the gamedesigninitiative at cornell university

Lecture 9

Memory Management: High-Level Overview

Gaming Memory (Last Generation)

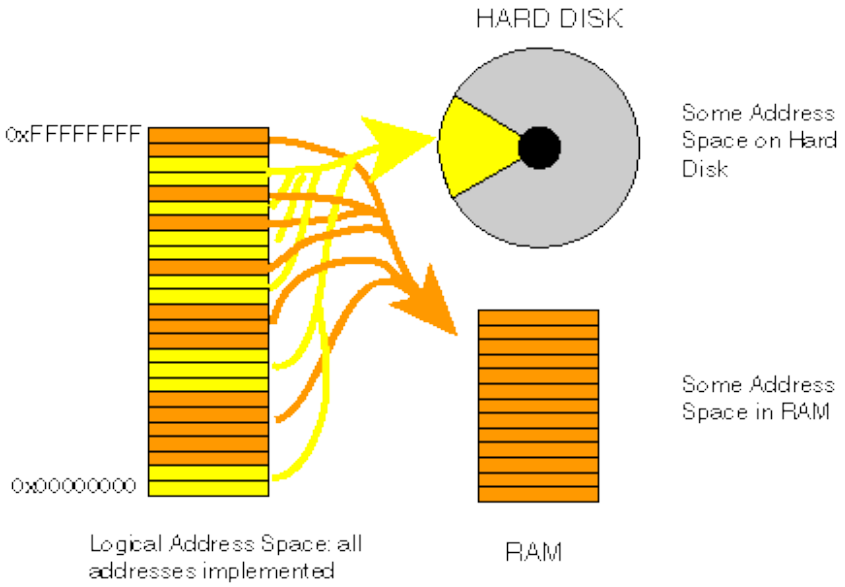
- Playstation 3
  - 256 MB RAM for system
  - 256 MB for graphics card
- X-Box 360
  - 512 MB RAM (unified)
- Nintendo Wii
  - 88 MB RAM (unified)
  - 24 MB for graphics card
- **iPhone/iPad**
  - **1 GB RAM (unified)**

Gaming Memory (Current Generation)

- Playstation 4
  - 8 GB RAM (unified)
- X-Box One
  - 8 GB RAM (unified)
  - 5 GB for games
- Nintendo Wii-U
  - 2 GB RAM (unified)
  - 1 GB only for OS
- **iPhone/iPad**
  - **1 GB RAM (unified)**

Why Not Virtual Memory?

- **Secondary storage** exists
  - Consoles have 500 GB HD
  - iDevices have 64 GB Flash
- But **access time** is slow
  - HDs transfer at ~160 MB/s
  - Best SSD is ~500 MB/s
- Recall **16 ms** per frame
  - At best, can access 8 MB
  - Yields uneven performance

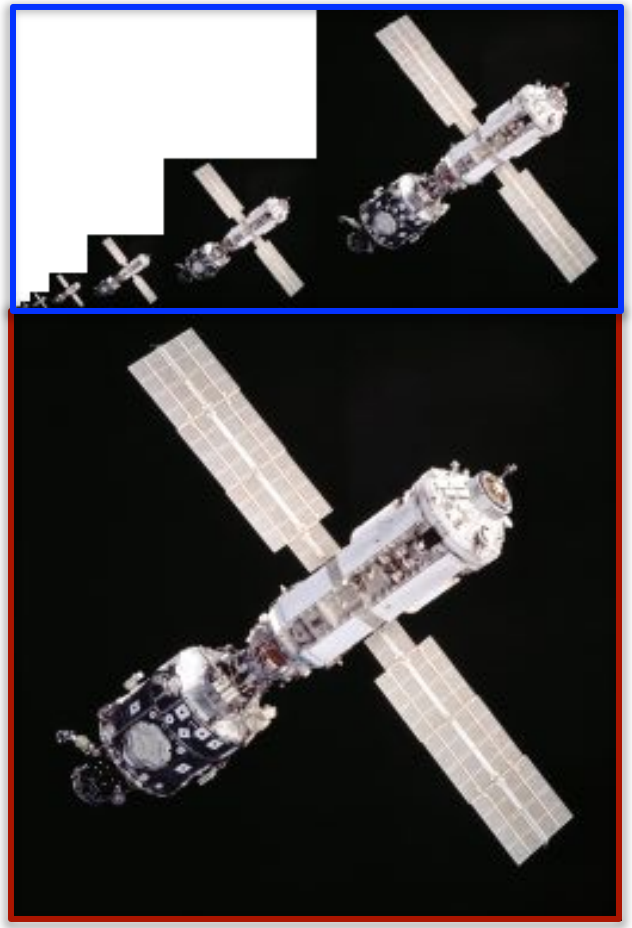


Memory Usage: Images

- 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

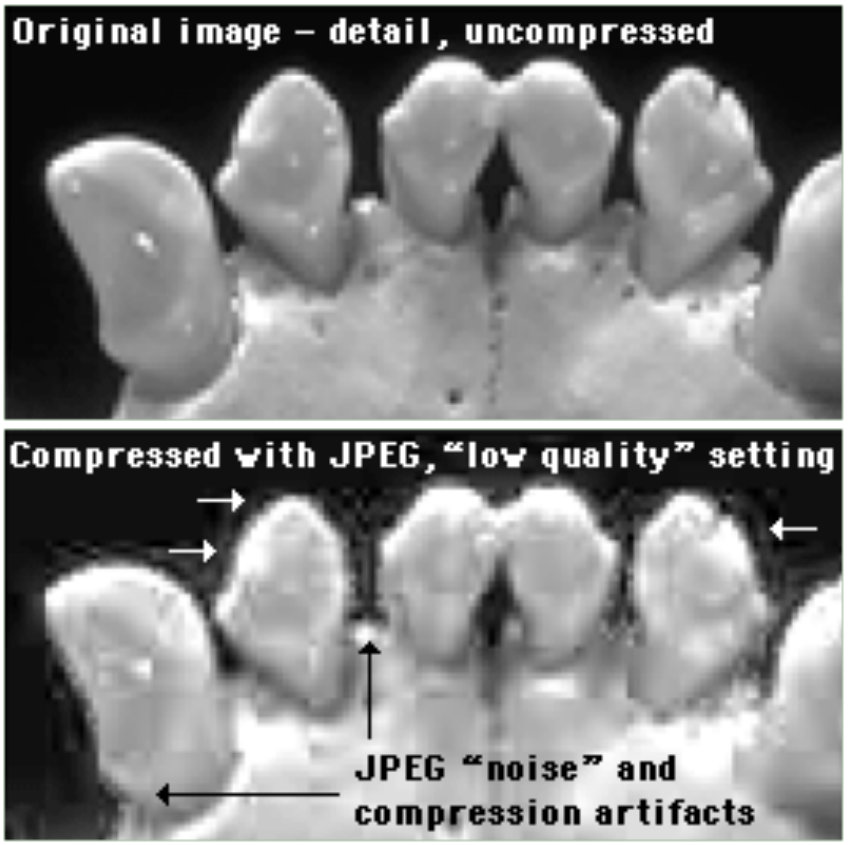
MipMaps

Original Image

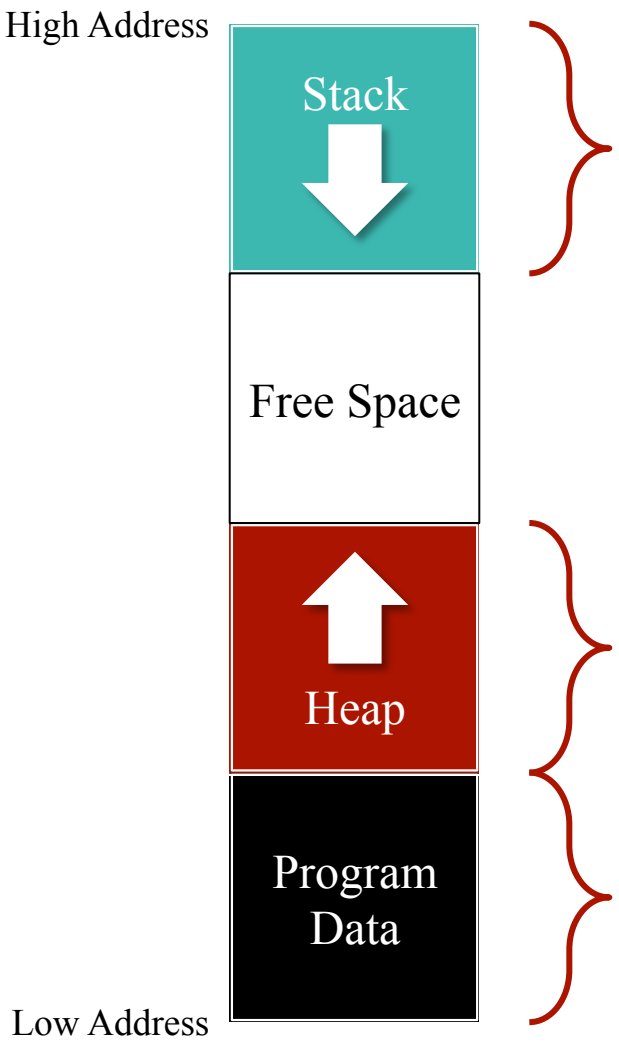


But My JPEG is only 8 KB!

