Software
Systems
Engineering

Variability Modeling and Implementation with EASy-Producer

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Vision of Product Line Engineering

Key Goal:

exploit commonality in externally (visible) properties of the software (system) in terms of commonality of the implementation

Product Line Engineering vs. Traditional Software Engineering

Project focus → Integrated development of a set of products

Complete Shift of Viewpoint

instead of **producing a product** and reusing parts
produce a set of products in an integrated manner

⇒ ***Engineer differences***

Product Line Engineering is..

..a systematic approach for developing a set of product variants

..the technological basis for software mass-customization

.. a comprehensive framework that consists of two different life-cycles for software engineering

Core idea:

Common	Variability	Product specific
↓	↓	↓
reuse always	selectable	specific development

.. variability management helps to organize this

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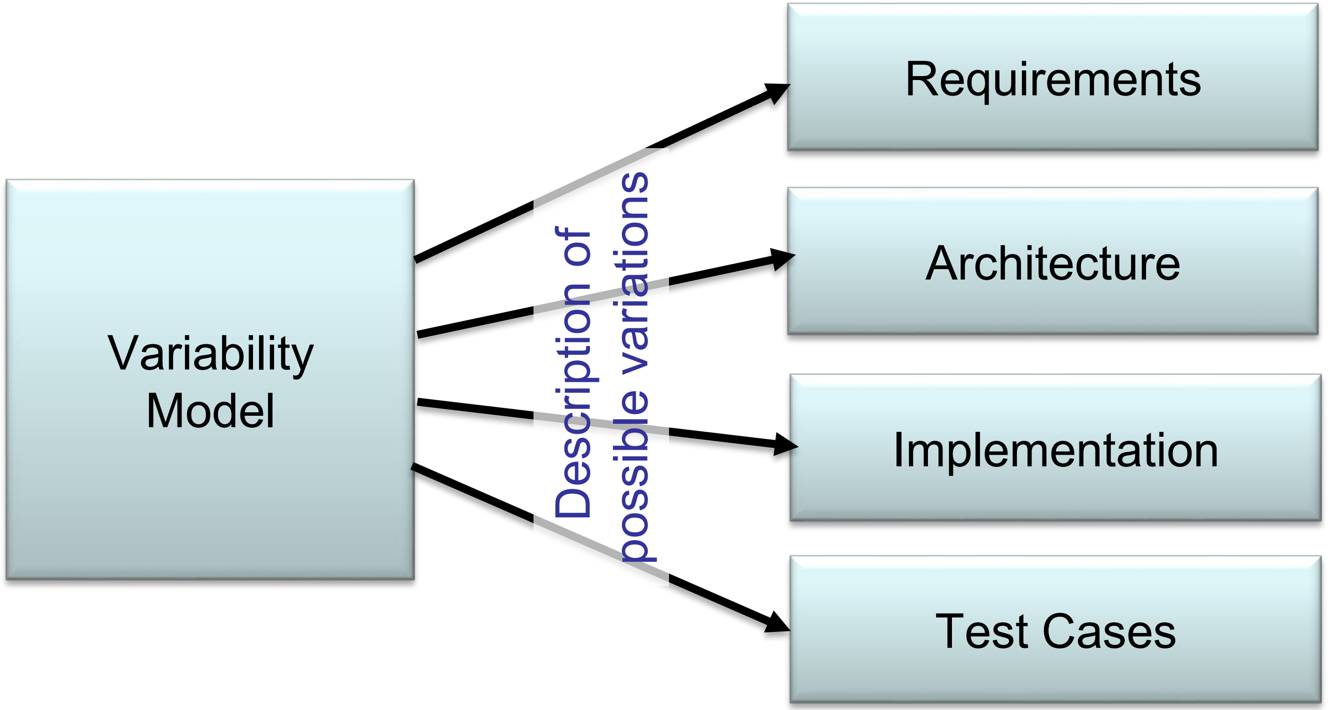
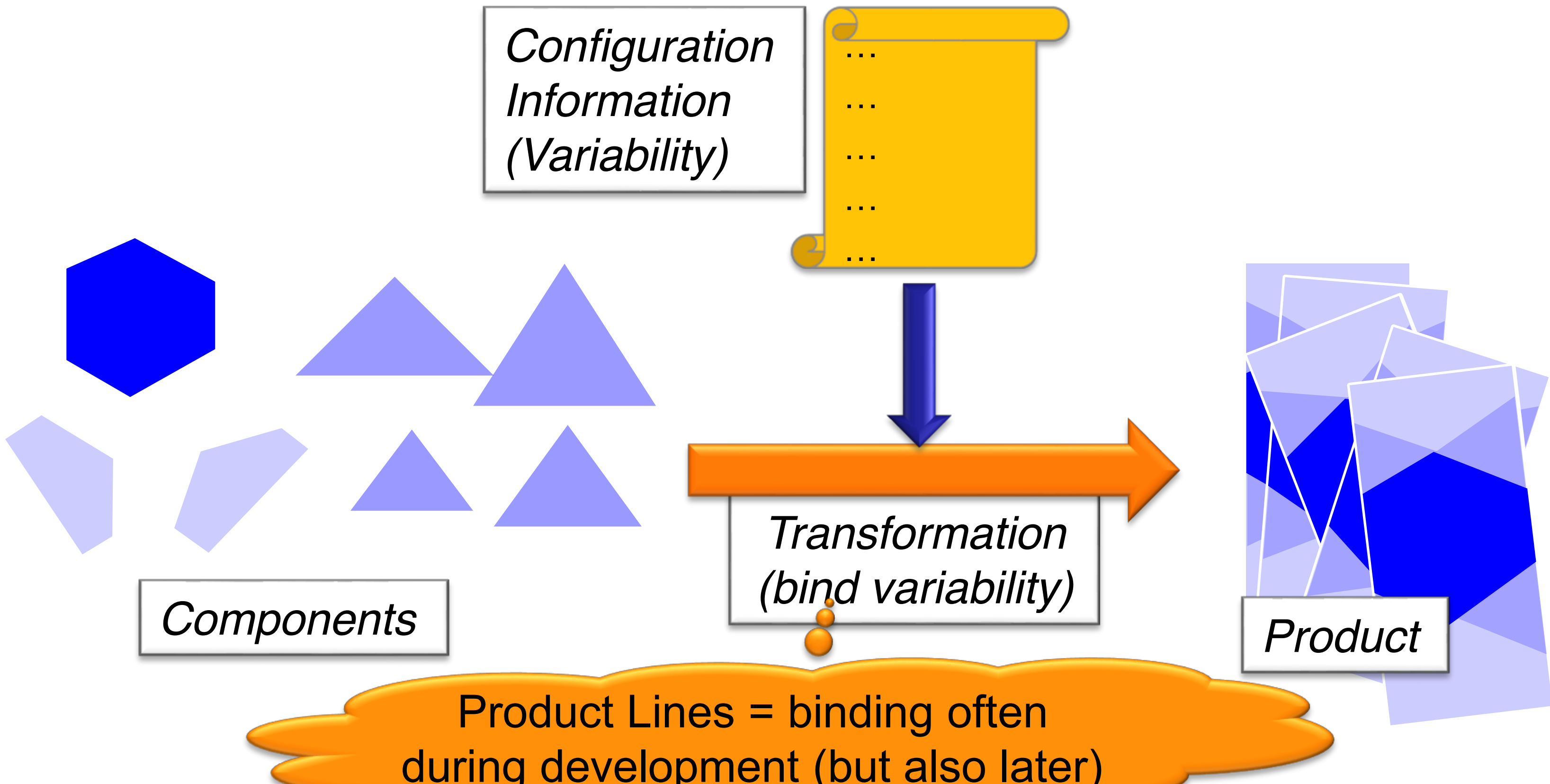
.. crosscutting variability

Ideally: central model that supports configuration of all parts



What is Product Line Development?

