



Architecture of software systems

Course 3: Basic design patterns

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);  
    }  
}
```



- » special behavior of concatenation operator (+)

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



- » 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;
```



- » 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;
```

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



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

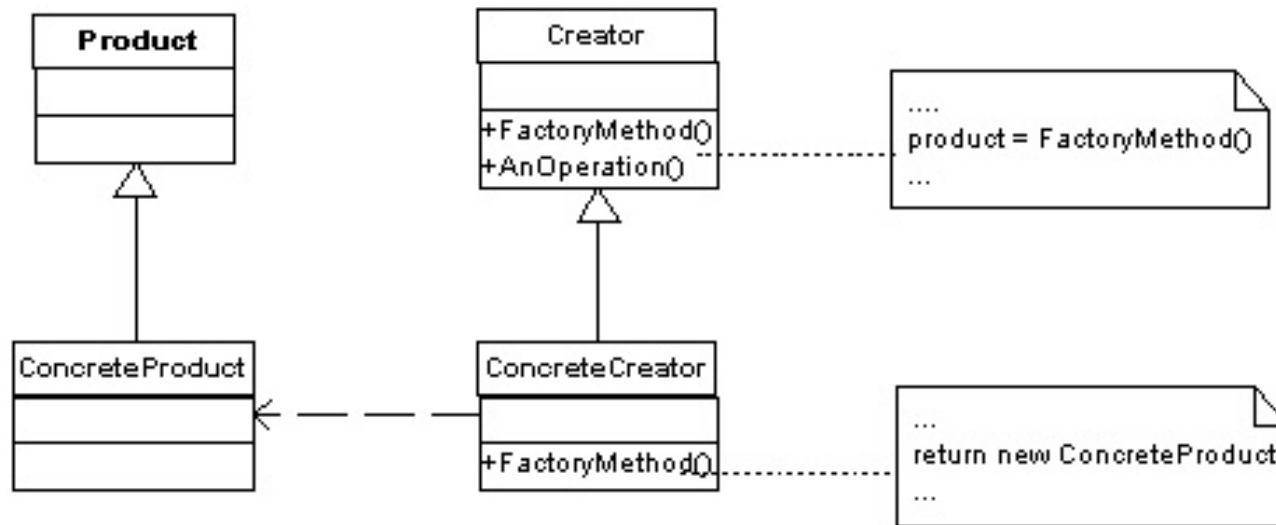
```
public static String valueOf(Object obj) {  
    return (obj == null) ? "null" : obj.toString();  
}
```

- » 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



- » *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



» 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 );  
    }  
}
```



» 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();
    }
}
```



- » 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;  
        }  
    }  
}
```



- » *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



- » *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;
    }
    // ...
}
```



- » *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?



- » **reduce the overhead** of acquiring a lock by use of **locking criterion**
- » common usage
 - » multi-threaded environment
 - » combination with lazy initialization
- » typical situation
 - » check the locking criterion without obtaining the lock
 - » obtain the lock
 - » double-check whether the variable has been already initialized
 - » otherwise, initialize



- » avoid expense of locking

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

    private MySingleton() {
        // ...
    }

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



- » 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;
    }
    // ...
}
```



- » 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;
    }
    // ...
}
```

- » will this work fine ?

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;
    }
    // ...
}
```

```
asm code generated for getInstance
054D2080 mov     eax,[049388C8]      ;load instance ref
054D2085 test    eax,eax           ;test for null
054D2087 jne     054D20D7
054D2089 mov     eax,14C0988h
054D208E call   503EF8F0           ;allocate memory
054D20C3 mov     [049388C8],eax     ;store pointer in
                                ;instance ref. instance
                                ;non-null and ctor
                                ;has not run
054D20C8 mov     ecx,dword ptr [eax]
054D20CA mov     dword ptr [ecx],1 ;inline ctor - inUse=true;
054D20D0 mov     dword ptr [ecx+4],5 ;inline ctor - val=5;
054D20D7 mov     ebx,dword ptr ds:[49388C8h]
054D20DD jmp     054D2080
```

- » will this work fine ?

- » yes, since JAVA 5

» *memory barrier*

- » no, in earlier VMs due to out-of-order writes (example from Sun and IBM JDK 1.4)

Singleton – double-checked locking for Java <5.0



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

    private MySingleton() {
        // ...
    }

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

» will this work fine ?

