An Introduction to Design Patterns

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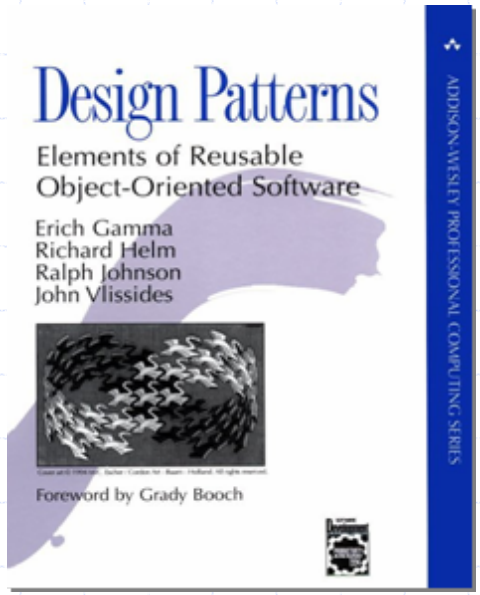


Based on material produced by John Vlissides

Overview

Part I: Motivation & Concept

- the issue
- what design patterns are
- what they're good for
- how we develop & categorize them

Overview (cont'd)

Part II: Application

- use patterns to design a document editor
- demonstrate usage & benefits

Part III: Wrap-Up

- observations, caveats, & conclusion

Part I: Motivation & Concept

OOD methods emphasize design notations

- Fine for specification, documentation

But OOD is more than just drawing diagrams

- Good draftsmen  good designers

Good OO designers rely on lots of experience

- At least as important as syntax

Most powerful reuse is *design* reuse

- Match problem to design experience

Recurring Design Structures

OO systems exhibit recurring structures that promote

- abstraction
- flexibility
- modularity
- elegance

Therein lies valuable design knowledge

Problem:

capturing, communicating, & applying this knowledge

A *Design Pattern*...

- abstracts a recurring design structure
- comprises class and/or object
  - dependencies
  - structures
  - interactions
  - conventions
- names & specifies the design structure explicitly
- distills design experience

Four Basic Parts

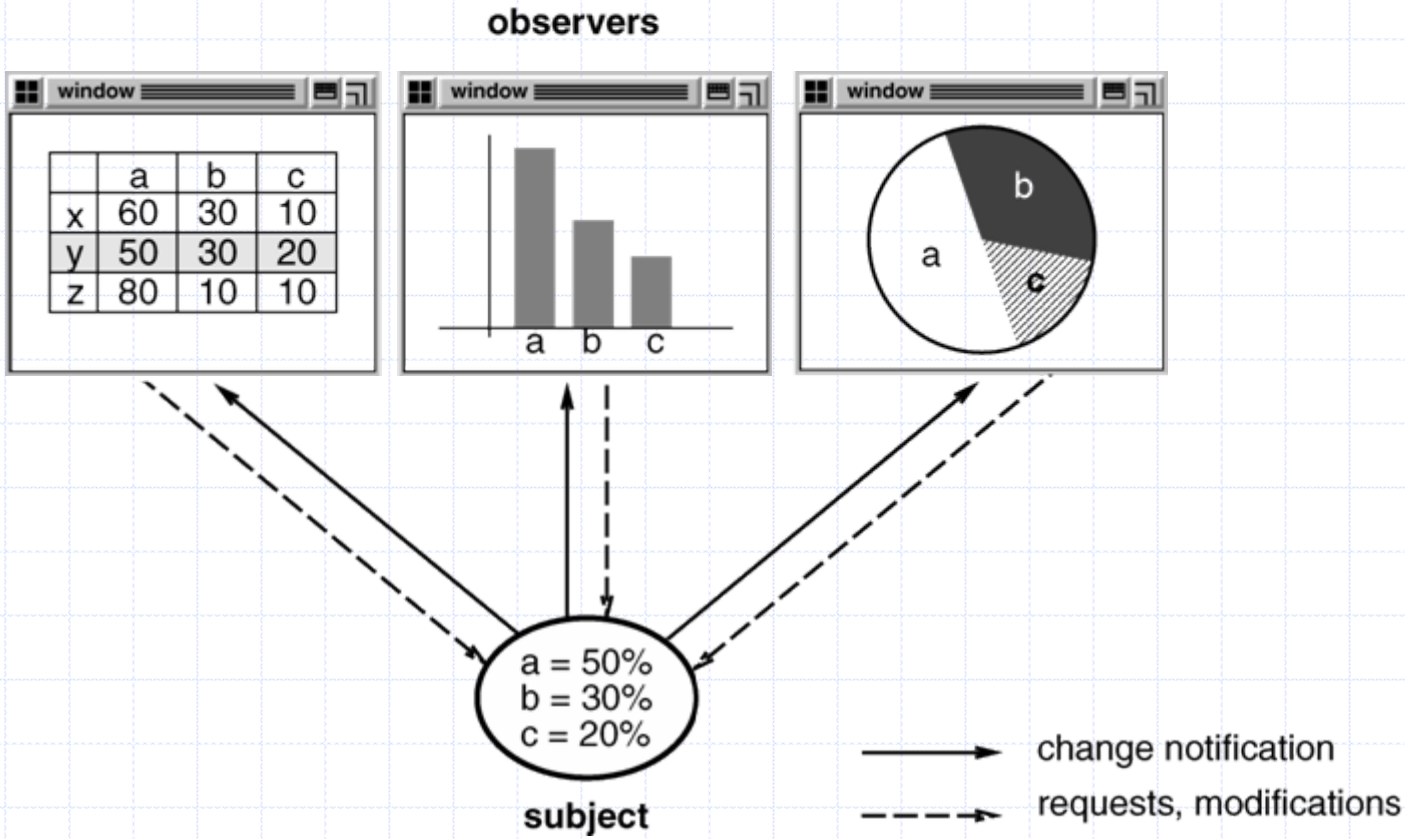
1. Name
2. Problem (including "forces")
3. Solution
4. Consequences & trade-offs of application

Language- & implementation-independent

A "micro-architecture"

Adjunct to existing methodologies (RUP, Fusion, SCRUM, etc.)

Example: OBSERVER



Goals

Codify good design

- distill & generalize experience
- aid to novices & experts alike

Give design structures explicit names

- common vocabulary
- reduced complexity
- greater expressiveness

Capture & preserve design information

- articulate design decisions succinctly
- improve documentation

Facilitate restructuring/refactoring

- patterns are interrelated
- additional flexibility

Design Space for GoF Patterns

		Purpose		
		Creational	**Structural**	**Behavioral**
Scope	**Class**	Factory Method	Adapter (class)	Interpreter Template Method
	Object	Abstract Factory Builder Prototype Singleton	Adapter (object) Bridge Composite Decorator Flyweight Facade Proxy	Chain of Responsibility Command Iterator Mediator Memento Observer State Strategy Visitor

Scope: domain over which a pattern applies

Purpose: reflects what a pattern does

Design Pattern Template (1st half)

NAME scope purpose

Intent

short description of the pattern & its purpose

Also Known As

short description of the pattern & its purpose

Motivation

motivating scenario demonstrating pattern's use

Applicability

circumstances in which pattern applies

Structure

graphical representation of the pattern using modified OMT notation

Participants

participating classes and/or objects & their responsibilities

Design Pattern Template (2nd half)

...

Collaborations
- how participants cooperate to carry out their responsibilities

Consequences
- the results of application, benefits, liabilities

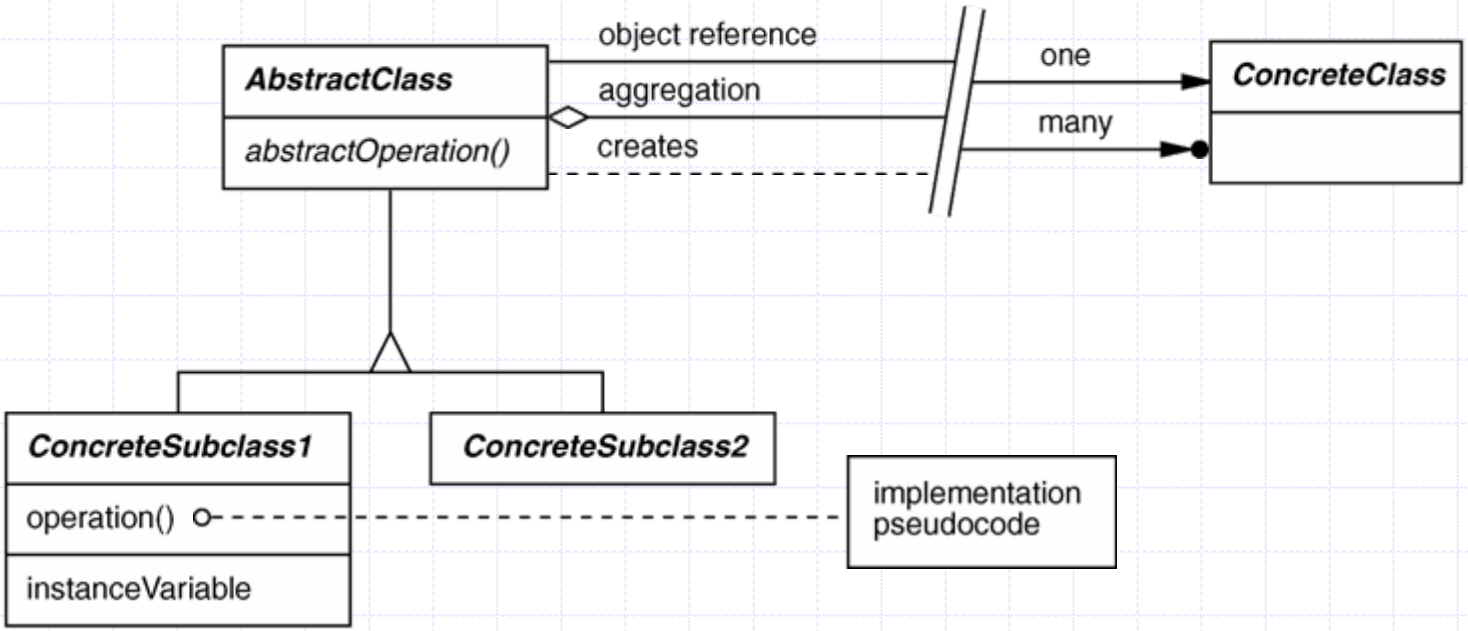
Implementation
- pitfalls, hints, techniques, plus language-dependent issues

Sample Code
- sample implementations in C++, Java, C#, Smalltalk, C, etc.

