Functional Programming at Work in Object-Oriented Programming

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version 2010

A Claim about Programming Styles

- **Claim:**

  Adding functional programming capabilities to an object-oriented language leads to benefits in object-oriented programming design.

Existing Languages with a FP-OOP Mix

- Some **old and less old languages with FP+OOP**:
  - For instance, **Smalltalk**, **Common Lisp** (CLOS).
  - More recently, **Python** or **Ruby**.

Notations: **FP**, Functional programming; **OOP**, Object-oriented programming,

FP techniques emulated in OOP

- Practices in OOP languages include **emulations of FP techniques**:
  - C++ programmers: **function pointers and overloadings of the () operator**, i.e. “object-functions” or functors.
  - Java programmers: **anonymous classes** and **introspection/reflexion**.

Existence of FP-OOP Comparison Points

- The idea of **using FP to enrich OOP** is old, see e.g. the discussions about the **problem of the user-defined datatype extension**:
  - ***User-defined types and procedural data structures as complementary approaches to data abstraction***. Reynolds. 1975.
  - ***The Expression Problem***. Wadler. 1998.

A Trend: FP Extensions for OO Languages

- A recent trend: to propose and include typed **FP extensions in mainstream static OO languages**.
  - Extensions for **C++** (see e.g. Laufer, Striegnitz, McNamara, Smaragdakis), and work in progress in the C++ standard committees.
  - **Java 7** expected to include FP constructs.
  - **C#** offers FP constructs (even more in its 3.0 version).
- Also in modern research languages with sophisticated typed frameworks: e.g., **OCaml**, **Scala**.

Purpose of the talk

- **Mix of FP with OOP** not so much practiced.
- $\Rightarrow$ **Purpose of this talk**: a practical synthesis about what a programer can expect when FP is available in OOP (using C# 3.0).

Some References

- ***Structure and Interpretation of Computer Programs***. Abelson, Sussman. MIT Press, 1985.
- ***Synthesizing Object-Oriented and Functional Design to Promote Re-Use***. Krishnamurthi, Felleisen, Friedman. 1998.
- ***Essentials of Programming Languages***. Friedman, Wand, Haynes. MIT Press, 1992.
- ***CLOS: integrating object-oriented and functional programming***. Gabriel, White, Bobrow. 1991.
- ***Bridging Functional and Object-Oriented Programming (FC++)***. Smaragdakis, McNamara. 2000.
- ***Confessions of a used programming language salesman***. Meijer. OOPSLA'07.
- ***C# 3.0 Design Patterns***. J. M. Bishop. O'Reilly, 2008.

Main Points

- **Specific points discussed in this talk**:
  1. **Criteria to check that FP techniques are possible**.
  2. **Idiomatic and architectural effects** of having FP capabilities in OOP.
  3. **FP analysis of some classic OO design patterns**.

Criteria for FP techniques

Criterion:

First-Class Values. *Functions/methods should be* first-class citizens*.*

Rule:

When Criterion 1 holds, most FP techniques can be applied.

Remark: First-class functions generally $\Rightarrow$ **anonymous functions**.

Criteria for FP techniques

Criterion:

Closures. *First-class functions/methods should be implemented as closures, i.e. they should be associated with specific private environments.*

Rule:

When Criterion 2 only holds with non-complete closures, most nice properties due to pure FP are expected to be lost. However, FP techniques can still be applied.

Granularity Mismatch

- FP and OOP operate on **different design granularity levels** :
  - **Functions/methods**: “programming in the small” level.
  - **Classes/objects/modules**: “programming in the large” level,

- $\Rightarrow$ At least **two questions**:
  - *Where do we locate the source of individual functions in an OOP architecture?*
  - *How do we relate such individual functions to an OOP architecture?*

- $\Rightarrow$ **design granularity mismatch**.

Criteria for FP techniques

Criterion:

FP-OOP interrelation tools: *Standalone functions/methods should be explicitly relatable to the class/object level.*

Rule:

When Criterion 3 holds, it helps solving some of the FP-OOP design granularity mismatch problem.

Criteria for FP techniques

Criterion:

FP Support: *The FP-oriented features should be reinforced by related constructs, predefined definitions, occurrences in standard libraries, etc.*

Rule:

When Criterion 4 holds, an OOP language acknowledges the fact that FP is one of its fully integrated tool.

An Object-Oriented FP Construct: the Delegates

- C# offers a FP feature called **delegates**:

```
delegate string StringFunType(string s); //declaration

string G1(string s) {// a method whose type matches StringFunType
   return "some string" + s;
}

StringFunType f1;          // declaration of a delegate variable
f1 = G1;                   // direct method value assignment
f1("some string");         // application of the delegate variable
```

- Delegates are **first-class values**.

1. Delegates as First-Class Values

- Delegate types **can type method parameters**, and delegates **can be passed as arguments** as any other values:

```
string Gf1(StringFun f, string s) { [...] }
                                    //delegate f as a parameter
WriteLine(Gf1(G1, "some string"));          //call
```

2. Delegates as First-Class Values

- Delegates **can be returned as a computation** of a method. For instance, assuming `G` is a method of type `string => string` and implemented in `SomeClass`:

```
StringFun Gf2() {  //delegate as a return value
    [...]
    return (new SomeClass()).G;
}

WriteLine(Gf2()("some string"));  //call
```

3. Delegates as First-Class Values

- Delegates can **take place into data structures**:

```
var l = new LinkedList<StringFun>();
                    // list of delegates
[...]
l.AddFirst(G1);     // insertion of a delegate in the list
WriteLine(l.First.Value("some string"));
                    // extract and call
```

Anonymous delegates

- C# delegates may be **anonymous**:

```
delegate(string s) { return s + "some string"; };
```

- Anonymous delegates can look even more like **lambda expressions**:

```
(s => { return s + "some string"});
s => s + "some string";
```

Closures

- **No strict closures** in C# (intrinsically “impure FP”):

```
StringFun f1, f2;
int counter = 1000;
f1 = s => s + counter.ToString();
f2 = s => s + counter.ToString();
```

- $\Rightarrow$ **Usual enclosing technique** in impure FP:

```
StringFun F() {
    int _counter = 1000;
    return s => { return s + _counter.ToString(); };
}
```

