Model Driven Architecture
Code Generation

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Contents

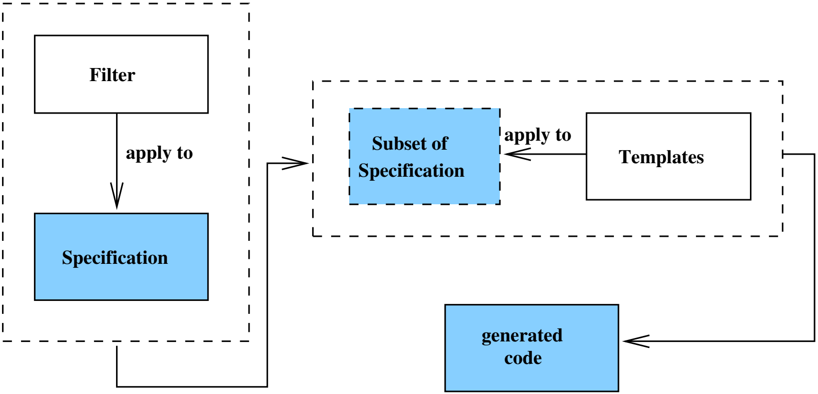
- Performance
- Code size
- Analyzability
- Early detection of errors
- Portability
- Restrictions in the programming language
- Aspects
- Introspection/Reflection

Code Generation

Instance of Metaprogramming

- Programs that generate programs (base programs)
- Staging of metaprograms
  - Independent of base programs (usually earlier)
    base program and metaprogram are kept separate
    Examples: MDE generators
  - During compilation of the base program
    static metaprogramming: generated program is unaware of the generation process
    Examples: C++ preprocessor, C++ templates
  - At run-time of the base program
    dynamic metaprogramming: base program can be extended and modified at run time
    Examples: metaobject protocol of CommonLisp
- Homogeneous vs heterogeneous metaprogramming

Code Generation Techniques
Templates and Filtering



Code Generation Techniques
Templates and Filtering/Example

- Code to be generated from templates
- Template variables may be bound to model values
- Example: generate JavaBean from XML specification

Code Generation Techniques

Templates and Filtering/Example

- Bean specification

```
<class name="Person" package="de.unifrei">
  <attribute name="name" type="String"/>
  <attribute name="age" type="int"/>
</class>
```

- expected generated code

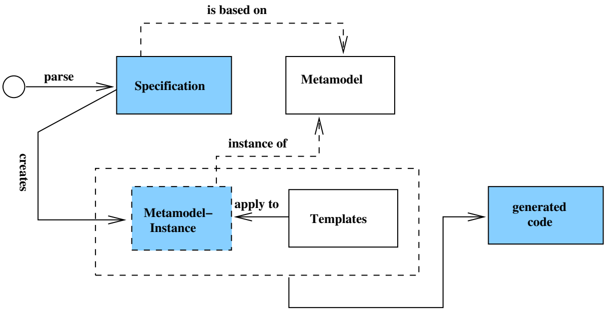
```
package de.unifrei;
public class Person {
  private String name;
  public String getName () {return name;}
  public void setName (String name) {this.name=name;}
  private int age;
  public int getAge () {return age;}
  public void setAge (int age) {this.age=age;}
}
```

Code Generation Techniques

Templates and Filtering/Example using XSLT

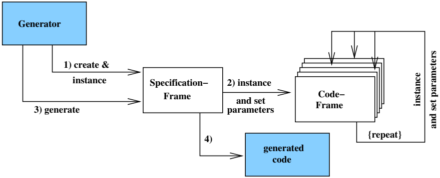
```
<xsl:template match="/class">
  package <xsl:value-of select="@package"/>;
  public class <xsl:value-of select="@name"/>
  { <xsl:apply-templates select="attribute"/> }
</xsl:template>

<xsl:template match="attribute">
  <xsl:variable name="capname"
    select="concat( translate(substring( @name, 1, 1),
                              ’abcdefghijklmnopqrstuvwxyz’,
                              ’ABCDEFGHIJKLMNOPQRSTUVWXYZ’ ),
              substring(@name, 2))" />
  private <xsl:value-of select="@type"/>
          <xsl:value-of select="@name"/>;
  public <xsl:value-of select="@type"/>
         get<xsl:value-of select="$capname" /> ()
    {return <xsl:value-of select="@name"/>;}
  public void set<xsl:value-of select="$capname" />
    (<xsl:value-of select="@type"/> <xsl:value-of select="@name"/>)
    {this.<xsl:value-of select="@name"/>=<xsl:value-of select="@name"/
</xsl:template>
```

