Lecture 16: Program design

Lecture goals

- Distinguish between heavyweight and lightweight design processes
- Document static and dynamic designs using UML diagrams
- Leverage design patterns to reuse solutions to common problems

Program design models

Program design

- Goal: represent software architecture in form that can be implemented as one or more executable programs
- Specifies:
    - Programs, components, packages, classes, class hierarchies
    - Interfaces, protocols
    - Algorithms, data structures, security mechanisms, operational procedures
- Historically (e.g. aerospace), program design done by domain engineers, implementation done by *programmers*

Heavyweight design

- Program design and coding are separate
    - Use models to specify program in detail, before beginning to code
    - UML provides modeling notation

Lightweight design

- Program design and coding are interwoven
    - Development is iterative
    - Assisted by integrating multiple development tools (IDEs)
- Fine line between "lightweight" and "sloppy"

Mixed approach

- Use models to specify outline design
- Work out details iteratively during coding

UML models for design

- Diagrams give general overview
    - Principal elements
    - Relationships between elements
- Specifications provide details about each element

In a heavyweight process, specifications should have sufficient detail so that corresponding code can be written unambiguously. Ideally, specification is complete before coding begins.

UML model choices

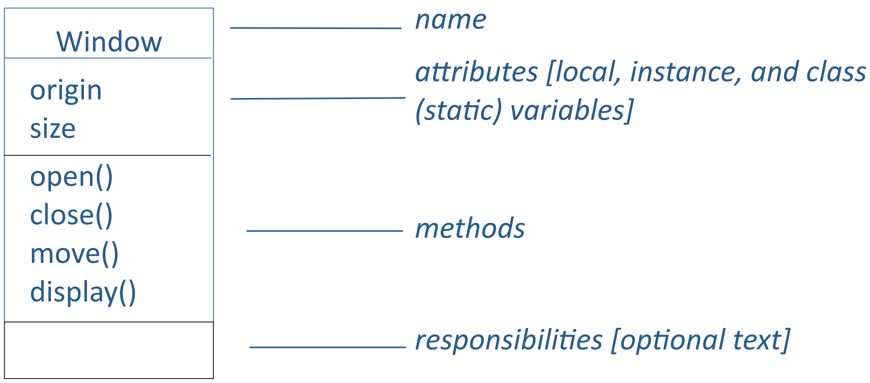
- Requirements
    - Use case diagram: use cases, actors, and relationships
- Architecture

  - Component diagram: interfaces and dependencies between components
  - Deployment diagram: configuration of processing nodes and the components that execute on them
- Program design
  - Class diagram (structural): classes, interfaces, collaborations, and relationships
  - Sequence diagram (dynamic): set of objects and their relationships

Structural (static) modeling

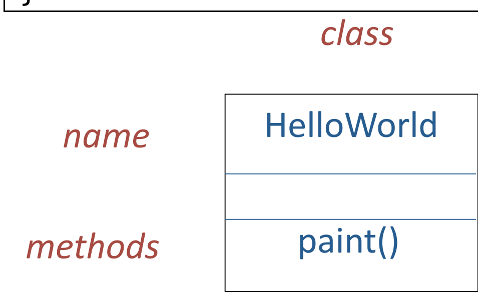
Class diagram

- Class: Set of objects with the same attributes, operations, relationships, and semantics
- "Operation" in UML = "method" in Java

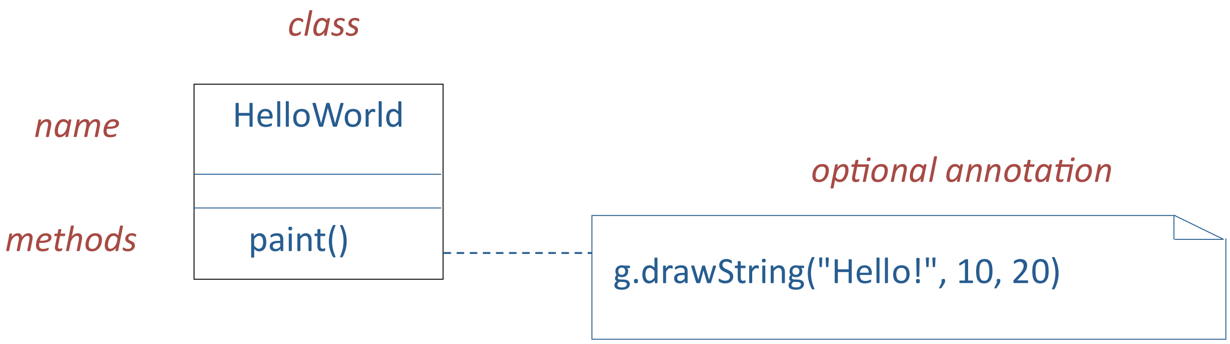


Example: Hello World applet

```
import java.applet.Applet;
import java.awt.Graphics;
class HelloWorld extends Applet {
  public void paint(Graphics g) {
    g.drawString("Hello!", 10, 20);
  }
}
```



