Lecture 12

Memory Management
Gaming Memory (Current Generation)

- **Playstation 4**
  - 8 GB RAM (unified)

- **X-Box One (X)**
  - 12 GB RAM (unified)
  - 9 GB for games

- **Nintendo Switch**
  - 3 GB RAM (unified)
  - 1 GB only for OS

- **iPhone/iPad**
  - 2 GB RAM (unified)
  - Better than an XBox 360
Memory Usage: Images

- Pixel color is 4 bytes
  - 1 byte each for r, b, g, alpha
  - More if using HDR color
- Image a **2D array** of pixels
  - 1280x1024 monitor size
  - 5,242,880 bytes ~ 5 MB
- More if using **mipmaps**
  - Graphic card texture feature
  - Smaller versions of image
  - Cached for performance
  - But can double memory use
But My JPEG is only 8 KB!

- Formats often **compressed**
  - JPEG, PNG, GIF
  - But not always TIFF
- Must **uncompress** to show
  - Need space to uncompress
  - In RAM or graphics card
- Only load when needed
  - Loading is primary I/O operation in AAA games
  - Causes “texture popping”
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Sounds have a similar problem
Loading Screens

Rebel Mages

Whereas the Circle was established not merely to protect the world from mages, but also to allow mages to practice their art safely and without fear, and,

Whereas under Lord Seeker Lambert’s command, the templars sworn to protect all people—including mages—from the harmful effects of magic, have instead persecuted mages with such biased judgment as to worsen the problems they were meant to mitigate, and,

Whereas the Rite of Tranquility, intended as a tool of last resort to stop uncontrolled mages from hurting themselves or others, has instead been used for punitive and political purposes to silence dissent and inhibit civilized discourse, and,

Whereas Andras herself intended the relationship between mage and templar to be one of practitioner and protector, not prisoner and
Problems with Asset Loading

- How to load assets?
  - May have a lot of assets
  - May have large assets

- Loading is **blocking**
  - Game stops until done
  - Cannot draw or animate

- May need to **unload**
  - Running out of memory
  - Free something first
Problems with Asset Loading

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Loading Screens

Minimal animation/feedback while loading assets
Solution: Asynchronous Loader

Game Thread

- Update
- Draw

Second Thread

- Asset Loader
- Specify Asset
- Notify done

Update and draw simple animations until assets loaded
Solution: Asynchronous Loader

Game Thread

- Update
- Draw

Second Thread

- Specify Asset
- Notify done

- Also an asset manager
  - Each asset given a key
  - Can access asset by key
  - Works like hash table
Solution: Asynchronous Loader

- Not always a good idea
- May need OpenGL utils
  - **Example**: Textures
- Limited to main thread
**Alternative: Iterative Loader**

Game Thread

- Update
- Draw

Asset Manager

- Initialize
- Update
- Access
Alternative: Iterative Loader

- Uses a time budget
  - Give set amount of time
  - Do as much as possible
  - Stop until next update

- Better for OpenGL
  - Give time to manager
  - Animate with remainder
  - No resource contention

- LibGDX approach
  - CUQL is asynchronous
Alternative: Iterative Loader

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- LibGDX approach
  - CUGL is asynchronous
Aside: When Do We Load Assets?

Choice affects **design** & **ownership** of the asset manager.
Assets Beyond Images

- AAA games have a lot of 3D geometry
  - Vertices for model polygons
  - Physics bodies **per polygon**
  - Scene graphs for organizing this data

- When are all these objects created?
  - At load time (filling up memory)?
  - Or only when they are needed?

- We need to understand memory better
Traditional Memory Organization

- **Stack**
  - Function parameters
  - Local variables
  - Return values

- **Heap**
  - Objects created via `new`
  - Allocations with `malloc`

- **Free Space**

- **Program Data**
  - Program Code
  - Static Variables

Dedicated to process.

Consists of machine addressable space.

Leverages Virtual Memory

Low Address

High Address
Mobile Memory Organization

Device Memory

Stack
Program Data

Stack
Program Data

Heap

Stack
Program Data

Stack
Program Data

Memory Management
How Do Apps Compete for Memory?

- Active app takes what it can
  - Cannot steal from OS
  - OS may *suspend* apps

- **App Suspension**
  - App quits; memory freed
  - Done only as needed

- Suspend apps can *recover*
  - OS allows limited paging
  - Page out on suspension
  - Page back in on restart
How Do Apps Compete for Memory?

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You must code this!
Otherwise, data is **lost**.
State Management in iOS 7+

- **Active**
  - Running & getting input

- **Inactive**
  - Running, but no input
  - Transition to suspended

- **Background**
  - Same as inactive
  - But apps can stay here
  - **Example**: Music

- **Suspended**
  - Stopped & Memory freed

Memory Management
State Management in iOS 7+

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  - Stopped & Memory freed

Write handlers to process entering, leaving each state

Memory Management
iOS State Handling

- `applicationDidBecomeActive`:  
  - Your app became (resumed as) the foreground app.  
  - Use this to recover memory state.

