How generic language extensions enable "open–world" design in Java

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Abstract

By open–world design we mean that collaborating classes are so loosely coupled that changes in one class do not propagate to the other classes, and single classes can be isolated and integrated in other contexts. Of course, this is what maintainability and reusability is all about.

In the paper, we will demonstrate that in Java even an open–world design of mere attribute access can only be achieved if static safety is sacrificed, and that this conflict is unresolvable even if the attribute type is fixed. With generic language extensions such as GJ, which is a generic extension of Java, it is possible to combine static type safety and open–world design. As a consequence, genericity should be viewed as a first–class design feature, because generic language features are preferably applied in many situations in which object–orientedness seems appropriate.

We chose Java as the base of the discussion because Java is commonly known and several advanced features of Java aim at a loose coupling of classes. In particular, the paper is intended to make a strong point in favor of generic extensions of Java.

Keywords

Java, GJ, Generic Programming, Data Accessor, Algorithm Engineering
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1 Introduction

If collaborating classes are strongly coupled with each other, none of them can be modified in isolation or incorporated into a different context. In other words, maintenance and reuse are seriously limited. Basically, collaboration of two classes $\mathcal{A}$ and $\mathcal{B}$ means that objects of class $\mathcal{A}$ access the methods of objects of class $\mathcal{B}$ (often also vice versa).

In many software designs, method access is the main reason for strong coupling: as long as objects of $\mathcal{B}$ are merely “passed on” by objects of $\mathcal{A}$ and no method of $\mathcal{B}$ is called inside $\mathcal{A}$, the implementation of $\mathcal{A}$ may treat $\mathcal{B}$ objects as more or less anonymous (e.g. as objects of type $\text{Object}$ in Java), so $\mathcal{A}$ and $\mathcal{B}$ are particularly loosely coupled.

Design concepts based on event sending (like in JavaBeans [6]) provide an alternative to direct method access, which allows a weaker coupling. However, such a design is certainly not a feasible alternative under all circumstances. Hence, the problem of flexible, yet safe method access is still important. By safe we mean statically safe in the first place, that is, if a method of an object is called in some piece of code, a static analysis of this piece of code at compile time is able to determine whether this object offers the required method and the signature of this method is also as required.

There has been a long–standing debate in various scientific and other communities whether static safety at compile time is important or dynamic checks at run time would be sufficient. In fact, various languages (notably Smalltalk) do not offer static safety at all. It is our feeling that there is no general answer to this question: static safety is highly desirable in some situations, and not of any use in other situations. We will analyze this problem in Section 2.3. It will turn out that the differences between these two kinds of situations are rather subtle.

The discussion in this paper will be along the lines of a concrete, step–by–step

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1Section 2.2 explains loose coupling in greater detail.
2We use the unspecific term “piece of code” here and at other points to avoid terms that are ambiguous (“component,” “module,” etc.) or whose meanings are too specific for our purposes (“subroutine,” “function,” “method,” etc.).
3The signature of a method comprises its name, list of argument types, return type, and the exceptions thrown by this method. The signature of a class or interface is determined by the signatures of its public methods.
case study, which is introduced in Section 2. This case study is taken from a realm that is quite common in Java programming: the processing of visual data.

Section 2 starts with a case study about attribute access in Java and the following sections describe the disadvantages of the first solution. Sections 2.2 and 2.3 explain in detail what is meant by loose coupling and static type safety. Sections 2.4–2.6 will demonstrate that even the advanced features, which are applicable for attribute access in Java do not sufficiently support these goals (not even in case the type of the attribute is fixed). Section 2.7 demonstrates the problems that are introduced when the attribute type is made variable in an algorithm. Section 2.8 shows how loose coupling and static type safety may be resolved through a parametrically polymorphic design, which is not possible in pure Java, but in generic language extensions such as GJ [2] (see [1] for a relatively recent survey of generic Java extensions).

From the reader we assume Java or C++ literacy and familiarity with object-oriented programming concepts such as classes and inheritance. The appendices at the end of the article briefly introduce specific Java and GJ concepts (enumerations, inner classes, reflection, and parametric polymorphism), which do not have exact counterparts in other object-oriented languages.

An extended version of the code examples quoted in this manuscript can be found at

http://www.mpi-sb.mpg.de/~marco/OpenWorld/
2 Simple Case Study

Our running example is a simple shape–oriented image–processing algorithm, which accesses abstract attributes of two–dimensional geometric shape objects via a pair of get/set methods.

For example, the color and texture of a (monochromatic) geometric object are two typical abstract attributes. If the borderline and the interior of a shape may have different colors, each geometric object has two color attributes: borderline color and interior color.

In this article, an (abstract) attribute of a class or interface is a conceptual, abstract entity. is associated with objects of class / interface . is publicly accessible. has a certain data type (primitive or class type).

Abstract means that its implementation is left open. The usual way of attaching an attribute to a class is to make it a private data member of and to add access methods for this member to the public part of (often, the word attribute is exclusively used to refer to data members of classes). However, other ways of realizing an abstract attribute are sometimes more suitable. We will come back to this point later on (Section 2.2).

It goes without saying that this simple example is only a representative of more complex scenarios, in which the problems discussed here are even more urgent.

2.1 Straightforward Implementation

For simplicity, we assume in our running example that geometric objects are purely monochromatic. However, we do not regard the color of an object as a single attribute, but as a composition of three attributes: red, green, and blue, according to the RGB encoding scheme. In other words, the color of a geometric object is represented by a triple (red,green,blue) of objects, each in the range

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from 0 to 1. Then (1,0,0) means plain red, (0,1,0) is green, and (0,0,1) is blue. The code (0,0,0) stands for black, and (1,1,1) for white, and so on. This encoding scheme for colors is also used in the Java color model, which is realized by class java.awt.image.ColorModel.

Two–dimensional geometric shapes may then be represented by an interface like the following, which we name GeomShape2D.

For technical reasons, which will become evident later on, we will not use the primitive type double, but the corresponding wrapper class java.lang.Double:

```java
public interface GeomShape2D {
    public Double getRed ();
    public Double getGreen ();
    public Double getBlue ();
    public void setRed (Double r);
    public void setGreen (Double g);
    public void setBlue (Double b);

    // Further general methods for arbitrary two-dimensional
    // shapes, e.g. for shifting or rotating a shape object
}
```

We have added UML diagrams to the source code examples to improve the understanding of the text.

UML means unified modelling language and can be used to describe e.g. class hierarchy and dependency. For example, in figure 2.1, class SomeShape is derived from the interface GeomShape2D. The line between Algorithm2 and GeomShape2D means that there is a relation. Here, the geometric shapes of the algorithm are weakly associated with the algorithm, i.e. the algorithm holds a set of references. We omitted the number of references, but in the whole paper, geom_shapes always represents a set of references, and all other relations are single references (like myColor in figure 2.2). The method adjustRed() is always annotated with a small box containing a fragment from its implementation. Sometimes the signatures of the methods are given as well - method ( parameter : Integer ) : Double means that this method takes a single parameter 'parameter' of type integer and returns an object of type Double.

