the gamedesigninitiative at cornell university

Lecture 13

Concurrency & Multithreading

Games are Naturally Multithreaded

- The core game loop is **time constrained**
  - Frame rate sets a budget of how much you can do
  - Exceeding that budget causes frame rate drops
- Sometimes we need an extra thread to …
  - Offload tasks that *block* drawing (**asset loading**)
  - Offload tasks that *slow* drawing (**pathfinding**)
  - Execute tasks *decoupled* from drawing (**audio**)
- Part of architecture spec: **computation model**

Multithreading in CUGL

- CUGL has **three** primary threads
  - The `Application`, or main graphics thread
  - The `AssetManager` thread, for loading assets
  - The `AudioEngine` thread, for audio playback
  - Note that only `Application` is required
- Also has tools for making your own threads
  - Most are built on top of C++ and `std::thread`
  - But there are some unique features too

Multithreading in CUGL

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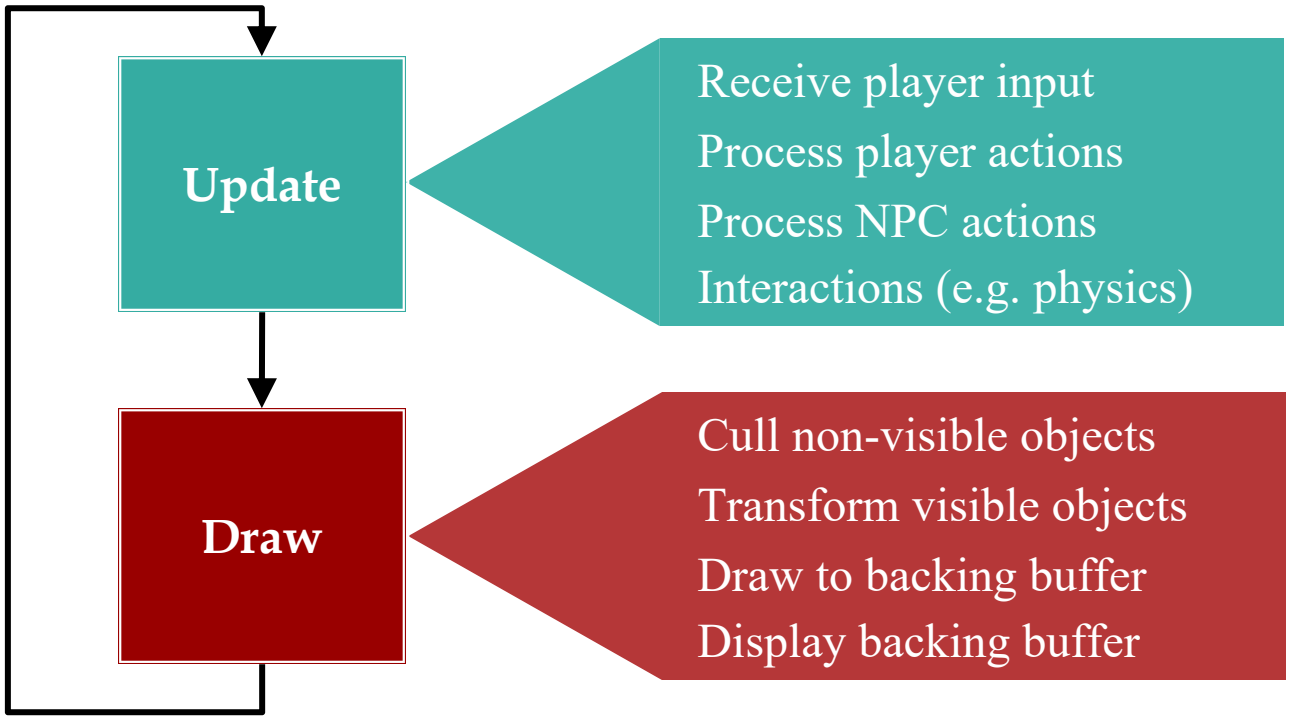
  - The `Application`, or main graphics thread
  - The `AssetManager` thread, for loading assets
  - Th
  - N

Understanding the three threads can help us to make our own.

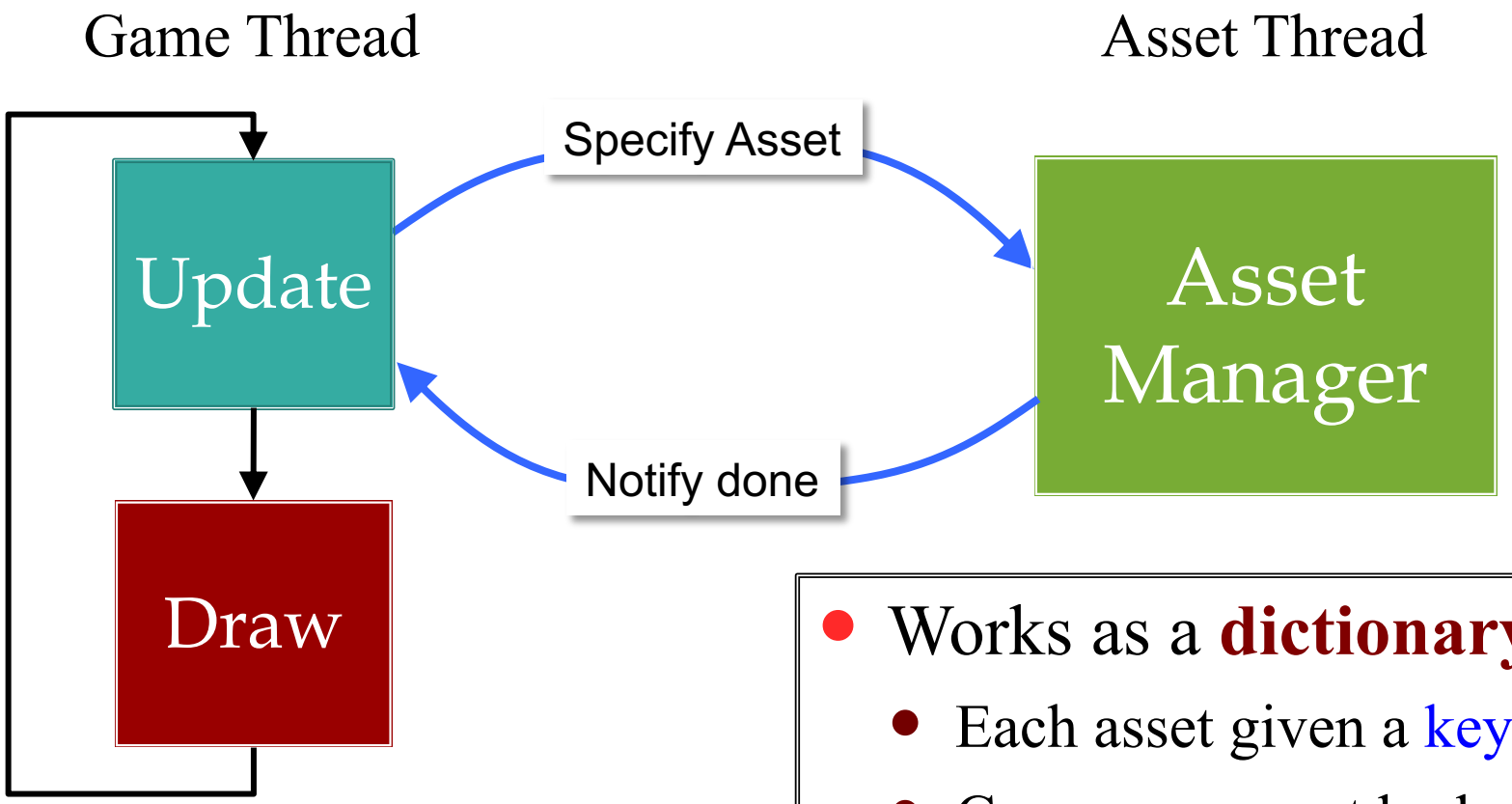
- Also has tools for making your own threads
  - Most are built on top of C++ and `std::thread`
  - But there are some unique features too