- Formats often **compressed**
  - JPEG, PNG, GIF
  - But not always TIFF
- Must **uncompress** to display
  - Need full pixels to uncompress
  - In RAM or graphics card
- Only load when needed
  - Texture loading is primary I/O operation in high-end games
  - Many tricks to optimize
  - The cause of "texture popping"



Traditional Memory Organization



Function parameters
Local variables
Return values

Easy to Track

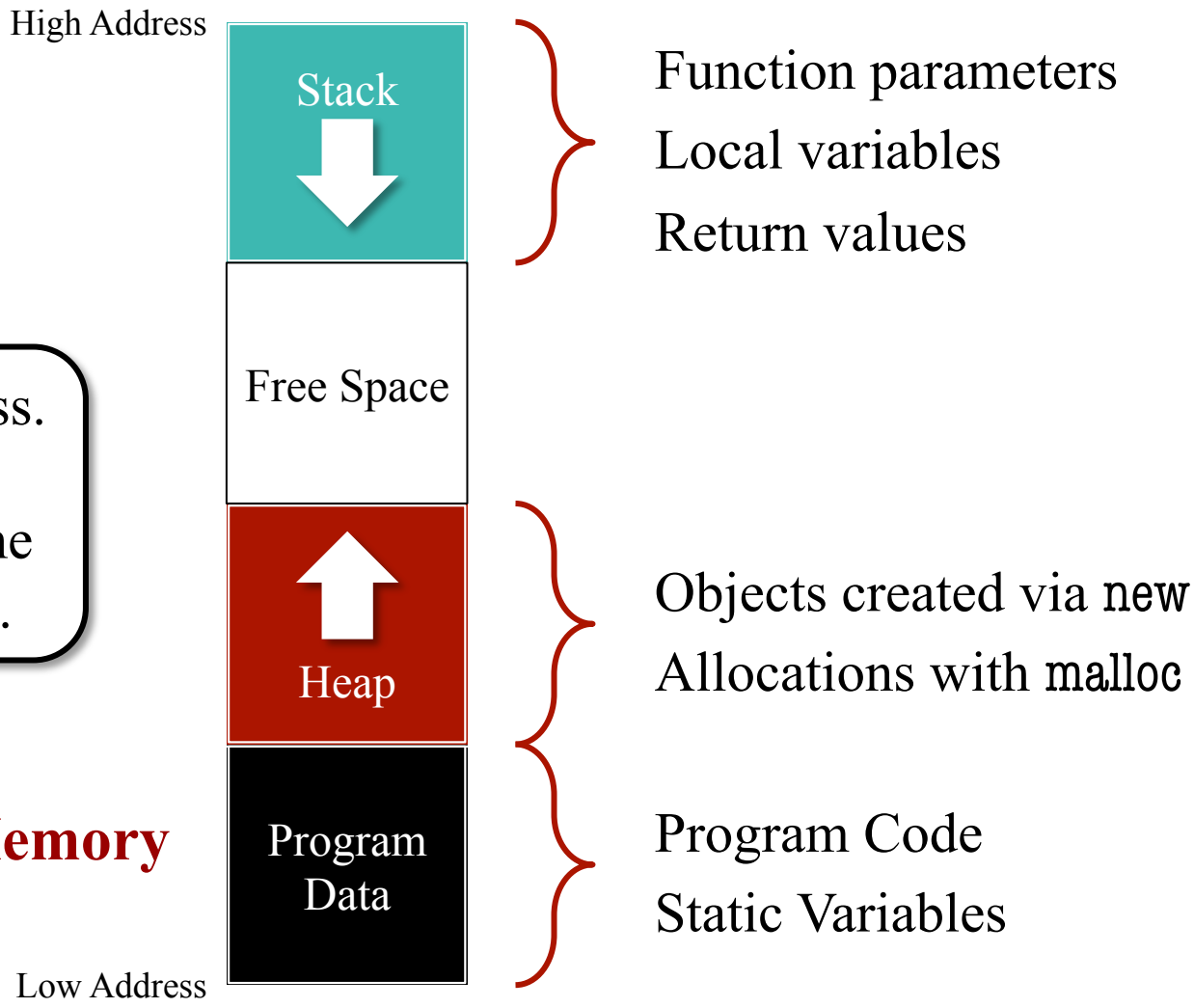
Objects created via `new`
Allocations with `malloc`

Problems!

Program Code
Static Variables

Easy to Track

Traditional Memory Organization



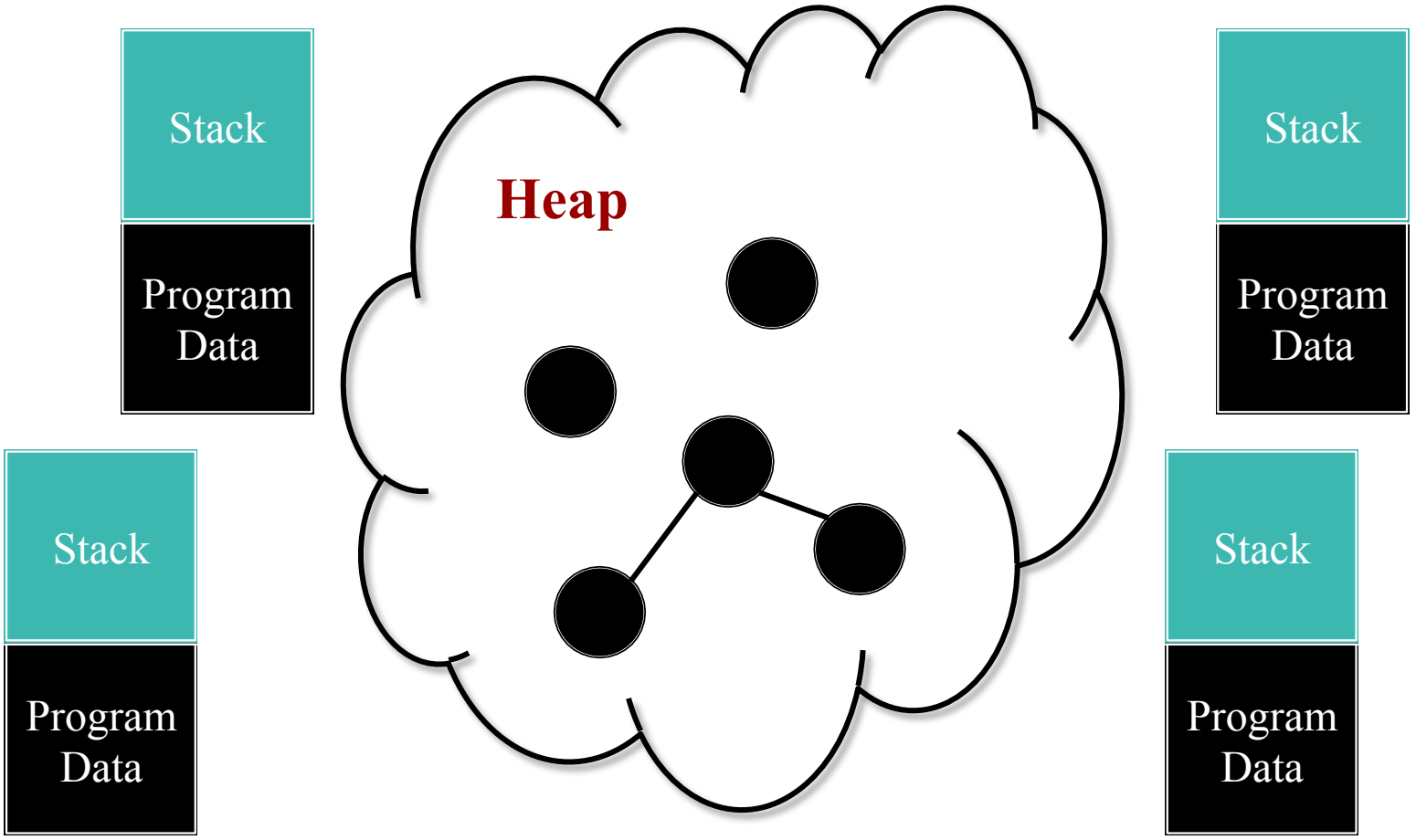
Dedicated to process.

Consists of machine addressable space.

Leverages Virtual Memory

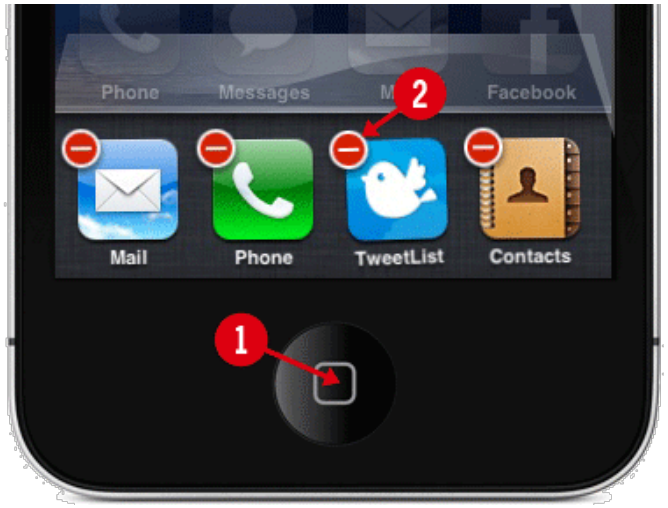
Mobile Memory Organization

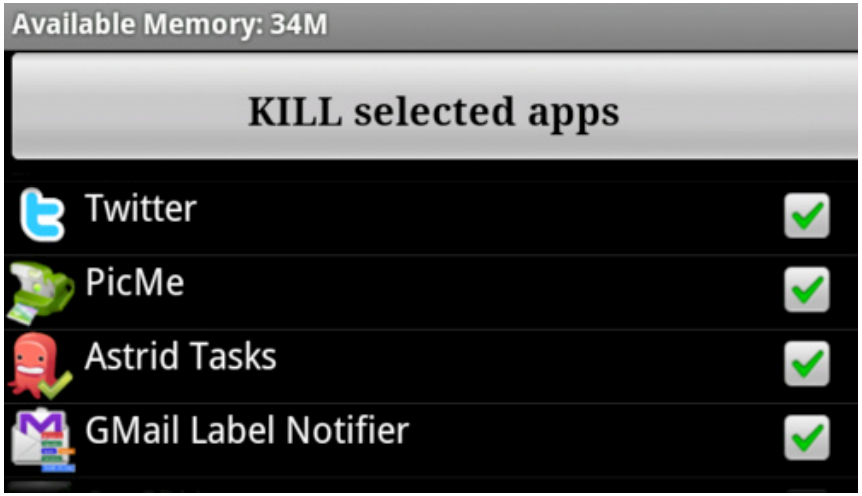
Device Memory



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
  - **iOS**: 5 min (or so) on exit
  - **Android**: If needed
- Suspend apps can *recover*
  - OS allows limited paging
  - Page out on suspension
  - Page back in on restart





