Michele Mischitelli

Unreal Engine 4: Delegates, Async and Subsystems

A follow up session on UE4's async execution model

Main topics of this meetup

Delegates

Data types that reference and execute member functions on C++ objects

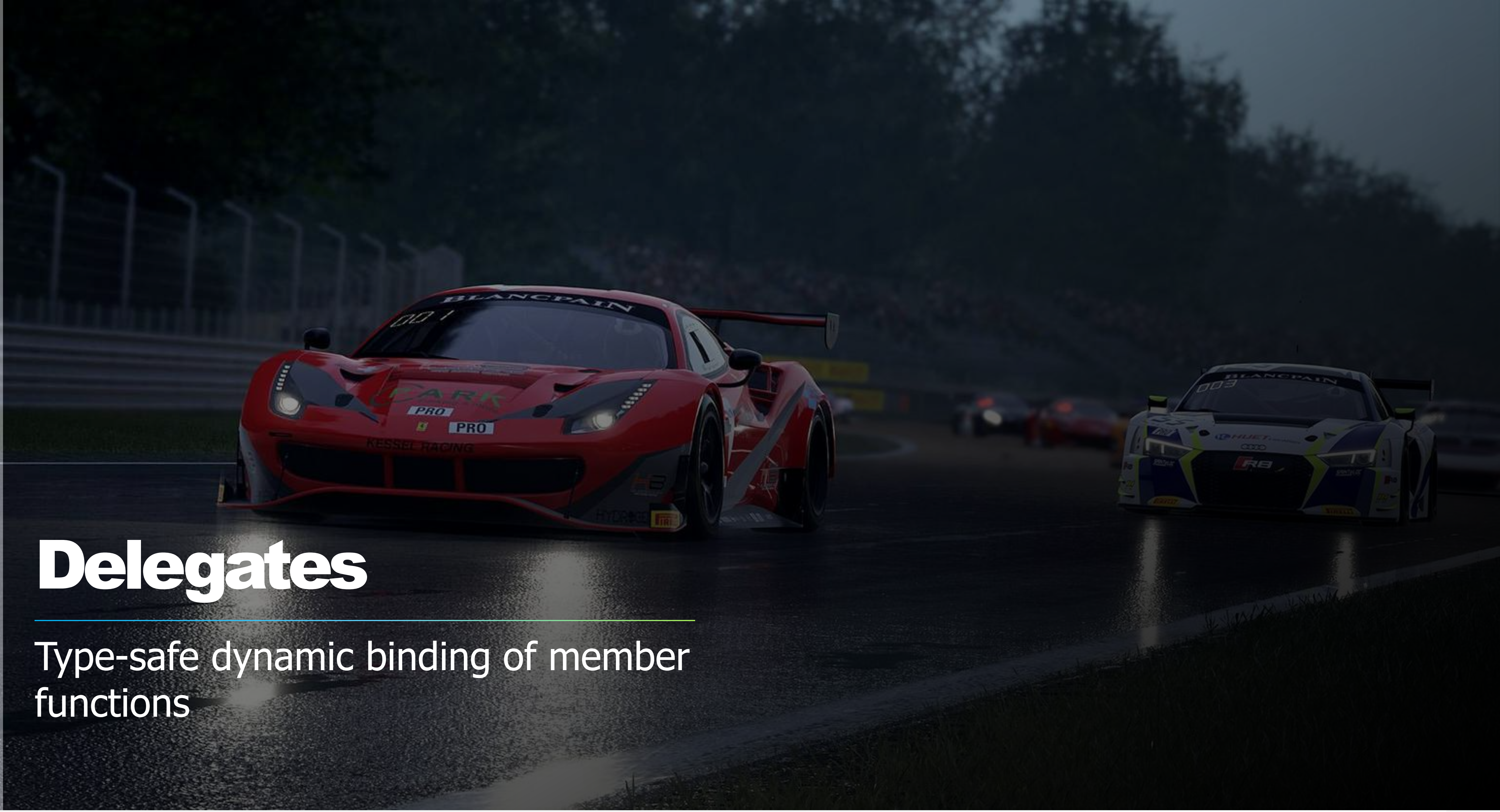
Asynchronous execution

Strategies and classes that allow devs to run asynchronous code using the UE4 framework