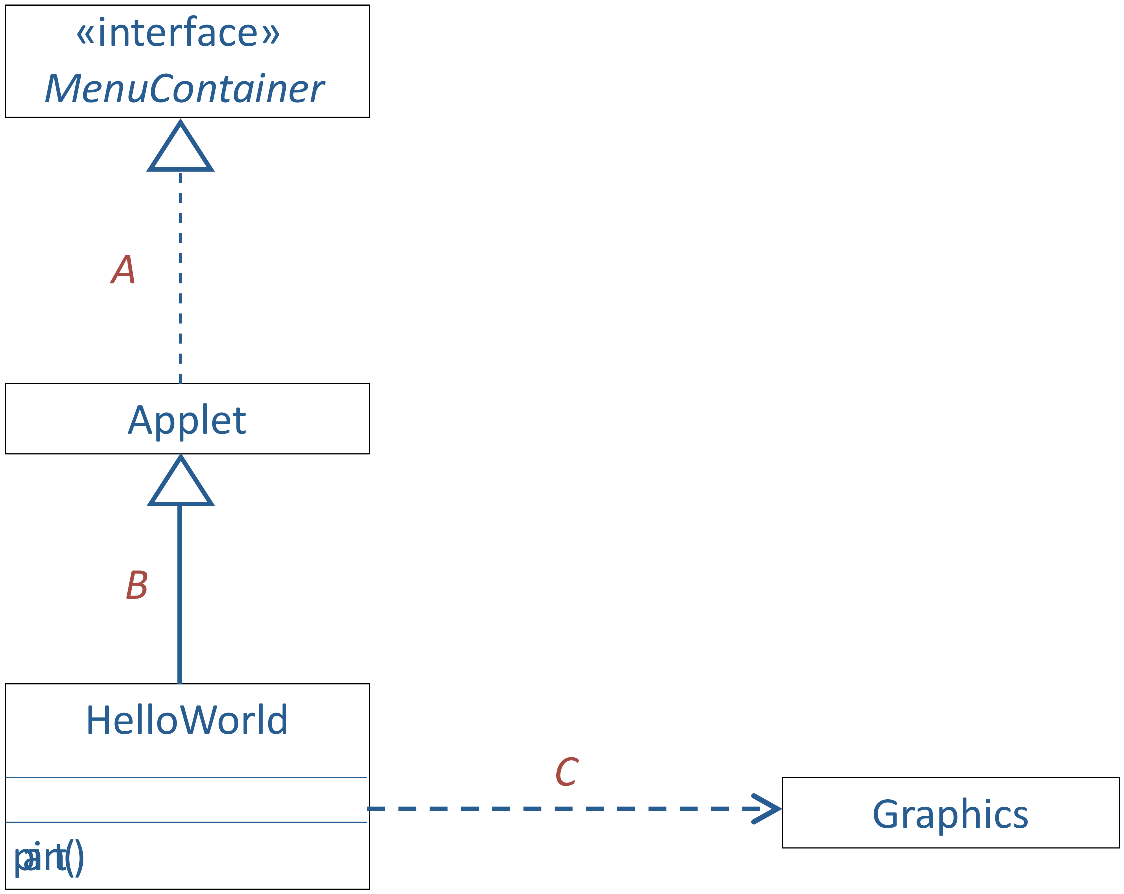
Annotations



Relationships

- Association: show multiplicity of links between instances of classes
  - Analogous to relations in entity-relation diagrams
  - Bidirectional – doesn't imply ownership or composition
  - Solid line with multiplicity at each end, optional label
  - See Sommerville, Figure 5.9
- Dependency
  - A change to one class may affect the semantics of another
  - Dashed arrow with stick head, pointing to the dependency
- Generalization (inheritance)
  - Objects of a specialized (child) class are substitutable for objects of a generalized (parent) class
  - Solid arrow with enclosed head pointing from child to parent
- Realization (interfaces)
  - A class is guaranteed to fulfil a contract specified by another class
  - Dashed arrow with enclosed head
- Aggregation
  - An instance of one class (the whole) is composed of objects of other classes (the parts)
  - To reduce coupling, prefer composition over inheritance
  - See Sommerville, Figure 5.13