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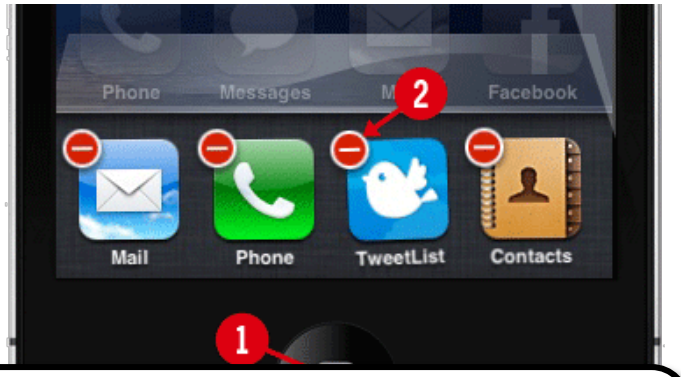

Can override in **iOS 7**

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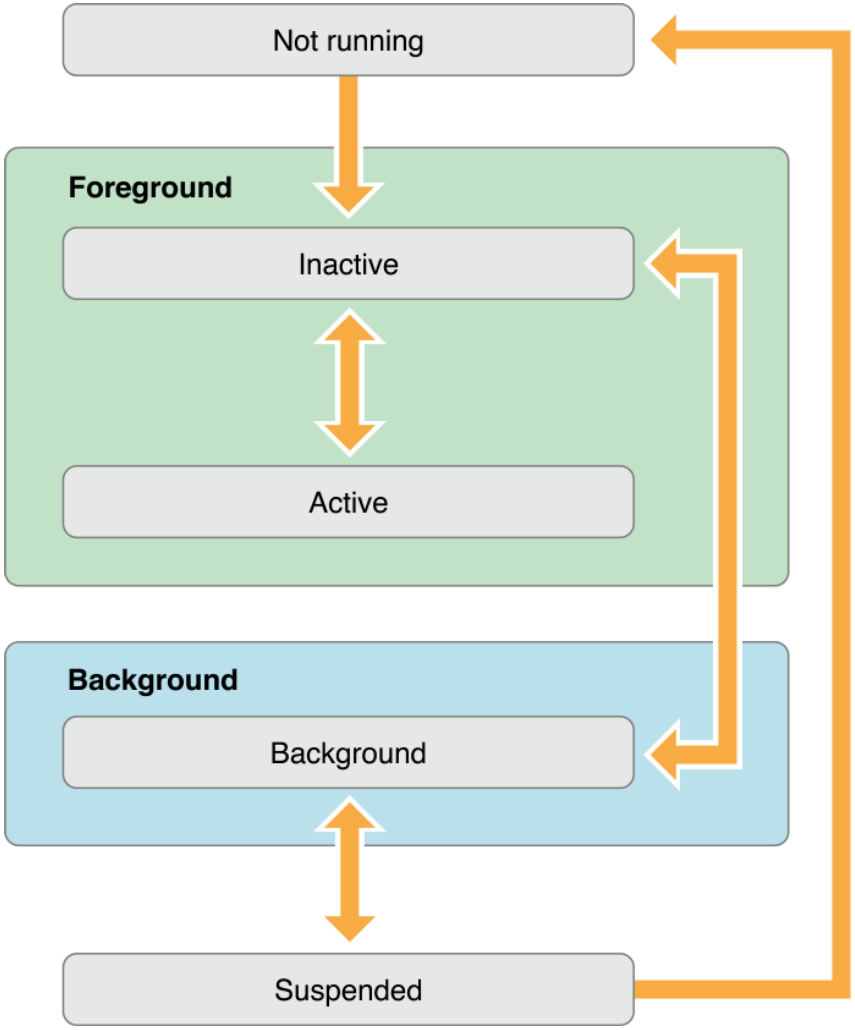
State Mangagement in iOS 7



- **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

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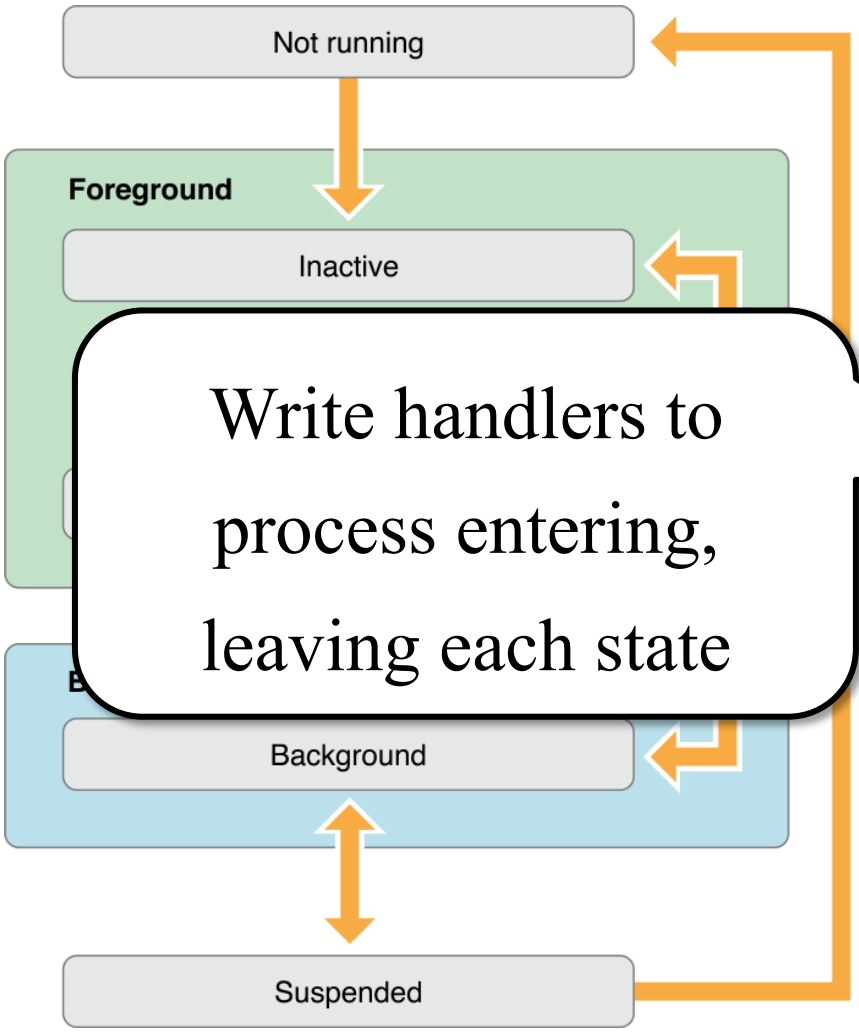

