CS 312

Specifications and modular programming

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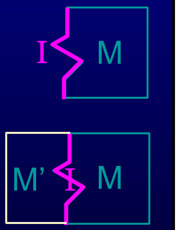
December 4, 2003

Modular design

- Hard to develop medium-to-large programs (>10k LOC)
  - Too complex to understand
  - May require domain-specific knowledge
- Must break into subsystems (modules) that can be designed separately
  - Must be possible to think about module behavior abstractly
  - Modules can be correct in isolation
  - Can identify source of failure
- Modules compose to make whole system

Interfaces

Good modular design reduces cost
  - Modules fit together
  - Modules can usually be changed without affecting other modules (loose coupling)
  - Design using local reasoning
  - Test modules in isolation



- For each module M provide interface I describing what it provides
  - A contract between modules

Language mechanisms

- ML: module = structure,
  interface = signature
- C: module = .c file,
  interface = .h file
- Java: module = class,
  interface = interface/javadoc
  - Deriving interface from code is dangerous

Example

- Module interface: usually collection of function declarations, plus some abstract data types *(ADTs)*
- Example: simple Java module for performing rational arithmetic

ADT

function/method declarations

```
interface Rational {
   Rational add(Rational);
   Rational multiply(Rational);
```

… implementation unspecified!

Interface and implementation(s)

```
class Rational {
  int p; int q;
  Rational add(x, y) {
     return new Rational(
  x.p*y.q+x.q*y.p, x.q*y.q);
}
```

```
Rational
add
multiply
subtract
```

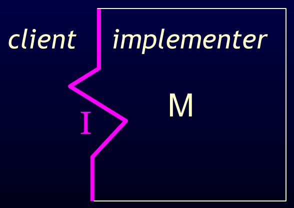
interface

2 possible implementations

```
class Rational {
   int p; int q;
   Rational add(x, y) {
      return new Rational(
   (x.p*y.q+x.q*y.p)/gcd(x.q,y.q),
    x.q*y.q/gcd(x.q,y.q));
   int gcd(int q1, int q2) {…}
}
```

Clients vs. Implementers

- Interface creates two roles:
  - Client writes code that uses the module via interface
  - Implementer writes code that implements module
- Obligations:
  - Clients should not rely on anything not in interface
  - Implementer should provide everything in interface
- Benefits
  - Lower cost : client doesn't have to know about module internals
  - Loose coupling: Can freely change module if interface unchanged
  - Can assign blame!

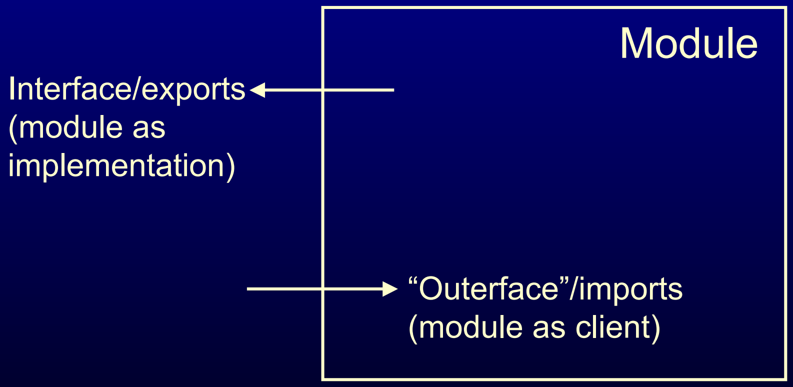


What makes an interface good?

- Tension between client and implementer
- Narrow (small, simple)
  - few exposed operations, types
  - easy to learn and understand
  - easy to implement & test
- Complete – supplies all needed functionality
  - But avoid unnecessary complexity!
  - Limit of short-term memory: ~7 things

	↔	
Narrow		Wide
Limited		Powerful
Simple		Complex
Loose coupling		Tight coupling
Easy to change		Hard to change

Loose coupling


Module

Interface/exports (module as implementation)

“Outerface”/imports (module as client)

- Keep both interactions simple!

Specifications

- Type declarations aren’t an adequate behavioral model; need specifications

  `val sqr: float -> float`

  - what does this do?
- Specification should include
  - Preconditions: requirements on the client to use operation/resource; implementer can rely on them
  - Postconditions: requirements on what the implemention does; client can rely on them
- Meaning: if the precondition is satisfied, then the postcondition will be satisfied

```
(* Requires: x>=0 (precondition)
   Results: sqr(x) is the positive
            square root of x (postcondition) *)
val sqr: float -> float
```

Using comments

- Goal: help people understand code
  - Client wants to understand what module does from interface
  - Implementer/maintainer wants to understand how module satisfies interface
  - Different kinds of comments!
- Interface (ML signature) contains:
  - function specifications
  - ADT overview
- Implementation (ML struct) contains:
  - algorithm explanations
  - data structure (representation) invariants
  - how to interpret data structure as abstract data type

