ICS 52: Introduction to Software Engineering

Fall Quarter 2001

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Lecture Notes: Software Architecture, Part II

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http://www.ics.uci.edu/~taylor/ics52_fq01/syllabus.html

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Today's Lecture

- Architectural design revisited
- Modules
- Interfaces

Design

- Architectural design
  - High-level partitioning of a software system into separate modules *(components)*
  - Focus on the interactions among parts *(connections)*
  - Focus on structural properties *(architecture)*
    - “How does it all fit together?”
- Module design
  - Detailed design of a component
  - Focus on the internals of a component
  - Focus on computational properties
    - “How does it work?”

Architectural Design

- A simple diagram is not enough
  - It is only a start
- Additional decisions need to be made
  - Define the primary purpose of each component
  - Define the interface of each component
    - Primary methods of access/use
    - As complete as possible
- Always requires multiple iterations
  - Cannot do it right in one shot
  - Use the fundamental principles

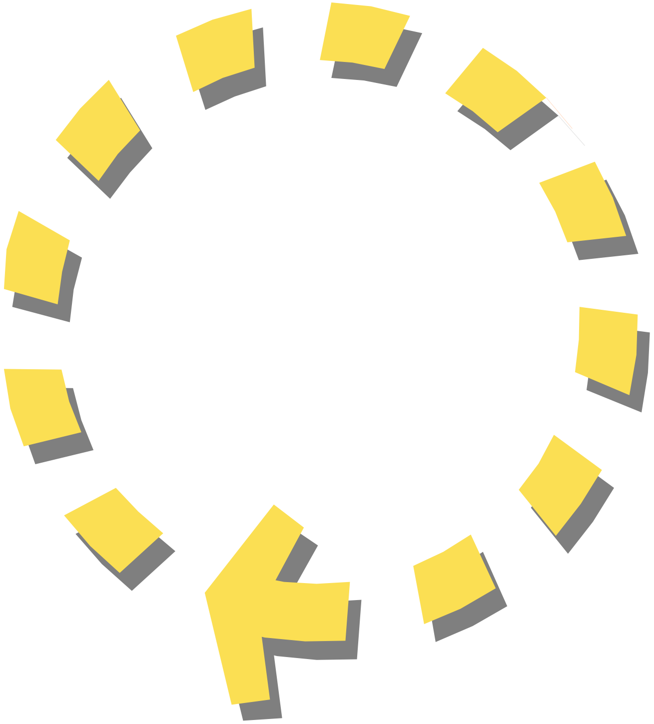
A Good Design…

- …is half the implementation effort!
  - Rigor ensures all requirements are addressed
  - Separation of concerns
    - Modularity allows work in isolation because components are independent of each other
    - Abstraction allows work in isolation because interfaces guarantee that components will work together
  - Anticipation of change allows changes to be absorbed seamlessly
  - Generality allows components to be reused throughout the system
  - Incrementality allows the software to be developed with intermediate working results

A Bad Design…

- …will never be implemented!
  - Lack of rigor leads to missing functionality
  - Separation of concerns
    - Lack of modularity leads to conflicts among developers
    - Lack of abstraction leads to massive integration problems (and headaches)
  - Lack of anticipation of change leads to redesigns and reimplementations
  - Lack of generality leads to “code bloat”
  - Lack of incrementality leads to a big-bang approach that is likely to “bomb”

Design Interaction



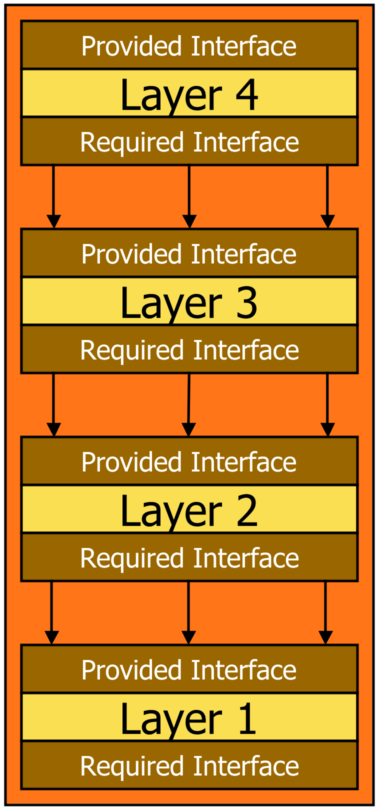
Architectural design
(previous lecture)

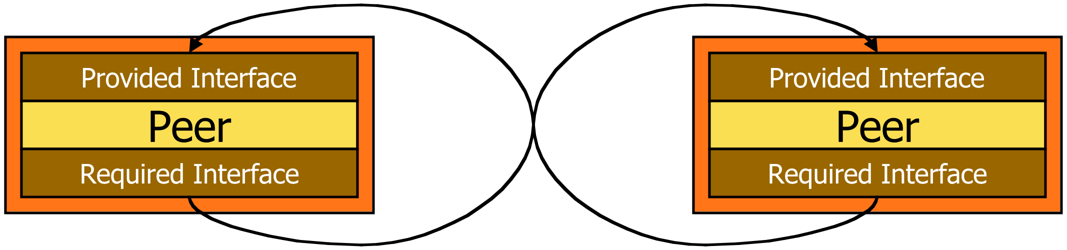
Module design
(this lecture)

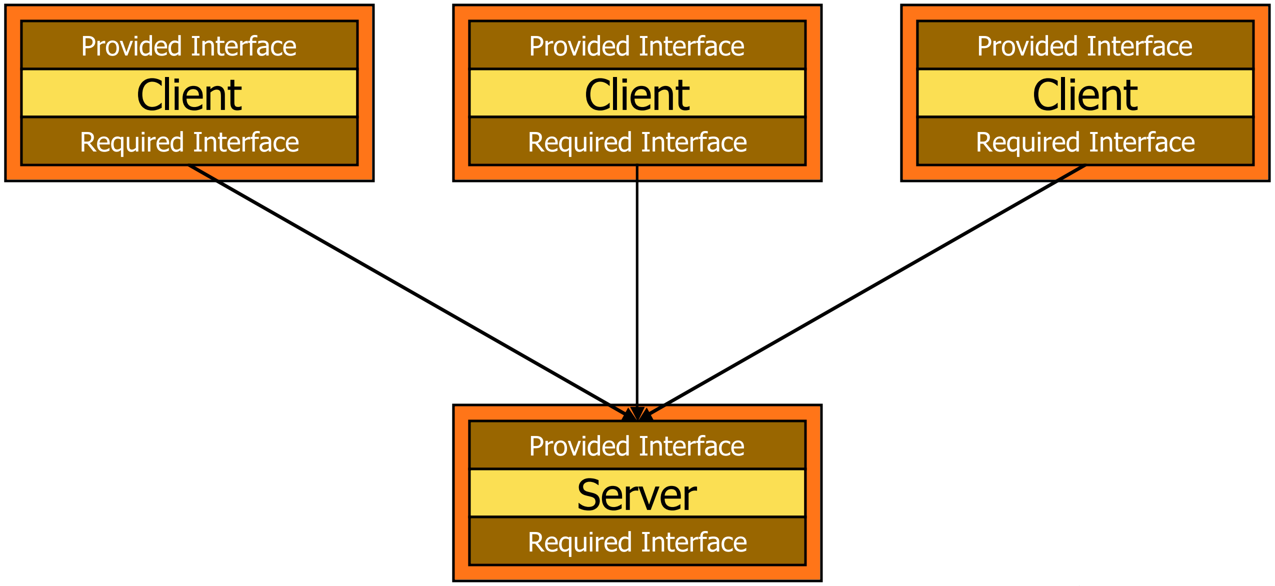
From Architecture to Modules

- Repeat the design process
  - Design the internal architecture of a component
  - Define the purpose of each module
  - Define the provided interface of each module
  - Define the required interface of each module
- Do this over and over again
  - Until each module has…
    - …a simple, well-defined internal architecture
    - …a simple, well-defined purpose
    - …a simple, well-defined provided interface
    - …a simple, well-defined required interface
- Until all modules “hook up”

But What About Those Interfaces?


