Lecture 7: Data Abstractions

Abstract Data Types

Data Abstractions

- How to define them
- Implementation issues
- Abstraction functions and invariants
- Adequacy (and some requirements analysis)

Towards Object Orientation

- differences between object oriented programming and data abstraction

Example

Imagine we want to hold information about dates

- E.g. year, month, day, hours, minutes, seconds, day of week, etc.
  - Could use an integer arrays: int date [3];
  - and write some support functions for computing day of week, comparing dates,…
- But suppose we then decide years need 4 digits rather than 2 (i.e. 2001 instead of 01)
  - we have to change every part of the program that uses dates

e.g. if we used arrays of int for date & time:

```
int today[3];
int lecture1_time[3];
…
today[0] = 01;
today[1] = 10;
today[2] = 01;
lecture1_time[0] = 9;
lecture1_time[1] = 0;
lecture1_time[2] = 0;
```

Encapsulation

distinguish the abstract notion of a 'date' from it's concrete representation

hide all the details about how dates are represented

Benefits:

modifiability, testability, readability, reduced complexity, [Y2K compliance(!?)]

Abstract Data Types (ADTs)

Programming languages provide:

- Some concrete data types
  - integers, characters, arrays,…
- Some abstract data types
  - floating point, lists, tables, two dimensional arrays, records,…
- Abstract data types are implemented using concrete data types
  - (but you don't need to know this to use them)

Operations are provided for each datatype

- e.g. creation, assignment, etc.
- … but you cannot muck around with the internal representations
  - e.g. float is represented in two parts, but you cannot access these directly
- But: some languages do allow you access to the internal representations
  - e.g. in C, you can use pointers to access the internals of arrays
  - this removes the distinction between the abstraction and the implementation
  - it destroys most of the benefits of abstraction
  - it causes confusion and error

Source: Liskov & Guttag 2000, p77-78

Home-made abstract data types

Encapsulation is improved if you create your own data abstractions

choice of what abstractions to create depends on the application

Application	*Useful data abstractions*
Compiler writing	tables, stacks, …
Banking	accounts, customers, …
Mathematical computing	matrices, sets, polynomials, …
Graph Editing	graphs, nodes, edges, positions …

choice of operations depends on how you want to manipulate the data

- e.g. bank accounts: open, close, make a deposit, make a withdrawal, check the balance, …
- e.g. graphs: initialize, add nodes, remove nodes, check whether there is an edge between two nodes, get the label for a node,…

Most languages support creation of new datatypes

… but they might not force you to specify the data abstraction

… and they might not enforce information hiding

Source: Liskov & Guttag 2000, p117-118

Operations on Data Abstractions

Four groups of operators:

Creators
- create new objects of the datatype

Producers
- take existing objects of the datatype and build new ones

Mutators
- modify existing objects of the datatype

Observers
- tell you information about existing objects of the datatype (without changing them)

Immutable datatypes…

…don't have mutators
- they can be created and destroyed, but not modified
- once you've created an object you cannot change it

Example: sets

Creators:
- create a new empty set,…

Producers:
- set union,
- set intersection,…

mutators:
- add an element,
- remove an element,…

observers:
- set size,
- set membership,
- set equality,
- test for empty set,…

Defining Data Abstractions

Source:
Liskov & Guttag 2000, section 5.1

The abstraction should:

- name the data type
- list its operations
- describe the data abstraction in English
  - say whether it's mutable or not
- give a procedural abstraction for each operation
  - the abstraction only lists the "public" operations
  - there may be other "private" procedures hidden inside…

```
/*
datatype set has operators create, insert, delete,
  member, size, union, intersection.
overview:
  sets are unbounded mathematical sets of integers.
  They are mutable: insert and delete are the
  mutation operations.
operations:
  procedure create () returns set
  effects: x is a new empty set

  procedure insert (set s, int x) returns null
  effects: adds x to the set s such that s' = s  {x}

  procedure delete (set s, int x) returns null
  requires: x  s
  effects: s' = s - {x}

… (etc) … */
```

