Software Design Fundamentals

CSCE 740 - Lecture 11 - 09/30/2015

Today’s Goals

- Define design
- Introduce the design process
- Preview two design strategies:
  - Functional Decomposition
  - Object-Oriented Design
- Overview of design criteria

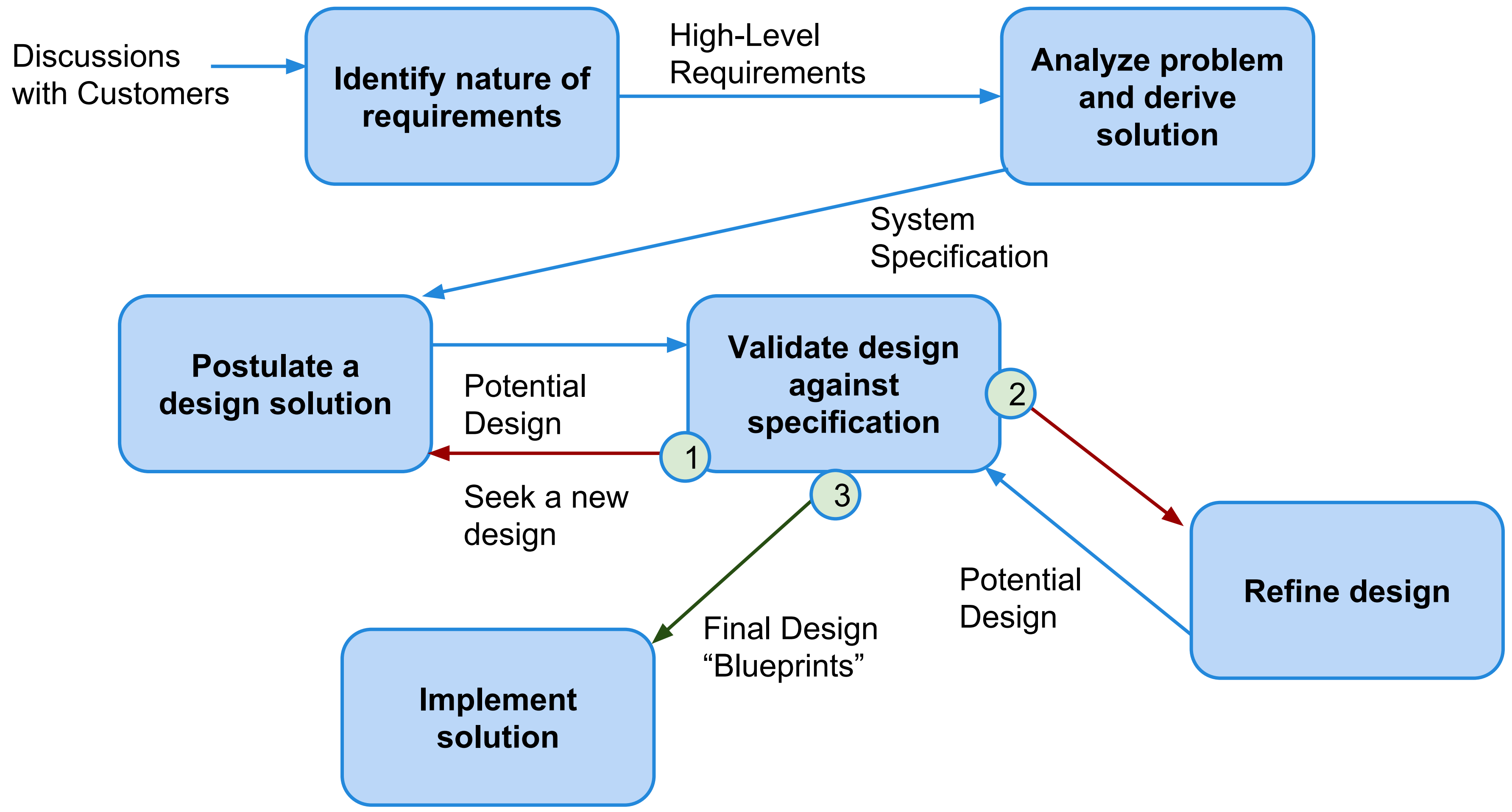
What is Design?

Design is the creative process of transforming a problem into a solution.

- In our case, transforming a requirements specification into a detailed description of the software to be implemented.

- Specification - *what* we're going to build.
- Design - *how* to build it. A description of the structure of the solution.

