ICS 52: Introduction to Software Engineering

Fall Quarter 2004

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Lecture Notes

Week 4 Design

http://www.ics.uci.edu/~taylor/ICS_52_FQ04/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…

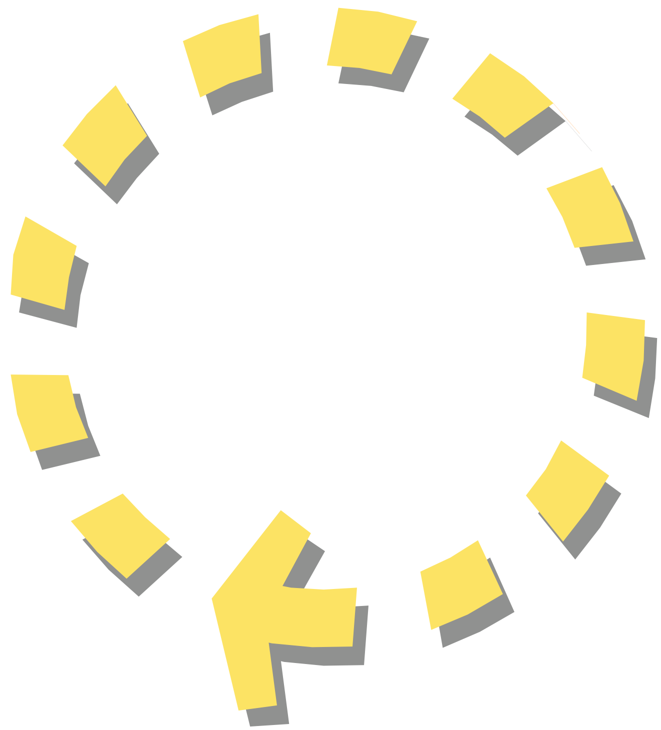
- …is half the implementation effort (at least)!
  - <u>Rigor</u> ensures all requirements are addressed
  - <u>Separation of concerns</u>
    - » <u>Modularity</u> allows work in isolation because components are independent of each other
    - » <u>Abstraction</u> allows work in isolation because interfaces guarantee that components will work together
  - <u>Anticipation of change</u> allows changes to be absorbed seamlessly
  - <u>Generality</u> allows components to be reused throughout the system
  - <u>Incrementality</u> 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)

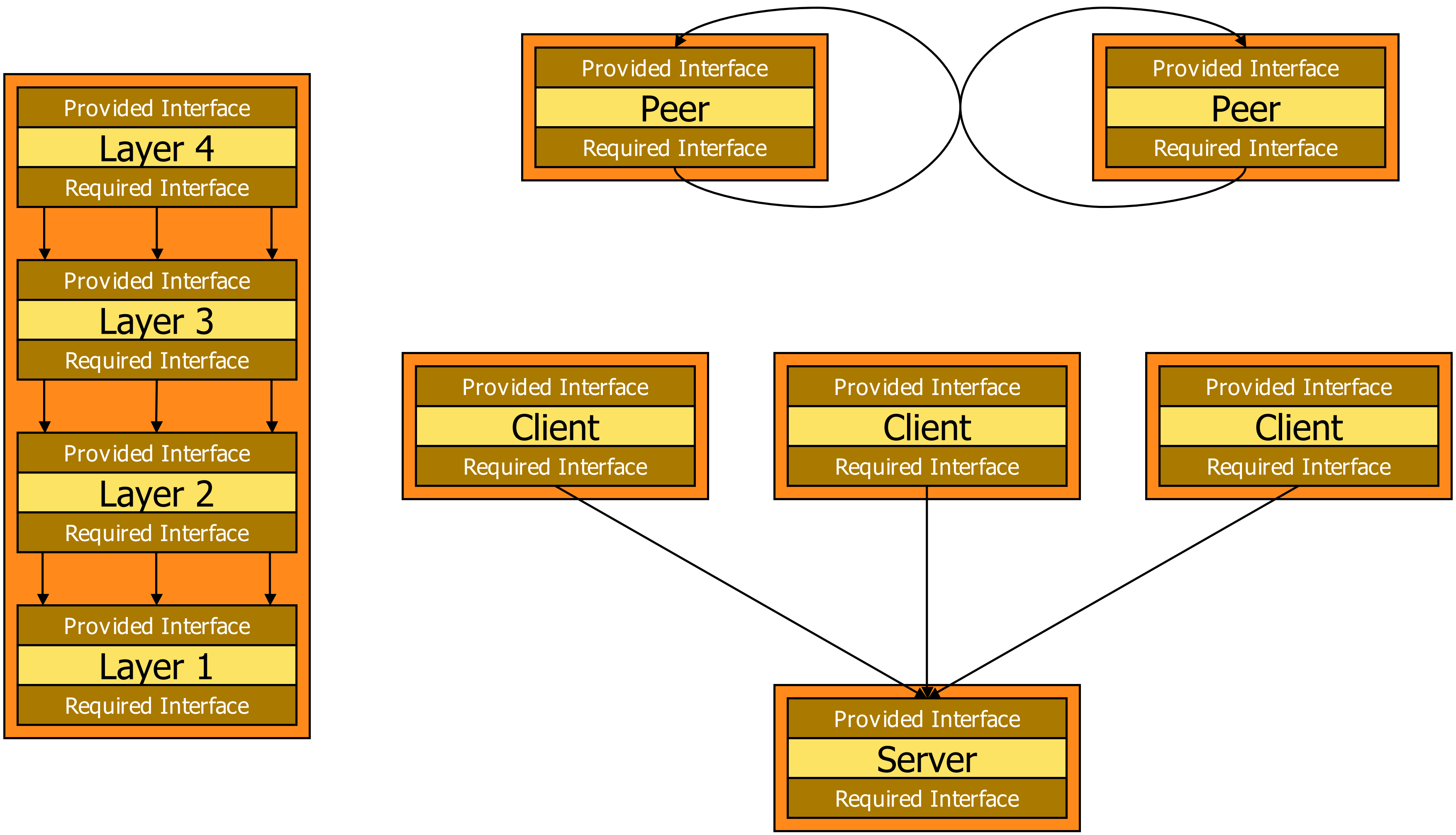


Module design
(this lecture)

From Architecture to Modules

- Repeat the design process
  - Design the internal architecture of a component
    - (Break it apart into several modules, and articulate their interconnections and dependencies)
  - 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?