Therefore we can describe figure 2.1 as follows: An algorithm class has a method adjustRed() which can be called to do some modification on a set of geometric two-dimensional shapes. A concrete shape (like a circle, line or square) may be derived from the base class. The method adjustRed accesses the attribute values through the interface of each shape, i.e. by calling the methods provided by GeomShape2D.

For example, an image composed of two–dimensional shapes may be modeled as an object of class java.util.Vector, whose items shall be objects of

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1The C++ literate reader may think of a pure abstract class.
classes implementing interface GeomShape2D:

```
Vector geom_shapes = new Vector();
```

For the sake of argument, suppose we want to perform the following simple image processing operation: the RGB-values of each geometric object in `geom_shapes` are modified such that the sum of the three color values (the brightness) is not changed, but the contribution of red is increased by 10%\(^2\). The mathematical details of the algorithm are not relevant. The main point is the impression that even such a simple algorithm may result in a complex, error-prone implementation, which is hard to understand and even harder to maintain.

\(^2\)If red already contributes more than 90% to the color of an object, we set the color of this object to plain red, that is \((1,0,0)\).
public static void adjustRed (Enumeration enum, double percentage) {
    // See Appendix A on Enumerations for a brief introduction into this Java feature.
    while (enum.hasMoreElements ()) {
        Object obj = enum.nextElement ();
        GeomShape2D shape =(GeomShape2D)(obj);
        double red = shape.getRed ().doubleValue ();
        if (red > 1-percentage/100) {
            shape.setRed (new Double (1));
            shape.setGreen (new Double (0));
            shape.setBlue (new Double (0));
        } else {
            double new_red = red + percentage/100;
            double green = shape.getGreen ().doubleValue ();
            double blue = shape.getBlue ().doubleValue ();
            shape.setRed (new Double (new_red));
            shape.setGreen (new Double ((1-new_red) *(green/(green+blue))));
            shape.setBlue (new Double (1-new_red-green));
        }
    }
}

Clearly, unlike in C and C++, every function must be a method of some class. Let’s assume the class of adjustRed is a mere container of geometric algorithms and called GeomAlgorithms. Then a call to adjustRed to increase the contribution of red by 10% looks like this:

GeomAlgorithms.adjustRed (geom.shapes.elements (), 10.0);

The key word static in the header of adjustRed allows a call to adjustRed without an actual object of class GeomAlgorithms, simply by qualifying the name of the class.

2.2 Goal 1: Loose Coupling

The fact that geometric objects are represented by interface GeomShape2D, and that the basic colors red, green, and blue are accessed by methods getRed, setRed, etc., is “hard–wired” in the algorithm adjustRed. Such a strong coupling of a piece of code with its context is generally undesirable:

1. It is very likely that future maintenance work will affect the protocol used to tie a piece of code together with its collaborators. It is even more likely that a new application context will impose a completely different protocol.

2. It is highly uneconomical and error–prone to implement non–trivial pieces of code repeatedly from scratch (or to revise them exhaustively) whenever
the context changes through maintenance work or the subroutine shall be applied in a different context.

The goal is to minimize strong coupling. A positive formulation is to design loosely coupled software.

To stick to our running example: for adjustRed this means it cannot be assumed that the underlying geometric shape class will always be named GeomShape2D, that the RGB values are always accessed through methods get/setRed, etc., and that these methods always have the same signatures as in GeomShape2D. Even a subroutine as simple as adjustRed is complex enough to make the adaptation to another “protocol” a potentially hazardous effort, because the “volatile” details are helplessly intermixed with the logic of the subroutine.

At first glance, this statement may look a bit too strong, because it seems that the details to be changed can be easily found in the code and modified by straightforward changes. However, the discussion of the following three variations will give an imagination how complex such a modification actually may be in practice. Each of these variations is realistic and has been found in projects, and adapting an algorithm such as adjustRed to any of them is by no means trivial.

2.2.1 First variation: combined attributes

In the first variation of GeomShape2D (i.e. interface GeomShape2D below), the three basic colors are not realized as three mutually independent attributes of GeomShape2D, but form one attribute of type RGBColor, say, which comprises three Double values (see figure 2.2 for the corresponding UML diagram):
class RGBColor {
    Double red, green, blue;
    RGBColor (Double red, Double green, Double blue) {
        this.red = red;
        this.green = green;
        this.blue = blue;
    }
    public Double getRedPart () {
        return red; }
    public Double getGreenPart () {
        return green; }
    public Double getBluePart () {
        return blue; }
    public void setRedPart (Double red) {
        this.red = red; }
    public void setGreenPart (Double green) {
        this.green = green; }
    public void setBluePart (Double blue) {
        this.blue = blue; }
}

Figure 2.2 UML-diagram for first variation
The following variant of `GeomShape2D` represents geometric objects whose colors are implemented by class `RGBColor`:

```java
public interface GeomShape2D2 {
    public RGBColor getColor ();
    // Further general methods for arbitrary two-dimensional shapes, e.g. for shifting or rotating a shape object
}
```

### 2.2.2 Second variation: separate attributes

So far, we did not distinguish between abstract attributes and data members of classes, which are also often called attributes. However, an attribute is not necessarily a data member but, more generally, a conceptual entity related to a class, which has a designated type and associates a value of this type to every object of the class. An attribute may be implemented as a data member of this class (for example, accompanied by a pair of get/set methods as above). However, it may also be implemented completely differently, as we will see in the scenario that we are going to discuss next.

If an attribute of a class $A$ is implemented as a data member of $A$, it is permanently associated with $A$. Sometimes it is useful or even necessary to attach an additional, temporary, attribute to existing objects of type $A$. For instance, if geometric shapes are not designed to have a color, the objects in a collection of `GeomShape2D` (such as `geom_shapes`) cannot be assigned color values other than by storing all of these values in separate, additional data structures. For example, in Java the three additional RGB values could be stored in three separate dictionaries from `java.util.Dictionary`, which are realized by `java.util.HashTable` (see again figure 2.3 for the corresponding UML-diagram):

```java
Dictionary red_dictionary   = new HashTable ();
Dictionary green_dictionary = new HashTable ();
Dictionary blue_dictionary  = new HashTable ();
```

The formal type of items in dictionaries is `Object`, however, the corresponding implementation of `adjustRed` assumes that all objects in these three dictionaries are of subtype `Double`:
Figure 2.3 UML-diagram for second variation

```java
public static adjustRed2(Enumeration enum, Dictionary red_dict, Dictionary green_dict, Dictionary blue_dict, double percentage) {
    while (enum.hasMoreElements ()) {
        Object obj = enum.nextElement ();
        double red = red_dict.get (obj).doubleValue ();
        if (red > 1-percentage/100) {
            red_dict.put (obj, new Double (1));
            green_dict.put (obj, new Double (0));
            blue_dict.put (obj, new Double (0));
        } else {
            // etc.
        }
    }
}
```

In other words, to set and retrieve a basic color of a geometric object obj, this object serves as the key to the methods put and get of Dictionary.