Example: Hello World applet relationships



Tools for UML-based design

- Rational Rose (and derivatives)

Lightweight design

- Less detail
    - Only show "interesting" behaviors and attributes with ownership significance
- Less permanent
    - May only exist on whiteboard during design brainstorming
    - Reduces maintenance of keeping documents in-sync with code
- Less sequential
    - Only design what you need for current task
    - Use lessons from implementation to iterate on designs
- Leverage tooling and modern languages
    - Generate diagrams from source code
    - Generate specifications from comments
    - IDEs highlight attributes and methods
- Still need design activities, documentation to be successful

Class design

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- Step 1: Identify set of candidate classes
    - What terms do users and implementers use to describe the system?
    - Is each candidate class crisply defined?
    - What are the candidate classes' responsibilities? Are they balanced?
    - What attributes and methods does each class need to carry out its responsibilities?
- Step 2: Refine list of classes
    - Improve clarity of design
    - Increase coherence within classes, reduce coupling between classes

Application and solution classes

- Application classes represent application concepts.
    - Use Noun Identification to generate candidate application classes
- Solution classes represent system concepts
    - User interface objects, databases, etc.

Example

Noun identification

The library contains books and journals. It may have several copies of a given book. Some of the books are reserved for short-term loans only. All others may be borrowed by any library member for three weeks. Members of the library can normally borrow up to six items at a time, but members of staff may borrow up to 12 items at one time. Only members of staff may borrow journals.

The system must keep track of when books and journals are borrowed and returned, and enforce the rules.

Candidate classes

Noun	Comments	Candidate
Library	*the name of the system*	no
Book		yes
Journal		yes
Copy		yes
ShortTermLoan	*event*	no (?)
LibraryMember		yes
Week	*measure*	no
MemberOfLibrary	*repeat of LibraryMember*	no
Item	*book or journal*	yes (?)
Time	*abstract term*	no
MemberOfStaff		yes
System	*general term*	no
Rule	*general term*	no

