Design Patterns
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How Do We Design Software?

- We all understand
  - Algorithms
  - Data structures
  - Classes

- When describing a design, algorithms/data structures/classes form the vocabulary

- But there are higher levels of design

What are Design Patterns?

- "A pattern describes a problem that occurs often, along with a tried solution to the problem"
  - Christopher Alexander, 1977

- Descriptions of communicating objects and classes that are customized to solve a general design problem in a particular context
  - Not individual classes or libraries
    - Such as lists, hash tables
  - Not full designs

Design Patterns: History

- Christopher Alexander
  - An architect
  - A Berkeley professor
  - The father of design patterns
    - As applied to architecture
    - "Pattern Languages" (1977)

- The Gang of Four
  - Erich Gamma, Richard Helm, Ralph Johnson, John Vlissides
  - Application of design patterns to object-oriented programming
  - Book: Design Patterns: Elements of Reusable Object-Oriented Software
Elements of a Design Pattern

1. Pattern name
   - Useful part of design vocabulary
2. Problem solved and applicability
   - When to apply the pattern
3. Solution
   - Participants and their relationships
4. Consequences
   - Costs of applying the pattern, space and time trade-offs

More Specifically

- Teaching and learning
  - It is much easier to learn architecture from descriptions of design patterns than from reading code

- Teamwork
  - Members of a team have a way to name and discuss the elements of their design

Improved Communication

One of the main benefits of design patterns is that they name common (and successful) ways of building software.

Example: A Text Editor

- Describe a text editor using patterns
  - A running example

- Introduces several important patterns

- Gives an overall flavor of pattern culture

Note: This example is from the "Design Patterns" book.
Text Editor Requirements

- A WYSIWYG editor
- Text and graphics can be freely mixed
- Graphical user interface
  - Toolbars, scrollbars, etc.
- Multiple windowing systems
- Traversal operations: spell-checking, hyphenation

The Game

- I describe a design problem for the editor
- I ask "What is your design?"
  - This is audience participation time
- I give you the wise and insightful pattern

Problem: Document Structure

A document is represented by its physical structure:
- Primitive glyphs
  - characters, rectangles, circles, pictures, ...
- Lines
  - A sequence of glyphs
- Columns
  - A sequence of lines
- Pages
  - A sequence of columns
- Documents
  - A sequence of pages

What is your design?

Alternative Designs

- Classes for Character, Circle, Line, Column, Page, ...
  - Not so good
  - A lot of code duplication
- One (abstract) class of Glyph
  - Each element realized by a subclass of Glyph
  - All elements present the same interface
    - How to draw
    - Compute bounding rectangle
    - Mouse hit detection
    - ...
  - Makes extending the class easy
  - Treats all elements uniformly
Notes

- **Drawing**
  - Each primitive element draws itself
    - At its assigned location
  - Each compound element recursively calls draw on its elements
    - But doesn’t care what those elements are

```java
Line::Draw(Window w) {
    for each c in children do
        c->Draw(w);
}
```

Composites

- This is the *composite* pattern
  - Goes by many other names
    - Recursive composition, structural induction, tree walk, ...
    - Predates design patterns

- Applies to any hierarchical structure
  - Leaves and internal nodes have same functionality
  - Composite implements the same interface as the contained elements
Problem: Formatting

- A particular physical structure for a document
  - Decisions about layout
  - Must deal with e.g., line breaking
- Design issues
  - Layout is complicated
  - No best algorithm
    - Many alternatives, simple to complex

What is your design?

Not So Good

- Add a format method to each Glyph class
- Problems
  - Can’t modify the algorithm without modifying Glyph
  - Can’t easily add new formatting algorithms

The Core Issue

- Formatting is complex
  - We don’t want that complexity to pollute Glyph
  - We may want to change the formatting method
- Encapsulate formatting behind an interface
  - Each formatting algorithm an instance
  - Glyph only deals with the interface

Diagram
Strategies

• This is the strategy pattern
  - Isolates variations in algorithms we might use
  - Formatter is the strategy, Compositor is context

• General principle
  - *encapsulate variation*

• In OO languages, this means defining abstract classes for things that are likely to change

Problem: Enhancing the User Interface

• We will want to decorate elements of the UI
  - Add borders
  - Scrollbars
  - Etc.

• How do we incorporate this into the physical structure?

  *What is your design?*

Not So Good

• Object behavior can be extended using inheritance
  - Major drawback: inheritance structure is static

• Subclass elements of Glyph
  - BorderedComposition
  - ScrolledComposition
  - BorderedAndScrolledComposition
  - ScrolledAndBorderedComposition
  - ...