It is beyond the scope of this paper to discuss whether storing attributes in separate containers is a reasonable approach (see Section 2.2 of [7] for an in–depth discussion). Here we only note that designs like this actually appear in practice and have to be coped with.

2.2.3 Third variation: different encoding

RGB is but one possible encoding scheme for colors. For example, it is also possible to express every color as a composition of a hue value, a saturation value, and a brightness value. This is the well–known HSB encoding scheme for colors. The RGB and HSB encoding schemes are equivalent in the sense that there are two algorithms that translate an RGB specification into an HSB specification and vice versa. The following, third version of GeomShape2D represents the color of a geometric object according to the HSB scheme (see figure 2.4 for the corresponding UML-diagram):
public interface GeomShape2D3 {
    public Double getHue();
    public Double getSaturation();
    public Double getBrightness();
    public void setHue(Double h);
    public void setSaturation(Double s);
    public void setBrightness(Double b);

    // Further general methods for arbitrary two-dimensional
    // shapes, e.g. for shifting or rotating a shape object
}

Figure 2.4 UML-diagram for third variation

Summary of Section 2.2
A feature of a class (even a feature as simple as a single
attribute!) may appear in quite different ways in the
class’ interface. A true open–world design of a client
must be able to cope with all of them.

2.3 Goal 2: Static Safety

This section is intended to clarify our viewpoint on static (type) safety. Static safety
can be destroyed by an evaluation of run–time type information. For example, the
down–cast in adjustRed from Object to GeomShape2D implicitly evaluates the run–time information whether or not the argument’s class implements the inter-
face GeomShape2D. In Java, this information can be explicitly queried through
operator instanceof. On the other hand, reflection (Appendix C) allows the
run–time access to detailed information about the properties of an object’s type.

3Casts in C and C++ are another example of implicit run–time type evaluation, which is even
more dangerous, because here a type error does not raise an exception but may result in undefined
behavior.
We do not regard every application of run–time type information as loss of static safety. In fact, we will distinguish between two fundamentally different use scenarios of run–time type information, which look very similar but have fundamentally different semantics. In the first use scenario, a maximum degree of reliability is achieved despite the fact that run–time type information is heavily incorporated. In contrast, the second use scenario reveals a serious gap in static safety.

Note that the implementation of adjustRed in Section 2.1 is not really complete, because a failure of the down–cast from Object to GeomShape2D is not caught. We will consider two different ways of catching such a failure. It will turn out that these two ways are quite representative for the two different use scenarios.

A brief sketch of the first variant:

```java
public static void adjustRed\(_2\)(Enumeration enum, double percentage) {
    while (enum.hasMoreElements ()) {
        Object obj = enum.nextElement ();
        if (obj instanceof GeomShape2D) {
            GeomShape2D shape = (GeomShape2D)(obj);
            // Proceed with the algorithm...
        } else {
            throw MyFavoriteException ();
        }
    }
}
```

And here is the second variant:

```java
public static void adjustRed\(_4\) (Enumeration enum, double percentage) {
    while (enum.hasMoreElements ()) {
        Object obj = enum.nextElement ();
        if (obj instanceof GeomShape2D) {
            GeomShape2D shape = (GeomShape2D)(obj);
            // Proceed with the algorithm...
        }
    }
}
```

Technically speaking, the only difference is the missing else–part in adjustRed\(_4\). However, from an abstract viewpoint both versions implement fundamentally different algorithms. In fact, adjustRed\(_4\) implements the algorithm,

“modify all GeomShape2D objects that are found in geom\_shapes,”

whereas adjustRed\(_3\) implements the algorithm,

“modify all items of geom\_shapes(assuming that all of them are GeomShape objects).”
In other words, the application of instanceof and the down–cast are integral ingredients of the algorithm’s logic in method adjustRed. In contrast, in adjustRed3 they are only used to check and reconstruct certain type information, which was lost due to the type anonymity of the objects in the container geom_shapes.

If the test for the correct type is part of the algorithm, a quest for more static type safety certainly does not make any sense. Hence, we regard adjustRed as fully statically safe. However, in the other case such a quest makes perfect sense: if the code does not compile unless all items in geom_shapes are of types implementing interface GeomShape2D, we lose nothing but gain a much higher degree of reliability. This is a case in which we regard an evaluation of run–time type information as statically unsafe.

We believe that the general debate on static safety suffers from a lack of accurate distinction between these two use scenarios. In fact, this distinction seems to be crucial for that discussion. Our example shows that this distinction might be rather subtle, and that the implementations of both use scenarios only differ in (seemingly) minor details, so it is not surprising that there is a lot of confusion in this debate.

In the rest of the paper, we will concentrate on the second, unsafe, use scenario.

Summary of Section 2.3
An evaluation of run–time type information that does not belong to the logic of a piece of code but is merely used to reconstruct lost type information indicates an unnecessary (and potentially dangerous) lack of static safety.

2.4 “Non–Solutions”

Clearly, an implementation of the general design pattern adapter [3] seems the right way of achieving loose coupling. We will come back to adapters in the very next section. In this section, we will dwell a bit on certain advanced features of Java, which also aim at loose coupling: inner classes and reflection. Besides their unquestionable merits, both of them miss both goals stated in Sections 2.2 and 2.3. It might be instructive to analyze this failure before going on with adapters.

2.4.1 Inner classes

A common idiom in Java is the usage of inner classes as wrappers (see Appendix B). For example, the next variant of our interface for geometric shapes, GeomShape2D, is based on the following wrapper class, which is named DataWrapper:
public interface DataWrapper {
    public Double getValue ();
    public void setValue (Double value);
}

public interface GeomShape2D4 {
    public DataWrapper getRedWrapper ();
    public DataWrapper getGreenWrapper ();
    public DataWrapper getBlueWrapper ();

    // Further general methods for arbitrary two-dimensional shapes, 
    // e.g. for shifting or rotating a shape object
}

The idea is this: getRedWrapper returns a DataWrapper whose methods read and overwrite the red color of the corresponding shape object (getGreenWrapper and getBlueWrapper analogously). The following implementation of the interface GeomShape2D4 demonstrates this technique:

public class GeomShape2DWithColorWrappers implements GeomShape2D4 {
    Double red;
    Double green;
    Double blue;

    // Color wrappers:
    public class RedWrapper implements DataWrapper {
        public Double getValue () {
            return GeomShape2DWithColorWrappers.this.red;
        }
        public void setValue (Double red) {
            GeomShape2DWithColorWrappers.this.red = red;
        }
    }

    public DataWrapper getRedWrapper () {
        return new RedWrapper ();
    }

    // Analogous inner classes Green/BlueWrapper and methods getGreen/BlueWrapper
    // Further methods of GeomShape2D4
}