Code Generation Techniques
Templates and Metamodel



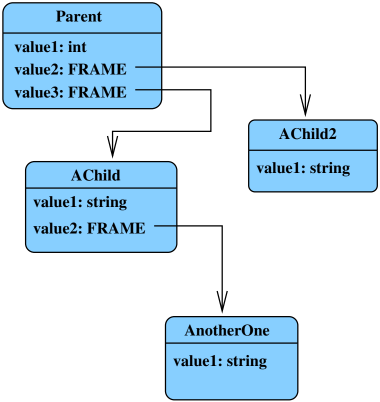
- parse XML and map to user-defined metamodel
- generate code from template and metamodel

Code Generation Techniques
Frame Processors



- A *frame* is an object consisting of slots and a code template
- Control iterates over frame instantiation
- Exporting of the final frame structure generates the code

Code Generation Techniques
Frame Processors/Example Frame Hierarchy



Frame specification

```
.Frame GenNumberElement (Name, MaxValue)
  .Dim vIntQual = (MaxValue > 32767) ? "long" : "short"
  .Dim sNumbersInitVal
  <!vIntQual!> int <!Name!> <?= <!sNumbersInitVal!>?>;
.End Frame
```

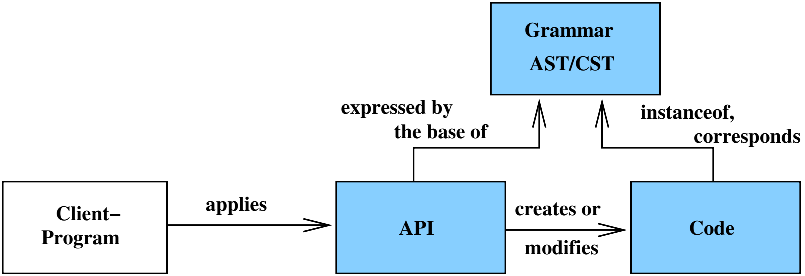
Frame instantiation

```
.myNumberElem = CreateFrame ("GenNumberElement", "aShortNumber", 100)
```

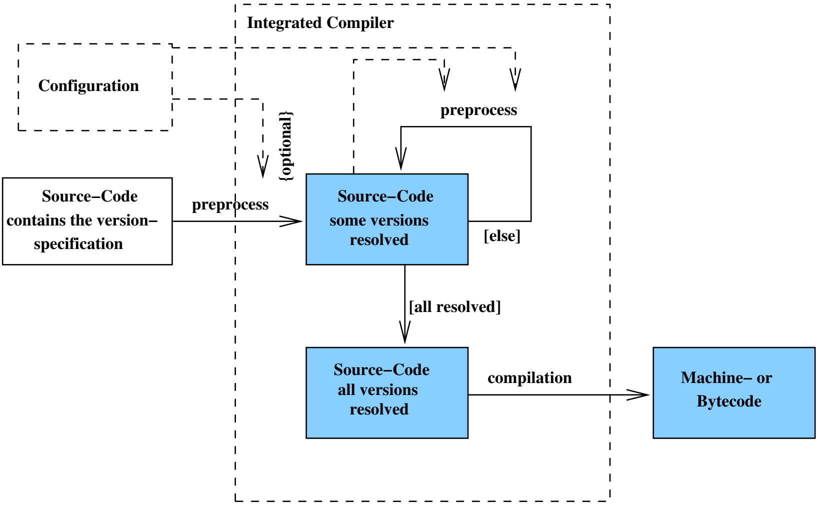
Code generation

```
.Export myNumberElem
```

