

Lecture 12

Memory Management

Take-Aways for Today

- Why does memory in games matter?
 - Is there a difference between PC and mobile?
 - Where do consoles fit in all this?
- Do we need to worry about it in Java?
 - Java has garbage collection
 - Handles the difficult bits for us, right?
- What can we do in LibGDX?

Gaming Memory (Generation 7)

- **Playstation 3**

- 256 MB RAM for system
- 256 MB for graphics card



- **X-Box 360**

- 512 MB RAM (unified)

- **Nintendo Wii**

- 88 MB RAM (unified)
- 24 MB for graphics card



- **iPhone/iPad**

- 1 GB RAM (unified)

Gaming Memory (Generation 8)

- **Playstation 4**

- 8 GB RAM (unified)



- **X-Box One**

- 12 GB RAM (unified)
- 9 GB for games



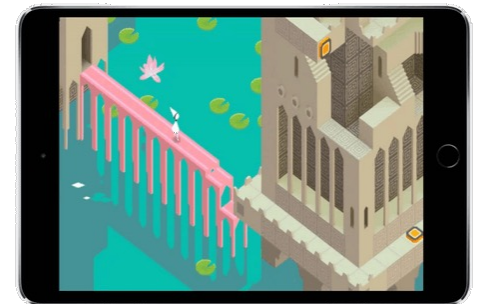
- **Nintendo Wii-U**

- 2 GB RAM (unified)
- 1 GB only for OS



- **iPhone/iPad**

- 2 GB RAM (unified)



Gaming Memory (Current Generation)

- **Playstation 5**

- 16 GB RAM (unified)
- **Speed 448GB/s**



- **X-Box Series X**

- 16 GB RAM (unified)
- **Speed 560-336GB/s**



- **Nintendo Switch**

- 3 GB RAM (unified)
- **Speed 25.6 GB/s**



- **iPhone/iPad**

- 6 GB RAM (unified)
- **Speed 42.7 GB/s**



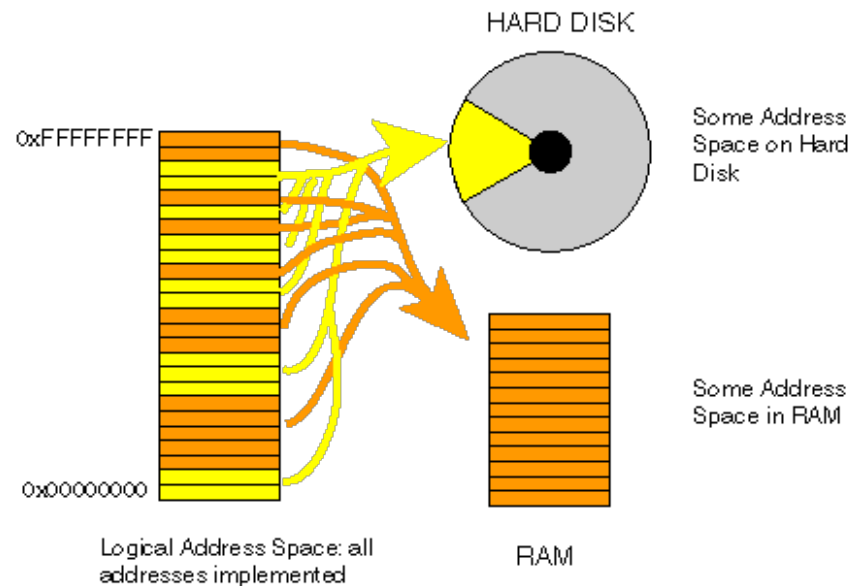
Aside: Memory Affects Games

- **Generation 7**
 - Modern(ish) GPUs
 - Horrible memory
 - **Pretty, but short games**
- **Generation 8**
 - Minor GPU increases
 - Massive memory increases
 - **Open world games**
- **Generation 9**
 - Minor GPU, memory boosts
 - Massive bandwidth boosts
 - **Shorter loading time = ???**



What About Virtual Memory?

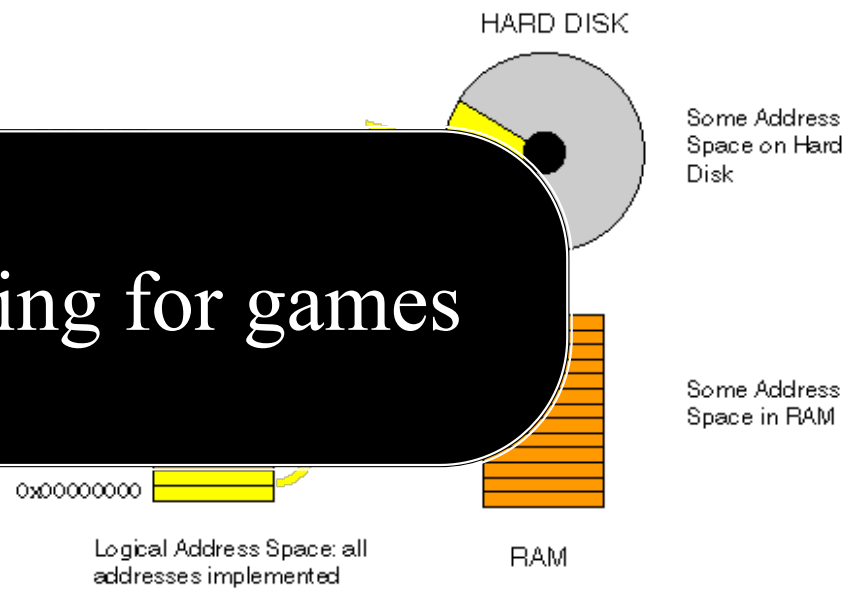
- **Secondary storage** exists
 - Consoles/iPad have 1 TB
 - Most platforms solid state
- **Bandwith** is improving!
 - *Good* SSDs hit 2.5 GB/s
 - PS5 5.5 GB/s, XBX 4.8 GB/s
- BUT recall **16 ms** per frame
 - At best, can access 90 MB
 - Yields uneven performance



What About Virtual Memory?

- **Secondary storage** exists
 - Consoles/iPad have 1 TB
 - Most platforms solid state
- **Bandwidth**
 - *Good*
 - PS5 5
- BUT recall **16 ms** per frame
 - At best, can access 90 MB
 - Yields uneven performance

Not really a thing for games



Aside: Java Memory

- Initial heap size
 - Memory app starts with
 - Can get more, but stalls app
 - Set with `-Xms` flag

```
> java -cp game.jar GameMain
```
- Maximum heap size
 - OutOfMemory if exceed
 - Set with `-Xmx` flag

```
> java -cp game.jar -Xms:64m  
GameMain
```
- Defaults by RAM installed
 - Initial 25% RAM (<16 MB)
 - Max is 75% RAM (<2 GB)
 - Need more, then set it

```
> java -cp game.jar -Xms:64m  
-Xmx:64m GameMain
```

