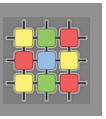
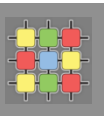


# Architecture of software systems

Course 3: Design patterns, class loaders, reflection

David Šišlák
david.sislak@fel.cvut.cz

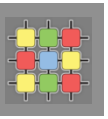
# Immutable object



- thread-safe object
- all fields are **final** (and often **private**)
- no “setters”
- block changes by finalization of the class
- block override use private constr. and static factories
- don’t need a copy constr.
- no clone needed
- hashCode can use lazy initialization and cache
- no defensive copy when used as a field
- suitable for map and set elements

```
final public class ImmutableRGB {

    //Values must be between 0 and 255.
    final private int red;
    final private int green;
    final private int blue;
    final private String name;

    private void check(int red, int green, int blue) {
        if (red < 0 || red > 255
                || green < 0 || green > 255
                || blue < 0 || blue > 255) {
            throw new IllegalArgumentException();
        }
    }

    public ImmutableRGB(int red, int green, int blue, String name) {
        check(red, green, blue);
        this.red = red;
        this.green = green;
        this.blue = blue;
        this.name = name;
    }


    public int getRGB() {
        return ((red << 16) | (green << 8) | blue);
    }

    public String getName() {
        return name;
    }

    public ImmutableRGB invert() {
        return new ImmutableRGB(255 - red, 255 - green, 255 - blue,
                "Inverse of " + name);
    }
}
```

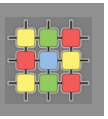
# Immutable object - String



» special behavior of concatenation operator (+)

```
String a = "a";
String b = "b";
String c = "c";

String q = a + b +c;
```

# Immutable object - String



- special behavior of concatenation operator (+)
  - implemented through the **StringBuilder** and its *append* method

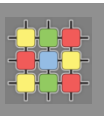
```
String a = "a";
String b = "b";
String c = "c";

String q = a + b +c;
```

```
StringBuilder temp = new StringBuilder(a);
temp.append(b);
temp.append(c);
String q = temp.toString();
```

- but what about?

```
String q = a;
q += b;
q += c;
```

# Immutable object - String



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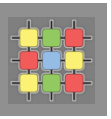
```
StringBuilder temp = new StringBuilder(a);
temp.append(b);
temp.append(c);
String q = temp.toString();
```

- but what about?

```
String q = a;
q += b;
q += c;
```

  - implies 4 object allocations !!!
- consider manual usage of **StringBuilder** or **StringBuffer** (thread-safe)

# Immutable object



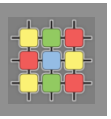
- concatenation of non-String types:
  - String.valueOf({primitives})
  - or

```
public static String valueOf(Object obj) {
return (obj == null) ? "null" : obj.toString();
}
```

- make collections/list/map/set immutable (UnsupportedOperationException):
  - **Collections.unmodifiableCollection(…)**
  - **Collections.unmodifiableList(…)**
  - **Collections.unmodifiableMap(…)**
  - **Collections.unmodifiableSet(…)**
  - **Collections.unmodifiableSortedMap(…)**
  - **Collections.unmodifiableSortedSet(…)**

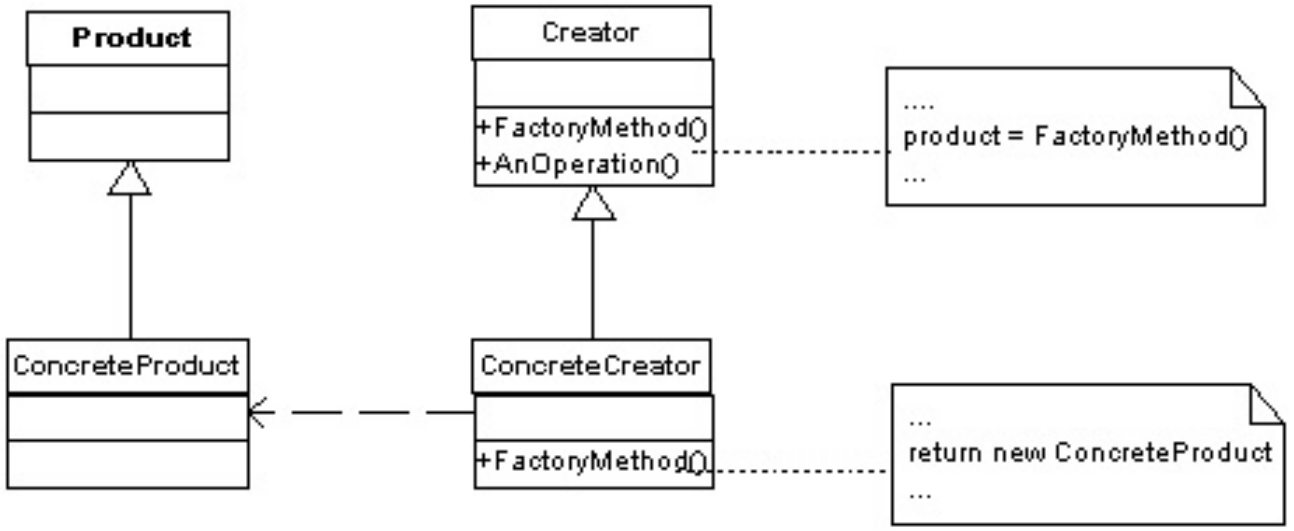
  - elements are not protected !!! use immutable elements too