- Many Systems – a single basis for implementation
- Selection of implementation using configuration



Challenges in Product Line Engineering

- Need to describe configurations
  - Very expressive
  - Easy-to-use (known concepts)
    - Decision Modeling
    - Similarity to programming

IVML

- Need to describe transformations
  - Very expressive
  - Flexible with respect to technologies
  - Open to integration of arbitrary third-party tools

VIL

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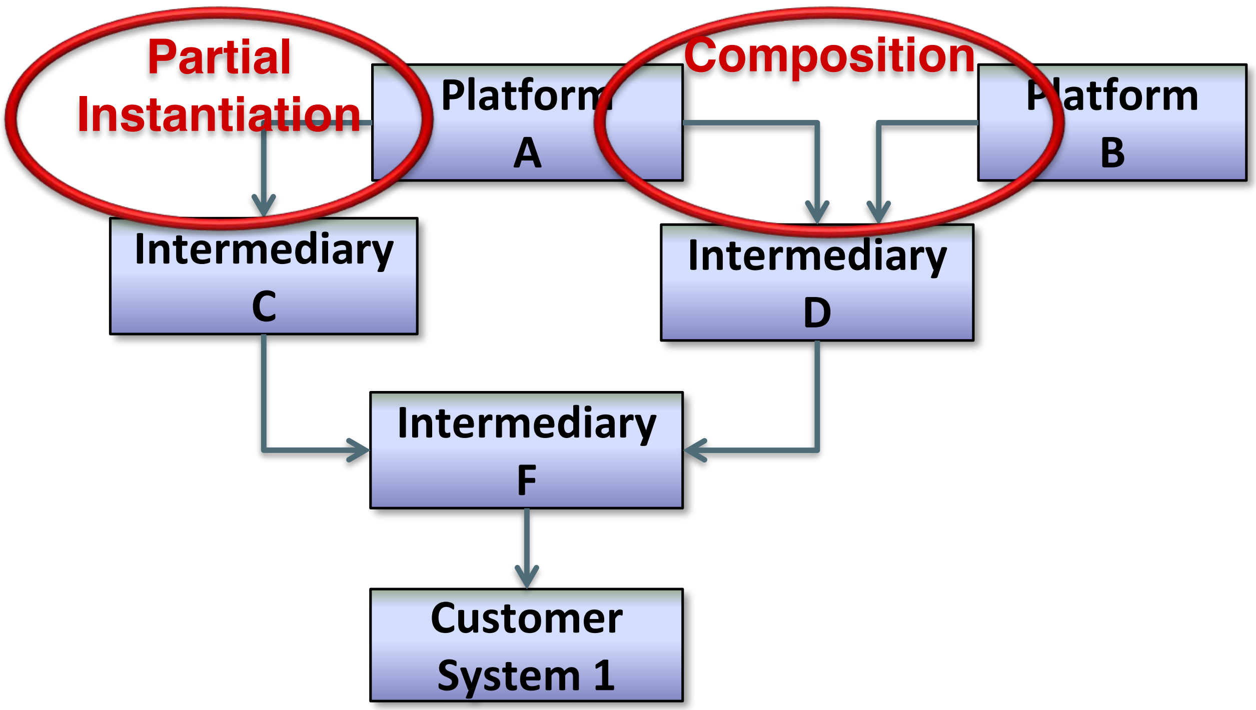
EASy-Producer supports software product line ecosystems



Variant-rich Infrastructure = Derived infrastructure + new implementation

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Challenges in Variant-Rich Software Ecosystems

- Introduction of: Product Line Project
  - Derivation (from preceding) units
  - Provisioning of new variability
  - Combine variability and infrastructure / code

- Support
  - Composition operation (➔ multi-product lines)
  - Staged derivation
  - Heterogeneous artifacts
  - Different instantiation mechanisms (even for the same artifact, based on origin of artifact)
  - Complex dependency management

Specific Characteristics of the EASy-Producer Approach

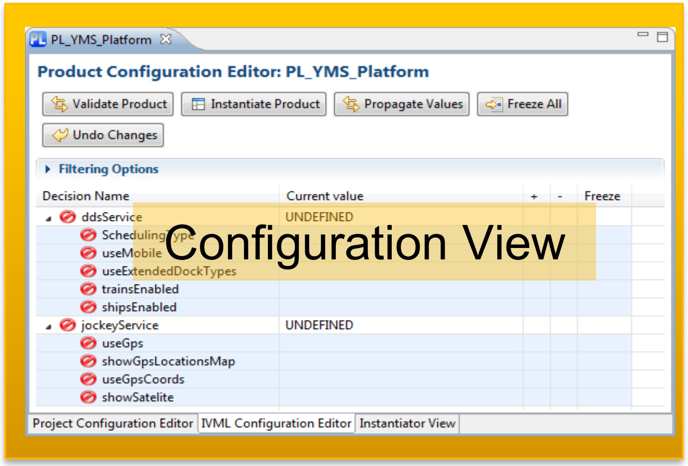
- Product Line Project (PLP) as a single, independent unit (separate configuration management)
  - Acts as product **AND** infrastructure
  - Supports independent product-specific parts
- Pull-only derivation to support decoupled evolution
- Rich, expressive variability-modelling language (IVML)
- Special language for configurable asset transformation (VIL)
  - Staged configuration support
  - Multi-project composition support
- Integrated template language
- Development and runtime support
- Fast reasoner
- Extendable asset model