Subsystems

4.22

Automatically instantiated classes with managed lifetimes



Delegates

Type-safe dynamic binding of member functions

There are 4+2 types of delegates in UE4

Single

A single function is bound to the delegate

Multicast

Delegates that can be bound to multiple functions and execute them all at once

Dynamic

Delegates that can be serialized and rely on reflection (instead of function pointers)

Dynamic Multicast Sparse

4.23

1-byte multicast implementation. Even slower than dynamic multicast

Events

Similar to multicast, but only the class that declares it can Broadcast

- **Safe to copy**
  - Prefer passing by ref
- **Declared using MACROs**
  - In global scope
  - Inside a namespace
  - Within a class declaration
- **Support for signatures that**
  - Return a value
  - Are const
  - Have up to 8 arguments
  - Have up to 4 additional payloads

Single (or unicast) delegate type

Declaration | Binding | Usage

```
void Function()
DECLARE_DELEGATE( DelegateName )

void Function( <Param1> )
DECLARE_DELEGATE_OneParam( DelegateName, Param1Type )

void Function( <Param1>, ... )
DECLARE_DELEGATE_<Num>Params( DelegateName, Param1Type, ... )

<RetVal> Function()
DECLARE_DELEGATE_RetVal( RetValType, DelegateName )

<RetVal> Function( <Param1> )
DECLARE_DELEGATE_RetVal_OneParam( RetValType, DelegateName, Param1Type )

<RetVal> Function( <Param1>, ... )
DECLARE_DELEGATE_RetVal_<Num>Params( RetValType, DelegateName, Param1Type, ... )
```

Single (or unicast) delegate type

Declaration | **Binding** | Usage

- `BindStatic(func, args…)`
  - Binds a raw C++ pointer global function delegate
- `BindLambda(func, args…)`
  - Binds a C++ lambda delegate
  - Technically this works for any functor types, but lambdas are the primary use case
- `BindRaw(obj*, func, args…)`
  - Binds a raw C++ pointer delegate
  - Raw pointer doesn't use any sort of reference, so may be unsafe to call if the object was deleted. Be careful when calling `Execute()`!

- `BindSP(objPtr, func, args…)`
  `BindThreadSafeSP(…)`
  - Shared pointer-based member function delegate
- `BindUFunction(uObj*, funcName, args…)`
  - UFunction-based member function delegate
- `BindUObject(uObj*, func, args…)`
  - UObject-based member function delegate
- `BindWeakLambda(obj*, func, args…)`
  - Just like the non-weak variant

These keep a weak reference to your object. You can use `ExecuteIfBound()` to call them

Single (or unicast) delegate type

Declaration | Binding | **Usage**

```
DECLARE_DELEGATE_OneParam(FDataIsReadyDelegate, float, value)
UCLASS()
class TEST_API UProducer : public UObject
{
public:
    FDataIsReadyDelegate OnDataIsReady;
    void Register() {
        auto funName = GET_FUNCTION_NAME_CHECKED(UProducer, Receive);
        OnDataIsReady.BindUFunction(this, funName, true);
    }
    void Invoke() const {
        OnDataIsReady.ExecuteIfBound(10.0f);
    }
    UFUNCTION()
    void Receive(float arg1, bool payload1) { … … }
};
```

Multicast delegate type

```
void Function()
DECLARE_MULTICAST_DELEGATE( DelegateName )
void Function( <Param1> )
DECLARE_MULTICAST_DELEGATE_OneParam( DelegateName, Param1Type )
void Function( <Param1>, ... )
DECLARE_MULTICAST_DELEGATE_<Num>Params( DelegateName, Param1Type, ... )
```

Similar to unicast delegates, both in declaration and in usage

Can register multiple functions, thus binding methods are more array-like in semantics

Registered functions are stored in an invocation list

The order in which bound functions are called is not defined

`Broadcast()` is always safe to call

Dynamic delegate variants

```
void Function()
DECLARE_DYNAMIC_DELEGATE( DelegateName )
void Function( <Param1> )
DECLARE_DYNAMIC_MULTICAST_DELEGATE_OneParam( DelegateName, Param1Type )
void Function( <Param1>, ... )
DECLARE_DYNAMIC_MULTICAST_DELEGATE_<Num>Params( DelegateName, Param1Type, ... )
```