# Factory method



- *creational* design pattern
- based on the concept of factories
- define a method for **creating objects in the interface which are subclasses of specific product**
- implementers can decide which class is instantiated (e.g. based on params)
- common usage
  - **toolkits and frameworks**
    - library code needs to create objects of types which are sub-classed by application using the framework
  - **test-driven development**
    - unit tests can use mock objects to simulate operations
- limitations
  - if use private constructors -> class cannot be extended
  - if use protected constructors -> subclass must re-implement all factory methods with exactly the same signatures (BUT if **static** still not work properly !!!)

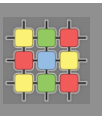
# Factory method




» Creator can define default implementation returning default factory product

» Note:
  » static factory methods – cannot be overridden !
  » Factory object can be instance

# Factory method – example



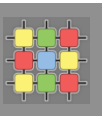
» product interface

```
public interface Trace {
	// turn on and off debugging
	public void setDebug( boolean debug );
	// write out a debug message
	public void debug( String message );
	// write out an error message
	public void error( String message );
}
```

» product A

```
public class SystemTrace implements Trace {
	private boolean debug;
	public void setDebug( boolean debug ) {
		this.debug = debug;
	}
	public void debug( String message ) {
		if( debug ) {  // only print if debug is true
			System.out.println( "DEBUG: " + message );
		}
	}
	public void error( String message ) {
		// always print out errors
		System.out.println( "ERROR: " + message );
	}
}
```

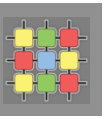
# Factory method – example



» product B

```
public class FileTrace implements Trace {

	private java.io.PrintWriter pw;
	private boolean debug;
	public FileTrace() throws java.io.IOException {
		// a real FileTrace would need to obtain the filename somewhere
		// for the example I'll hardcode it
		pw = new java.io.PrintWriter( new java.io.FileWriter( "c:\trace.log" ) );
	}
	public void setDebug( boolean debug ) {
		this.debug = debug;
	}
	public void debug( String message ) {
		if( debug ) {  // only print if debug is true
			pw.println( "DEBUG: " + message );
			pw.flush();
		}
	}
	public void error( String message ) {
		// always print out errors
		pw.println( "ERROR: " + message );
		pw.flush();
	}
}
```

# Factory method – example



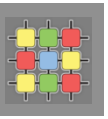
- direct usage
  - need change

  all instantiations

  to modify behavior

```
//... some code ...
SystemTrace log = new SystemTrace();
//... code ...
log.debug( "entering loog" );
// ... etc ...
```

# Factory method – example



» direct usage
  » need change
  all instantiations
  to modify behavior

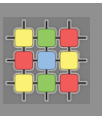
```
//... some code ...
SystemTrace log = new SystemTrace();
//... code ...
log.debug( "entering loog" );
// ... etc ...
```

» factory method
  » just one place
  to modify behavior

```
public class TraceFactory {
      public static Trace getTrace() {
            return new SystemTrace();
      }
}
//... some code ...
Trace log =     TraceFactory.getTrace();
//... code ...
log.debug( "entering loog" );
// ... etc ...
```

```
public class TraceFactory {
      public static Trace getTrace() {
            try {
                  return new FileTrace();
            } catch ( java.io.IOException ex ) {
                  Trace t = new SystemTrace();
                  t.error( "could not instantiate FileTrace: " + ex.getMessage() );
                  return t;
            }
      }
}
```

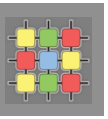
# Lazy initialization



- *delay operation until the first time it is needed*
  - **lazy object creation**
  - **lazy calculation of a value**
  - **lazy class loading**
  - **lazy other expensive process**
- use a flag indicating that the process has taken place
- if not used -> save memory usage and/or processing time

- **lazy class loading**
  - classes are loaded only when they are first referenced
  - *use interfaces or parent classes for field types*

# Lazy initialization – example



```
public class MyFrame extends Frame
{
  private MessageBox mb_ = new MessageBox();
  //private helper used by this class
  private void showMessage(String message)
  {
    //set the message text
    mb_.setMessage( message );
    mb_.pack();
    mb_.show();
  }
}
```

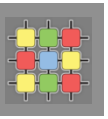
VS

```
public final class MyFrame extends Frame
{
  private MessageBox mb_ ; //null, implicit
  //private helper used by this class
  private void showMessage(String message)
  {
    if(mb_==null)//first call to this method
      mb_=new MessageBox();
    //set the message text
    mb_.setMessage( message );
    mb_.pack();
    mb_.show();
  }
}
```