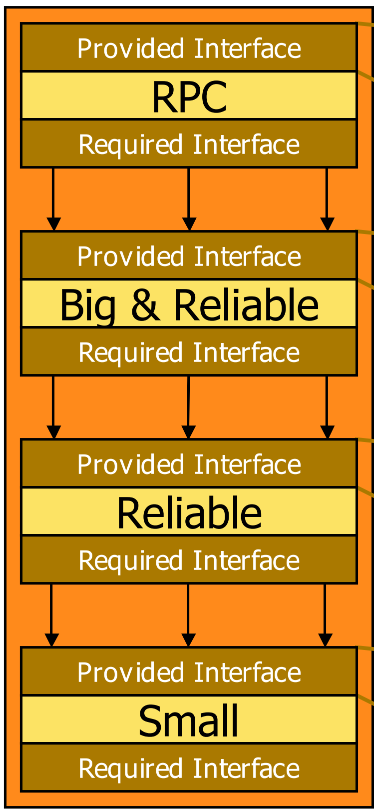


Interfaces

- 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
    - Perhaps with 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)



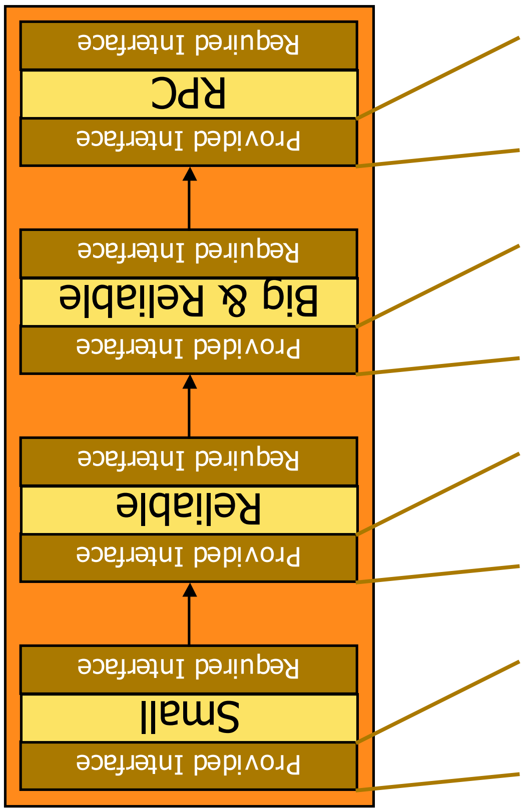
Result callRemoteFunction(Function f)

boolean sendReliableBigPacket(Packet p)

boolean sendReliableSmallPacket(Packet p)

boolean sendSmallPacket(Packet p)

Example: Network Protocols (2)



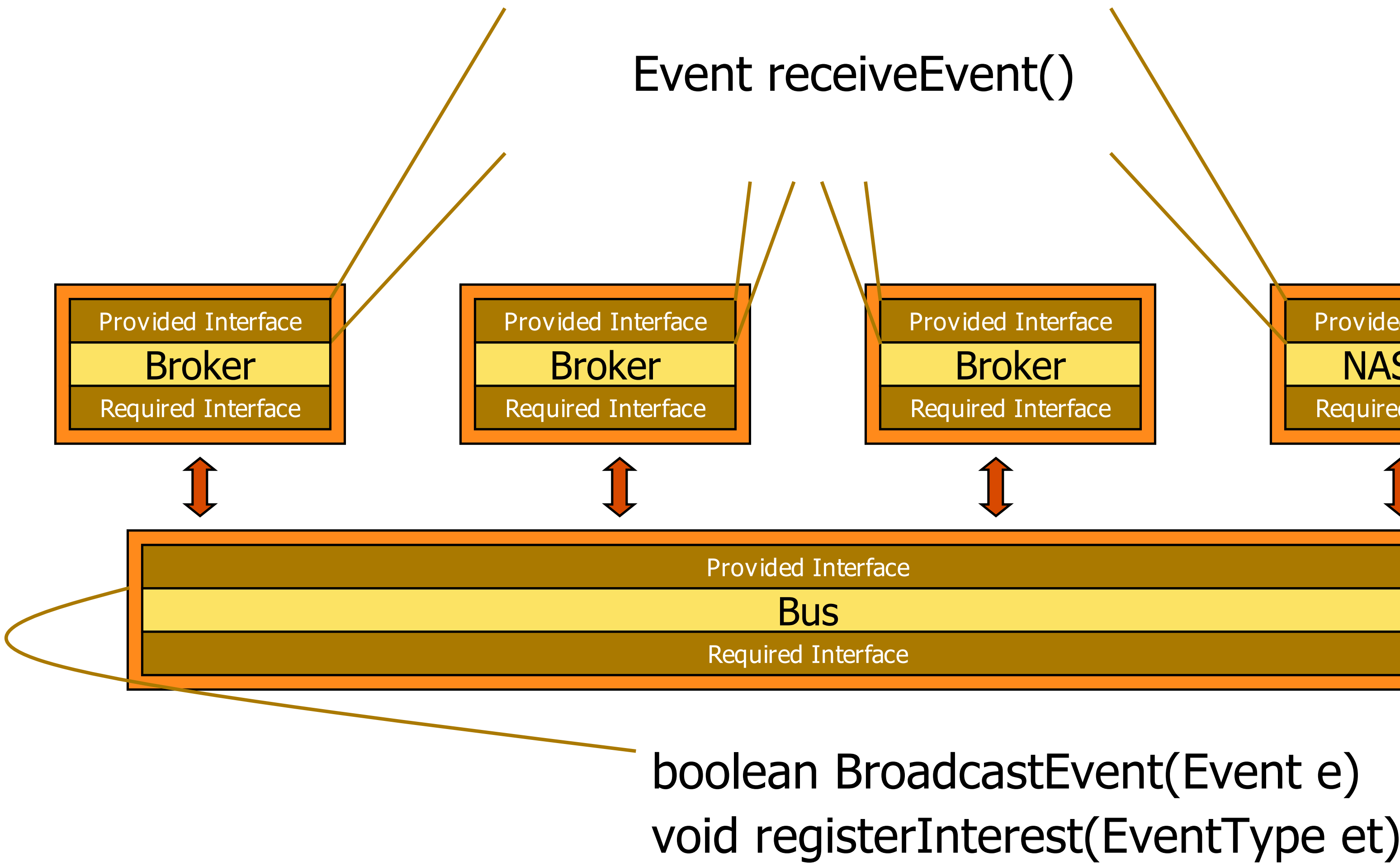
Result RemoteFunction(Function f)