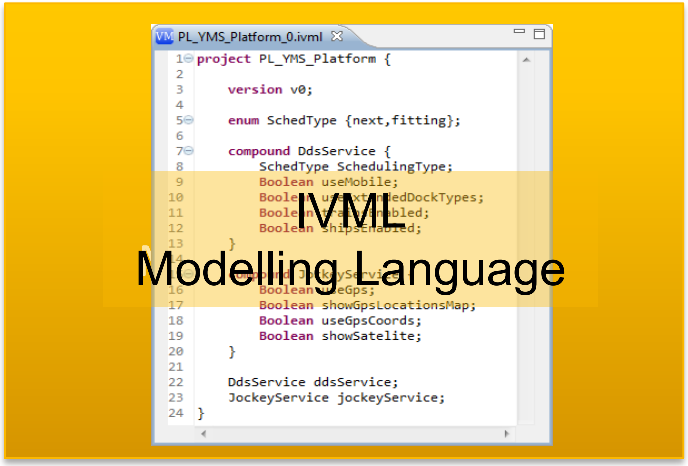
The Toolset

Interactive

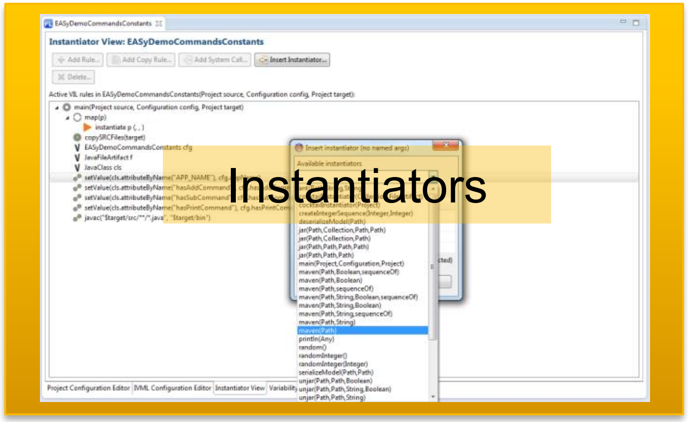
DSL-based

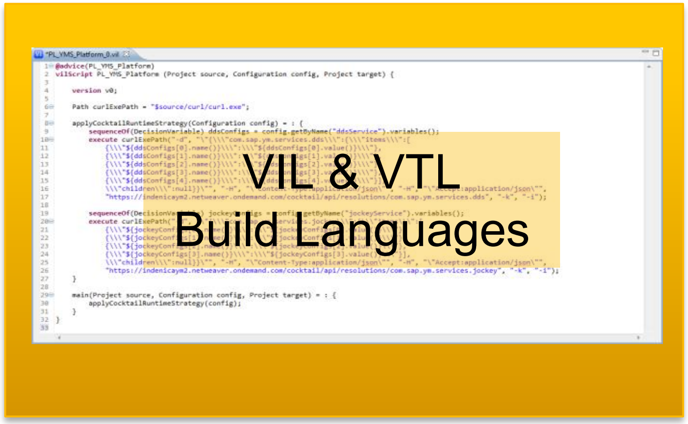
Configuration





Instantiatiation

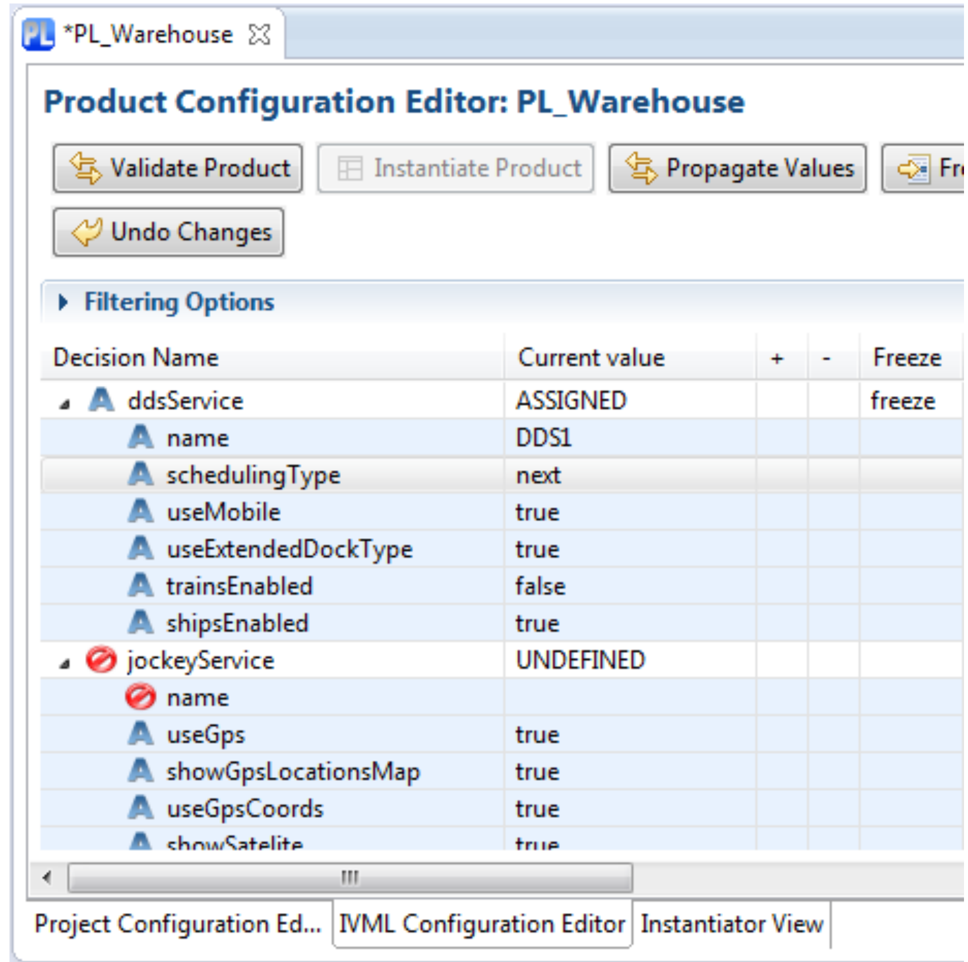




Configuration View

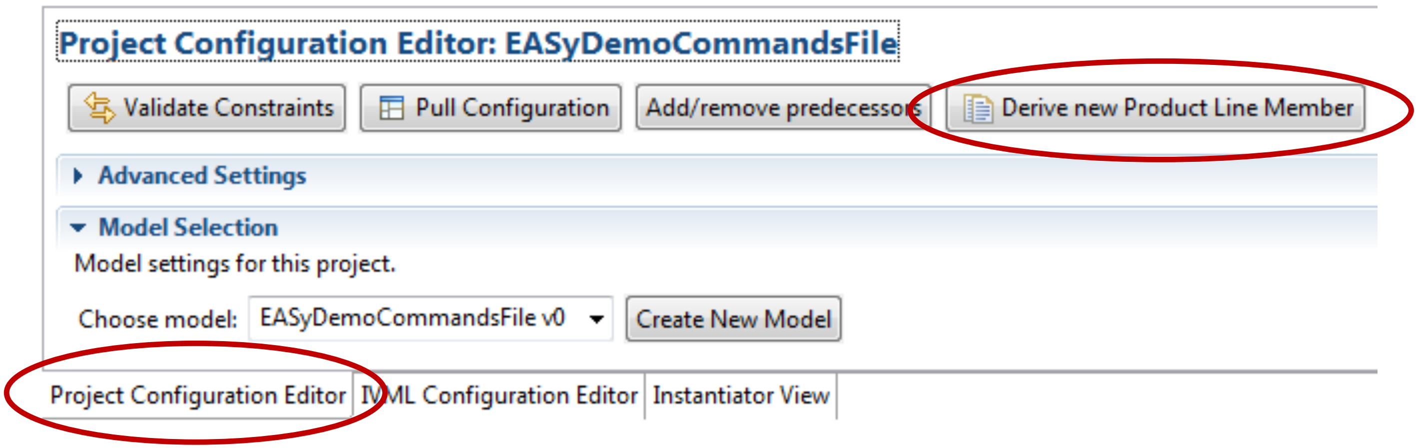
Configuration

- Table-based editor
  - Supports defaults (and freeze)
  - Hierarchical structure
  - Arbitrary non-boolean values
- Supported by reasoning
  - Consistency checking
  - Value propagation



Configuration steps

- **Important:** Derive a new product

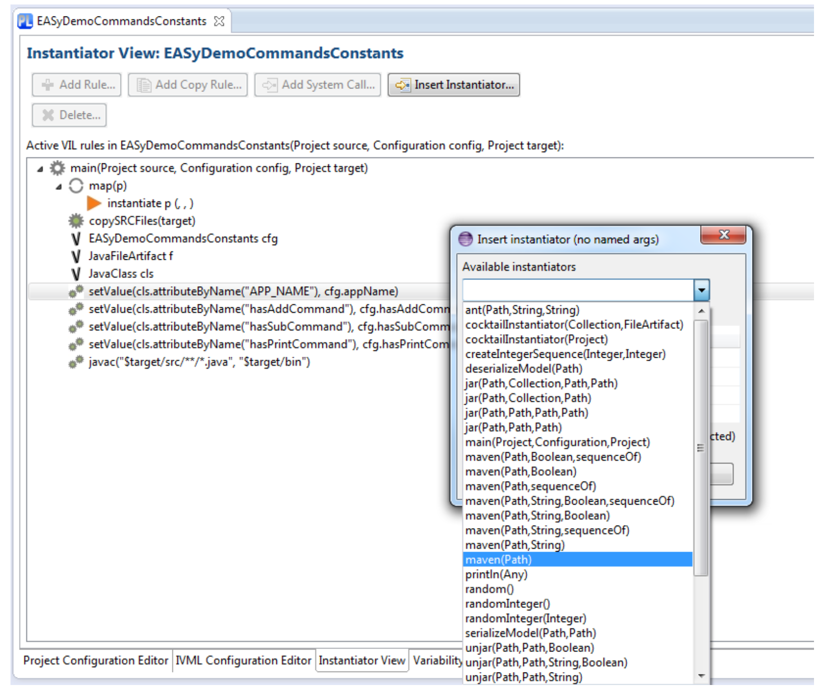


- In the **new product**
  - Change the configuration settings
  - Validate the configuration

Instantiation View

Instantiation by Instantiators

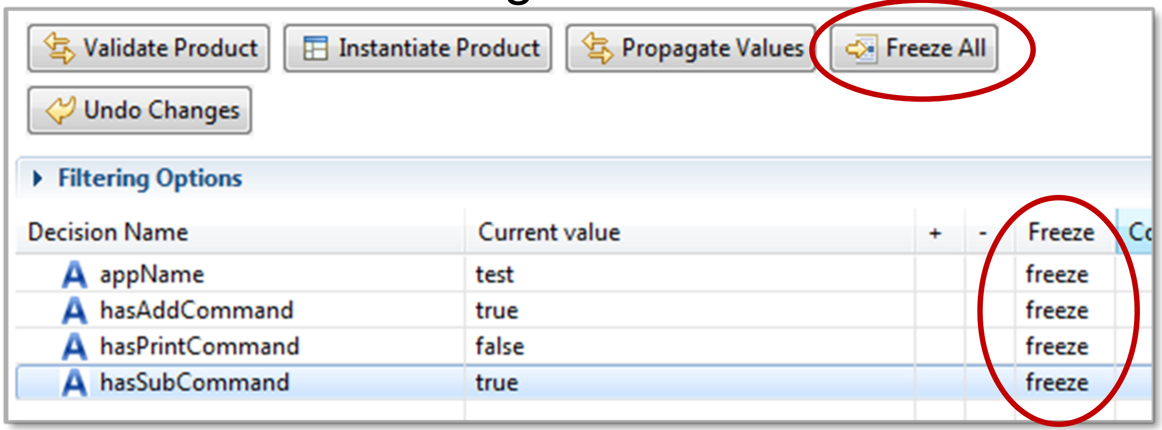
- Use of known instantiation plugins
- Instantiation process:
  - Sequence of instantiators
  - Associated artifacts
- Composition:
  - Linking or copying
  - Conflict resolution: Namespace manipulation



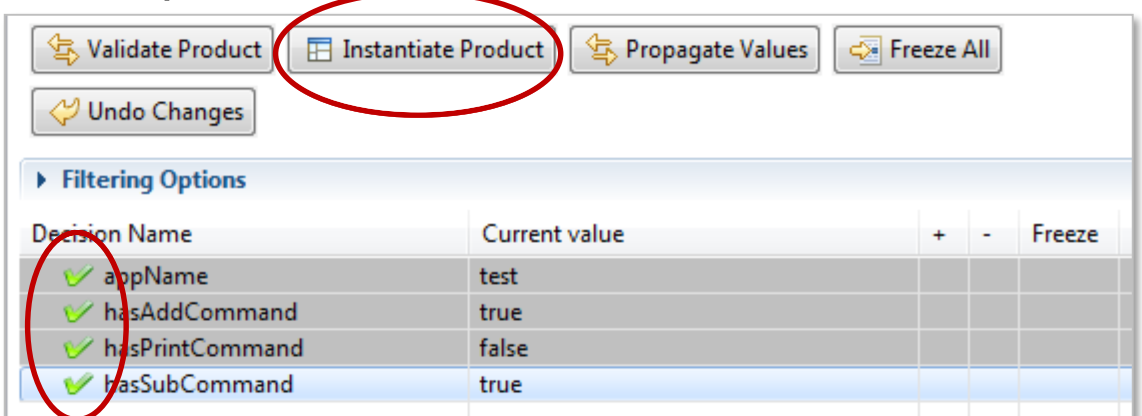
- **More flexibility:** DSL
- **Integration of complex instantiators:**
  - System call
  - Programming a new plugin