An implementation of adjustRed in which inner classes encapsulate the method access:
public static void adjustRed(Enumeration enum, double percentage) {
    while (enum.hasMoreElements ()) {
        Object obj = enum.nextElement ();
        if (obj instanceof GeomShape2D) {
            GeomShape2D shape = (GeomShape2D)(obj);
            DataWrapper red_wrapper = shape.getRedWrapper ();
            DataWrapper green_wrapper = shape.getGreenWrapper ();
            DataWrapper blue_wrapper = shape.getBlueWrapper ();
            double red = red_wrapper.getValue ().doubleValue ();
            if (red > 1-percentage/100) {
                red_wrapper.setValue (new Double (1));
                green_wrapper.setValue (new Double (0));
                blue_wrapper.setValue (new Double (0));
            } else {
                // etc.
            }
        } else throw MyFavoriteException ();
    }
}

It might be obvious from this example that inner classes do not really solve the problem we addressed in Section 2.2.\footnote{At first glance, there seems to be an elegant workaround: the methods \texttt{getRed/ Green/ BlueWrapper} are not called inside \texttt{adjustRed}. Instead, \texttt{adjustRed} has three enumerations arguments, which refer to sequences of \texttt{DataWrapper} objects for all three colors. More specifically, for every item in the original sequence \texttt{geom\_shapes} there is a \texttt{DataWrapper} object in each of the new sequences, which refers to the original item. However, static safety is still missing, and a really loose coupling is not achieved either, because \texttt{adjustRed} still depends on the existence of inner classes implementing \texttt{DataWrapper}. In other words, \texttt{adjustRed} would not depend on the exact signatures of \texttt{getRed/ Green/ BlueWrapper} anymore but still on the \texttt{16

2.4.2 Reflection

Run–time type information can be used to access all methods of a class without knowing in advance which methods this class offers and which signatures they have. In Java, reflection is implemented by the \texttt{reflection API}\footnote{\texttt{}}. This package cannot handle primitive types, which is one of the reasons why the design of the case study from Section 2.1 relies on class \texttt{Double} instead of primitive type \texttt{double}.

A variant of method \texttt{adjustRed} based on reflection (sketched) can be seen in figure 2.5.

Clearly, static safety is completely missed. On the other hand, the names
Figure 2.5 A variant of method adjustRed based on reflection (sketched).

```java
class public void adjustRed(Enumeration enum,
    String name_of_red_get_method, String name_of_red_set_method,
    String name_of_green_get_method, String name_of_green_set_method,
    String name_of_blue_get_method, String name_of_blue_set_method,
    double percentage) {
    String argument_types_of_red_get = new Class [0];
    String argument_types_of_red_set = new Class [1];
    String argument_values_of_red_get = new Object [0];
    String argument_values_of_red_set = new Object [1];
    try {
        argument_types_of_red_set[0] = Class.forName("java.lang.Double");
    }
    catch (Exception e) {
        // Do some reasonable exception handling
    }
    // Analogously green and blue

    while (enum.hasMoreElements ()) {
        Object obj = enum.nextElement ();
        java.lang.reflect.Method get_red;
        java.lang.reflect.Method set_red;
        try {
            get_red = obj.getClass ().getMethod (name_of_red_get_method, argument_types_of_red_get);
            set_red = obj.getClass ().getMethod (name_of_red_set_method, argument_types_of_red_set);
        }
        catch (Exception e) {
            // Do some reasonable exception handling
        }
        // Analogously green and blue

        Double red_obj = get_red.invoke (obj, argument_values_of_red_get);
        double red = red_obj.doubleValue ();
        if (red > 1 - percentage/100) {
            set_red.invoke (obj, new Double (1));
            set_green.invoke (obj, new Double (0));
            set_blue.invoke (obj, new Double (0));
        } else {
            // etc.
        }
    }
}
```
and signatures of the color–accessing methods are not hard–wired in the code of adjustRed. However, we note that adjustRed is not really independent of these methods, because the number of arguments of these methods are still hard–wired.\footnote{In principle, Java’s reflection mechanism is powerful enough even to render the number of arguments variable. However, then the problem remains what adjustRed should do in case of, say, additional arguments, that is, what values they should be assigned by adjustRed.}

### Summary of Section 2.4

Even advanced features such as inner classes and reflections, which are specifically intended to implement loose coupling, are not sufficient to achieve the goals in Sections 2.2 and 2.3 simultaneously.

#### 2.5 Adaptation

The adapter pattern \cite{3} can be used to decouple a class from its clients. In our case study, this means that a subroutine such as adjustRed is not based on the comprehensive interface GeomShape2D, which captures various aspects of geometric shapes, but on a small interface, which only captures the aspects relevant for adjustRed, for example, leaned on the signature of GeomShape2D (see figure 2.6 for the corresponding UML-diagram):

```java
public interface RGBHandler {
    public double getRed (Object obj);
    public double getGreen (Object obj);
    public double getBlue (Object obj);
    public void setRed (Object obj, Double r);
    public void setGreen (Object obj, Double g);
    public void setBlue (Object obj, Double b);
}
```

A variant of adjustRed based on RGBHandler could look like this (sketched):

existence of these three methods (having whatever signatures).
\footnote{See Appendix C or java.lang.reflect.*.}
Figure 2.6 UML-diagram for rgb handlers

```java
public static void adjustRed(Enumeration enum, RGBHandler rgb, double percentage) {
    while (enum.hasMoreElements()) {
        Object obj = enum.nextElement();
        double red = rgb.getRed(obj).doubleValue();
        if (red < 1 - percentage / 100) {
            rgb.setRed(obj, new Double(1));
            rgb.setGreen(obj, new Double(0));
            rgb.setBlue(obj, new Double(0));
        } else {
            // etc.
        }
    }
}
```

Notice that down-casts are not avoided but moved from the algorithm to the adapting class. To apply `adjustRed` to a class like `GeomShape2D`, a class `GeomShape2D_RGBHandler`, say, is defined, which implements `RGBHandler` and “knows” all relevant details of `GeomShape2D`: 

```java
public static void adjustRed(Enumeration enum, RGBHandler rgb, double percentage) {
    while (enum.hasMoreElements()) {
        Object obj = enum.nextElement();
        double red = rgb.getRed(obj).doubleValue();
        if (red < 1 - percentage / 100) {
            rgb.setRed(obj, new Double(1));
            rgb.setGreen(obj, new Double(0));
            rgb.setBlue(obj, new Double(0));
        } else {
            // etc.
        }
    }
}
```
public class GeomShape2D_RGBHandler implements RGBHandler {
    public Double getRed (Object obj) {
        if (obj instanceof GeomShape2D) {
            return ((GeomShape2D)obj).getRed();
        } else throw MyFavoriteException();
    }

    public void setRed (Object obj, Double r) {
        if (obj instanceof GeomShape2D) {
            ((GeomShape2D)obj).setRed (r);
        } else throw MyFavoriteException();
    }
    // Green and blue analogously
}