Known Uses
- examples drawn from existing systems

Related Patterns
- discussion of other patterns that relate to this one

Modified UML/OMT Notation



OBSERVER — object behavioral

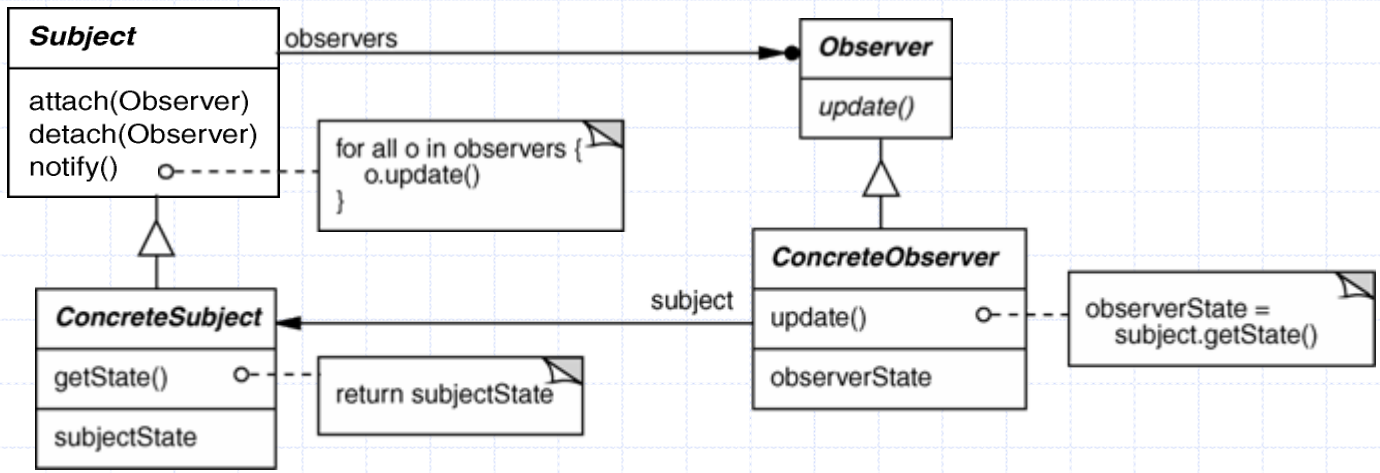
Intent

define a one-to-many dependency between objects so that when one object changes state, all dependents are notified & updated

Applicability

- an abstraction has two aspects, one dependent on the other
- a change to one object requires changing untold others
- an object should notify unknown other objects

Structure



OBSERVER (cont'd) object behavioral

Consequences

- \+ modularity: subject & observers may vary independently
- \+ extensibility: can define & add any number of observers
- \+ customizability: different observers offer different views of subject
- – unexpected updates: observers don't know about each other
- – update overhead: might need hints or filtering

Implementation

- subject-observer mapping
- dangling references
- update protocols: the push & pull models
- registering modifications of interest explicitly

Known Uses

- Smalltalk Model-View-Controller (MVC)
- InterViews (Subjects & Views, Observer/Observable)
- Andrew (Data Objects & Views)
- Mailing lists

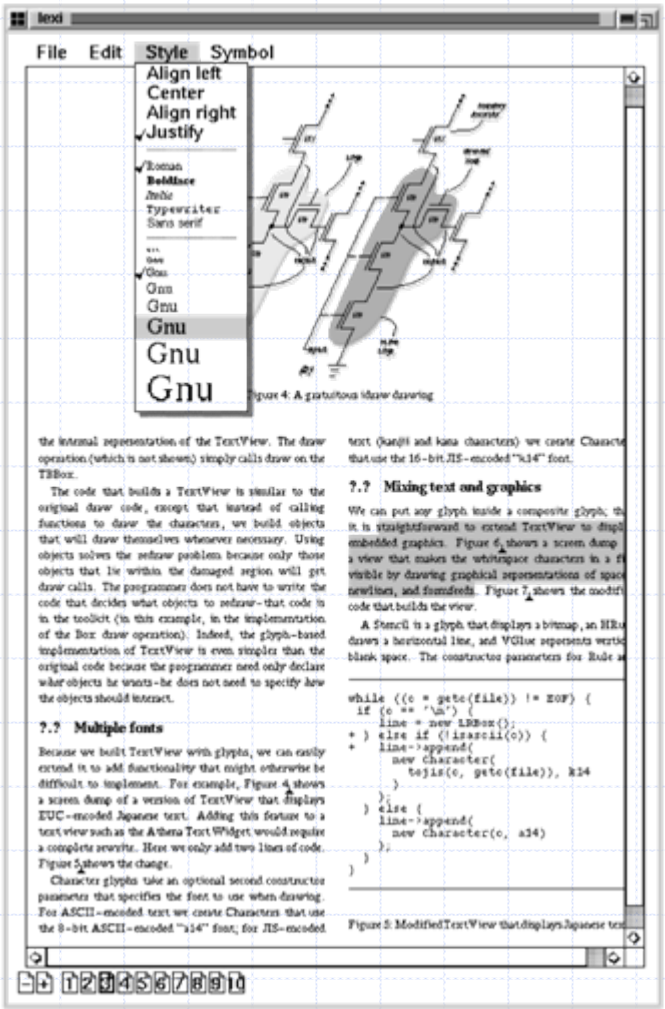
Benefits of Patterns

- *Design* reuse
- Uniform design vocabulary
- Enhance understanding, restructuring, & team communication
- Basis for automation
- Transcends language-centric biases/myopia
- Abstracts away from many unimportant details

Liabilities of Patterns

- Require significant tedious & error-prone human effort to handcraft pattern implementations *design* reuse
- Can be deceptively simple uniform design vocabulary
- Leaves some important details unresolved

Part II: Application: Document Editor (Lexi)



7 Design Problems

1. Document structure
2. Formatting
3. Embellishment
4. Multiple look & feels
5. Multiple window systems
6. User operations
7. Spelling checking & hyphenation

Document Structure

Goals:

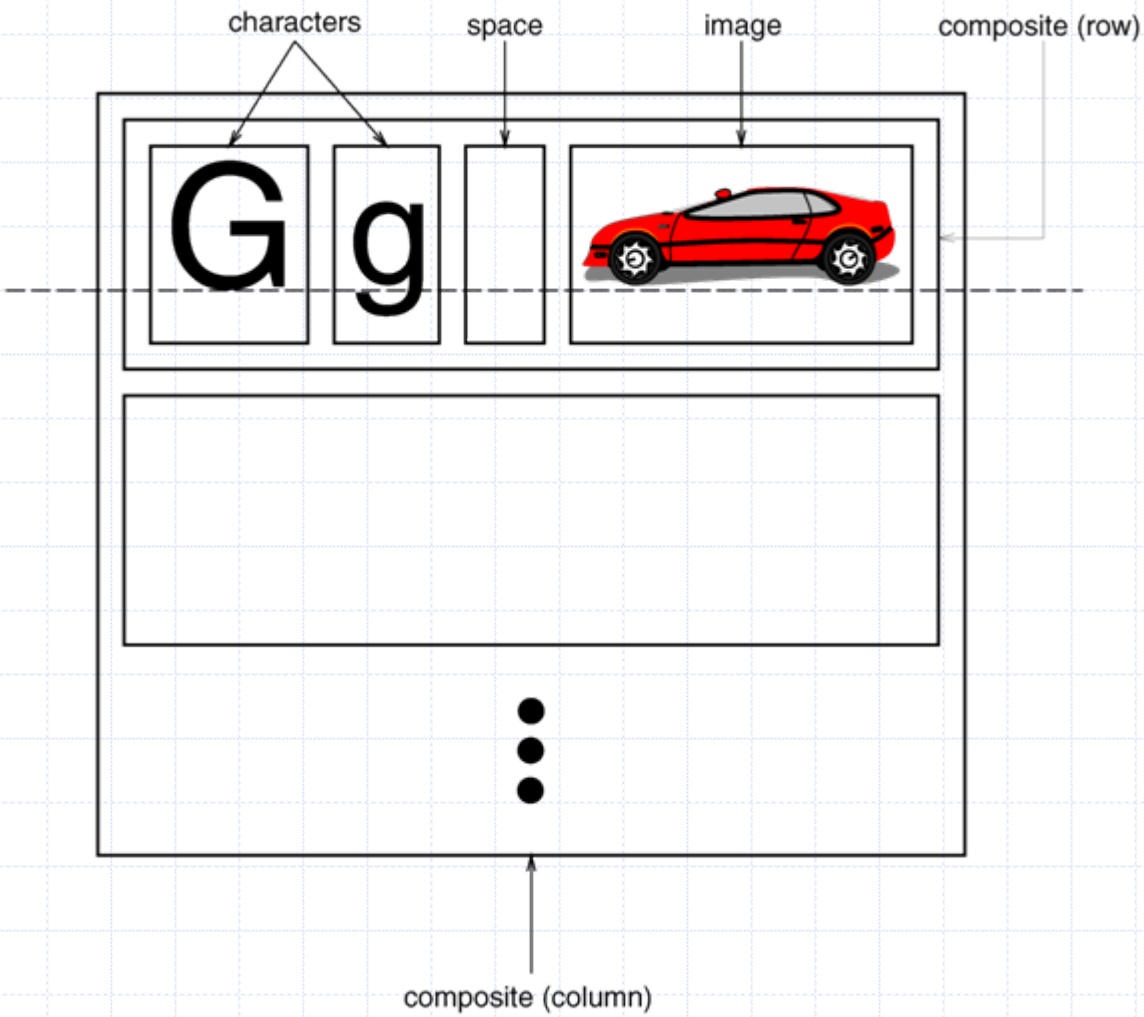
- present document's visual aspects
- drawing, hit detection, alignment
- support physical structure (e.g., lines, columns)

Constraints/forces:

- treat text & graphics uniformly
- no distinction between one & many

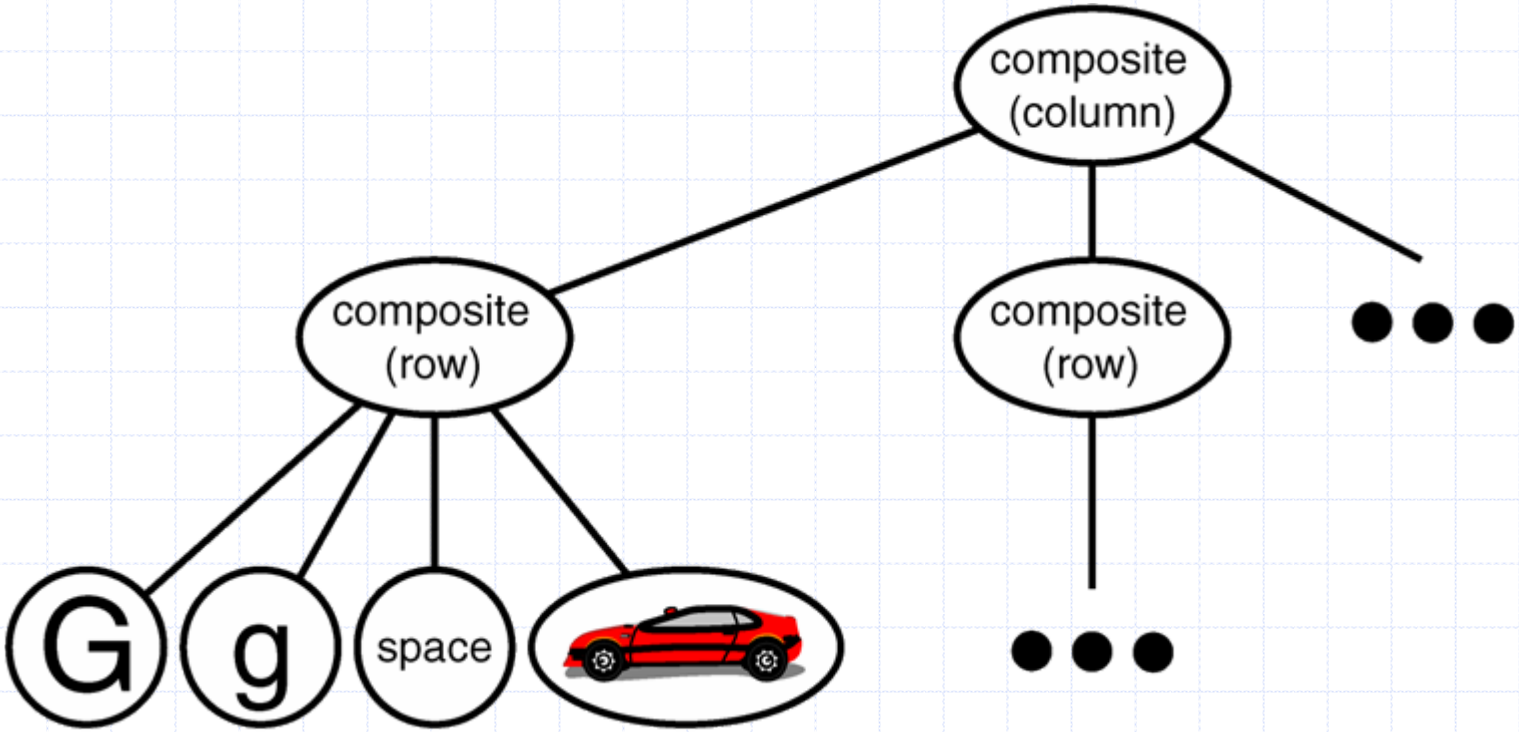
Document Structure (cont'd)