Recall: The Application Thread

60 times/s
=
16.7 ms

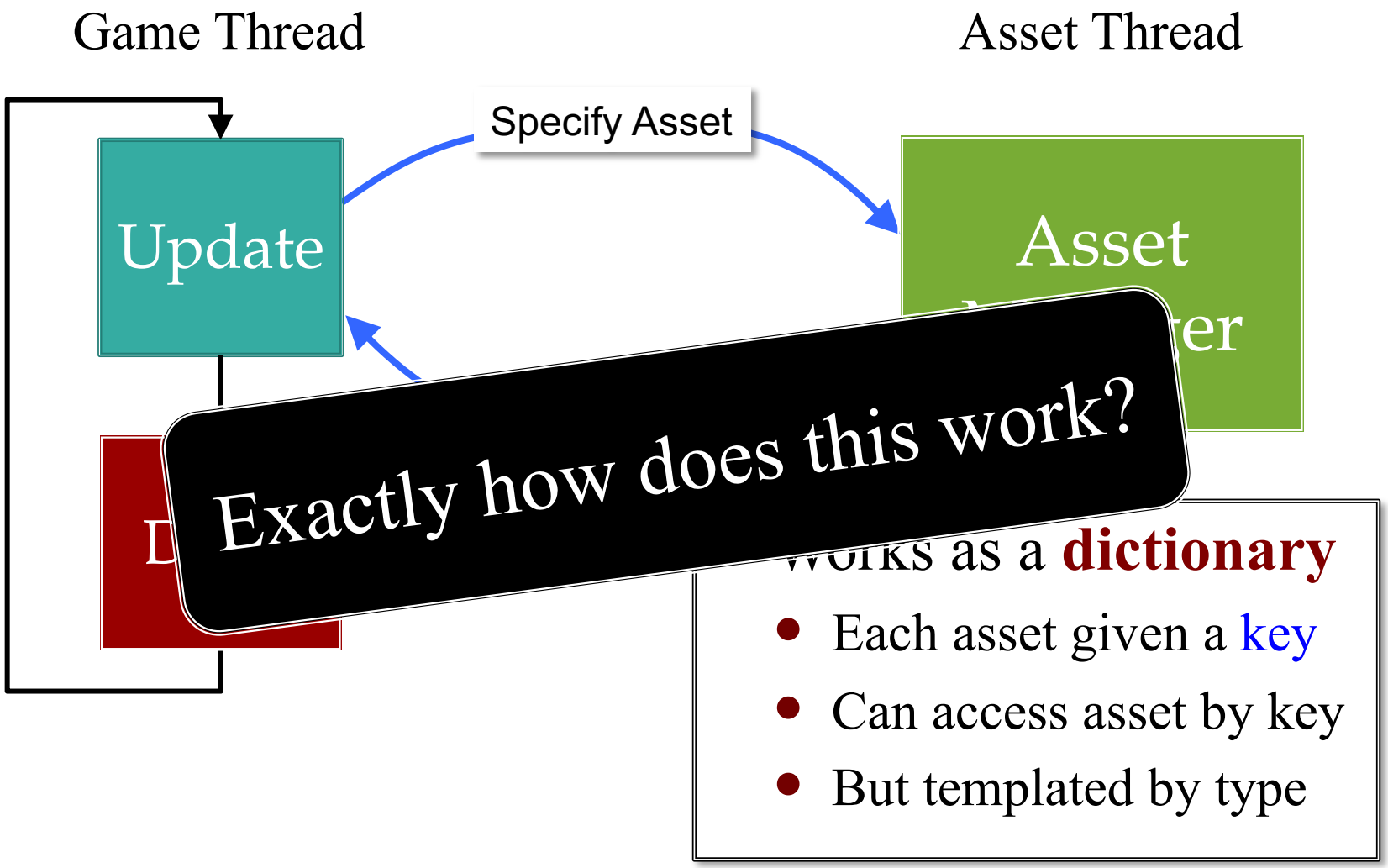


Recall: The AssetManager Thread



- Works as a **dictionary**
  - Each asset given a key
  - Can access asset by key
  - But templated by type

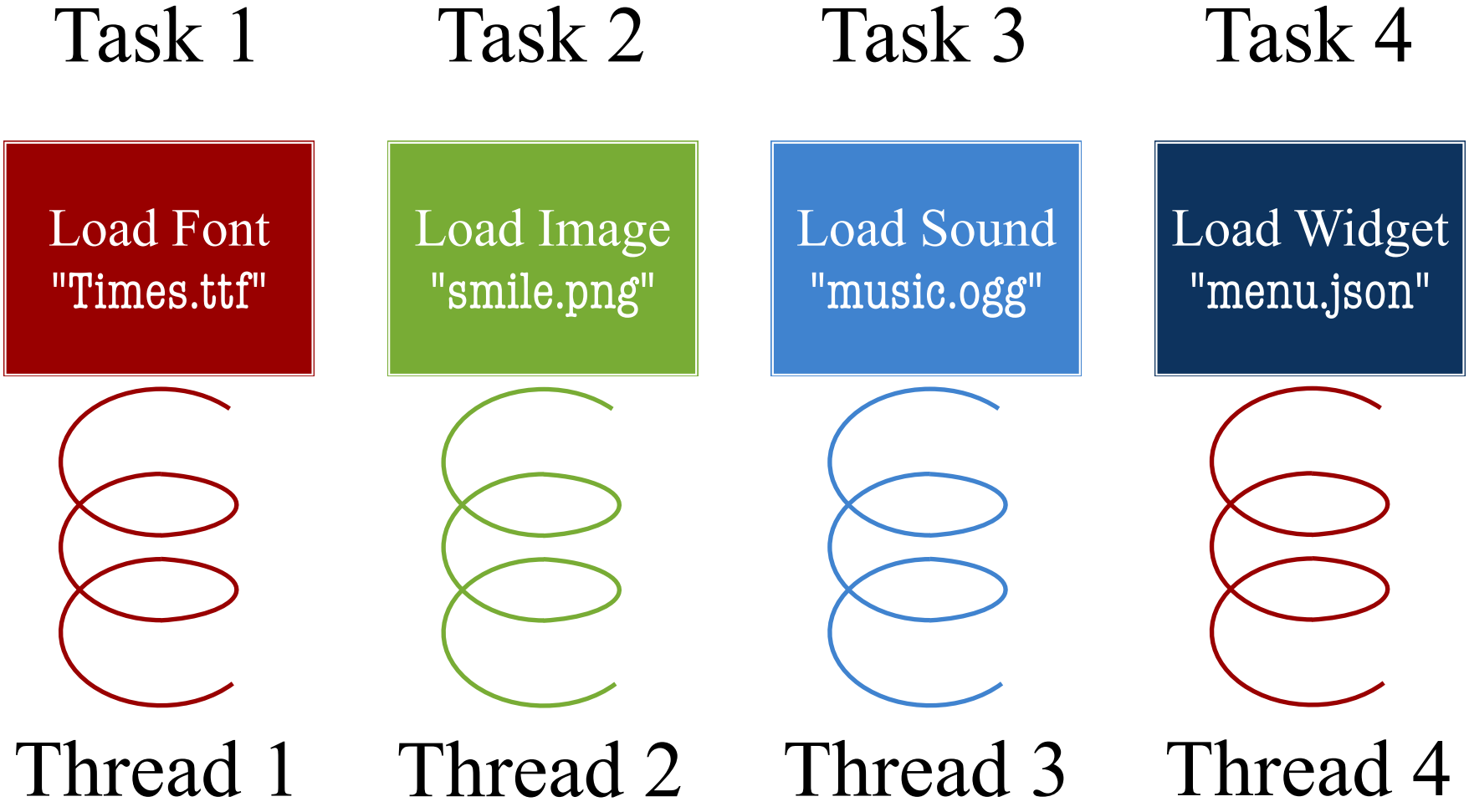
Recall: The AssetManager Thread



Asset Loading Consists of Tasks

Task 1	Task 2	Task 3	Task 4
Load Font "Times.ttf"	Load Image "smile.png"	Load Sound "music.ogg"	Load Widget "menu.json"

Ideally, Each One is a Thread



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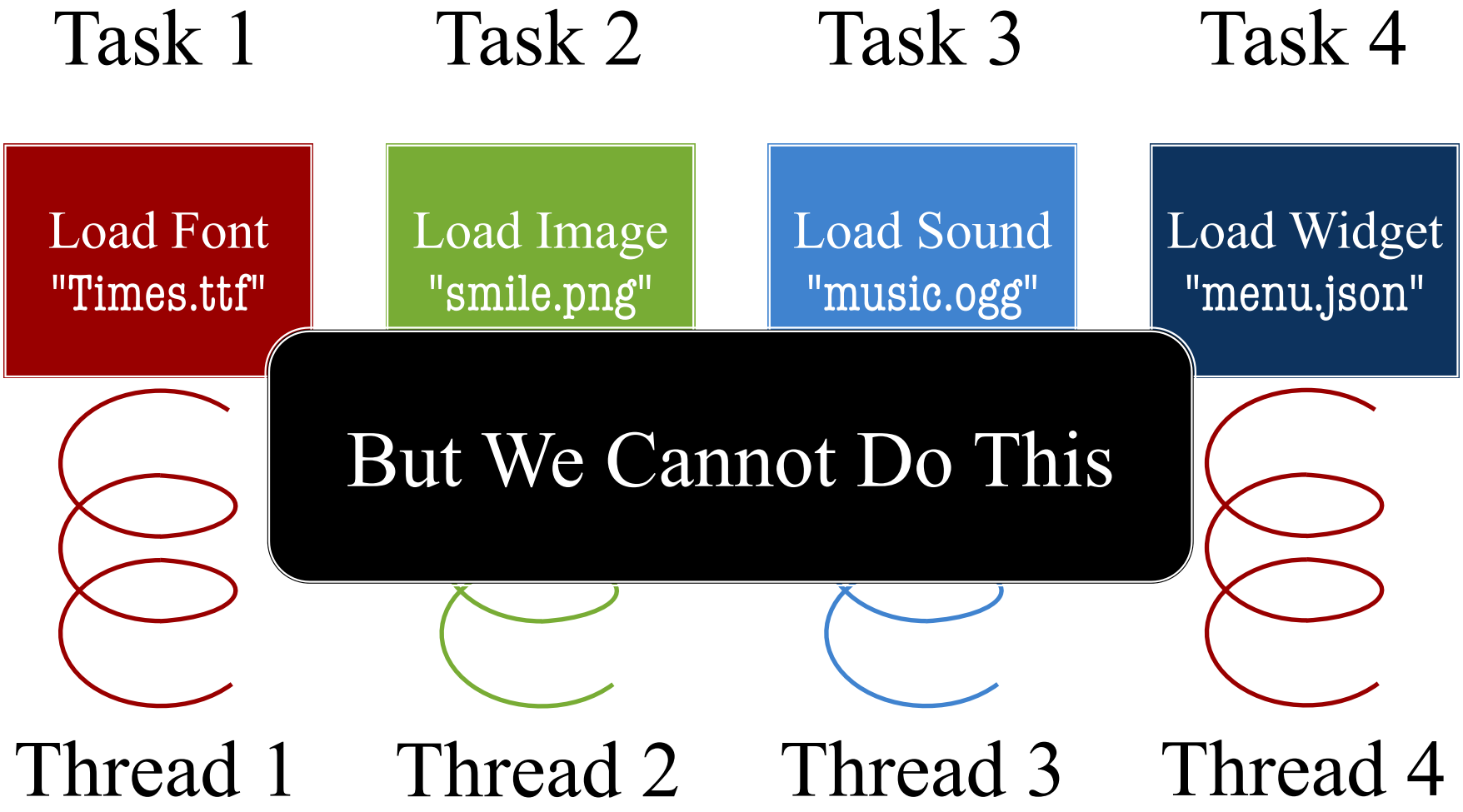
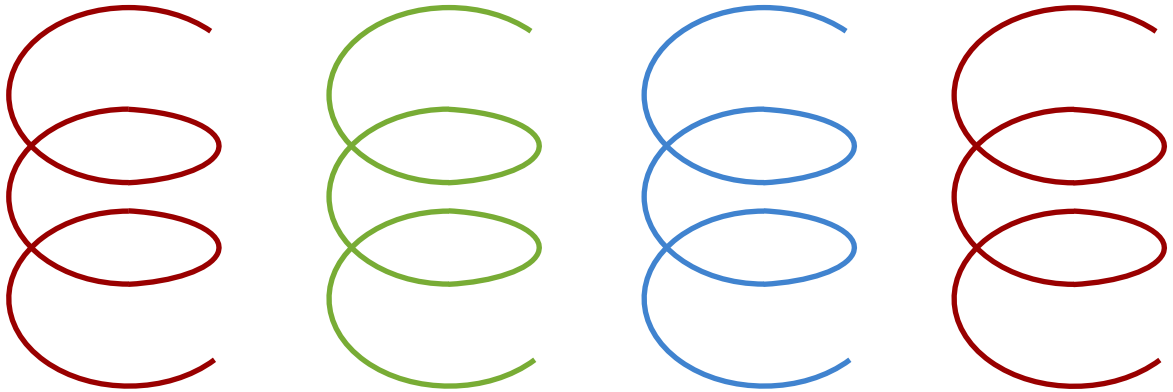


What is the Problem?