Source: adapted from Liskov & Guttag 2000, p81

Java Example

```
public class IntSet {
  //Overview: IntSets are mutable, unbounded sets of integers. A
  typical IntSet is {x1, …xn}

  //Creators
  public IntSet ()
    //effects: Initializes this to be the empty set

  //Mutators
  public void insert (int x)
    //effects: adds x to the set this such that this’ = this □ {x}

  public void delete (int x)
     //requires: x □ this
    //effects: this’ = this - {x}

  //Observers
  public boolean member (int x)
    //effects: returns true if x □ this, false otherwise

  //Producers
  public IntSet intersection (IntSet a)
    //effects: returns a new set representing a □ this
}
```

Source:
Liskov & Guttag 2000, section 5.3

Implementing Data Abstractions

Choose a representation that:
- permits all operations to be implemented easily (and reasonably efficiently)
- permits frequent operations to run faster

Example: sets
- an unsorted array with repeated elements
  - insert is very fast, union is fast, intersection and member are slow, delete is very slow
- a sorted array
  - insert is very slow, member is very fast, intersection is fast, union is slow
- a linked list
  - insert is fast, delete is fast, union is slow, takes more memory

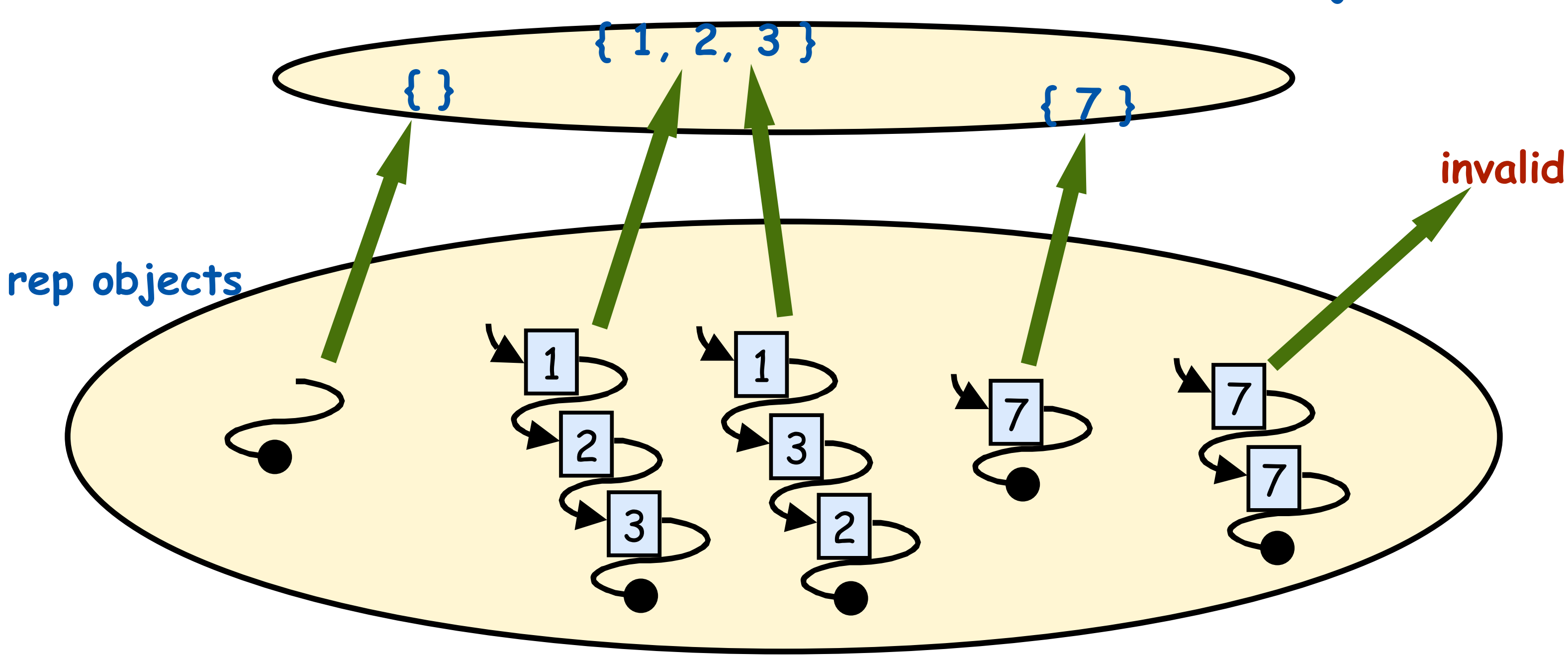
Choose a programming mechanism
- Package
  - hides 'private' code, package has to be 'imported' (e.g. Ada, C, Modula)
- Object
  - provides inheritance, operations called by message passing (e.g. C++, Java)
- Abstract datatype
  - provides strong type checking, object becomes part of the language (e.g. C, ML)