General Design Stages

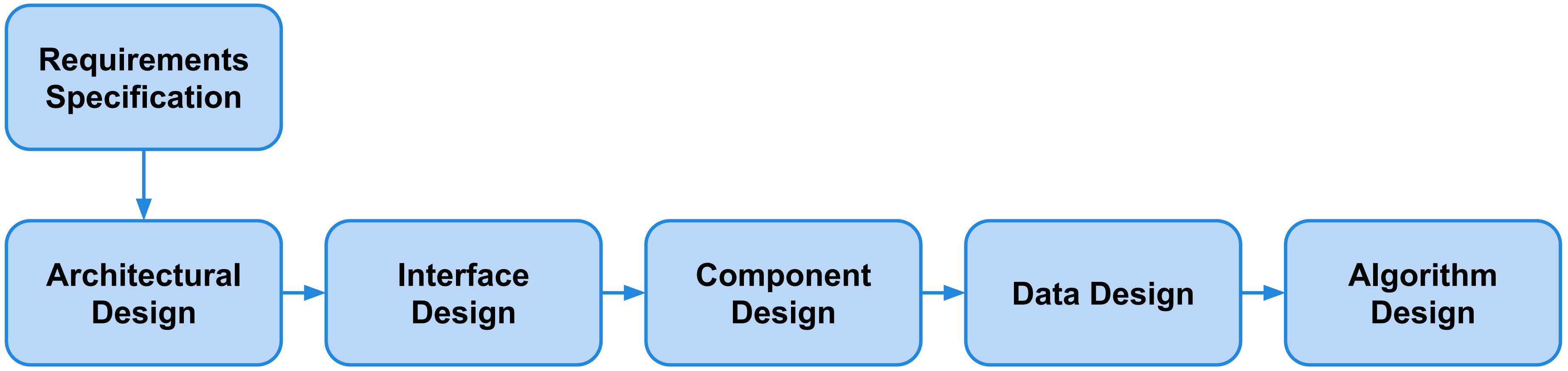

Discussions with Customers
Identify nature of requirements
High-Level Requirements
Analyze problem and derive solution
System Specification
Postulate a design solution
Potential Design
Validate design against specification
1
Seek a new design
2
Refine design
Potential Design
3
Final Design "Blueprints"
Implement solution

Stages of Design

Three repeating stages:

- Problem Understanding
  - Look at the problem from different angles to discover what needs the design needs to capture.
- Identify Solutions
  - Evaluate possible solutions and choose the most appropriate in terms of available resources.
- Describe and Document Chosen Solution
  - Use graphical, formal, or other descriptive notations to describe the components of the design.

Design Activities



System architecture (high-level breakdown of system)

How subsystems interact with each other and how external users and systems interact with your system

A listing of the individual classes within your system

The format of data that is produced and consumed by your system

Algorithms used to implement system functionality.

The Design Process

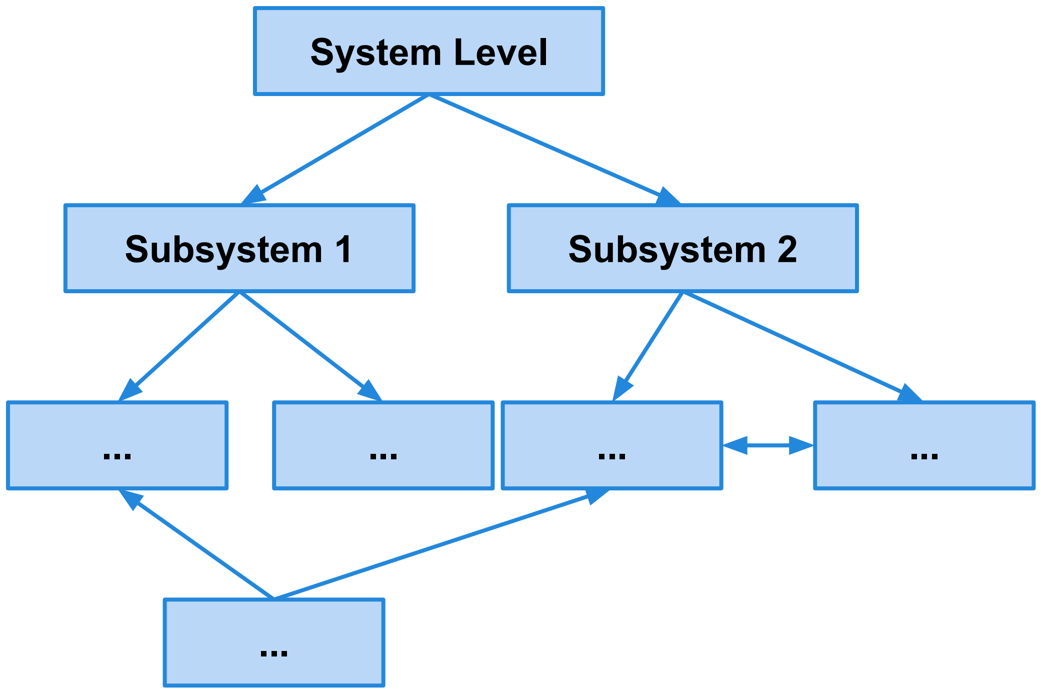
- Design takes place in overlapping stages.
  - It is artificial to separate them into distinct phases. Some separation occurs, but these phases take place largely at the same time.
- In practice - design is an exercise in starting from an abstraction and filling in the missing details.
  - However, don't forget about the big picture. Keep looking at all levels of abstraction to make sure you're designing the right solution.