boolean receiveReliableBigPacket(Packet)

boolean receiveReliableSmallPacket(Packet)

boolean receiveSmallPacket(Packet)

Example: Stock Market



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
  - 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 (un)anticipated 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
  - 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 interfaces "hook up"

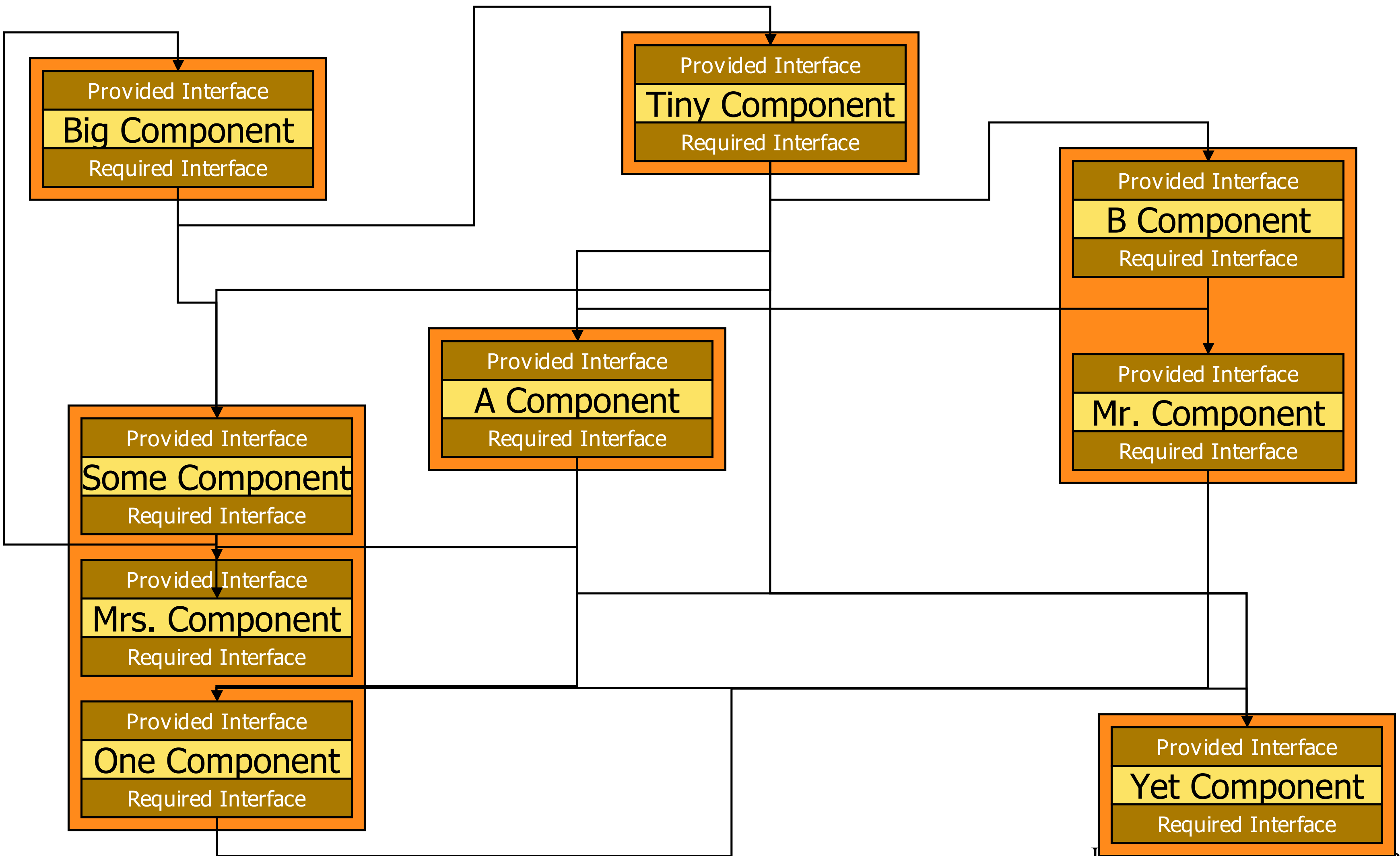
Good Examples of Modules

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

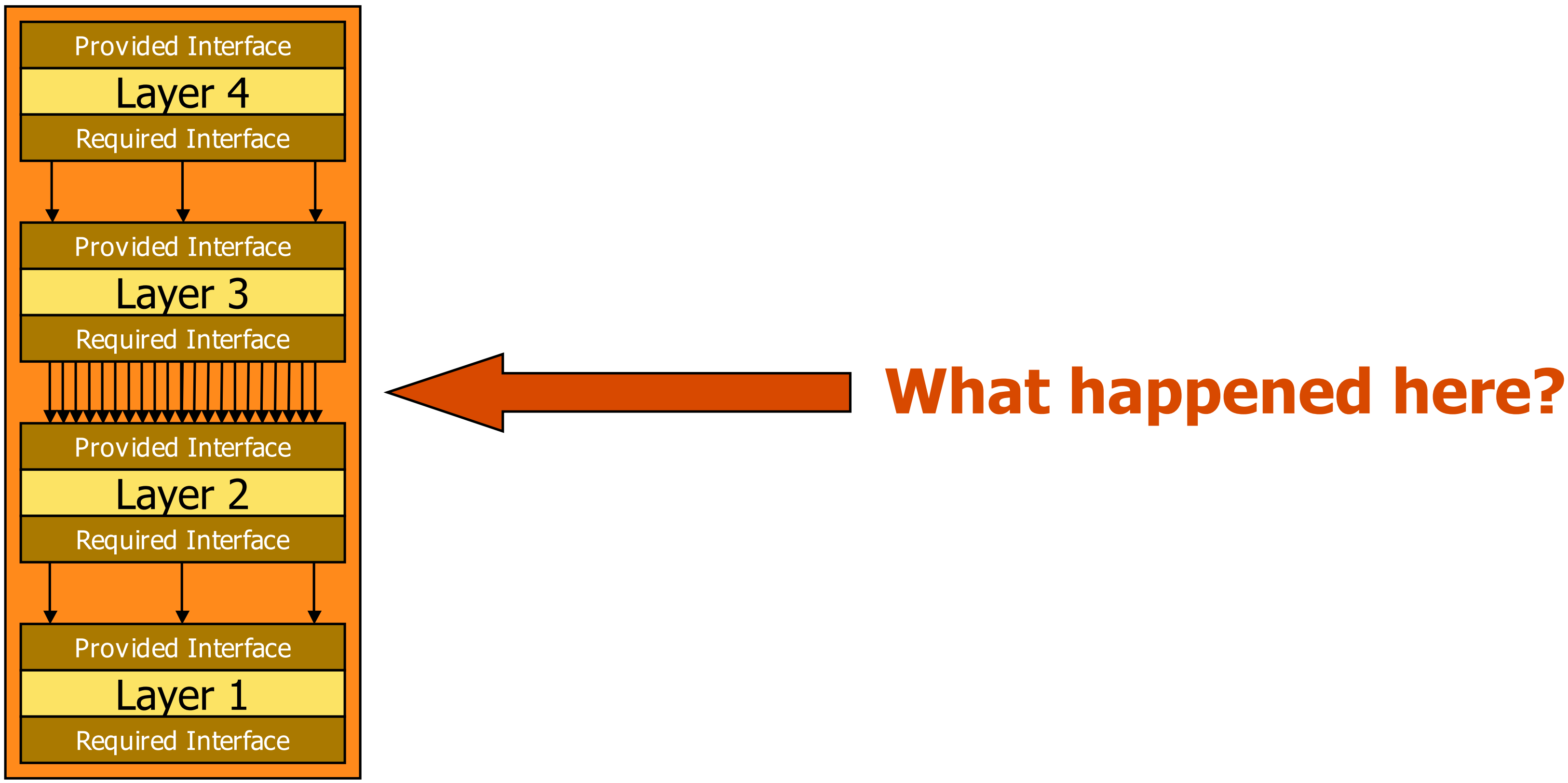
Next Topics

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

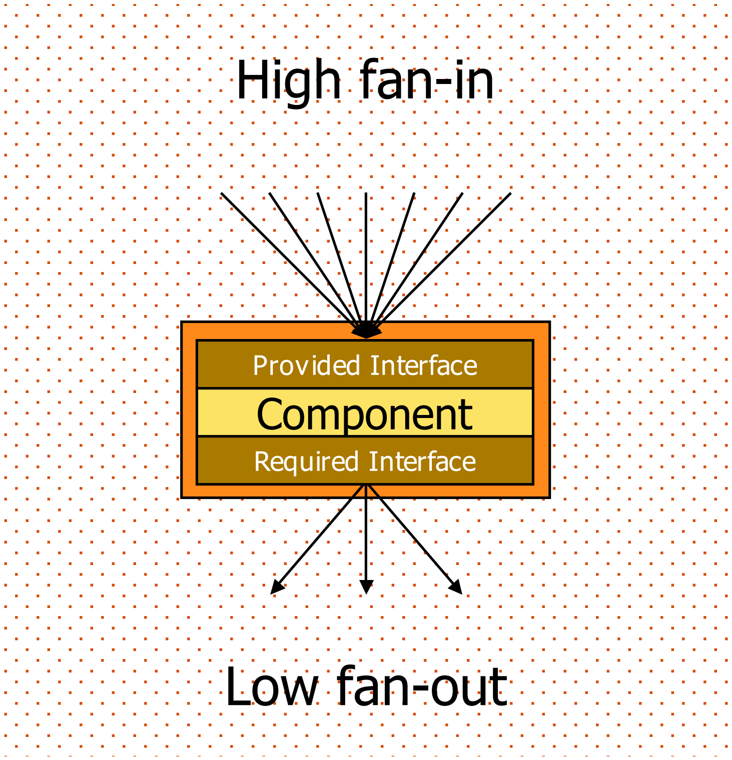
In Design, We Can Do Anything…



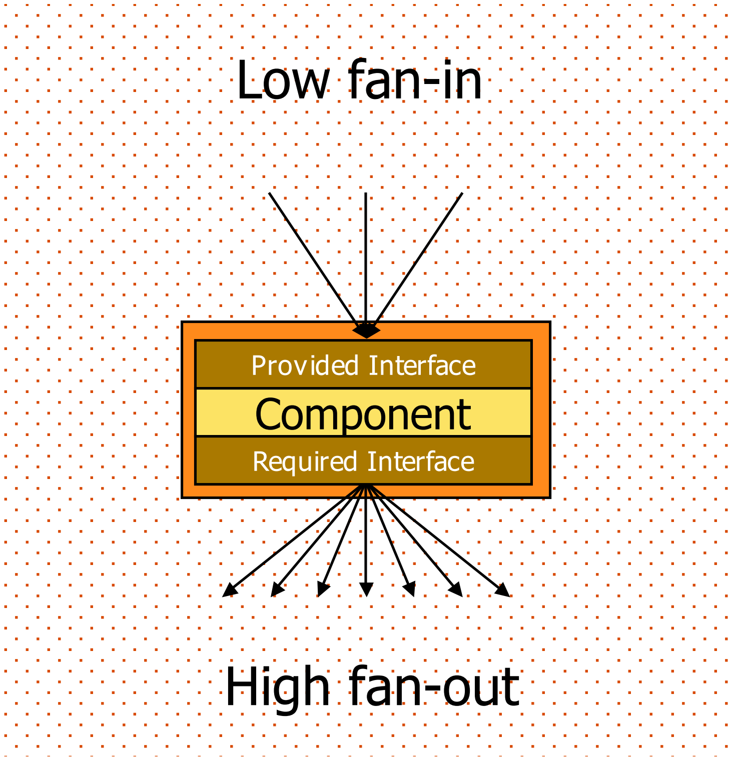
…Even when Restricted by Style



Fan-in and Fan-out



USUALLY GOOD!