Code Generation Techniques
API-based Generators



Code Generation Techniques
Inline Generation



- Annotate code with active comments
- Examples: JavaDoc, XDoclet (supported by Eclipse)

```
/**
 * @ejb:bean type="Stateless"
 *           name="vvm/VVMQuery"
 *           local-jndi-name="/ejb/vvm/VVMQueryLocal"
 *           jndi-name="/ejb/vvm/VVMQueryRemote"
 *           view-type="both"
 */
public abstract class VVMQueryBean
  /**
   * @ejb:interface-method view-type="both"
   */
  public List getPartsForVehicle ( VIN theVehicle ) {
    return super.getPartsForVehicle ( theVehicle );
  }
}
```

- .NET supports attributes that can be attached to parts of C#programs

```
[AttributeUsage(AttributeTargets.All,
                Inherited=true,
                AllowMultiple=true)]
public class MyCustomAttribute: System.Attribute
{
  private string desc;
  private string name;
}
```

- Similar feature: Metadata (aka Annotations) in Java5

Code Generation Techniques

Excursion: Metadata in Java5

- Many APIs require extra data that must be kept in sync with the code
- Java 5 defines a general purpose annotation facility that permits the definition and use of customized annotation types (generalizing javadoc, @deprecated, transient, etc)
- Java 5 annotations consist of
  - syntax for declaring annotation types,
  - a syntax for annotating declarations,
  - APIs for reading annotations,
  - a class file representation for annotations,
  - an annotation processing tool (apt)
- Annotations do not affect semantics directly, but may influence the execution context
- Annotations can be read from source files, class files, or reflectively at run time
- (Used in EJB 3.0)

```
/**
 * Describes the Request-For-Enhancement(RFE) that
 * to the presence of the annotated API element.
 */
public @interface RequestForEnhancement {
    int    id();
    String synopsis();
    String engineer() default "[unassigned]";
    String date()     default "[unimplemented]";
}
```

```
@RequestForEnhancement(
    id        = 2868724,
    synopsis = "Enable time-travel",
    engineer = "Mr. Peabody",
    date      = "4/1/3007"
)
public static void
travelThroughTime(Date destination) { ... }
```

- annotation is special kind of modifier
- precedes all other modifiers

Code Generation Techniques
Summary

	Staging	program/ metaprogram	generated/ manual
Templates and Filtering	before	separate	separate
Template and Metamodel	before	separate	separate
Frame Processors	before	separate	separate
API-based Generators	before/during/after	separate	separate
Inline Generation	before/during	mixed	integrated
Code Attributes	before/during	(mixed)	separate

Pragmatics of Code Generation

- Which functionality to generate
  - not provided by the platform
  - describable with a DSL
- Generating the final application
  - one build process which regenerates all generated and transformed artifacts
  - without manual intervention or fixing
- Exploiting the model beyond generated code
  - Component tests
  - Simple GUIs
  - Database generation scripts
  - Component configurations

Code Generation
Examples for Configurations

- Software
  - EJB deployment descriptors
  - Behavior for web frameworks like Struts
  - Hibernate configurations
  - CORBA IDL
- Hardware (from deployment diagrams)
  - Installation of components on particular machines
  - Generation of database tables
  - Infrastructure like load balancers

Code Generation

Pretty Code

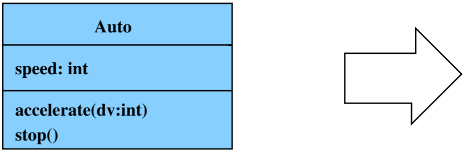
- People look at generated code
  - They do not trust the generator (initially)
  - Debugging
  - Checking the configuration of the generator
- How to improve acceptance
  - Generate comments with information from the models
  - Pretty printer for code formatting
  - Use “location strings”

    ```
    [2006-07-02 10:58:36]
    GENERATED FROM TEMPLATE MdsdBook
    MODEL ELEMENT aChapter::aSection::generate()
    ```
- Exception: portions optimized for performance

- Keep generated and hand-written code separate as much as possible
- Use a suitable software architecture for this task
  - what is generated
  - what is written manually
  - how the two are combined
  - tools: interfaces, abstract classes, delegation, design patterns (Factory, Strategy, Bridge, Template Method)
- Generated code should be a throw-away product!