Design Descriptions

All of these notations may be used in system design:

- Graphical Notations
  - Used to display component relationships.
- Structured Description Languages
  - Textual description of design written in syntax similar to programming languages (i.e., pseudocode).
- Informal Text
  - Natural language description

Design Strategies



People tend to design systems as a hierarchy of components.

- We have this system.
- Great, let's break it into subsystems.
- Now, what classes do we need for each subsystem.
- What common functionality do those classes need?

Top-Down Design

- In principle, top-down design involves starting at the uppermost components, design those, and work down the hierarchy level-by-level.

- In practice, large system design is never truly top-down.
    - Some branches are designed before others.
    - Designers reuse experience (and sometimes components) during the design process.
    - Sometimes, the lower levels need to be designed for the top-level to be completed.

Bottom-Up Design

- In principle,bottom-up design involves starting with functionality, designing components to perform each function, then assembling them into a complete system.

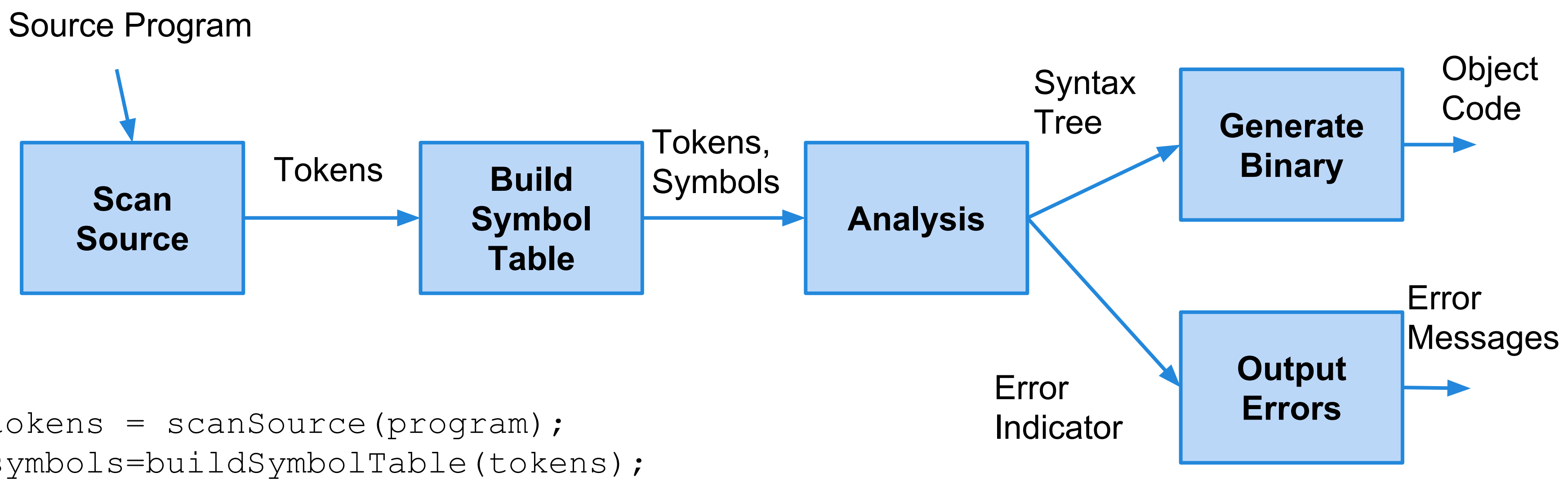
- In practice, large system design is never truly bottom-up.
    - An efficient system cannot be designed without planning for integration. The complete picture must be kept in mind.