An Interrelation FP/OOP: the Extension Methods

- **Extension methods**: enable a programmer to add methods to existing classes without creating new derived classes:

```
static int SimpleWordCount (this String str) {
   return str.Split(new char[] { ' ' }).Length;
}

String s1 = "aaa bb cccc";

String s1 = "some chain";
s1.SimpleWordCount();    // usable as a String method
SimpleWordCount(s1);     // also usable as a standalone method
```

An Interrelation FP/OOP: the Extension Methods

- Another **classic example** of extension method:

```
static IEnumerable<T> MySort<T>(this IEnumerable<T> obj)
    where T : IComparable<T> {
    [...]
}

List<int> someList = [...];
someList.MySort();
```

An Interrelation FP/OOP: the Extension Methods

- **Functions/methods implemented for delegates are often defined as extension methods.**
- Extension methods: related to "**open-classes**" (see e.g., CLOS, Ruby, Multijava).
- Extension methods have harsh constraints in C#:
  - Only static !
  - Not polymorphic (not virtual) !
- For Java 7, **closure conversions** are proposed.
- In Groovy, **explicit closure conversions** exist.

FP Integration in C#

- **Basic Delegates Predefinitions**. C# offers functional and procedural generic delegate predefined types for arity up to 4... (respectively under the name `Func` and `Action`):

```
delegate TResult Func<TResult>();
delegate TResult Func<T,TResult>(T a1);
delegate TResult Func<T1,T2,TResult>(T1 a1, T2 a2);
delegate void Action<T>(T a1);
[...]
```

- NB: overloading applies for generic delegates too.

FP Integration in C#

- **First-Class Multiple Invocation and Multicasting**. A delegate may itself contain an "**invocation list**" of delegates.
- When such delegate is called, methods of the included delegate are invoked in the order in which they appear in the list.
- The result value is determined by the last method called in the list.
- Management of multicasting: + and − are overloaded to act on these invocation lists:

```
menuItem1.Click += [...]; // some delegate
```

FP Integration in C#

- **Function Marshalling and Serialization**. C# allows lambda expressions to be represented as data structures called *expression trees*:

```
Expression<Func<int,int>> expression = x => x + 1;

var d = expression.Compile();
d.Invoke(2);
```

- As such, they may be **stored and transmitted**.

General FP Techniques in OOP

- Some **idiomatic and technical effects** of having FP capabilities in OOP:
  1. Code factoring at a function/method granularity level,
  2. Generic iterator and loop operations
  3. Operation compositions (and sequence comprehensions).
  4. Function partial applications and currying.

Code Abstraction at a Function/Method Level

- A simple code:

```
float M(int y) {
    int x1 = [...]; int x2 = [...];
    [...]
    [...code...]; //some code using x1, x2, y
    [...]
}
```

- With **functional abstraction**:

```
public delegate int Fun(int x, int y, int z);
float MFun(Fun f, int x2, int y) {
    int x1 = [...];
    [...]
    f(x1, x2, y);
    [...]
}

int z1 = MFun(F1, 1, 2);
int z2 = MFun(F2, 3, 4);
```

- $\Rightarrow$ **No local duplications + separation of concerns.**

Generic Iterator and Loop Operations

- A simple and effective application of the functional abstraction: generic **higher-order iterated operations over data**.
- For instance, the **internal iterators** (Maps):

```
IEnumerable<T2>
Map<T1, T2>(this IEnumerable<T1> data, Func<T1, T2> f) {
    foreach (T1 x in data)
        yield return f(x);
}
```

```
someList.Map(i => i * i );
```

Operation Compositions

- FP $\Rightarrow$ **Easy operation compositions.**
- An initial method code:

```
public static void PrintWordCount(string s) {
    String[] words = s.Split(' ');
    for (int i = 0; i < words.Length; i++)
        words[i] = words[i].ToLower();
    var dict = new Dictionary<string, int>();
    foreach (String word in words)
        if (dict.ContainsKey(word))
            dict[word]++;
        else dict.Add(word, 1);
    foreach (KeyValuePair<String, int> x in dict)
        Console.WriteLine("{0}: {1}", x.Key,
                                      x.Value.ToString()));
}
```

Operation Compositions

- A **first factoring using higher-order functions**:

```
public static void PrintWordCount(string s) {
    String[] words = s.Split(' ');
    String[] words2 =
        (String[]) Map(words, w => w.ToLower());
    Dictionary<String, int> res =
        (Dictionary<String, int>) Count(words2);
    App(res, x => Console.WriteLine("{0}: {1}",
                    x.Key, x.Value.ToString()));
}
```

Operation Compositions

- **A second factoring using extension methods**:

```
public static void PrintWordCount(string s) {
    s.Split(' ')
     .Map(w => w.ToLower())
     .Count()
     .App(x => WriteLine("{0}: {1}",
                         x.Key, x.Value.ToString()));
}
```

- $\Rightarrow$ **Increased readability**.

Operation Compositions

- In C#, such operation compositions are often used with the "**Language Integrated Query**" (LINQ) – defined to unify programming with relational data or XML, e.g. (Meijer):

```
var q = programmers
    .Where(p => p.Age > 20)
    .OrderByDescending(p => p.Age)
    .GroupBy(p => p.Language, p.Name)
    .Select(g => new{ Language = g.Key,
       Size = g.Count(), Names = g});
```

- $\Rightarrow$ **Solve some of the "impedance mismatch"** between OOP and data base exploitation.

Function Partial Applications and Currying

- With first-class functions, every ***n*-ary function can be transformed** into a composition of *n* unary functions, that is, into a **curried function**:

```
Func<int, int, int> lam1 = (x, y) => x + y;

Func<int, Func<int, int>> lam2 = x => (y => x + y);

Func<int, int> lam3 = lam2(3); //partial application
```

- **Curryfying**:

```
public static Func<T1, Func<T2, TRes>>
    Curry<T1, T2, TRes> (this Func<T1, T2, TRes> f) {
        return (x => (y => f(x, y)));
}

Func<int, int> lam4 = lam1.Curry()(3);  //partial application
```

Architectural FP Techniques in OOP

- Some **architectural effects** of having FP capabilities in OOP:
  1. Reduction of the number of object/class definitions.
  2. Name abstraction at a function/method level.
  3. Operation compositions (and sequence comprehensions).
  4. Function partial applications and currying.