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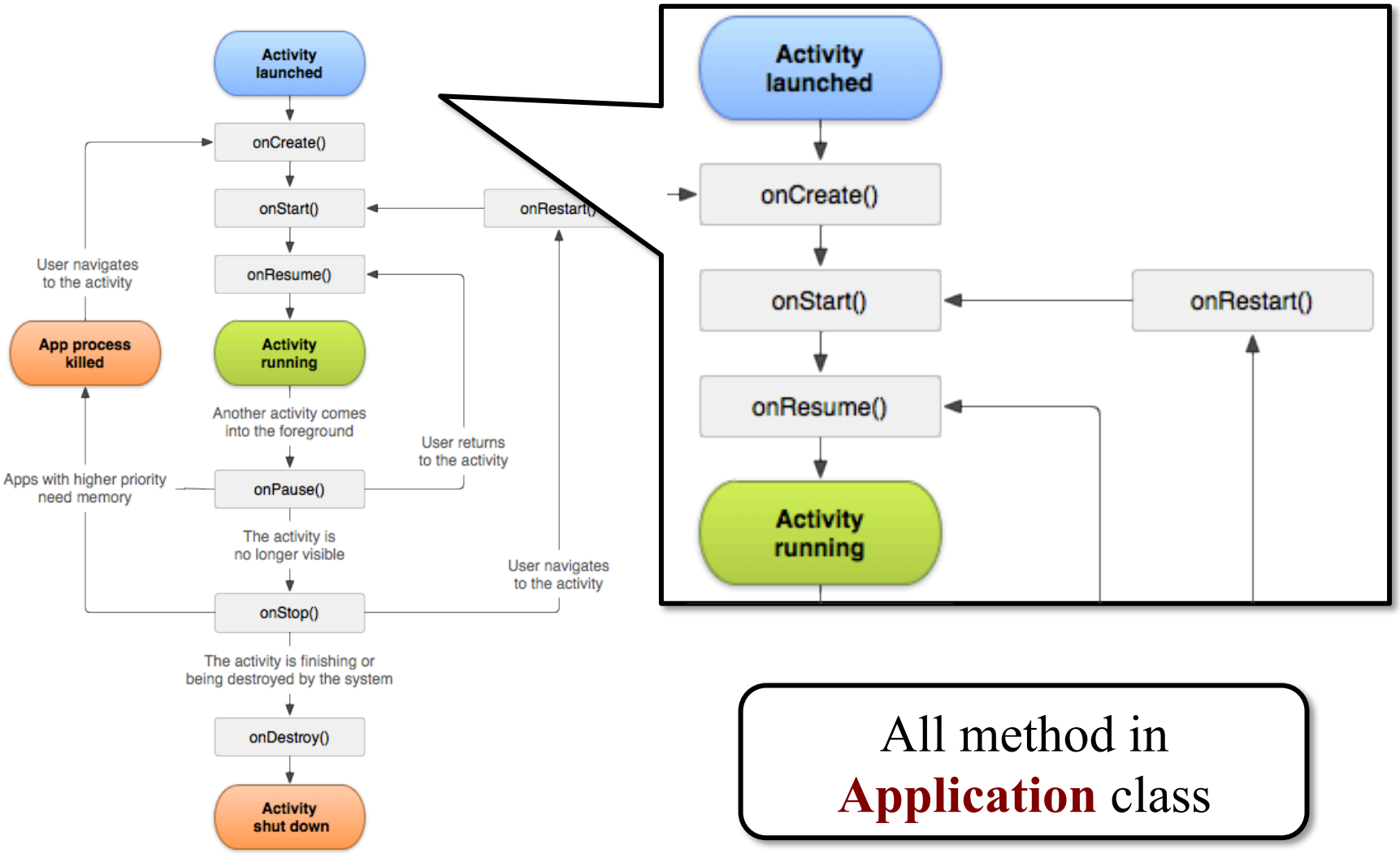
- **Suspended**
  - Stopped & Memory freed

iOS State Handling

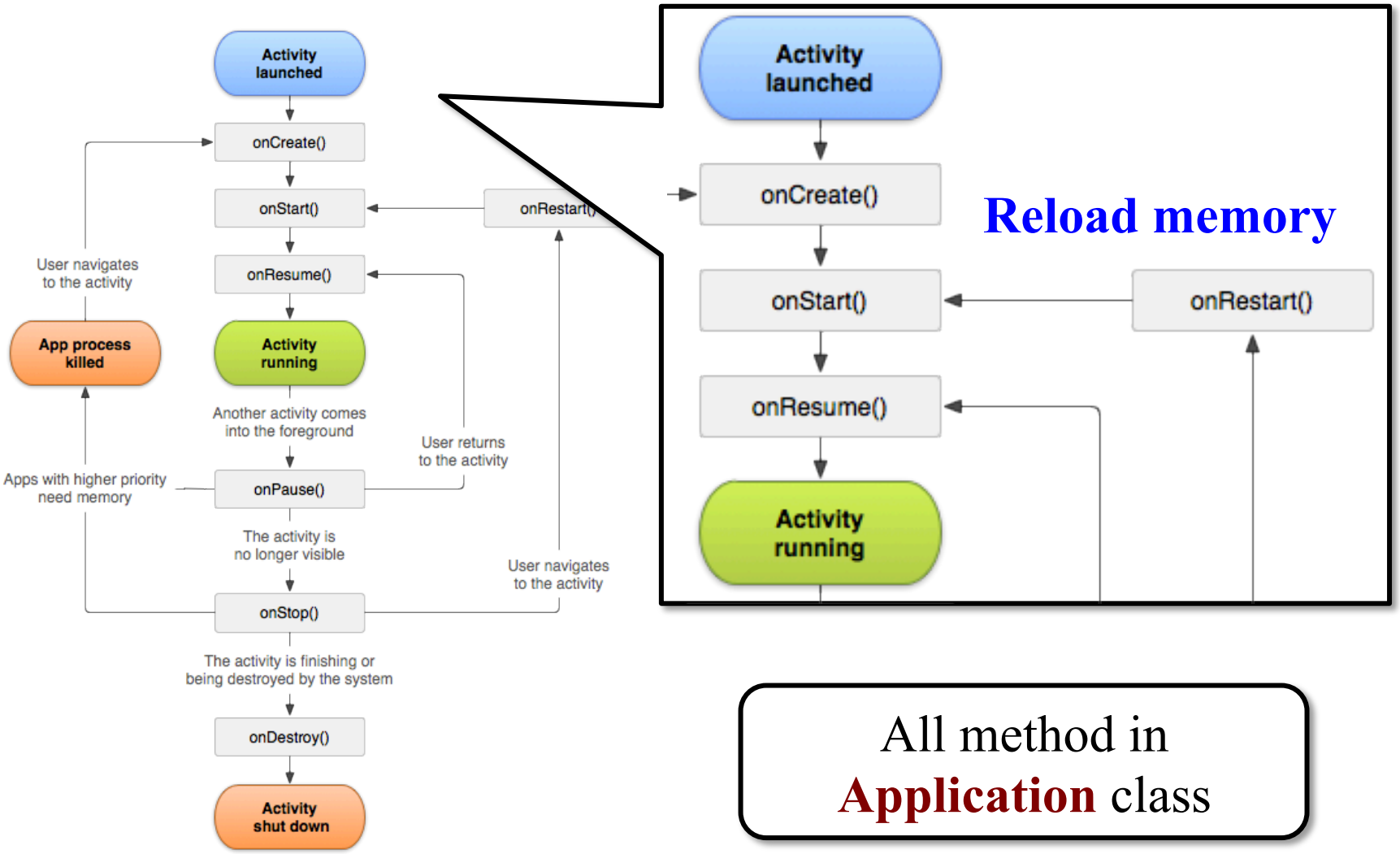
- `applicationDidBecomeActive:`
  - Your app became (resumed as) the foreground app.
  - Use this to recover memory state.
- `applicationWillResignActive:`
  - Your app will switch to inactive or background.
  - Stop the game loop and page out memory.
- `applicationDidEnterBackground:`
  - Your app is in the background and may be suspended.
- `applicationWillEnterForeground:`
  - Your app is leaving the background, but is not yet active.

Android State Handling



All method in **Application** class

Android State Handling



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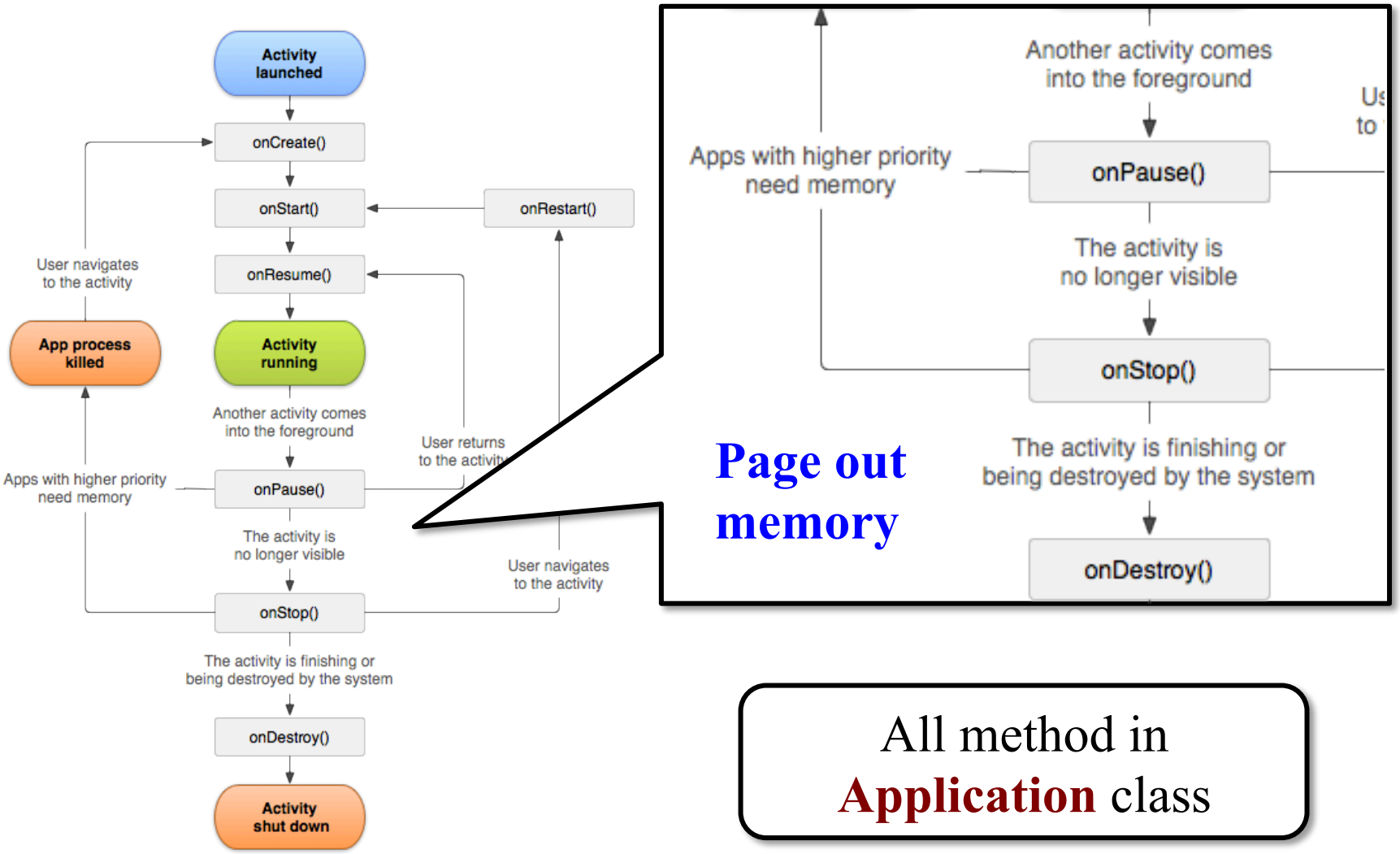