Instantiation steps

- **Important:** Freeze the configuration



- Instantiate the product



IVML – A Textual DSL for Configuration

IVML Configuration Capabilities (1)

- Decision-modeling based
- Text-based
- Typed variables (Boolean, non-Boolean including compounds and container, may have default values)
- Derivation and extension for complex types
- User-defined operations
- Introduction of defaults to distinguish “must” vs. local decisions
- Multi-stage default-handling, including default constraints
- Expressive constraint language
- Meta-information: typed annotations

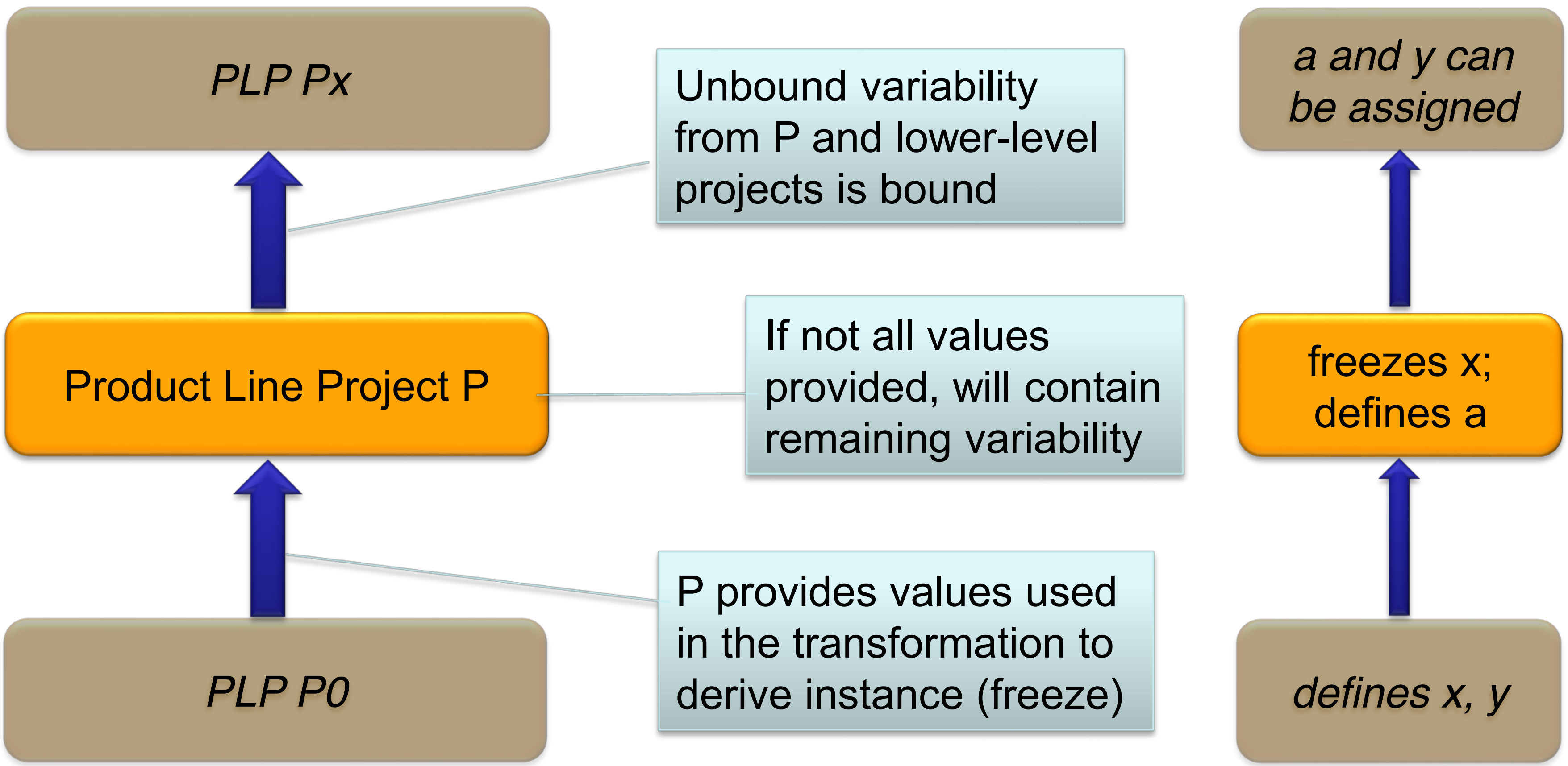
***Note:** every interactive change is mapped to IVML*

IVML Configuration Capabilities (2)

- Project handling: composition, versioning
- Scalability mechanisms: information hiding
- Name-space capabilities to handle conflict-free composition
- Modularization through variability interfaces

➔ IVML (Integrated Variability Modeling Language)

IVML-Support for handling multiple stages



Creation of Configuration Approach

Phase 1: Creation of an integrated, formal approach

- Focus on enabling to express dependencies in a way that:
  - Evolution issues are minimized
  - Dependencies are expressed in a canonical source-indepedendent way
- Requires:
  - Multi-stage default logic
  - Default constraints (vs. mandatory constraints)

Phase 2: Generalization

- Basis for IVML
- Used in several different projects

H. Eichelberger, K. Schmid. *Mapping the design-space of textual variability modeling languages: a refined analysis*. International Journal on Software Tools for Technology Transfer, 1-26, 2014.

H. Brummermann, M. Keunecke, K. Schmid. *Formalizing distributed evolution of variability in information system ecosystems*. VaMoS '12, 11-19, 2012.

IVML: Basic capabilities

- Every configuration is a project
- Variability is structured by a rich type system including containers such as sets and sequences and variables are defined based on this
- Variables can have default values

Type definitions

Variables

Note, this is a default value

```
project contentSharing {
     enum ContentType {text, video, audio, threeD, blob};
     typedef Bitrate Integer with (Bitrate >= 128 and
                                   Bitrate <= 256);

     ContentType content;
     Bitrate     contentBitrate = 128;
     contentBitrate = 128 implies content = text;
}
```

Advanced Variability Modeling: Refinement of Structures

- Decision Variables may be structured in terms of compounds
- Inheritance from compounds is possible

```
compound Content {
    String name;
    Integer bitrate;
}
compound ExternalContent refines Content{
    String contentPath;
    String accessPassword;
}
```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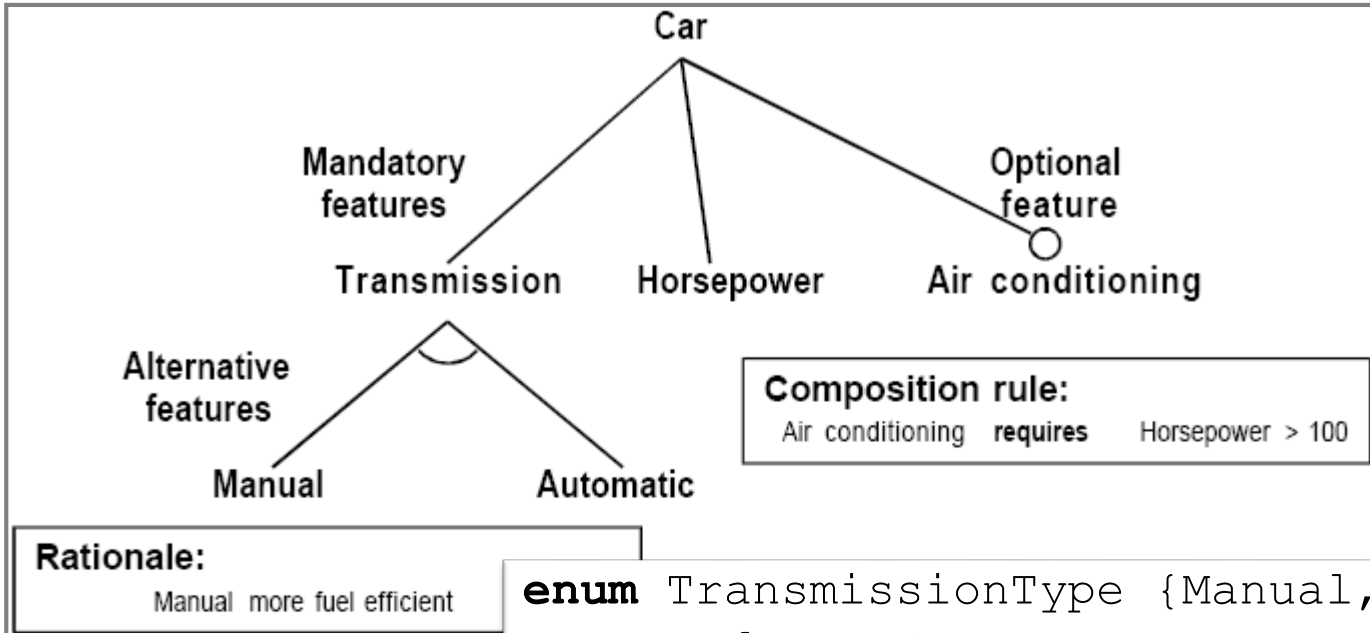
Example