- `applicationWillResignActive`:  
  - Your app will switch to inactive or background.  
  - Stop the game loop and page out memory.

- `applicationDidEnterBackground`:  
  - Your app is in the background and may be suspended.

- `applicationWillEnterForeground`:  
  - Your app is leaving the background, but is not yet active.
Android State Handling

All methods in **Application** class
Android State Handling

All methods in Application class

Reload memory
Android State Handling

Activity launched
- onCreate()
- onStart()
- onResume()
- onRestart()

Activity running
- Activity
- onPause()
- onStop()

App process killed
- Apps with higher priority need memory
- onPause()
- onStop()
- onDestroy()

Another activity comes into the foreground
- onPause()
- onStop()

Using to

Page out memory

All methods in Application class

Memory Management
CUGL is Simplified Android Model

- **onStartup()**
  - Initialized and now active
- **onSuspend()**
  - Sent to background
  - Gives you chance to save
  - Also time to pause music
- **onResume()**
  - Returns to app to active
  - Allows you to restore state
- **onShutdown()**
  - Stopped & memory freed

Memory Management
CUGL is Simplified Android Model

- **onLowMemory()**
  - Warning memory is low
  - Gives you chance to unload
  - Else app will shut down

- **onStartup()**
  - Initialized and now active

- **onSuspend()**
  - Sent to background
  - Gives you chance to save
  - Also time to pause music

- **onResume()**
  - Returns to app to active
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- **onShutdown()**
  - Stopped & memory freed
Memory Organization and Games

Inter-Frame Memory
Carries over across frame boundaries

Update

Intra-Frame Memory
Recovered each frame

Draw
Memory Organization and Games

- **Inter-Frame Memory**
  - Carries over across frame boundaries

- **Heap or Stack?**
  - Does it matter?

- **Draw**

- **Intra-Frame Memory**
  - Recovered each frame
# Distinguishing Data Types

## Intra-Frame
- **Local computation**
  - Local variables (managed by compiler)
  - Temporary objects (not necessarily managed)
- **Transient data structures**
  - Built at the start of update
  - Used to process update
  - Can be deleted at end

## Inter-Frame
- **Game state**
  - Model instances
  - Controller state
  - View state and caches
- **Long-term data structures**
  - Built at start/during frame
  - Lasts for multiple frames
  - May adjust to data changes
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**Inter-Frame**
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  - Game objects and caches
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  - Adjusts to data changes

- **Long-term data structures**
  - Built at start of the frame
  - Caches and other long-term structures

*Memory Management*
# Handling Game Memory

<table>
<thead>
<tr>
<th>Intra-Frame</th>
<th>Inter-Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Does not need to be paged</td>
<td>• Potential to be paged</td>
</tr>
<tr>
<td>• Drop the latest frame</td>
<td>• Defines current game state</td>
</tr>
<tr>
<td>• Restart on frame boundary</td>
<td>• Memory may be recycled, but not automatic</td>
</tr>
<tr>
<td>• Want size reasonably fixed</td>
<td>• No. of objects is variable</td>
</tr>
<tr>
<td>• Local variables always are limited allocations</td>
<td>• Subsystems may turn on/off</td>
</tr>
<tr>
<td>• Limit new inside loops</td>
<td>• User settings may affect</td>
</tr>
<tr>
<td>• Often use custom allocator</td>
<td>• OS allocator okay, but…</td>
</tr>
<tr>
<td>• GC at frame boundaries</td>
<td>• Recycle with free lists</td>
</tr>
</tbody>
</table>

- Topic of Next Lecture

- Memory Management
**Advanced: Spatial Loading**

- Most game data is *spatial*
  - Only load if player nearby
  - Unload as player moves away
  - Minimizes memory used

- Arrange memory in *cells*  
  - Different from a memory pool
  - Track player visibility radius
  - Load/unload via outer radius

- **Alternative**: loading zones  
  - Elevators in *Mass Effect*
Advanced: Spatial Loading

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Spatial Loading in Assassin’s Creed
Implementing Spatial Loading

- Part of serialization model
  - Level/save file has the cells
  - Cell *addresses* in memory
  - Load/page on demand
- Sort of like virtual memory
  - But paging strategy is spatial
Spatial Loading Challenges

- **Not same** as virtual memory
  - Objects unloaded do not exist
  - Do not save state when unload
  - Objects loaded are new created

- Can lead to *unexpected states*
  - “Forgetful” NPCs
  - Creative *Assassin’s Creed* kills

- **Workaround**: Global State
  - Track major game conditions
  - **Example**: Guards Alerted
  - Use to load objects in standard, but appropriate, configurations

See *Piazza* for
There is No Spoon
Next Time: Low-Level Details