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



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MipMaps

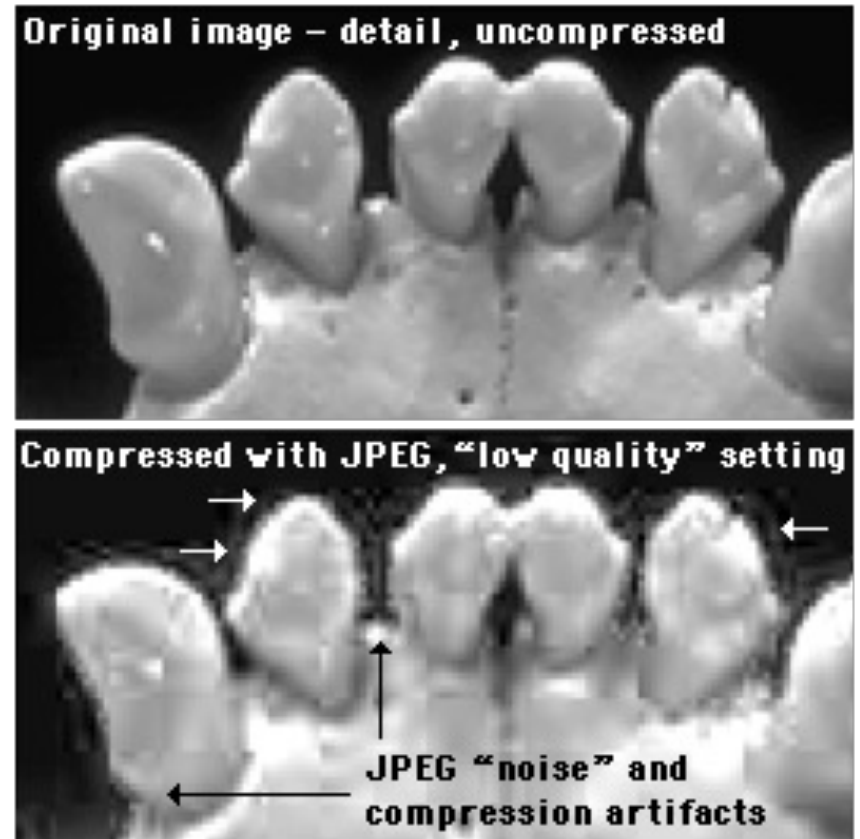


Original Image



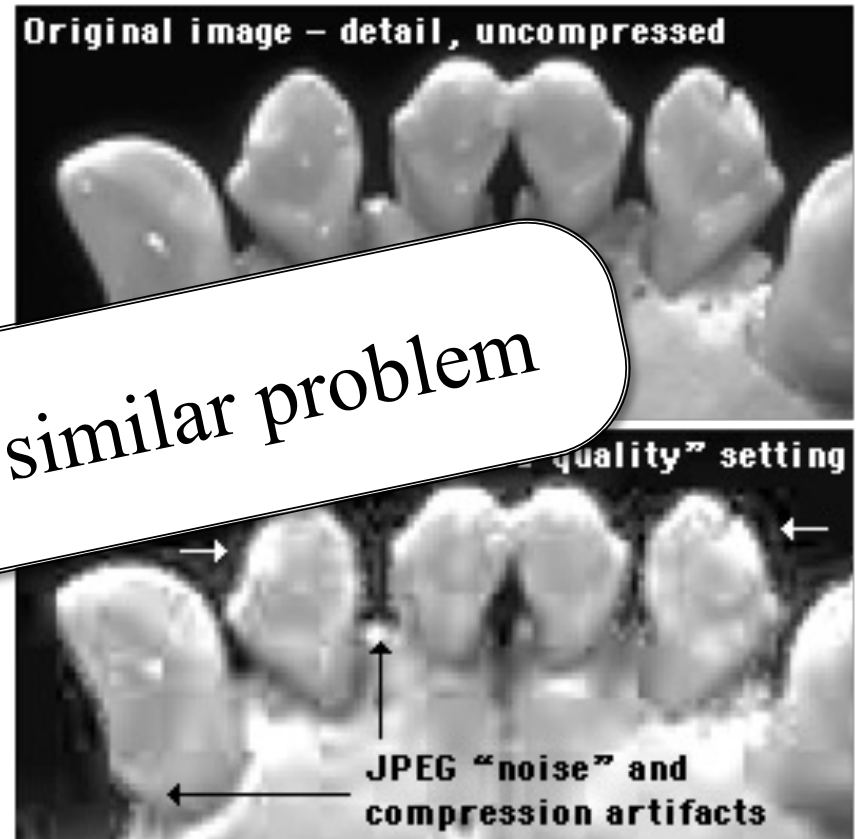
But My JPEG is only 8 KB!

- Formats often **compressed**
 - JPEG, PNG, GIF
 - But not always TIFF
- **Uncompress** to display
 - 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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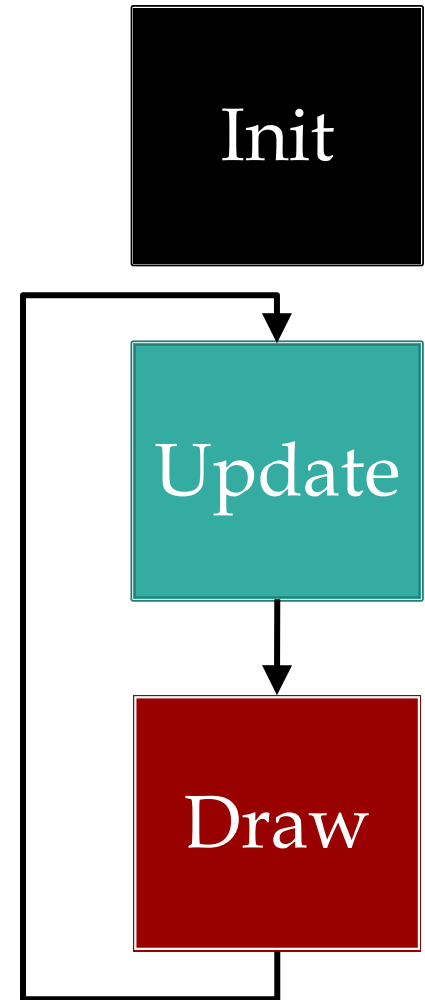