Kyo C. Kang, Sholom G. Coh
Peterson. *Feature-Oriented D*
Technical Report CMU/SEI-9

```
enum TransmissionType {Manual, Automatic};
compound Car {
    // Manual more fuel efficient
    TransmissionType transmission;
    Integer horsepower;
    Boolean airConditioning;
    airConditioning implies horsepower > 100;
}
Car car;
```

Advanced Variability Modeling: References

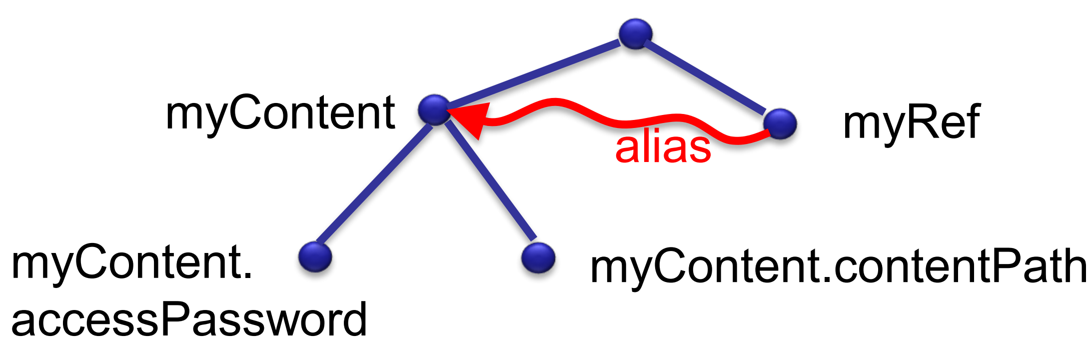
- A variability can reference another variability (with the meaning: whatever is configured by this)
- Multiple references may point to the same shared variable, in particular useful when references are stored in containers (not shown)

```
compound ExternalContent {
    String contentPath;
    String accessPassword;
}
ExternalContent myContent;
refTo(ExternalContent) myRef = myContent;
refBy(myRef).contentPath
    = "http://anyserver.org/content";
```

Advanced Variability Modeling: References

```
compound ExternalContent {
    String contentPath;
    String accessPassword;
}

ExternalContent myContent;
refTo(ExternalContent) myRef = myContent;
refBy(myRef).contentPath
    = "http://anyserver.org/content";
```



Advanced Variability Modeling: Project Handling (Composition)

- Arbitrary derivation chains
  (arbitrary deep derivation, arbitrary composition)
- Projects have versions
- While (re)using the projects it is possible to
  - require certain versions
  - exclude certain versions

```
project contentSharing {
    version v0;
    import application;
    import targetPlatform with (targetPlatform.version>=v1.3);
    conflicts application with (application.version>=v2.0);
     application::name = "myApp";
     targetPlatform::name = "myPlatform";
}
```

Note, these are other (possibly external) projects

Advanced Variability Modeling: Annotations

- Variability description entities (and the corresponding assets) can be further annotated
- Goal: simple support for meta-variability
- Annotations may reuse any form of variability concept

```
project contentSharing {
  enum BindingTime {configuration=0, compile=1,
                    runtime=2};
  // Attaching an annotation to the entire project.
  annotate BindingTime binding = BindingTime.compile
       to contentSharing;
}
```

Advanced Variability Modeling: Annotations

Annotations can be attached to arbitrary sub-groups of variables

```
compound Content {
   String  name;
   Integer bitrate;
}
Content content;

enum BindingTime {compile, loadtime, runtime};
annotate BindingTime binding = BindingTime.compile
    to content;
```

```
content = {name="Video", bitrate=128,
     name.binding     = BindingTime.compile,
     bitrate.binding = BindingTime.runtime};
```

More language capabilities

- Project interfaces
- Collection
  - Set
  - Sequence

```
setOf(Type) variableName2;
sequenceOf(Type) variableName1;
```

- Derived types

```
typedef AllowedBitrates setOf(Integer);
typedef Bitrate Integer
        with(Bitrate >= 128 and Bitrate <= 256);
```

More language capabilities

- Freezing variables

```
freeze {
    contentSharing;
} but (v|v.binding == BindingTimes.runtime)
```

- Explicit evaluation (eval)
- Constraint variables

```
Integer    a, b;
Constraint x;
x = (a > b);
```

- Handling of undefined variables: constraints are not explicitly evaluated

Expression language

- Strongly based on OCL

- Rich set of base relations and functions
- Set and sequence operations
- Quantification

```
contents->forAll(t|t.highBitrate <= 512);
contents->exists(t|t.highBitrate <= 512);
```

- A more complex example

```
parameters2->forAll(p2 | parameters1->
                         exists(p1| p1.name==p2.name and
                                typeOf(p1)==typeOf(p2)));
```

EASy Producer: Syntax-driven IVML editor

PL_Content_Sharing | PL_Content_Sharing_0.ivml

```
project PL_Content_Sharing {

    version v0;

    enum ContentType {Text, Video, Audio, ThreeD, BLOB};
    enum ContainerType {Tomcat, IIS, JBoss};
    enum DatabaseType {AzureSQL, AmazonS3, MySQL};
    enum DeploymentTarget {Traditional, Eucalyptus, Amazon, Azure};

    compound Content {
        ContentType type;
    }

    compound VideoContent refines Content {
        Content.type = ContentType.Video;
        Integer bitrate;
    }

    compound ThreeD refines Content {
        Content.type = ContentType.ThreeD;
        refTo(Container) threedContainer;
    }

    compound BLOB refines Content {
        Content.type = ContentType.Audio;
        refTo(Container) blobContainer;
    }

    compound Container {
        ContainerType type;
    }

    compound Database {
        DatabaseType type;
```

Task List | Outline

- PL_Content_Sharing
  - v0
  - Project Contents
    - ContentType
    - ContainerType
    - DatabaseType
    - DeploymentTarget
    - Content
    - VideoContent
    - ThreeD
    - BLOB
    - Container
    - Database
    - Application
      - DV setOf(Content) appContent
      - DV Container appContainer
      - DV Database appDatabase
    - TargetPlatform
      - DV DeploymentTarget platTarget
      - DV Boolean isPublic
    - DV Application app
    - DV TargetPlatform plat

Experiences with IVML-based Modeling

Initial development

- Based on industrial experience
- Various „Challenge“-Workshops with industrial partners

Further evaluation in different projects:

- All relevant dependencies and configuration capabilities could be represented
- Improved documentation of dependencies
- Easy to learn

Current status

- Successfully evaluated for Klug IS (expressiveness / learnability)
- Is applied for real systems in prototypical manner
- Transition to production use ongoing

Projects:

- EasyCar with Robert Bosch GmbH
- ScaleLog (BMWi / Klug IS)
- EU-Project INDENICA
- EU-Project QualiMaster
- HIS eG

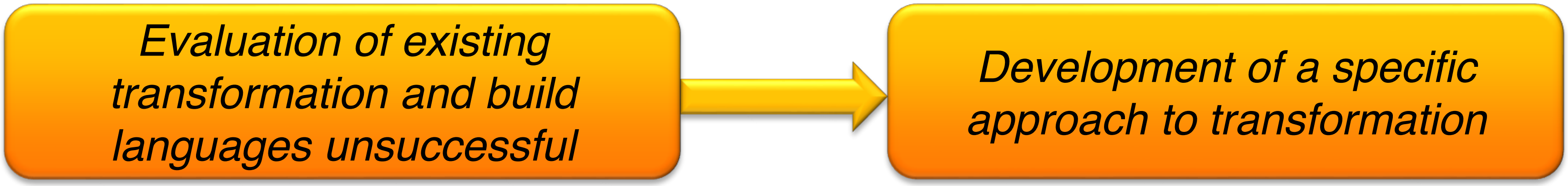
VIL – A Textual DSL for Transformation

The Transformation Problem

Initial development

Complexity of transformation

- Different artifacts require different techniques
- Influence of configuration options
- Multiple levels of composition
- Various binding times
- Support for derivation networks:
  Assets must inherit their original instantiation mechanism



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Transformation language: VIL (Variability Instantiation Language)