Now we can apply adjustRed7 to a sequence of GeomShape2D objects:

GeomShape2D_RGBHandler rgb = new GeomShape2D_RGBHandler;
GeomAlgorithms.adjustRed7(geom_shapes.elements (), rgb, 10.0);

In general, the individual attributes of a class are not as strongly coupled as the RGB color values of a geometric shape. Hence, in general it might be preferable to provide one separate handler object for each attribute. Such a one–to–one correspondence between attributes and handlers would exactly implement the data–accessor concept as introduced in [4] or [5] and discussed in [7]. Note however, that although adapter and data accessor are similar on the implementation side, they are completely different in their intent (see [5] for a detailed discussion): the intent of data accessors is to encapsulate the access to attributes of classes in small, light–weight classes. This allows a common, uniform interface for all attributes of all classes, which means that classes and attributes are easily exchangeable in an attribute–accessing client such as adjustRed.7 To emphasize that the following data–accessor interface only applies to attributes of type Double, we will call the interface DoubleAccessor (see figure 2.7 for the UML-diagram):

public interface DoubleAccessor {
    public Double get (Object obj);
    public void set (Object obj, Double value);
}

7Note that the JavaBeans convention for method signatures [6] does not provide a uniform interface to attributes in the strong sense as used in this paper. In the JavaBeans approach, the signatures of a pair of get/set methods depend on the name of the attribute in a disciplined manner. In contrast, the signatures of the get/set methods of a data accessor do not at all depend on the name and type of the attribute. This difference results from different goals: the JavaBeans approach allows an easy access of each attribute given the name of the attribute, whereas we need a convention that renders the name of the attribute completely anonymous to allow an easy exchange.

20
And the corresponding implementation of adjustRed (see figure 2.8 for a UML-diagram):

```java
public static void adjustRed(Enumeration enum, DoubleAccessor red_acc, DoubleAccessor green_acc, DoubleAccessor blue_acc, double percentage) {
    while (enum.hasMoreElements()) {
        Object obj = enum.nextElement();
        double red = red_acc.get(obj).doubleValue();
        if (red > 1 - percentage / 100) {
            red_acc.set(obj, Double.valueOf(1));
            green_acc.set(obj, Double.valueOf(0));
            blue_acc.set(obj, Double.valueOf(0));
        } else {
            // etc.
        }
    }
}
```

For ease of exposition, we will use the variant adjustRed in the rest of the paper.
2.6 Data Accessors and Down–Casts

Unfortunately, using data accessors in Java results in many down–casts due to the fact that the object type is left open in the interface `DoubleAccessor` (it is `Object`). We will illustrate this problem by sketching the implementation of an appropriate data–accessor class for the basic scenario from Section 2.1 and for the variations from Section 2.2.

The crucial impression to be taken from the examples is this: each scenario will require a down–cast of the kind that indicates an unnecessary lack of static safety. For ease of exposition, we omit all exception handling, and we only give the accessors for the red color value.

2.6.1 Data Accessor for Straightforward Implementation

Here is a data–accessor class for the red color value based on interface `GeomShape2D` from Section 2.1, page 5:

```java
public class RedAccessor implements DoubleAccessor {
    public Double get (Object obj) {
        return ((GeomShape2D)obj).getRed ();
    }
    public Double set (Object obj, Double value) {
        ((GeomShape2D)obj).setRed (value);
    }
}
```

2.6.2 First variation: combined attributes

For `GeomShape2D₂` (i.e. first variation in Section 2.2, page 2.2.1):

```java
public class RedAccessor₂ implements DoubleAccessor {
    public Double get (Object obj) {
        GeomShape2D₂ shape = (GeomShape2D₂) obj;
        return shape.getColor ().getRedPart ();
    }
    public Double set (Object obj, Double value) {
        GeomShape2D₂ shape = (GeomShape2D₂) obj;
        shape.getColor ().setRedPart (value);
    }
}
```
2.6.3 Second Variation: Dictionaries

The data-accessor class for the second variation from Section 2.2, page 2.2.2 is somewhat different. Since the color values are stored outside the shape class, they must be handed over to the data accessors in a way that does not affect the code of adjustRed. In other words, the data accessors must receive the color values before adjustRed is called (e.g. as an argument to the constructor). Interestingly, this particular data-accessor class is not bound to a specific implementation of geometric shapes, not even to a specific attribute, because the shape object is merely handed over anonymously to the dictionary of attribute values. In fact, DoubleDictAccessor only depends on the attribute type Double, which enforces another down-cast:

```java
public class DoubleDictAccessor implements DoubleAccessor {
    Dictionary dictionary;
    public DoubleDictAccessor (Dictionary dictionary) {
        this.dictionary = dictionary;
    }
    public Double get (Object obj) {
        Object item = dictionary.get (obj);
        return (Double)item;
    }
    public void set (Object obj, Double value) {
        dictionary.put (obj, value);
    }
}
```

2.6.4 Third variation: different encoding

Next we consider a data-accessor class for GeomShape2D (third variation in Section 2.2, page 11). The following implementation, RedHSBAccessor, is based on three further data accessors, which access the hue, saturation, and brightness value of the geometric shape object, respectively. Hence, this class, which performs non-trivial algorithmic tasks, is also decoupled from all “volatile” details of the underlying shape class and might itself be better maintainable and reusable.

\[\text{For ease of exposition, the conversion algorithms RGB-HSB are integrated in the data-accessor class. In a more realistic design they would be implemented as methods of a separate class.}\]
public class RedAccessor
implements DoubleAccessor {
    DoubleAccessor hue_acc;
    DoubleAccessor saturation_acc;
    DoubleAccessor brightness_acc;
    public RedAccessor(DoubleAccessor hue_acc, 
                        DoubleAccessor saturation_acc, DoubleAccessor brightness_acc) {
        this.hue_acc = hue_acc;
        this.saturation_acc = saturation_acc;
        this.brightness_acc = brightness_acc;
    }
    public Double get (Object obj) {
        Double hue = hue_acc.get (obj);
        Double saturation = saturation_acc.get (obj);
        Double brightness = brightness_acc.get (obj);
        Double red = /* Red part of result HSB → RGB */
                     return red;
    }
    public void set (Object obj, Double value) {
        Double hue = hue_acc.get (obj);
        Double saturation = saturation_acc.get (obj);
        Double brightness = brightness_acc.get (obj);
        Double green;
        Double blue;
        /* Compute green and blue from hue, saturation, and brightness */
        /* Compute the new values of hue, saturation, 
        and brightness from the RGB triple (value,green,blue) */
        hue_acc.set (obj, hue);
        saturation_acc.set (obj, saturation);
        brightness_acc.set (obj, brightness);
    }
}