» higher importance for complex objects (e.g. Image, DB connection)

» used often for lazy hash code computation in immutable objects

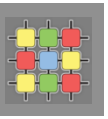
# Singleton



- *class has only one instance with a global point of access to it*
- often used to control access to native resources like database connections or sockets
- unique repository of state, alternatively can be implemented as static
- lazy instantiation:

```
public static class MySingleton {
    private static MySingleton _instance;

    private MySingleton() {
        // ...
    }

    public static MySingleton getInstance() {
        if (_instance==null) {
            _instance = new MySingleton();
        }
        return _instance;
    }
    // ...
}
```

# Singleton

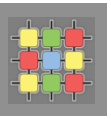


- *class has only one instance with a global point of access to it*
- often used to control access to native resources like database connections or sockets
- unique repository of state, alternatively can be implemented as static
- lazy instantiation:

```
public static class MySingleton {
    private static MySingleton _instance;

    private MySingleton() {
        // ...
    }

    public static synchronized MySingleton getInstance() {
        if (_instance==null) {
            _instance = new MySingleton();
        }
        return _instance;
    }
    // ...
}
```

- how to avoid locking?

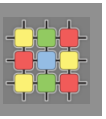
# Double-checked locking



- **reduce the overhead** of acquiring a lock by use of **locking criterion**
- common usage
  - multi-threaded environment
  - combination with lazy initialization

- typical use pattern
  - check the locking criterion without obtaining the lock
  - obtain the lock
  - double-check whether the variable has been already initialized
  - otherwise, initialize

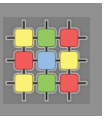
# Singleton – double-checked locking



» avoid expense of locking

```
public static class MySingleton {
    private static MySingleton _instance;

    private MySingleton() {
        // ...
    }

    public static MySingleton getInstance() {
        if (_instance==null) {
            synchronized (MySingleton.class) {
                if (_instance==null) {
                    _instance = new MySingleton();
                }
            }
        }
        return _instance;
    }
    // ...
}
```

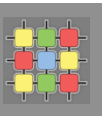
# Singleton – double-checked locking



» avoid expense of locking

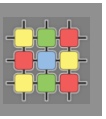
```
public static class MySingleton {
    private static volatile MySingleton _instance;

    private MySingleton() {
        // ...
    }

    public static MySingleton getInstance() {
        if (_instance==null) {
            synchronized (MySingleton.class) {
                if (_instance==null) {
                    _instance = new MySingleton();
                }
            }
        }
        return _instance;
    }
    // ...
}
```

# Singleton – issues



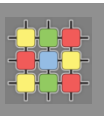
- don't allow subclassing due to static getInstance():
  - factory class with method returning singleton instance (requires non-private constructor)
- issue with more VMs in distributed system (e.g. RMI) -> singleton should not be used to store state !!!
- classloaders -> one singleton per each classloader
- *in older JVMs private static references for non-reachable objects was not enough to keep that instance*

# Singleton initialization – eager initialization



```
public static class MySingleton {
    private static MySingleton _instance =
     new MySingleton();

    private MySingleton() {
        // ...
    }

    public static MySingleton getInstance() {
     return _instance;
    }

    // ...
}
```

# Singleton initialization - lazy initialization



» initialization on demand holder idiom

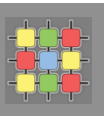
```
class Foo {
    private static class HelperHolder {
       public static Helper helper = new Helper();
    }
    public static Helper getHelper() {
        return HelperHolder.helper;
    }
}
```

» inner class are not loaded until they are referenced

» BUT

  » if construction fail, it throws **NoClassDefFoundError** during run-time !

# Multiton

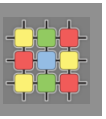


- *parametric singleton*, single instance with given parameter
- often in combination with immutable object