Solution: Recursive Composition



Document Structure (cont'd)

Object Structure



Document Structure (cont'd)

Glyph

Base class for composable graphical objects

Basic interface:

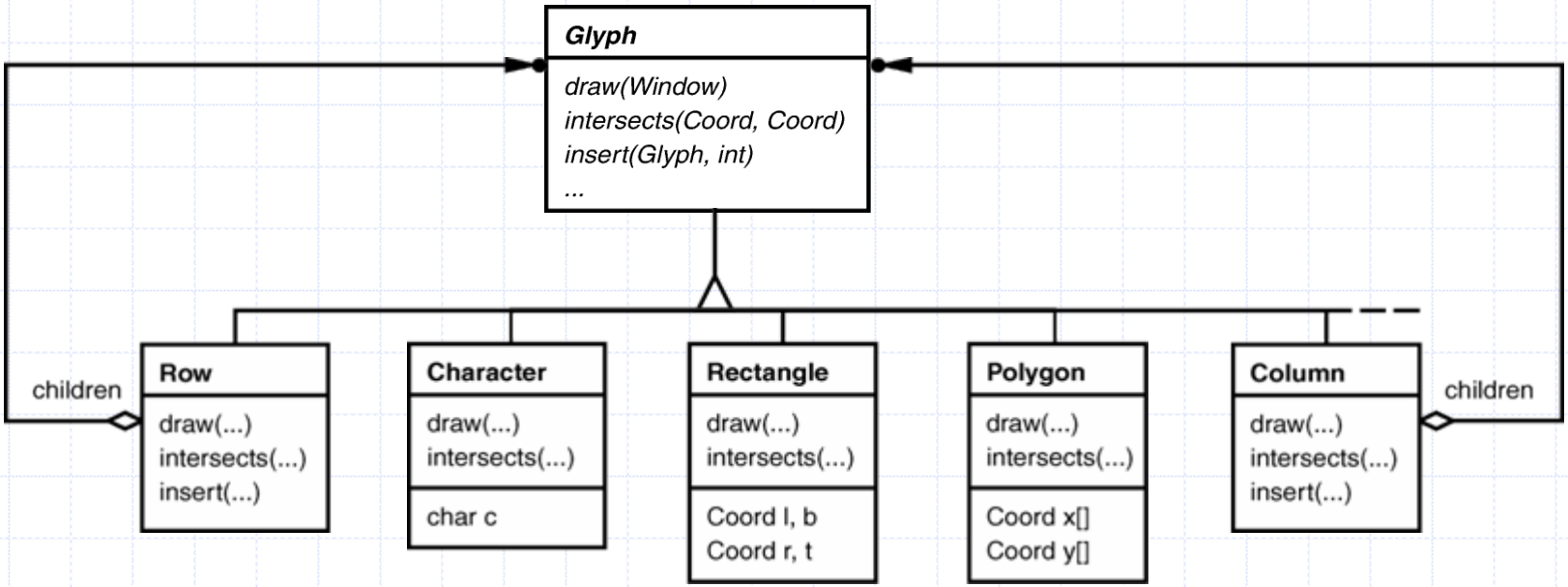
Task	Operations
appearance	`void draw(Window)`
hit detection	`boolean intersects(Coord, Coord)`

structure	`void insert(Glyph)`
	`void remove(Glyph)`
	`Glyph child(int)`
	`Glyph parent()`

Subclasses: Character, Image, Space, Row, Column

Document Structure (cont'd)

Glyph Hierarchy



Note the inherent recursion in this hierarchy

- i.e., a Row *is a* Glyph & a Row also *has* Glyphs!

COMPOSITE — object structural

Intent

treat individual objects & multiple, recursively-composed objects uniformly

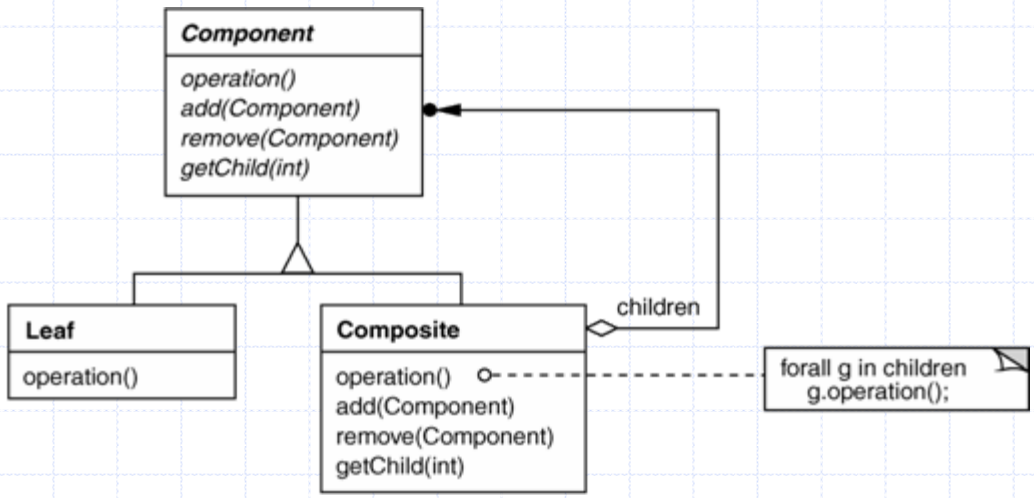
Applicability

objects must be composed recursively,

and no distinction between individual & composed elements,

and objects in structure can be treated uniformly

Structure



COMPOSITE (cont'd) object structural

Consequences

+ uniformity: treat components the same regardless of complexity
+ extensibility: new Component subclasses work wherever old ones do
– overhead: might need prohibitive numbers of objects

Implementation

- do Components know their parents?
- uniform interface for both leaves & composites?
- don't allocate storage for children in Component base class
- responsibility for deleting children

Known Uses

- ET++ Vobjects
- InterViews Glyphs, Styles
- Unidraw Components, MacroCommands

Formatting

Goals:

- automatic linebreaking, justification

Constraints/forces:

- support multiple linebreaking algorithms
- don’t tightly couple these algorithms with the document structure

Solution: Encapsulate Linebreaking Strategy

Compositor

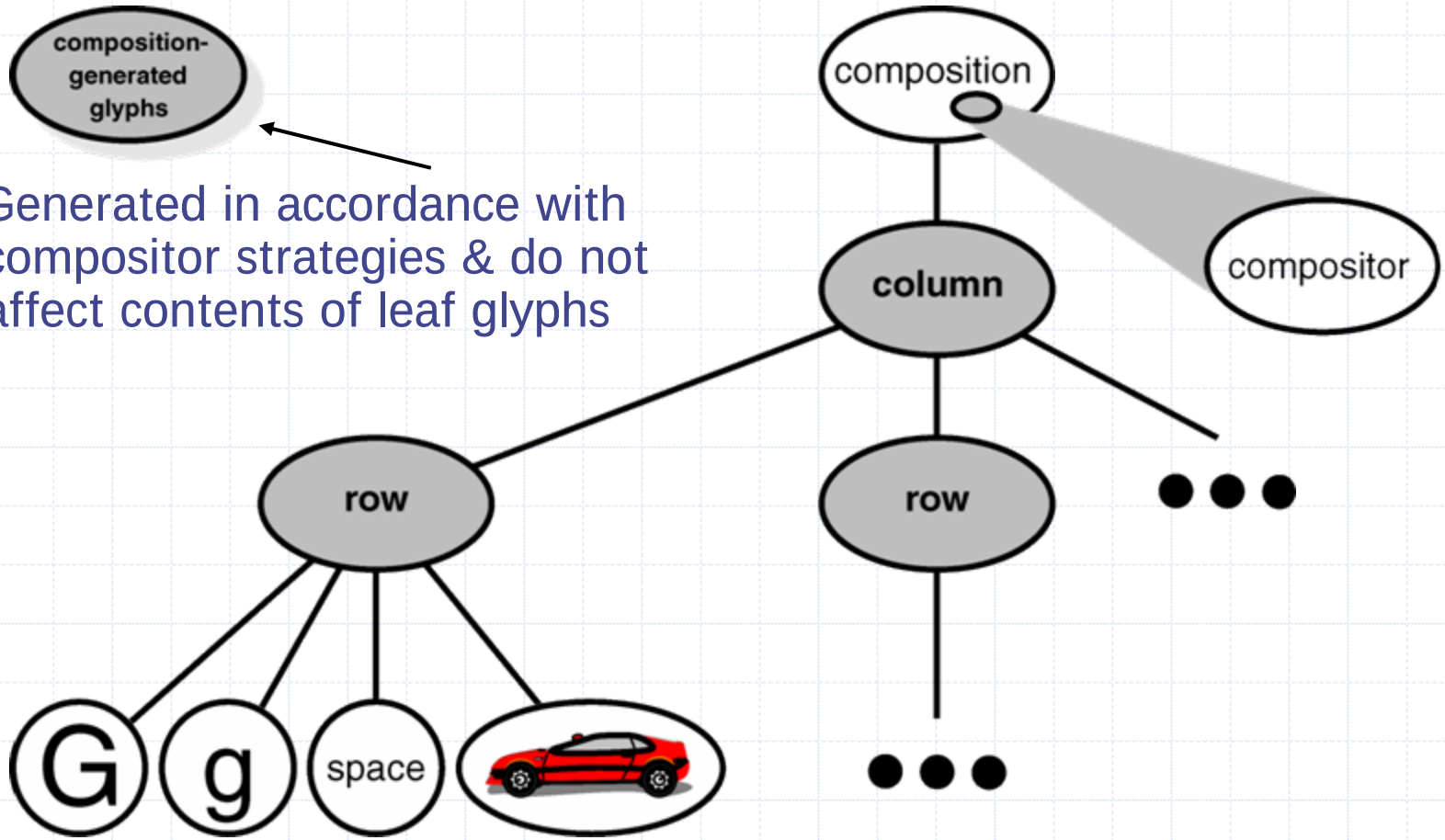
- base class abstracts linebreaking algorithm
- subclasses for specialized algorithms, e.g., **SimpleCompositor**, **TeXCompositor**

Composition

- composite glyph
- supplied a compositor & leaf glyphs
- creates row-column structure as directed by compositor

Formatting (cont'd)

New Object Structure



Generated in accordance with compositor strategies & do not affect contents of leaf glyphs