Limitation of the Number of Object/Class Definitions

- Functional abstraction $\Rightarrow$ **Avoid cluttering the OO architecture with new classes**:

```
interface IFun{ int F(int x, int y, int z);}

class F1 : IFun {
    public int F(int x, int y, int z) { [...] } }
class F2 : IFun {
    public int F(int x, int y, int z) { [...] } }

float M(IFun funobj, int x2, int y) {
    int x1 = [...val1...]
    [...]
    funobj.F(x1, x2, y);
    [...]
}
int z1 = M(new F1(), 1, 2);
int z2 = M(new F2(), 3, 4);
```

Name Abstraction at a Method Level

- Using first-class methods allows parameters **to be instantiated by any method satisfying their declared types.**

```
interface IStringFun{ string F1(string s); }

IStringFun obj1 = [...];
[...] obj1.F1 [...]
```

- $\Rightarrow$ **Name abstraction**.
- $\Rightarrow$ **Induce some "structuralness" into nominal-oriented OOP**, i.e. **flexibility**.

Name Abstraction at a Method Level

- Example of **name abstraction** with a **Bridge**:
  - The initial code:

```
public class Window {
    private WindowSys _imp;
    void DrawFigure ([...]) {
        _imp.DeviceFigure([...]);
}
```

  - With delegates:

```
public delegate void DeviceFigureFun([...]);
public class Window {
    private DeviceFigureFun _devfig;
    void DrawFigure ([...]) {
        _devfig([...]);
  }
```

  - Without delegates: **must use Adapters** (see e.g. `ActionListener` in Java).

Name Abstraction at a Method Level

- Another example of **name abstraction** with an **Abstract Factory**:
  - The initial code:

```
public interface Maze{[...]};
public interface Wall{[...]};
public interface Room{[...]};
public interface MazeFactory {
    Maze MakeMaze();
    Wall MakeWall();
    Room MakeRoom();
}
```

  - With delegates:

```
public delegate Maze MakeMazeFun();
public delegate Wall MakeWallFun();
public delegate Room MakeRoomFun();

public abstract class MazeFactoryFun {
    MakeMazeFun MakeMaze;
    MakeWallFun MakeWall;
    MakeRoomFun MakeRoom;
}
```

Name Abstraction at a Method Level

- **Name abstraction** $\Rightarrow$ **More flexibility**.
- But also $\Rightarrow$ **More looseness** and **problems of architecture organization**.

FP Design Granularity Mismatch

- **Where do we put the sources of the standalone methods?**:
  - **Solution with Basic Modules**: functions as static methods in some utility class or module.
    $\Rightarrow$ **Not easily extensible, and does not mix so well with class hierarchy**.
  - **Solution with anonymous constructs**: function implementations of function directly into the calls:

```
int z1 = MFun((x1, x2, x3) => [...<F1 code>...], 1, 2);
int z2 = MFun((x1, x2, x3) => [...<F2 code>...], 3, 4);
```

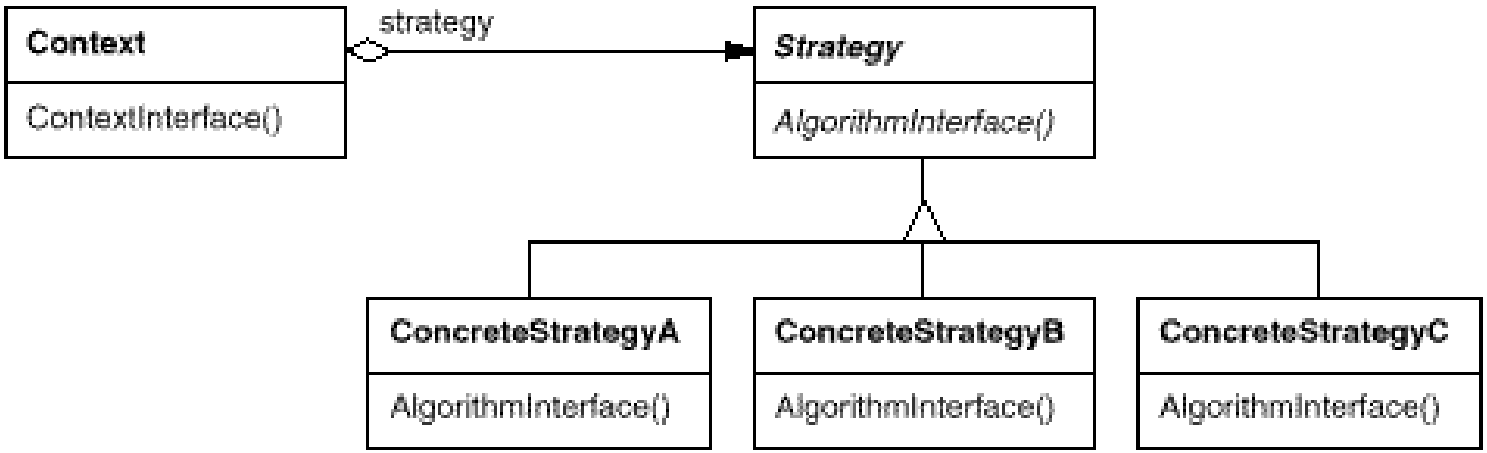
  $\Rightarrow$ **Spread the code all over the calls, and may lead to no reusability.**

Some classic OOP Design Patterns with FP

- Some of the **classic OOP Design Patterns** can be considered under FP influence...:
  1. Strategy, Command.
  2. Observer.
  3. Proxy.
  4. Visitor.

Strategy

- A **Strategy** pattern is to ***let an algorithm vary independently of clients that use it***.