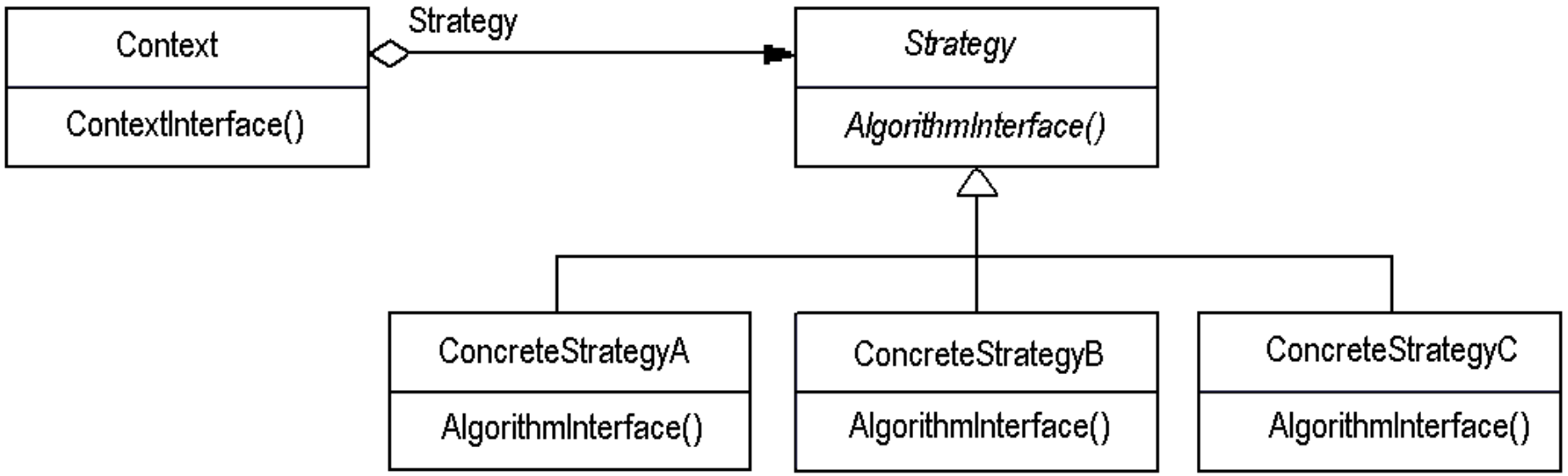
```
public static class MyMultiton {
    private static final Map<Object, MyMultiton> instances = new HashMap<Object, MyMultiton>();

    private final Object attribute;

    private MyMultiton(final Object attribute) {
        this.attribute = attribute;
    }

    public static MyMultiton getInstance(Object attribute) {
        synchronized (instances) {
            MyMultiton instance = instances.get(attribute);
            if (instance == null) {
                instance = new MyMultiton(attribute);
                instances.put(attribute, instance);
            }
            return instance;
        }
    }
}
```

- beware memory consumption !
- use WeakReference or SoftReference

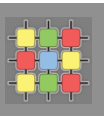
# Strategy



- *behavioral* design pattern
- **selection of algorithm in runtime**
- define common interface for family of algorithms
- make different implementations interchangeable
- usually strategy is selected independently from clients that use it



# Strategy - example



» Strategy

```
public interface SortInterface {
public void sort(double[] list);
}
```

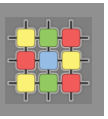
» Context

```
public class SortingContext {
private SortInterface sorter = null;

public void sortDouble(double[] list) {
 sorter.sort(list);
}

public SortInterface getSorter() {
 return sorter;
}

public void setSorter(SortInterface sorter) {
 this.sorter = sorter;
}
}
```

» Initialization

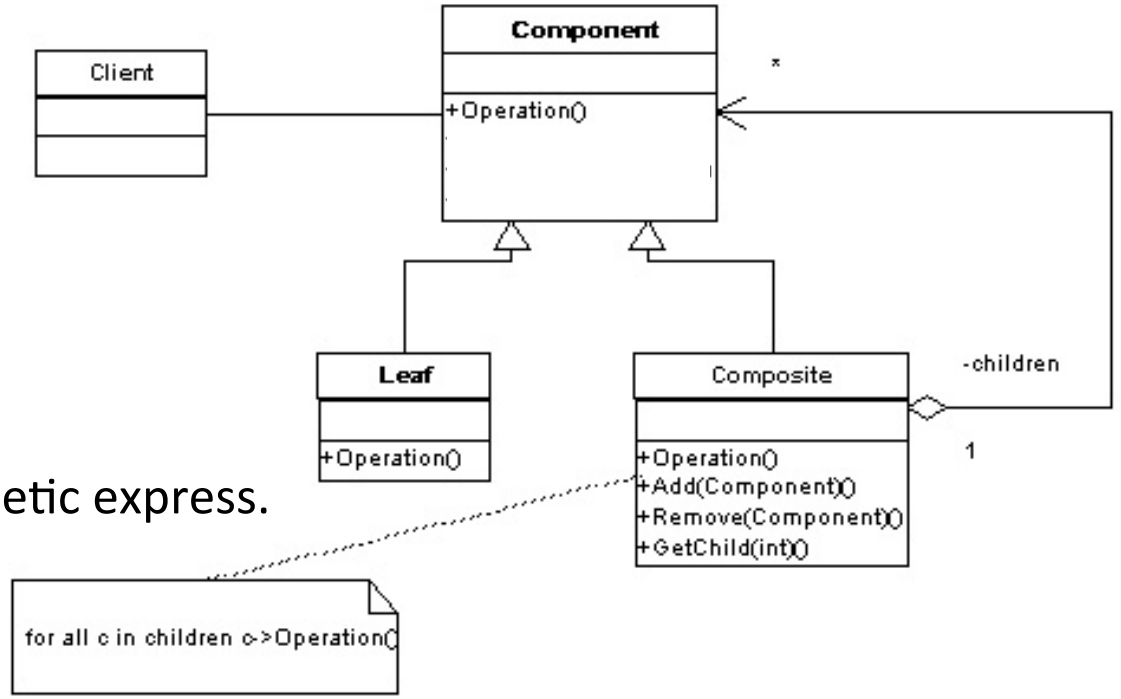
```
public class SortingClient {
public class SortingClient {
 public static void main(String[] args) {
  double[] list = {1,2.4,7.9,3.2,1.2,0.2,10.2,22.5,19.6,14,12,16,17};
  SortingContext context = new SortingContext();
  context.setSorter(new BubbleSort());
  context.sortDouble(list);
  for(int i =0; i< list.length; i++) {
   System.out.println(list[i]);
  }
 }
}
```

