Lecture 13

Architecture Design
Take Away for Today

- What should the lead programmer do?
- How do CRC cards aid software design?
  - What goes on each card?
  - How do you lay them out?
  - What properties should they have?
- How do activity diagrams aid design?
  - How do they relate to CRC cards?
- Difference between design & documentation
Role of Lead Programmer

- Make high-level **architecture decisions**
  - How are you splitting up MVC?
  - What is your computation model?
  - What is stored in the data files?
  - What third party libraries are you using?

- **Divide** the work among the **programmers**
  - Who works on what parts of the game?
  - What do they need to coordinate?
Architecture: The Big Picture

Game Engine
- Input Devices
- Discrete Simulation Engine
- Compiler
- Character Scripts
- Character Data
- UI Elements
- Models and Textures
- Sounds

Player
- GUI
- Render Engine
- Audio Engine

Programmer
- Physics Engine
- AI Engine (e.g. Pathfinding)

Designer or Modder
- Game Content

Architecture Design
Identify Modules (Subsystems)

• **Modules**: logical unit of functionality
  • Often reusable over multiple games
  • Implementation details are hidden
  • API describes interaction with rest of system

• Natural way to break down work
  • Each **programmer** decides implementation
  • But entire **team** must agree on the API

• **Specification** first, then **programming**
Architecture: The Big Picture

**Diagram Description**

- **Game Engine**
  - API
  - Event Devices
  - Subsystem or Module

- **Player**
  - Rendering Engine
  - Audio Engine

- **Game Content**
  - Character Scripts
  - Character Data
  - UI Elements
  - Models and Textures
  - Sounds

- **Programmer**
  - Physics Engine
  - AI Engine (e.g. Pathfinding)

- **Designer or Modder**
  - Compiler
  - Data Management Layer
**Example:** Physics Engines

- API to manipulate objects
  - Put physics objects in “container”
  - Specify their connections (e.g. joints)
  - Specify forces, velocity

- Everything else hidden from user
  - Collisions detected by module
  - Movement corrected by module
Relationship Graph

- Shows when one module “depends” on another
  - Module A calls a method/function of Module B
  - Module A creates/loads instance of Module B

- **General Rule**: Does $A$ need the API of $B$?
  - How would we know this?

Module 1 does not “need” to know about Module 3
Edges in relationship graph are often **directed**
- If $A$ calls a method of $B$, is $B$ aware of it?

But often undirected in architecture diagrams
- Direction clear from other clues (e.g. layering)
- Developers of both modules should still agree on API

Does Module 1 need to know about Module 2?
Dividing up Responsibilities

- Each programmer has a module
  - Programmer **owns** the module
  - Final word on implementation
- Owners collaborate w/ **neighbors**
  - Agree on API at graph edges
  - Call meetings “Interface Parties”
- Works, but…
  - **must agree on modules and responsibilities ahead of time**
Nested (Sub)modules

- Can do this **recursively**
  - Module is a piece of software
  - Can break into more modules

- Nested APIs are **internal**
  - Only needed by module owner
  - Parent APIs may be different!

- Critical for very **large groups**
  - Each small team gets a modules
  - Inside the team, break up further
  - Even deeper hierarchies possible
Architecture: The Big Picture

Game Engine:
- Input Devices
- Discrete Simulation Engine
- Rendering Engine
- Audio Engine

Player:
- GUI

Nested Module

Programmer:
- Physics Engine
- AI Engine (e.g. Pathfinding)

Designer or Modder:
- Game Content
  - Character Scripts
  - Character Data
  - UI Elements
  - Models and Textures
  - Sounds

Architecture Design
How Do We Get Started?

- Remember the design caveat:
  - Must agree on module responsibilities first
  - Otherwise, code is duplicated or even missing

- Requires a high-level architecture plan
  - Enumeration of all the modules
  - What their responsibilities are
  - Their relationships with each other

- Responsibility of the lead architect
Design: CRC Cards

- **Class-Responsibility-Collaboration**
  - **Class**: Important class in subsystem
  - **Responsibility**: What that class does
  - **Collaboration**: Other classes required
    - May be part of another subsystem

- **English description of your API**
  - Responsibilities become **methods**
  - Collaboration identifies **dependencies**
# CRC Card Examples

## Controller

<table>
<thead>
<tr>
<th>Responsibility</th>
<th>Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pathfinding</strong>: Avoiding obstacles</td>
<td>Game Object, Scene Model</td>
</tr>
<tr>
<td><strong>Strategic AI</strong>: Planning future moves</td>
<td>Player Model, Action Model</td>
</tr>
<tr>
<td><strong>Character AI</strong>: NPC personality</td>
<td>Game Object, Level Editor Script</td>
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</tbody>
</table>