- Some tasks have **shared resources**
  - **Example:** Fonts all use same engine to make atlases
  - Cannot execute without protecting critical section
  - Typically easier to just **not** do them concurrently
- Some tasks have **dependencies**
  - **Example:** Widgets must come after images, fonts
  - Forces an order on the asset loading
- What we want is a task **service manager**
  - Executes given tasks in a *partial order*

Solution: Thread Pool

- Threads + scheduler
- Scheduler puts tasks thread
- Uses first available thread
- Holds tasks if all busy



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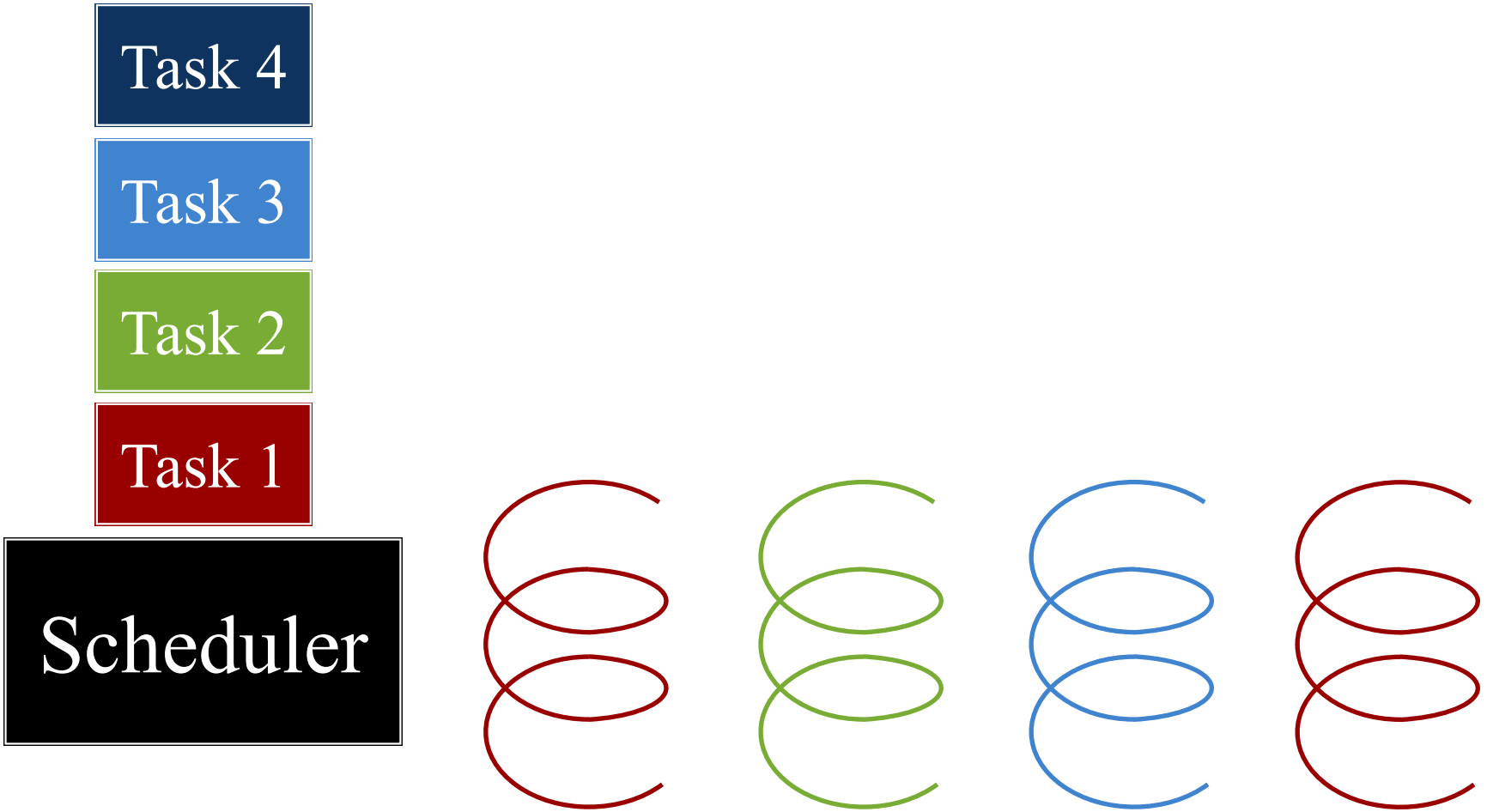

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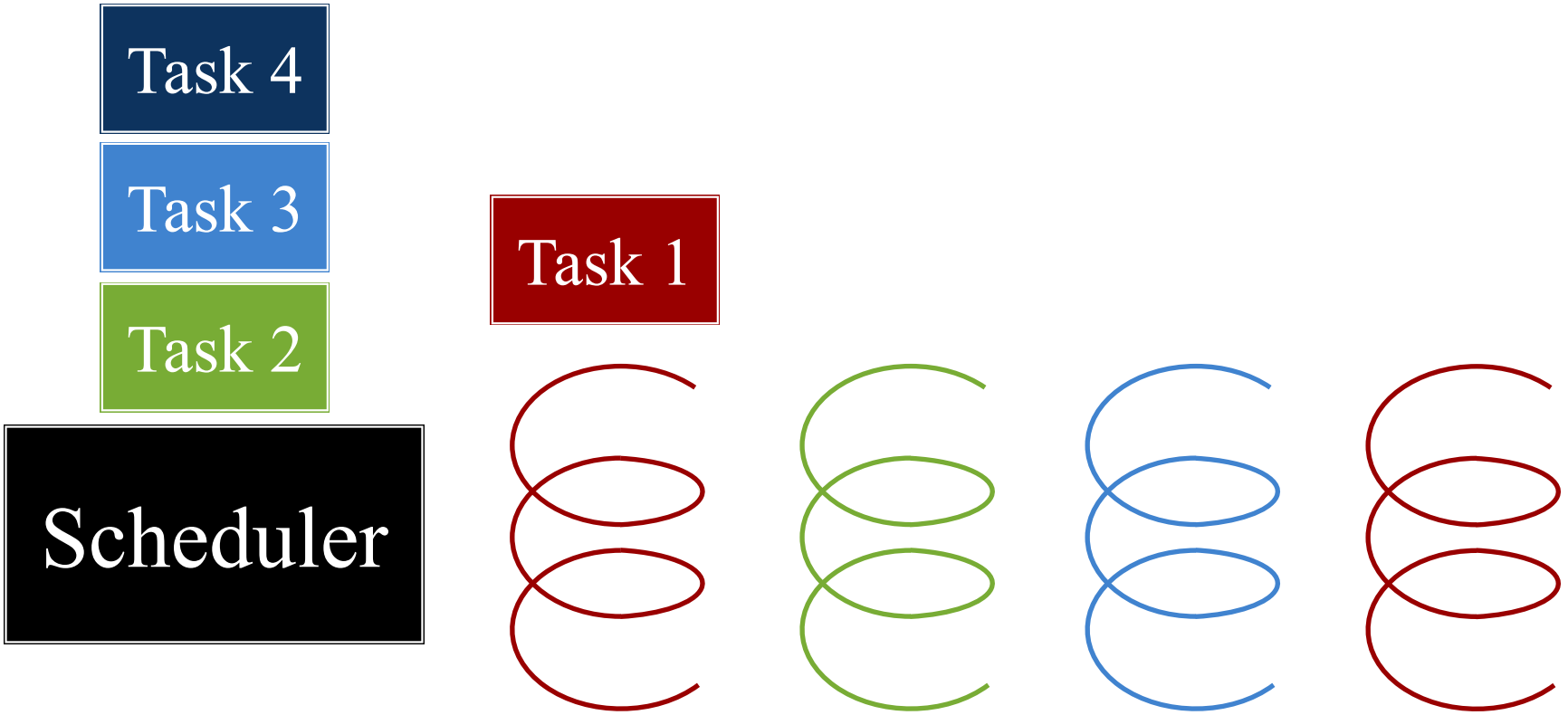

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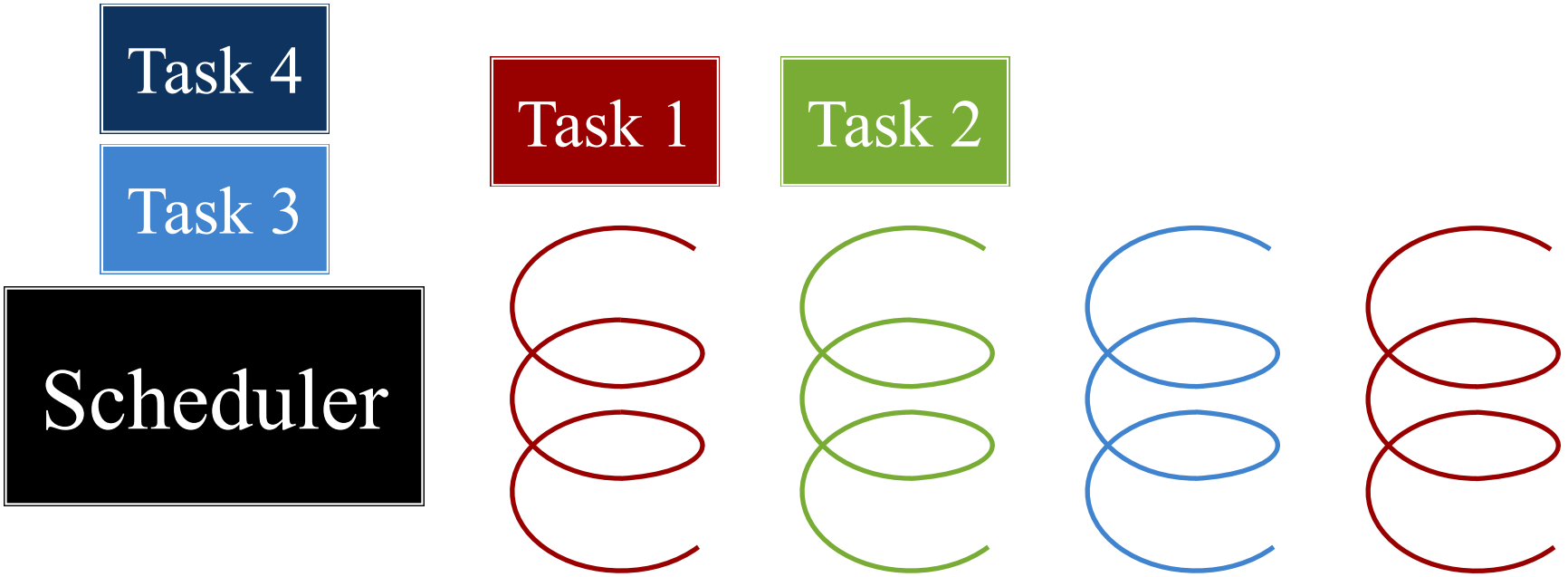