Loading Screens



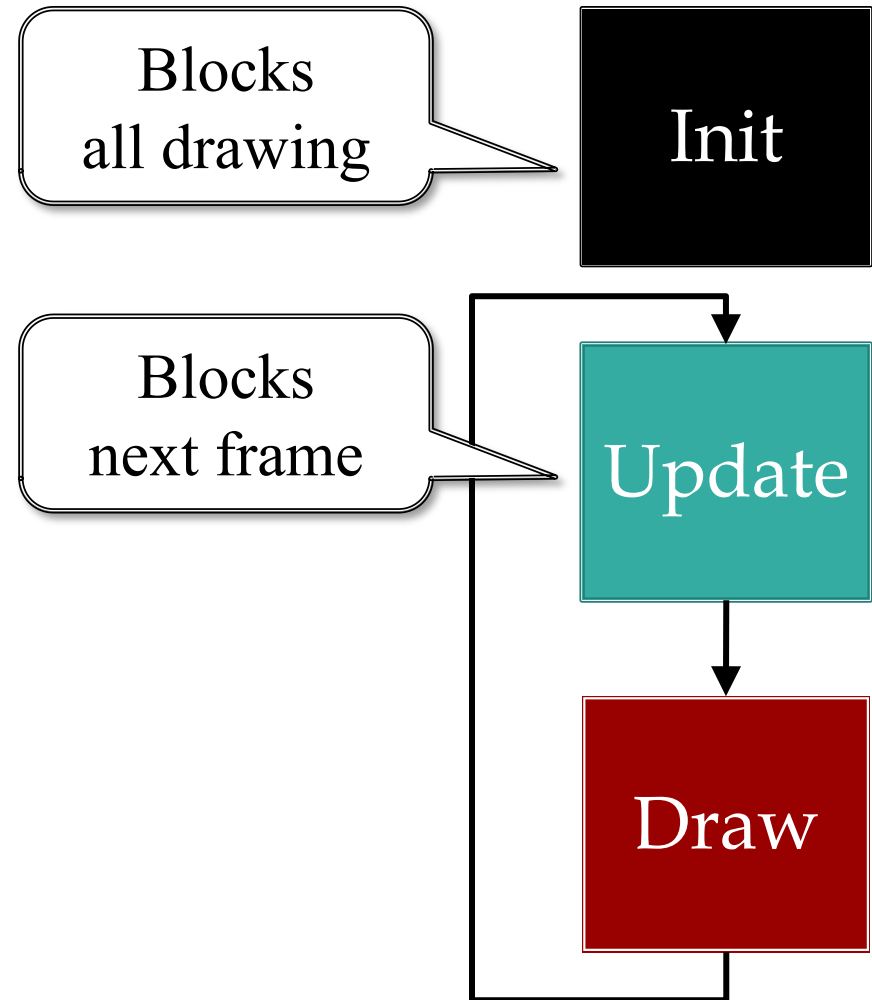
Problems with Asset Loading

- 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

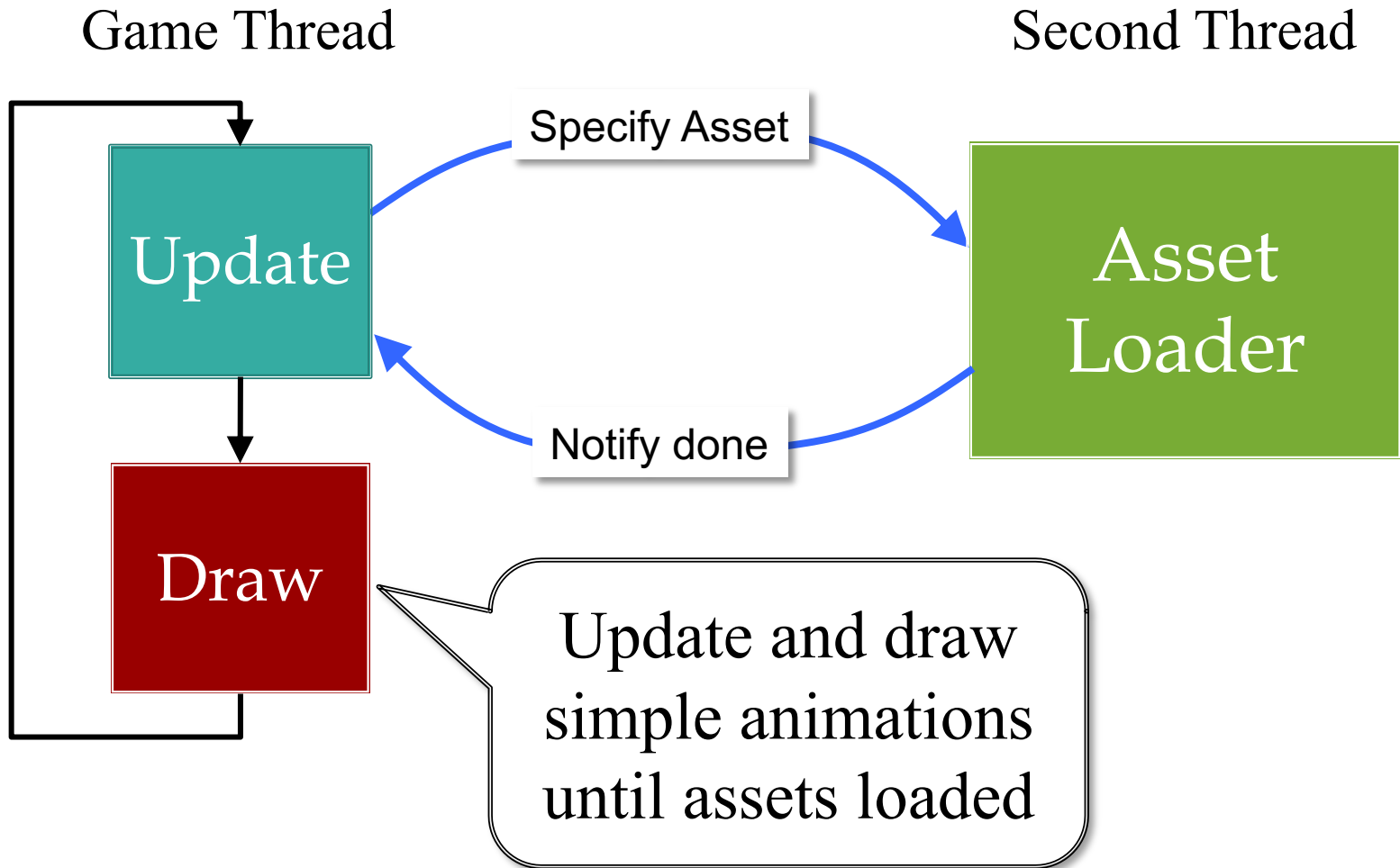
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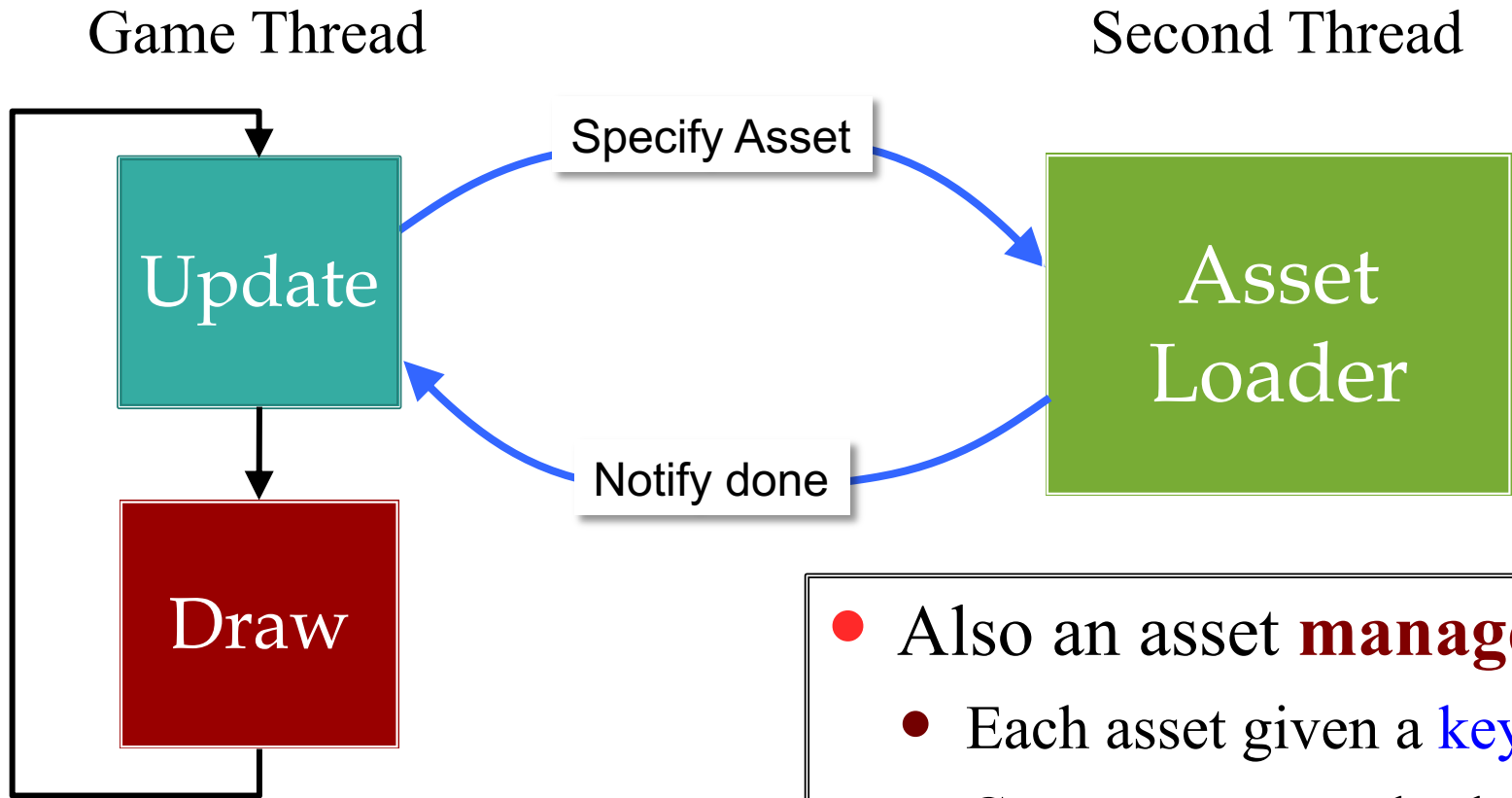
Loading Screens