# Composite



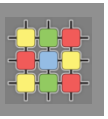
- *structural* design pattern
- **compose objects into tree structures**
- group of objects are treated as a single instance of an object
- clients do not need to use difference between compositions and individuals

- component – interface
- leaf – behavior for primitive objects, no children
- composite – stores child components
- client – manipulates objects using component



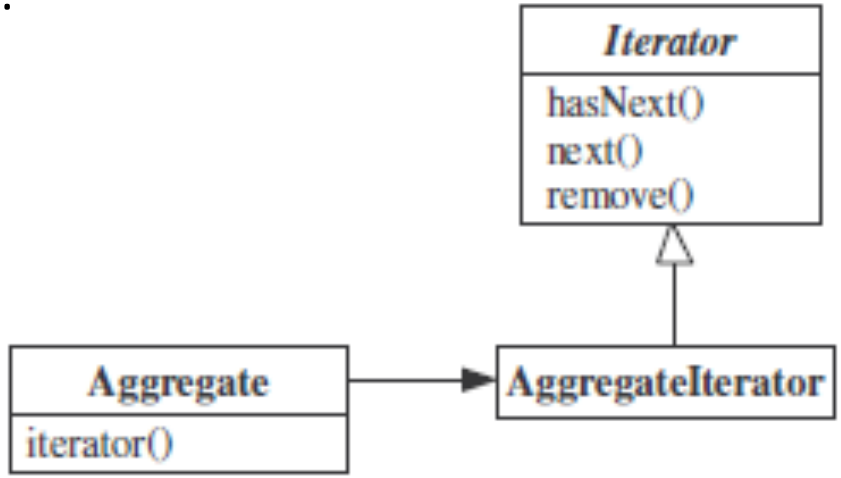

- Example – Graphics, arithmetic express.

# Iterator



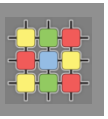
- *behavioral* design pattern
- iterator is used to **access elements of an aggregate object** (Collection)
- sequential without exposing underlying implementation
- very common in Java libraries (Aggregate – Iterable)
  - List, HashSet, HashMap, Tree, …

```
Set items = new TreeSet();
...
Iterator seq = items.iterator();
while (seq.hasNext())
{
    Item item = (Item) seq.next();
    ...
    if (...) seq.remove();
}
```




- Collection can be changed only through iterator -> if changed throws ConcurrentModificationException

# Iterator



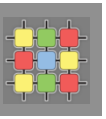
- ListIterator - List.listIterator()
  - hasPrevious(), previous()
  - nextIndex(), previousIndex()
  - add(...), set(…)

- since Java 1.5

```
Set<Item> items = new TreeSet<Item>();
...
for (Item item : items)
{   ...
}
```