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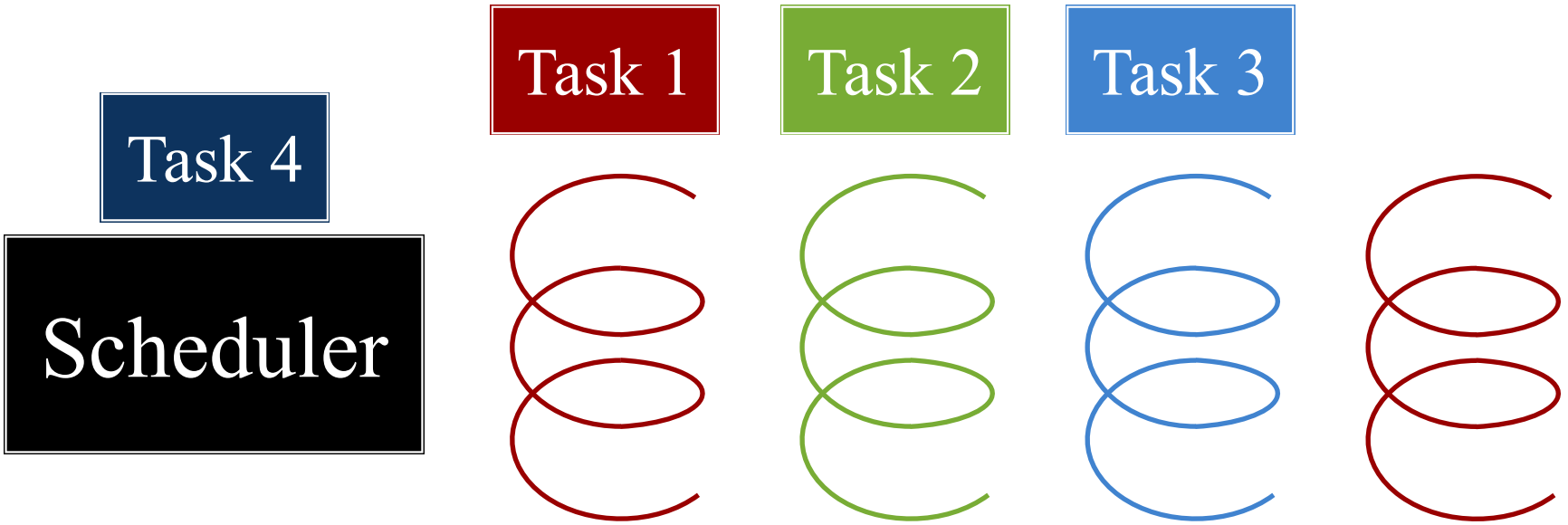

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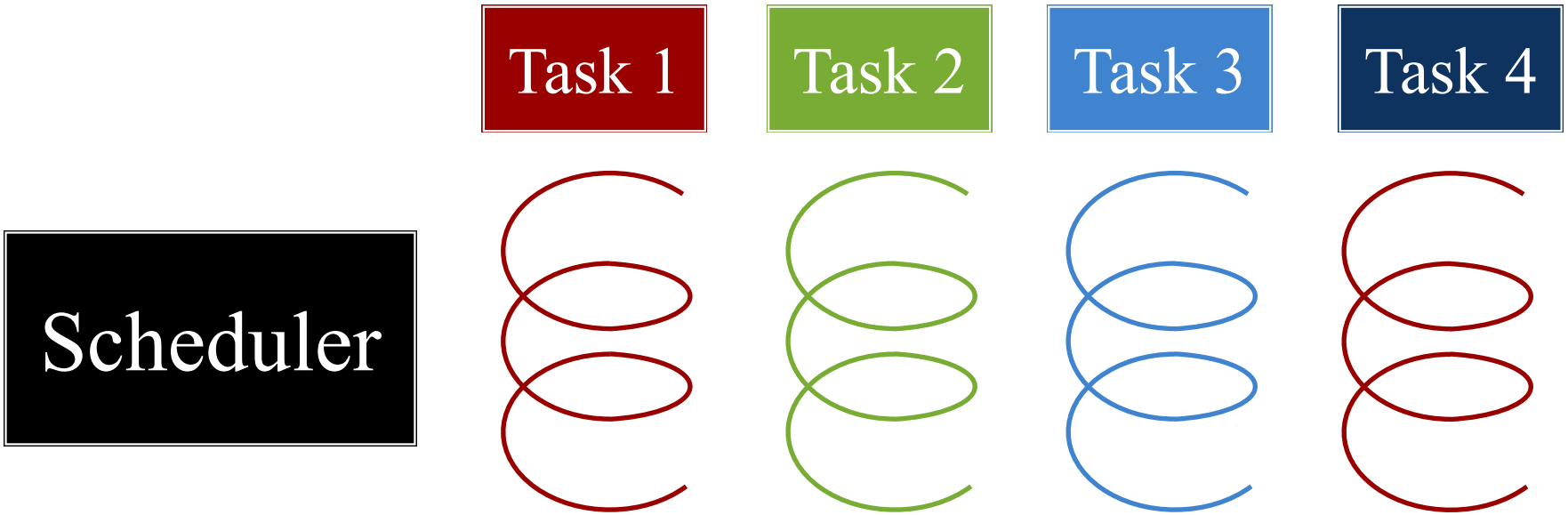

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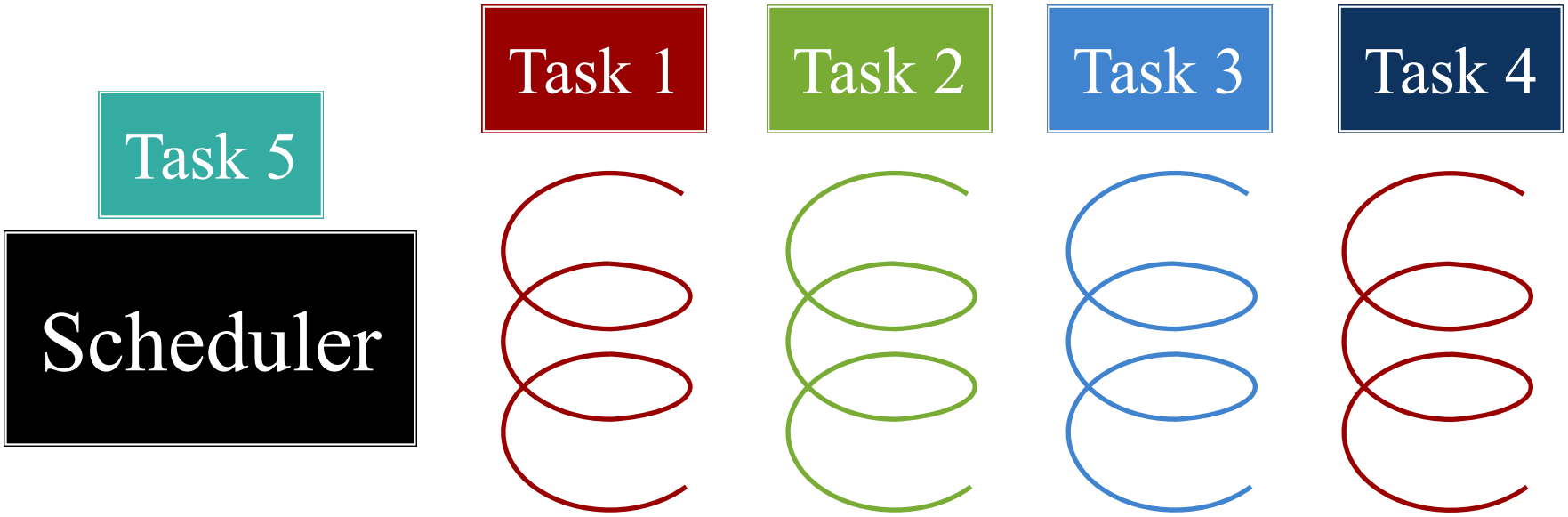

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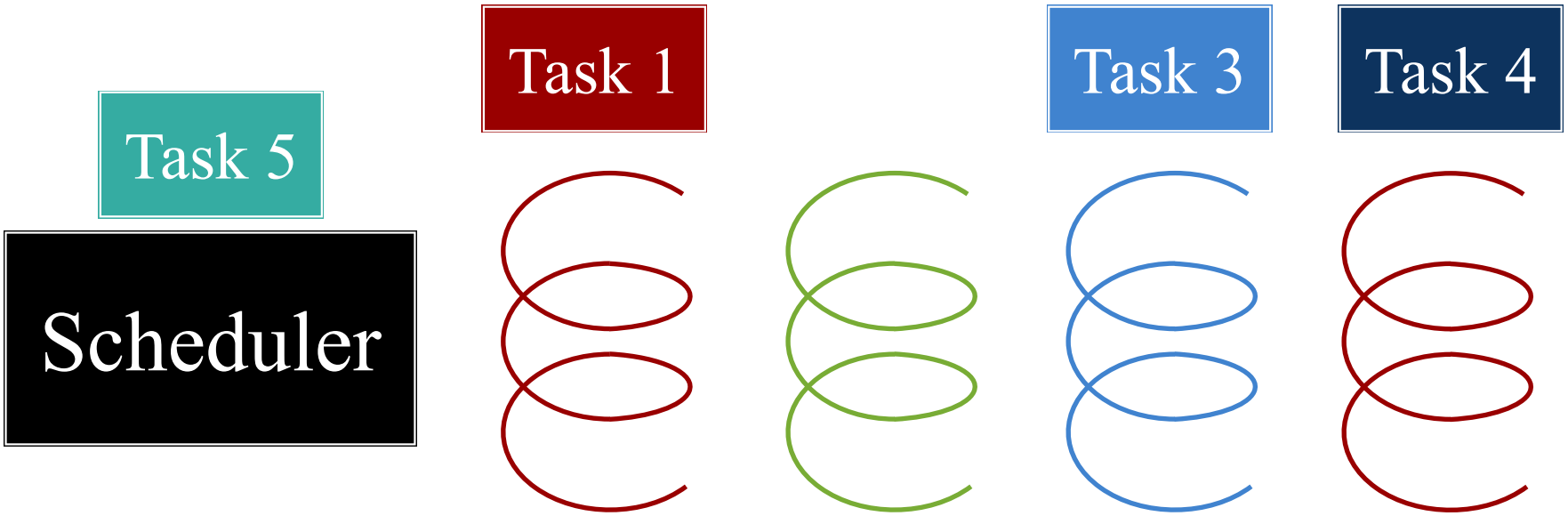