Solution: Asynchronous Loader

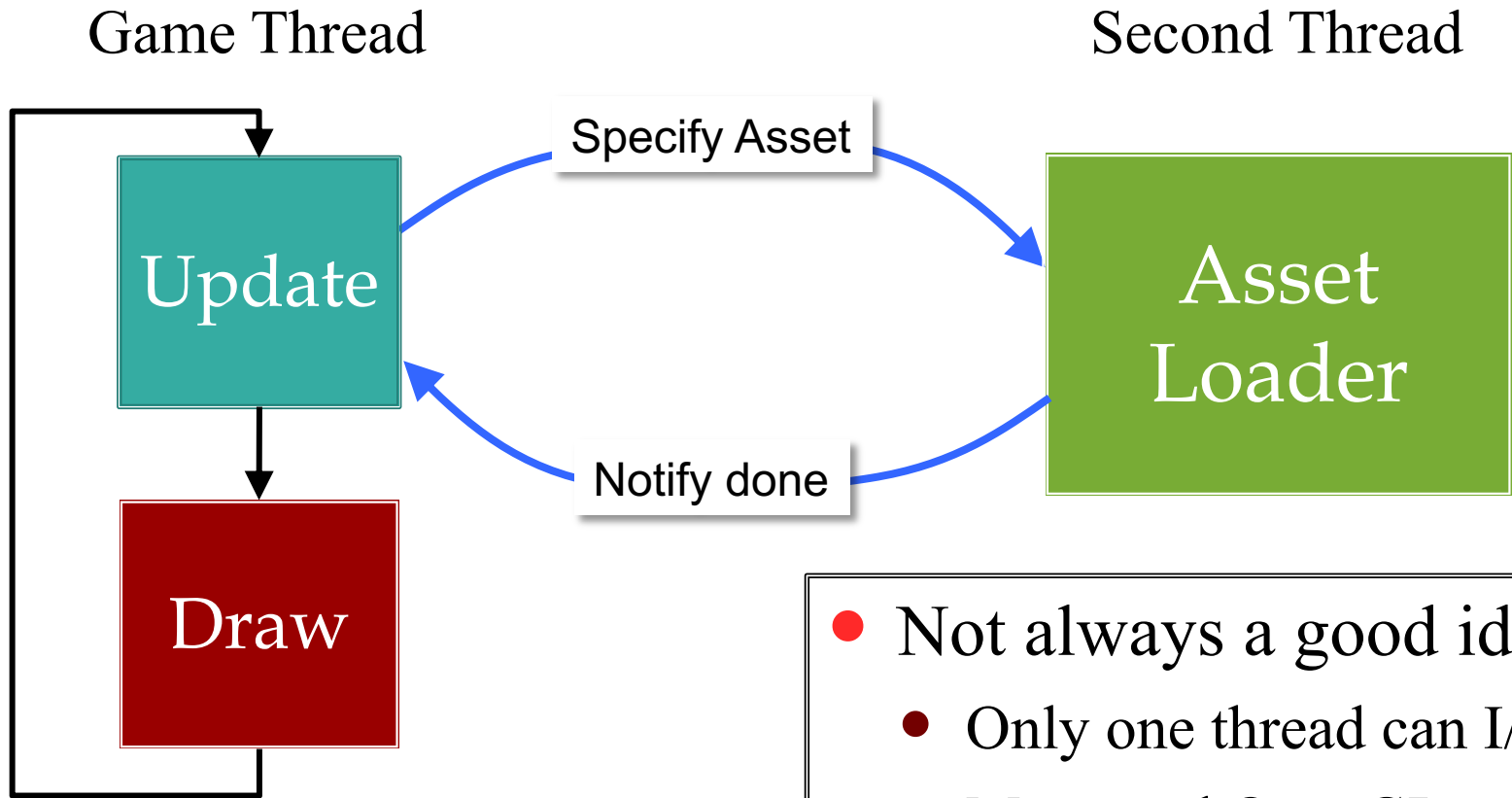


Solution: Asynchronous Loader



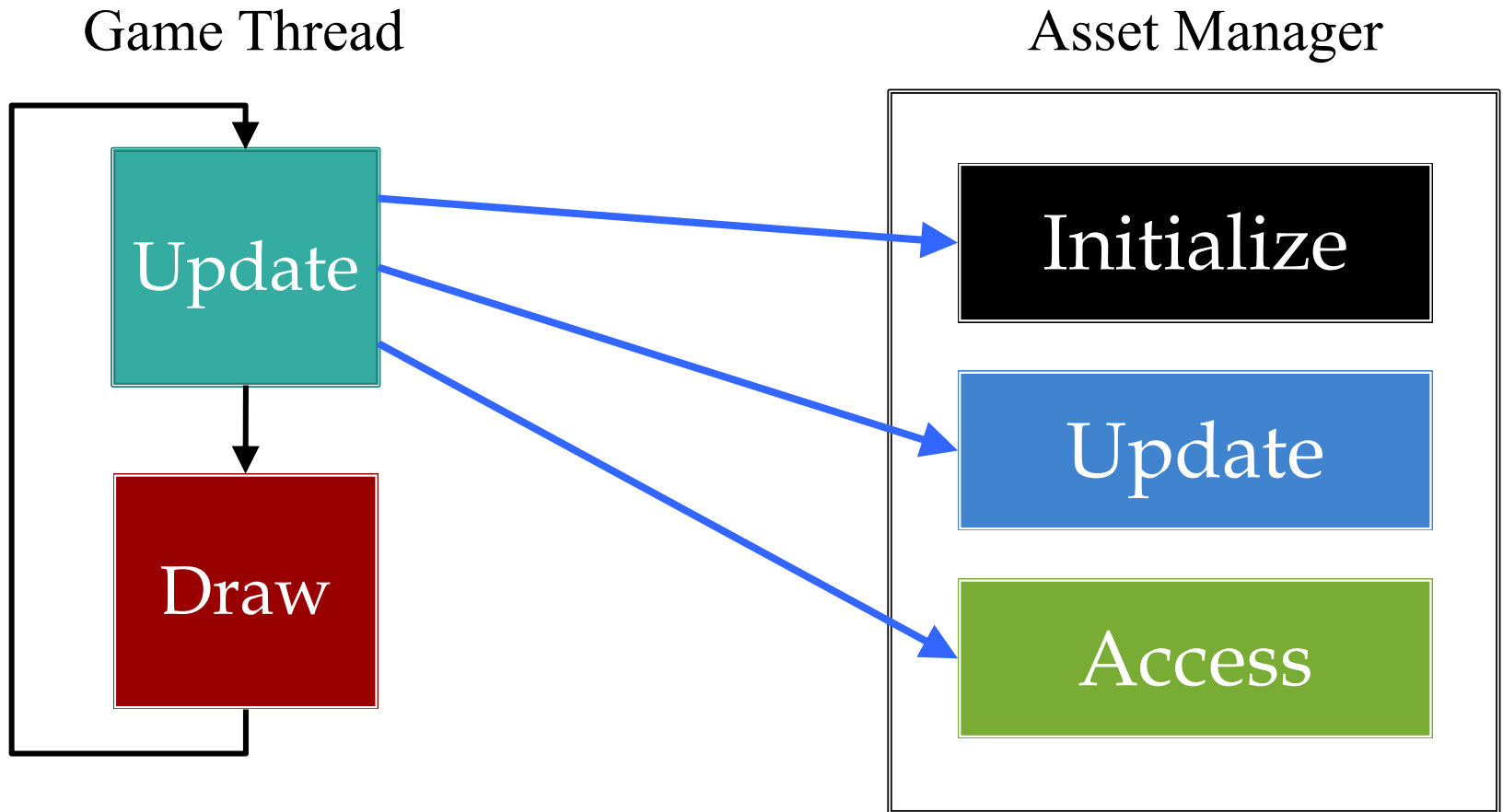
- Also an asset **manager**
 - Each asset given a **key**
 - Can access asset by key
 - Works like Java Map

Solution: Asynchronous Loader



- Not always a good idea
 - Only one thread can I/O
 - May need OpenGL utils
 - ...so will block drawing

Alternative: Iterative Loader



Alternative: Iterative Loader

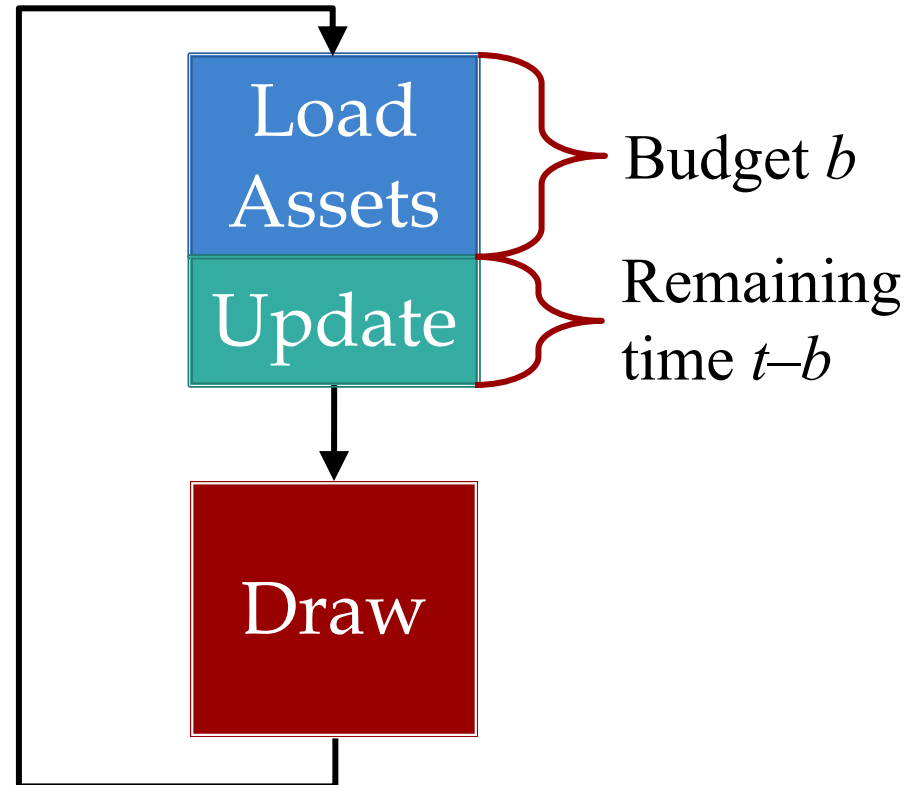
- Uses a time budget
 - Give set amount of time
 - Do as much as possible
 - Stop until next update
- Better for OpenGL
 - Give time to manager
 - Animate with remainder
 - No resource contention
- LibGDX approach
 - Re-examine game labs

Asset Manager



Alternative: Iterative Loader

- Uses a time budget
 - Give set amount of time
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- Better for OpenGL
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 - No resource contention
- **LibGDX approach**
 - Re-examine game labs



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
- **How do we load these things?**
 - Managers handle built-in asset types
 - What if we need to make a custom data type?
- And exactly when do we load these?