Provided Interface
Layer 4
Required Interface
Provided Interface
Layer 3
Required Interface
Provided Interface
Layer 2
Required Interface
Provided Interface
Layer 1
Required Interface


Provided Interface
Peer
Required Interface
Provided Interface
Peer
Required Interface

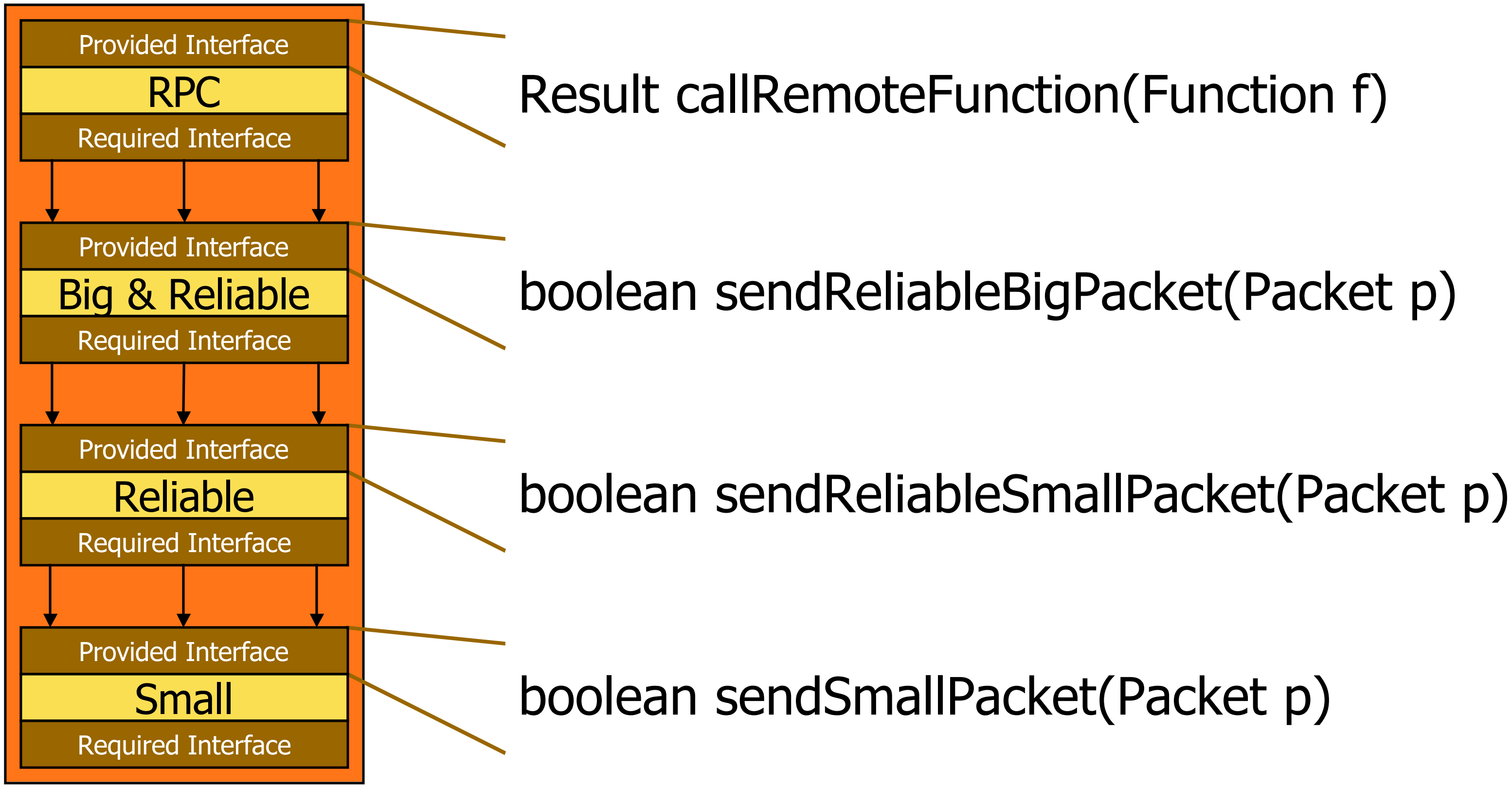

Provided Interface
Client
Required Interface
Provided Interface
Client
Required Interface
Provided Interface
Client
Required Interface
Provided Interface
Server
Required Interface

Interfaces

- Abstraction of the functionality of a component
  - Defines the set of services that a component provides or requires
  - Other components use or supply these services
  - Components themselves implement the services
    - With or without the help of other components
- Serves as a contract
  - Other components rely on the contract
  - Any change can have far-reaching consequences

Interfaces are the key to proper design

Example: Network Protocols (1)



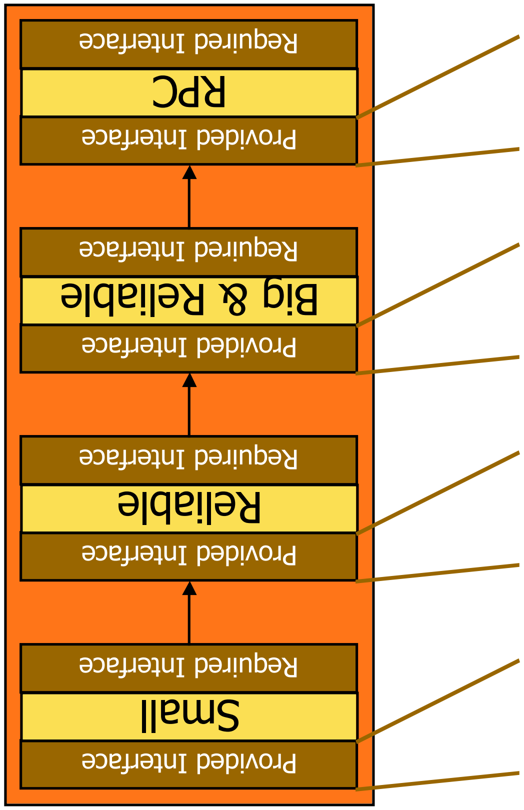
Result callRemoteFunction(Function f)

boolean sendReliableBigPacket(Packet p)

boolean sendReliableSmallPacket(Packet p)

boolean sendSmallPacket(Packet p)

Example: Network Protocols (2)