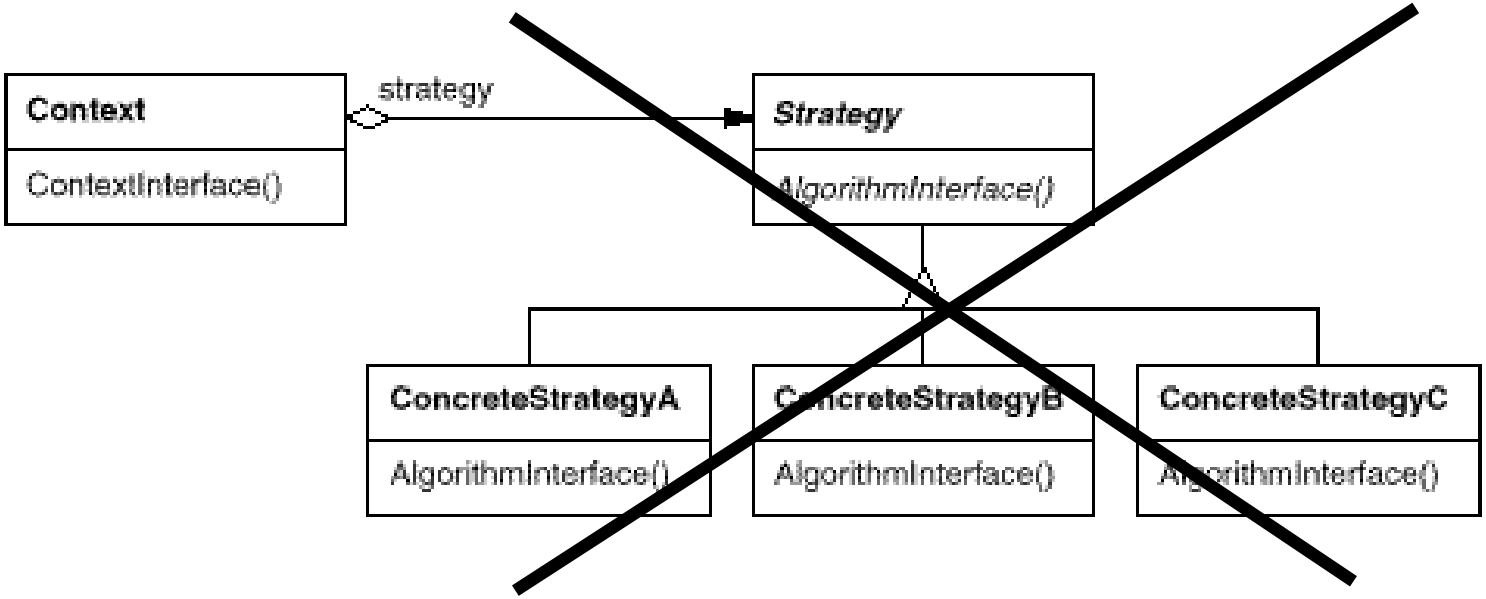
(The pattern figures are taken from the GoF book.)

Strategy with FP

- A **Strategy**: just **a case of abstracting code at a method level** ($\Rightarrow$ **No need of OO encapsulation and new class hierarchies**).
- For instance in the .NET Framework:

```
public delegate int Comparison<T>(T x, T y)
public void Sort(Comparison<T> comparison)

public delegate bool Predicate<T>(T obj)
public List<T> FindAll(Predicate<T> match)
```

Strategy with FP

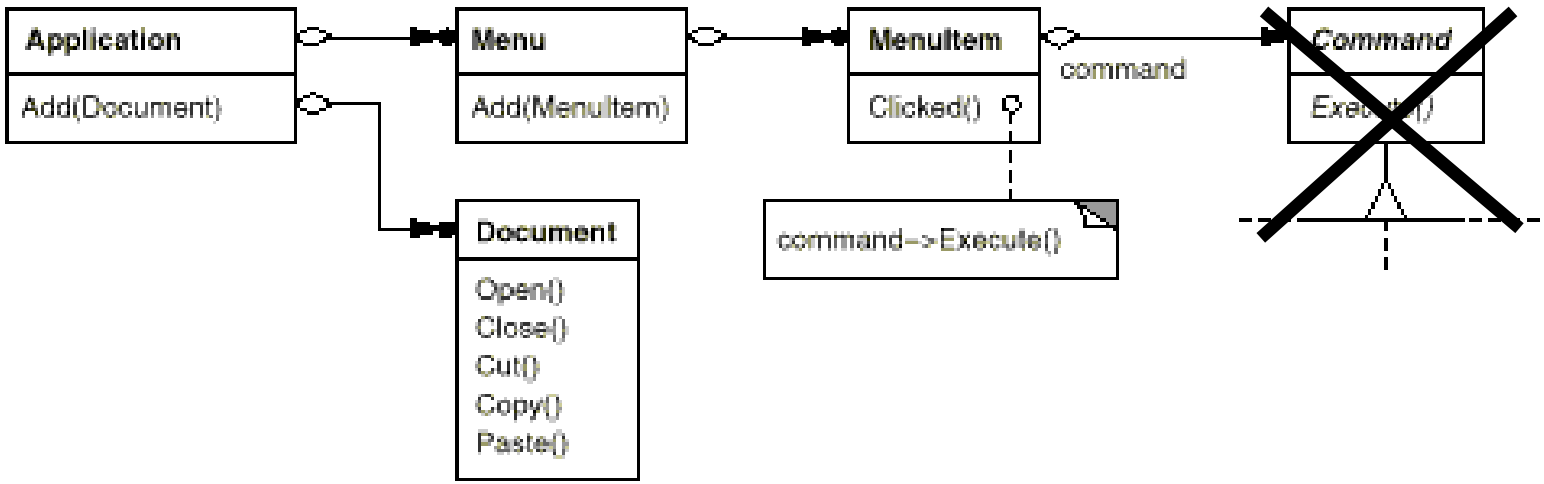


Command

- The **Command** pattern ***encapsulates requests (method calls) as objects*** so that they can easily be transmitted, stored, and applied.
- $\Rightarrow$ **Same as Strategy**.
- For instance, **menu implementations**:

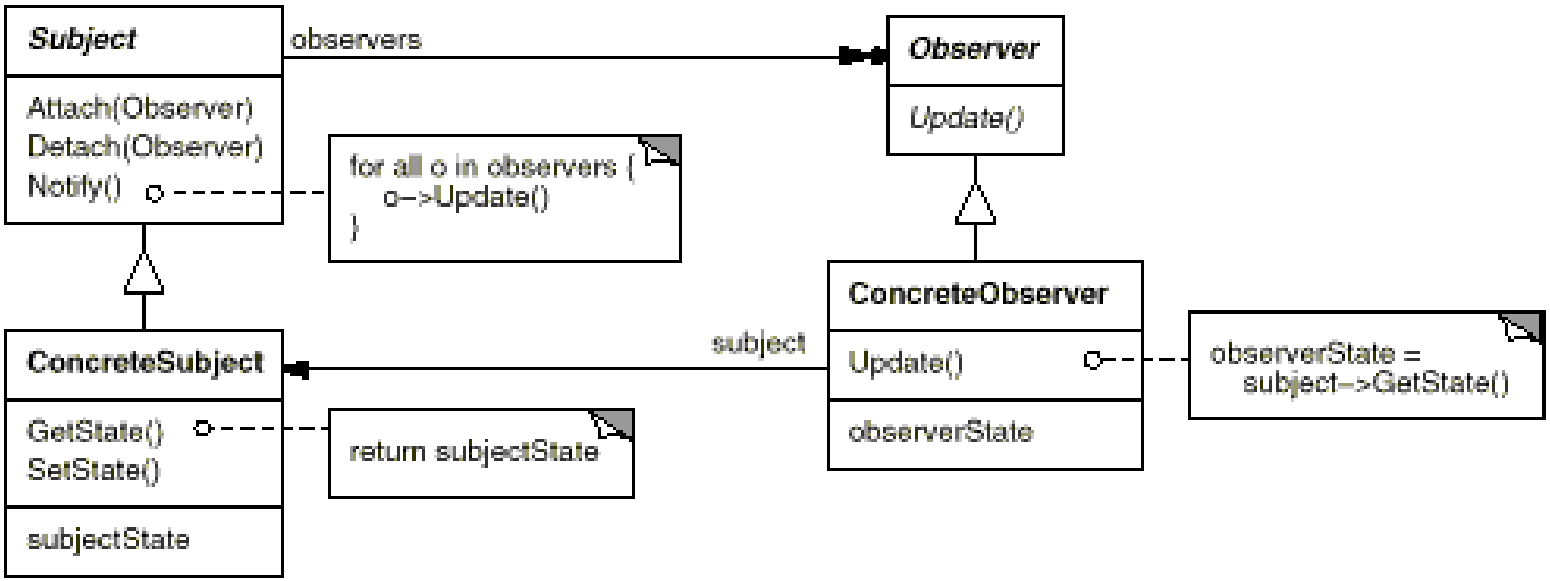
```
public delegate void EventHandler(Object sender, EventArgs e)
public event EventHandler Click

private void menuItem1_Click(object sender, System.EventArgs e) {
    OpenFileDialog fd = new OpenFileDialog();
    fd.DefaultExt = "*.*"; fd.ShowDialog();
}
public void CreateMyMenu() {
    MainMenu mainMenu1 = new MainMenu();
    MenuItem menuItem1 = new MenuItem();
    [...]
    menuItem1.Click += new System.EventHandler(menuItem1_Click);
}
```

Command with FP



Observer

- The **Observer** pattern: ***a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated.***



Classic Observer

```
public interface Observer<S> {
     void Update(S s);
}

public abstract class Subject<S> {
  private List<Observer<S>> _observ = new List<Observer<S>>();

  public void Attach(Observer<S> obs) {
          _observ.Add(obs);
  }
  public void Notify(S s) {
          foreach (Observer<S> obs in _observ) {
                  obs.Update(s);
                }
     }
}
```

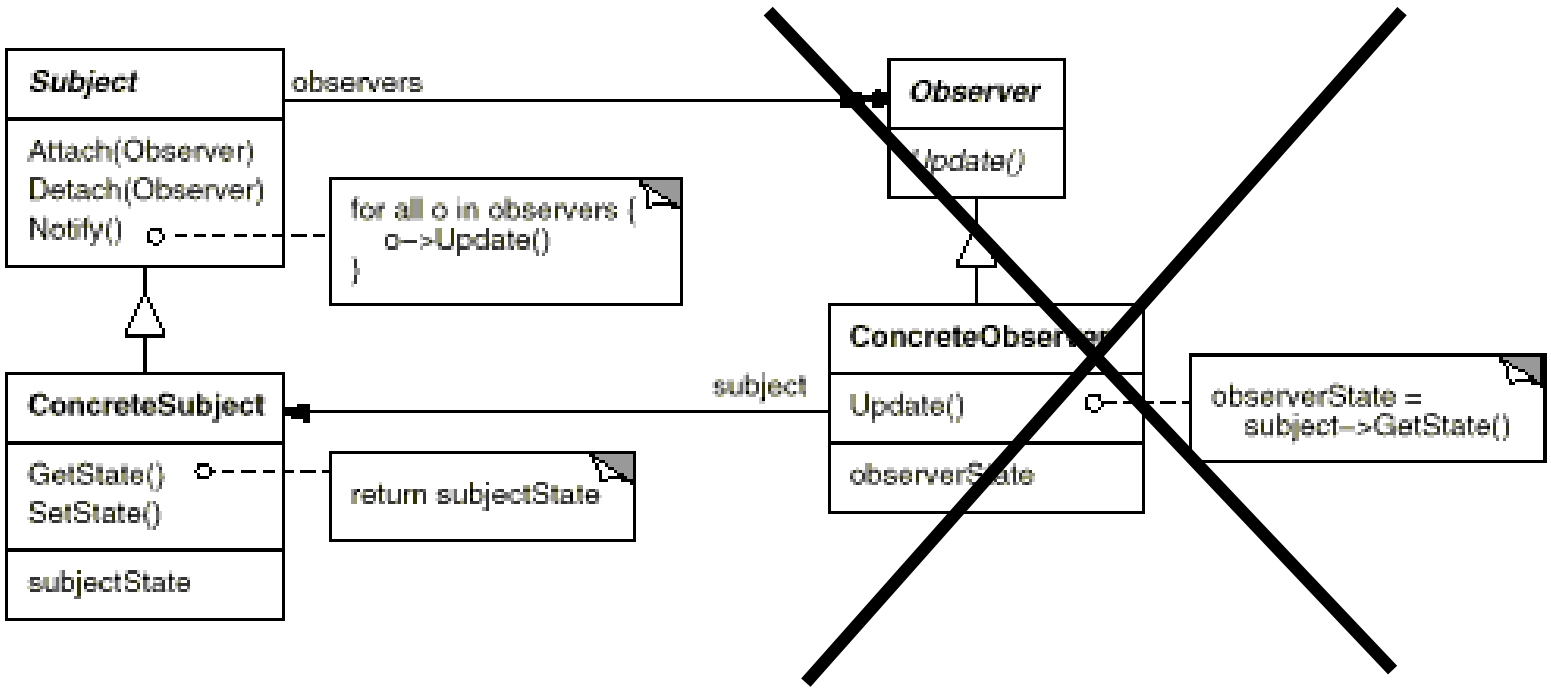
Observer with FP

- FP $\Rightarrow$ **Observer with functional values as updaters**:

```
public delegate void UpdateFun<S>(S s);

public abstract class Subject<S> {
    private UpdateFun<S> _updateHandler;

 public void Attach(UpdateFun f) {
       _updateHandler += f;
 }
 public void Notify(S s) {
        _updateHandler(s);
    }
}
```