Design Strategies

Functional (Centralized) Design

- System is designed from a functional viewpoint: call and return model.
- Execution is controlled from a central point in the system.
  - A method is called, the result is passed back to the controlling location, then that is passed into the next method.
- The system state is centralized and shared between the functions operating on that state.
  - Information is passed down an assembly line where each step transforms the data until the final solution is returned.

Functional View of a Compiler



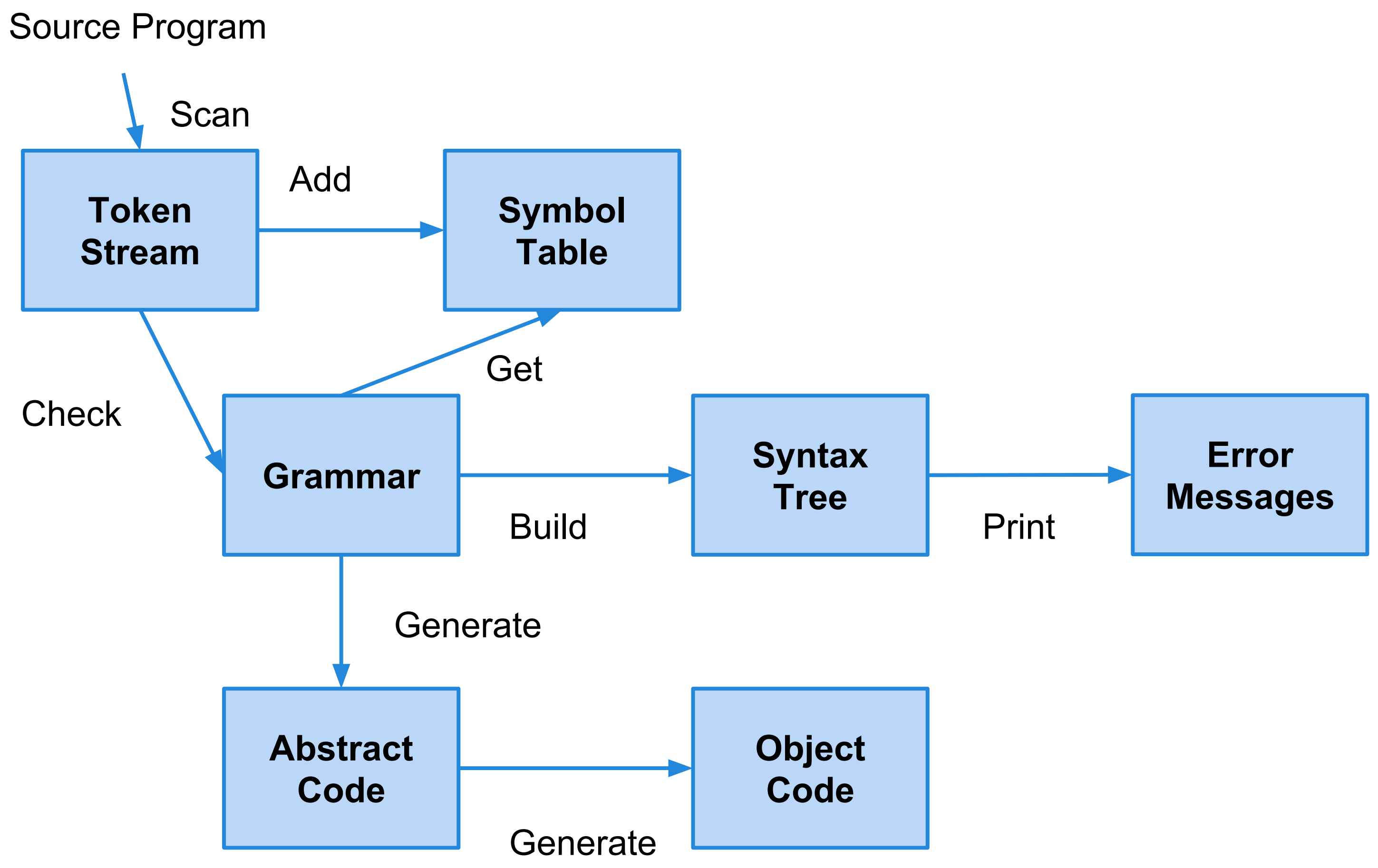
```
tokens = scanSource(program);
symbols=buildSymbolTable(tokens);
try{
    tree=analysis(tokens,symbols);
    generateBinary(tree);
catch(errors){
    print errors
}
```

Design Strategies

Object-Oriented (Decentralized) Design

- System is designed as a collection of interacting objects.
- System state is decentralized and each object manages its own data.
- Multiple instances of an object may exist and communicate.
- How most systems are designed.
    - Easier to isolate errors in one component.