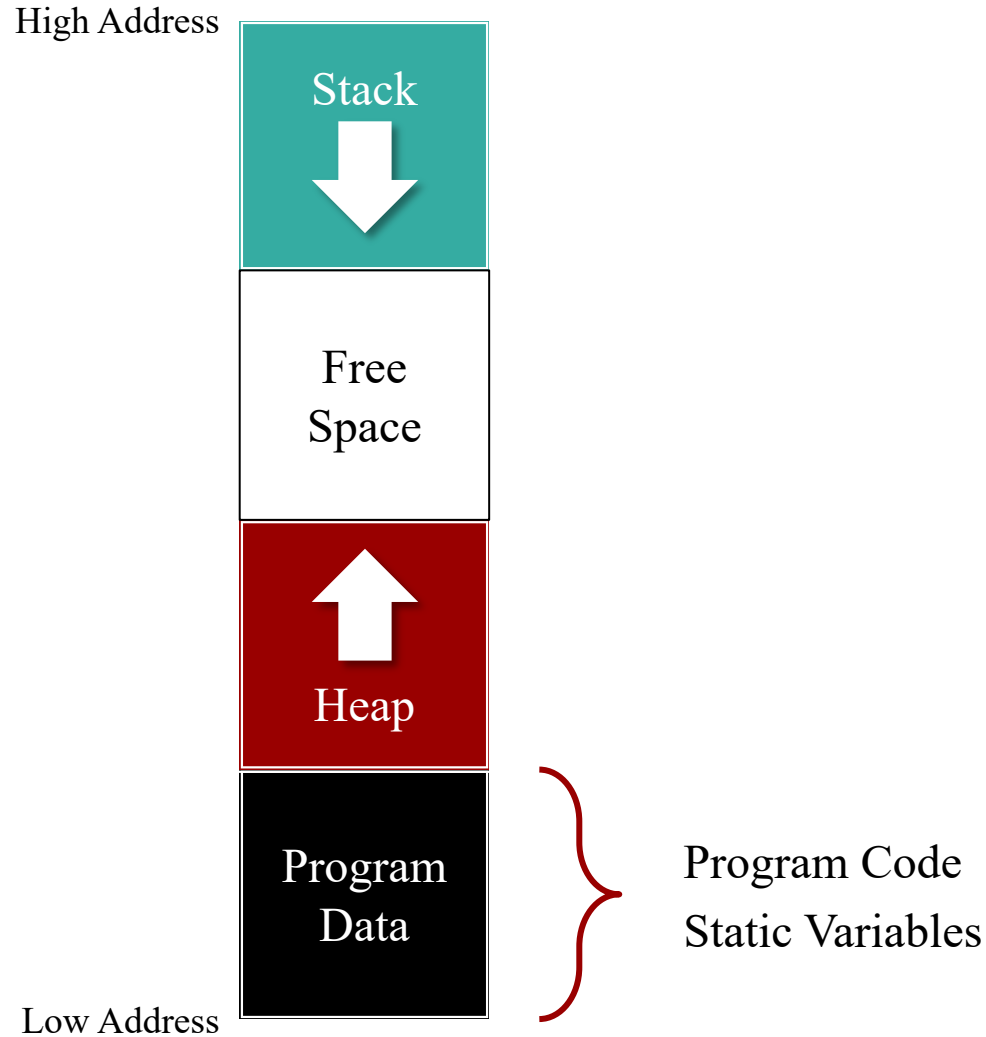
Custom Loaders in LibGDX

- The LibGDX asset system is modular
 - Use an asset manager to load/store assets
 - But each asset type has an associate **loader**
- A loader class has the following
 - Inner subclass of [AssetLoaderParameters](#)
 - Method [loadSync](#) for loading in main thread
 - Method [loadAsync](#) safe for separate threads
- GDIAC extensions have associated **parsers**
 - Reads asset json and sends information to loaders
 - Primarily an iterator for [AssetLoaderParameters](#)

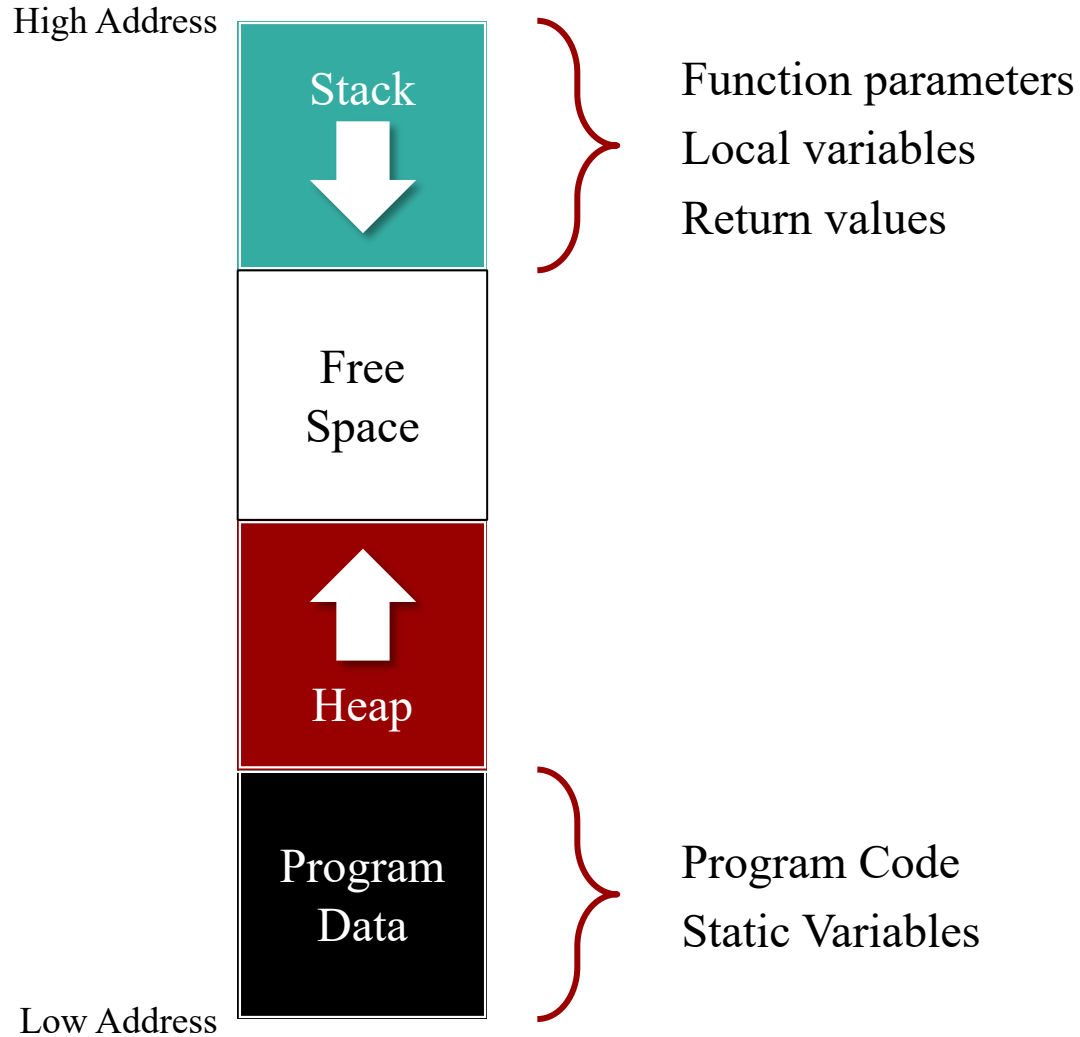
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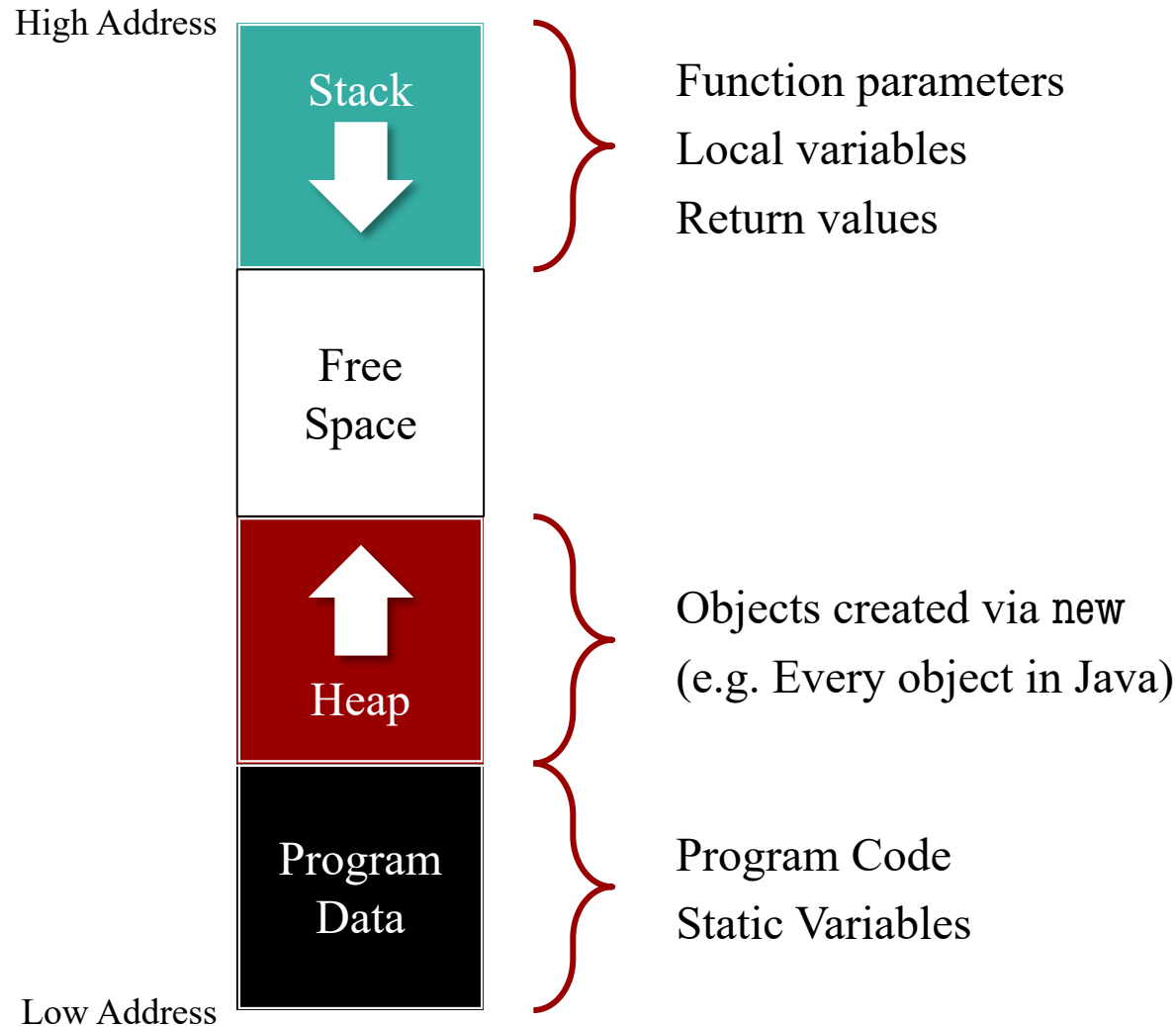
Traditional Memory Organization