STRATEGY — object behavioral

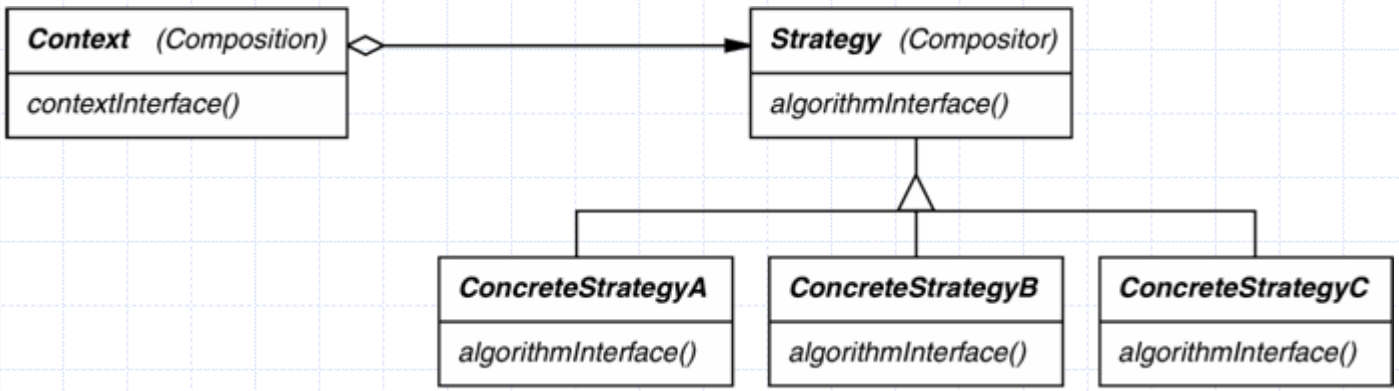
Intent

define a family of algorithms, encapsulate each one, & make them interchangeable to let clients & algorithms vary independently

Applicability

when an object should be configurable with one of many algorithms,
and all algorithms can be encapsulated,
and one interface covers all encapsulations

Structure



STRATEGY (cont'd) object behavioral

Consequences

- \+ greater flexibility, reuse
- \+ can change algorithms dynamically
- – strategy creation & communication overhead
- – inflexible Strategy interface
- – semantic incompatibility of multiple strategies used together

Implementation

- exchanging information between a Strategy & its context
- static strategy selection via templates

Known Uses

- InterViews text formatting
- RTL register allocation & scheduling strategies
- ET++SwapsManager calculation engines

See Also

- Bridge pattern (object structural)

Embellishment

Goals:

- add a frame around text composition
- add scrolling capability

Constraints:

- embellishments should be reusable without subclassing, i.e., so they can be added dynamically at runtime
- should go unnoticed by clients

Embellishment (cont'd)

Solution: "Transparent" Enclosure

Monoglyph

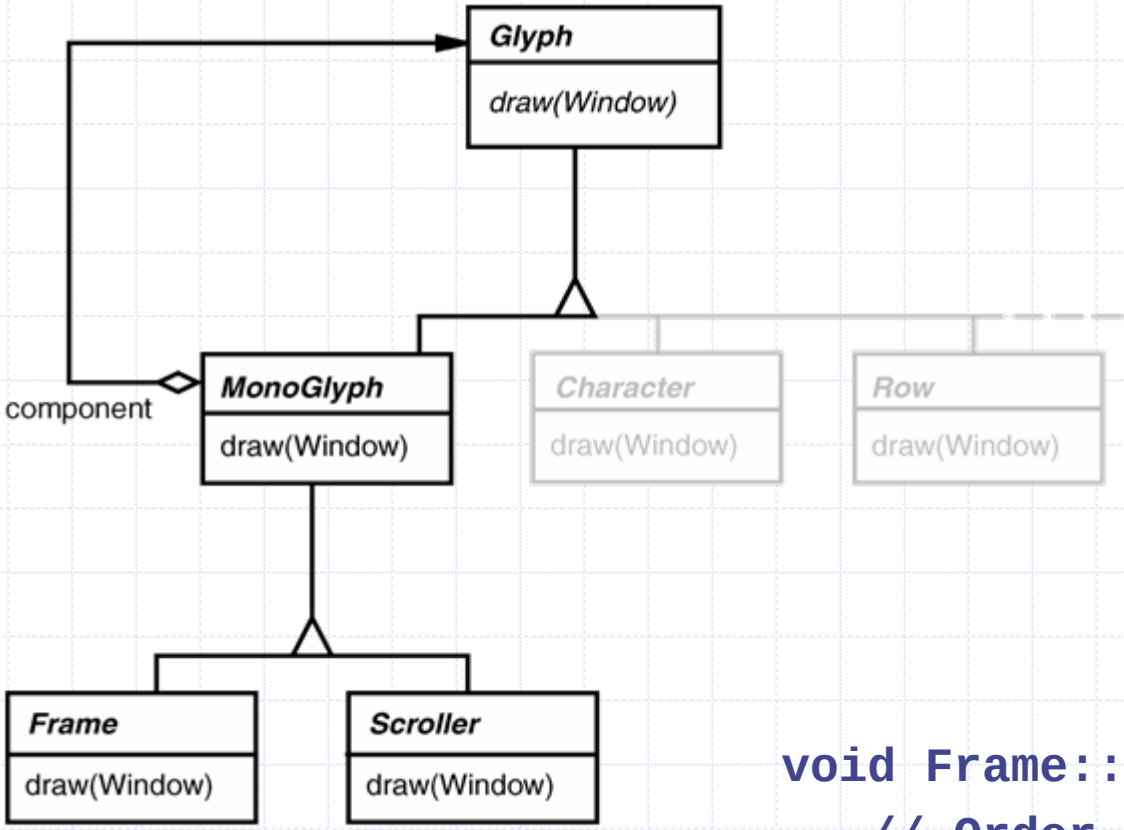
- base class for glyphs having *one* child
- operations on MonoGlyph pass through to child

MonoGlyph subclasses:

- **Frame**: adds a border of specified width
- **Scroller**: scrolls/clips child, adds scrollbars

Embellishment (cont'd)

MonoGlyph Hierarchy

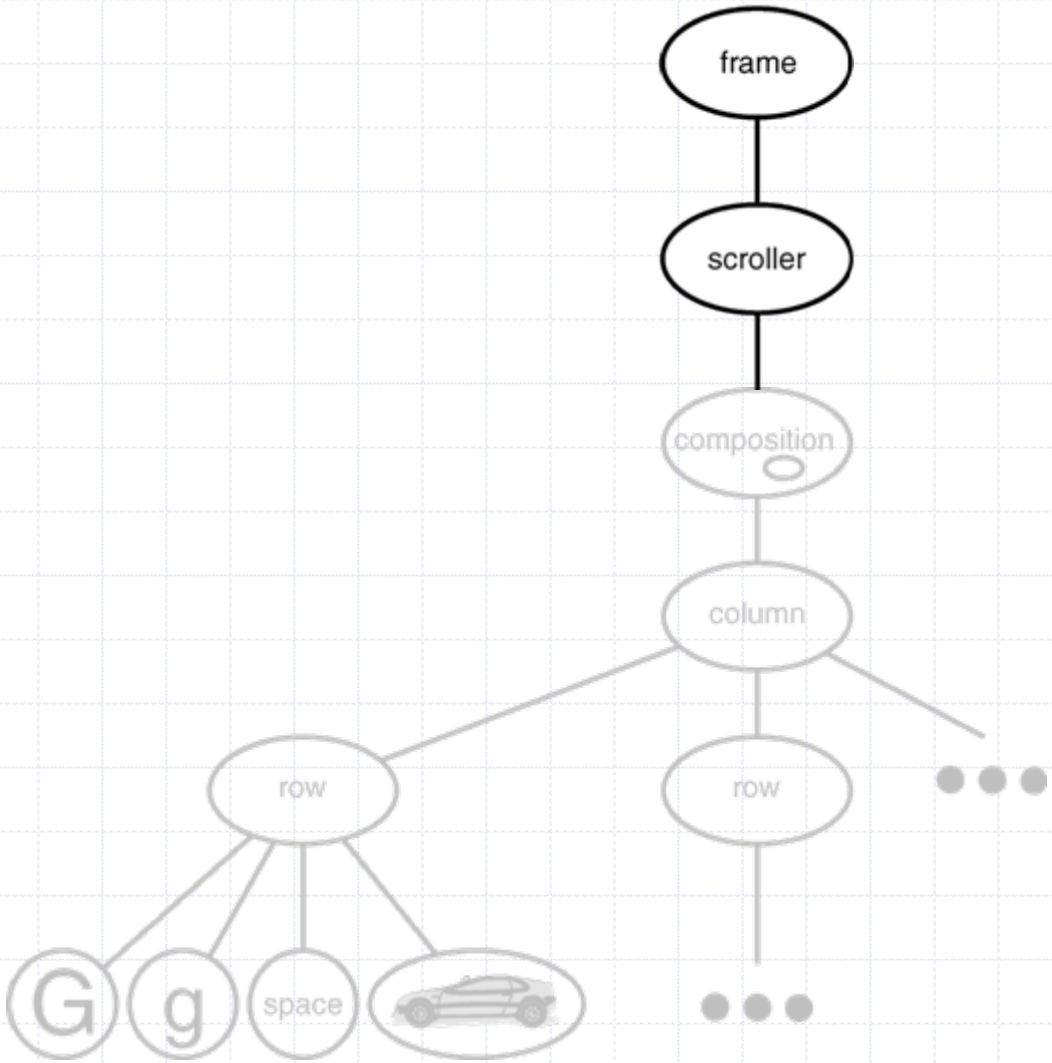



```
void MonoGlyph::draw (Window &w) {
    component->draw (w);
}
```

```
void Frame::draw (Window &w) {
    // Order may be important!
    MonoGlyph::draw (w);
    drawFrame (w);
}
```

Embellishment (cont'd)

New Object Structure



Embellishment (cont'd)

DECORATOR — object structural

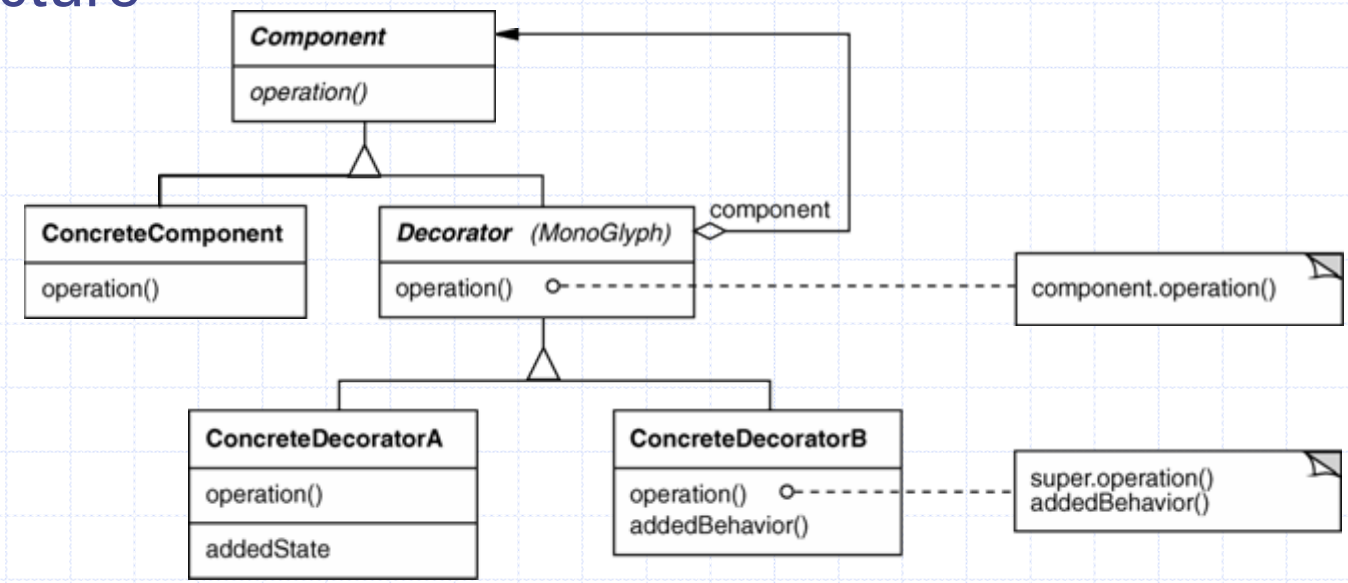
Intent

augment objects with new responsibilities

Applicability

- when extension by subclassing is impractical
- for responsibilities that can be withdrawn

Structure



DECORATOR (cont'd) object structural

Consequences

+ responsibilities can be added/removed at run-time
+ avoids subclass explosion
+ recursive nesting allows multiple responsibilities
– interface occlusion
– identity crisis

Implementation

- interface conformance
- use a lightweight, abstract base class for Decorator
- heavyweight base classes make Strategy more attractive

Known Uses

- embellishment objects from most OO-GUI toolkits
- ParcPlace PassivityWrapper
- InterViews DebuggingGlyph

Multiple Look & Feels

Goals:

- support multiple look & feel standards
- generic, Motif, Swing, PM, Macintosh, Windows, ...
- extensible for future standards

Constraints:

- don’t recode existing widgets or clients
- switch look & feel without recompiling

Multiple Look & Feels (cont'd)

Solution: Abstract Object Creation

Instead of

```
Scrollbar *sb = new MotifScrollbar();
```

use

```
Scrollbar *sb = factory->createScrollbar();
```

where **`factory`** is an instance of **MotifFactory**

- BTW, this begs the question of who created the **`factory`**!