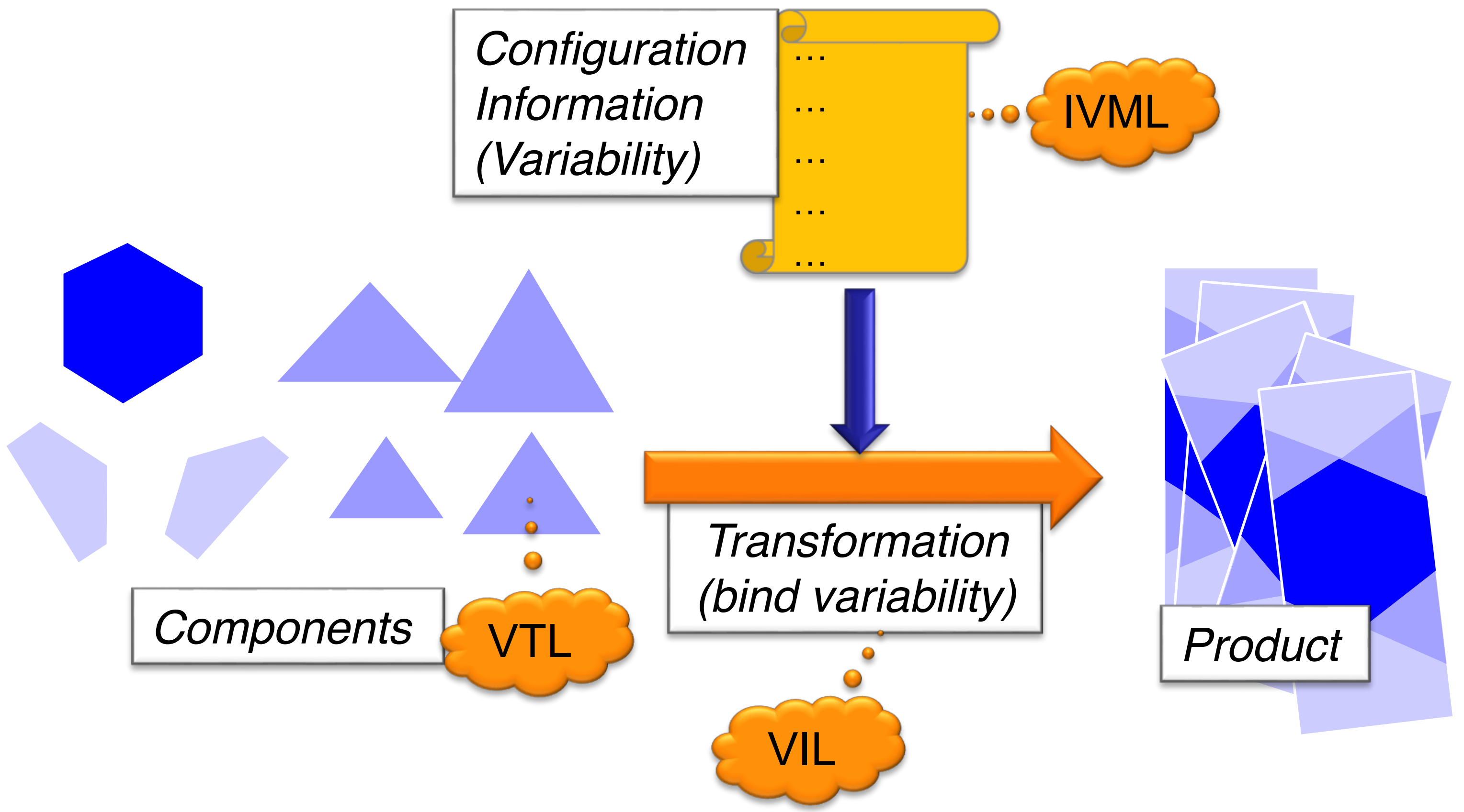
Combines a number of different programming models

- Object-oriented artifact model
- Procedural Programming
- Rule-based Programming
  - Parameterized rules
  - Wildcard selectors
- Functional elements

\+ Use of arbitrary external programs (black-box instantiators)

> The language can be used as an arbitrary build language (among other things)

The realization perspective on product lines



Transformation language: VIL (Variability Instantiation Language)

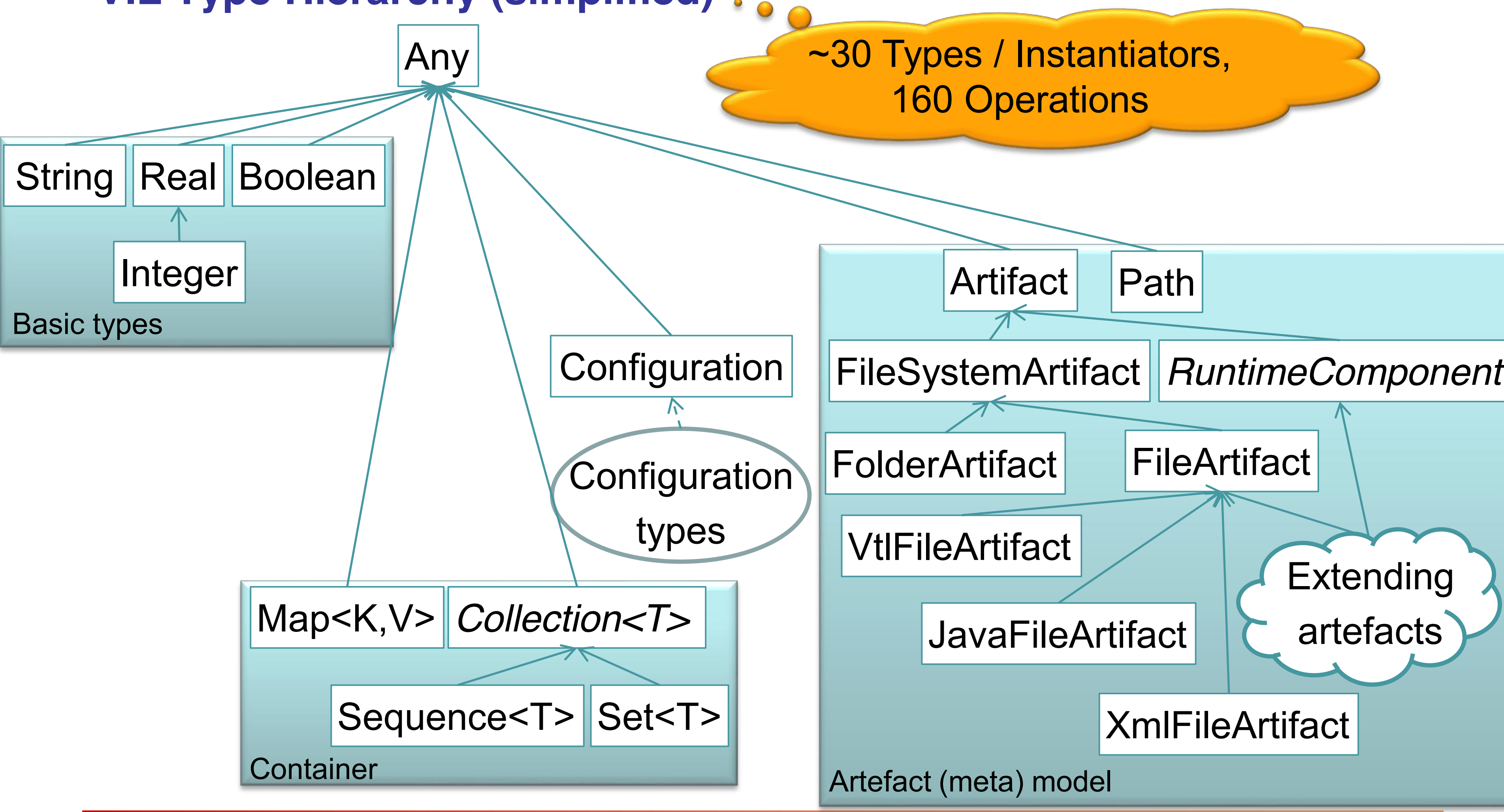
```
vilScript New_Product (Project source, Configuration conf, Project
target) {
  version v0;

  copySRCFiles() = "$target/src/**/*.java" : "$source/src/**/*.java" {
    RHS.copy(LHS);
  }

  copyRESFiles() = "$target/resources/**/*" : "$source/resources/**/*" {
    RHS.copy(LHS);
  }

  main(Project source, Configuration conf, Project target) = : {
    copySRCFiles();
    copyRESFiles();
    velocity("$target", conf);
  }
}
```

Rules

Object-oriented artifact-model

procedural

VIL Type Hierarchy (simplified)



Variables / Types

Not only filesystem

- Types similar to IVML
- Additional `Path` type – arbitrary reference to transformable element
- `Any` type – subsumes all possible types
- Container types
  - `Collection` – abstract supertype of all containers:
    - `Set` – no duplicates, no order
    - `Sequence` – duplicates, order
  - `Map` – associative container (e.g., to represent mappings between different namings)
- `const` & `protected` modifiers
- `new` method – allows temporary artefacts

Basic ideas

- @advice: relate the script to the referenced variability model
- Typed language
- Basic script structure
  - `main` as implicit starting goal
  - rules ➔ functions are regarded as a special case

```
vilScript New_Product (Project source, Configuration conf,
                       Project target) {

  version v0;

  method1(param) = postcondition : precondition {
    statements;
  }
  …
}
```

Basic ideas

- Combine
  - Procedural
  - Rule-based
  - OO-approach
- Rules may rely on artifact relations:

```
copySRCFiles() = "$target/src/**/*.java" : "$source/src/**/*.java" {
    RHS.copy(LHS);
}
```

- Benefits
  - Only do necessary rework
  - Let the infrastructure determine what to work on

Basic ideas

- Rules may rely on the explicit handling of logical expressions:

```
Boolean processed;
Boolean compiled;

processSRCFiles() = processed==true :  {
    …
}

compileSRCFiles() = compiled==true : processed==true {
    …
}
```