Generated vs Non-Generated

Standard Solution: Protected Regions

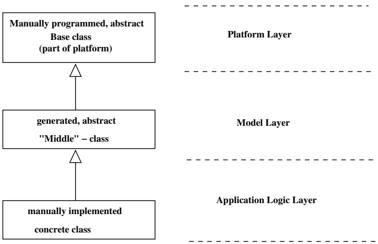



```
public class Auto{
        int speed = 0;
        public void accelerate (int dv){
        //protected area begin – 0001
        //insert your code here
        //protected area end –0001
        }
        public void stop(){
        //protected area begin – 0002
        //insert your code here
        //protected area end – 0002
        }
  }
```

- complex generation
- not always possible to preserve contents
- weak separation between generated and non-generated code

Generated vs Non-Generated

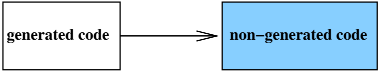
Alternative Solution: Layered Implementation



- Three layers of functionality
  - identical for all components of a certain kind
  - different for each component, but can be generated from the model
  - manual implementation

Generated vs Non-Generated

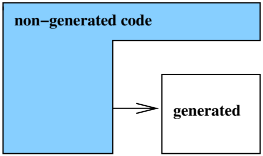
Combination a



- Generated code calls non-generated code
- Advice: only generate a small portion of code at a time and integrate with existing, tested code

Generated vs Non-Generated

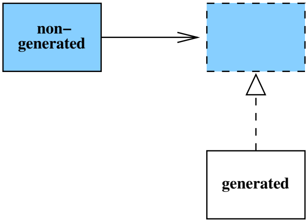
Combination b



- Manual code calls generated code
- Requires knowledge of generated code
- May generate dependencies in the build process

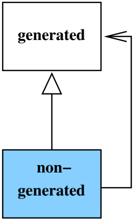
Generated vs Non-Generated

Combination c



- Generated code
  - inherits from manual code or
  - implements a manual interface
- Manual code
  - has some interface to program against
  - can instantiate generated code via Factory pattern

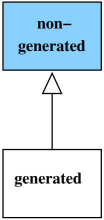
Generated vs Non-Generated
Combination d



- Manual code inherits from generated code
- Implementation may override generated, generic behavior
- Factory

Generated vs Non-Generated

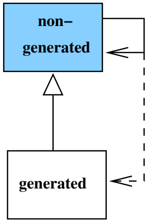
Combination e



- Generated code inherits from manual code
- Invokes operations in manual code

Generated vs Non-Generated

Combination f



- Manual class invokes operations of generated subclass
- Template Method pattern
- Superclass defines abstract operations
- Generated subclass implements these operations

Generated vs Non-Generated

Consequences for Methodology

- Multi-layer generation may be necessary because of dependencies
- First generation step:
  - generates set of base classes from certain model elements
  - yields “API” for the manual part
- Second generation step:
  - generation involves all model elements
  - references (potentially) manually written parts

Generated vs Non-Generated
Constraints

- The programmer shoud not be able to subvert the model constraints.

Generated vs Non-Generated

Constraints and Protected Regions

```
// generated
class Account {
  int balance;
  public void increase ( int amount ) {
    assert (amount > 0);
    // check precondition
    int balance_atPre = balance;
    // saved for postcondition
    // --- protected region begin ---

    // --- protected region end ---
    assert (balance = balance_atPre + amount);
    // check postcondition
  }
}
```

- insufficient protection
- simple inheritance does not help, either

Generated vs Non-Generated

Constraints and Template Method

```
// generated
class Account {
  int balance;
  public final void increase ( int amount ) {
    assert (amount > 0);          // check precondition
    int balance_atPre = balance; // saved for postcondition
    increase_internal (amount);
    assert (balance = balance_atPre + amount); // chk postcondition
  }
  protected abstract void increase_internal (int amount);
}
```