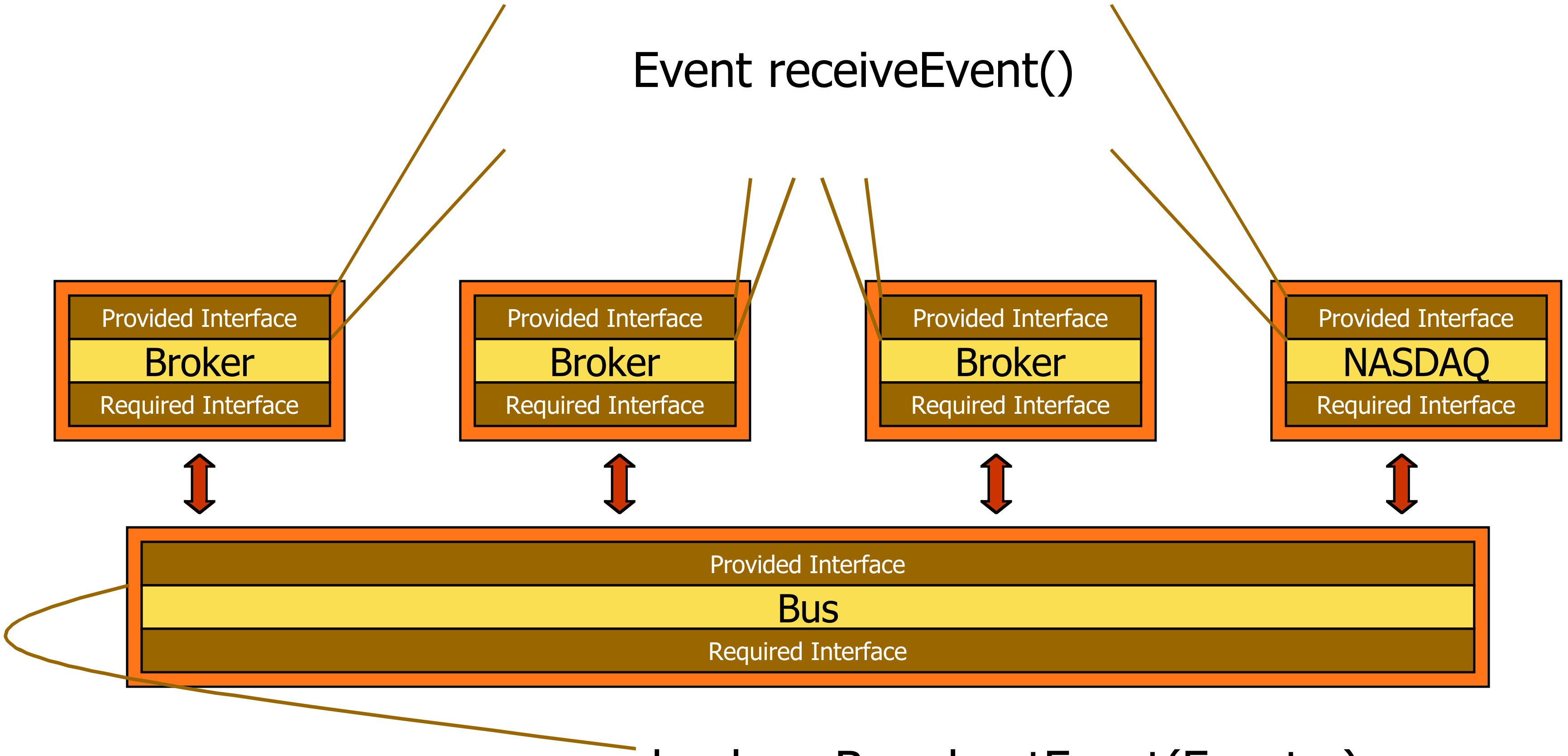
Result RemoteFunction(Function f)

Packet receiveReliableBigPacket()

Packet receiveReliableSmallPacket()

Packet receiveSmallPacket()

Example: Stock Market



Event receiveEvent()

Provided Interface

Broker

Required Interface

Provided Interface

Broker

Required Interface

Provided Interface

Broker

Required Interface

Provided Interface

NASDAQ

Required Interface

Provided Interface

Bus

Required Interface

boolean BroadcastEvent(Event e)
void registerInterest(EventType et)

Interfaces and Fundamental Principles

- Interfaces are rigorously and formally defined
- Interfaces separate concerns
  - Interfaces modularize a system
  - Interfaces abstract implementation details
    - With respect to what is provided
    - With respect to what is required
- (Good) Interfaces anticipate change

Tools of the Trade

- Apply information hiding
  - “Secrets should be kept from other modules”
  - Abstract data types
- Use requirements specification
  - Objects, entities, relationships, algorithms
- Determine usage patterns
- Anticipate change
- Design for generality and incrementality
  - Reuse
- Design for program families

Apply Information Hiding

- One module “hides secret information” from other modules
  - Data representations
  - Algorithms
  - Input and output formats
  - Sequencing of processing
- Why?
  - To create a clean separation of concerns

Abstract Data Types

- Goal: Encapsulate the concrete representation of a data structure will all functions that access the representation
- Users see only the abstract characteristics of the structure
- Access to the structure is only through the provided access functions
- No extraneous functions included
- Notes
  - Abstract does not mean ``vague''
  - Abstract does not mean highly mathematical
  - Abstract means conceived apart from special cases or instances
  - Abstract implies a many-to-one mapping that models some aspects of an entity, but not all

Specification and Implementation of ADTs

- Specification of an Abstract Data Type
  - Domain: the types(s) of the functions
    - one domain/type is being defined; the others are assumed to be known
    - objects may have structure, but aspects of the structure are only observable as functions are applied
  - Access Functions (semantics)
    - Primitive constructors
    - Combinational constructors
    - Query functions
  - Exceptions
- Implementation of ADTs
  - Internal objects
  - Internal functions
  - Internal errors and error handling
- Examples: Stacks and queues; date packages

Rational Numbers Package:Definition (Ada)

```
package rational_numbers is
   type rational is limited private;
   function "="   (x,y: rational) return boolean;
   function "+"   (x,y: rational) return rational;
   function "-"   (x,y: rational) return rational;
   function "*"   (x,y: rational) return rational;

   function "/"  (x,y: rational) return rational;
   function "/"  (x,y: integer)  return rational;

   procedure assign (x: out rational; y: rational);
   zero_denominator: exception;
private
   -- some information for the compiler
end;
```

Rational Numbers: Use

```
with rational_numbers;
declare
   use rational_numbers;
   x, y, z: rational;
begin
   assign (x,3/4);
   assign (y, 6/8);
   if  x=y then put ("equal");
          else put ("not equal");
   end if;
   assign (z, x*y);
end;
```

Rational Numbers: Implementation

```
private
   type rational is
      record
         numerator: integer;
         denominator: integer range 1..integer'last;
      end record;
package body rational_numbers is
   procedure same_denominator (x,y: in out rational) is
      begin
      -- changes x and y to have the same denominator
      end;
   function "=" (x,y: rational) return boolean is
      u,v: rational:
      begin
         u := x;
         v := y;
         same_denominator (u,v);
         return (u.numerator = v.numerator);
      end "=";
    function "/" (x,y: integer) return rational is
       begin
         return (x,y);
       end "/";
    -- you can guess what +, -, * look like
    -- and of course the other "/" must be defined
end rational_numbers;
```

Use Requirements Specification

- A requirements specification contains lots of useful information to be leveraged during design
  - Nouns: modules / classes (SOMETIMES!)
  - Verbs: methods (SOMETIMES!)
  - Adjectives: properties/attributes/member variables (SOMETIMES!)
- Why?
  - To identify likely design elements

Determine Usage Patterns

- Usage patterns are incredible sources of information
  - Common tasks often can be placed into a single interface method
    - Specific combinations of method invocations
    - Specific iterations over a single method
  - Some usage patterns require non-existing functions
- Why?
  - To refine the interface of a module

Anticipate Change

- Wrap items likely to change within modules
  - Design decisions
  - Data representations
  - Algorithms
- Design module interfaces to be insensitive to change
  - The changeable items go into the module itself
- Why?
  - To limit the effects of unanticipated system modifications

Design for Generality/Incrementality

- Design a module to be usable in more than one context
  - Generalize the applicability of methods
    - Do not just draw red squares
    - Do not just stack integers
  - Allow for the addition of extra methods
- Why?
  - To increase reuse

Design for Program Families

- A system is typically used in more than one setting
  - Different countries
    - Different languages
    - Different customs
    - Different currencies
  - Different hardware/software platforms
- Why?
  - To enhance applicability
  - To keep your company in the black!