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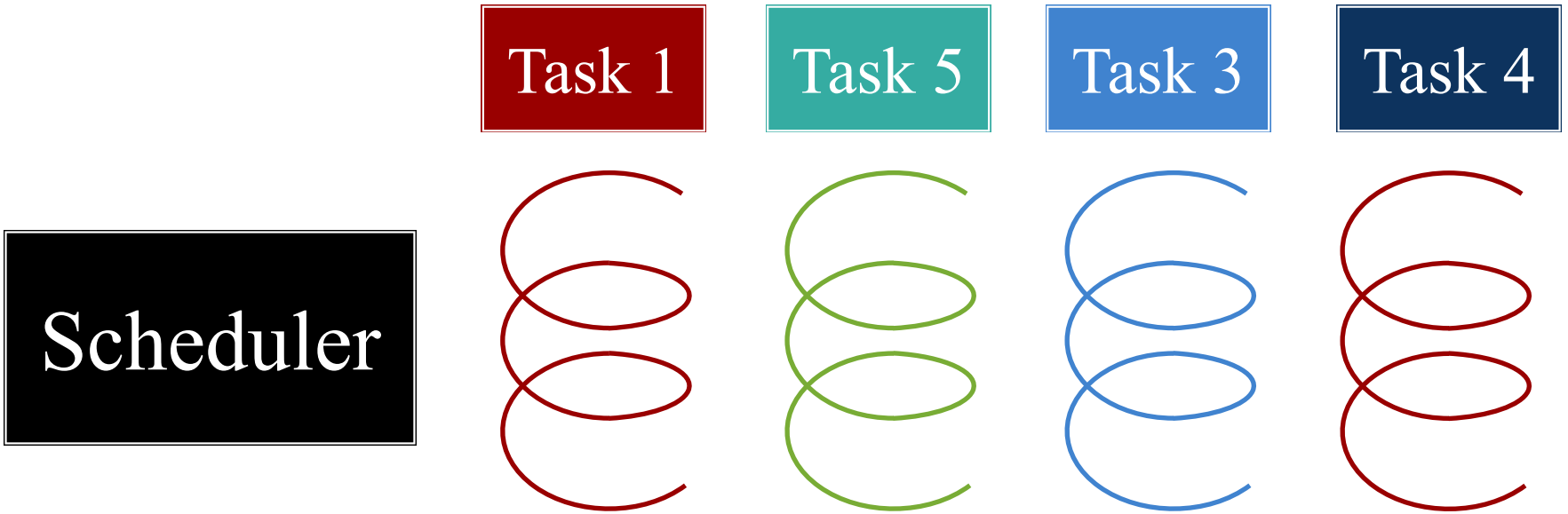

CUGL Support: ThreadPool

```
/**
 * Returns a thread pool with the given number of threads.
 *
 * @param threads   the number of threads in this pool
 *
 * @return a thread pool with the given number of threads.
 */
static std::shared_ptr<ThreadPool> alloc(int threads = 4)
```

```
/**
 * Adds a task to the thread pool.
 *
 * @param  task     the function to add to the thread pool
 */
void addTask(const std::function<void()> &task)
```

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void addTask(const std::function<void()> &task)
```

AssetManager is a **one** thread pool

Recall: Custom Loaders

- void read(key, src, cb, async)
  - Reads asset from file src
  - async indicates if in sep thread
  - Callback cb executed when done

Thread Safe

- void read(json, cb, async)
  - Values key and src now in json
  - As are other special properties

Thread Safe

- void materialize(key, asset, cb)
  - Code to "finish" asset
  - Always in the **main thread**

Main Thread Only

Recall: Custom Loaders

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  - As are other special properties
- void materialize(key, asset, cb)
  - Code to "finish" asset
  - Always in the **main thread**

Each of these is its own task

Executing Tasks on the Main Thread

- Any other thread can access the `Application`
  - Use the static method `Application::get()`
  - This class is essentially a singleton
- That object has a `schedule` method
  - Works much like `addTask` in thread pool
  - But executes that task on the main thread
  - Executed just before the call to your `update`
- **Scheduling** this task is thread safe

The Schedule Method

```
/**
 * Schedules a task function on the main thread.
 *
 * @param cb    The task callback function
 * @param ms    The number of milliseconds to delay
 *
 * @return a unique identifier for the task
 */
Uint32 schedule(std::function<bool()> cb, Uint32 ms)
```

The Schedule Method

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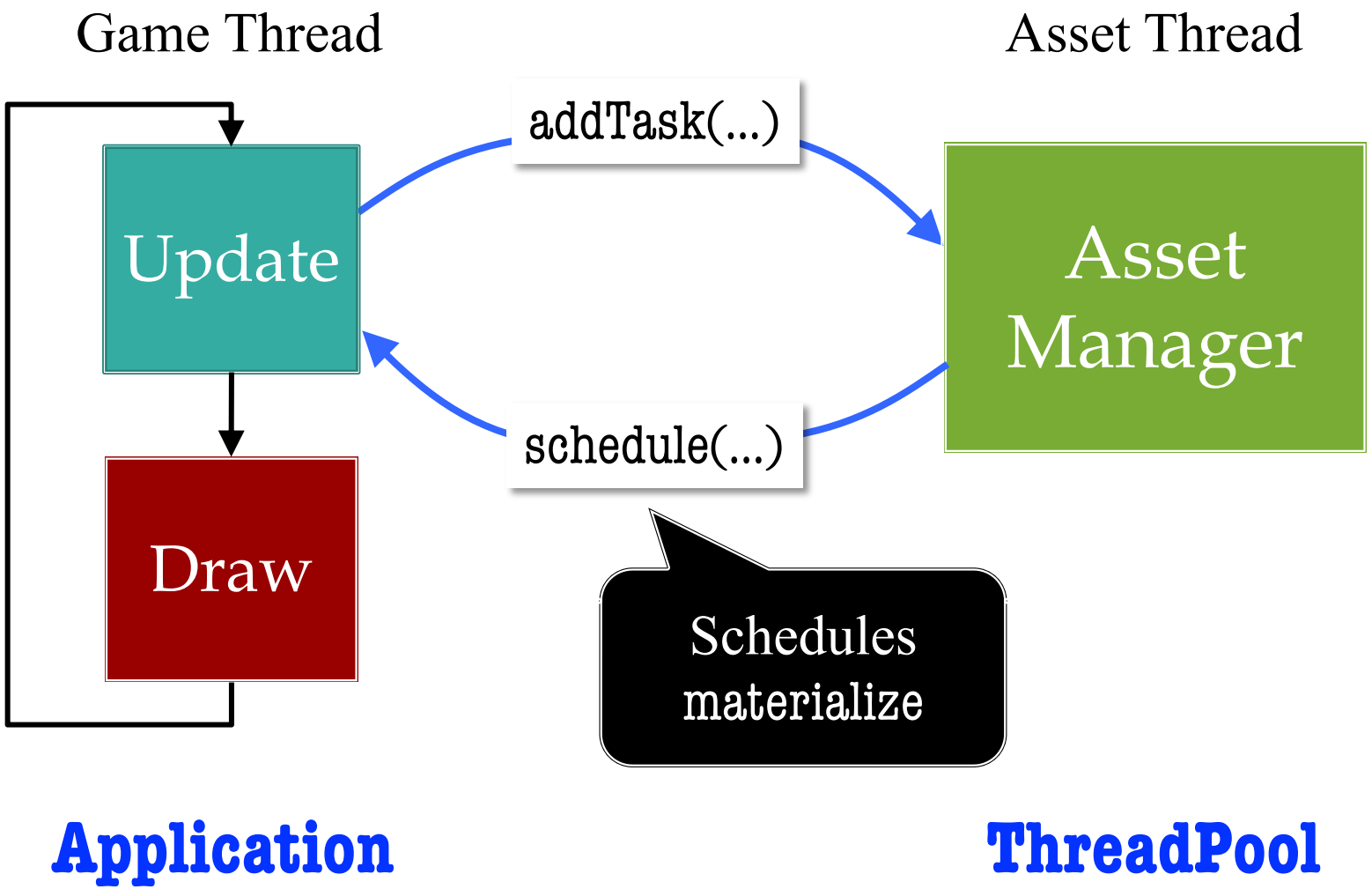
```