Function specifications

- Useful to have a standard form: clauses
- Requires clause: preconditions on calling a function
- Results clause: postconditions
- Checks clause: preconditions with a description of failure behavior (default: throw exception to terminate program)

```
(* sqr(x) is the positive square root of x
   Checks: x>=0 *)
```

- Modifies/effects clause: specifies all side effects of call (not needed in functional style)

```
(* Effects: copy(a,b) copies all elements of
            a into b
   Requires: a and b are different hash tables *)
val copy: hashTable*hashTable -> unit
```

Avoiding overspecification

- Definitional spec describes external behavior

```
fun find(a: int vector, y: int): int = …
   (* Operational: loop j from 0 up to
           a.length-1 and return j if a[j] = y
      Definitional: return j such that a[j] = y *)
```

- Allows new implementations, easier for clients to use, easier to spot omissions

Definitional	⟷	Operational
Loose coupling		Tight coupling
Easy to change		Hard to change

- Nondeterministic specification: can have more than one result

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Formal specifications

```
   (* let j = find(a,y)
      pre:  exists(i) Vector.sub(a,i) = y
      post: 0<=j & j<=Vector.length(a) &
            Vector.sub(a,j) = y
      modifies: none
   *)
val find: int vector * int -> int;
```

- Automatic theorem prover can show that implementation satisfies spec
  - Java ESC
  - Larch C

Refinement

- Specification is stronger if it constrains behavior more, e.g.

1. f(y) is an integer if y < 0
2. f(y) is an integer less than y
3. f(y) is a prime factor of y

- A stronger specification refines a weaker specification (reduces set of poss. behaviors)
  - Stronger is not necessarily better…
- 1 refines 2 if: $pre_2 \Rightarrow pre_1 \wedge post_1 \Rightarrow post_2$
- Refining specification will not break clients
- An implementation is a specification too!
- Correct implementation is a refinement of its specification : its behaviors are allowed

Hierarchical decomposition

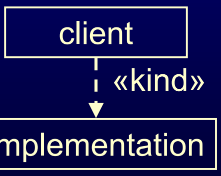
- In well-designed code:
  - Bottom level code units are methods/functions (~1–100 LOC)
  - Modules have up to a couple of dozen ops
  - At most a couple of dozen modules to implement related functionality
- Top-level modules scale to ~10k LOC progs
- Modularity alone isn't enough for large systems—need hierarchy of modules

Hierarchical decomposition

- Divide and conquer: must break large modules into smaller modules
- Multiple levels of hierarchy
- Good design if: only need to think about one module, one level at a time
- How to manage large-scale design?

Module dependency diagram

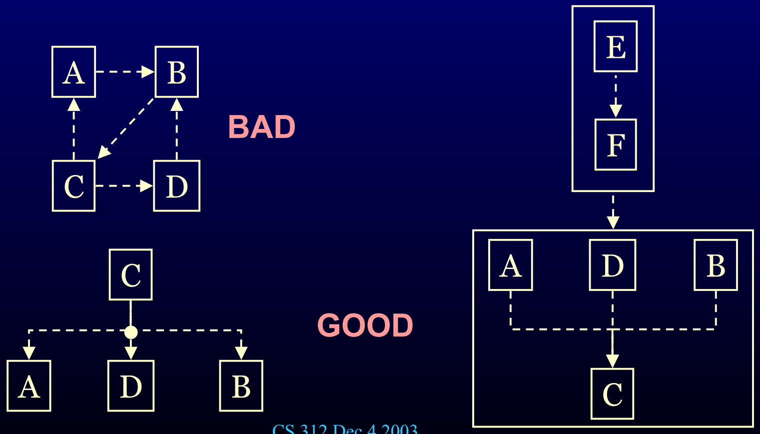
- When design of one module changes, other modules may need corresponding changes – how to identify?
- Module dependency diagram (MDD) gives high-level overview of system structure



- Different kinds of dependency: «uses», «accesses», «references», «derives»

Keeping dependencies simple

- Too many dependencies or cycles: harder to debug, maintain, extend software



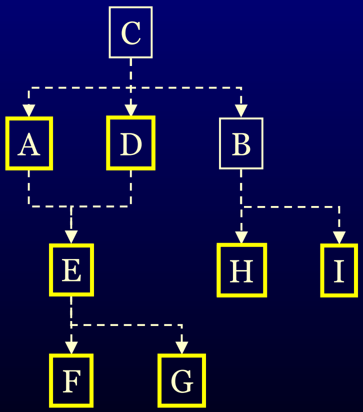
Design/implementation strategy

- Step 1: define interface that partitions problem
- Step 2: implement module

In hierarchy, what order?

Bottom-up implementation

- Bottom-up: develop modules before the modules that depend on them
- Advantage: catch key technology/performance issues early
- Advantage: always working code, easy testing
- Disadvantage: catch large-scale design flaws late



Top-down implementation

- Top-down: develop using modules before modules they depend on
- Advantage: get high-level design right from start, early prototype
  Advantage: easier to design interfaces well, quickly spec out system
- Disadvantage: harder to test until program complete