Singleton – double-checked locking for Java <5.0



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

    private MySingleton() {
        // ...
    }

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



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

    private MySingleton() {
        // ...
    }

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

- » will this work fine ?
 - » **NO** – due to optimization



- » 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 – eager initialization



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

    private MySingleton() {
        // ...
    }

    public static MySingleton getInstance() {
        return _instance;
    }

    // ...
}
```



- » 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**



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

    private MySingleton() {
        // ...
    }

    public static MySingleton getInstance()
    {
        return _instance;
    }
    // ...
}
```

» is this correct singleton?



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

    private MySingleton() {
        // ...
    }

    public static MySingleton getInstance()
    {
        return _instance;
    }
    // ...
}
```

- » is this correct singleton?
 - » **NO** – due to serialization which will create new instance
- » Fix – using read resolve

```
private Object readResolve() {
    return _instance;
}
```



```
public enum MySingleton {  
    INSTANCE;  
  
    private boolean test;  
  
    MySingleton() {  
        test = true;  
    }  
  
    public void myMethod() {  
        // ...  
    }  
}
```

- » serialization issue is fixed by default
- » creation is thread-safe
- » cannot inherit other enums or classes (only can implement interfaces)
- » no lazy initialization
- » different classloaders is still an issue



- » *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



» usage of reflection to create instance

```
public static void main(String[] args) throws Exception {
    MySingleton s = MySingleton.getInstance();

    Class<?> cl = MySingleton.class;

    Constructor<?> cons = cl.getDeclaredConstructor();
    cons.setAccessible(true);

    MySingleton s2 = (MySingleton) cons.newInstance();
}
```

» Fix 1

```
SecurityManager mgr = new SecurityManager();
System.setSecurityManager(mgr);
```



```
Exception in thread "main" java.security.AccessControlException: access denied (java.lang.reflect.ReflectPermission suppressAccessChecks)
    at java.security.AccessControlContext.checkPermission(AccessControlContext.java:323)
    at java.security.AccessController.checkPermission(AccessController.java:546)
    at java.lang.SecurityManager.checkPermission(SecurityManager.java:532)
    at java.lang.reflect.AccessibleObject.setAccessible(AccessibleObject.java:107)
```



» usage of reflection to create instance

```
public static void main(String[] args) throws Exception {
    MySingleton s = MySingleton.getInstance();

    Class<?> cl = MySingleton.class;

    Constructor<?> cons = cl.getDeclaredConstructor();
    cons.setAccessible(true);

    MySingleton s2 = (MySingleton) cons.newInstance();
}
```

» Fix 2

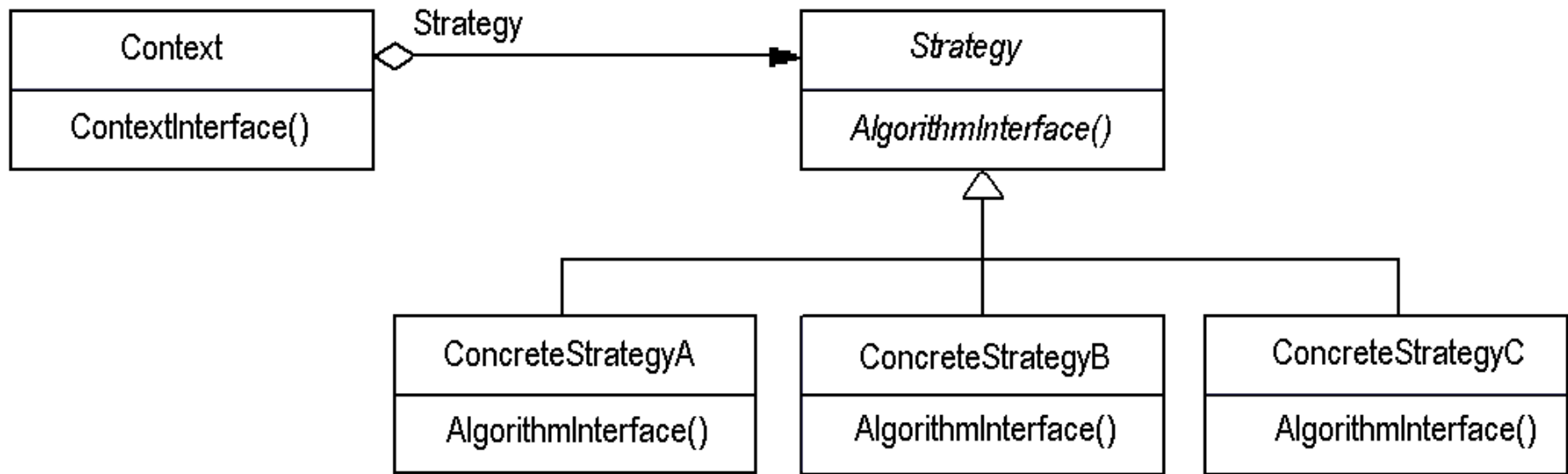
```
public static class MySingleton {
    private static MySingleton _instance = new MySingleton();