Special case of generality and incrementality at the system level

From Architecture to Modules

- Repeat the design process
  - Design the internal architecture of a component
  - Define the purpose of each module
  - Define the provided interface of each module
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    - …a simple, well-defined purpose
    - …a simple, well-defined provided interface
    - …a simple, well-defined required interface
- Until all interfaces “hook up”

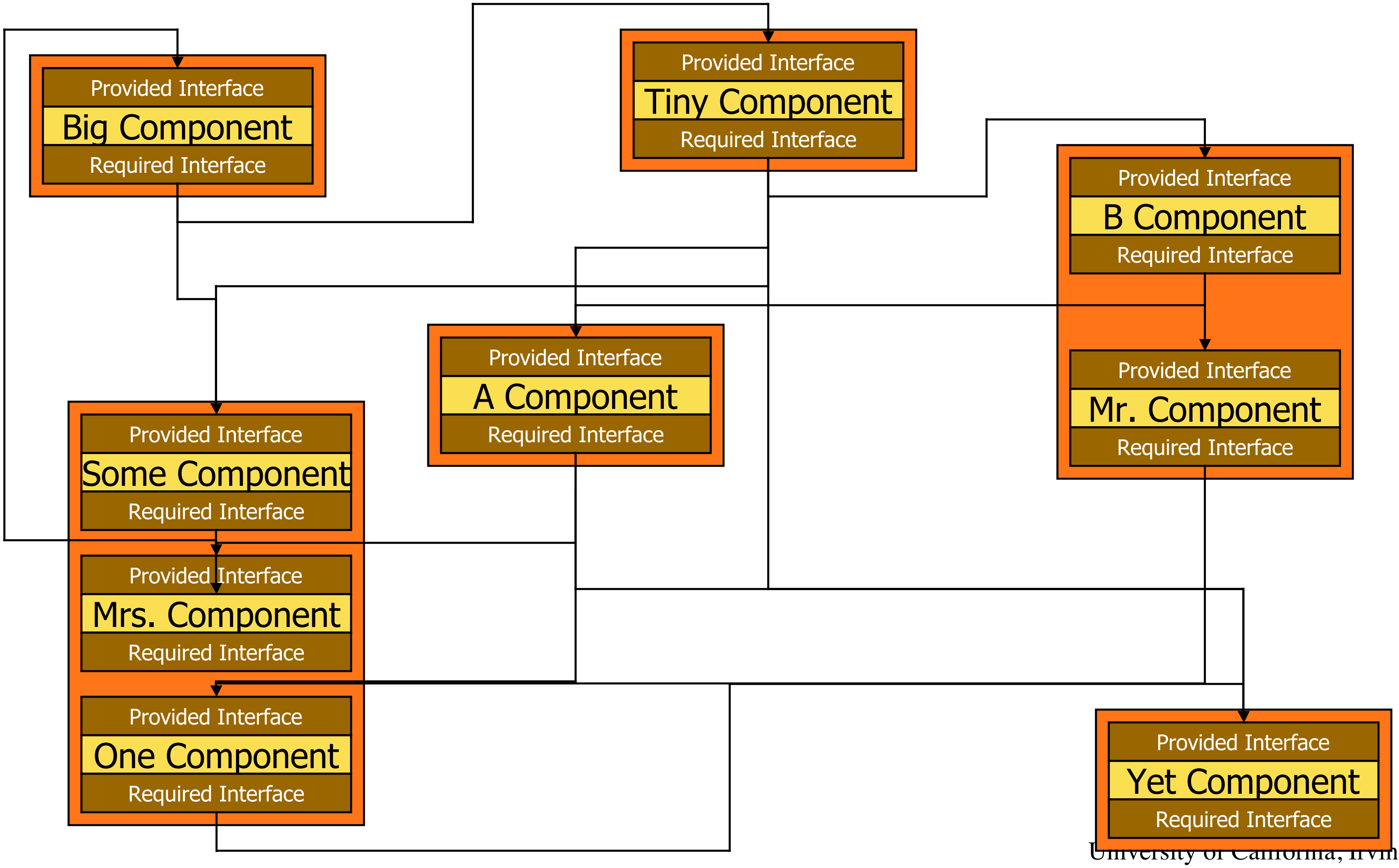
Good Examples of Modules

- Java 1.3 collection classes
- Standard template library for C++

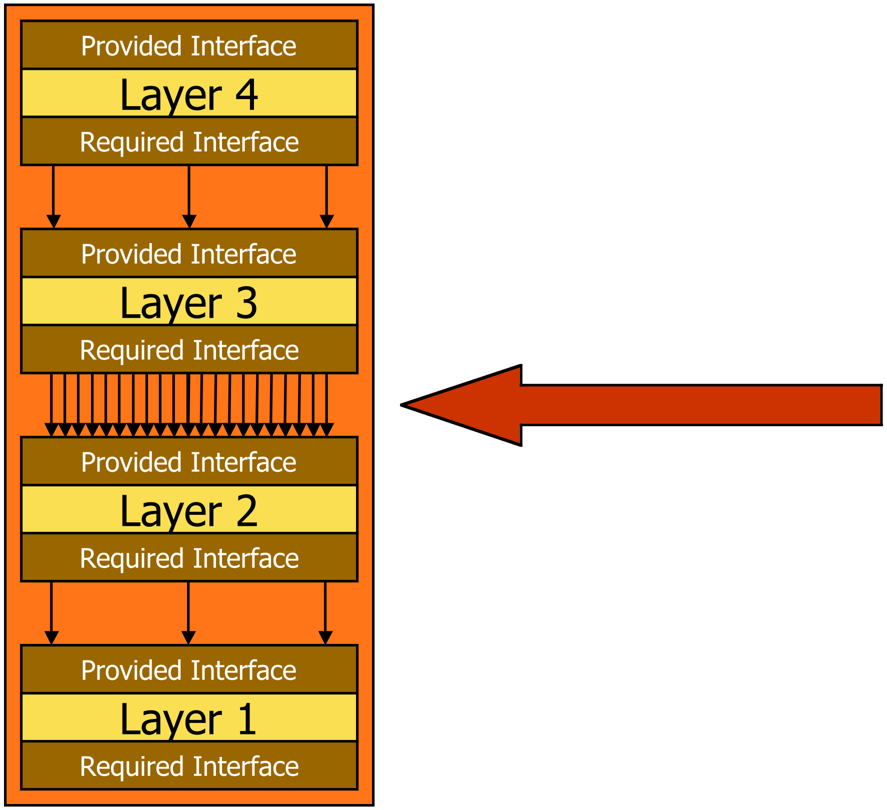
Next Topics

- USES relation
- IS-COMPOSED-OF relation
- COMPRISES diagram
- USES diagram
- [Stepwise refinement]
- Information hiding