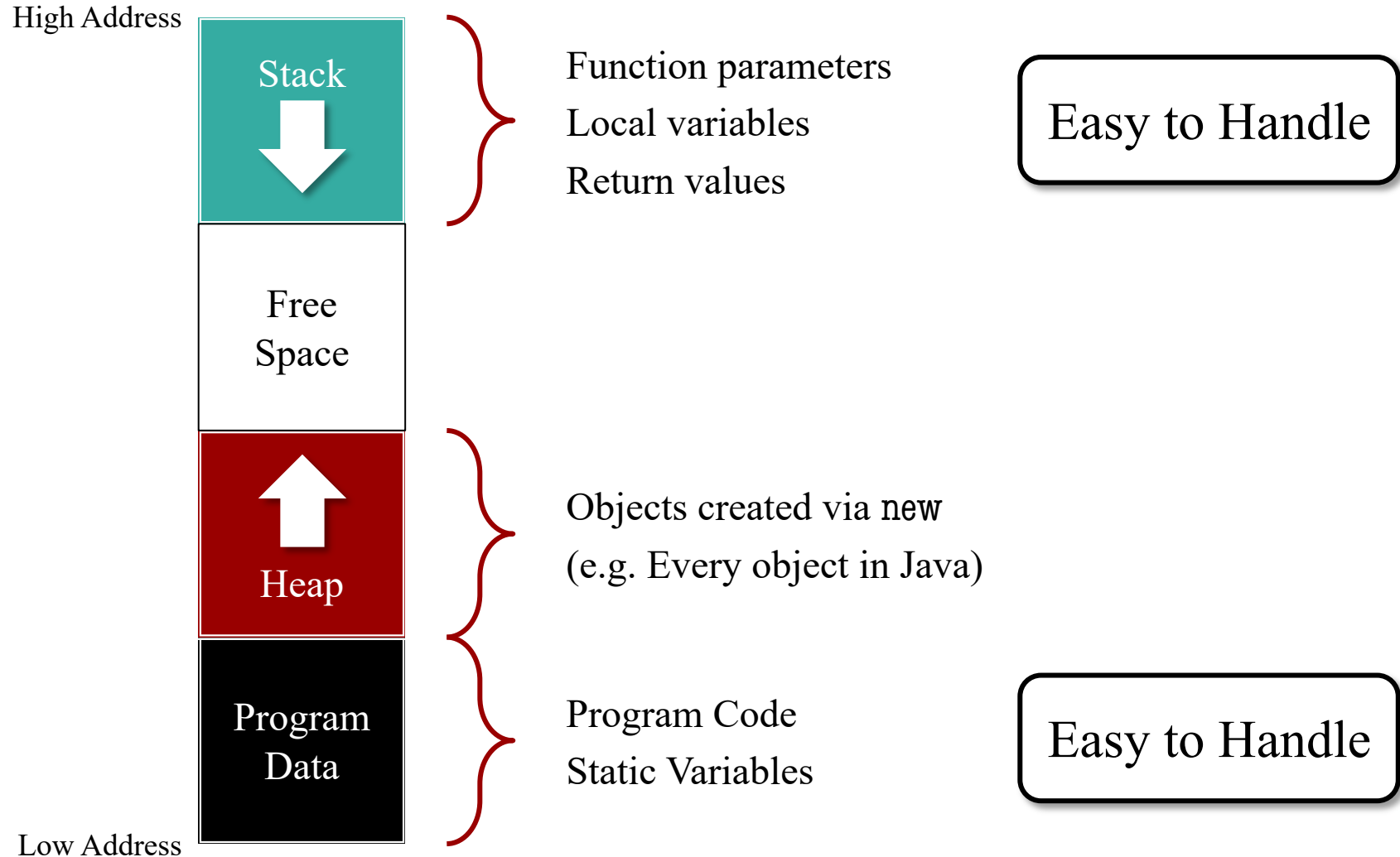
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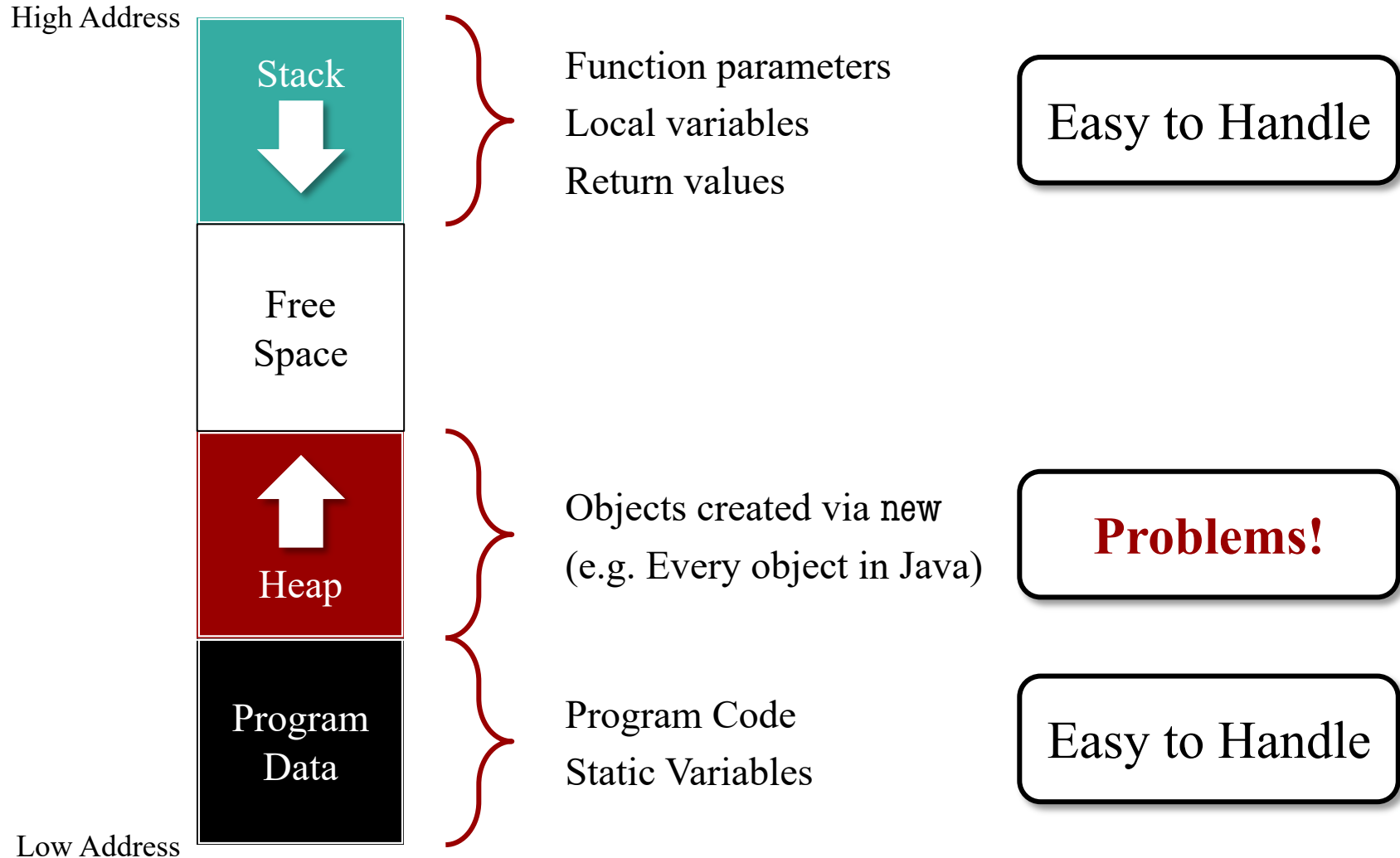
Traditional Memory Organization