## AI Controller

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<thead>
<tr>
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<tr>
<td>Enumerates game objects in scene</td>
<td>Game Object</td>
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<tr>
<td>Adds/removes game objects to scene</td>
<td>Game Object</td>
</tr>
<tr>
<td>Selects object at mouse location</td>
<td>Mouse Event, Game Object</td>
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## Model

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Creating Your Cards

- Start with MVC Pattern
  - Gives 3 basic subsystems
  - List responsibilities of each
  - May be all that you need (TemperatureConverter)
- Split up a module if
  - Too much for one person
  - API for module too long
- Don’t need to nest (**yet**)
  - Perils of **ravioli code**

<table>
<thead>
<tr>
<th>Module</th>
<th>Responsibility</th>
<th>Collaboration</th>
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- Don’t need to nest *(yet)*
  - Perils of *ravioli code*

<table>
<thead>
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<th>Module 1</th>
<th>Module 2</th>
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<tbody>
<tr>
<td>Responsibility</td>
<td>Collaboration</td>
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</tbody>
</table>
Avoid Cyclic Collaboration

collaborates with

collaborates with

Controller

collaborates with

Architecture Design
Avoid Cyclic Collaboration

- **Example**: Lab 3
  - Ship fires projectiles
  - Must add to game state

- Originally all in model
  - Ship referenced game state
  - And game state stored ship
  - **Cyclic Reference**

- We added a new controller
  - It references game state
  - Only it adds to game state
  - **Cycle broken**
Avoid Cyclic Collaboration

- **Example**: Lab 3
  - Ship fires projectiles
  - Must add to game state

- Originally all in model
  - Ship referenced game state
  - And game state stored ship
  - **Cyclic Reference**

- We added a new controller
  - It references game state
  - Only it adds to game state
  - **Cycle broken**
Alternative: Interfaces

- Relationships are for APIs
  - Implementation not relevant
  - Can be class or interface
- Interfaces can break cycles
  - Start with single class
  - Break into many interfaces
  - Refer to interface, not class
- Needed if actions in model
  - Abstracts game state
  - Hides all but relevant data
Architecture: The Big Picture

Diagram of game architecture showing:
- Game Content (e.g., Character Scripts, Character Data)
- Designer or Modder (Input Devices, Compiler)
- Player (GUI, Rendering Engine, Audio Engine)
- Simple (Planar) Graph (AI Engine, e.g., Pathfinding)
CRC Index Card Exercise

Try to make collaborators adjacent

<table>
<thead>
<tr>
<th>Class 1</th>
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</thead>
<tbody>
<tr>
<td>Responsibility</td>
<td>Collaboration</td>
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<tr>
<td>...</td>
<td>Class 2</td>
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<td>...</td>
<td>Class 3</td>
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<tr>
<td>...</td>
<td>Class 4</td>
<td></td>
</tr>
</tbody>
</table>

If cannot do this, time to think about nesting!

<table>
<thead>
<tr>
<th>Class 2</th>
<th>Responsibility</th>
<th>Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td>...</td>
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</table>

<table>
<thead>
<tr>
<th>Class 3</th>
<th>Responsibility</th>
<th>Collaboration</th>
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</thead>
<tbody>
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<td>...</td>
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<table>
<thead>
<tr>
<th>Class 4</th>
<th>Responsibility</th>
<th>Collaboration</th>
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</thead>
<tbody>
<tr>
<td>...</td>
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</tbody>
</table>
Designing Class APIs

- Make classes formal
- Turn responsibilities into methods
- Turn collaboration into parameters

### Scene Model

<table>
<thead>
<tr>
<th>Responsibility</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enumerates game objects</td>
<td>Iterator&lt;GameObject&gt; enumObjects()</td>
</tr>
<tr>
<td>Adds game objects to scene</td>
<td>void addObject(gameObject)</td>
</tr>
<tr>
<td>Removes objects from scene</td>
<td>void removeObject(gameObject)</td>
</tr>
<tr>
<td>Selects object at mouse</td>
<td>GameObject getObject(mouseEvent)</td>
</tr>
</tbody>
</table>
Documenting APIs

• Use a formal documentation style
  • What parameters the method takes
  • What values the method returns
  • What the method does (side effects)
  • How method responds to errors (exceptions)

• Make use of documentation comments
  • Example: JavaDoc in Java
  • C# uses an XML style for comments
public Image getImage(URL url, String name) {
    try {
        return getImage(new URL(url, name));
    } catch (MalformedURLException e) { return null; } }