In Design, We Can Do Anything…

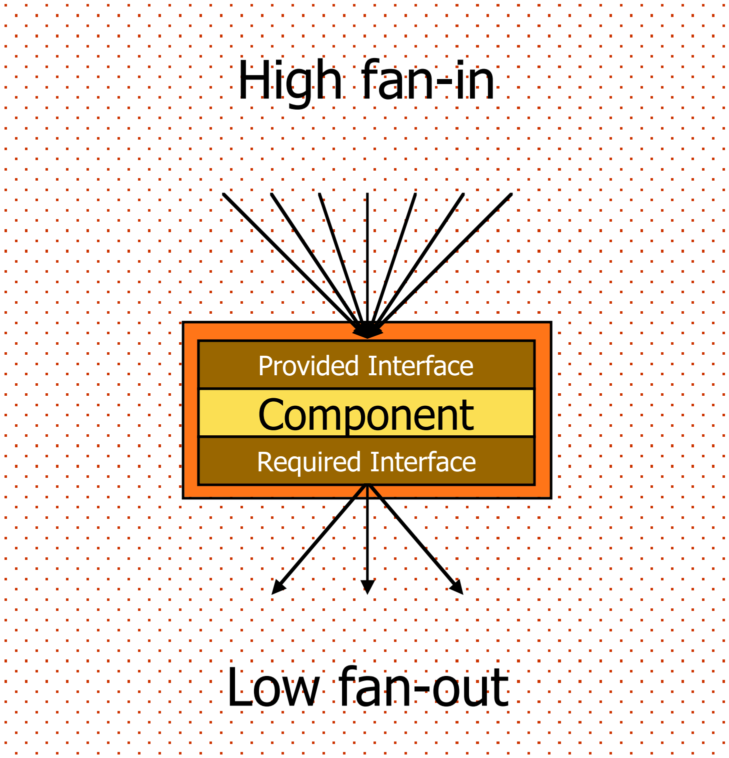


…Even when Restricted by Style



What happened here?

Fan-in and Fan-out



High fan-in

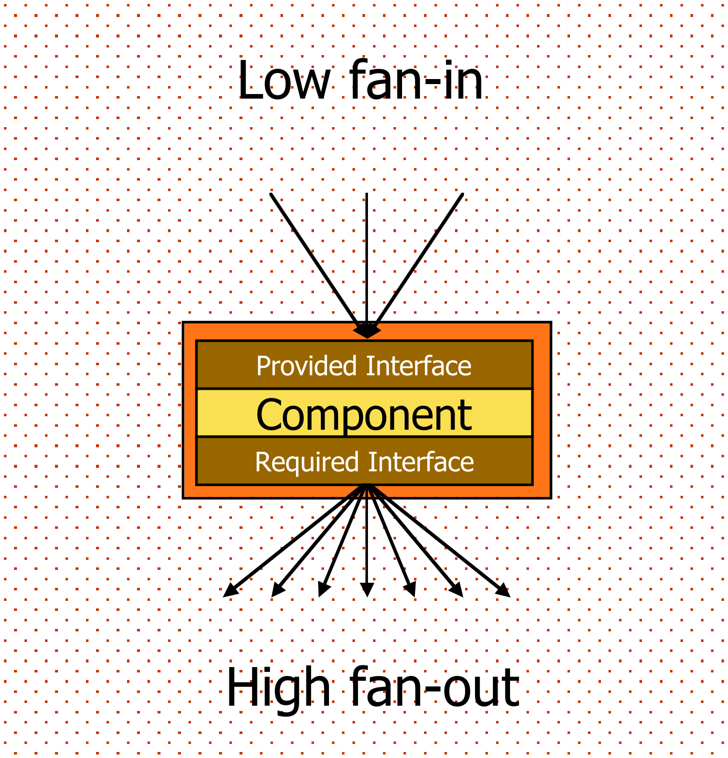
Provided Interface

Component

Required Interface

Low fan-out

USUALLY GOOD!



Low fan-in

Provided Interface

Component

Required Interface

High fan-out

USUALLY BAD!

The Uses Relation

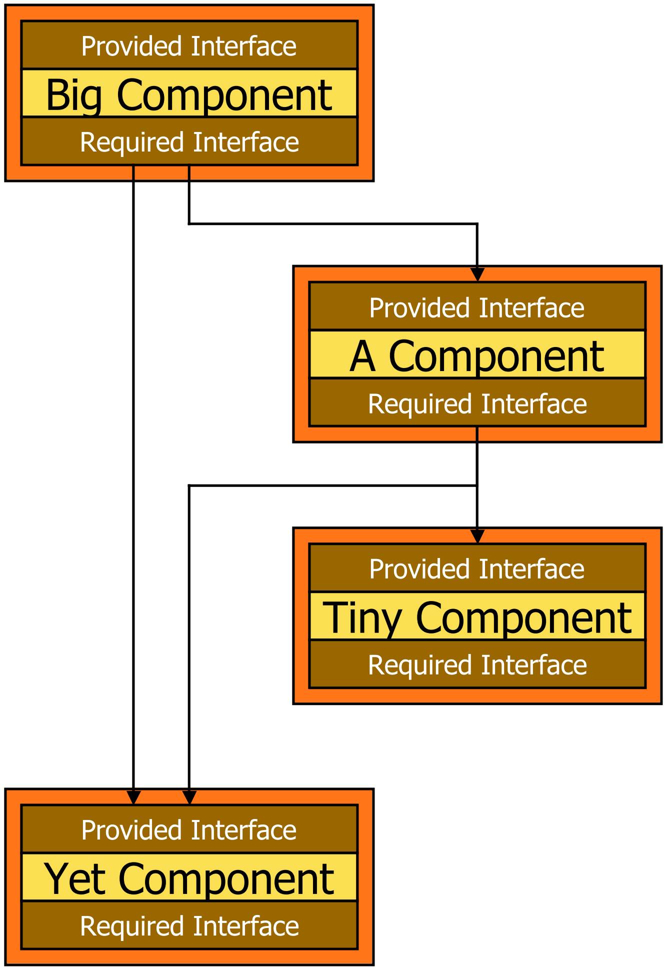
- A useful concept for examining a set of modules w.r.t. flexibility, reuse, and incremental testability
- Definition: M_i uses M_j if an only if correct execution of M_j is necessary for M_i to complete the task described in its specification.
- Note: uses is not the same as invokes:
  - Some invocations are not uses
    - they are just transfers of control
  - Some uses don't involve invocations
    - interrupt handlers
    - shared memory (gag!)

USES Relation

- Definition
  - Level 0: those modules that do not use any other modules
  - Level i: those modules that use at least one module at level i– 1 and use no modules at level i or greater
- Use
  - Determine flexibility
  - Determine reuse
  - Determine incremental testability

CAUTION: This is a different definition than used by van der Hoek (the numbering is opposite)!