2.6.5 Inner classes

For completeness, we will also show how to bring interface GeomShape2D₄ from 
Section 2.4 into the game:
public class RedAccessor implements DoubleAccessor {
    public Double get (Object obj) {
        GeomShape2D shape = (GeomShape2D)obj;
        return shape.getRedWrapper().getValue();
    }
    public void set (Object obj, Double value) {
        GeomShape2D shape = (GeomShape2D)obj;
        shape.getRedWrapper().setVal (value);
    }
}

2.6.6 Reflection

To conclude this section, it might be instructive to see how a data accessor may be based on reflection instead of mere down-casts. Of course, this does not change the overall conclusion that there remains a lack of static safety.
public class ReflectionAccessor implements DoubleAccessor {
    String name_of_get_method, name_of_set_method;
    Class [] argument_types_of_get, Class [] argument_types_of_set;
    Object [] argument_values_of_get, Object [] argument_values_of_set;
    ReflectionAccessor (String name_of_get_method,
        String name_of_set_method) { 
        this.name_of_get_method = name_of_get_method;
        this.name_of_set_method = name_of_set_method;
        argument_types_of_get = new Class [0];
        argument_types_of_set = new Class [1];
        argument_values_of_get = new Object [0];
        argument_values_of_set = new Object [1];
        try {
            argument_types_of_set[0] = Class.forName("java.lang.Double");
        } 
        catch (Exception e) {
            // Do some reasonable exception handling
        }
    }
    public Double get (Object obj) {
        GeomShape2D3 shape = (GeomShape2D3) obj;
        try {
            Method get = shape.getClass ().getMethod (name_of_get_method, argument_types_of_get);
            Object return_obj = get.invoke (shape, argument_values_of_get);
            return (Double) return_obj;
        } 
        catch (Exception e) {
            // Do some reasonable exception handling
        }
    }
    public void set (Object obj, Double value) {
        GeomShape2D3 shape = (GeomShape2D3) obj;
        argument_values_of_set[0] = value;
        try {
            Method set = shape.getClass ().getMethod (name_of_set_method, argument_types_of_set);
            set.invoke (shape, argument_values_of_set);
        } 
        catch (Exception e) {
            // Do some reasonable exception handling
        }
    }
}
Summary of Section 2.6

In pure Java, a true open–world design results in a serious lack of static safety (indicated by down–casts or other ways of evaluating run–time type information). Adapters may encapsulate but not remove this gap.

2.7 Making the Attribute Type Generic

So far, we did not vary the types of the attributes to work out the crucial point more clearly: even if the type of an attribute is fixed, an open–world design of attribute access results in a serious type–safety problem. In this section, we will require for true “open–worldness” that the attribute type is also left variable. It is not surprising that static safety will be seriously affected. However, the extent to which this will happen might be surprising: we will have to introduce an additional, auxiliary interface (named Traits below), and the attribute type and the traits type have to fit together exactly.

To make our algorithm applicable to various attribute types, we have to replace Double by a more general type; Object is the prime candidate for that:

```java
public interface ObjectAccessor {
    public Object get (Object obj);
    public void set (Object obj, Object value);
}
```

Here is an appropriate implementation of ObjectAccessor for the red color value of GeomShape2D:

```java
public class ObjectAccessorRedGeomShape2D implements ObjectAccessor {
    public Object get (Object obj) {
        GeomShape2D shape = (GeomShape2D)obj;
        return shape.getRed ();
    }
    public void set (Object obj, Object value) {
        GeomShape2D shape = (GeomShape2D)obj;
        Double val_obj = (Double)value;
        shape.setRed (val_obj);
    }
}
```

So far, nothing changed. The new problem is due to the fact that our algorithm applies certain operations to objects of the attribute type: the four basic numerical operations and a comparison operation. In view of Section 2.2, we cannot assume that all potential attribute types provide a common signature for all of these operations. Hence, to write down these operations without knowing the concrete
attribute type, we collect these operations in an additional object traits. In the following, a traits object is an instance of a class that implements the following interface:

```java
public interface Traits {
    public Object generate (double x);
    public Object plus (Object val1, Object val2);
    public Object minus (Object val1, Object val2);
    public Object mult (Object val1, Object val2);
    public Object div (Object val1, Object val2);
    public boolean isGreaterThan (Object val1, Object val2);
}
```

The first method returns a reference to an object of the anonymous attribute type, and the value of this object shall represent the value of x. We will only use this method to generate objects representing 0, 1, and 100, respectively. The requirement that these three values are feasible might not cause any problem for any class type that represents real numbers.

The other methods assume that their arguments are of the attribute type. Methods #2–6 are also required to return references to objects of the attribute type. These methods perform the basic arithmetical operations on the attribute type. Finally, the last method returns true if and only if the first argument is to be regarded as greater than the second argument.

Now we are able to formulate a version of adjustRed in which the attribute type is left open. A brief sketch:

---

9The name is borrowed from the analogous traits idiom in C++, which is heavily used in the standard library.
public void adjustRed(Enumeration enum, ObjectAccessor red_acc, ObjectAccessor green_acc, ObjectAccessor blue_acc, Object percentage, Traits traits) {
    Object zero = traits.generate (0);
    Object one = traits.generate (1);
    Object hundred = traits.generate (100);
    Object fraction = traits.div (percentage, hundred);
    Object threshold = traits.minus (one, fraction);
    while (enum.hasMoreElements ()) {
        Object obj = enum.nextElement ();
        Object red = red_acc.get (obj);
        if (traits.isGreaterThan (red, threshold)) {
            obj.setRed (one);
            obj.setGreen (zero);
            obj.setBlue (zero);
        } else {
            // etc.
        }
    }
}

Here is a concrete example of such a traits class, which would perfectly collaborate with ObjectAccessorRed/Green/BlueGeomShape2D via class Double:

```java
public class DoubleTraits implements Traits {
    public Object generate (double x) {
        return new Double (x);
    }
    public Object plus (Object val1, Object val2) {
        double d1 =((Double )val1).doubleValue ();
        double d2 =((Double )val2).doubleValue ();
        return new Double (d1+d2);
    }
    // Analogously: minus, mult, div, isGreaterThan
}
```

Such a design requires even more care, because it must be additionally guaranteed by the software developer that the attribute type and the traits type fit correctly together. Clearly, this kind of unsafe collaborations increases the potential for pitfalls dramatically and is much harder to debug.
Summary of Section 2.7

A generic attribute type requires an unsafe collaboration between the attribute type itself and additional, auxiliary types.