/**
 * Returns an Image object that can then be painted on the screen. The url
 * argument must specify an absolute [@link URL]. The name argument is
 * a specifier that is relative to the url argument.
 * <p>
 * This method always returns immediately, whether or not the image exists.
 * When this applet attempts to draw the image on the screen, the data will
 * be loaded. The graphics primitives that draw the image will incrementally
 * paint on the screen.
 * <p>
 * @param url an absolute URL giving the base location of the image
 * @param name the location of image, relative to the url argument
 * @return the image at the specified URL
 * @see Image
 */
/// <summary>
/// Returns an Image object that can then be painted on the screen. The url
/// argument must specify an absolute <see cref="URL"/>. The name argument
/// is a specifier that is relative to the url argument.
/// <p/>
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/// be loaded. The graphics primitives that draw the image will incrementally
/// paint on the screen.
/// </summary>
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/// <param name="name">the location of image, relative to the url argument</param>
/// <returns>the image at the specified URL</returns>

public Image getImage(URL url, String name) {
    try {
        return getImage(new URL(url, name));
    } catch (MalformedURLException e) { return null; }
}
Taking This Idea Further

- **UML**: Unified Modeling Language
  - Often used to specify class relationships
  - But expanded to model other things
  - **Examples**: data flow, human users

- **How useful is it?**
  - Extremely useful for documentation
  - Less useful for design (e.g. before implementation)
  - A language to program in another language
Activity Diagrams

- Define the **workflow** of your program
  - Very similar to a standard flowchart
  - Can follow simultaneous paths (threads)

- Are an *component* of **UML**
  - But did not originate with UML
  - Mostly derived from **Petri Nets**
  - One of most useful **UML design** tools

- Activity diagrams are only **UML** we use
Activity Diagram Example

1. **Find Beverage**
2. **[found coffee]**
   - **Put Coffee in Filter**
   - **Put Filter in Machine**
   - **Turn On Machine**
   - **Brew Coffee**
   - **[coffee dispensed]**
   - **Pour Coffee**
   - **[no coffee]**
   - **[found cola]**
3. **Get Can of Cola**
4. **Get Cups**
5. **Add Water to Reservoir**
6. **[no cola]**
7. **[no coffee]**
8. **Drink Beverage**
Activity Diagram Example

Start

Find Beverage

Find Beverage

Add Water to Reservoir

Get Cups

Get Can of Cola

Put Filter in Machine

Put Filter in Machine

Turn On Machine

Brew Coffee

[found coffee]

[no coffee]

[no cola]

[found cola]

[coffee dispensed]

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Activity Diagram Components

- **Synchronization Bars**
  - **In**: Wait until have happened
  - **Out**: Actions “simultaneous”
  - … or order does not matter

- **Decisions**
  - **In**: Only needs one input
  - **Out**: Only needs one output

- ** Guards**
  - When we can follow edge
  - * is iteration over container
Asynchronous Pathfinding

- Get Input
  - *[for each selected]*
    - Determine Goal
      - Measure to Goal
        - *[for each object]*
          - [all objects checked]
            - Move Object
              - Draw
              - *[for each object]*

- [new goal]
  - *[
    - [path found]
      - *

- [path found]
  - *[
    - Find Path
      - Reset Pathfinder

Asynchronous Pathfinding

Iteration

Get Input

*[for each selected]

Determine Goal

*[for each object]

Measure to Goal

[all objects checked]

*[for each object]

Move Object

*[for each object]

Draw

[all objects checked]

* [new goal]

[all objects checked]

Reset Pathfinder

Buffer

Find Path

Task Separator
Asynchronous Pathfinding

Get Input

Iteration

Determine Goal

Synchronization + Guard
Think of as multiple outgoing edges (with guard) from bar

Task Separator

Reset Pathfinder

Draw

Move Object

Measure to Goal

[all objects checked]

*[for each object]

*[for each selected]

* [for each object]

*[for each selected]

[new goal]

[path found]

[all objects checked]
Expanding Level of Detail

1. Get Input
2. Measure to Goal
3. Determine Goal
4. [for each object]
5. [for each selected]
6. [all objects checked]
7. [for each object]
8. Move Object
9. Draw

- Draw Background
- Draw Objects
- Draw HUD

- Find Path
- Reset Pathfinder

Architecture Design
Using Activity Diagrams

- Good way to identify major subsystems
  - Each action is a responsibility
  - Need extra responsibility; create it in CRC
  - Responsibility not there; remove from CRC

- Do activity diagram first?
  - Another iterative process
  - Keep level of detail simple
  - Want outline, not software program
Architecture Specification

• Identify major subsystems in CRC cards
  • List responsibilities
  • List collaborating subsystems

• Draw activity diagram
  • Make sure agrees with CRC cards
  • Revise CRC cards if not

• Create class API from CRC cards
  • Recall intro CS courses: specifications first!
Programming Contract

• Once create API, it is a **contract**
  • Promise to team that “works this way”
  • Can change **implementation**, but not **interface**

• If change the interface, must **refactor**
  • Restructure architecture to support interface
  • May change the CRCs and activity diagram
  • Need to change any written code
Summary

• Architecture design starts at a high level
  • Class-responsibilities-collaboration
  • Layout as cards to visualize dependencies

• Activity diagrams useful for update loop
  • Outline general flow of activity
  • Identifies dependencies in the process

• Must formalize class APIs
  • Same detail as Java documentation
  • Creates a contract for team members