Example



Level 3

Level 2

Level 1

Level 0

Observations

- The USES relation does not necessarily form a hierarchy
  - An acyclic directed graph is good
  - Cycles generally are bad
    - Indication of high coupling
    - Indication of broken separation of concerns
- Rules of thumb: allow *a* to use *b*…
  - …if it makes *a* simpler
  - …if *b* is not only used by *a* but also by other components

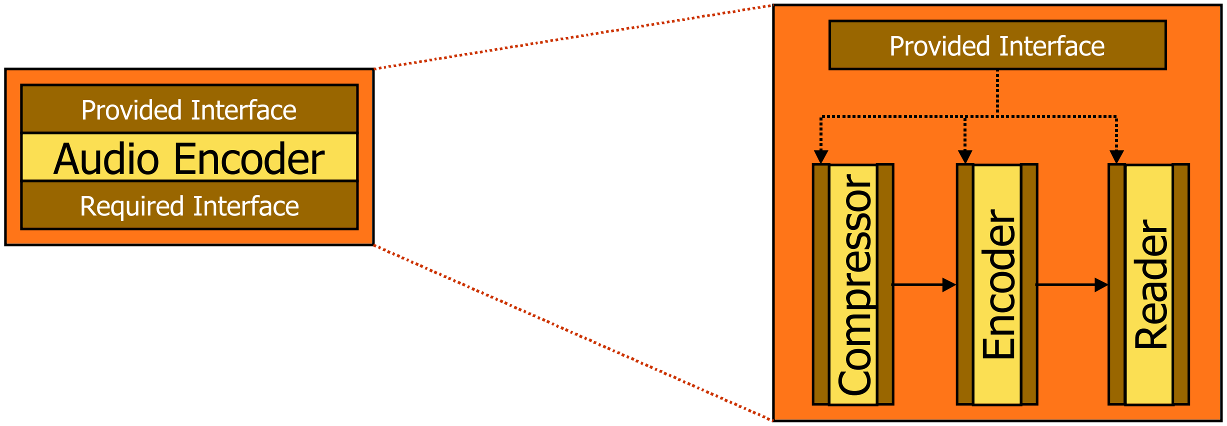
Observations

- Some invocations are *not* USES
    - Consider a transfer of control
    - Consider a scheduler inside a program
- Some USES do *not* involve invocations
    - Consider interrupt handlers
    - Consider global variables
    - Consider a blackboard

IS-COMPONENT-OF Relation

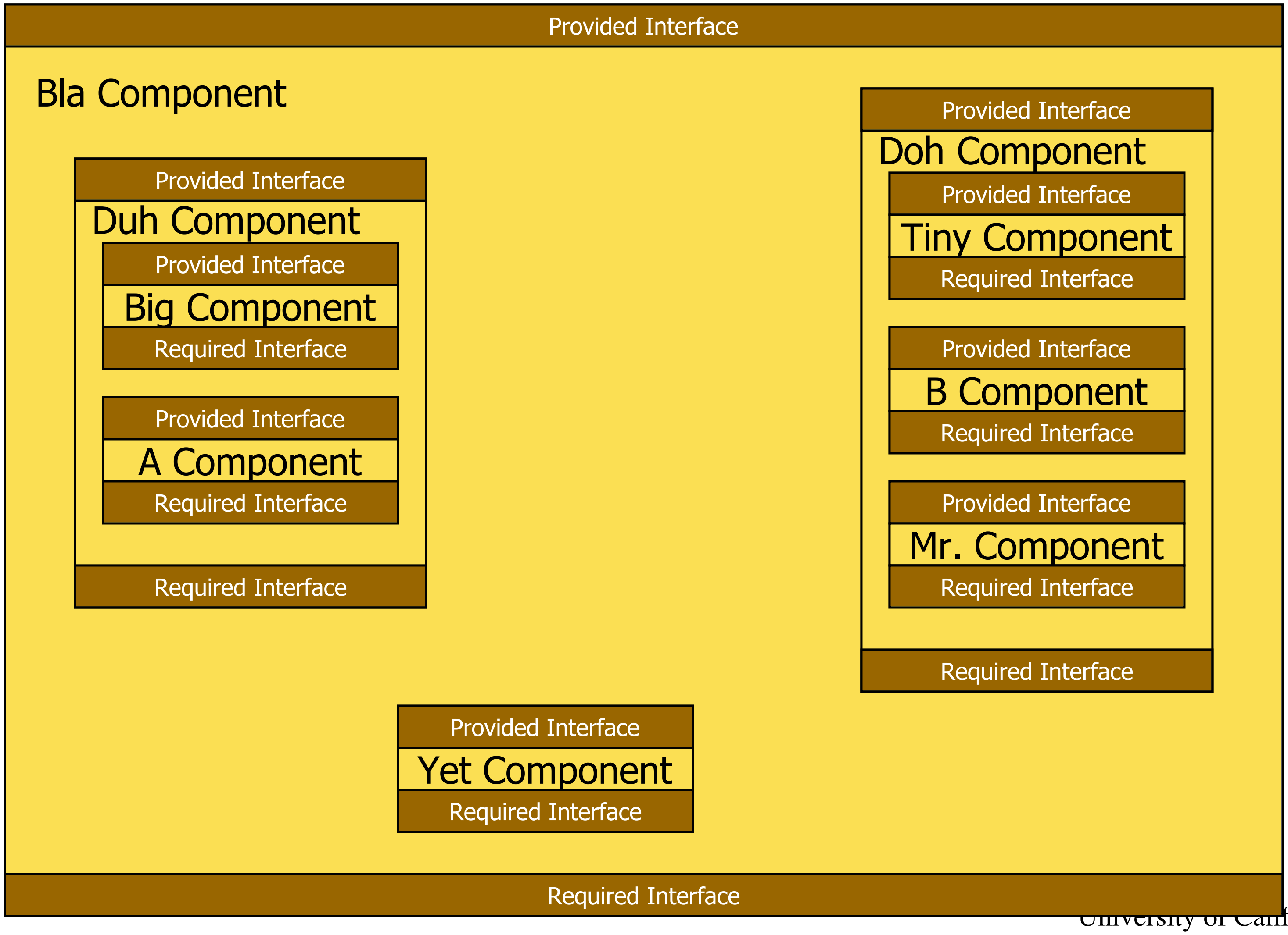
- Definition
  - Module M_i IS-COMPONENT-OF module M if M is realized by aggregating several modules, one of which is M_i
  - The combined set of all modules that exhibit the IS-COMPONENT-OF relation with respect to module M are said to implement module M
- Use
  - Determine hierarchical decomposition of a component in its subcomponents
  - Abstract details

Example



Compressor IS-COMPONENT-OF Audio Encoder
Encoder IS-COMPONENT-OF Audio Encoder
Reader IS-COMPONENT-OF Audio Encoder
Compressor, Encoder, and Reader IMPLEMENT Audio Encoder
Audio Encoder IS-COMPOSED-OF Compressor, Encoder, and Reader