Can be serialized
Functions can be found by name (reflection)
Slower than regular delegates as functions are found via reflection compared to C++ functors
Binding via helper macros `AddDynamic(obj*, &Class::Func)`, `BindDynamic(…)`, `RemoveDynamic(…)`
Executed via `Execute()`, `ExecuteIfBound()`, `IsBound()`

Event delegate type

```
void Function()
DECLARE_EVENT( OwningType, EventName )
void Function( <Param1>, ... )
DECLARE_EVENT_<Num>Params( OwningType, EventName, Param1Type, ... )
void Function( <Param1>, ... )
DECLARE_DERIVED_EVENT( DerivedType, ParentType::PureEventName, OverriddenEventName )
```

It's a multicast delegate

Any class can bind to events but only the one that declares it may invoke `Broadcast()`, `IsBound()` and `Clear()` functions

Event objects can be exposed in a public interface without worrying about who's going to call these functions

Use case: callbacks in purely abstract classes

`Broadcast()` is always safe to call

Sparse dynamic multicast delegate type

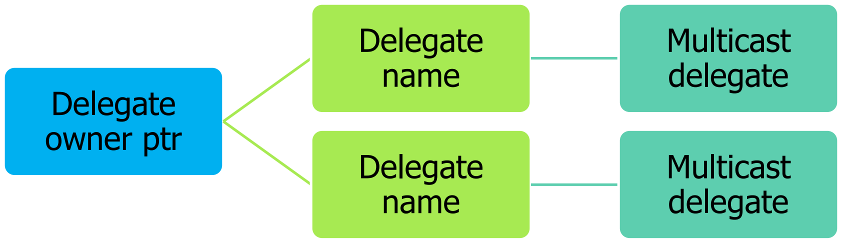
4.23

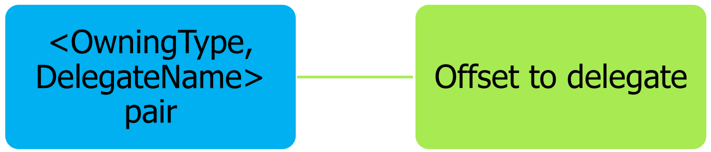
```
void Function()
DECLARE_DYNAMIC_MULTICAST_SPARSE_DELEGATE( DelegateClass, OwningType, DelegateName )
void Function( <Param1>, ... )
DECLARE_DYNAMIC_MULTICAST_SPARSE_DELEGATE_<Num>Params( ... )
```