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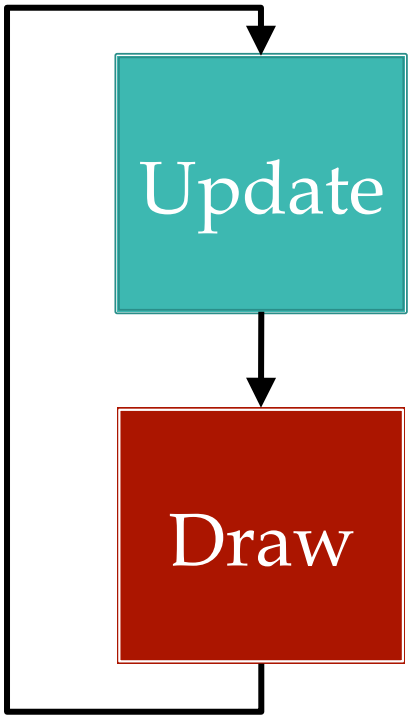
Memory Organization and Games

Inter-Frame Memory

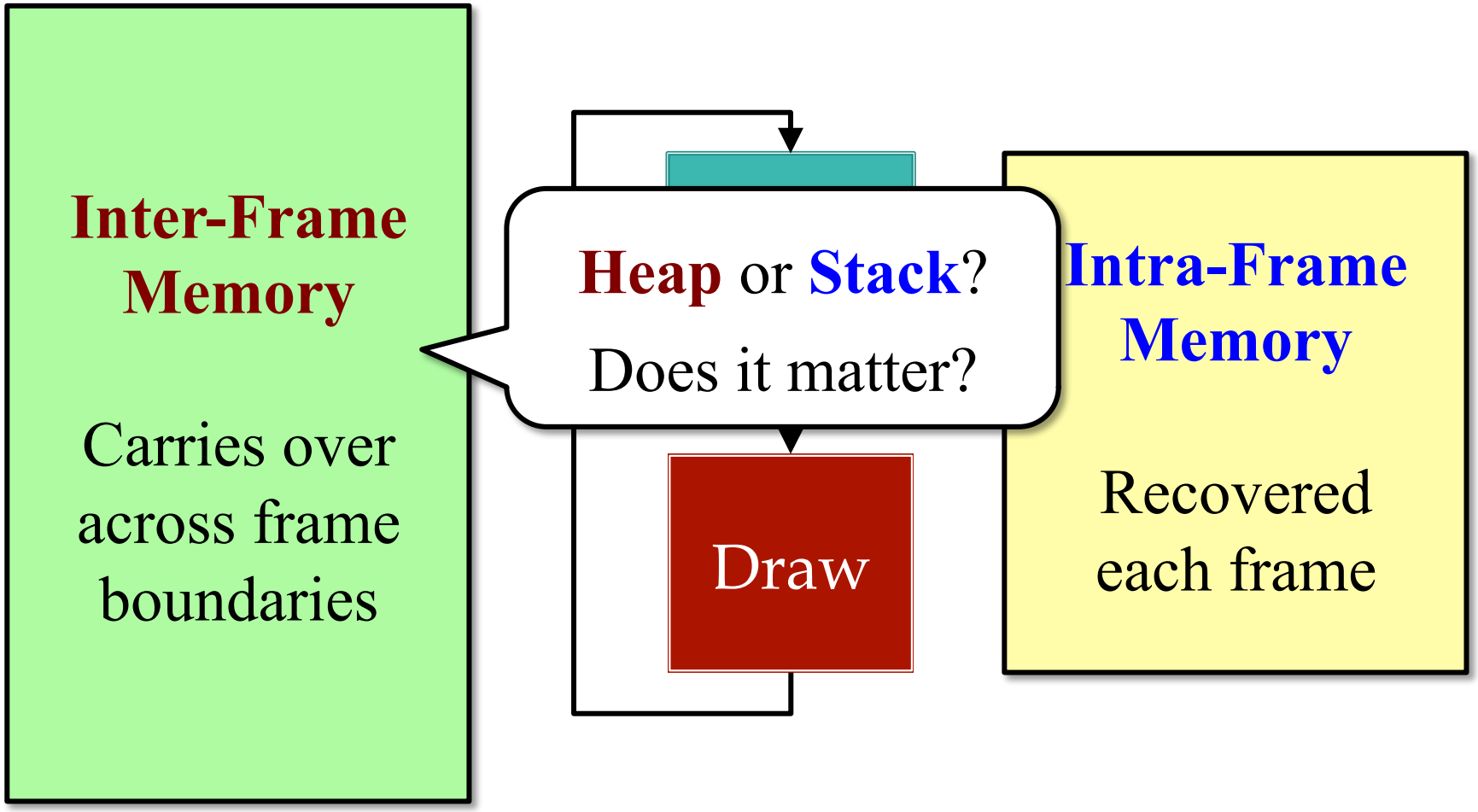
Carries over across frame boundaries



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

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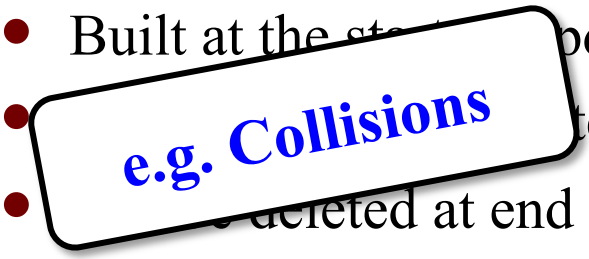

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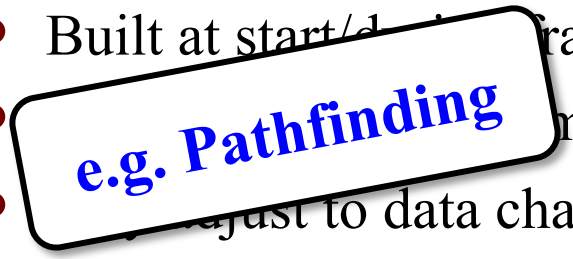


Handling Game Memory

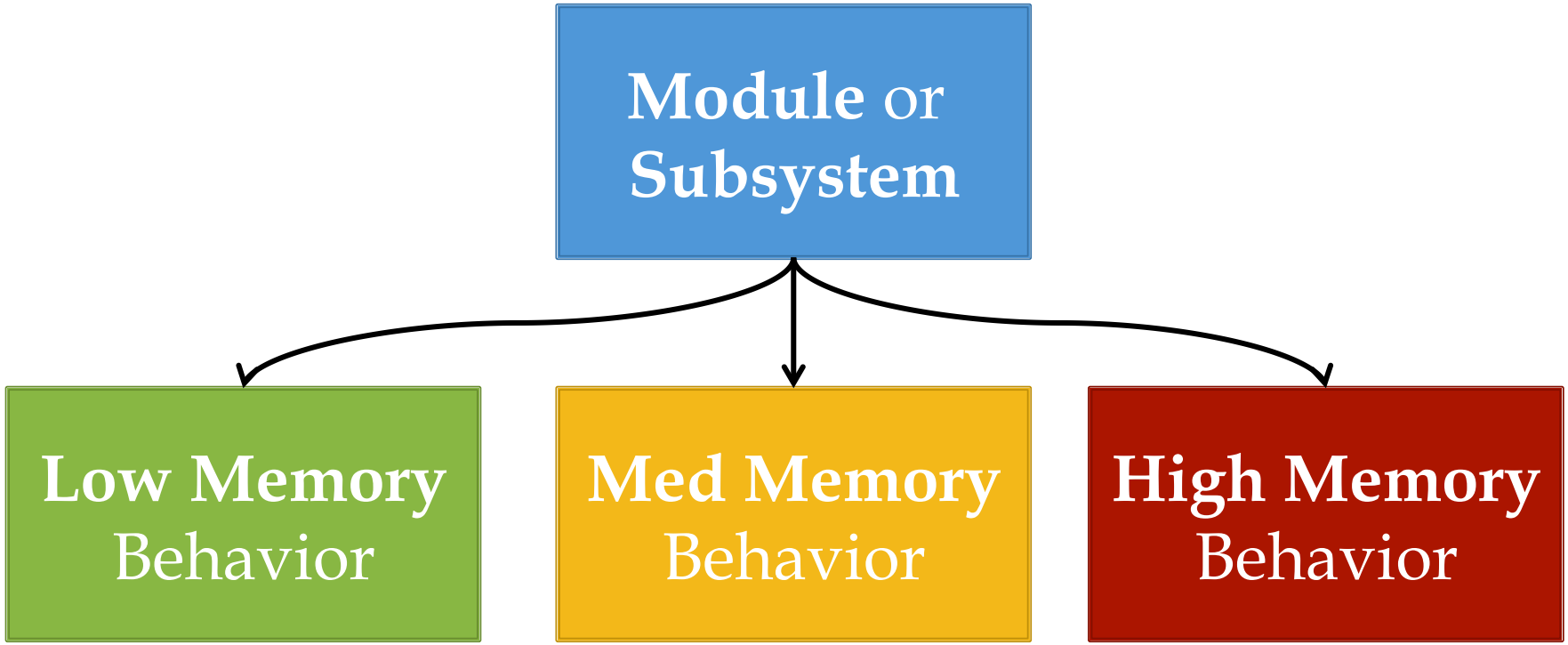
Intra-Frame

- 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
- Often use **custom allocator**
  - GC at frame boundaries