- no way to subvert the dynamic contract monitoring

```
// manually written code
class AccountImpl extends Account {
  protected void increase_internal (int amount) {
    balance += amount;
  }
}
```

Generated vs Non-Generated

Consistency

- The programmer still has to follow some conventions in manually written code
  - Naming conventions
  - Class must inherit from a certain generated class and must override certain operations
  - Class must implement certain interfaces
  - Class must implement certain operations
- Check these conventions by generating code that tests them

Generated vs Non-Generated
Consistency Example

```
// generated
public abstract class SomeGeneratedBaseClass
  extends SomePlatFormClass {
  protected abstract void someOperation ();
  public void someOtherOp() {
    someOperation();
  }
}
```

- Obligations of the developer
  - must inherit from this class
  - must override `someOperation()`
  - must name the class `...Impl`
  - must implement `IExampleInterface`

Generated vs Non-Generated

Consistency Example: Good Implementation

```
public class SomeGeneratedBaseClassImpl
    extends SomeGeneratedBaseClass
    implements IExampleInterface {
  protected void someOperation () {
    // do something
  }
  public void anOperationFromExampleInterface() {
    // ...
  }
```

Generated vs Non-Generated

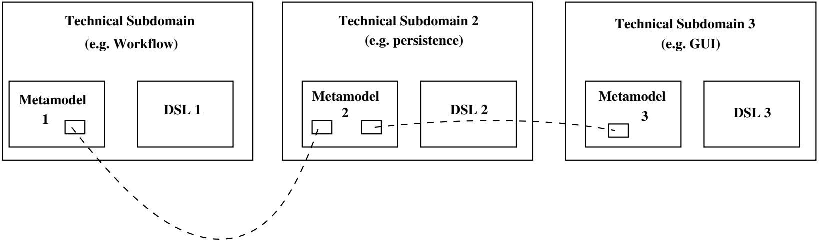
Consistency Example: Enforcement by Compiler

```
public abstract class SomeGeneratedBaseClass
    extends SomePlatFormClass {
  // (see above)
  private void dontCallMe () {
    new SomeGeneratedBaseClassImpl();
      // checks that class is present
      // and not abstract
    SomeGeneratedBaseClass a =
      new SomeGeneratedBaseClassImpl ();
      // checks that class is subclass
    IExampleInterface x =
      new SomeGeneratedBaseClassImpl ();
      // checks that class implements
  }
}
```

Splitting in Technical Subdomains

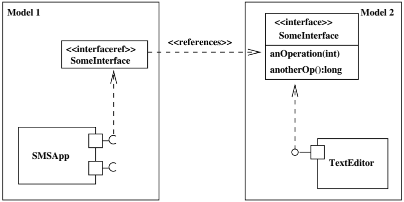
- Large systems have a multitude of aspects
- Consequently
  - models become large
  - one single DSL not adequate
  - splitting of tasks for multiple teams hard
- Multiple DSLs with different modeling required
- Generator unifies the different models
- Must communicate via *gateway metaclasses*

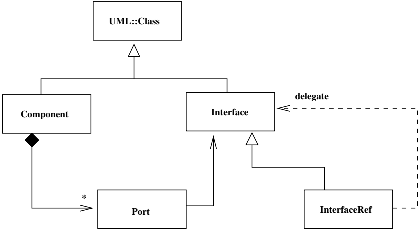
Splitting in Technical Subdomains
Gateway Metaclasses



- Metamodel elements which are used in multiple metamodels
- May result in information duplication because multiple definitions of a modeling element must be kept consistent
- Solved via proxy elements that reference modeling elements in another metamodel

Splitting in Technical Subdomains
Proxy Elements





Metaobjects
The Problem

- Some applications need model information at runtime
  - for scripting
  - for debugging
- How can model information be transported to runtime?
- Example: Logging of generated objects should happen with attribute names and attribute values
- Reflection helps only partially, it still cannot provide info from the underlying model (before model transformation)
- Solution: generate metaobjects that contain the desired information
- Association with concrete objects
  - via generated `getMetaObject ()` operations
  - via central registry

Metaobjects
Example