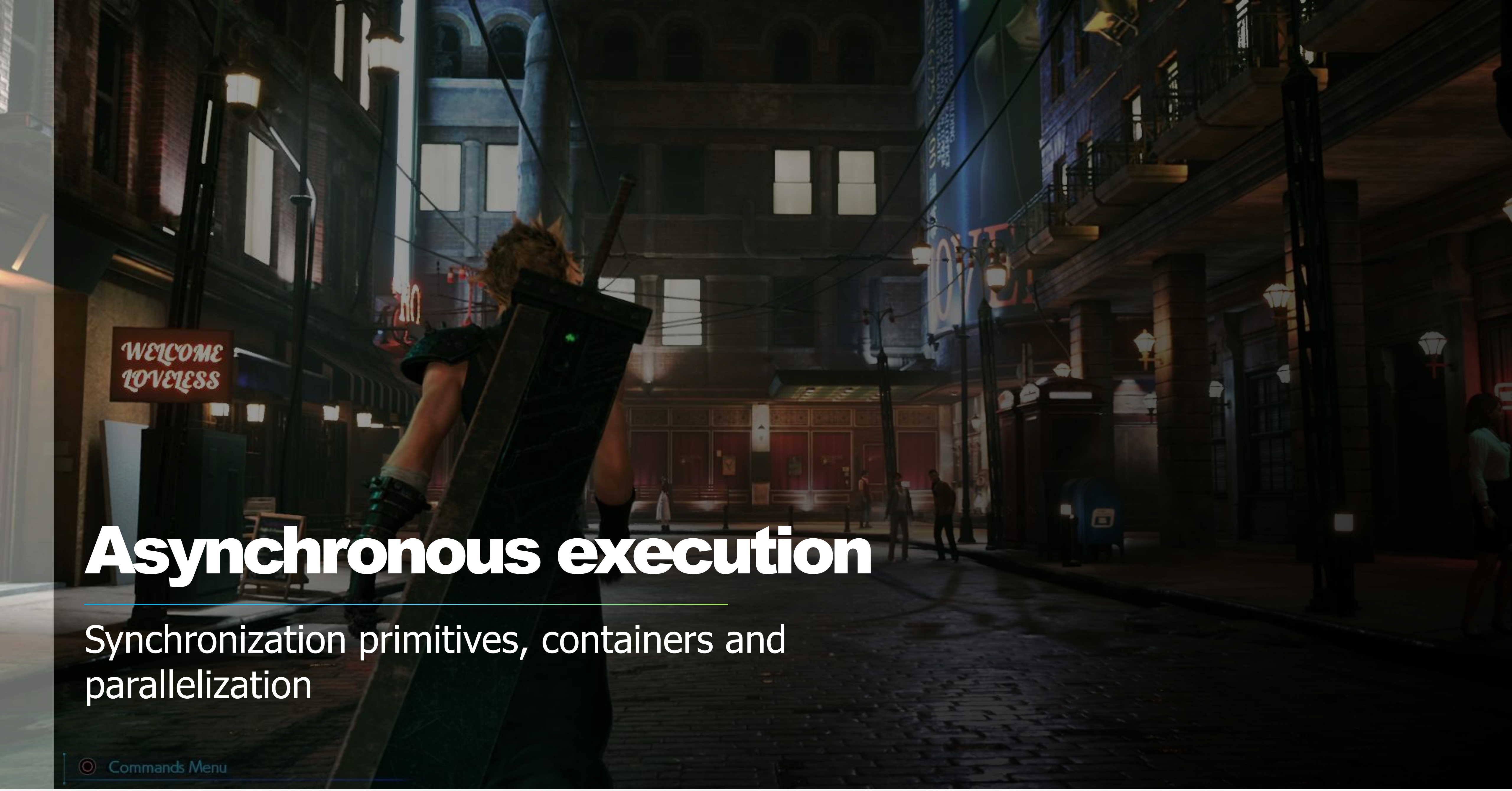
It works just like a (slower) dynamic multicast delegate

Stores just a bool in the owner, signalling whether it’s bound or not

There’s a global static manager that stores:







Asynchronous execution

Synchronization primitives, containers and parallelization

Synchronization primitives

Atomics | Locking | Signalling | Waiting

- ## FPlatformAtomics
  - `InterlockedAdd`
  - `InterlockedCompare{Exchange,Pointer}`
  - `Interlocked{Decrement,Increment}`
  - `InterlockedExchange[Ptr]`
  - `Interlocked{And,Or,Xor}`

- ## What are atomics?
  - Operations that allow lockless concurrent programming
  - Atomic operations are indivisible
  - Are also free of data races

```
class FThreadSafeCounter
{
    volatile int32 m_Counter;
public:
    int32 Add(int32 value) {
        return FPlatformAtomics::InterlockedAdd(&m_Counter, value);
    }
};
```

Synchronization primitives

Atomics | **Locking** | Signalling | Waiting

○ Critical Sections

- `FCriticalSection` synchronization object (mutex)
  - OS-independent: `PThreads` (Android, iOS, Mac, Unix), `CRITICAL_SECTION` (Windows, HoloLens)
- `FScopeLock(mutex*)` for scope level locking
  - The mutex is released in the scope lock's destructor
  - Very useful to prevent deadlocks
- Fast if the lock is not activated

```
class FScopeLockTest
{
    bool m_Toggle = false;
    FCriticalSection m_Mutex;

public:
    // Thread safe toggling
    void Toggle() {
        FScopeLock lock(m_Mutex);
        m_Toggle = !m_Toggle;
    }
};
```

Synchronization primitives

Atomics | Locking | **Signalling** | Waiting

- **FSemaphore**
  - Like mutex with signalling mechanism
  - Only implemented for Windows and hardly used
  - Don't use ☺
  - `FEvent` is there for you!

```
class FSemaphore
{
    std::mutex mtx;
    std::condition_variable cv;
    unsigned int count;
public:
    FSemaphore(unsigned int count);
    void Notify() {
        std::unique_lock<std::mutex> Lk(mtx);
        ++count;
        cv.notify_one();
    }
    void Wait(); // Block until counter > 0
    bool TryWait(); // Non-blocking Wait()
    template<class C, class D>
    bool WaitUntil(const time_point<C,D>& p);
};
```