- Statements can also be handled like normal methods (no post-/pre-conditions)

Commands

- Commands given by artifacts
  - Depend on artifacts
  - Generic operations (on any artifact): `new, rename, delete`
  - FileArtifacts (e.g.): `copy`
- `execute` – start any system command
  if cmd is a path to an executable command:

```
cmd.execute(params)
```

Extensions

- Specialized commands that are treated like language primitives (but are externally realized)
  - Java compiler

```
setOf(FileArtifact) javac(Path s, Path t, ...)
```

  - Velocity

```
setOf(FileArtifact) velocity(FileArtifact t,
                       Configuration c)
```

  - Others: Maven, ANT, XVCL, AspectJ
  - Extendable by further bundles
  - Specialized template language VTL

```
setOf(FileArtifact) vilTemplateProcessor(String n,
                   Configuration c, Artifact a, …)
```

Connecting Decisions and Scripts

- A configuration can be made known – advice-annotation

```
@advice(ivmlName)
vilScript name (parameterList) extends name1 {
// scriptbody
}
```

This allows to access configuration variables arbitrarily, also in the editor

- `join` – combine elements from configuration with elements from script:

```
join(d:config.variables(), a:"$source/src/**/*.java")
  with (a.text().matches("${" + d.name() + "}")) {
    // operate on decision variable d and
    // related artifact a
```

Control-Flow (1)

- `if` – conditional execution

```
if (expression) ifStatement else elseStatement
```

- `switch` – multiple alternatives

```
switch (expression) {
   expression1 : expression2,
   expression3 : expression4,
   default : expression5
}
```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Control-Flow (2)

- `for` – iterate over a number of items, collecting the result

```
for (d = config.variables()) {
    // operate on the iterator variable d of type
    // DecisionVariable (see Section 3.4.5.6)
};
```

- `map` – iterate over a number of items, collecting the results

```
map(d = config.variables()) {
    // operate on the iterator variable d of type
    // DecisionVariable (see Section 3.4.5.6)
};
```


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Script relations

- A script may explicitly extend another one
- Explicit instantiate of a higher level script

```
instantiate name (argumentList) [with (version op vNumber.Number)]
```

- Explicit reference to higher-level method

```
super.operationName(argumentList)
```

An Example Script

Copy all sourcefiles and apply velocity on them

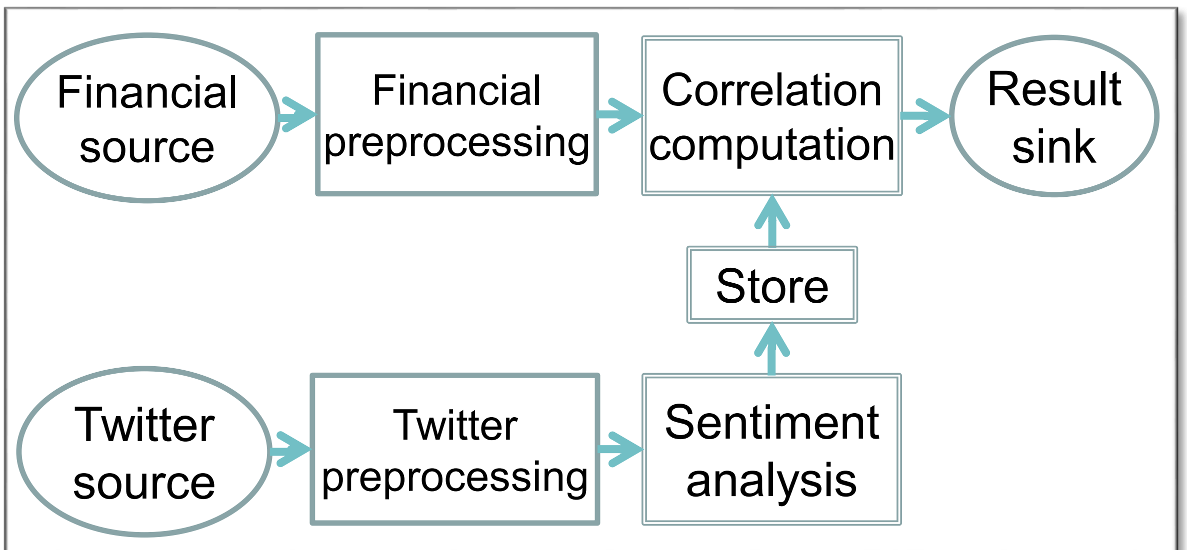
```
vilScript New_Product(Project source,Configuration conf,Project target){
  version v0;

  copySRCFiles() = "$target/src/**/*.java" : "$source/src/**/*.java" {
    RHS.copy(LHS);
  }

  main(Project source, Configuration conf, Project target) = : {
    copySRCFiles();
    velocity("$target/**/*.java", conf);
  }
}
```

Modelling data processing pipelines

1. Define elements as configuration types
2. Define specific configuration as values (development time)



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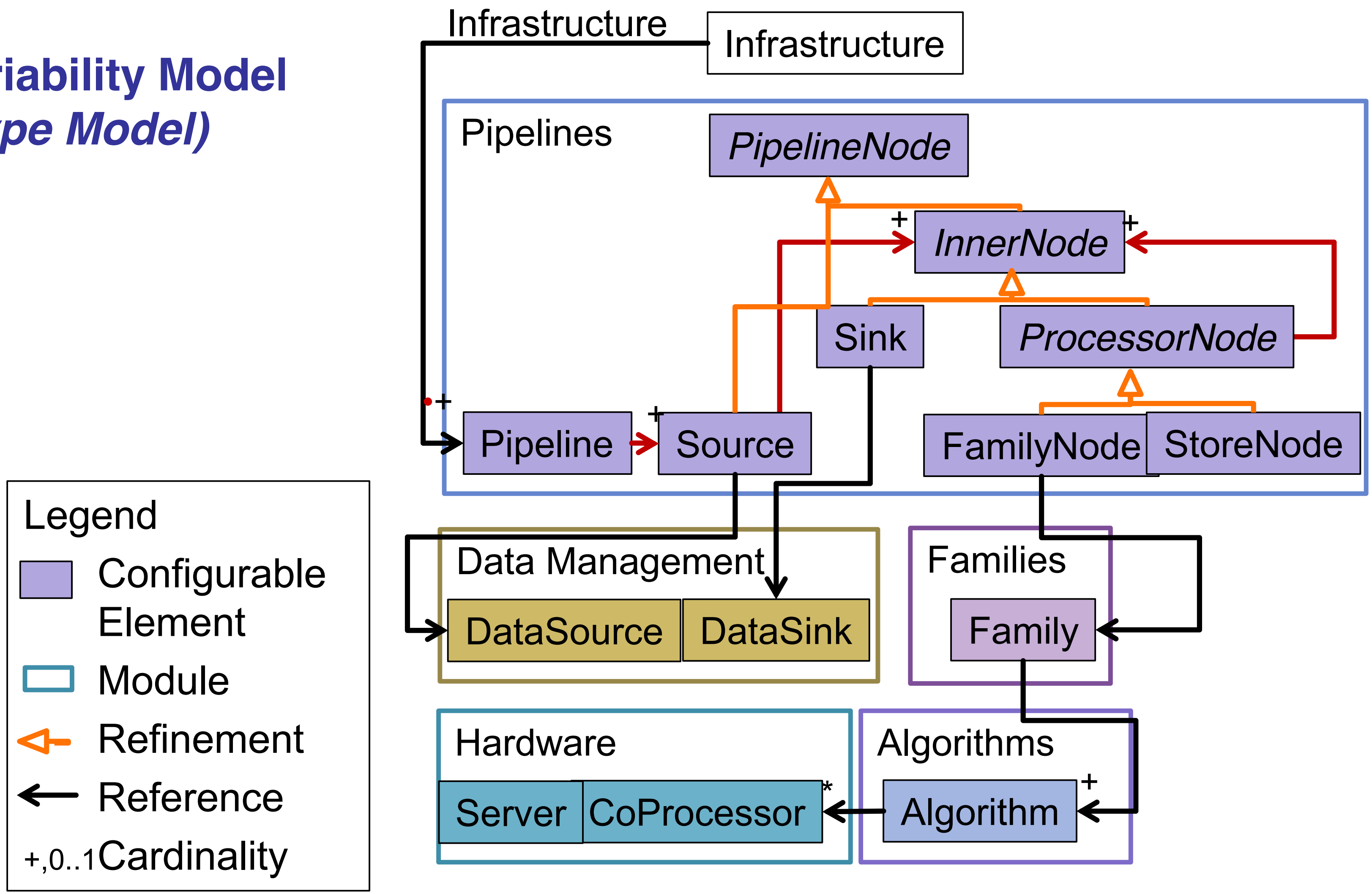
Variability Model *(Type Model)*