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
- **OS allocator** okay, but…
  - May want to use a **budget**

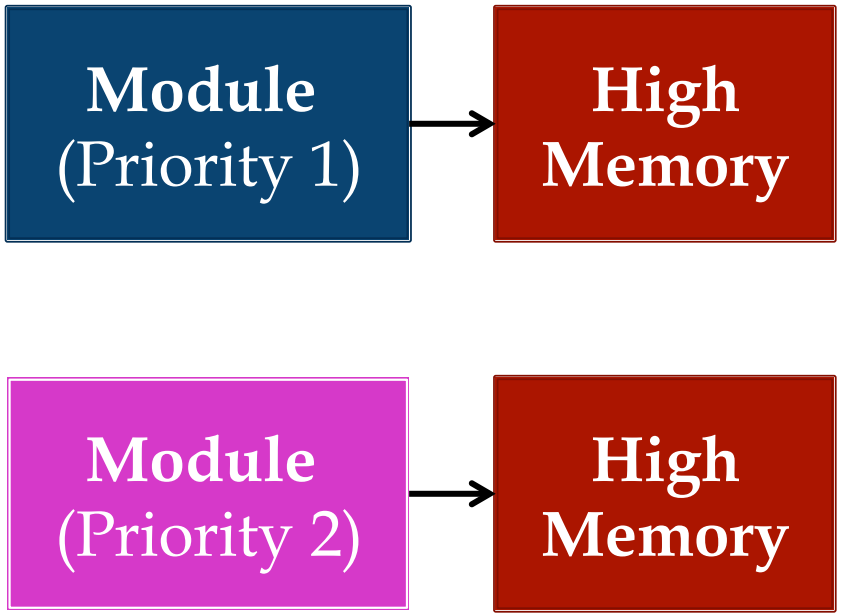
Budgeting Memory



Design each of these separately

Budgeting Memory

- Module chooses approach
  - Based on priority setting
  - Based on previous attempts
- At **each allocation** checks
  - Is there enough memory?
  - Conflict with other module?
  - Has my priority changed?
- If it must **downgrade**
  - Release all allocations
  - Start over completely



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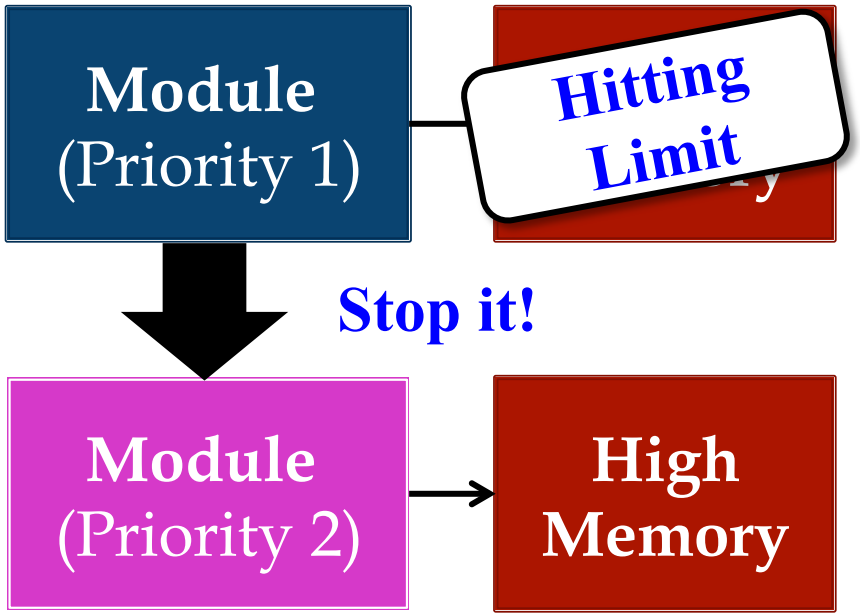

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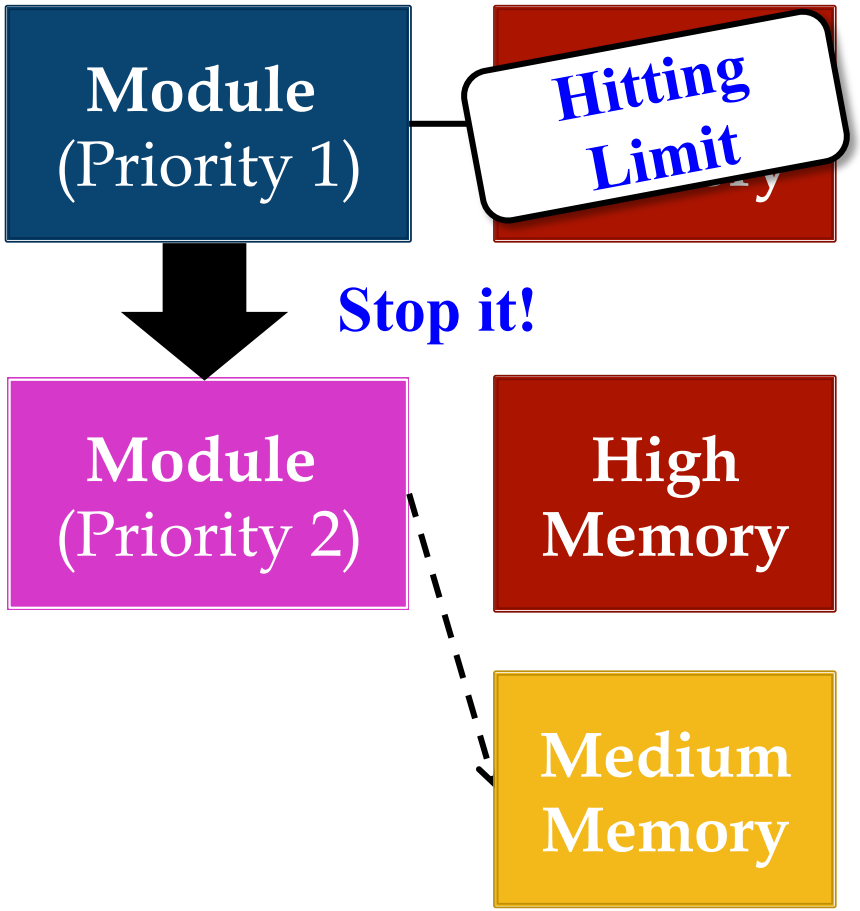
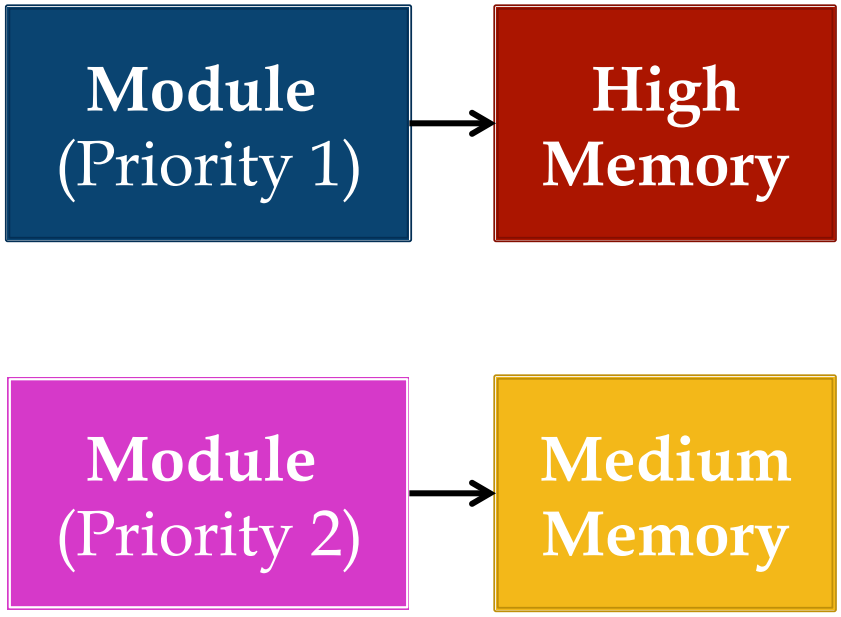