Synchronization primitives

Atomics | Locking | Signalling | **Waiting**

- **FEvent**
  - Blocks a thread until triggered or timed out
  - Frequently used to wake up worker threads
- **FScopedEvent**
  - Wraps an `FEvent` that blocks on scope exit

```
void SomeFunction
{
    FScopedEvent Event;
    DoWorkOnAnotherThread(Event.Get());

    // stalls here until the other thread calls Event.Trigger();
}
```

High level constructs

Containers

- **General thread-safety info**
  - Most containers (`TArray`, `TMap`, etc..) are not thread safe
  - Use synchronization primitives if needed
- **TLockFreePointerList**
  - Lock free, stack based and ABA resistant
  - Used by Task Graph system
- **TQueue**
  - Uses a linked list under the hood
  - Lock and contention free for Single-Producer, Single-Consumer (SPSC)
  - Lock free for MPSC

Helpers

- **ABA Problem (lock-free data structs)**
  - Process P1 reads value A from shared memory
  - P1 is put on hold while P2 is allowed to run
  - P2 modified the shared memory A to B and then back to A before P2 is put on hold
  - P1 continues execution without knowing that the memory has changed
- **Lock vs contention**
  - Lock is one of the possible scenarios that cause contention
  - Contention can happen on lock-free resources as well: two threads atomically accessing some variable
  - The result is that one thread runs slower than the other one

High level constructs

Containers | **Helpers**

- **FThreadSafe**
  - Counter, Counter64, Int32, Int64, Bool
- **TThreadSingleton**
  - Creates only one instance for each thread
- **FMemStack**
  - Fast, temporary per-thread memory allocation
- **TLockFreeClassAllocator, TLockFreeFixedSizeAllocator**
  - Thread safe, lock free pooling allocator of memory for instances of T
- **FThreadIdleStats**
  - Measures how often a thread is idle

Parallelization

Threads | Task Graph | Processes | Messaging

FRunnable

- Platform-agnostic interface
- Override just 4 methods: `Init`, `Run`, `Stop` and `Exit`
- Launch with `FRunnableThread::Create()`

AsyncPool (Global)

- Execute a given function on the specified thread pool

AsyncThread (Global)

- Execute a given function using a separate thread

Game Thread

- All game code, Blueprints and UI
- UObjects are not thread-safe

Render Thread

- Proxy objects for materials, primitives run in this one

Stats Thread

- Engine performance counters

Parallelization

Threads | **Task Graph** | Processes | Messaging

Task based multithreading

- Small units of work are pushed to available worker threads
- Tasks can have dependencies to each other
- Task Graph will figure out order of execution
- Used internally for a lot of things:
  - Animations, message dispatch, object reachability analysis in GC, render and physics subsystems…

AsyncTask (Global)

- Execute a given function on the task graph

ParallelFor

- General purpose parallel for that uses the task graph

```
ParallelFor(num, [](int32 idx){
    ...
}, bForceSingleThread);
```

```
FConstructor taskCtor = TGraphTask<TAsyncGraphTask<ResultType>>::CreateTask();
taskCtor.ConstructAndDispatchWhenReady(args…); // This or even...
taskCtor.ConstructAndDispatchWhenReady(MoveTemp(func), MoveTemp(future));

// Or, for something a little bit different...
AsyncTask(ENamedThread::AnyNormalThreadNormalTask, [](){ ... });
```

Parallelization

Threads | Task Graph | **Processes** | Messaging

- **FPlatformProcess**
  - `CreateProc()` executes an external program
  - `LaunchURL()` launches the default program for a URL
  - `IsProcRunning()` checks whether a process is running
  - And many more utils for process management
- **FMonitoredProcess**
  - Convenience class for keeping track of some process
  - Even delegates for cancellation, competition and output