Object-Oriented View of a Compiler



Key Points

- Design activities include architectural design, interface design, component design, data design, and algorithm design.
  - But this is a messy process where phases overlap and activities cycle.
- Functional decomposition considers the system as an assembly line of functional units.
- Object-oriented decomposition considers the system as a set of entities responsible for their own data.

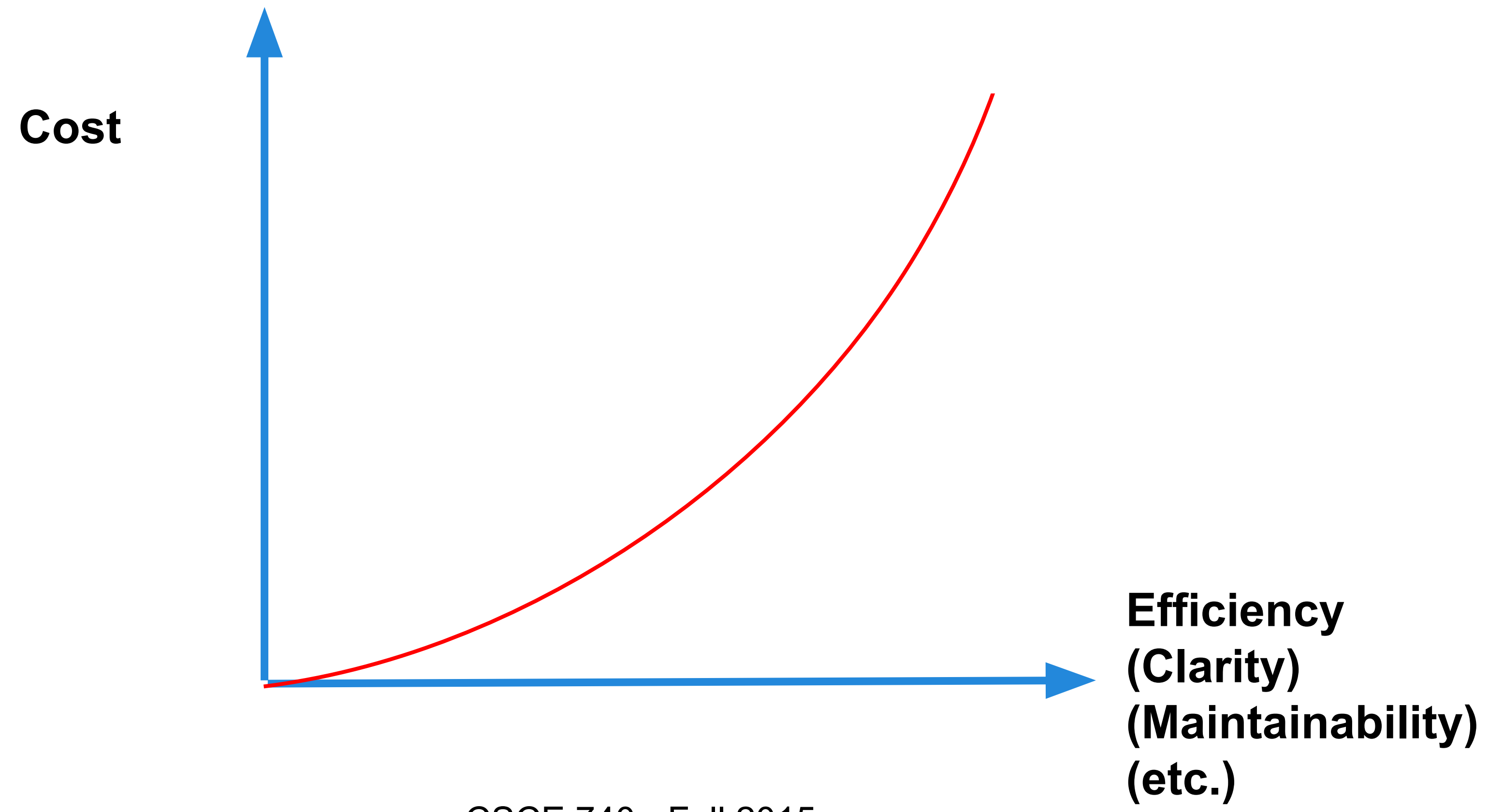
What are the criteria for a “good” design?