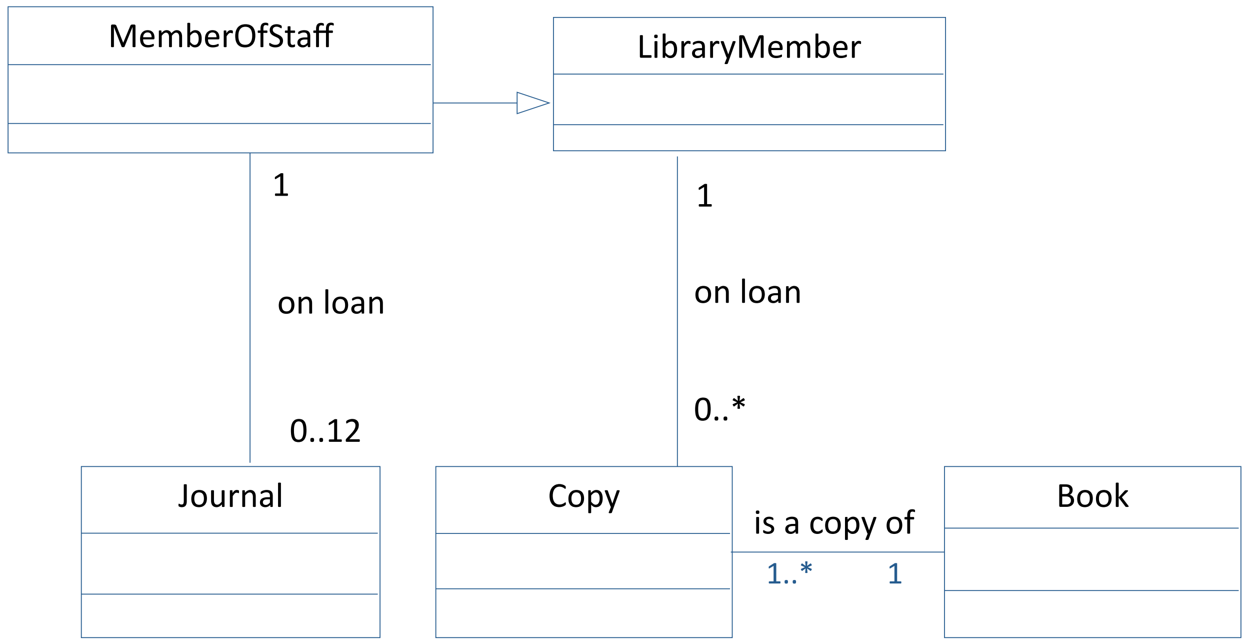
Candidate relations

Book	is an	Item
Journal	is an	Item
Copy	is a copy of a B	ook
LibraryMember		
Item		
MemberOfStaff	is a	LibraryMember

Candidate methods

LibraryMember	borrows	Copy
LibraryMember	returns	Copy
MemberOfStaff	borrows	Journal
MemberOfStaff	returns	Journal

Candidate class diagram



Moving towards final design

- Reuse: Wherever possible use existing components, or class libraries
    - They may need extensions.
- Restructuring: Change the design to improve understandability, maintainability
    - Merge similar classes, split complex classes
- Optimization: Ensure that the system meets anticipated performance requirements
    - Change algorithms, more restructuring
- Completion: Fill all gaps, specify interfaces, etc.
- Design is *iterative*
    - As the process moves from preliminary design to specification, implementation, and testing it is common to find weaknesses in the program design. Be prepared to make major modifications.

Class design advice

- Classes should be easy to use correctly and hard to use incorrectly
    - See Effective C++, Third Edition
- Avoid cyclic dependencies (tight coupling)
    - While allowed, can lead to awkwardness in build procedure, limit portability

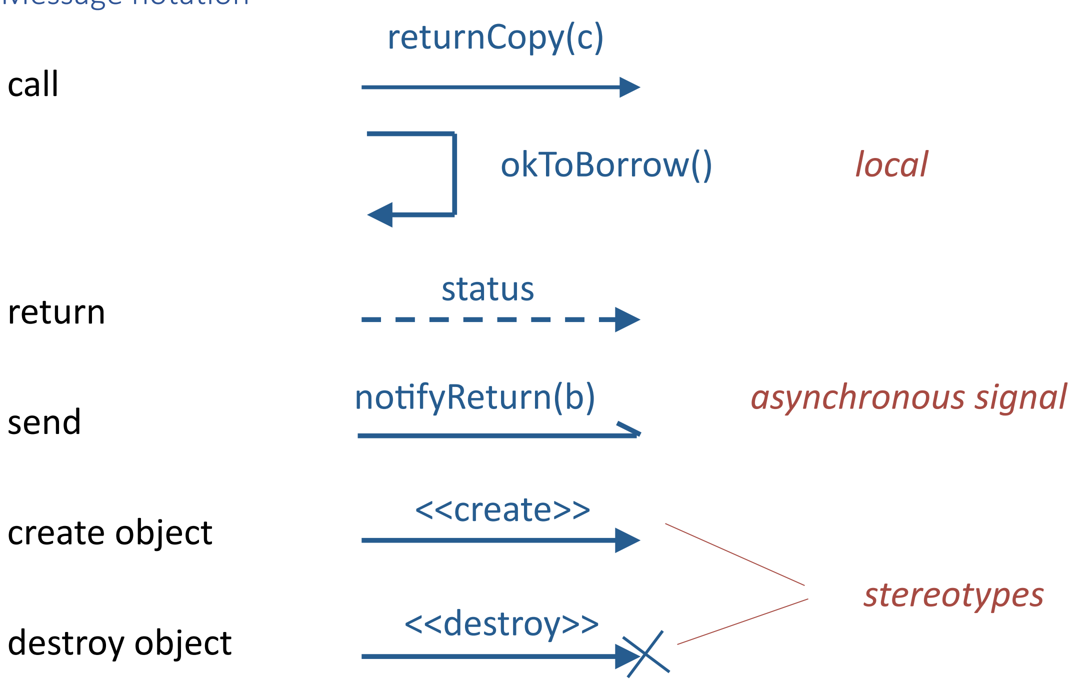
Dynamic modeling

- Interaction diagrams: show a set of *objects* and their relationships
    - Includes messages sent between objects
- Sequence diagrams: time ordering of messages