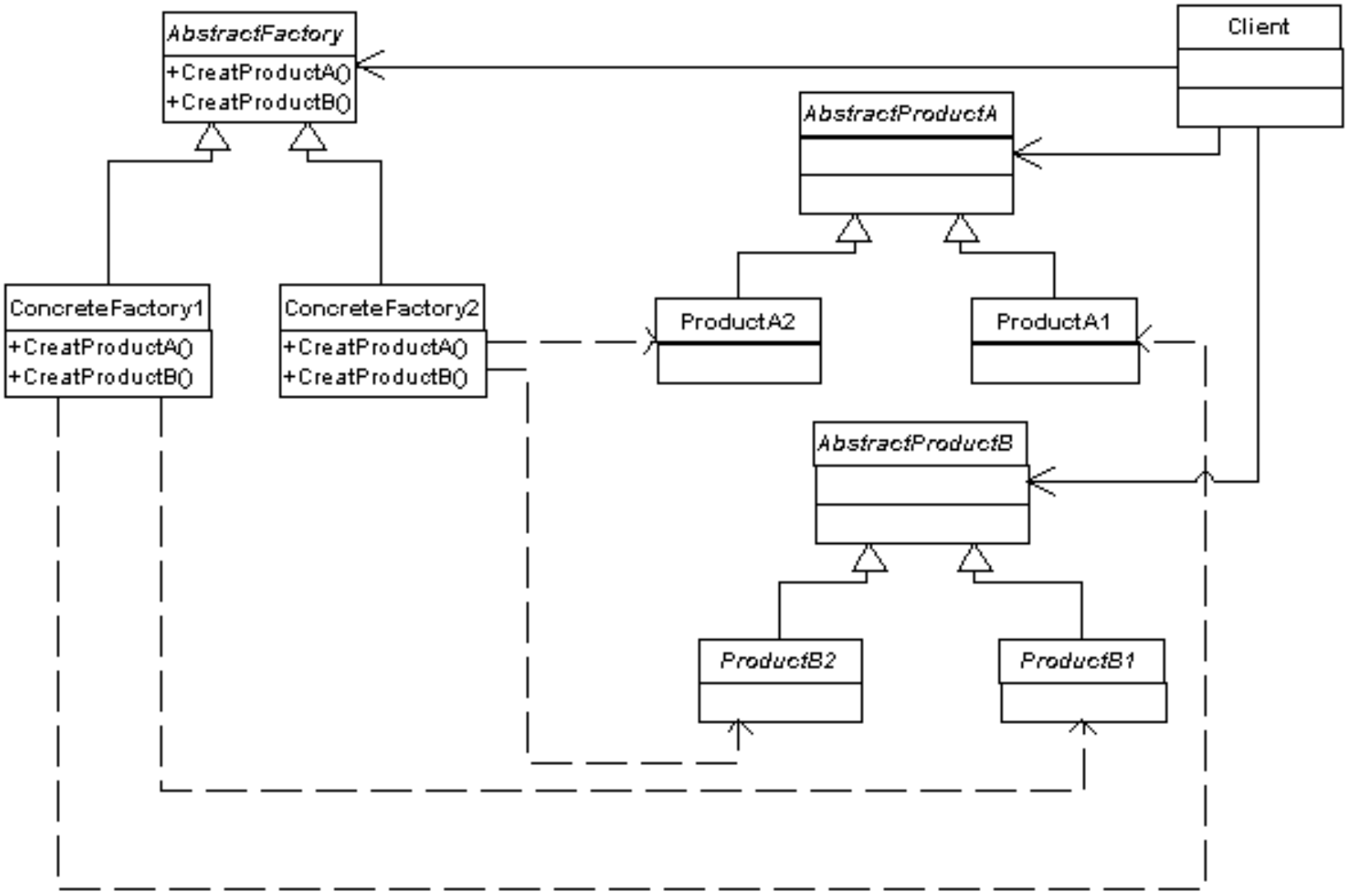
  - works on arrays, anything implements Iterable

# Abstract Factory



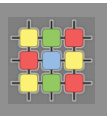
- *creational* design pattern
- extension of Factory pattern
- encapsulate a **group of individual factories having common theme**
  - multiple **factory methods**
- user creates concrete implementation of abstract factory and then uses generic interface to create concrete objects

# Abstract Factory




» Example: multiple look-and-feels in GUIs (e.g. Linux vs. Windows)

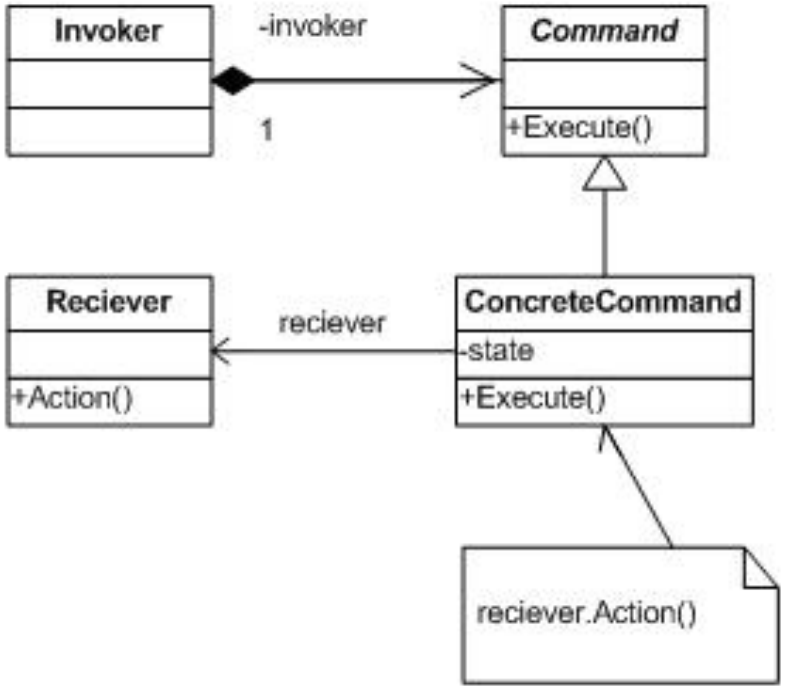
# Command



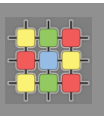
- *behavioral* design pattern
- **encapsulate all information needed to call a method at a later time**