• Leads to an explosion of classes

Decorators

• Want to have a number of decorations (e.g., Border, ScrollBar, Menu) that we can mix independently
  - \( x = \text{new ScrollBar(new Border(new Character))} \)

  - We have \( n \) decorators and \( 2^n \) combinations
Transparent Enclosure

- Define Decorator
  - Implements Glyph
  - Has one member Glyph decorated
  - Border, ScrollBar, Menu extend Decorator

Border::Draw(Window w) {
  decorated->draw(w);
  drawBorder(decorated->bounds());
}

Decorators

- This is the *decorator* pattern
- A way of adding responsibilities to an object
- Commonly extending a composite
  - As in this example

Problem: Supporting Look-and-Feel Standards

- Different look-and-feel standards
  - Appearance of scrollbars, menus, etc.
- We want the editor to support them all
  - What do we write in code like
    ```
    ScrollBar scr = new ?
    ```

*What is your design?*
The Not-so-Good Strawmen

- Terrible
  ScrollBar scr = new MotifScrollBar

- Little better
  ScrollBar scr;
  if (style == MOTIF) then scr = new MotifScrollBar
  else if (style == ...) then ...
  - will have similar conditionals for menus, borders, etc.

Abstract Object Creation

- Encapsulate what varies in a class

- Here object creation varies
  - Want to create different menu, scrollbar, etc
  - Depending on current look-and-feel

- Define a GUIFactory class
  - One method to create each look-and-feel dependent object
  - One GUIFactory object for each look-and-feel
  - Created itself using conditionals
Factories

- This is the *abstract factory* pattern
- A class which
  - Abstracts the creation of a family of objects
  - Different instances provide alternative implementations of that family
- Note
  - The "current" factory is still a global variable
  - The factory can be changed even at runtime

Problem: Supporting Multiple Window Systems

- We want to run on multiple window systems
- Problem: Wide variation in standards
  - Big interfaces
    - Can't afford to implement our own windowing system
  - Different models of window operations
    - Resizing, drawing, raising, etc.
  - Different functionality

  *What is your design?*

A First Cut

- Take the intersection of all functionality
  - A feature is in our window model if it is in every real-world windowing system we want to support
- Define an abstract factory to hide variation
  - Create windowing objects for current window system using the factory
- Problem: intersection of functionality may not be large enough

Second Cut

- Define our own abstract window hierarchy
  - All operations we need represented
  - Model is tuned to our application
- Define a parallel hierarchy
  - Abstracts concrete window systems
  - Has all functionality we need
    - I.e., could be more than the intersection of functions
    - Requires writing methods for systems missing functionality
User Commands

- User has a vocabulary of operations
  - E.g., jump to a particular page
  - Operations can be invoked multiple ways
    - By a menu
    - By clicking an icon
    - By keyboard shortcut
  - Want undo/redo/command line option/menu option

- How do we represent user commands?

  What is your design?

Bridges

- This is the bridge pattern

- Note we have two hierarchies
  - Logical
    - The view of our application, tuned to our needs
    - Implementation
      - The interface to the outside world
      - Abstract base class, with multiple implementations
  - Logical, implementational views can evolve
    - independently,
    - So long as the "bridge" is maintained

A Good Design

- Define a class of user operations
  - Abstract class
  - Presents interface common to all operations
    - E.g., undo/redo

- Each operation is a subclass
  - Jump to a page, cut, paste, ...
Problem: Spell Checking

- Considerations
  - Spell-checking requires traversing the document
    - Need to see every glyph, in order
    - Information we need is scattered all over the document
  - There may be other analyses we want to perform
    - E.g., grammar analysis

What is your design?
**Notes**

- Iterators work well if we don’t need to know the type of the elements being iterated over.
  - E.g., send kill message to all processes in a queue.
- Not a good fit for spell-checking
  ```
  for(i = i->first(); !i->isDone(); i = i->next())
      { ... do something with Glyph i->current() ... }
  ```
- Must cast `i->current()` to spell-check it...
  ```
  if(i instanceof Char) { ... } else { ... }
  ```

**Visitors**

- The visitor pattern is more general
  - Iterators provide traversal of containers
  - Visitors allow
    - Traversal
    - And type-specific actions
- The idea
  - Separate traversal from the action
  - Have a "do it" method for each element type
    - Can be overridden in a particular traversal
Visitor Comments

- The dynamic dispatch on Glyph::Scan achieves type-safe casting
  - dynamic dispatch to Char::Scan, Picture::Scan, ...
- Each of the Glyph::Scan
  - calls the visitor-specific action (e.g., Visitor:visitChar)
  - implements the search (e.g., in Line::Scan)
- Have a visitor for each action (e.g., spell-check, search-and-replace)

Design Patterns

- A good idea
  - Simple
  - Describe useful "micro-architectures"
  - Capture common organizations of classes/objects
  - Give us a richer vocabulary of design
- Relatively few patterns of real generality
- Watch out for the hype . . .