Return false to stop execution

Picks first frame after ms millisec

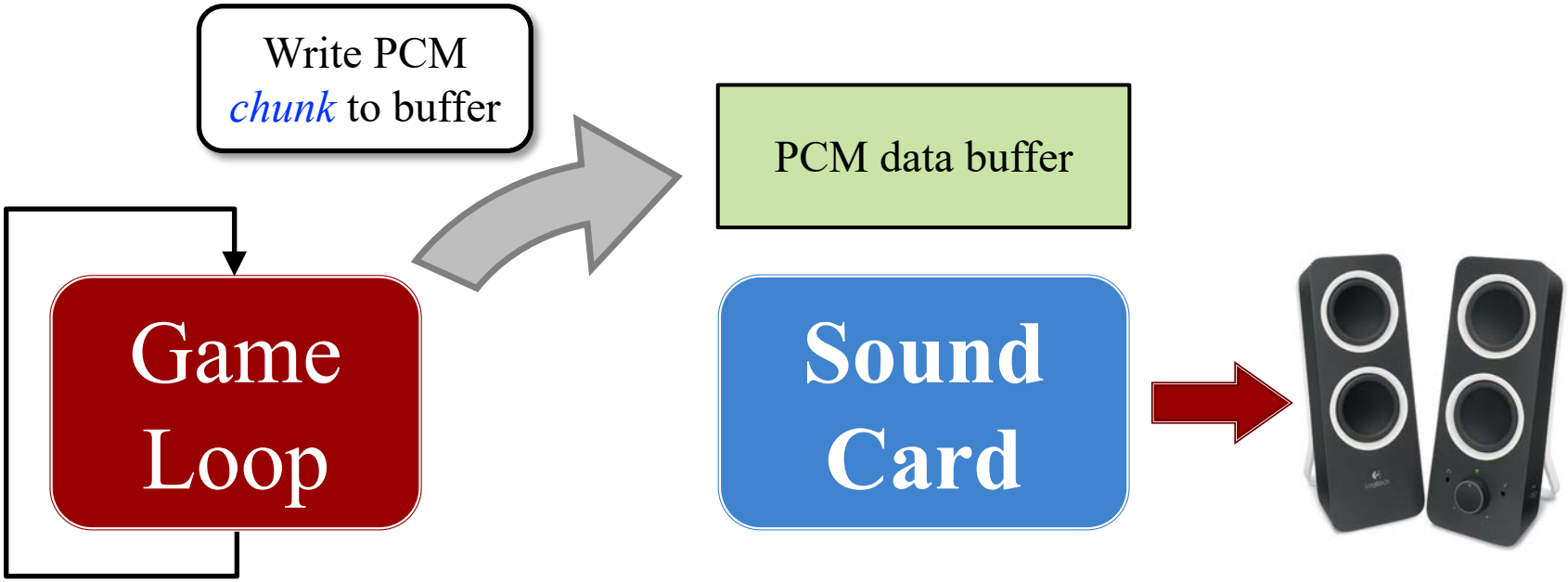
Putting it All Together



Aside: Schedule is Useful in General

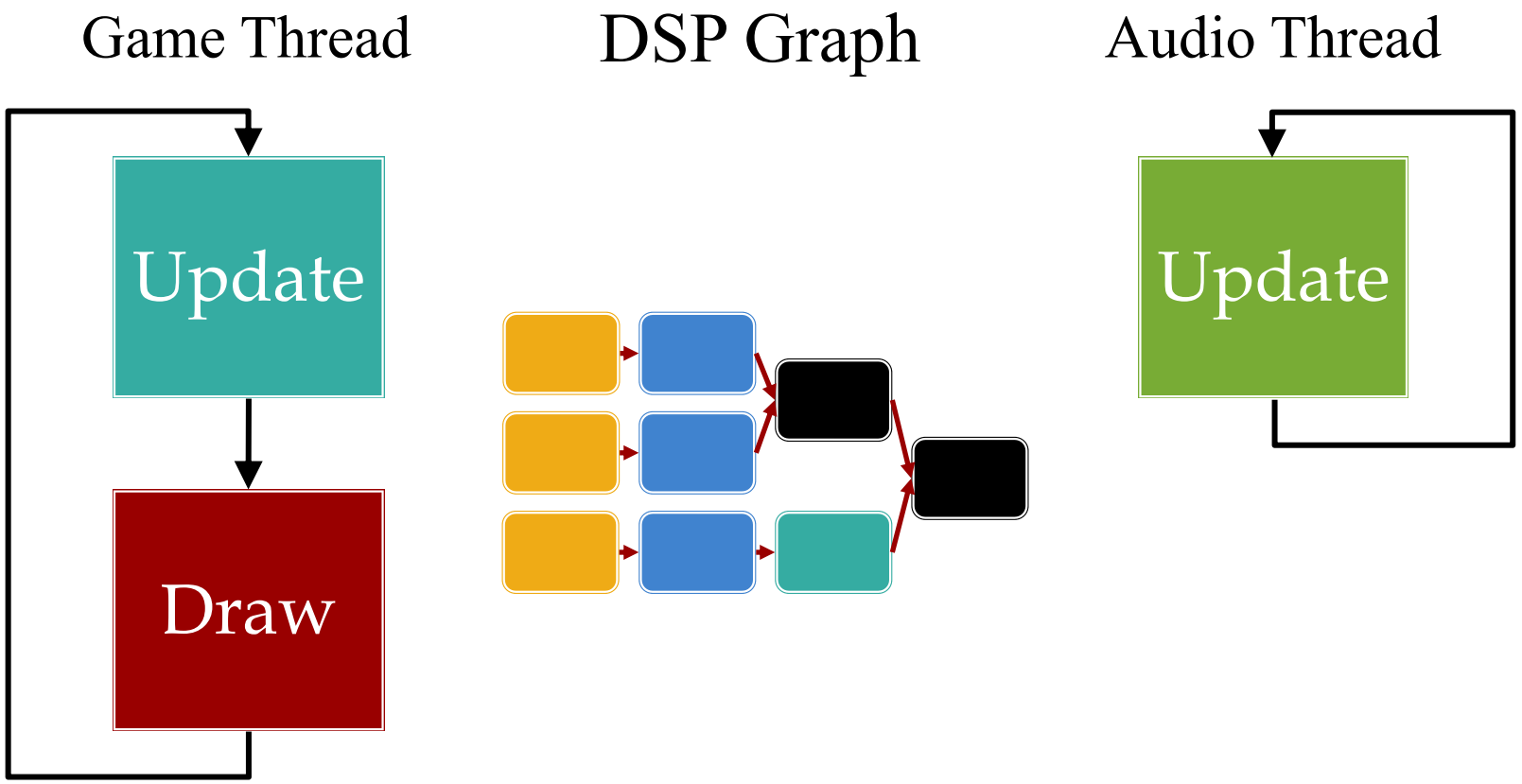
- Can specify an event to **run in the future**
  - This is the purpose of the milliseconds
  - May be easier than tracking a timer yourself
- Can specify a task to **run periodically**
  - **Example:** Spawning enemies
  - The task returns `true` if it wants to run again
  - Same delay is applied as the first time
  - Alternate `schedule` separates **delay** and **period**