USUALLY BAD!

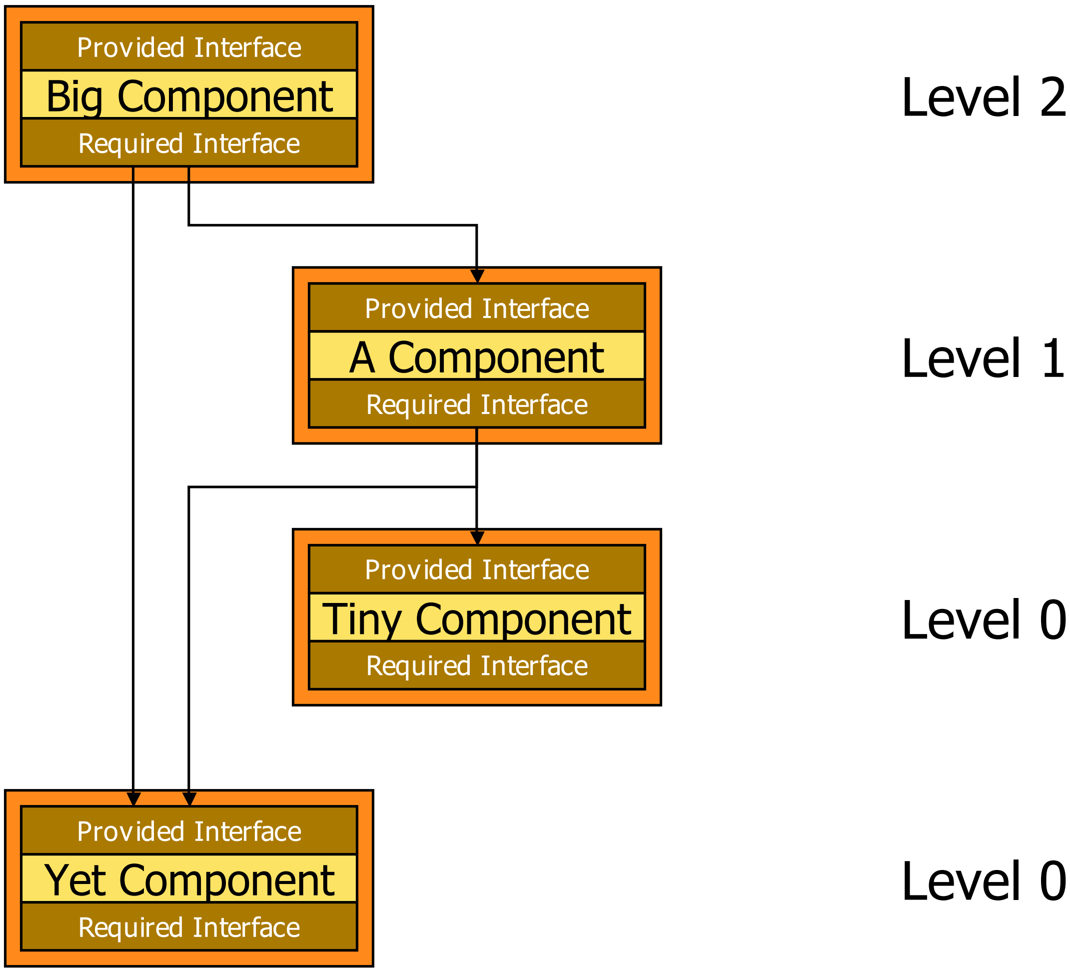
The Uses Relation

- 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

Example


Provided Interface
Big Component
Required Interface
Provided Interface
A Component
Required Interface
Provided Interface
Tiny Component
Required Interface
Provided Interface
Yet Component
Required Interface
Level 2
Level 1
Level 0
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