Design Quality

- Design quality is an elusive concept.
  - Depends on organizational priorities, and involves balancing competing objectives.
- A “good” design may be the most efficient, the cheapest, the most maintainable, the most reliable, etc…
- Key attributes usually involve clarity and maintainability.
- Quality characteristics are equally applicable to function-oriented and object-oriented design.

Expensive to Maximize Attributes

Costs rise exponentially if very high levels of an attribute are required.



Focus on Clarity and Ease of Change

- Simplicity
- Modularity
  - Low Coupling
  - High Cohesion
  - Information Hiding
  - Data Encapsulation
- Other “abilities”
  - Adaptability
  - Traceability
  - etc...

Modularity

A complex system must be broken down into smaller modules.

Three goals of modularity:

- Decomposability
  - Break the system down into understandable modules.
- Composability
  - Construct a system from smaller pieces.
- Ease of Understanding
  - The system will change, we must understand it.

Modularity Properties

- Cohesion = The degree to which modules are compatible.
- Coupling = The degree of interdependence between modules.

We want **high** cohesion and **low** coupling.

Cohesion

- The degree to which modules are compatible. A measure of how well a component “fits together”.
- A component should implement a single logical entity or function of the software.
- A high level of cohesion is a desirable design attribute because changes are localized to a single, cohesive component.

Types of Cohesion

- Logical Cohesion (weak)
  - Components that perform similar functions are grouped.
- Temporal Cohesion (weak)
  - Components that are activated at the same time are grouped.
- Procedural Cohesion (weak)
  - The elements in a component make up a single control sequence.
- Sequential Cohesion (medium)
  - The output for one part of a component is the input to another part.

Levels of Cohesion

- Communicational Cohesion (medium)
  - All of the elements of a component operate on the same input or produce the same output.
- Functional Cohesion (strong)
  - Each part of a component is necessary for the execution of a single system function.
- Object/Data Cohesion (strong)
  - Each operation modifies or allows inspection of stored object attributes.

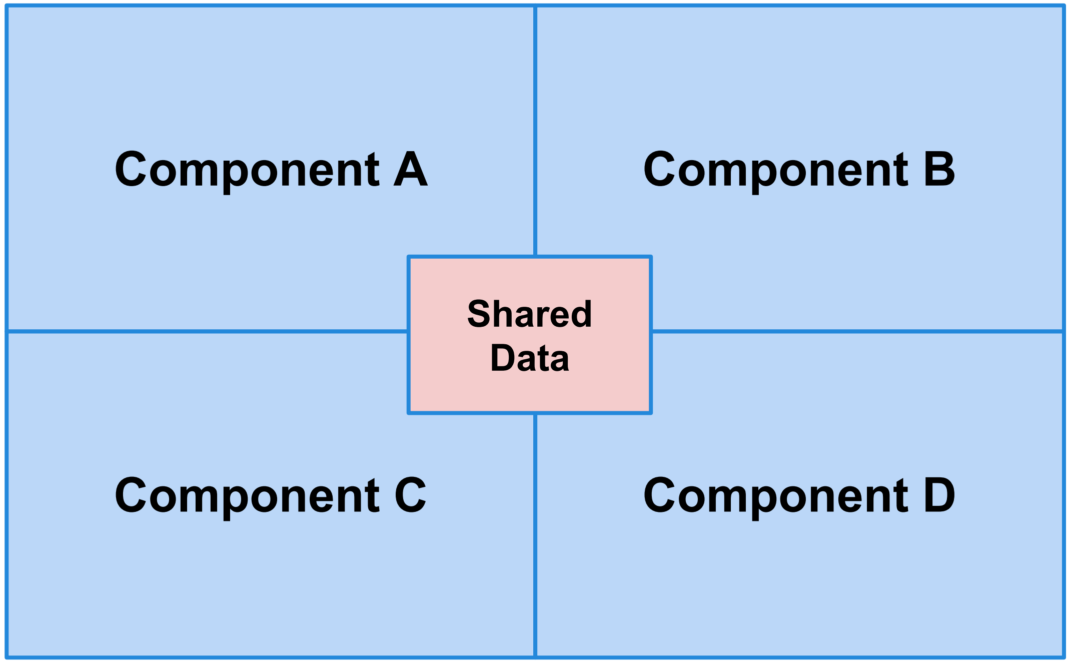
Cohesion as a Design Attribute

- Not well-defined.
  - Despite guidelines, cohesion is subjective and can’t be easily measured.
  - Often very difficult to figure out what is related.
    - Some code is used by multiple classes.
- Inheriting attributes from super-classes weakens cohesion.
  - To understand a component, the super-classes as well as the component class must be examined.