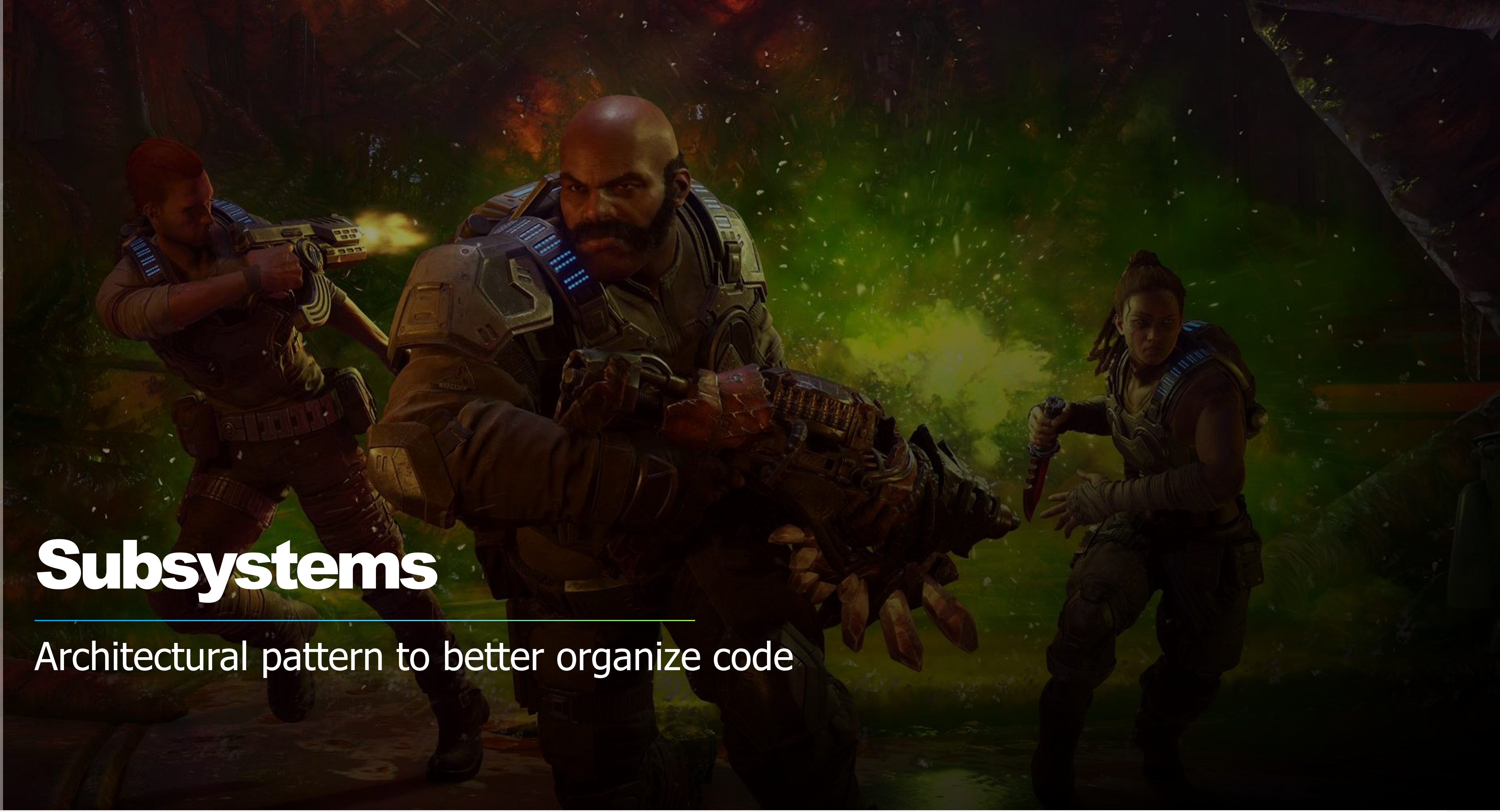
```
FMonitoredProcess Process(*Executable, *Arguments, true/*hidden*/, true/*piped out*/);
Process.OnOutput().BindLambda([](){ ... });
Process.Launch();

while(Process.Update()) {
    ...
}
```