Traditional Memory Organization



Traditional Memory Organization



Problem with Heap Allocation

- It can be slower to access
 - Not always contiguous
 - Stacks are nicer for caches
- Garbage collection is brutal
 - Old collectors would block
 - New collectors are better...
 - ...but slower than manual
- Very bad if high churn
 - Rapid creation/deletion
 - **Example:** Particle systems

```
private void handleCollision(Shell s1, Shell s2) {  
    // Find the axis of "collision"  
    Vector2 axis = new Vector2(s1.getPosition());  
    axis.sub(s2.getPosition());  
  
    ...  
  
    // Compute the projections  
    Vector2 temp1 = new Vector2(s2.getPosition());  
    temp1.sub(s1.getPosition()).nor();  
    Vector2 temp2 = new Vector2(s1.getPosition());  
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    // Compute new velocities  
    temp1.scl(temp1.dot(s1.getVelocity()));  
    temp2.scl(temp2.dot(s2.getVelocity()));  
  
    // Apply to the objects  
    s1.getVelocity().sub(temp1).add(temp2);  
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}
```


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    axis.sub(s2.getPosition());
```

...

Created/deleted every frame

```
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```

```
}
```

Aside: Stack Based Allocation

- C++ can put objs on stack
 - Object deleted at end of call
 - No GC computation at all
 - Good for short-life objects
- Java can *approximate* this
 - Checks if local to function
 - If so, will delete it
- But not a perfect solution
 - Can never **return** object
 - Init has hidden costs

```
void getCollides(Shell s1, Shell s2) {  
    // Find collision axis  
    Vector2 axis = new  
        Vector2(s1.getPosition());  
    axis.sub(s2.getPosition());  
    axis.nor();  
    axis.scale(s1.getRadius());  
  
    // Find collision location  
    Vector2 spot = new  
        Vector2(s1.getPosition());  
    spot.add(axis);  
  
    return spot;  
}
```

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    axis.sub(s2.getPosition());  
    axis.nor();  
    axis.scale(s1.getRadius());  
  
    // Find collision  
    Vector2 spot = Vector2(s1.getPosition());  
    spot.add(axis);  
  