2.8 Parametric Polymorphism: GJ

Of course, the best way to avoid trouble with down–casts is to avoid down–casts at all. However, it seems that in plain Java, down–casts cannot be avoided, unless all data structures are “hard–wired” in the algorithms. Clearly, this would destroy all hope even for a rudimentary form of open–world design. As we saw, this conflict does not seem to be resolvable in plain Java. In this section, we will show that it is resolvable in generic language extensions such as GJ [2]. The essential feature missing in Java is parametric polymorphism(see Appendix D). We will start right from Section 2.7, because the genericity of the attribute type will come as a by–product.

To begin with, we replace the interface ObjectAccessor from Section 2.7 by the interface GenericAccessor, which is equally general, but will not enforce any down–casts\(^\text{10}\) in the classes implementing this interface:

\[
\text{public interface } \text{GenericAccessor}\langle\text{ObjectType}, \text{ValueType}\rangle \{ \\
\text{public ValueType get (ObjectT ype obj);} \\
\text{public void set (ObjectT ype obj, ValueT ype value);} \\
\}
\]

The formal type argument ObjectType stands for the class to which the attribute is associated (i.e. GeomShape2D in our running example), whereas ValueType stands for the attribute type. The goal is to use GenericAccessor to eliminate the need for Object in the definition of adjustRed. Since java.lang.Enumeration also works on Object, we have to replace Enumeration by a variant that is parameterized by the item type of the underlying container:

\[
\text{public interface } \text{GenericEnumeration}\langle\text{ObjectType}\rangle \{ \\
\text{public boolean hasMoreElements ();} \\
\text{public ObjectT ype nextElement ();} \\
\}
\]

Now, our Vector object geom_shapes may be replaced by a vector that is specific to the interface GeomShape2D:

\(^{10}\)According to [2], generic type parameters are internally realized by down–casts in GJ. However, this is an implementation detail of the compiler and does not affect the static safety offered to the developer.
Vector<GeomShape2D> geom_shapes = new Vector<GeomShape2D>();

The traits interface introduced in Section 2.7 is also replaced by a generic one:

```
public interface GenericTraits <ValueType> {
    public static ValueType generate (double x);
    public static ValueType plus (ValueType val1, ValueType val2);
    public static ValueType minus (ValueType val1, ValueType val2);
    public static ValueType mult (ValueType val1, ValueType val2);
    public static ValueType div (ValueType val1, ValueType val2);
    public static boolean isGreaterThan (ValueType val1, ValueType val2);
}
```

Now we are in a position to implement a truly generic version of adjustRed, which we call adjustRed10. This algorithm will be a method of a variant of class GeomAlgorithms from Section 2, which is parameterized by ObjectType and ValueType:

```
public class GeomAlgorithms_<ObjectType, ValueType> {
    public static void adjustRed10 (GenericEnumeration<ObjectType> enum, 
        GenericAccessor<ObjectType, ValueType> red_acc, 
        GenericAccessor<ObjectType, ValueType> green_acc, 
        GenericAccessor<ObjectType, ValueType> blue_acc, 
        ValueType percentage, 
        GenericTraits<ValueType> traits) {
        ValueType zero = traits.generate (0); 
        ValueType one = traits.generate (1); 
        ValueType hundred = traits.generate (100); 
        ValueType fraction = traits.div (percentage, hundred); 
        ValueType threshold = traits.minus (one, fraction); 
        while (enum.hasMoreElements ()) {
            ObjectType shape = enum.nextElement (); 
            ValueType red = red_acc.get (shape); 
            if (traits.isGreaterThan (red, threshold)) {
                shape.setRed (one); 
                shape.setGreen (zero); 
                shape.setBlue (zero); 
            } else { 
                // etc. 
            }
        }
    }
}
```

The following variant is a concrete example of how the interface Generic-
cAccessor may be implemented in order to access a concrete attribute of a concrete class/interface such as GeomShape2D.

```java
public class AccessorRedGeomShape2D implements GenericAccessor<GeomShape2D, Double> {
    public Double get (GeomShape2D shape) {
        return shape.getRed ();
    }
    public void set (GeomShape2D shape, Double value) {
        shape.setRed (value);
    }
}
```

To realize the last argument of adjustRed10, we let a variant of Double-Traits (see Section 2.7) implement GenericTraits<Double>:

```java
public class DoubleTraits2 implements GenericTraits<Double> {
    public Double generate (double x) {
        return new Double(x);
    }
    public Double plus (Double val1, Double val2) {
        double d1 = val1.doubleValue ();
        double d2 = val2.doubleValue ();
        return new Double(d1+d2);
    }
    // Analogously minus, mult, div, and isGreaterThan
}
```

Finally, here is the call to the generic version of adjustRed:

```java
AccessorRedGeomShape2D red_acc = new AccessorRedGeomShape2D ();
AccessorGreenGeomShape2D green_acc = new AccessorGreenGeomShape2D ();
AccessorBlueGeomShape2D blue_acc = new AccessorBlueGeomShape2D ();
DoubleTraits2 traits = new DoubleTraits2();
GeomAlgorithms2 adjustRed10 (geom.shapes.elements (),
    red_acc, green_acc, blue_acc, 10.0, traits);
```

These code snippets might give an idea how parametric polymorphism may be applied in the second use scenario of Section 2.2. The result is as flexible as possible, absolutely safe, and even simpler than any of the previous designs in plain Java.
3 Conclusion

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<td>value type fixed</td>
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</tr>
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<tr>
<td>Java + GJ</td>
<td>ok</td>
<td>ok</td>
<td>use of traits</td>
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<td>C++</td>
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In view of maintenance and reuse, it is desirable to render the coupling between collaborating classes as loose as possible, but nonetheless (statically) safe. We have seen that this is a serious problem even for the access to a single attribute via a pair of get/set methods (even if the attribute type is fixed). The language features of Java cannot resolve the contradiction between loose coupling and safety (see figure 3.1 for a summary of the discussion). With a generic language extension like GJ or by using C++, it is possible to enable static type safety. However, only in C++, the traits mechanism can be avoided by using operator overloading.

We have identified a key feature, which can help to overcome this conflict: parametric polymorphism (genericity). As we have seen, this feature is helpful beyond its original intention (namely to implement parameterized algorithms and data structures). In our opinion, this is a strong argument that genericity should be treated as a first-class design feature rather than a mere “implementation trick” for type-independent algorithms and data structures.

An in-depth discussion of genericity as a design feature is beyond the scope of this paper. A single paper of this length cannot give more than a base for such a discussion.

