G^S \]
Data Validation Constraints in MDE

Diagram Predicate Framework (DPF)

Syntax

\[ \Sigma_{struct}-\text{specification} \]

\[ S = (G^S, C^S) \]

\[ \Sigma_{struct} = (\Pi, \alpha) \]

<table>
<thead>
<tr>
<th>Relation</th>
<th>( \alpha )</th>
<th>Proposed visual.</th>
<th>Intended semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>[mult(n,m)]</td>
<td>1 \xrightarrow{f} 2</td>
<td>( X \xrightarrow{f_{[n..m]}} Y )</td>
<td>( \forall x \in X : n \leq</td>
</tr>
<tr>
<td>[inverse]</td>
<td>1 \xleftarrow{g} 2</td>
<td>( X \xleftarrow{g_{[inv]}} Y )</td>
<td>( \forall x \in X, \forall y \in Y : y \in f(x) \text{ iff } x \in g(y) )</td>
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Data Validation Constraints in MDE

Diagram Predicate Framework (DPF)

Syntax

\( \Sigma_{\text{struct}-\text{specification}} \)

\( S = (G^S, C^S) \)

\( G^S \)

\( C^S \)

\[ (p, \delta) \] \[ \alpha(p) \] \[ \delta(\alpha(p)) \]

\[ ([\text{mult}(1, \infty), \delta_1]) \]

\[ 1 \xrightarrow{x} 2 \quad \text{Employee} \xrightarrow{\text{eDep}} \text{Department} \]

\[ ([\text{inverse}], \delta_2) \]

\[ 1 \underset{y}{\xrightarrow{x}} 2 \quad \text{Employee} \xrightarrow{\text{eDep}} \text{Department} \]

\[ \Sigma_{\text{struct}} = (\Pi, \alpha) \]

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<td>([\text{mult}(n, m)])</td>
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<td>( X \xrightarrow{f} [n,m] Y )</td>
<td>( \forall x \in X : n \leq</td>
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<tr>
<td>([\text{inverse}])</td>
<td>1 ( y \xrightarrow{x} 2 )</td>
<td>( X \xrightarrow{f} \text{[inv]} \text{[g]} Y )</td>
<td>( \forall x \in X ), ( \forall y \in Y : y \in f(x) \text{ iff } x \in g(y) )</td>
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### Signature $\Sigma_{struct}$

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<td>$[\text{mult}(n,m)]$</td>
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<td>$\begin{array}{c} \fbox{X} \ f \end{array}$</td>
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<tr>
<td>$[\text{injective}]$</td>
<td>$1 \xrightarrow{x} 2$</td>
<td>$\begin{array}{c} \fbox{X} \ f \end{array}$</td>
<td>$\forall x, x' \in X : f(x) = f(x')$ implies $x = x'$</td>
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<tr>
<td>$[\text{surjective}]$</td>
<td>$1 \xrightarrow{x} 2$</td>
<td>$\begin{array}{c} \fbox{X} \ f \end{array}$</td>
<td>$f(X) = Y$</td>
</tr>
<tr>
<td>$[\text{jointly-injective}]^3$</td>
<td>$1 \xrightarrow{x} 2$</td>
<td>$\begin{array}{c} \fbox{X} \ \text{[ji]}^3 \ f \end{array}$</td>
<td>$\forall x, x' \in X : f(x) = f(x')$ and $g(x) = g(x')$ and $h(x) = h(x')$ implies $x = x'$</td>
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<td>$[\text{subset}]$</td>
<td>$1 \xrightarrow{x} 2$</td>
<td>$\begin{array}{c} \fbox{X} \ [\sqsubseteq] \ f \end{array}$</td>
<td>$\forall x \in X : f(x) \subseteq g(x)$</td>
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International money transfers

- **IBAN**: standard for identifying bank accounts internationally
- Countries not adopting IBAN: *clearing code* together with *account number*
- **BIC**: standard for identifying banks globally
Payment form example

Diagrammatic specification

Requirements

1. The BIC code of the beneficiary’s bank is required
2. Either the IBAN or both clearing code and the account number are required
\[ \Sigma_{sec}\text{-specification} \]

\[ S = (G^S, C^S) \]

Diagram:

- PaymentForm
  - bic
  - iban
  - account [eon]
  - clearingCode [aonn]

- String
$\Sigma_{sec}$-specification

$S = (G^S, C^S)$

Diagram:

$G^S$

PaymentForm $\xrightarrow{bic}$ String

PaymentForm $\xrightarrow{iban}$ String

PaymentForm $\xrightarrow{account}$ String

PaymentForm $\xrightarrow{clearingCode}$ String

[eon]

[string]

[aonn]
**Data Validation Constraints in MDE**

**DPF and Data Validation**

**Syntax**

\[ \Sigma_{sec}-\text{specification} \]

\[ S = (G^S, C^S) \]

\[ \Sigma_{sec} = (\Pi, \alpha) \]

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<td>( \forall x \in X :</td>
</tr>
<tr>
<td>[exactly-one-null]</td>
<td>1 ( \xrightarrow{x} 2 ) ( \xrightarrow{y} 3 )</td>
<td>( X \xrightarrow{f} Y ) ( g \xrightarrow{[\text{eon}]} Z )</td>
<td>( \forall x \in X : (</td>
</tr>
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</table>
\[ \sum_{sec}\text{-specification} \]

\[ S = (G^S, C^S) \]

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<tr>
<td>([\text{required}], \delta_1 )</td>
<td>( 1 \xrightarrow{x} 2 )</td>
<td>( \text{PaymentForm} \xrightarrow{\text{bic}} \text{String} )</td>
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<tr>
<td>([\text{exactly-one-null}], \delta_2 )</td>
<td>( 1 \xrightarrow{y} 2 )</td>
<td>( \text{PaymentForm} \xrightarrow{\text{account}} \text{String} )</td>
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<td>$\forall x \in X : (</td>
</tr>
<tr>
<td>[all-or-none-null]$^2$</td>
<td>$1 \xrightarrow{x} 2$</td>
<td><img src="image" alt="Diagram" /></td>
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Java class with annotation

```java
public class PaymentForm {
    String bic, iban, account, clearingCode;

    @Required
    public String getBic() { return bic; }

    @ExactlyOneNull
    @NotRequired
    public String getIban() { return iban; }

    @ExactlyOneNull
    @AllOrNoneNull
    @NotRequired
    public String getAccount() { return account; }

    @AllOrNoneNull
    @NotRequired
    public String getClearingCode() { return clearingCode; }
}
```
SHIP Validator tests represented by annotations
- e.g. @Required: input from the user must be available via getter methods
- Relevant getter methods annotated
- Corresponding tests run when the object is passed to the Validator at runtime
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Related work

- Jürjens
  - Secure Systems Development with UML
  - Usage of UML extension mechanisms
Summary

- DPF enables constraining multiple, interdependent structural features of models
  - no need for attached OCL constraints
- Data validation constraints at the model level mapped to corresponding tests at the code level
Future work

- Logic for dependencies between predicates
- Prototype tool
- Fully-fledged case study
Thank you!

Questions?