    return spot;  
}
```

Deleted

Not Deleted

Aside: Java Garbage Collection

- **Parallel Garbage Collector** (The Default)
 - **Freezes your application** when it collects
- **Serial Garbage Collector** (-XX:+UseSerialGC)
 - Like PGC but better for simple programs
- **CMS Garbage Collector** (-XX:+UseParNewGC)
 - Concurrent mark-and-sweep rarely freezes app
- **G1 Garbage Collector** (-XX:+UseG1GC)
 - Even less app freezing at cost of large heap size

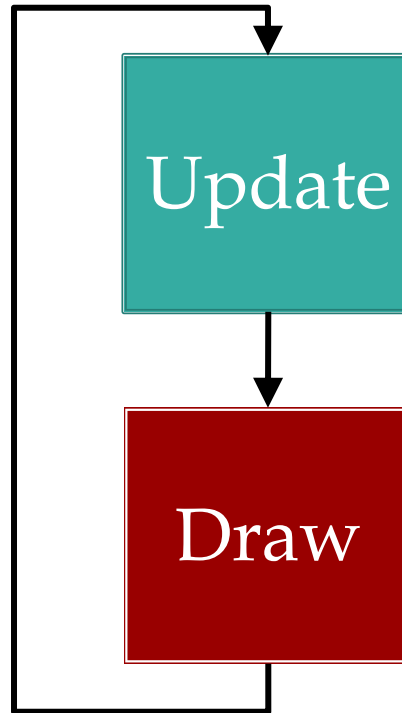
Aside: Java Garbage Collection

- **Parallel Garbage Collector** (The Default)
 - **Freezes your application** when it collects
- **Serial Garbage Collector** (-XX:+UseSerialGC)
 - Like PG
- **CMS Garbage Collector** (-XX:+UseCMSGC) **Andrew Myer's preferred GC for high performance Java**
 - Concurrent **stop-the-world** sweep **freezes app**
- **G1 Garbage Collector** (-XX:+UseG1GC)
 - Even less app freezing at cost of large heap size

Memory Organization and Games

Inter-Frame Memory

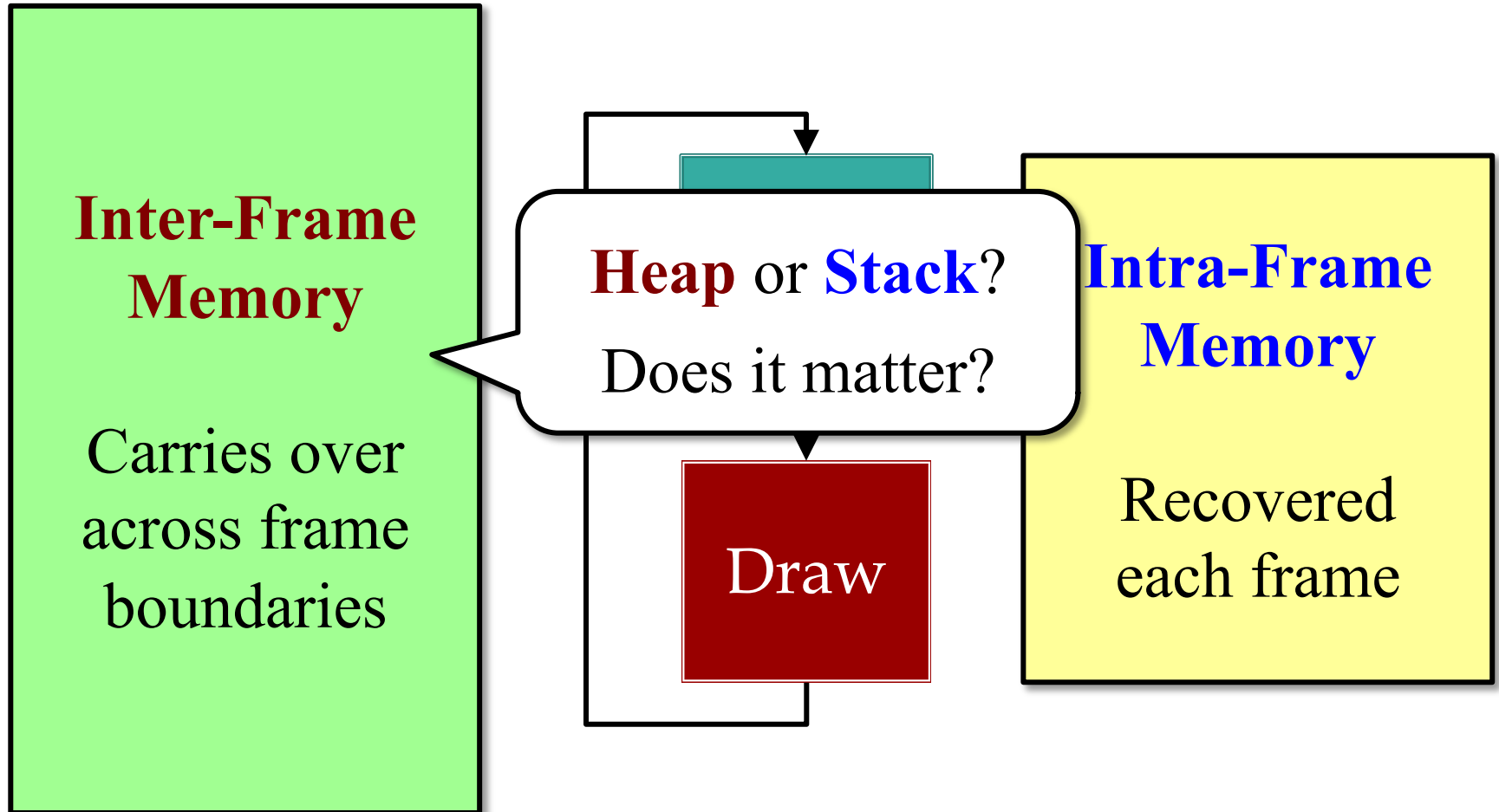
Carries over across frame boundaries



Intra-Frame Memory

Recovered each frame

Memory Organization and Games



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

Distinguishing Data Types

Intra-Frame

- **Local computation**

- Local variables
(memory objects per frame)
- **Local Variables**
(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
- **Object Fields**
(state and caches)

- **Long-term data structures**

- Built at start/during frame
- Lasts for multiple frames
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Distinguishing Data Types

Intra-Frame

- **Local computation**

- Local variables
(memory objects)
- **Local Variables**
(not necessarily managed)

- **Transient data structures**

- Built at the start of the frame and updated
- **e.g. Collisions**
- Deleted at end of frame

Inter-Frame

- **Game state**

- Model instances
- **Object Fields**
- Caches and caches

- **Long-term data structures**

- Built at start/end of frame
- **e.g. Pathfinding**
- Adjust to data changes

Handling Game Memory

Intra-Frame

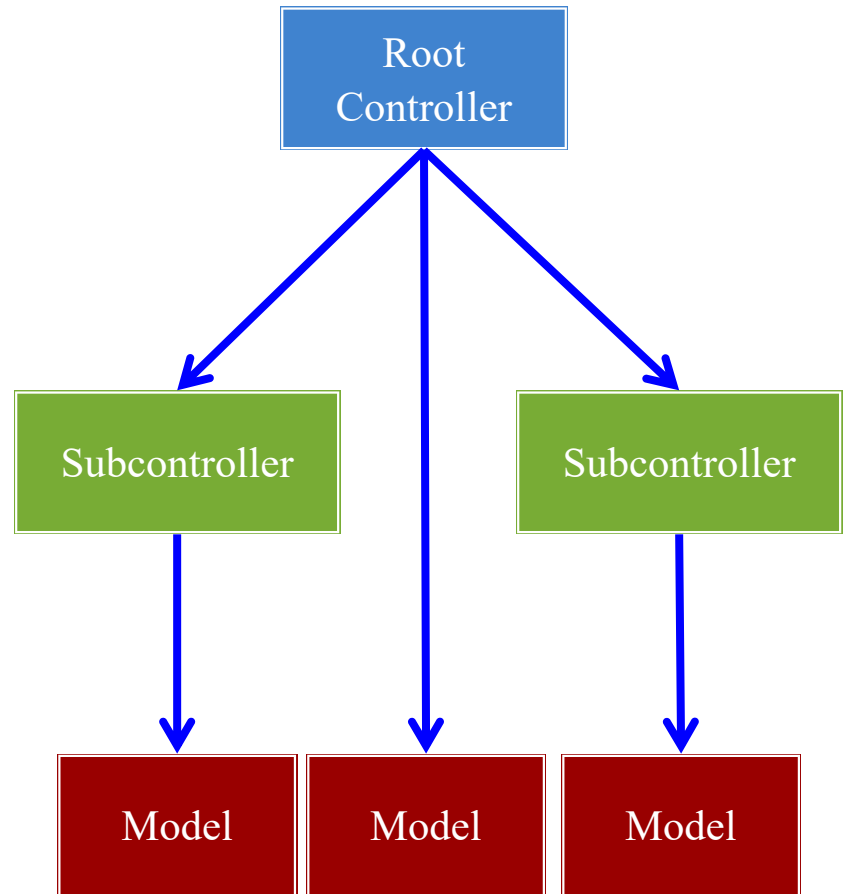
- Does not need to be paged
 - Drop the latest frame
 - Restart on frame boundary
- Want size reasonably **fixed**
 - Local variables always are
 - Limited # of allocations
 - Limit new inside loops
- Make use of **cached objects**
 - Requires careful planning

Inter-Frame

- Potential to be paged
 - Defines current game state
 - May just want level start
- Size is more **flexible**
 - No. of objects is variable
 - Subsystems may turn on/off
 - User settings may affect
- **Preallocate** as possible
 - Recycle with **free lists**

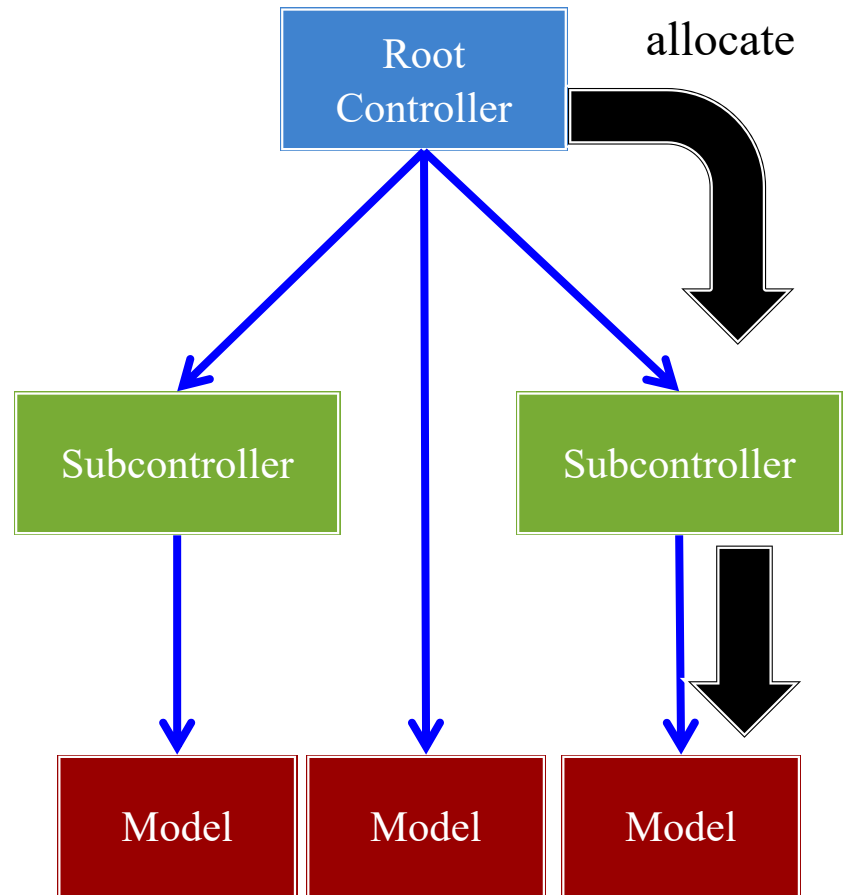
Rule of Thumb: Limiting new

- Limit new to constructors
 - Identify the object owner
 - Allocate in owner constructor
- **Example:** cached objects
 - Look at what algorithm needs
 - Allocate all necessary objects
 - Algorithm just sets the cache
- **Problem:** readability
 - Naming is key to readability
 - But new names = new objects
 - Make good use of comments



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private void handleCollision(Shell s1, Shell s2) {  
    // Find the axis of "collision"  
    axis.set(s1.getPosition());  
    axis.sub(s2.getPosition());  
  
    ...  
  
    // Compute the projections  
    temp1.set(s2.getPosition());  
    temp1.sub(s1.getPosition()).nor();  
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    // Apply to the objects  
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```

Object Preallocation

- **Idea:** Allocate before need
 - Compute maximum needed
 - Create a list of objects
 - Allocate contents at start
 - Pull from list when needed

```
// Allocate all of the particles
Particle[] list = new Particle[CAP];
for(int ii = 0; ii < CAP; ii++) {
    list[ii] = new Particle();
}
```

- **Problem:** Running out
 - Eventually at end of list
 - Want to reuse older objects
 - Easy if deletion is FIFO
 - But what if it isn't?

```
// Keep track of next particle
int next = 0;
```

...

```
// Need to “allocate” particle
Particle p = list[next++];
p.set(...);
```

- Motivation for **free list**

Free Lists

- Create an object **queue**
 - Separate from preallocation
 - Stores objects when “freed”
- To allocate an object...
 - Look at front of free list
 - If object there take it
 - Otherwise make new object
- Preallocation unnecessary
 - Queue wins in long term
 - Main performance hit is garbage collector

```
// Free the new particle  
freelist.push(p);
```

```
...
```

```
// Allocate a new particle  
Particle q;
```

```
if (!freelist.isEmpty()) {  
    q = freelist.pop();  
} else {  
    q = new Particle();  
}
```

```
q.set(...)
```

LibGDX Support: Pool

Pool<T>

- `public void free(T obj);`
 - Add an object to free list
- `public T obtain();`
 - Use this in place of new
 - If object on free list, use it
 - Otherwise make new object
- `public T newObject();`
 - Rule to create a new object
 - Could be preallocated

Pool.Poolable

- `public void reset();`
 - Erases the object contents
 - Used when object freed
- Must be implemented by T
 - Parameter free constructors
 - Set contents with initializers
- See MemoryPool demo
 - Also PooledList in Lab 4

Summary

- Memory usage is always an issue in games
 - Uncompressed images are quite large
 - Particularly a problem on mobile devices
- Asset loading must be balanced with animation
 - LibGDX uses an incremental approach
- Limit calls to new in your animation frames
 - **Intra-frame** objects: **cached objects**
 - **Inter-frame** objects: **free lists**