Multiple Look & Feels (cont'd)

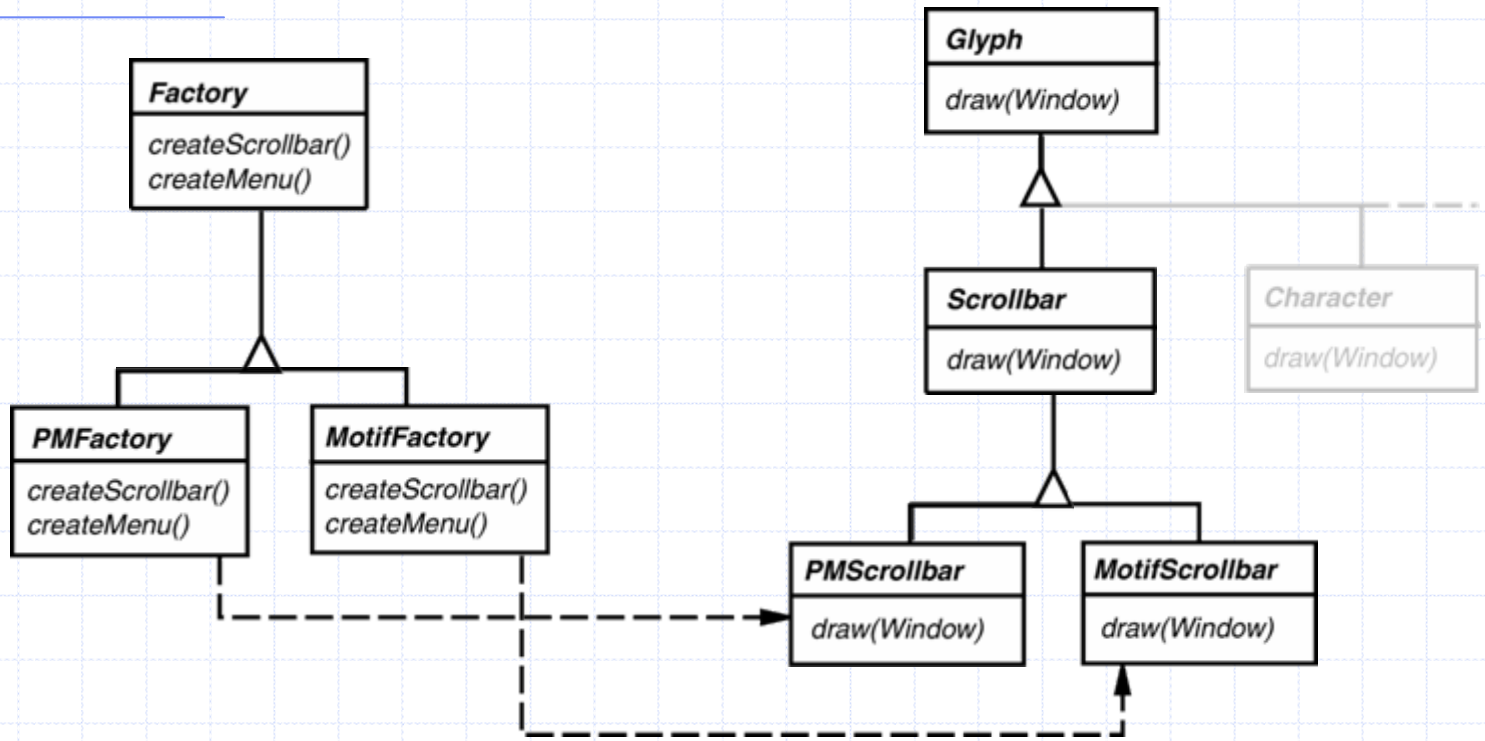
`Factory` Interface

- defines "manufacturing interface"
- subclasses produce specific products
- subclass instance chosen at run-time

```
// This class is essentially a Java interface
class Factory {
public:
    Scrollbar *createScrollbar() = 0;
    Menu *createMenu() = 0;
    ...
};
```

Multiple Look & Feels (cont'd)

Factory Structure




```
Scrollbar *MotifFactory::createScrollBar () {
    return new MotifScrollbar();
}
Scrollbar *PMFactory::createScrollBar () {
    return new PMScrollbar();
}
```

Multiple Look & Feels (cont'd)

ABSTRACT FACTORY — object creational

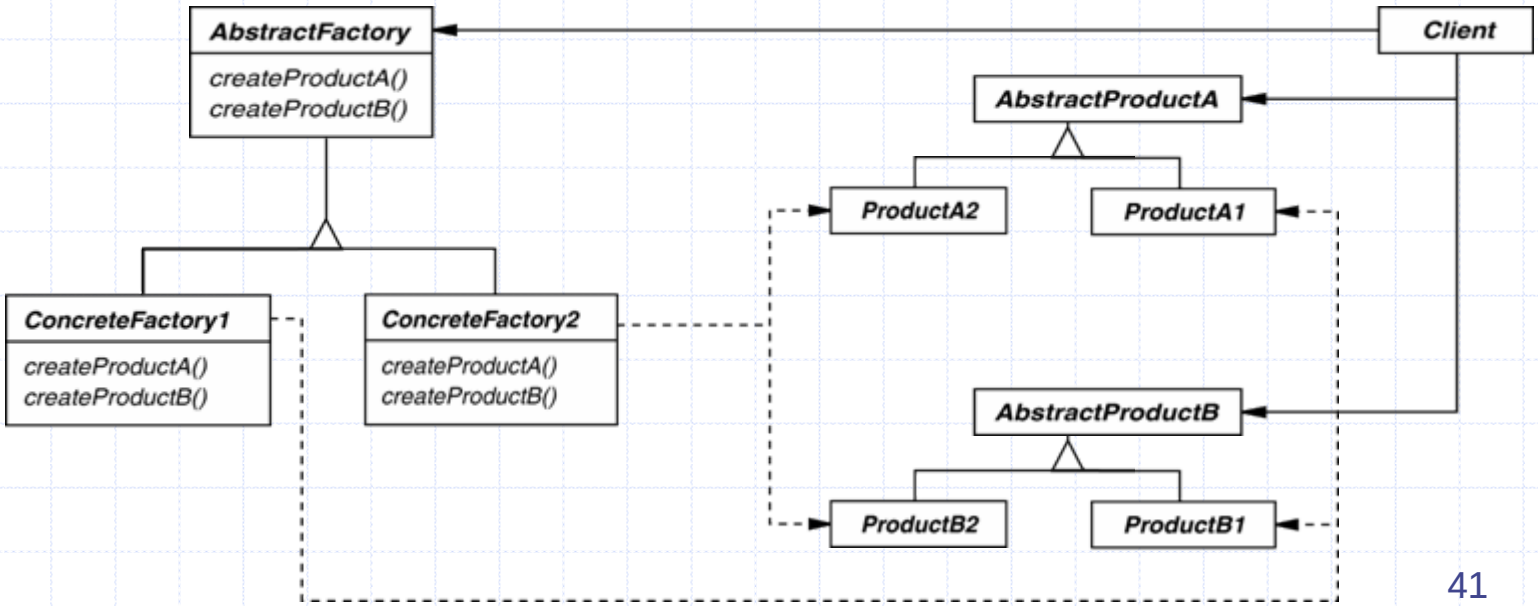
Intent

create families of related objects without specifying class names

Applicability

when clients cannot anticipate groups of classes to instantiate

Structure



Multiple Look & Feels (cont'd)

ABSTRACT FACTORY (cont'd) object creational

Consequences

- \+ flexibility: removes type dependencies from clients
- \+ abstraction: hides product's composition
- – hard to extend factory interface to create new products

Implementation

- parameterization as a way of controlling interface size
- configuration with Prototypes, i.e., determines who creates the factories

Known Uses

- InterViews Kits
- ET++ WindowSystem
- AWT Toolkit

Multiple Window Systems

Goals:

- make composition appear in a window
- support multiple window systems

Constraints:

- minimize window system dependencies in application & framework code

Multiple Window Systems (cont'd)
Solution: Encapsulate Implementation Dependencies

Window

- user-level window abstraction
- displays a glyph (structure)
- window system-independent
- task-related subclasses
  (e.g., IconWindow, PopupWindow)

Multiple Window Systems (cont'd)

`Window` Interface

```
class Window {
public:
    ...
    void iconify();          // window-management
    void raise();
    ...
    void drawLine(...);      // device-independent
    void drawText(...);      // graphics interface
    ...
};
```

Multiple Window Systems (cont'd)

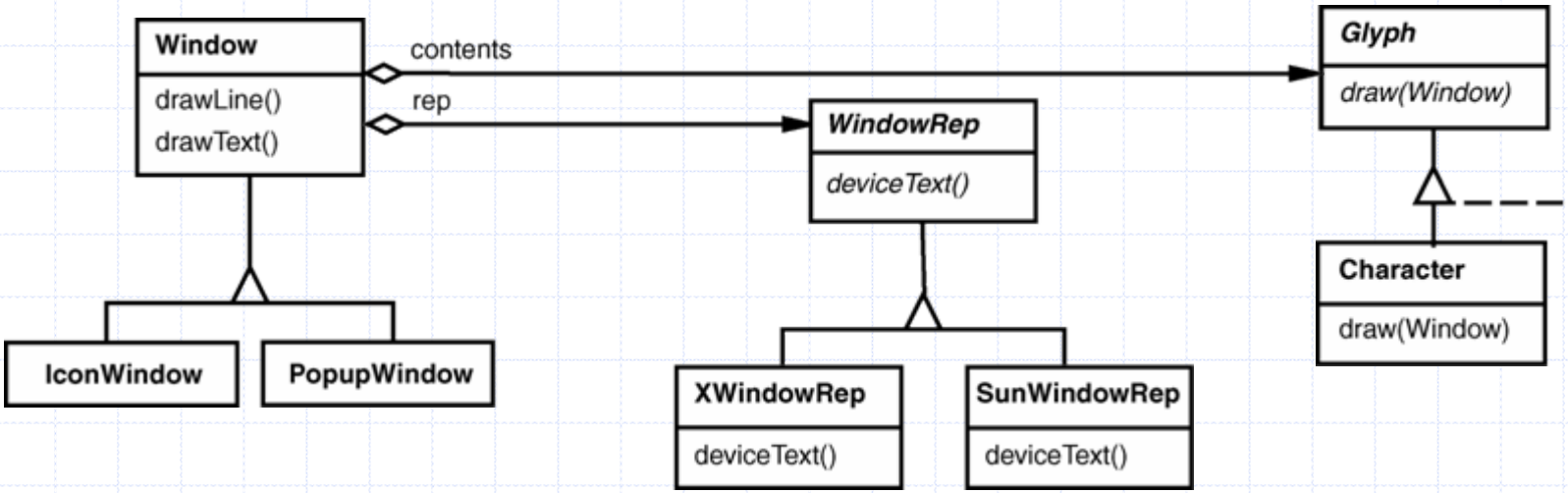
Window uses a **WindowRep**

- abstract implementation interface
- encapsulates window system dependencies
- window systems-specific subclasses (e.g., XWindowRep, SunWindowRep)

An Abstract Factory can produce the right WindowRep!