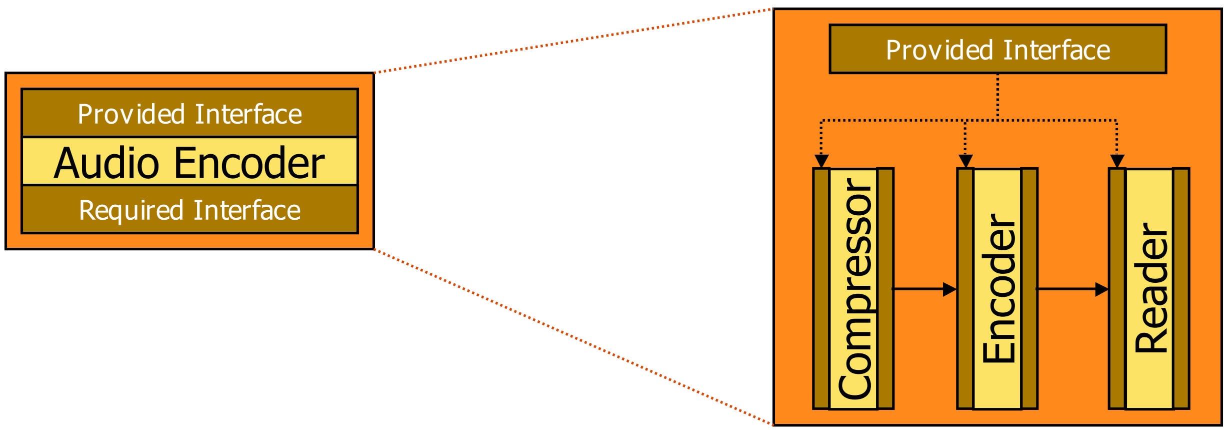
Observations

- 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

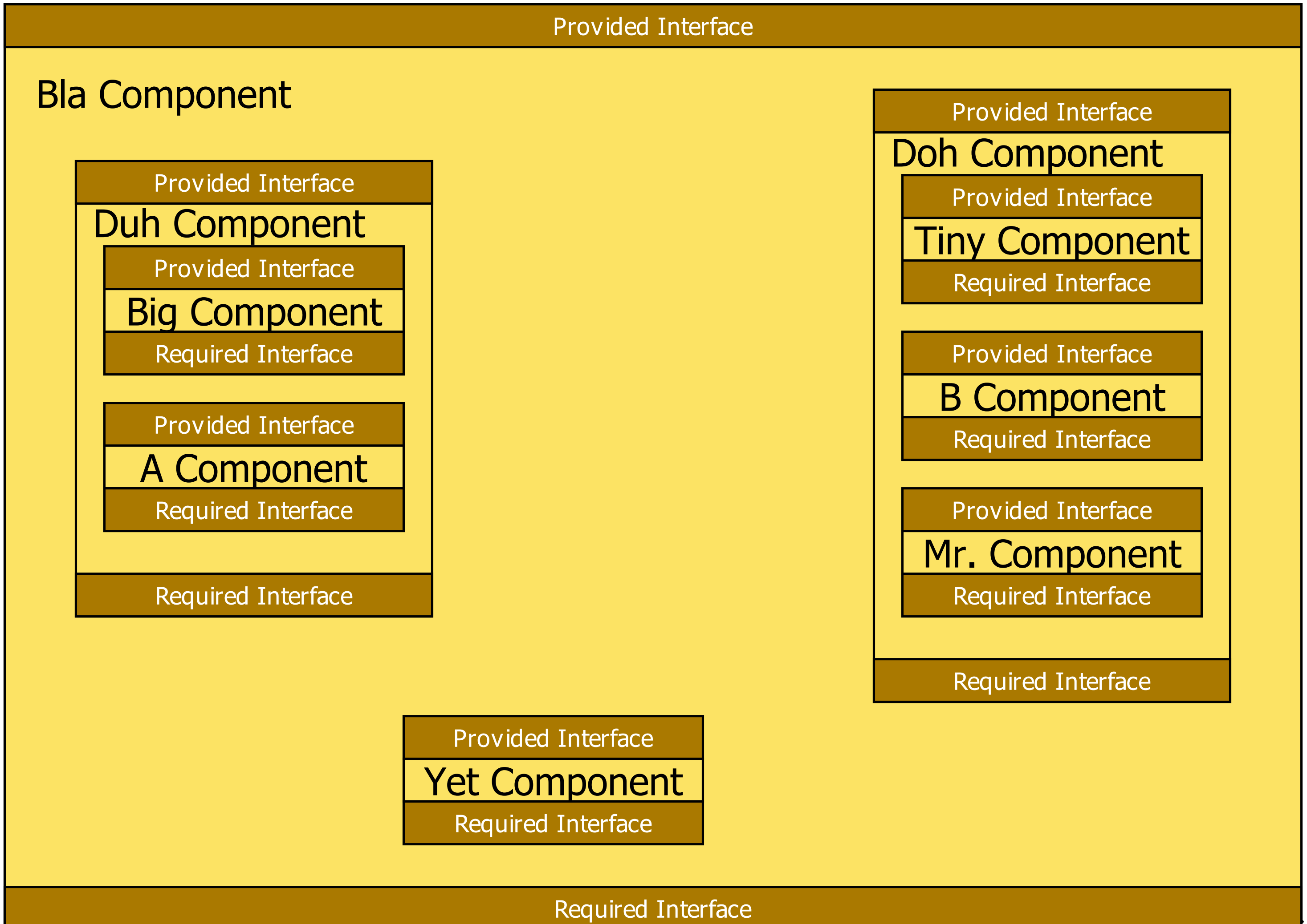
- Definition
  - Module M_i IS-COMPONENT-OF module M if M is realized by aggregating several modules, one of which is M_i
  - The combined set of all modules that exhibit the IS-COMPONENT-OF relation with respect to module M are said to implement module M
- Use
  - Determine hierarchical decomposition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