Source: Liskov & Guttag 2000, p99-100

Abstraction vs. Implementation

There is a mapping between abstract objects and their representations

- several rep objects might map to the same abstraction object
- some rep objects might be invalid
- every abstract object must have a rep object



Adequacy

Source: *Liskov & Guttag 2000, p118-9*

A data abstraction is adequate if…

…it provides all the operations the 'users' (e.g. other programmers!) will need

Choices, choices, choices…

- e.g. for sets, member(s,x) isn't strictly necessary:
  - …could do intersection(s,create_set(x)) and test if the result is empty
  - …could do delete(s,x) and see if we get an error message
  - but member(s,x) is much more convenient.
- Such choices affect functionality, convenience & efficiency
  - functionality: make sure all required operations are possible
  - convenience: make sure that typical/frequent operations are simple to use
  - efficiency: make frequent operations cheaper (usually by choosing an appropriate rep type - this should not affect the choice of abstraction)

Some requirements analysis is needed

- What data objects will be needed?
- What operations will need to be performed on them?
- What usage patterns are typical?
  - "use cases" / "scenarios" are helpful here

Source: van der Linden, 1996, chp2, and Blum, 1992, pp313-329

Object Orientation

Object Orientation extends data abstraction

- Data abstraction becomes the main structuring mechanism for programs
  - No fixed control structure
- Object Oriented programming languages have:
  - Abstraction
  - Encapsulation - *methods and objects are bundled together*
  - Polymorphism - *same name can be used for different objects' methods*
  - Dynamic binding - *don't know which method/object is referred to until runtime*
  - Inheritance - *can extend existing data abstractions to create new ones*

Use *OO design principles* in any programming language

- Write data abstractions for all complex data structures
  - Hide the implementations using ADTs or packages
  - Only access the data abstractions through their defined operations (□'methods')
- Some OOP mechanisms are less important
  - Polymorphism & dynamic binding are not relevant at the design level (these are programming tricks that make programs more complex)
  - Inheritance can be done manually

Summary

Data Abstractions lead to good program design

- They help with encapsulation (information hiding)
- They help reduce the complexity of software interfaces
- They make programs more modifiable

Need some analysis to choose good data abstractions

- Adequacy: have you included all the operations that users need
- can switch between implementations to improve efficiency

Data abstraction ≠ abstract data types

- ADTs are one way to implement data abstraction
- can also use packages, objects,…

Data abstraction ≠ object-oriented programming

- data abstraction is really a design technique (the basis of OOD)
- can use it in any programming language
- some programming languages provide more support than others

References

Liskov, B. and Guttag, J., "Program Development in Java: Abstraction, Specification and Object-Oriented Design", 2000, Addison-Wesley.

- Chapter 5 provides a thorough coverage of data abstractions.

Blum, B. "Software Engineering: A Holistic View". Oxford University Press, 1992

- see especially section 4.2 for comments on data abstraction and object oriented design. (historical note: Java is conspicuously absent from Blum's list of object oriented languages. The technology has changed dramatically in eight years! However, the principles are the same)

van der Linden, P. "Just Java". 1996, Sunsoft Press

- A rare book on object oriented programming in Java written by someone that can explain it properly.

van Vliet, H. "Software Engineering: Principles and Practice (2nd Edition)" Wiley, 1999.

- mentions data abstraction only in passing in section 11.1. Chapter 15 gives a much more formal coverage of specifying data abstractions via algebraic specs (15.3), and via formal pre- and post-conditions (15.4). This is more formal than I expect to use on this course, but worth a read to see where some of the ideas came from.