Multiple Window Systems (cont'd)

Window/WindowRep Structure



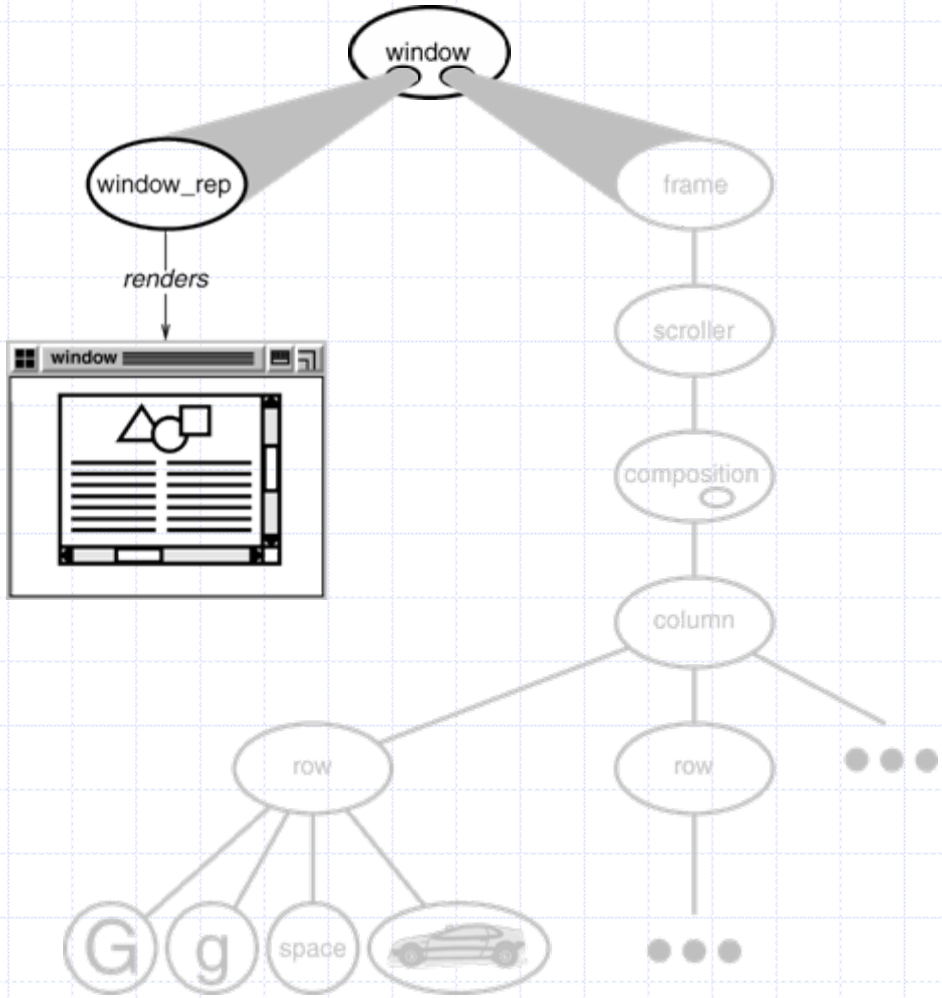

```
void Character::draw (Window &w) {
    w.drawText(...);
}

void Window::drawText (...) {
    rep->deviceText(...);
}

void XWindowRep::deviceText (...) {
    XText(...);
}
```

Multiple Window Systems (cont'd)

New Object Structure



Note the decoupling between the logical structure of the contents in a window from the physical rendering of the contents in the window

Multiple Window Systems (cont'd)

BRIDGE — object structural

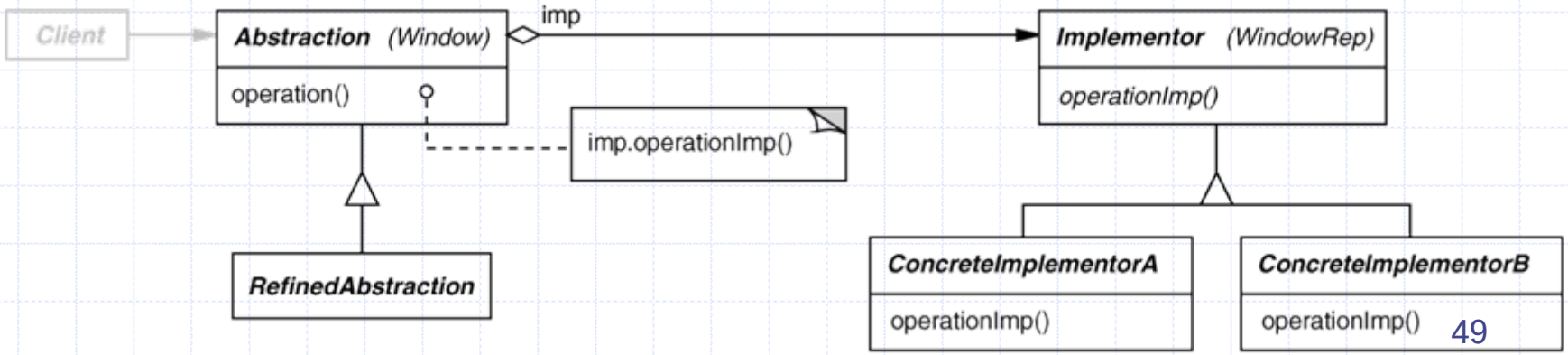
Intent

separate a (logical) abstraction interface from its (physical) implementation(s)

Applicability

- when interface & implementation should vary independently
- require a uniform interface to interchangeable class hierarchies

Structure



BRIDGE (cont'd) object structural

Consequences

+ abstraction interface & implementation are independent
+ implementations can vary dynamically
– one-size-fits-all Abstraction & Implementor interfaces

Implementation

- sharing Implementors & reference counting
- creating the right implementor

Known Uses

- ET++ Window/WindowPort
- libg++ Set/{LinkedList, HashTable}
- AWT Component/ComponentPeer

User Operations

Goals:

- support execution of user operations
- support unlimited-level undo

Constraints:

- scattered operation implementations
- must store undo state
- not all operations are undoable

User Operations (cont'd)

Solution: Encapsulate Each Request

A **Command** encapsulates

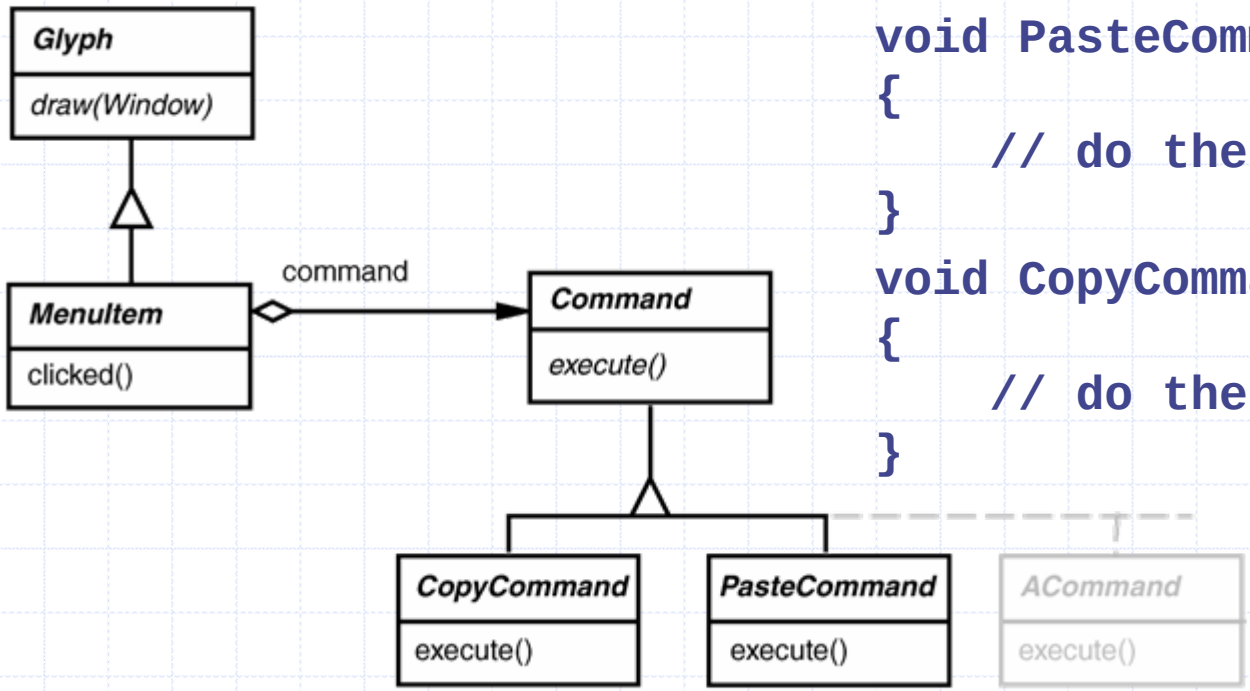
- an operation (**`execute()`**)
- an inverse operation (**`unexecute()`**)
- a operation for testing reversibility (**`boolean reversible()`**)
- state for (un)doing the operation

Command may

- implement the operations itself, *or*
- delegate them to other object(s)

User Operations (cont'd)

Command Hierarchy




```
void PasteCommand::execute ()
{
    // do the paste
}
void CopyCommand::execute ()
{
    // do the copy
}
```