Example

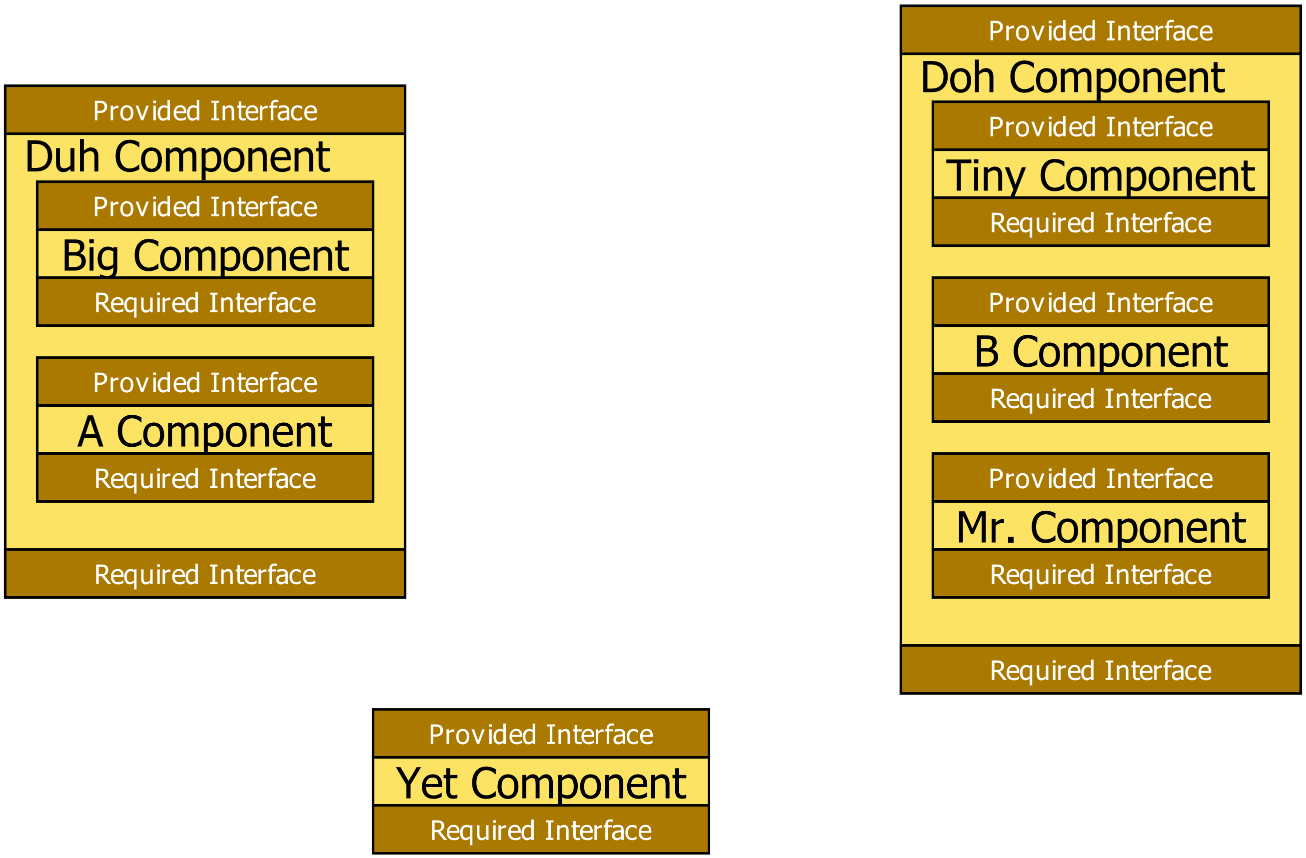


Compressor IS-COMPONENT-OF Audio Encoder
Encoder IS-COMPONENT-OF Audio Encoder
Reader IS-COMPONENT-OF Audio Encoder
Compressor, Encoder, and Reader IMPLEMENT Audio Encoder
Audio Encoder IS-COMPOSED-OF Compressor, Encoder, and Reader