Communication Can Be Sophisticated



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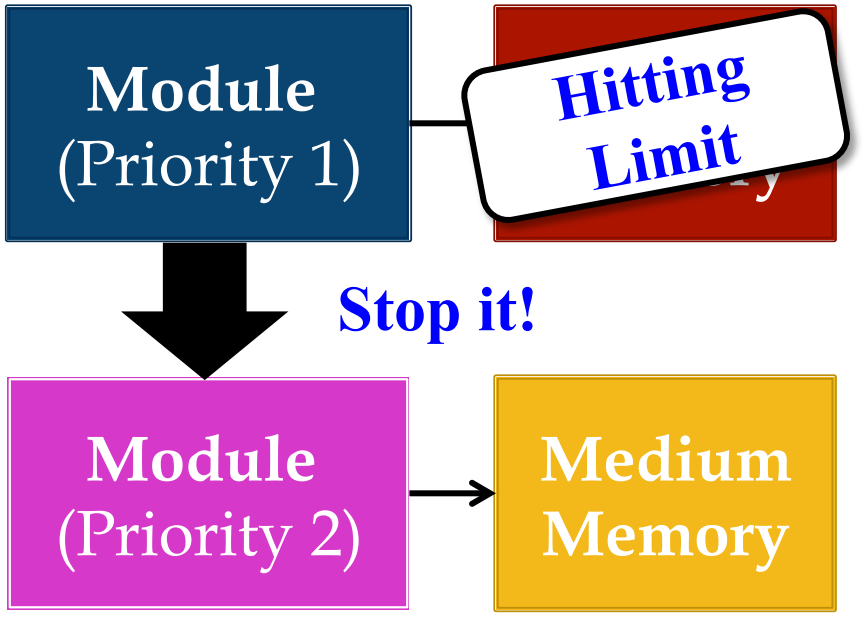

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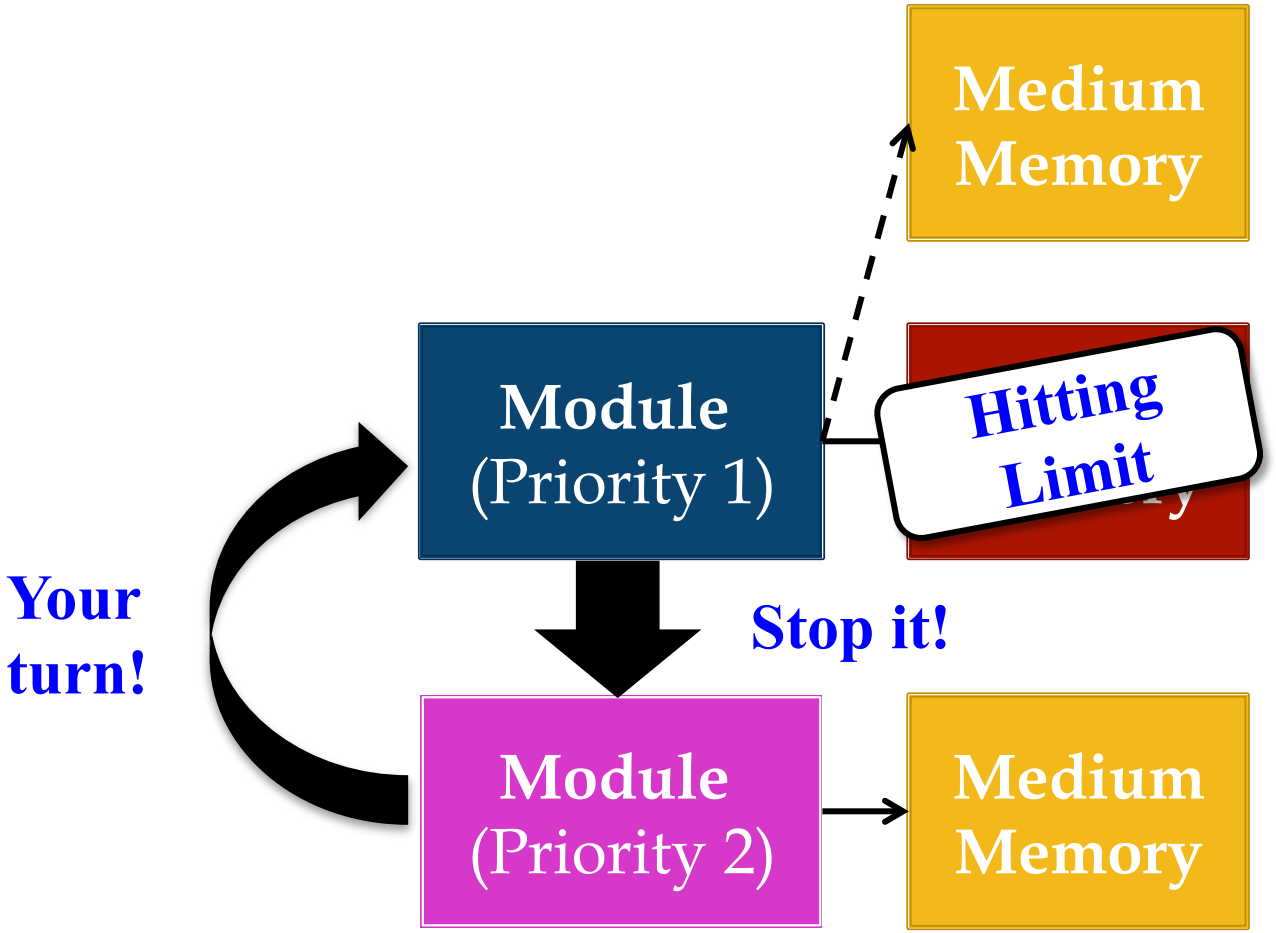
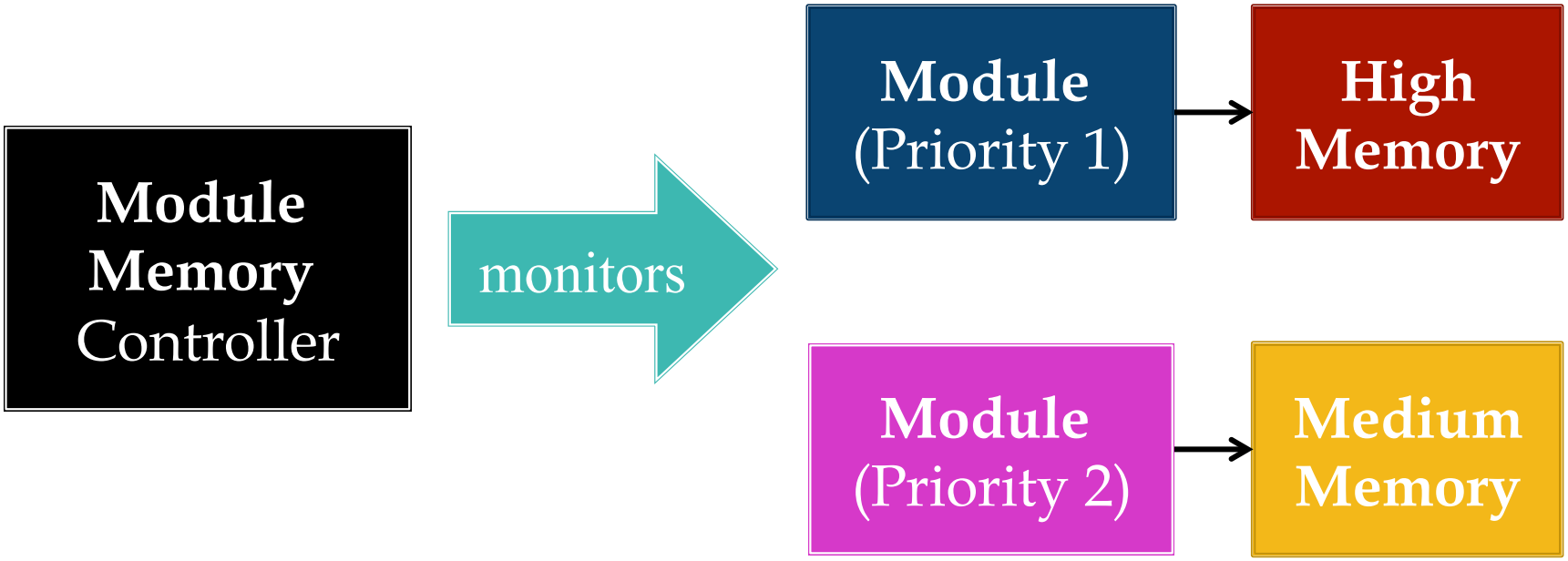
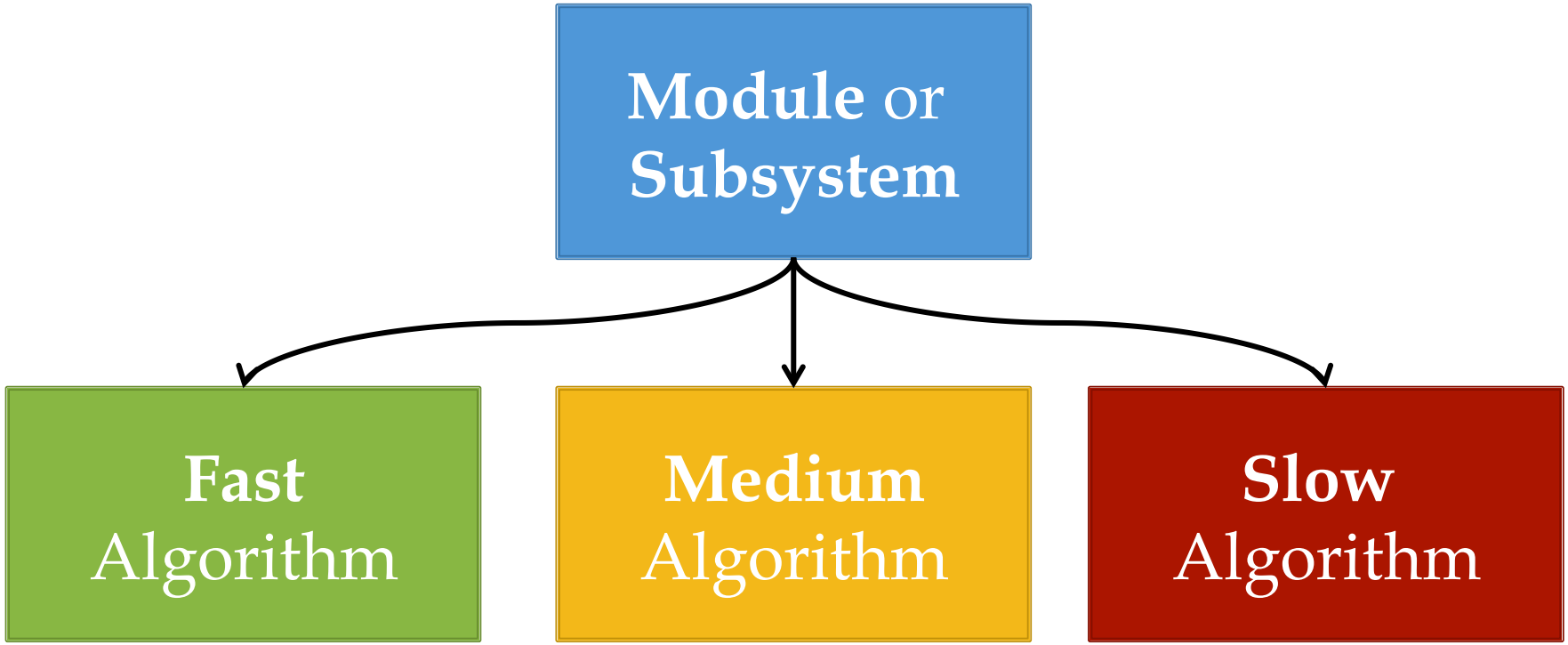