Parallelization

Threads | Task Graph | Processes | **Messaging**

- **Unreal Message Bus (UMB)**
  - Zero configuration intra/inter-process communication
  - Request-Reply and Publish-Subscribe patterns
  - Messages are simple `UStruct`s
  - Notable classes: `FMessageBus`, `FMessageRouter`, `FMessageEndpoint`
- **IMessageTransport**
  - Seamlessly connect processes across machines
  - Can use this interface to implement custom network protocols or API
  - Implemented for TCP and UDP for the moment
- **FGenericPlatformNamedPipe**
  - Yeah, named pipes..

```
auto Endpoint = FMessageEndpoint::Builder(TEXT("SomeName"))
    .ReceivingOnThread(ENamedThread::GameThread)
    .WithCatchall(this, &FMyEndpoint::InternalHandleMessage)
    .NotificationHandling(FOnBusNotification::CreateRaw(this, &FMyEndpoint::OnNotify));

Endpoint->Subscribe(MessageTypeFName, EMessageScope::Thread | EMessageScope::Network);
Endpoint->Send(...);
```



Subsystems

Architectural pattern to better organize code

Subsystems intro

Automatically instanced

- Instantiated, initialized and destroyed by the engine
- No need to wire up systems to spawn and track this object

Managed lifetime

- Five different ones to choose from
- Multiple instances of the same object if it makes sense for the chosen lifetime

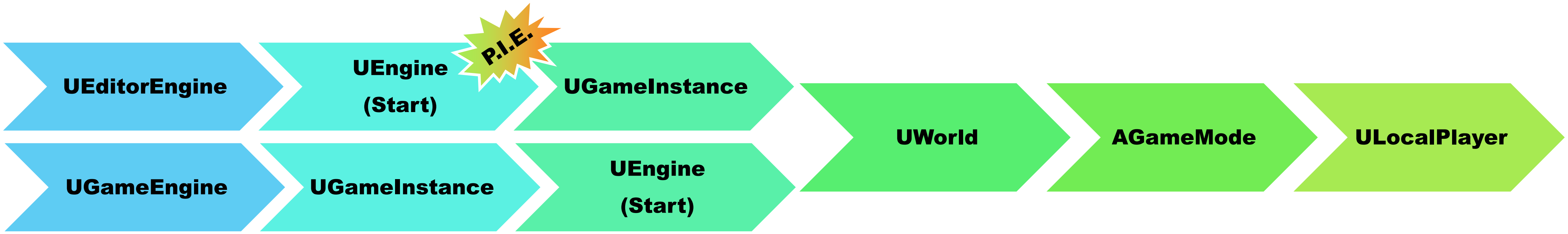
WHY ?!

- Architectural pattern
- Improved modularity
- Especially useful in plugins
- Save both programming time AND lines of code