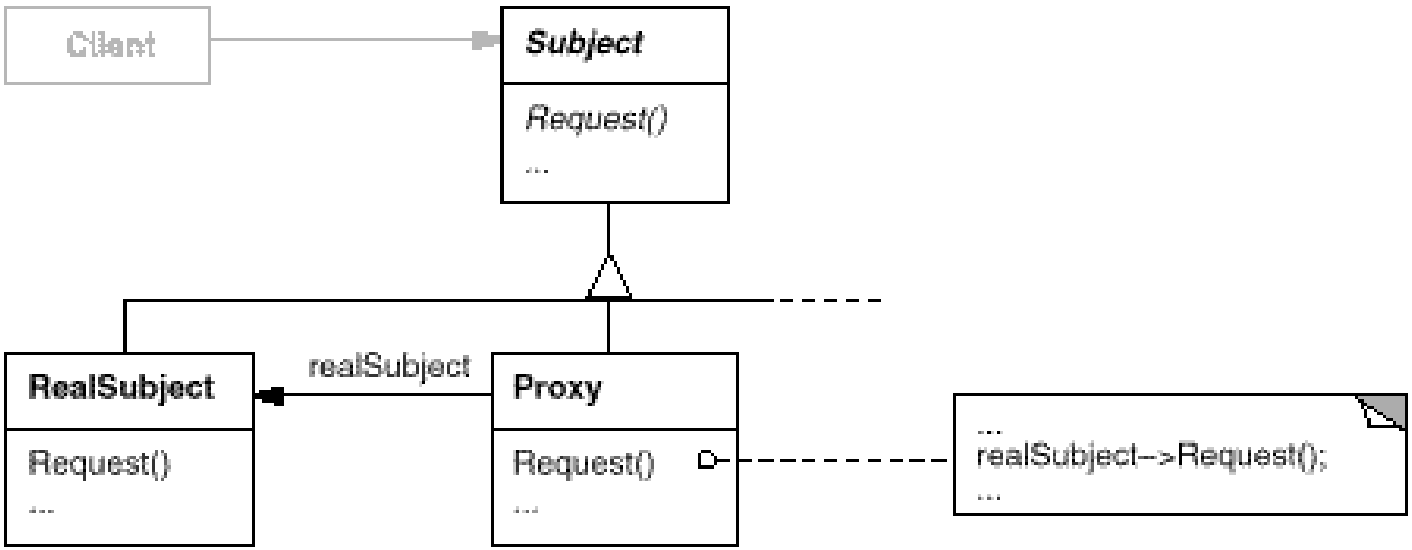
- $\Rightarrow$ **No need of observer classes with methods called** `Update()`.

Observer with FP



Virtual Proxy

- The **Virtual Proxy** pattern: ***placeholders for other objects such that their data are created/computed only when needed***.



Classic Virtual Proxy

```
public class SimpleProxy : I {
    private Simple _simple;
    private int _arg;
    protected Simple GetSimple() {
        if (_simple == null)
            this._simple = new Simple(this._arg);
        return _simple;
    }
    public SimpleProxy(int i) { this._arg = i; }
    public void Process() {
       GetSimple().Process();
    }
}
```

Virtual Proxy with FP Lazyness

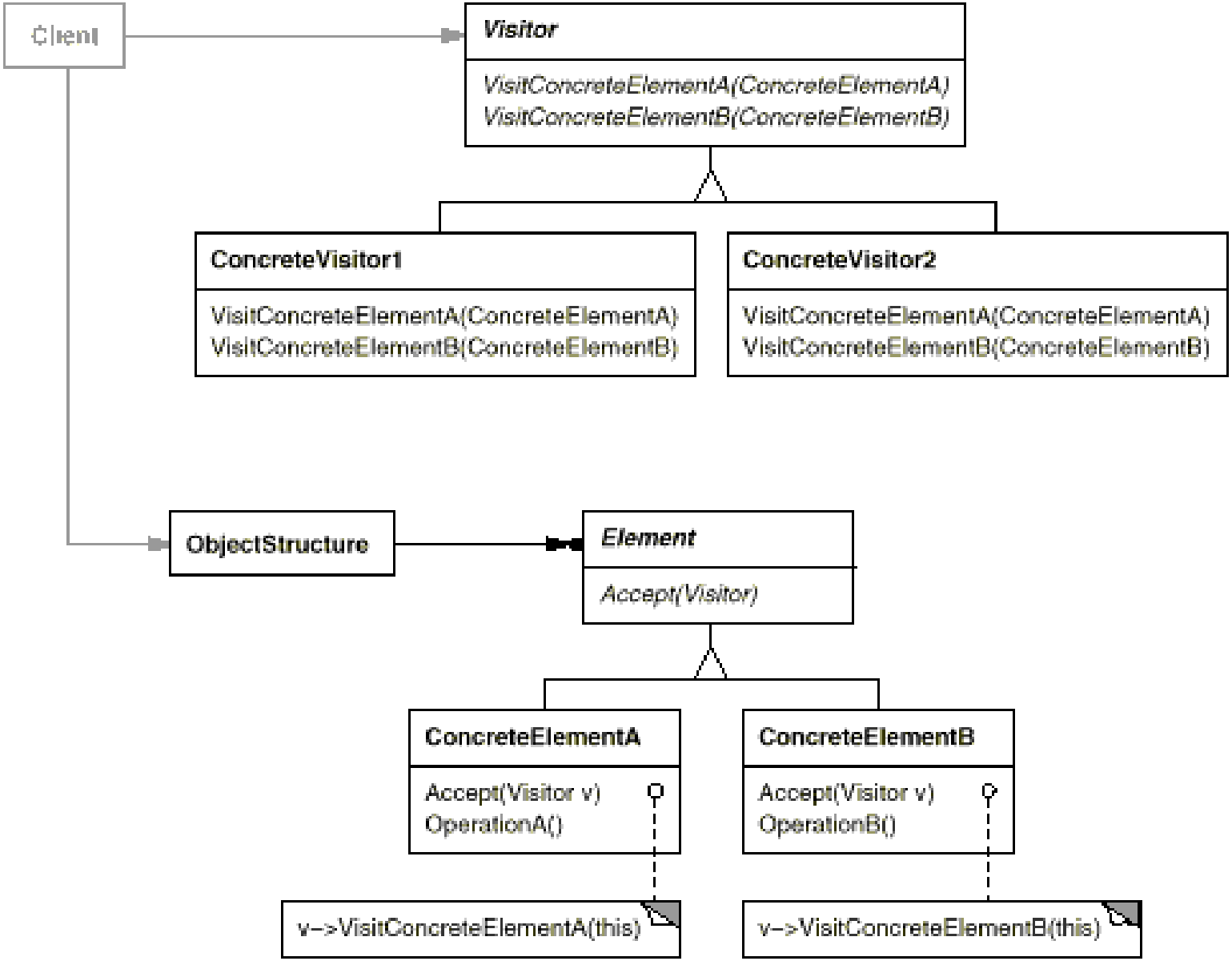
- FP $\Rightarrow$ **Less need of specific Proxy classes**:

```
public class SimpleLazyProxy : I {
    private Lazy<Simple> _simpleLazy;
    public SimpleLazyProxy(int i) {
        this._simpleLazy =
            new Lazy<Simple>(() => new Simple(i));
    }
    public void Process() {
        this._simpleLazy.Value.Process();
    }
}
```