Recall: Playing Sound Directly



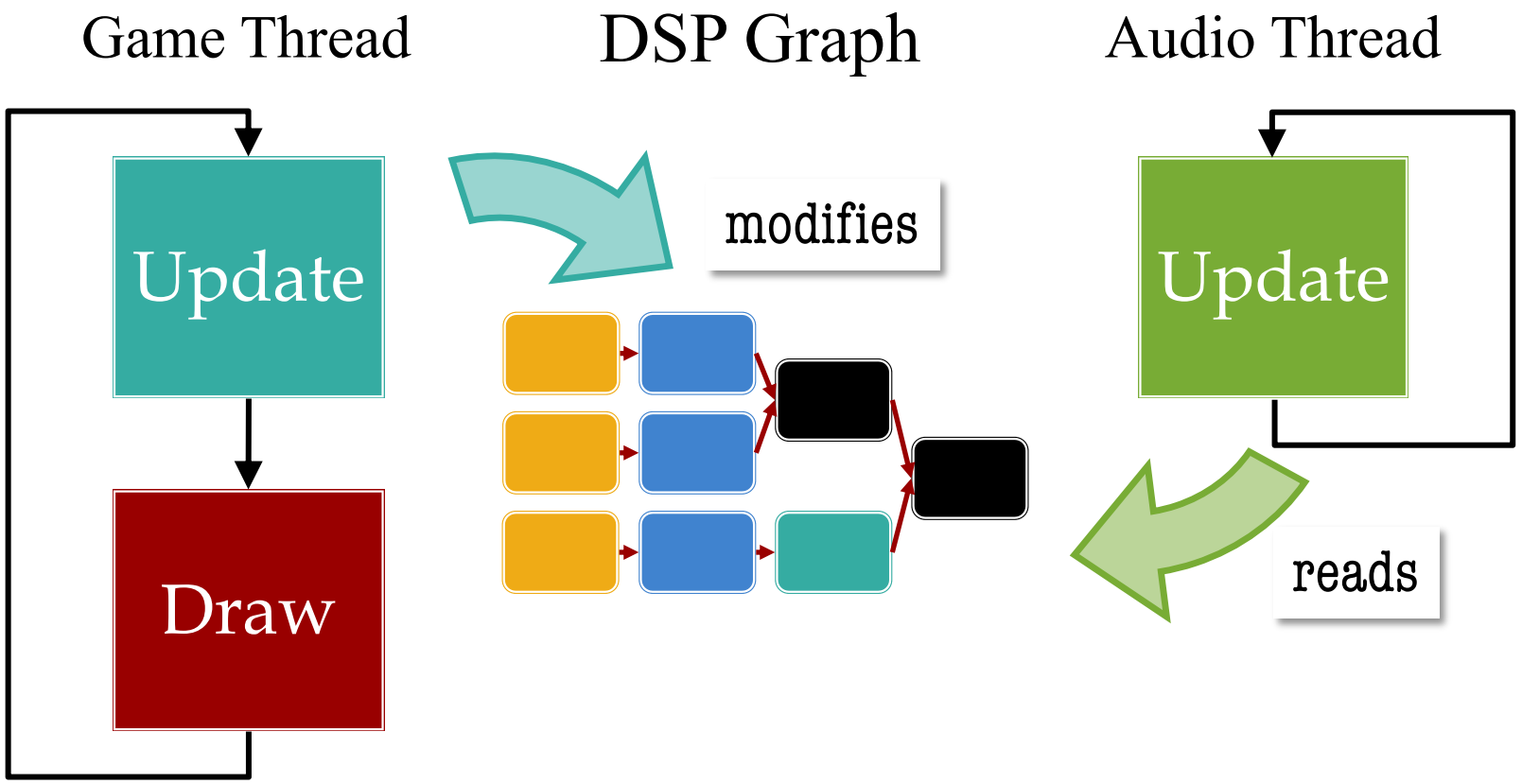
Missing a write causes pops/clicks

The CUGL Approach



Application **Thread**

The CUGL Approach



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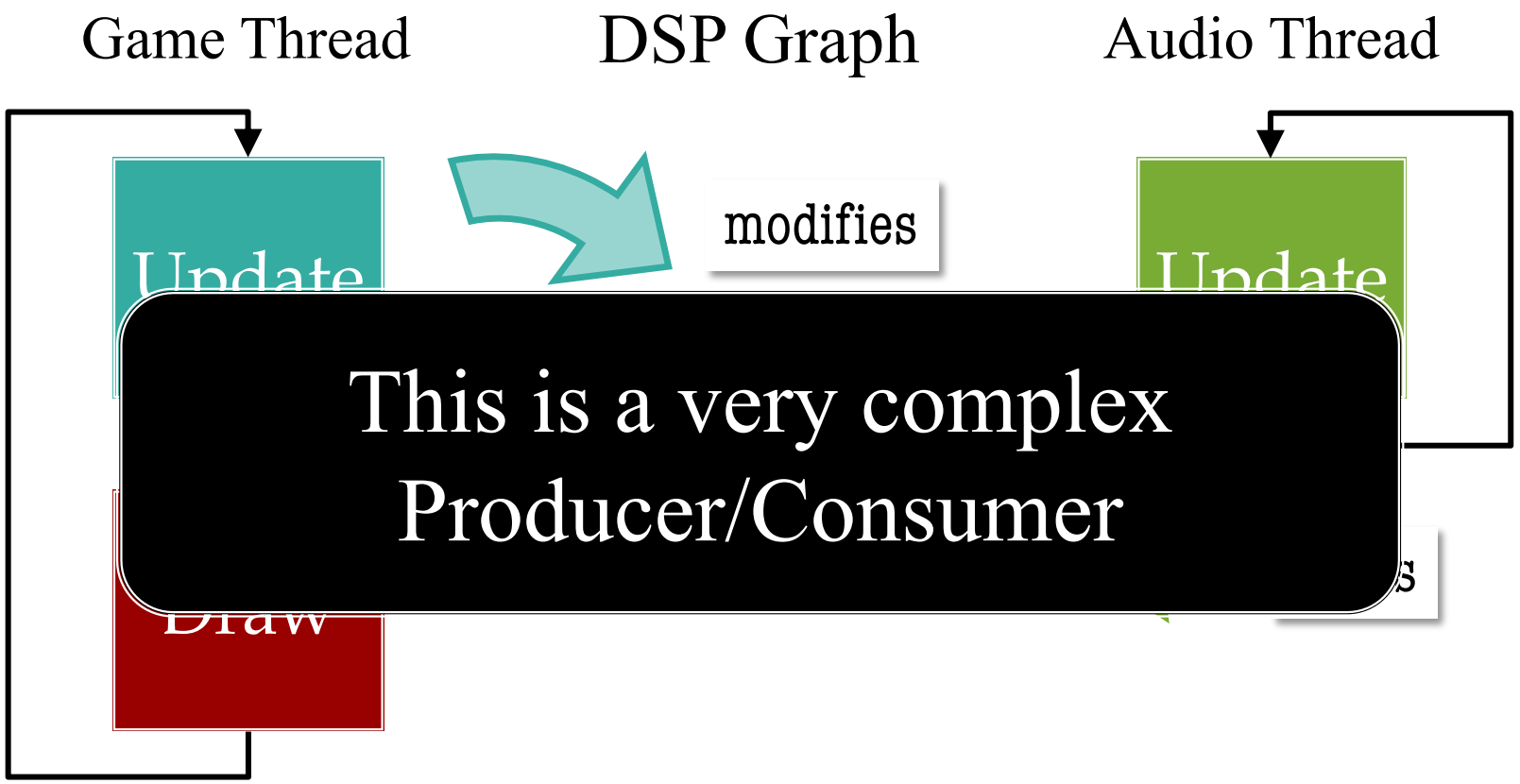
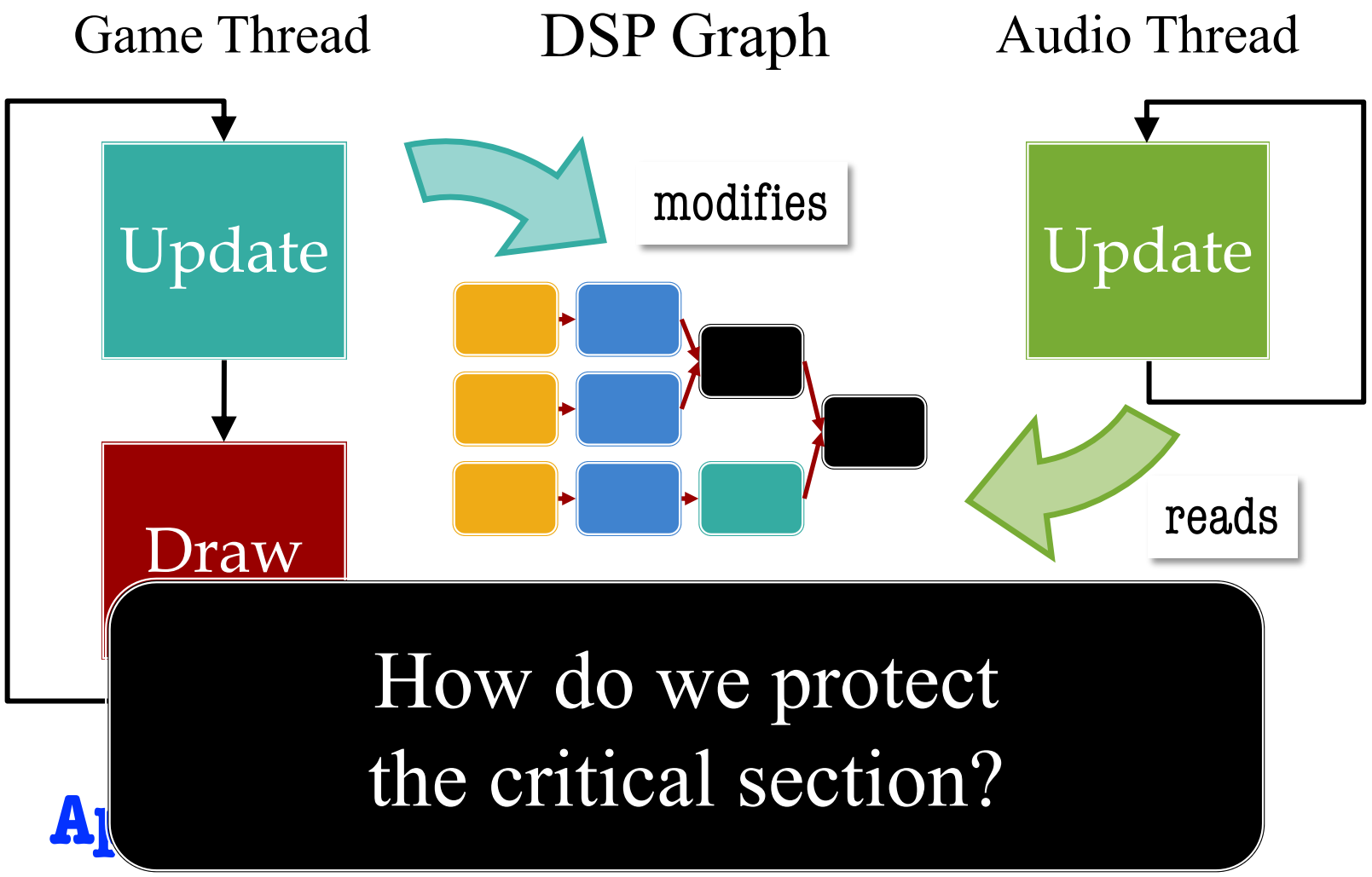


Aside: Audio is Not a ThreadPool

- Audio is a dedicated `std::thread`
  - Because it needs to run as long as the game does
  - Started when you initialized `AudioEngine`
- But process is similar to `ThreadPool`
  - Package your task as a `std::function<void()>`
  - Pass this when you create the thread object
- Difference is that task is in a loop
  - Has an attribute called `running` to manage loop
  - When you set to `false`, the thread is done

The CUGL Approach



The Java Approach: Synchronized

```
public class CriticalSection {
    synchronized void method1() {…}

    synchronized void method2() {…}

    synchronized void method3() {…}
}
```

Locked to one thread at a time

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Locked to one thread at a time

Lock applies to **all** of the methods

C++ Actually Has Two Tools

std::mutex

- Used to protect a **code block**
  - Places lock on code block
  - Only one thread can access
- **Advantages**
  - Can replicate `synchronized`
  - Relatively easy to use
- **Disadvantages**
  - Locking has some cost
  - Deadlocks easy if careless

std::atomic

- Used to protect a **variable**
  - Prevents data races
  - Useful for shared setters
- **Advantages**
  - 10x faster than `std::mutex`
  - *Sometimes* easy to use
- **Disadvantages**
  - Extremely limited in use
  - Advanced use is **advanced**

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Audio thread uses only when it must do so

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  - Extremely limited in use
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Audio thread uses whenever it is possible

Replicating Synchronized

```
class CriticalSection {
private:
    /** Mutex to synchronize methods */
    std::mutex _mutex;

public:
    void method() {
        _mutex.lock();      // Lock method code
        ...
        _mutex.unlock();    // Release when done
    }
}
```

Obervations About std::mutex

- It is **not** a **reentrant lock** (unlike `synchronized`)
  - Locking it again inside same class will deadlock
  - This matters when you have locks on helpers
  - Must use `std::recursive_mutex` for reentrant lock
- Manual lock/unlock calls are **frowned upon**
  - To easy to forget to unlock and deadlock
  - Preferred way is to attach a **locking object**
  - When locking object is deleted, so is lock

Using a Locking Object

```
class CriticalSection {
private:
    /** Mutex to synchronize methods */
    std::mutex _mutex;

public:
    void method() {
        std::lock_guard<std::mutex> lock(_mutex);
        ...
        // Mutex unlocked once lock variable deleted
    }
}
```

What If Critical Section is a Variable?