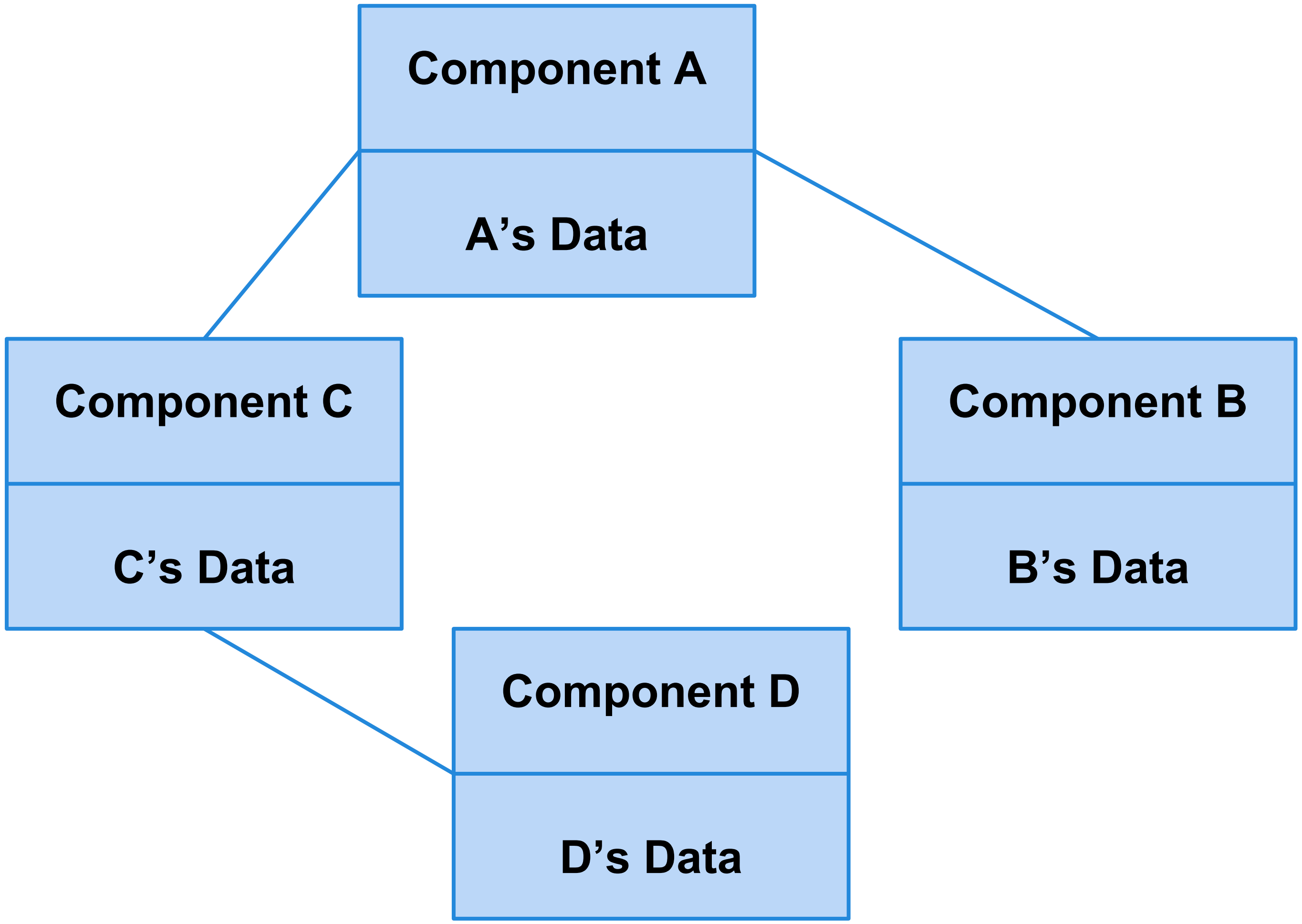
Coupling

- The degree of interdependence between modules. A measure of the strength of the interconnections between components.
  - Is code from another class called often?
  - How much data is passed during those calls?
- Loose coupling means component changes are unlikely to affect other components.
  - Loose coupling can be achieved by storing local data in objects and communicating solely by passing data through component’s parameters.