Comprises Diagram



Provided Interface

Bla Component

Provided Interface

Duh Component

Provided Interface

Big Component

Required Interface

Provided Interface

A Component

Required Interface

Required Interface

Provided Interface

Doh Component

Provided Interface

Tiny Component

Required Interface

Provided Interface

B Component

Required Interface

Provided Interface

Mr. Component

Required Interface

Required Interface

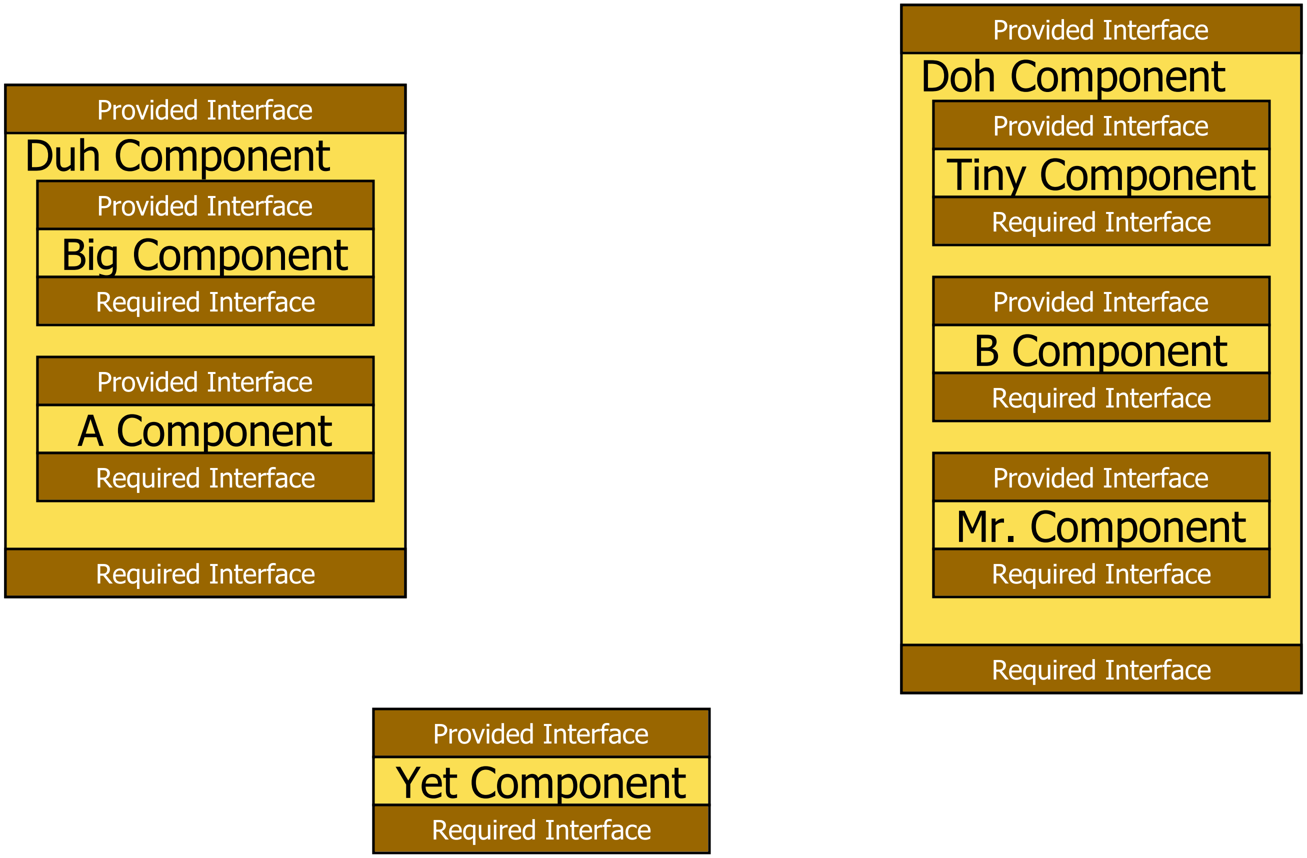
Provided Interface

Yet Component

Required Interface

Required Interface

USES Diagram – Step 1



Provided Interface

Duh Component

Provided Interface

Big Component

Required Interface

Provided Interface

A Component

Required Interface

Required Interface

Provided Interface

Doh Component

Provided Interface

Tiny Component

Required Interface

Provided Interface

B Component

Required Interface

Provided Interface

Mr. Component

Required Interface

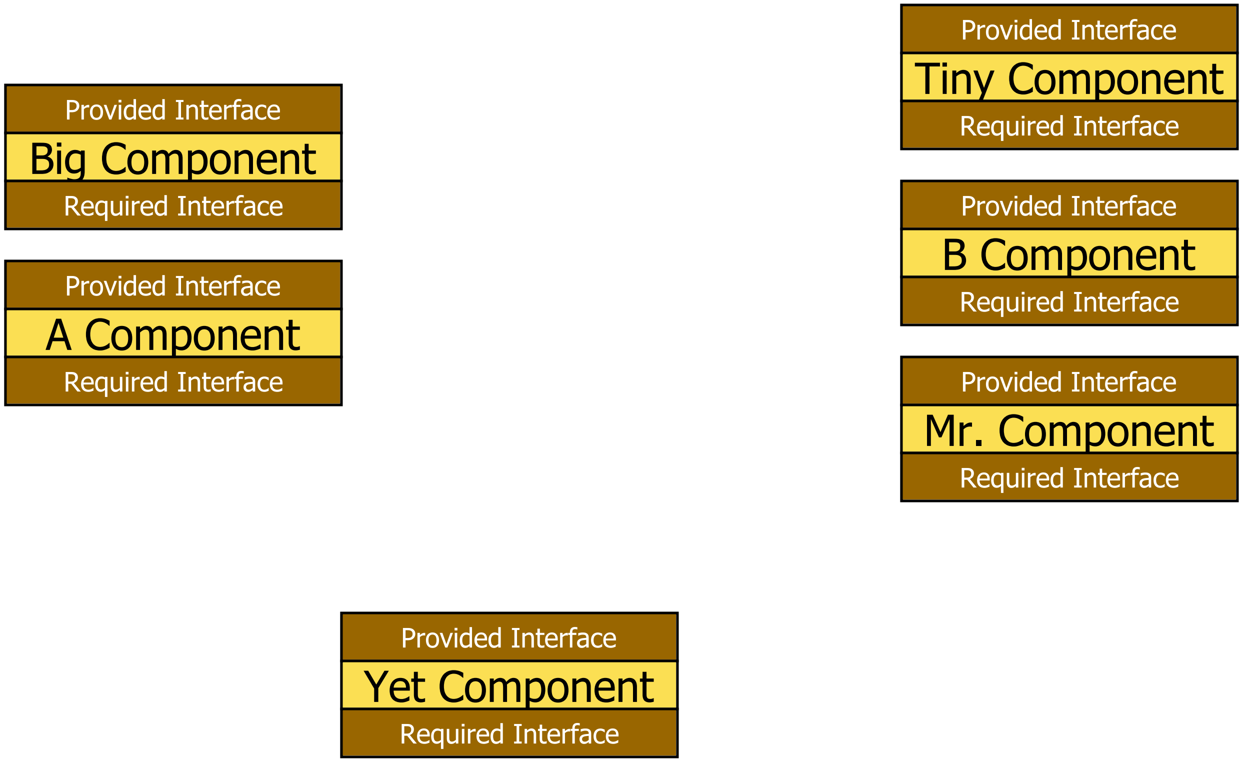
Required Interface

Provided Interface

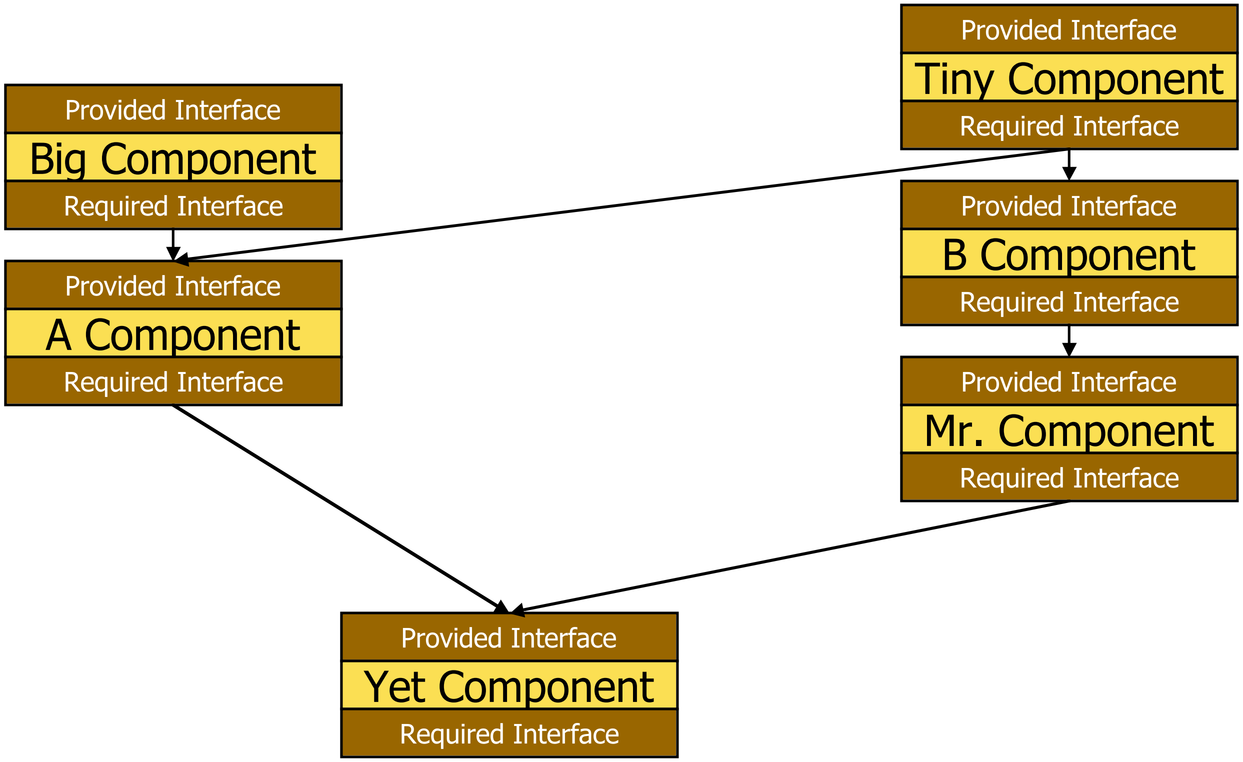
Yet Component

Required Interface

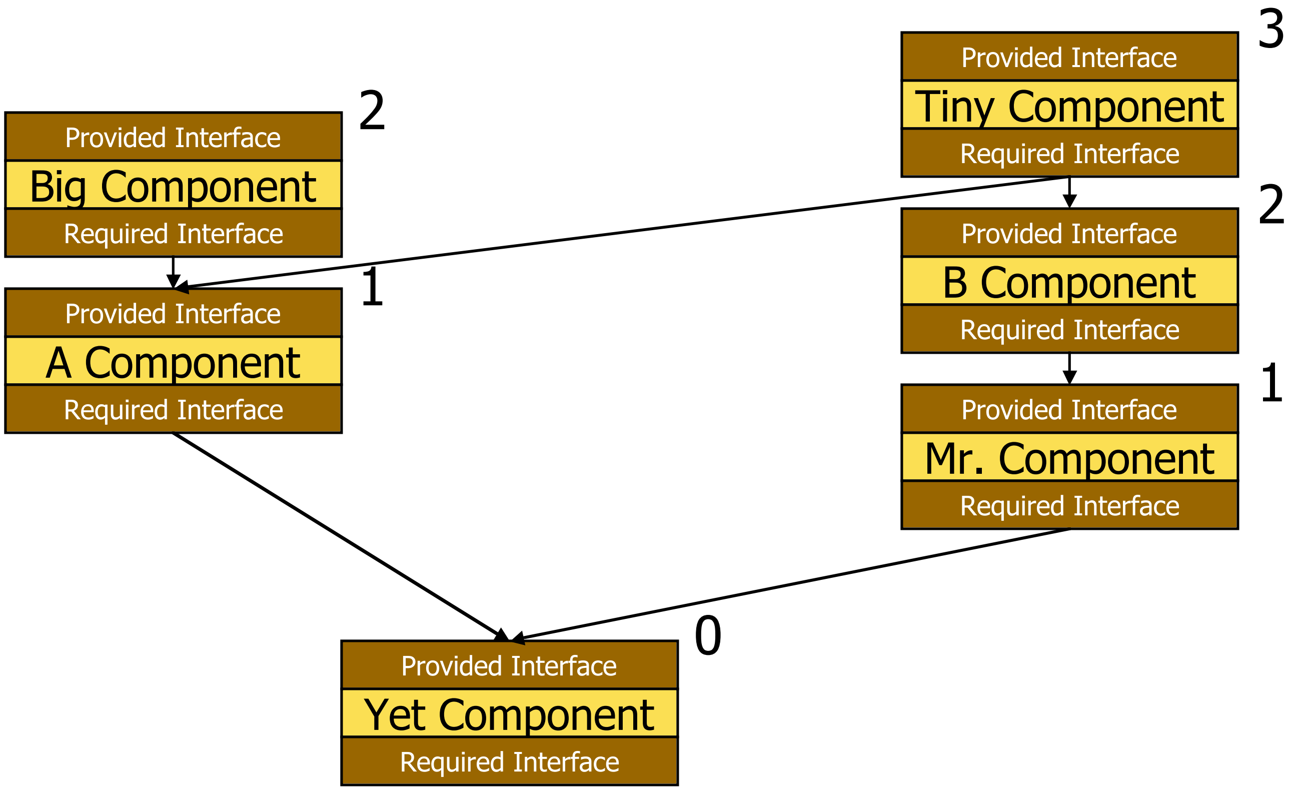
USES Diagram – Step 2



USES Diagram – Step 3



USES Diagram – Step 4



Observations

- Why do we identify higher-level modules in the first place?
  - Understanding
  - Abstraction through composition
- IS-COMPONENT-OF is not
  - is-attribute-of
  - is-inside-of-on-the-screen
  - is-subclass-of
  - is-accessed-through-the-menu-of

The Design Process

- Repeat the design process
  - Design the internal architecture of a component
  - Define the purpose of each module
  - Define the provided interface of each module
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    - …a simple, well-defined provided interface
    - …a simple, well-defined required interface
- Until all modules "hook up"

Techniques to Use

- Tools of the trade
  - Apply information hiding
  - Use requirements specification
  - Determine usage patterns
  - Anticipate change
  - Design for generality/incrementality
  - Design for program families
- Strive for
  - Low coupling/high cohesion
  - A clean IS-COMPOSED-OF structure
  - A clean USES structure

Low-Coupling/High-Cohesion

- Cohesion measures the rate of interconnectedness within a module.
- Coupling measures the rate of interconnectedness among modules.

- Shows critical issues:
  - a rate, rather than an absolute number (we like percentages)
  - what it measures: interconnectedness (how well it all hangs together)
  - within or among a module