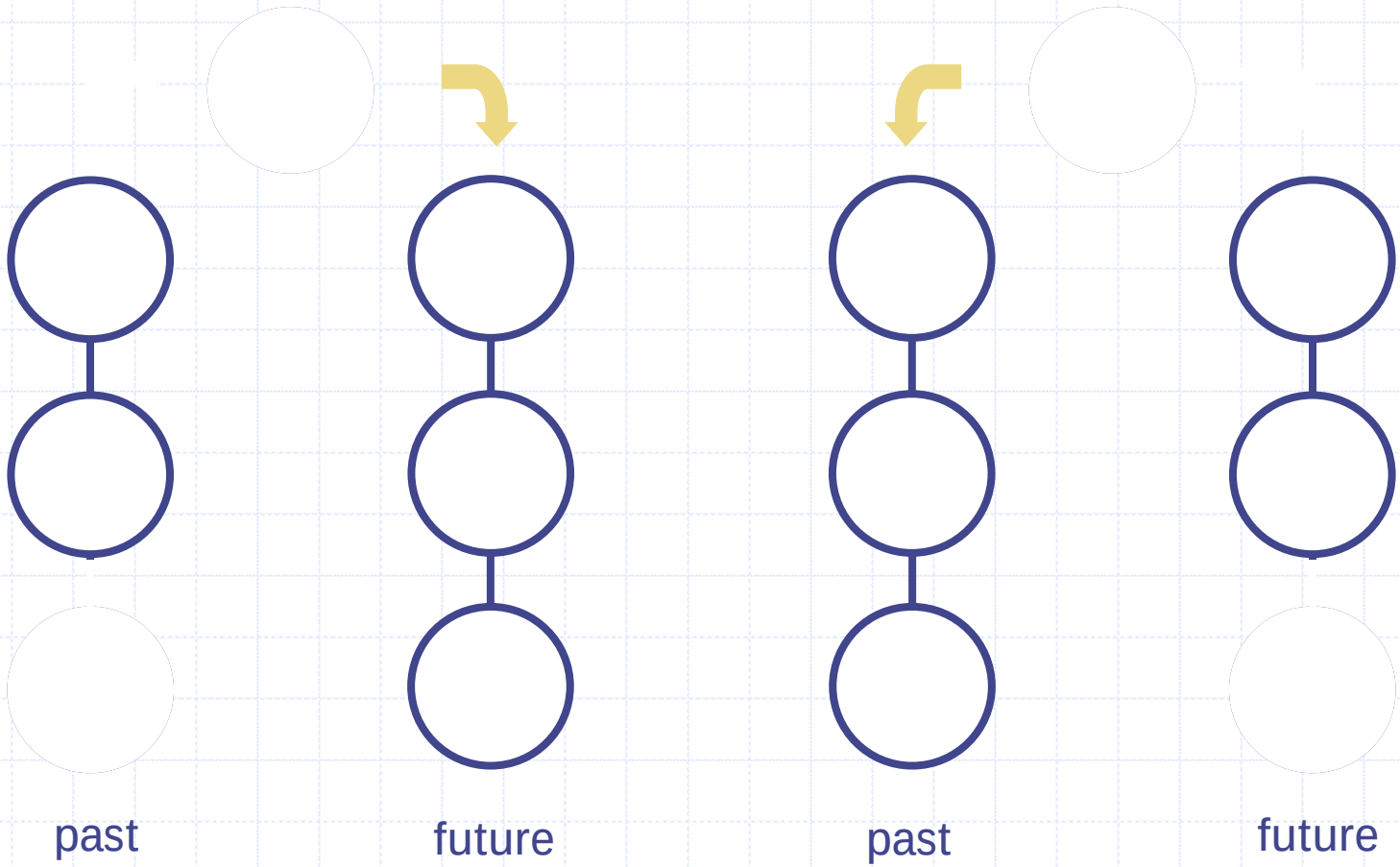
```
void MenuItem::clicked ()
{
    command->execute();
}
```

User Operations (cont'd)

List of Commands = Execution History

Undo:

Redo:



User Operations (cont'd)

COMMAND — object behavioral

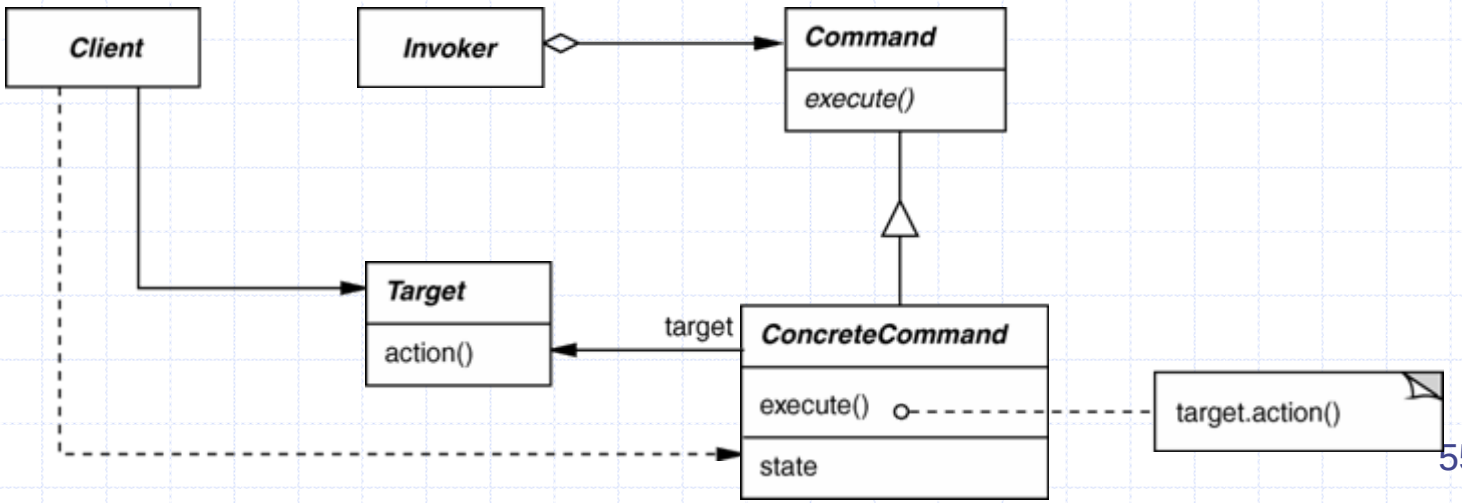
Intent

encapsulate the request for a service

Applicability

- to parameterize objects with an action to perform
- to specify, queue, & execute requests at different times
- for multilevel undo/redo

Structure



COMMAND (cont'd) object behavioral

Consequences

+ abstracts executor of a service
+ supports arbitrary-level undo-redo
+ composition yields macro-commands
– might result in lots of trivial command subclasses

Implementation

- copying a command before putting it on a history list
- handling hysteresis
- supporting transactions

Known Uses

- InterViews Actions
- MacApp, Unidraw Commands
- JDK's UndoableEdit, AccessibleAction

Spelling Checking & Hyphenation

Goals:

- analyze text for spelling errors
- introduce potential hyphenation sites

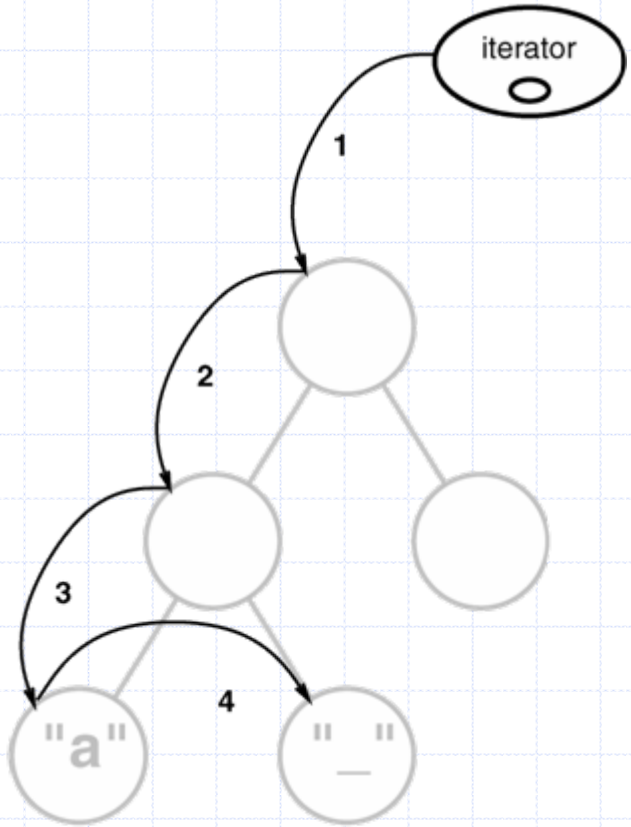
Constraints:

- support multiple algorithms
- don’t tightly couple algorithms with document structure

Solution: Encapsulate Traversal

Iterator

- encapsulates a traversal algorithm without exposing representation details to callers
- uses Glyph's child enumeration operation
- This is an example of a "preorder iterator"



Spelling Checking & Hyphenation (cont'd)

ITERATOR — object behavioral

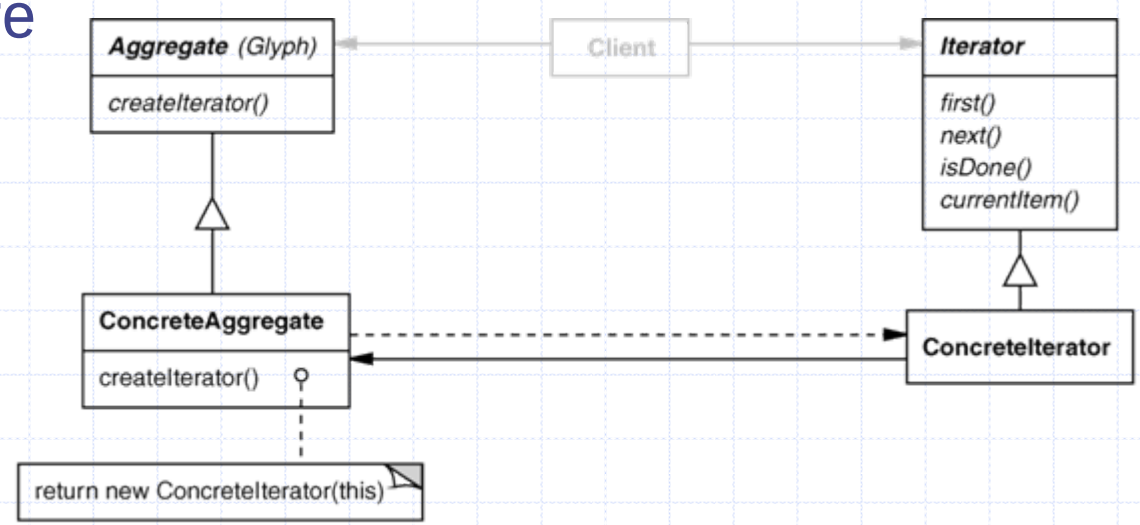
Intent

access elements of a container without exposing its representation

Applicability

- require multiple traversal algorithms over a container
- require a uniform traversal interface over different containers
- when container classes & traversal algorithm must vary independently

Structure



ITERATOR (cont'd) object behavioral

Iterators are used heavily in the C++ Standard Template Library (STL)

```
int main (int argc, char *argv[]) {
   vector<string> args;

   for (int i = 0; i < argc; i++)
      args.push_back (string (argv[i]));

   for (vector<string>::iterator i (args.begin ());
        i != args.end ();
        i++)
     cout << *i;

   cout << endl;
   return 0;
}
```

The same iterator pattern can be applied to any STL container!