Tight Coupling



Loose Coupling



Food for Thought

- How does an OO language like Java or C++ support low coupling and high cohesion?
    - How can we mess it up?

More Food for Thought

- How do global variables affect coupling?
- How about complex data structures?
    - … and pointers?
- What does inheritance do to coupling and cohesion?

Coupling and Inheritance

- Object-oriented systems can be loosely coupled because there is no need for shared state and objects communicate using message passing.
- However, an object class is coupled to its super-classes.
  - Changes made to the attributes or operations in a super-class propagate to all sub-classes. Such changes must be carefully controlled.

Information Hiding

- Put the complexity inside of a “black box”
  - Hide it from the components that use that “box”.
  - The user does not need to know *how* the box works, just *what* it does.
- Greatly reduces the amount of information the designer needs to understand at once.
- Examples:
  - Functions, Interfaces, Classes, Libraries
- If used properly, ensures loose coupling.

Information Hiding Example

```
int[] sortAscending(int[] unsorted, int
length);
```

- We do not know what sort routine is used.
- All we know is what the interface is and what the module accomplishes.

Data Encapsulation

- Encapsulation is the principle of building a barrier around a collection of items.
- Encapsulate the data a module is working on.
  - Protect the data from unauthorized access.
  - Nobody else can mess with the data.
  - If it gets corrupted, it must have been the fault of this component.
- Makes the design more robust.

Encapsulation Example

Version 1:

```
class Adder{

     int total;
     void addNum(int number){
          total += number;
     }
};


int main( )
{
   Adder a;

   a.addNum(10);
   a.addNum(20);
   a.addNum(30);

   cout << "Total " << a.total <<endl;
   return 0;
}
```

Version 2:

```
class Adder{

     private int total;
     void addNum(int number){
          total += number;
     }

     int getTotal(){

          return total;

     }
};
int main( )
{
   Adder a;
   a.addNum(10);
   a.addNum(20);
   a.addNum(30);
   cout << "Total " << a.getTotal() <<endl;
   return 0;
}
```

Abstraction and Encapsulation

- Abstraction is the process of identifying the important aspects of a problem and ignoring the other details.
- This is the basis of modularity - divide and conquer the functionality.

- Abstraction identifies what should be “visible” and “hidden.” Encapsulation packages the details.

Understandability

The design should be understandable by the developers - unambiguous and easy to follow. Related to many component characteristics:

- Cohesion
  - Can each component be understood on its own?
- Naming
  - Are meaningful component (class, method, variable) names used?
- Documentation
  - Is the design well-documented? Are decisions justified? Rationale noted?
- Complexity
  - Are complex algorithms used?

Understandability

- Informally, high complexity means many relationships between different entities in the design.
  - Hence, the design is hard to understand.
- Most “measurements” of design quality measure the complexity.
  - They tell you to avoid high complexity (high number of relations between components).
  - These metrics tend to be of little use - the number is irrelevant - instead, be careful to only include necessary relations.

Adaptability

- A design is adaptable if:
  - Its components are loosely coupled.
  - It is well-documented and the documentation is kept up to date.
  - There is an obvious correspondence between design levels (interface, components, data, etc).
  - Each component is a self-contained entity (strong cohesion).
- To adapt a design, it must be possible to trace the links between design components so that change consequences can be analyzed.

Adaptability and Inheritance

Inheritance improves adaptability.

- Components may be expanded without change by deriving a sub-class and modifying that derived class.
- However, we the depth of the inheritance hierarchy increases, so does complexity.
  - Complexity must be periodically reviewed and restructured.

Design Traceability

For a design to be adaptable and understandable, we must be able to link:

- Components to their data.
- Components to their related components.
- Data to related data.
- Components to their requirements.
- Components to their test cases.

We Have Learned

- Functional decomposition considers the system as a set of functional units.
- Object-oriented decomposition considers the system as a set of entities.
- There are desirable design attributes.
- Coupling and cohesion are central to good software engineering.
    - Always keep these in mind.
- Information hiding and data encapsulation can protect a system from misuse.

Next Time

- Midterm Review

- Homework 2 due soon.
- Practice Midterm up on Moodle.
- Questions?