Subsystem lifetimes / types

The base class you derive from determines also the lifetime of your subsystem

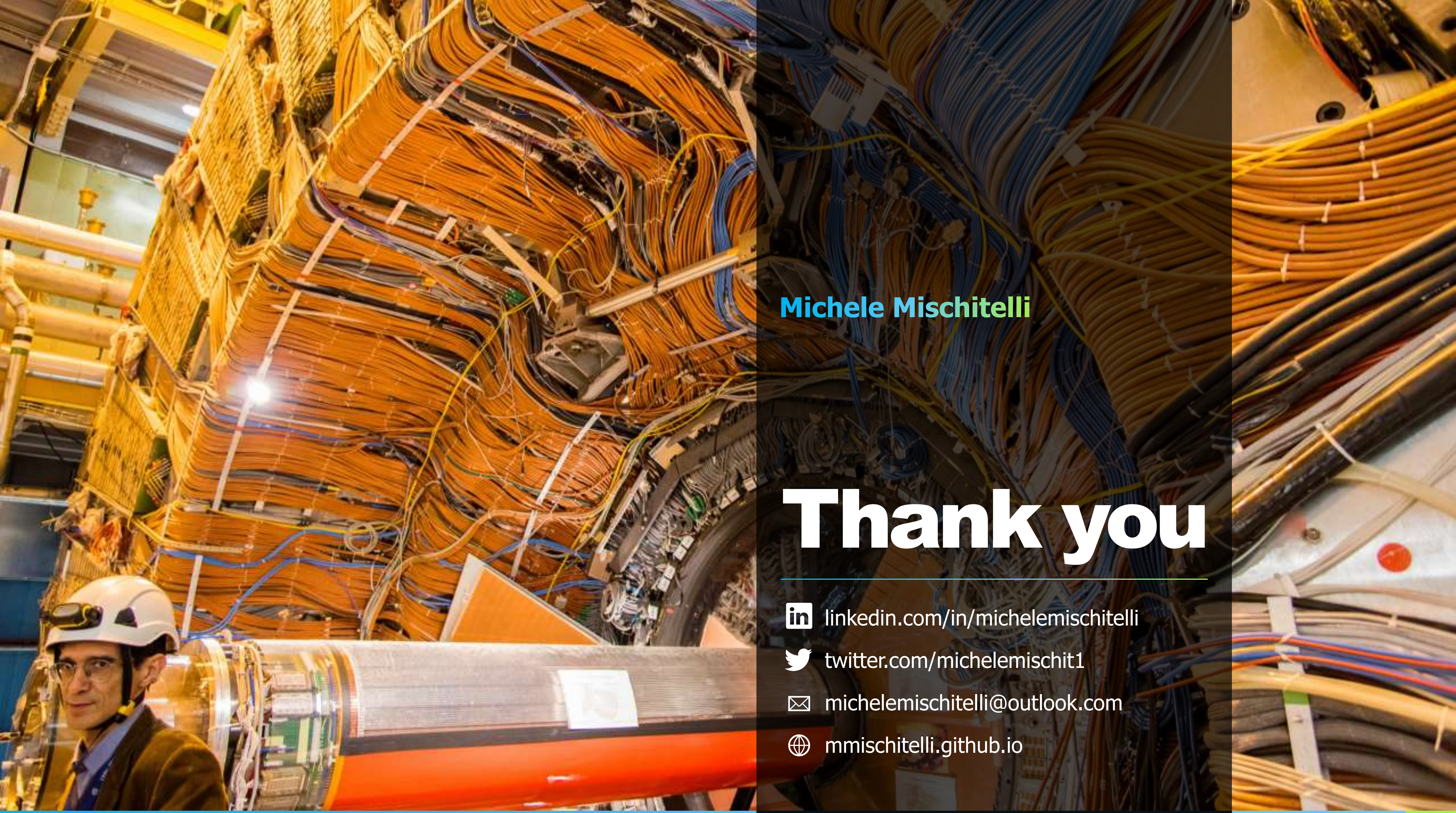
- **Game-centric Subsystems**
  - `UGameInstanceSubsystem`: lives before the world. Persists when changing levels (maps) in the game
  - `ULocalPlayerSubsystem`: each player active on the current client is represented by an instance of `ULocalPlayer`
  - 4.24 `UWorldSubsystem`: a world can be a single persistent level with a list of streaming levels or composition of worlds
- **Advanced Subsystems**
  - `UEngineSubsystem`
  - `UEditorSubsystem`



Subsystem example

```
UCLASS(DisplayName = "PrinterSubsystem")
class MEETUPNOV2019_API UPrinterSubsystem : public UGameInstanceSubsystem
{
    GENERATED_BODY()

    UPROPERTY(EditAnywhere, BlueprintSetter = SetColor, BlueprintGetter = GetColor, meta = (DisplayName="Color", AllowPrivateAccess=true))
    FColor m_Color = FColor::Yellow;
    UPROPERTY(EditAnywhere, BlueprintSetter = SetLifetime, BlueprintGetter = GetLifetime, meta = (DisplayName = "Lifetime", AllowPrivateAccess = true))
    float m_Lifetime = 4.0f;

public:

    UFUNCTION(BlueprintCallable, Category = PrinterSubsystem)
    void PrintString(const FString& str) const;
    void PrintString(uint64 key, const FString& str) const;

    UFUNCTION(BlueprintCallable, Category = PrinterSubsystem)
    void SetColor(const FColor& color) { m_Color = color; }
    UFUNCTION(BlueprintCallable, Category = PrinterSubsystem)
    FColor GetColor() const { return m_Color; }

    UFUNCTION(BlueprintCallable, Category = PrinterSubsystem)
    void SetLifetime(float duration) { m_Lifetime = duration; }
    UFUNCTION(BlueprintCallable, Category = PrinterSubsystem)
    float GetLifetime() const { return m_Lifetime; }
};
```

```
void UProducerSubsystem::Initialize(FSubsystemCollectionBase& Collection)
{
    // Tells Unreal that this subsystem depends on UPrinterSubsystem
    Collection.InitializeDependency(UPrinterSubsystem::StaticClass());
```



Michele Mischitelli

Thank you

linkedin.com/in/michelemischitelli

twitter.com/michelemischit1

michelemischitelli@outlook.com

mmischitelli.github.io