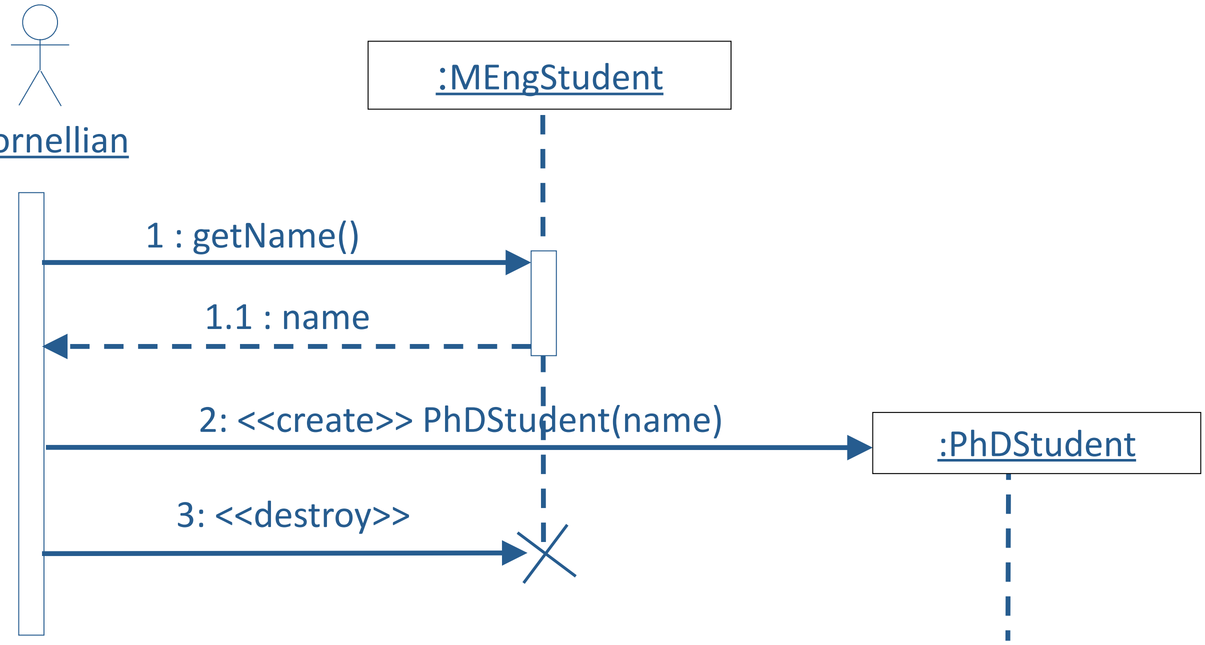
Object notation

Classes	Objects
AnyClass attribute1 attribute2 method1() method2()	<u>anObject:AnyClass</u>
	or
	<u>:AnyClass</u>
or	*or*
	<u>anObject</u>
AnyClass	The names of objects are underlined.

Message notation



Example: Sequence diagram for changing student program



See also Sommerville, Figure 7.7

Design patterns

Reusable design patterns

- Design templates that solve recurring problems in a variety of different systems
- Popularized by "Gang of Four"
    - E. Gamma, R. Helm, R. Johnson, and J. Vlissides, *Design Patterns: Elements of Reusable Object-Oriented Software*. Addison-Wesley, 1994
- Avoid reinventing the wheel; adopt proven solutions with known tradeoffs
- When developers are familiar with design patterns, they can be used to quickly communicate complex relationships between classes

Properties of patterns

- Meaningful name
- Description of the problem setting
    - Explains where pattern may be applied
- Description of solution
    - Not a library, but a "design template"; can be instantiated in different ways
    - Often expressed graphically
- Statement of consequences
    - Results and tradeoffs of applying the pattern in the problem setting

Implementation

- Design patterns make extensive use of inheritance and abstract classes/interfaces
    - Classes that provide concrete implementations for abstract methods can participate in the pattern

Observer pattern

- Setting: A variety of entities (for example, different graphical views) need to be updated whenever the state of an object changes
- Solution
    - Observers: notified when Subject state changes; should update (i.e. display) accordingly
    - Subject: notifies Observers when its state changes
- Consequences
    - Subject not coupled to concrete Observers
    - Lack of coupling may impede performance optimizations
    - Redundant updates may be triggered
    - Control flow for Observers is inverted, can be hard to trace

See Sommerville, Figure 7.12

Examples

- Swing JButton (subject) and ActionListener (observer)