Visitor

- The **Visitor** pattern: ***lets you define new operations without changing the classes of the elements on which they operate***
- Without Visitors, each subclass of a hierarchy has to be edited or derived separately.
- NB: Visitors are **at the crux of many of the programming design problems**...

Visitor


Client
Visitor
VisitConcreteElementA(ConcreteElementA)
VisitConcreteElementB(ConcreteElementB)
ConcreteVisitor1
VisitConcreteElementA(ConcreteElementA)
VisitConcreteElementB(ConcreteElementB)
ConcreteVisitor2
VisitConcreteElementA(ConcreteElementA)
VisitConcreteElementB(ConcreteElementB)
ObjectStructure
Element
Accept(Visitor)
ConcreteElementA
Accept(Visitor v)
OperationA()
ConcreteElementB
Accept(Visitor v)
OperationB()
v->VisitConcreteElementA(this)
v->VisitConcreteElementB(this)

Classic Visitor

```
public interface IFigure {
    String GetName();
    void Accept<T>(IFigureVisitor<T> v);
}
public class SimpleFigure : IFigure {
    private String _name;
    public SimpleFigure(String name) { this._name = name; }
    public String GetName() { return this._name; }
    public void Accept<T>(IFigureVisitor<T> v) {
        v.Visit(this);
    }
}
public class CompositeFigure : IFigure {
    private String _name;
    private IFigure[] _figureArray;
    public CompositeFigure(String name, IFigure[] s) {
        this._name = name; this._figureArray = s;
    }
    public String GetName() { return this._name; }
    public void Accept<T>(IFigureVisitor<T> v) {
        foreach (IFigure f in _figureArray)
            f.Accept(v);
        v.Visit(this);
    }
```

Classic Visitor

```
public interface IFigureVisitor<T> {
    T GetVisitorState();
    void Visit(SimpleFigure f);
    void Visit(CompositeFigure f);
}
```

```
public class NameFigureVisitor : IFigureVisitor<string> {
    private string _fullName = "";
    public string GetVisitorState() { return _fullName; }
    public void Visit(SimpleFigure f) {
        _fullName += f.GetName() + " ";
    }
    public void Visit(CompositeFigure f) {
        _fullName += f.GetName() + "/";
    }
}
```

Weaknesses of Visitors

- Some well-known **weaknesses of Visitors**:
  - **Refactoring Resistance**. A Visitor definition is dependent on the set of client classes on which it operates.
  - **Staticness**. A Visitor is static in its implementation (type-safety but less flexibility).
  - **Invasiveness**. A Visitor needs that the client classes anticipate and/or participate in making the selection of the right method.
  - **Naming Inflexibility**. A Visitor needs that all the different implementations of the visit methods be similarly named.

Visitor and Extension Methods

- An **attempt to solve Visitor problems with extension methods** (cf. “open classes” – but not ok in C#):

```
public interface IFigure {
     String GetName();    // no Accept method required
 }

[...]

public static class NameFigureVisitor  {
    public static void NameVisit(this SimpleEFigure f)
        { _state = f.GetName() + " " + _state; }

    static void NameVisit(this CompositeFigure f) {
       _fullName = f.GetName() + ":" + _fullName;
       foreach (IFigure g in f.GetFigureArray())
           g.NameVisit();  // !!! dynamic dispatch required...
     }
     [...]
 }
```