ITERATOR (cont'd) object behavioral

Consequences

+ flexibility: aggregate & traversal are independent
+ multiple iterators & multiple traversal algorithms
– additional communication overhead between iterator & aggregate

Implementation

- internal versus external iterators
- violating the object structure's encapsulation
- robust iterators

Known Uses

- C++ STL iterators
- JDK Enumeration, Iterator
- Unidraw Iterator

Spelling Checking & Hyphenation (cont'd)

Visitor

- defines action(s) at each step of traversal
- avoids wiring action(s) into Glyphs
- iterator calls glyph's **`accept(Visitor)`** at each node
- **`accept()`** calls back on visitor (a form of "static polymorphism" based on method overloading by type)

```
void Character::accept (Visitor &v) { v.visit (*this); }

class Visitor {
public:
    virtual void visit (Character &);
    virtual void visit (Rectangle &);
    virtual void visit (Row &);
    // etc. for all relevant Glyph subclasses
};
```

Spelling Checking & Hyphenation (cont'd)

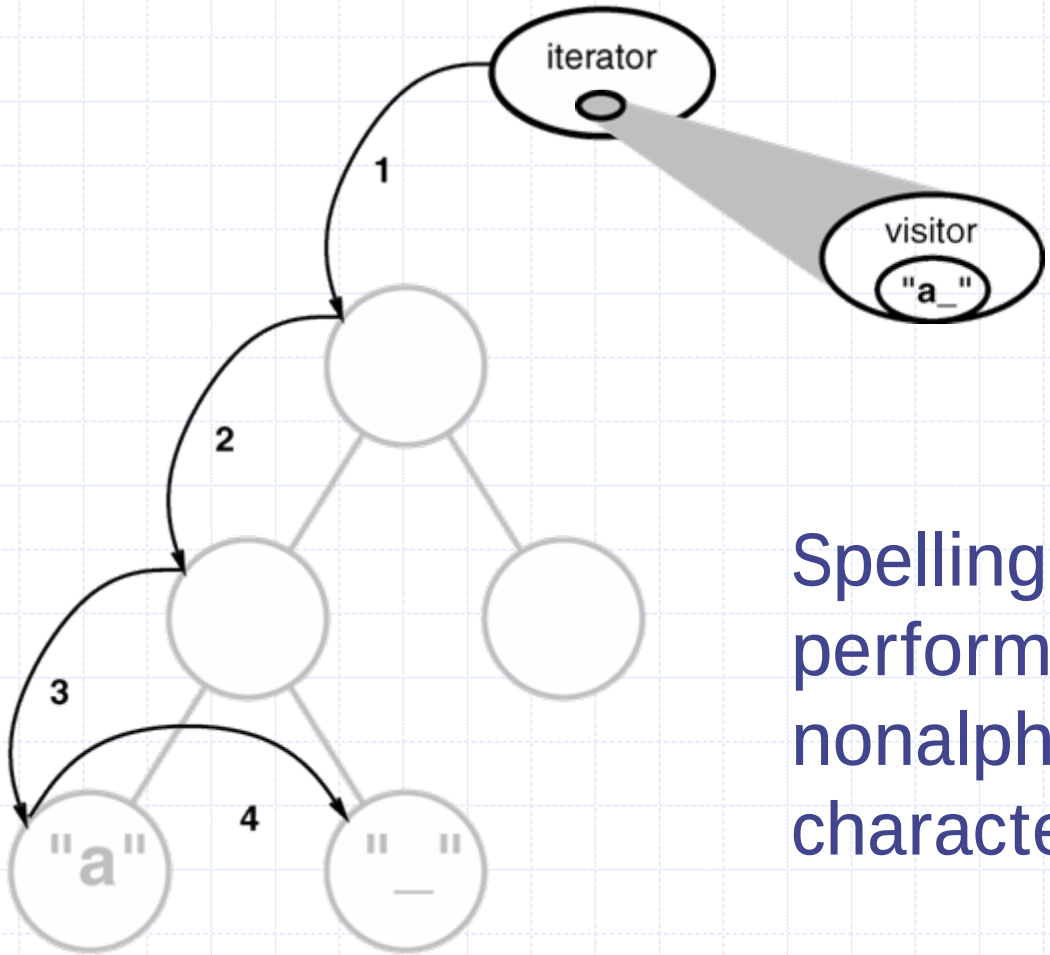
SpellingCheckerVisitor

- gets character code from each character glyph

  Can define **`getCharCode()`** operation just on **`Character()`** class
- checks words accumulated from character glyphs
- combine with **PreorderIterator**

```
class SpellCheckerVisitor : public Visitor {
public:
    void visit (Character &);
    void visit (Rectangle &);
    void visit (Row &);
    // etc. for all relevant Glyph subclasses
};
```

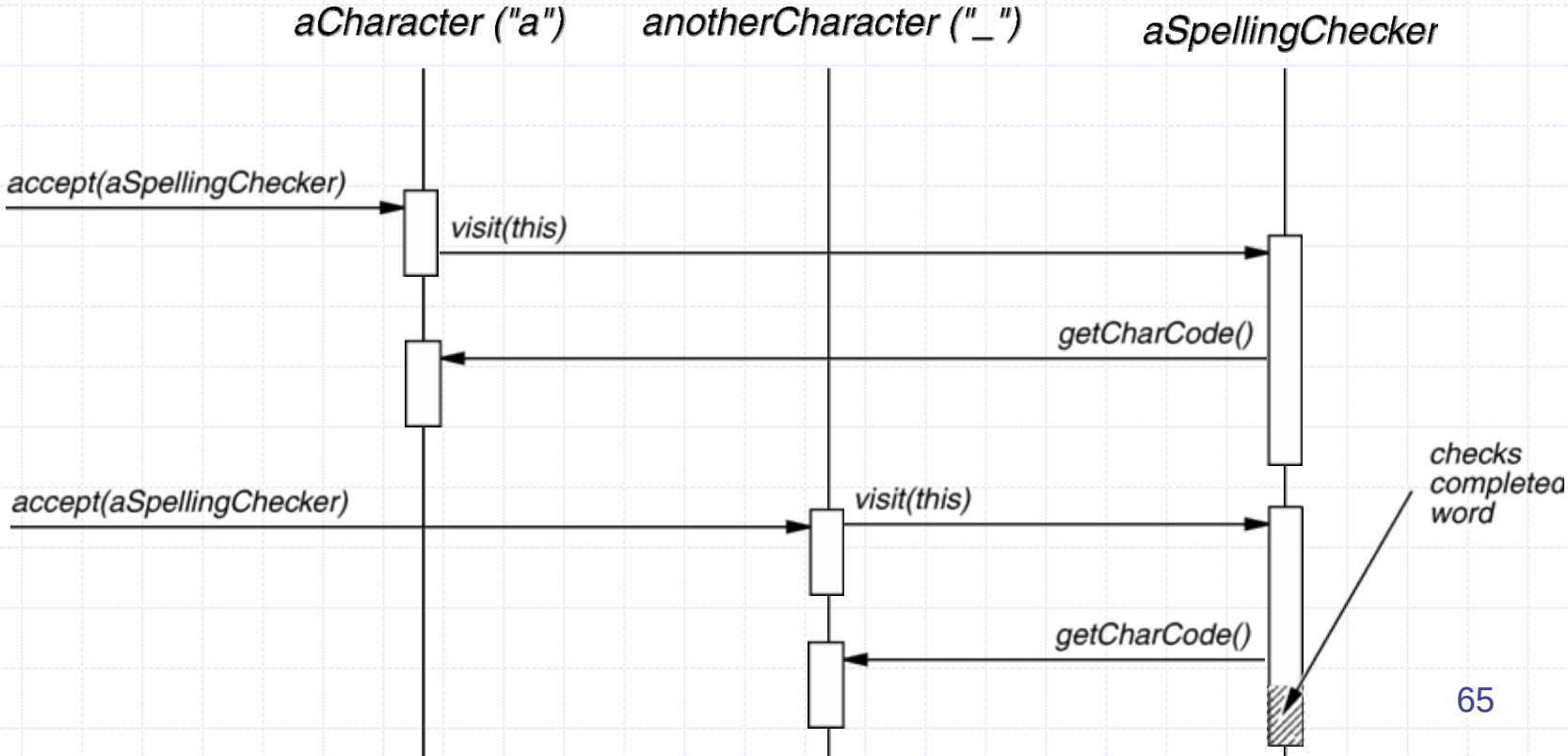
Accumulating Words



Spelling check performed when a nonalphabetic character it reached

Interaction Diagram

- The iterator controls the order in which accept() is called on each glyph in the composition
- accept() then "visits" the glyph to perform the desired action
- The Visitor can be subclassed to implement various desired actions



Spelling Checking & Hyphenation (cont'd)

HyphenationVisitor

- gets character code from each character glyph
- examines words accumulated from character glyphs
- at potential hyphenation point, inserts a...

```
class HyphenationVisitor : public Visitor {
public:
    void visit (Character &);
    void visit (Rectangle &);
    void visit (Row &);
    // etc. for all relevant Glyph subclasses
};
```

Spelling Checking & Hyphenation (cont'd)

Discretionary Glyph

- looks like a hyphen when at end of a line
- has no appearance otherwise
- Compositor considers its presence when determining linebreaks

aluminum alloy *or* aluminum al-
loy

Spelling Checking & Hyphenation (cont'd)

VISITOR — object behavioral

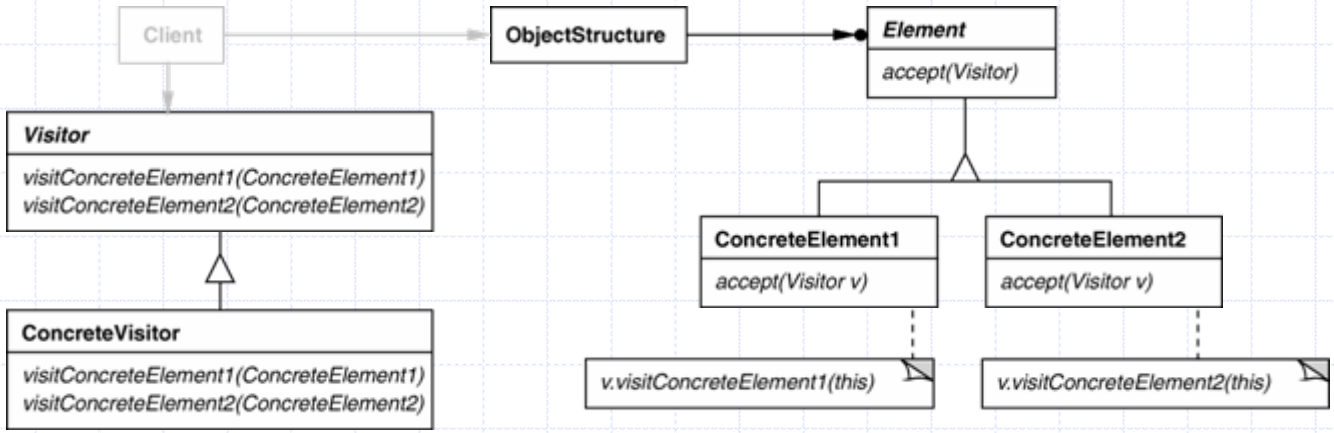
Intent

centralize operations on an object structure so that they can vary independently but still behave polymorphically

Applicability

- when classes define many unrelated operations
- class relationships of objects in the structure rarely change, but the operations on them change often
- algorithms keep state that's updated during traversal

Structure



VISITOR (cont'd) object behavioral

Consequences

+ flexibility: visitor & object structure are independent
+ localized functionality
– circular dependency between Visitor & Element interfaces
– Visitor brittle to new ConcreteElement classes

Implementation

- double dispatch
- general interface to elements of object structure

Known Uses

- ProgramNodeEnumerator in Smalltalk-80 compiler
- IRIS Inventor scene rendering
- TAO IDL compiler to handle different backends

Part III: Wrap-Up

Observations

Patterns are applicable in all stages of the OO lifecycle

- design & reviews
- realization & documentation
- reuse & refactoring

Patterns permit design at a more abstract level

- treat many class/object interactions as a unit
- often beneficial *after* initial design
- targets for class refactorings

Variation-oriented design

- consider what design aspects are variable
- identify applicable pattern(s)
- vary patterns to evaluate tradeoffs
- repeat

Part III: Wrap-Up (cont'd)

But...

- Don't apply them blindly
  - Added indirection can yield increased complexity, cost
- Resist branding everything a pattern
  - Articulate specific benefits
  - Demonstrate wide applicability
  - Find at least *three* existing examples from code other than your own!
- Pattern design even harder than OO design!

Part III: Wrap-Up (cont'd)

Concluding Remarks

- *design* reuse
- uniform design vocabulary
- understanding, restructuring, & team communication
- provides the basis for automation
- a "new" way to think about design

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PLoP 2006: Pattern Languages of Programs October 2006, Collocated with OOPSLA

EuroPLoP 2006, July 2006, Kloster Irsee, Germany

...

See hillside.net/conferencesnavigation.htm for up-to-the-minute info.

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