- client
  - instantiates the command
  - provides information required
- invoker
  - decides when to call the method
- receiver
  - contains method's code

- Example
  - Thread pools (java.lang.Runnable)
  - GUI Action

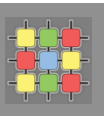


# Java virtual machine – start-up



- create initial class
  - must be present in bootstrap class loader
- links the initial class
  - cause loading, linking and invocation of other classes
- initialize class (class vs. instance initialization !)
- start public void main (String[])

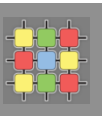
# Loading and Linking



- **Loading**
  - finding binary form of class or interface (e.g. computing on the fly)
  - form **Class**
  - implemented by **ClassLoader**
    - can cache binary representations (can decrypt, verify dig. signature)
    - prefetch them based on expected usage
    - load group of related classes together

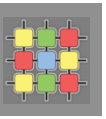
- **Linking**
  - binary form into run-time state in JVM
  - verification – structural check (correct opcodes, branches, …)
  - preparation
    - create static fields, fill default values (no initializers !)
    - precompute additional data structures (e.g. method table)
  - resolution of symbolic references – validation, direct reference

# Class initialization



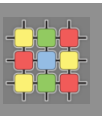
- class is being initialized in the following cases:
  - instance of class has to be created
  - static method of class is invoked
  - non-constant static field of class is used
  - sub-class is initialized
  - invocation of reflective methods over class
  - it is initial class for start-up
- class is not initialized
  - when static final field is initialized with compile-time constant
- **class initialization sequence**
  - super class initialization
  - initialization in declaration order (you cannot use values after, compiled into "<clinit>:()V") :
    - user class static initializers
    - initializers static fields (class + interfaces – by default public static final)

# Class initialization vs. Class instance initialization



- requires careful synchronization (synchronized on class object)
- **Class object state**
  - verified and prepared
  - being initialized by some thread
  - fully initialized and ready for use
  - in error state – verification failed, initialization failed
    (throws NoClassDefFoundError)
- **Class instance** initialization
  - memory allocation (fields in class + superclasses) -> OutOfMemoryError
  - all variables are set to default values (0, false, null)
  - prepare args for other/super constructor invocation (follow this(…) and follow super(…))
  - execute instance initializers + field initializers in declaration order (compiled into "<init>:()V")
  - execute the rest of the body of constructor

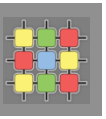
# Class instance finalization



- protected void finalize() throw Throwable
  - called before object space is reclaimed by GC
  - you shalll call super.finalize() !!!
  - do not call method explicitly !!!

- class/interface unloading
  - if its class loader is unreachable
  - bootstrap class loader is always reachable -> system classes are never unloaded !

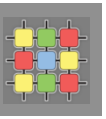
# Initializer block



```
public static class InitializerBlocks {

    public InitializerBlocks(){
        System.out.println("1");
    }

    {
        System.out.println("2");
    }

    {
        System.out.println("3");
    }

    public static void main(String[] args) {
        new InitializerBlocks();
    }
}
```

» what is the output?

# Initializer block



```
public static class InitializerBlocks {

    public InitializerBlocks(){
        System.out.println("1");
    }

    {
        System.out.println("2");
    }

    {
        System.out.println("3");
    }

    public static void main(String[] args) {
        new InitializerBlocks();
    }
}
```

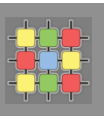
» what is the output?

2

3

1

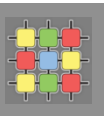
# Initializer block - alternative



```
public static class InitializerBlocks {
    private boolean boolField = privInstance();

    private final boolean privInstance() {
        System.out.println("2");
        return true;
    }

    public InitializerBlocks(){
        System.out.println("1");
    }

    public static void main(String[] args) {
        new InitializerBlocks();
    }
}
```

» what is the output?

# Initializer block - alternative



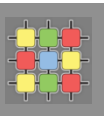
```
public static class InitializerBlocks {
    private boolean boolField = privInstance();

    private final boolean privInstance() {
        System.out.println("2");
        return true;
    }

    public InitializerBlocks(){
        System.out.println("1");
    }

    public static void main(String[] args) {
        new InitializerBlocks();
    }
}
```

» what is the output?

2

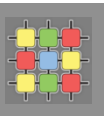
1

# Initializer block – static variant



```
public static class InitializerBlocks {
    private static final boolean boolField;

    static {
        // compute value for boolField ...
        boolField = true;
    }

}
```

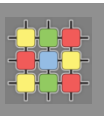
# Initializer block – static example



```
public static class A {
    public static final A A = new A();
    private A() { }

    private static final Boolean BOOL = true;

    private final Boolean bool = BOOL;

    public final Boolean bool() { return bool; }

    public static void main(String[] args) {
        System.out.println(A.bool() ?
                "yes" : "no");
    }
}
```

» what is the output?