Visitor with FP

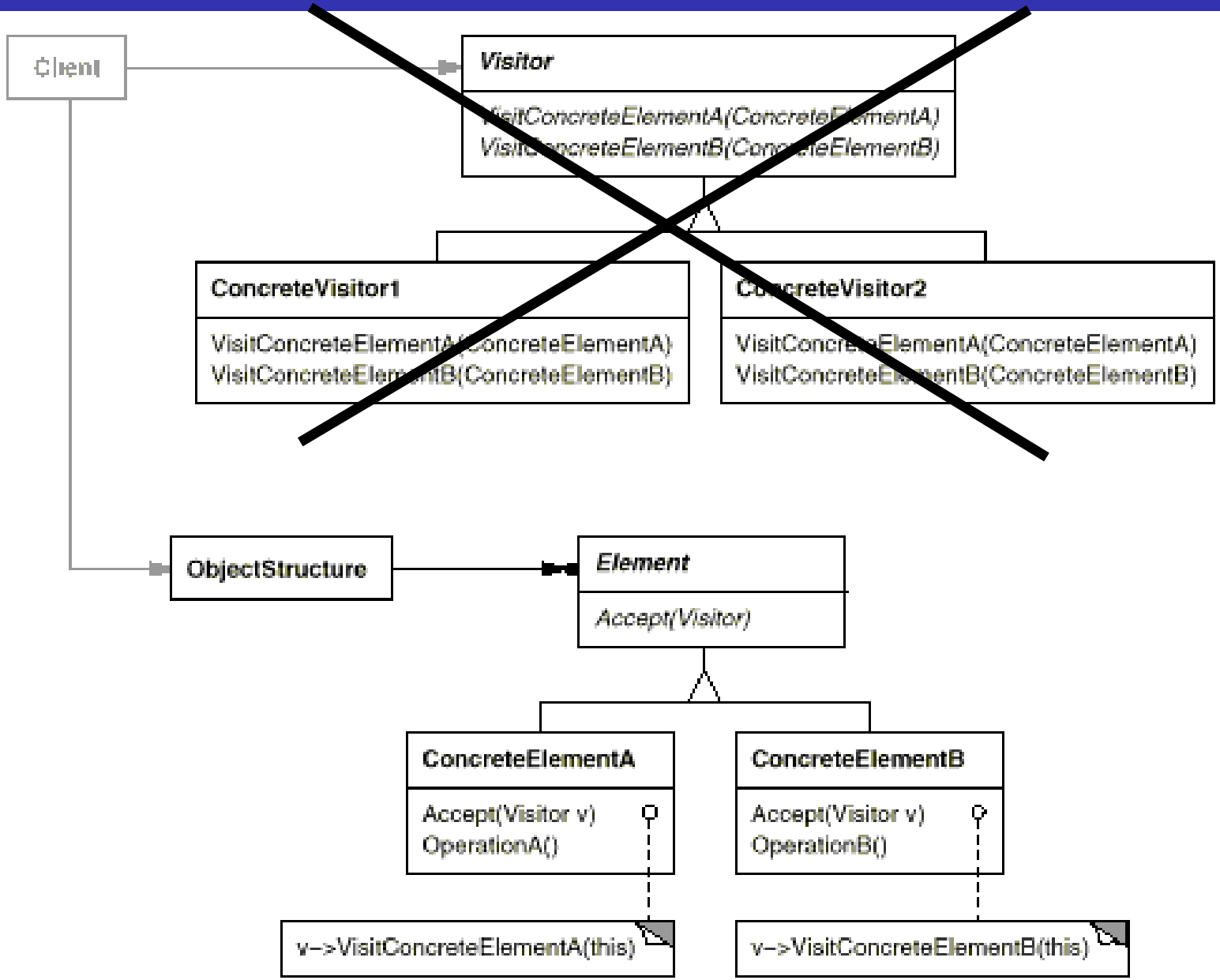
- FP $\Rightarrow$ **Visitors can be functions**:

```
public delegate T VisitorFun<V, T>(V f);

public interface IFigureF {
    String GetName();
    T Accept<T>(VisitorFun<IFigureF, T> v);
}
public class SimpleFigureF : IFigureF {
    private String _name;
    public SimpleFigureF(String name) { this._name = name; }
    public String GetName() { return this._name; }
    public T Accept<T>(VisitorFun<IFigureF, T> v) {
        return v(this);
    }
}
[...]
```

Visitor with FP

```
public class CompositeFigureF : IFigureF {
    private String _name;
    private IFigureF[] _figureArray;
    public CompositeFigureF(String name, IFigureF[] s) {
        this._name = name; this._figureArray = s;
    }
    public String GetName() { return this._name; }
    public T Accept<T>(VisitorFun<IFigureF, T> v) {
        foreach (IFigureF f in _figureArray) {
            f.Accept(v);
        }
        return v(this);
    }
}
```

Visitor with FP



Functional Visitors

- A **simple functional Visitor**:

```
public static VisitorFun<IFigureF, String>
  MakeNameFigureVisitorFun() {
    string _state = "";
    return obj => {
      if (obj is SimpleFigureF)
         _state += f.GetName() + " "; else
      if (obj is CompositeFigureF)
         _state += f.GetName() + "/";
      return _state;
    };
}
```

- But $\Rightarrow$ **Ad-hoc explicit selection needed...**

Visitor with Functional Data-Driven Programming

- A **Visitor** with **functional data-driven programming** made of:
  - Dictionaries of pairs in the form `(type, method)`.
  - Generic “accept” able to exploit these dictionnaries and call the right method corresponding to a given type.
- $\Rightarrow$ **Explicit generic selection mechanism**.

Visitor with Functional Data-Driven Programming

- **Use of data-driven oriented Visitor**:

```
var dict1 =
  new Dictionary<System.Type, VisitFun<IFigureF, String>>();

dict1.Add(typeof(SimpleFigureF),
                (f, s) => s + f.GetName() + " ");
dict1.Add(typeof(CompositeFigureF),
                (f, s) => s + f.GetName() + "/");

var nameFigureFunVisitor1 =
   MakeVisitorFun<IFigureF, String>(dict1);
```

Visitor with Functional Data-Driven Programming

- FP $\Rightarrow$ **Data-driven Functional Visitors**.
- $\Rightarrow$ **Less refactoring resistance, less name rigidity, and less staticness**.
- But $\Rightarrow$
  - **Possible type incoherences**...
  - **Syntax intricacies**...

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- In order **to get flexible code in classic OOP at a method level**, essentially two ways:
  - **Method encapsulation in objects** (rich but heavy).
  - **Method management by introspection/reflection and plug-in capabilities** (flexible but type unsafe and technically cumbersome).
- $\Rightarrow$ A possible answer is to **include a typed first-class method granularity level**.

Summing Up

- **OOP with FP granularity level** $\Rightarrow$
  - **Code Abstraction** at a function/method level.
  - **Convenient generic iterator/loop** implementations.
  - **Operation compositions**, sequence/query comprehensions.
  - **Function partial applications**.
  - **Limitations of the number of object/class** definitions.
  - **Name abstractions** at a function/method level.

- And :
  - **Lazyness emulations** (used e.g. in Virtual Proxies).
  - **Data-driven or table-driven programming** (used e.g. in Visitors).

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  - **Architecture inhomogeneity**.
  - **Lack of type coherence**.
  - **no easy reusability**.
- Some **partial solutions** of granularity mismatch:
  - **Specific modular organizations**.
  - **Anonymous constructs**.
  - **Interrelation means** like “extension methods”.

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- Remark: anyway, FP is expected in Java, C++, Sprutch...