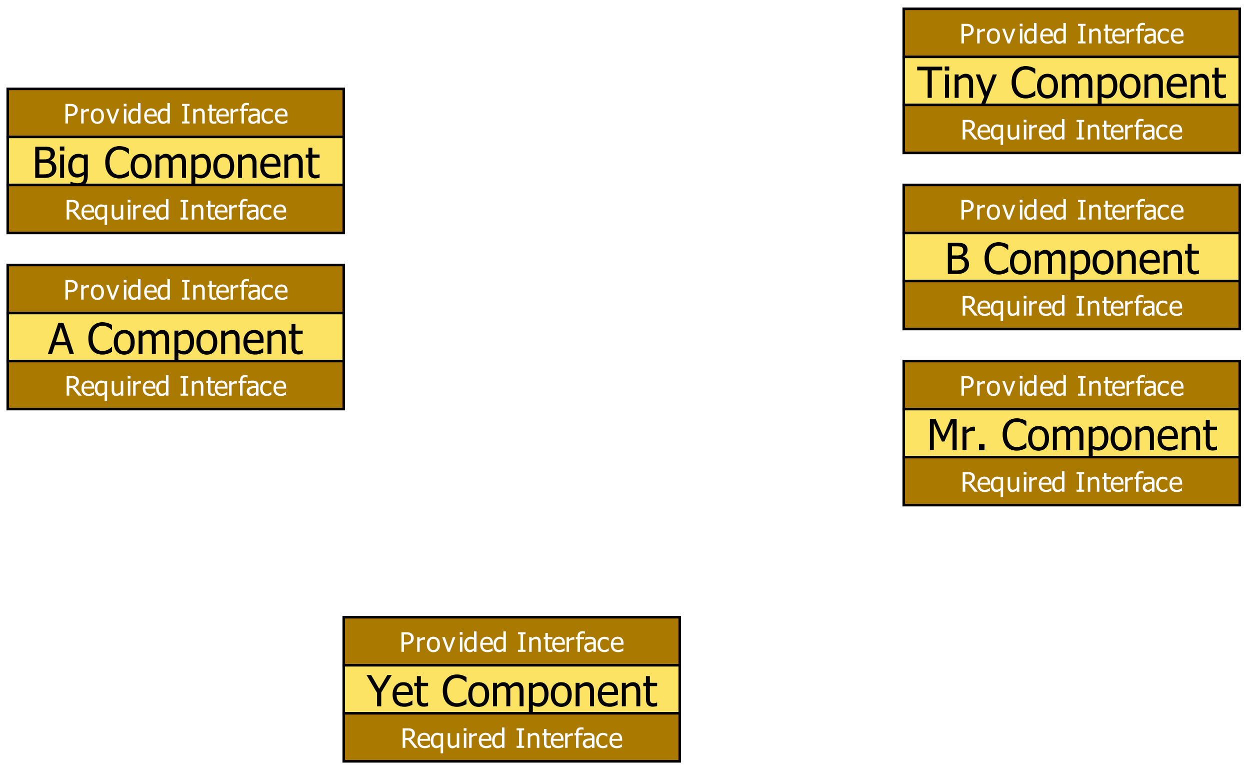
Comprises Diagram



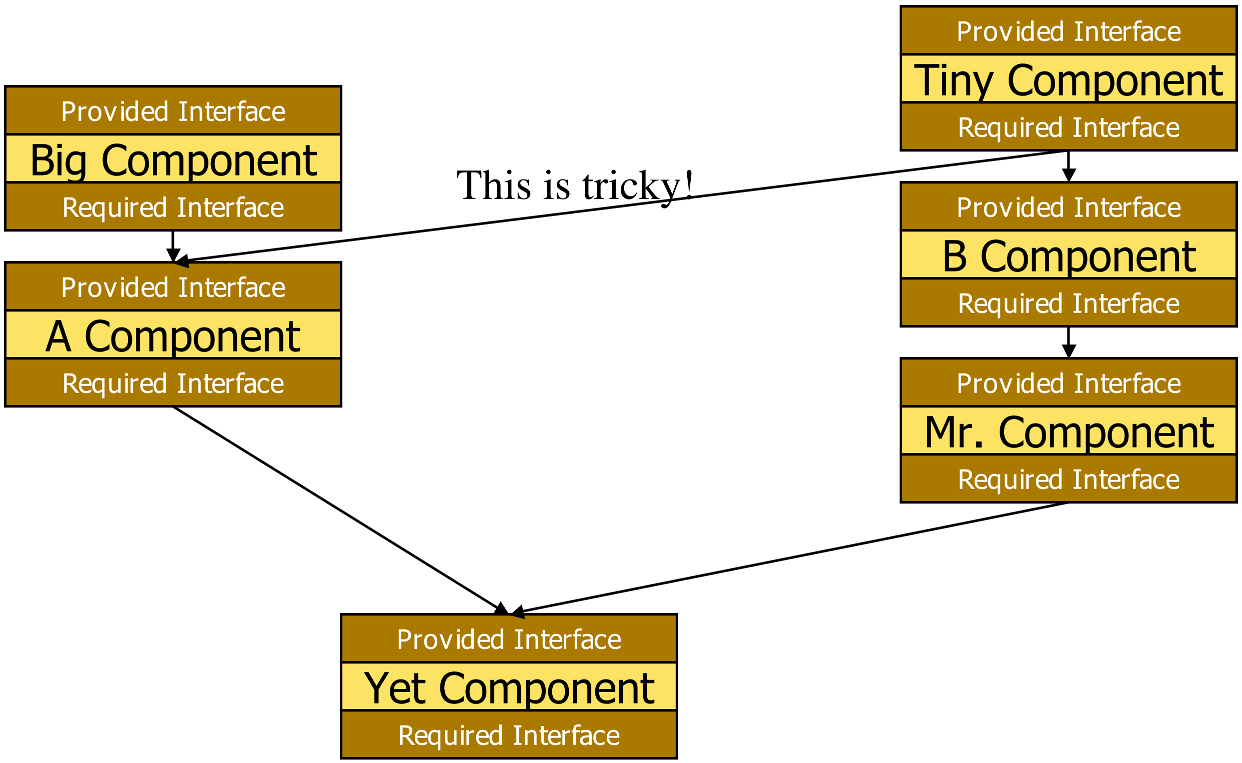
USES Diagram – Step 1



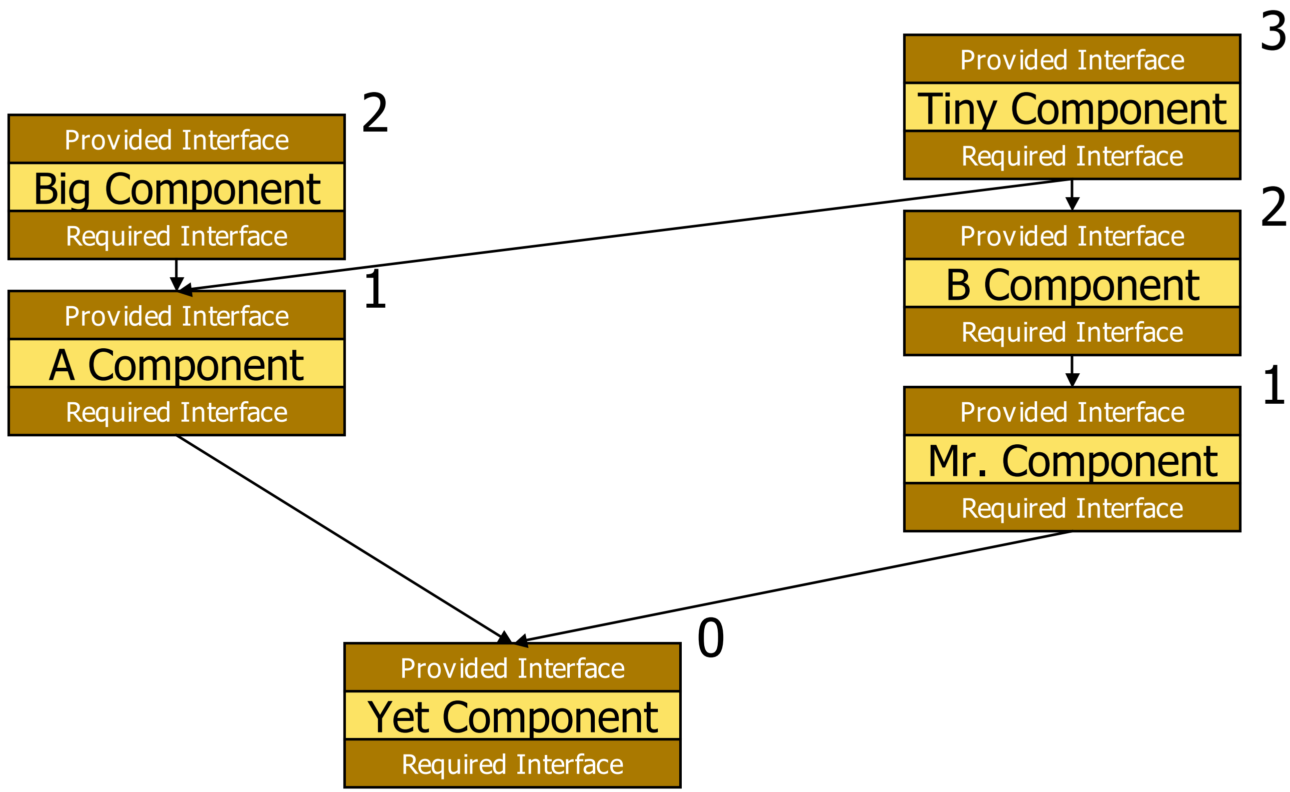
USES Diagram – Step 2



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
  - Define the required interface of each module
- Do this over and over again
  - Until each module has…
    - …a simple, well-defined internal architecture
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- 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