    private MySingleton() {
        if (_instance != null) {
            throw new IllegalStateException("Singleton instance already created")
        }
        // ...
    }

    public static MySingleton getInstance()
    {
        return _instance;
    }
    // ...
}
```




- » *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

```
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;  
    }  
}
```

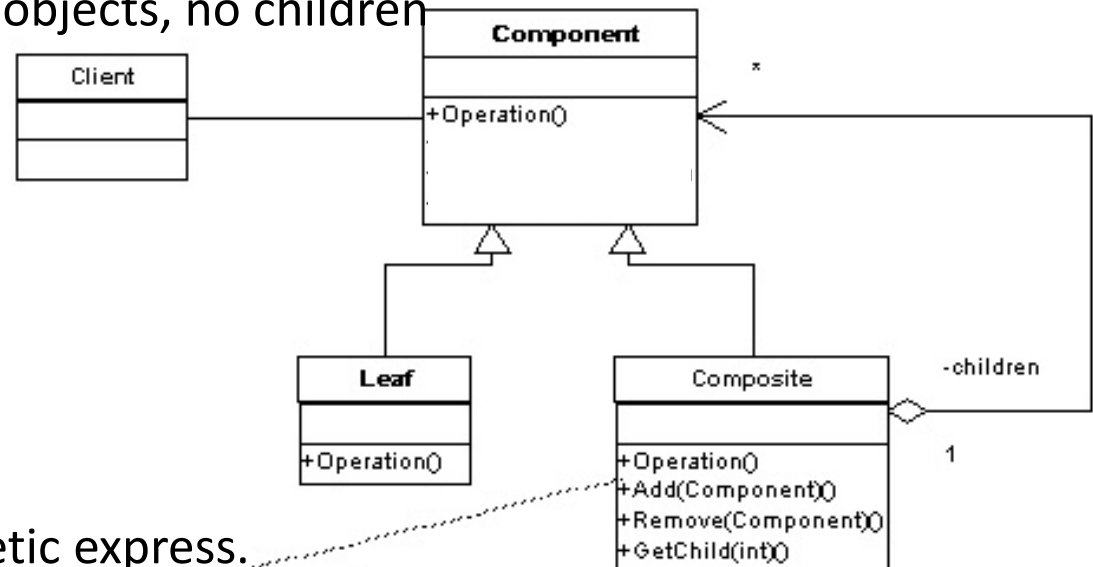
» Initialization