# Initializer block – static example



```
public static class A {
    public static final A A = new A();
    private A() { }

    private static final Boolean BOOL = true;

    private final Boolean bool = BOOL;

    public final Boolean bool() { return bool; }

    public static void main(String[] args) {
        System.out.println(A.bool() ?
                "yes" : "no");
    }
}
```

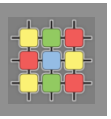
» what is the output?

» throws NullPointerException – due to recursive class initialization, and auto-unboxing

» correct:

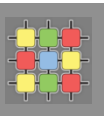
```
public static class A {
    private static final Boolean BOOL = true;

    public static final A A = new A();
    private A() { }

    private final Boolean bool = BOOL;

    public final Boolean bool() { return bool; }

    public static void main(String[] args) {
        System.out.println(A.bool() ?
                "yes" : "no");
    }
}
```

# Classloader



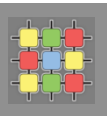
- classloader types:
  - **bootstrap class loader**
    - system class loader – searches runtime, inst. extension, class path
  - **user-defined class loader**
    - extraction from encrypted file, verify digital signature
    - loading from non-standard sources (e.g. network)
    - generate on the fly
- each class has
  - defining class loader – finally define Class
  - initiating class loader – initiate class loading (e.g. through other CL)
- class is uniquely identified by pair !
  - fully qualified name
  - defining class loader

# Classloader



- referenced classes from X are loaded by its defining CL
- each class is loaded only once if it is not previously unloaded
- method **Class loadClass(String)** - qualified name
  - a cache implemented by **Class findLoadedClass(String)**
  - get raw bytes from class from somewhere
  - if ok, define class from array of bytes using **Class defineClass(…)**
  - if failed, delegate loading to other class loader
    - e.g. **Class findSystemClass(String)**
    - e.g. **getParent().loadClass(String)** – CL which creates the current one
  - if still no class, throw **ClassNotFoundException**
  - if resolve is required call **void resolveClass(Class)** to link class
- **Class Class.forName(String)**, **Class.getSystemClassLoader().loadClass(String)**
- **cl.loadClass(String), c.newInstance(), constructor.newInstance(…)**

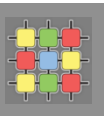
# Reflection



- can examine or modify the run-time behavior
  - create external classes by qualified name (through Class loaders) – do not need to have class during compilation
  - class browser – enumerate members
  - debugger – examine private members

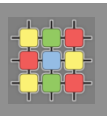
- BUT
  - performance overhead – dynamic resolution, slower
  - security restrictions – security context, e.g. Applet
  - unexpected side-effects – access private fields and methods

# Reflection



- retrieve Class object
  - **Class getClass()** – returns instance Class representation
  - **XXX.class** – from type, no instance
    - e.g. “aa”.class
  - **Class Class.forName(String), CL.loadClass(String)**
  - **Class.getSuperClass(), Class.getClasses(), Class.getDeclaredClasses(), Class.getEnclosingClass(), {Field|Method|Constructor}.getDeclaringClass()**
- examine class modifiers and types
  - **Class.getModifiers()**
  - **Class.getTypeParameters()** – get Generic types
  - **Class.getGenericInterfaces()**
  - **Class.getSuperclass()**
  - **Class.getAnnotations()**

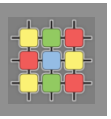
# Reflection



» discovering class members

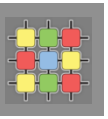
| Member | Class API | List of members? | Inherited members? | Private members? |
|---|---|---|---|---|
| Field | getDeclaredField() | no | no | yes |
| | getField() | no | yes | no |
| | getDeclaredFields() | yes | no | yes |
| | getFields() | yes | yes | no |
| Method | getDeclaredMethod() | no | no | yes |
| | getMethod() | no | yes | no |
| | getDeclaredMethods() | yes | no | yes |
| | getMethods() | yes | yes | no |
| Constructor | getDeclaredConstructor() | no | N/A[1] | yes |
| | getConstructor() | no | N/A[1] | no |
| | getDeclaredConstructors() | yes | N/A[1] | yes |
| | getConstructors() | yes | N/A[1] | no |

# Reflection



- Fields
  - get field types, generic types
  - get field modifiers
  - get and set field value (private if no security manager)
- Methods
  - get method types including attributes
  - get method modifiers
  - invoke method
- Constructors
  - find constructor with specific parameters
  - get constructor modifiers
  - create new class instance
- Arrays (through java.lang.reflect.Array)
  - get array types
  - create new array
  - get/set array components

# Reflection



» Method call example:

```
Class<T> c = Class.forName("MyClass"); // Class<T> c = MyClass.class;
Method m = c.getMethod(“myMethod”);
Object retVal = m.invoke(object, …);
```

» Field usage example:

```
Class<T> c = MyClass.class;
Field f = c.getField(“myField”);
Object value = f.get(object);
```