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Bibliography

[1] Ole Agesen, Stephen Freund, and John C. Mitchell:  
*Adding Type Parameterization to Java*  
Proceedings of the 12th ACM Symposium on Object–Oriented Programming, Systems, Languages, and Applications (OOPSLA ’97), 49–65

[2] Gilad Bracha, Martin Odersky, David Stoutamire, and Philip Wadler:  
*Making the Future Safe for the Past: Adding Genericity to the Java Programming Language*  

[3] Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides:  
*Design Patterns – Elements of Reusable Object–Oriented Software*  
Addison–Wesley, 1995

[4] Dietmar Kühl and Karsten Weihe:  
*Data Access Templates*  
C++ Report 9/7 (1997), 15–21

[5] Marco Nissen:  
*Design Pattern Data Accessor*  
Proceedings of the 4th European Conference on Pattern Languages of Programming (EuroPLoP ’99)

[6] Peter Wayner:  
*Java Beans for Real Programmers*  
AP Professional, 1998

[7] Karsten Weihe:  
*Reuse of Algorithms: Still a Challenge to Object–Oriented Programming*  
Appendix

Appendix A: Java Enumerations

Every container class in the Java utility library provides a method `elements ()`, which returns a reference to the interface `java.util.Enumeration`. This is the standard interface for iterator classes in Java. For example, a traversal of a vector `v` may be implemented like this:

```java
Vector v = new Vector ();
/* ... */
Enumeration enum = v .elements ();
while (enum.hasMoreElements ()) {
    Object obj = enum.nextElement ();
    // Do something reasonable with obj
}
```

Clearly, for every self-defined container class, one can also implement a specific `Enumeration` class. Hence, an algorithm that accesses containers exclusively through interface `Enumeration` is completely independent of the choice of the container class. This greatly improves maintainability and reusability.

Appendix B: Inner Classes

A nested class is a class that is defined inside another class. A nested, non-static class is commonly called an inner class. Here is a simple, illustrative example:
public class OuterClass {
    int n;
    public class InnerClass {
        public int get () {
            return n;
        }
    }
}

Note that \textit{InnerClass} is allowed to access non-static — even private — members of the class in which it is embedded (as opposed to nested classes in \textit{C++}). Inner classes are useful for many purposes. For example, they can be used to circumvent the restriction that no class may inherit from more than one class. Inner classes are also useful for lean implementations of adapters. The interested reader is referred to the overwhelming literature on the Java language.

The aspect in which we are specifically interested in view of our case study is the selection of class attributes. For sake of exposition, consider a simple business model, which is based on three classes, Employee, Customer, and Freelance. Among other attributes, we keep the employees’ salaries, the customers’ credits and debits, and the freelances’ contractual payments. Some accounting algorithms (\textit{e.g.} calculation of interest) might be generic in the sense that they are useful for each of these attributes. At first glance, it suffices to derive employees, customers, and freelances from a common base class or interface \textit{PersonWithMoneyAttribute}, say, which has a generic money attribute, and to implement every accounting algorithm on top of \textit{PersonWithMoneyAttribute} using this money attribute. However, customers have \textit{two} money attributes, so this idea simply fails. Even if customers only had one money attribute: a design that regards salaries, credits or debits, and contractual payments as conceptually identical might not be sound and thus should be avoided.

Inner classes offer a solution to this dilemma: every person class implements an inner class for every money attribute. All of these classes implement a common interface \textit{MoneyHandler}:

\begin{verbatim}
public interface MoneyHandler {
    MoneyType get ();
    void set (MoneyType amount);
}
\end{verbatim}

For example, class Customer would define one inner class for credits and one for debits:
An accounting algorithm may then be implemented on top of `MoneyHandler`:

```java
MoneyType myAccountingAlgorithm (MoneyHandler mh) {
    /* ... */
}
```

### Appendix C: Reflection

The package `java.lang.reflect` provides a means of analyzing objects of unknown classes at run time. For example, this includes means of retrieving the name of an object’s class, the names and types of its data members, and the names and argument lists of its methods. In this paper, we are particularly interested in another powerful feature: invoking a method whose signature is only known at run time. For example, the following method invokes a method of `obj` with one argument. The name of the method is given in the string `name_of_method`, the type
of the only argument is \texttt{argument\_type}, and \texttt{value} is to be used as the value of this argument when the method is invoked. The classes \texttt{Class} and \texttt{Method} are defined in \texttt{java.lang.Class} and \texttt{java.lang.reflect.Method}, respectively. As the class names indicate, an object of class \texttt{Class} (resp. \texttt{Method}) contains general information about a particular class (method of a class). Method \texttt{forName} of \texttt{Class} turns the (fully qualified) name of a class into an object for that class.

```java
public void invoke_method (Object obj, String name_of_method,
                          String argument_type, Object value) {
    Class obj_class_id = obj.getClass ();
    Class val_class_id = value.getClass ();
    String val_class_name = val_class_id.getName ();
    Class [] argument_types = new Class [1];
    Object [] argument_values = new Object [1];
    try {
        argument_types[0] = Class.forName (argument_type);
        argument_values[0] = value;
        Method method = obj_class_id.getMethod
                     (name_of_method, argument_types);
        method.invoke (obj, argument_values);
    }
    catch (Exception e) {
        // Do some reasonable exception handling
    }
}
```

**Appendix D: Parametric Polymorphism (GJ)**

GJ's [2] parametric polymorphism is very similar to \textit{templates} in C++, \textit{generics} in Ada, parametric polymorphism in functional languages, and various other generic extensions of Java [1]. This means that the concrete types on which a class definition is based may be left open. Such an “incomplete” class is called a \textit{parameterized class}. In the definition of such a parameterized class, these types are represented by \textit{formal type arguments}. Roughly speaking, a formal type argument is a placeholder for the actual type. The actual type must be specified when an object of the parameterized class is instantiated.

To give a simple example, the following stack class is parameterized by the type \texttt{T} of its items. In GJ style:
public class Stack <T> {
    public Stack () { /* . . . */ }
    public void push (T t) { /* . . . */ }
    public T top () { /* . . . */ }
    public void pop () { /* . . . */ }
    public int size () { /* . . . */ }
}

GJ does not allow that T is a primitive type such as int or double. In fact, T must be a class or interface (this is another reason why the case study from Section 2 uses class Double instead of primitive type double). The following code snippet demonstrates how a stack of Integer may be created and used:

```java
Stack<Integer> S1 = new Stack<Integer> ();
S1.push (new Integer (1));
// Should print '1':
System.out.println (S1.top ().intValue ());
S1.push (new Double (2));
// Compiler error: wrong type
```

Note that the compiler checks whether or not an object of the parameterized stack class is correct according to the concrete item type T: if we try to push a value of a wrong item type onto a stack, the compiler issues an error message. This is in great contrast to a generic stack class in plain Java, which must be based on comp.lang.Object:
```java
public class Stack {
    public Stack () {
        /* . . */
    }
    public void push (Object obj) {
        /* . . */
    }
    public Object top () {
        /* . . */
    }
    public void pop () {
        /* . . */
    }
    public int size () {
        /* . . */
    }
}
/* . . */

Stack S; // Intended to be a stack of Integer
/* . . */
S.push (new Double (5));
// Oops: no compiler error; S silently becomes inconsistent!
```

This is an example of the first, unsafe, use scenario in Section 2.3. This observation can be generalized: the cases for which genericity was originally introduced are a special case of the second use scenario.
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