```
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]);  
            }  
        }  
    }  
}
```



- » *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



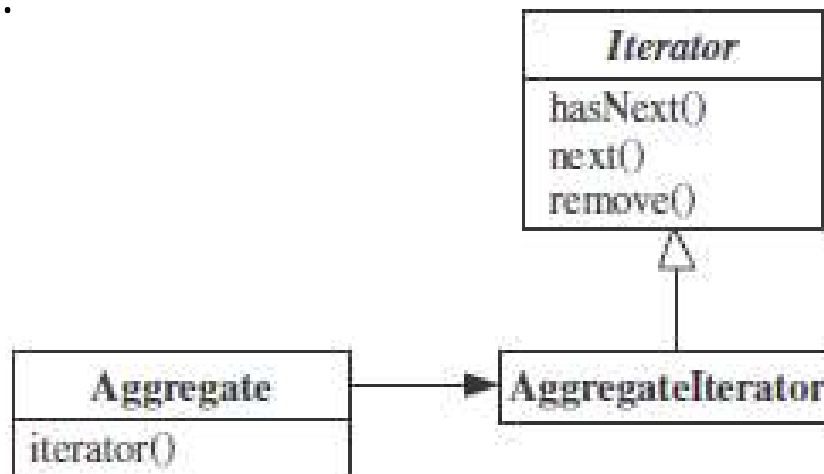
- » Example – Graphics, arithmetic express.

for all c in children c->Operation()



- » *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 change only through iterator -> if changed throws ConcurrentModificationException



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

- » since Java 1.5

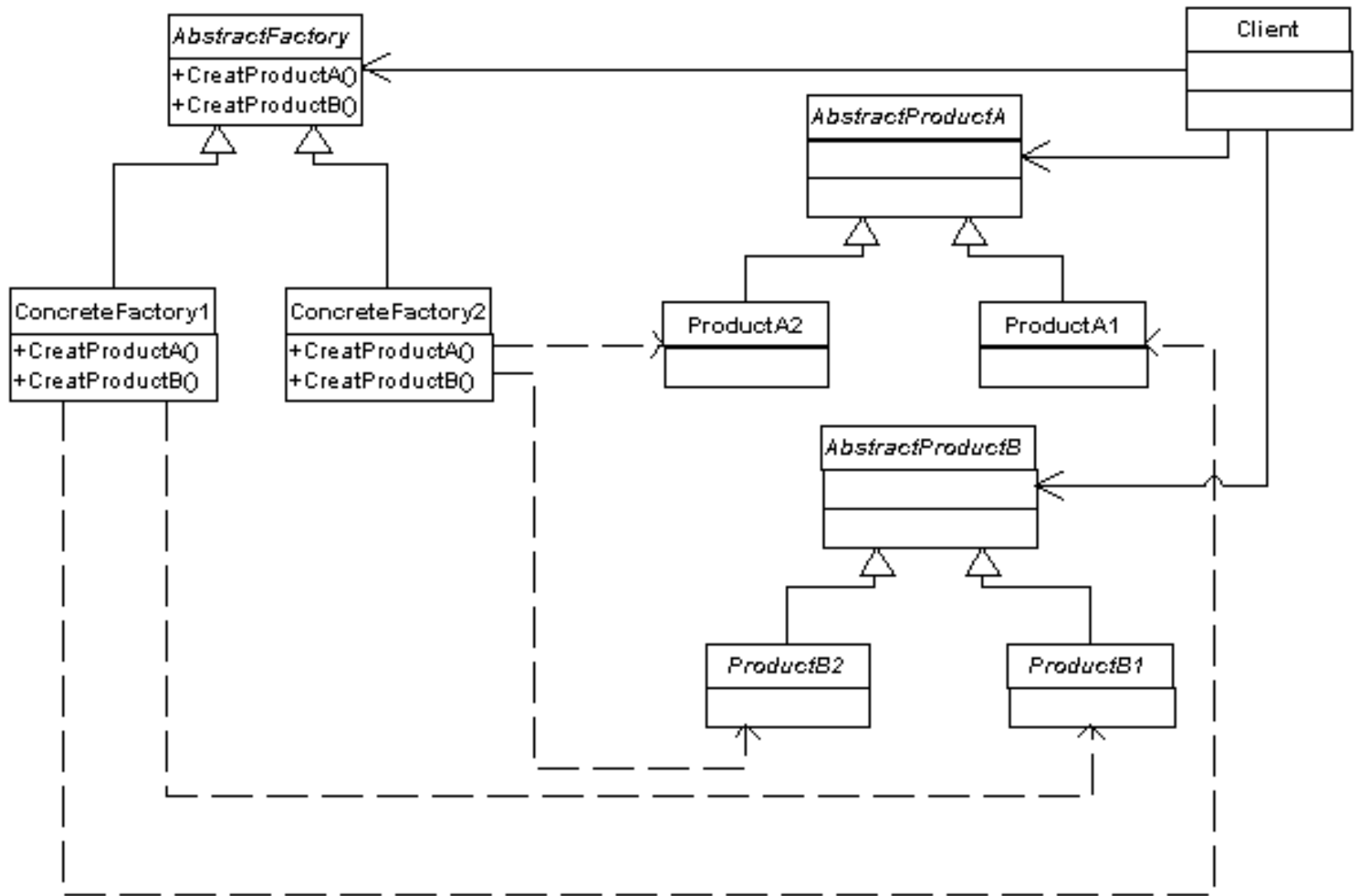
```
Set<Item> items = new TreeSet<Item> ();  
...  
for (Item item : items)  
{ ...  
}
```

- » works on arrays, anything implements Iterable



- » *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)



- » *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