- **Example**: `running` attribute controlling thread
  - Audio thread loops so long as it is `true`
  - Setting it to `false` stops the audio
- Mutexes exist to prevent **inconsistent states**
  - Either all code is executed, or none is
  - Cannot happen to variable assignment, right?
- C++ is not **assembly code**!
  - A single assignment is multiple lines of assembly
  - This is not thread safe (*especially* on Windows)

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- **Example**: `running` attribute controlling thread
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This leads to data races!

std::atomic Protects Assignment

- **Template** around a type: `std::atomic<int>`
  - Supports all primitive C++ types
  - Cannot apply to objects in general, but …
  - Is possible to make `std::shared_ptr` atomic
- Supported by two methods
  - `load()`: An atomic **getter** for the value
  - `store(value)`: An atomic **setter** for the value
  - Shared pointers are slightly more complicated

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Means assignment is atomic, **not** methods

Only Use If Read/Write Are Separate

```
class WithAtomics {
private:
    std::atomic<int> _xvar;   // Atomic integer
public:
   /** Change the value of X */
   void writeX(int val) { _xvar.store(val); }

   /** Use the value of X to compute something */
   void readX() {
      int x = _xvar.load();  // Copy value to local variable
      // Use x in local computation
   }
}
```

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```

Never **store _xvar** in same method

This Is Only Scratching the Surface

- C++ supports **monitors** and **semaphores**
  - These are used for producer/consumer problem
  - Monitor allows consumer to **wait** on producer
- C++ supports **promises**
  - These are threads that return a value
  - Simplify critical section in that case
- Atomics support **memory orders**
  - These are used to **optimize performance**
  - Best avoided unless you know what you are doing

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See readings if want more

So Why Do We Care?

- All of these threads are made for you!
- But how about making **your own threads**?
  - **Pathfinding** is a classic example
  - **NPC behavior** can also be long-running
- How can **extreme** can we go?
  - What if all **updates** are in separate thread?
  - Then the main thread just **draws**!
  - This can give us potentially very high FPS

This Will Not Quite Work

Frame 1

Frame 2

Frame 3

Without update, redraw **same** image.
We need animation in the core loop.

Recall: Two Approaches to Animation

Tweening

- Animates **timed actions**
  - Given a duration and a start
  - Interpolates scene over time
- Render thread simply…
  - accesses all active actions
  - moves them forward by `dt`
- Gameplay **creates** actions
  - Happens less frequently
  - Decoupled from render

Physics

- Animates **physical objects**
  - Bodies with force and mass
  - Also shape for collisions
- Render thread simply…
  - steps simulation forward
  - renders objects at end
- Gameplay **nudges** objects
  - *Might* be less frequent
  - If so, can also decouple

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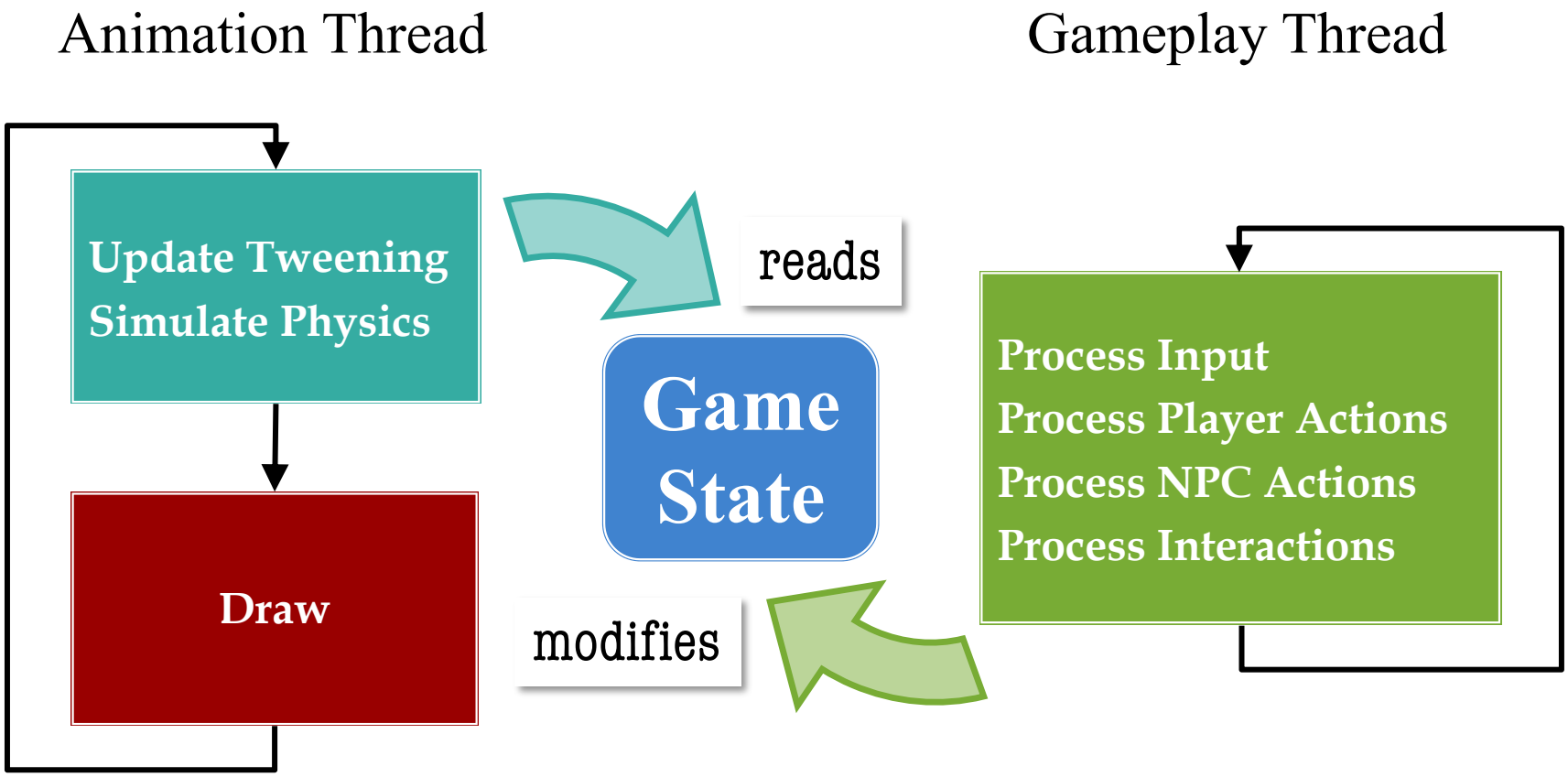
Like networking, animation uses *dead reckoning* when missing input

A New Architecture



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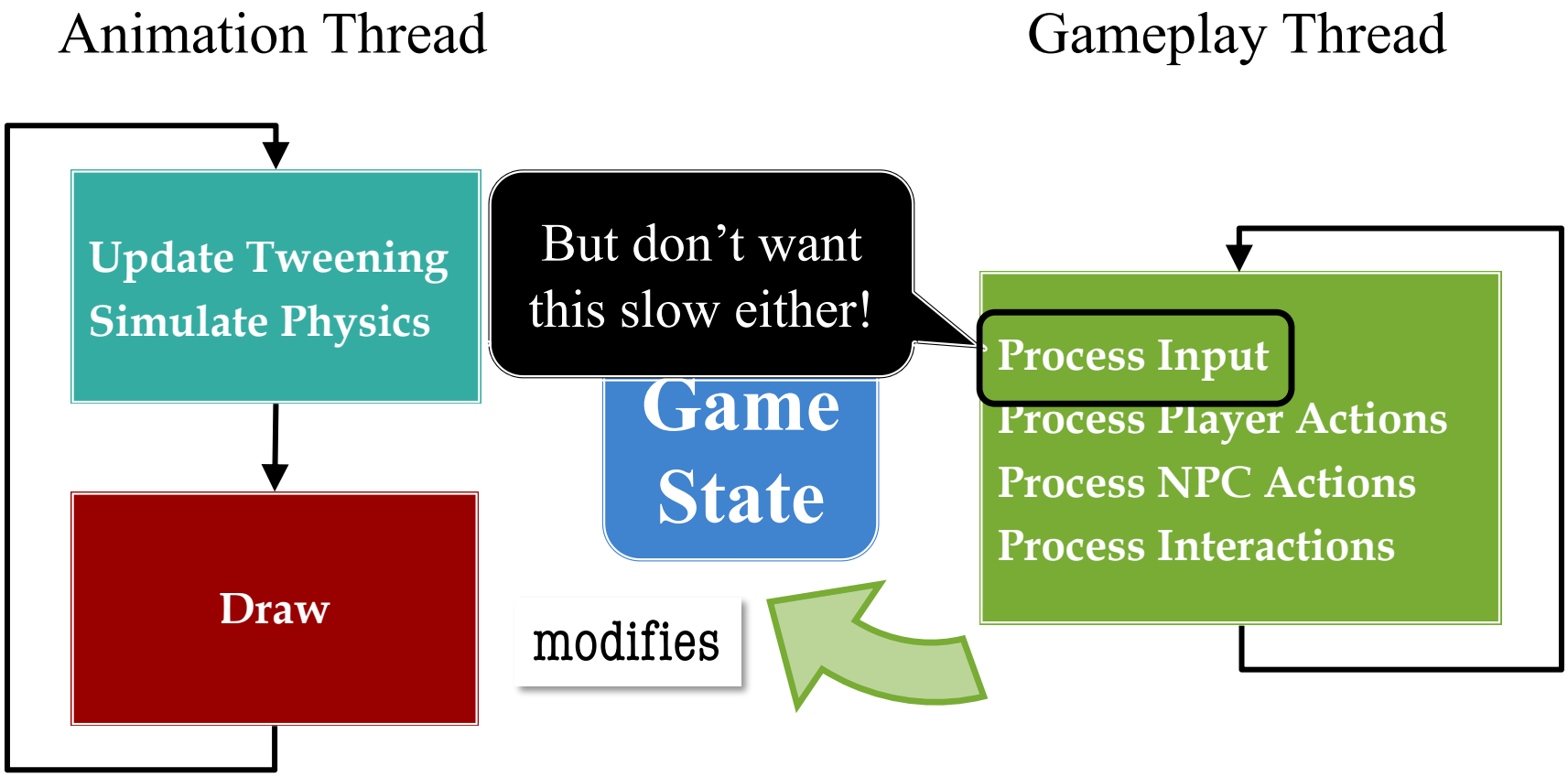

Summary

- Games engines are naturally multithreaded
  - Offload tasks that *block* drawing (**asset loading**)
  - Offload tasks that *slow* drawing (**pathfinding**)
  - Execute tasks *decoupled* from drawing (**audio**)
- CUGL has native **task-based parallelism**
  - `ThreadPool` for tasks off the main thread
  - `Application::schedule` for tasks on main thread
- C++ has general-purpose tools for parallelism
  - `std::thread` class for managing other threads
  - `std::mutex` and `std::atomic` for critical sections