Modelling and Implementation with EASy-Producer


```
project QM {
  typedef Tuples setOf(Tuple);
  // omitted: Server, CoProcessor, Tuple

  compound Algorithm {
    String name;
    Tuples input;
    Tuples output;
  }

  typedef Algorithms setOf(refTo(Algorithm));
  // omitted: DataSource, DataSink

  compound Family {
    String name;
    Algorithms members;
    Tuples input;
    Tuples output;
    members->forAll(m|input == m.input
      and output == m.output);
    members.size() > 0;
  }

  abstract compound PipelineNode {
    String name;
    Tuples input;
    Tuples output;
  }

  abstract compound InnerNode
    refines PipelineNode {
  }
```

```
project QMCfg {

  import QM;
  // omitted: resources, algorithms

  Source nFinancialSource = {
    name = "FinancialDataSource",
    source = refBy(financialSource),
    next = {refBy(nPreprocessor),
      refBy(nCorrelation)}
  };

  FamilyNode nPreprocessor = {
    name = "Preprocessor",
    family = refBy(fPreprocessor),
    next = {refBy(nCorrelation)}
  };

  FamilyNode nCorrelation = {
    name = "FinancialCorrelation",
    family = refBy(fCorrelation),
    next = {refBy(nSink)}
  };

  Sink nSink = {
    name = "Sink",
    sink = refBy(pipSink)
  };

  Pipeline pip = {
    name="Example pipeline",
    sources={refBy(nFinancialSource
      refBy(nTwitterSource)}
  };
```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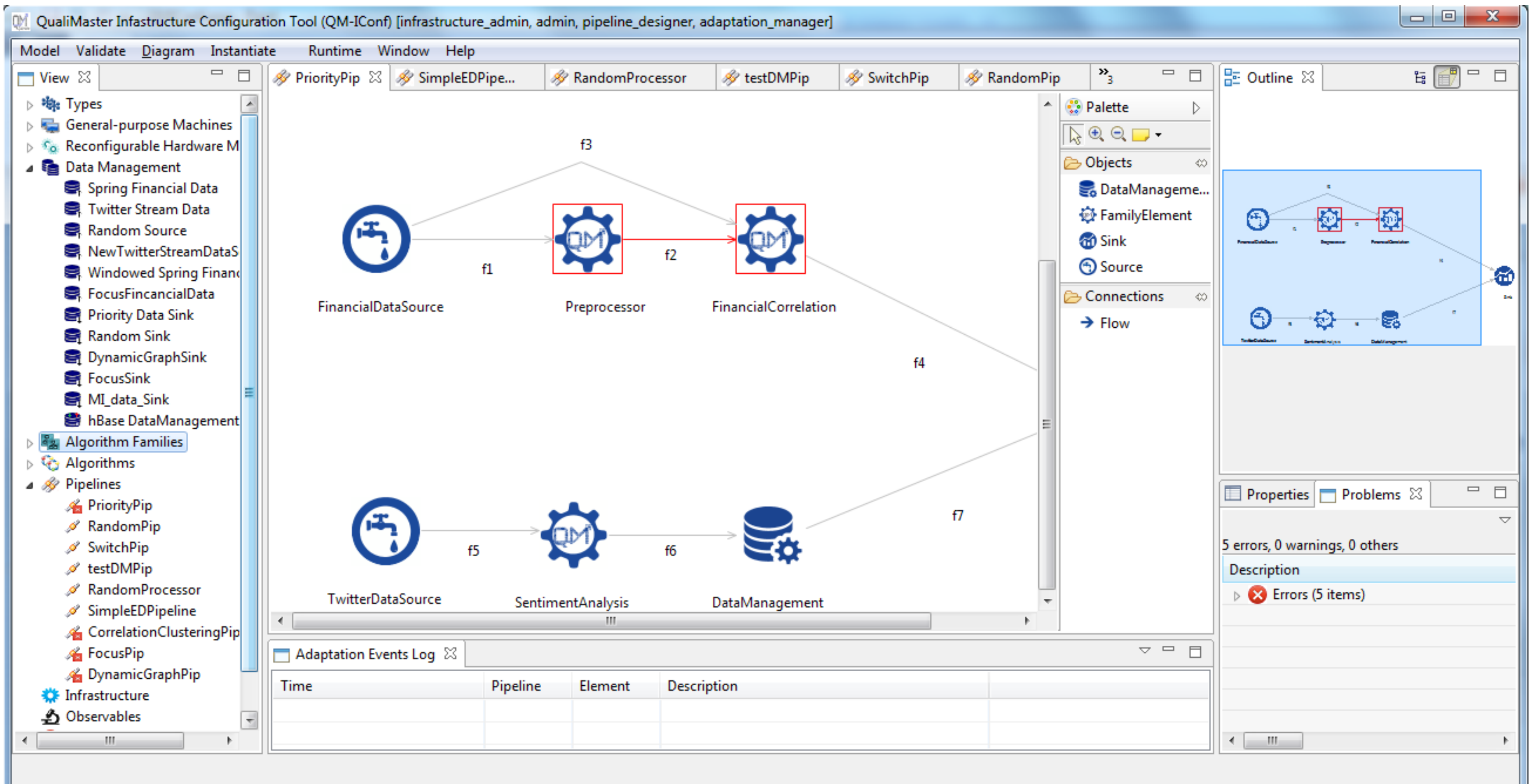
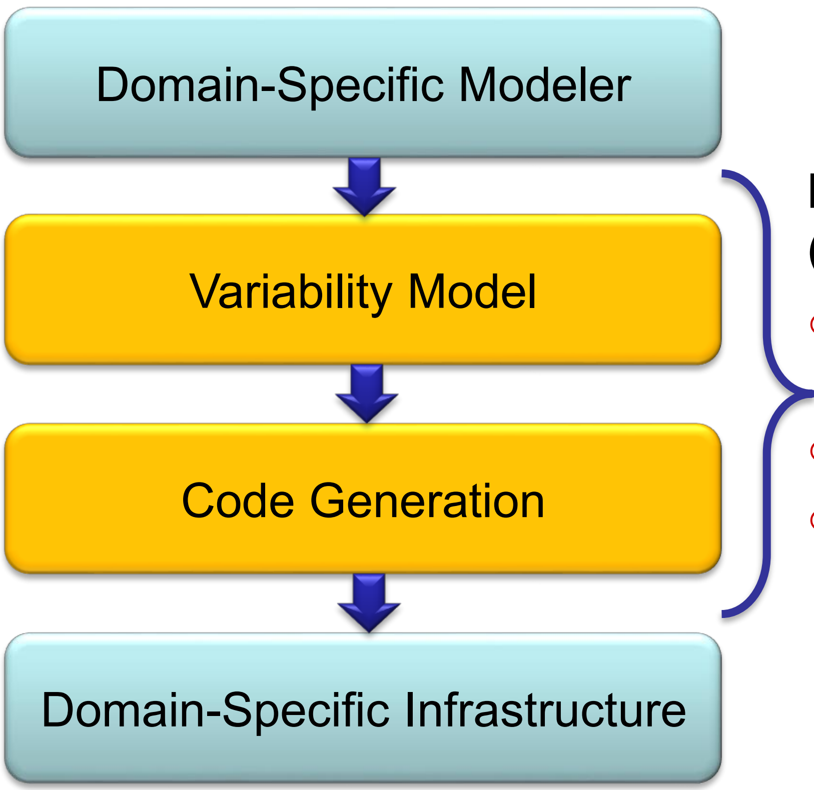
Domain-Specific Modelling



Application



Large parts of implementation “for free” (reusing EASy-producer)

- Powerful, but adequate modeling language
- Reasoner
- Transformation support

EASy-Producer

- Model with 9 pipelines
- Validation: 250ms
- Code generation
  - 4 Minutes
  - 30 KLOC in 195 artefakts
  - Integration of algorithms

Summary

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Summary-EASy-Producer

- Full support for typical product line problems
  - Interactively
  - Primarily as DSL (program your product line)
- Goals
  - Expressiveness
  - Possible to incrementally adopt
  - Representation: close to programming
  - Powerful reasoning and analysis
- Ecosystem extensions
  - (Partial) instantiation support
  - Composition
  - Openness & Modularization
- Has been applied to industrial problems
  ➔ but we are open to cooperate on more evaluations…

Summary IVML

- Very expressive approach
  - Expressiveness over analyzability
  - Can “simulate” feature models, but not restricted to this
  - Comparable to Ecore
- Representation
  - Similar to programming (ease of transition)
  - Includes concepts from OCL (constraints)
  - Constraints first class entities
  - Annotations: full expressiveness
- Reasoning
  - Very efficient forward reasoner
  - Aware of multi-step reasoning
  - Default logic (freezing
- Ecosystem extensions
  - Interfaces
  - Modules

Summary VIL

- Configurable transformation language
- Language is a transformation language
  - Rule-based
  - Extensible
    - In various ways
    - Extend wrt. transformation operations
    - Extend wrt. artefacts
- May recur to inherited models

Summary VTL (optional)

- Template language
- Especially for artefact creation

Material

- EASy-Producer web page
  - https://sse.uni-hildesheim.de/en/research/projects/easy-producer/
- EASy-Producer release and documentation page
  - http://projects.sse.uni-hildesheim.de/easy/
- EASy-Producer on the SSE github page
  - http://ssehub.github.io/