Probably Need a Separate Controller



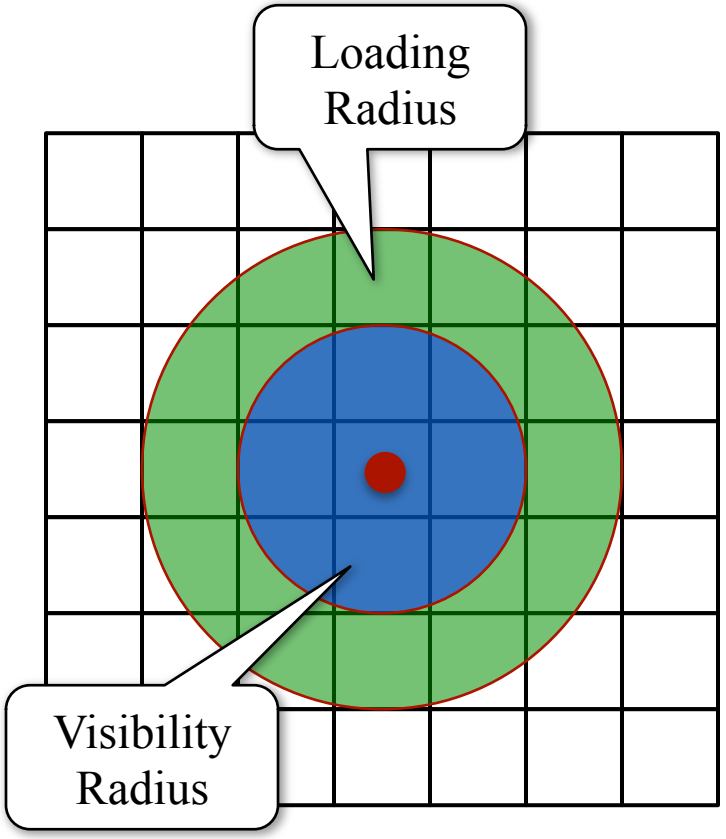
Can Budget Speed as Well



Check each **iteration** instead of **allocation**

Dynamic Loading

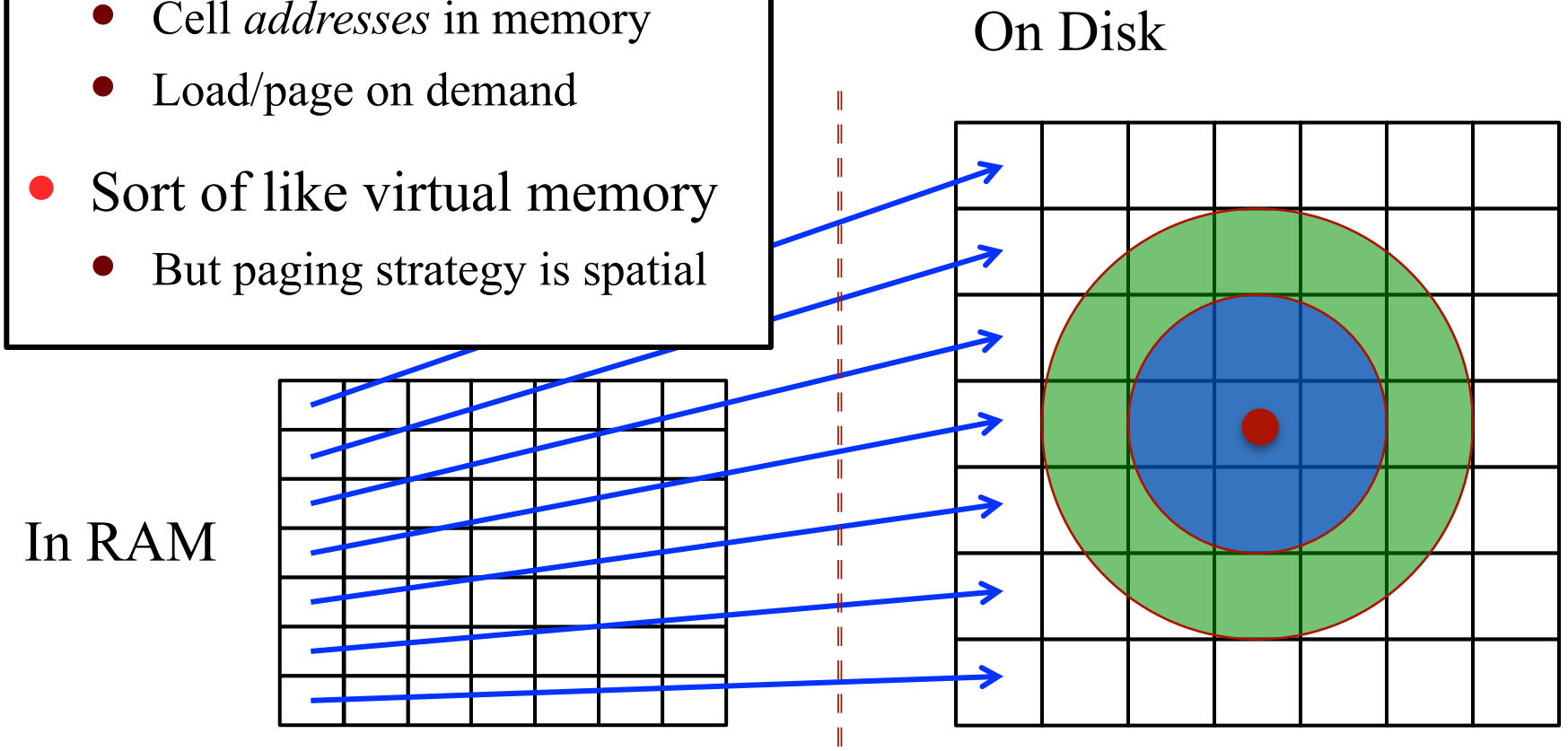
- Most game data is *spatial*
  - Only load if player nearby
  - Unload as player moves away
  - Minimizes memory used
- Arrange memory in *cells*
  - Different from a memory pool
  - Track player visibility radius
  - Load/unload via outer radius
- **Alternative**: loading zones
  - Elevators in *Mass Effect*



Dynamic Loading in *Assassin's Creed*

Implementing Dynamic 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

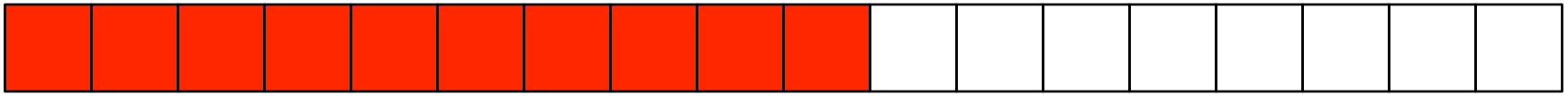


Dynamic Loading Challenges

- **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

Custom Allocators for Intra-Frame

Pre-allocated Array (called **Object Pool**)



Start **Free** **End**

- Instead of `new`, get object from array
  - Just reassign all of the fields
  - Use **Factory pattern** for constructor
- Delete all objects at frame end
  - Just reset free pointer to start
  - Do not worry about freeing mid frame

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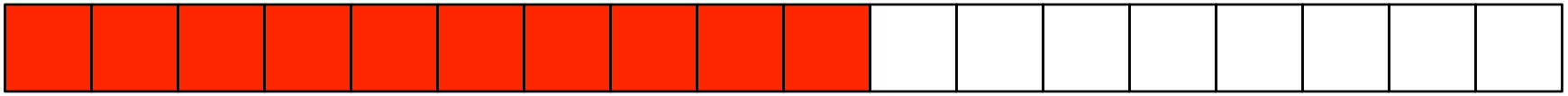

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Easy if only one object type to allocate

Next Time: Language-Specific Details