Mono for Game Developers

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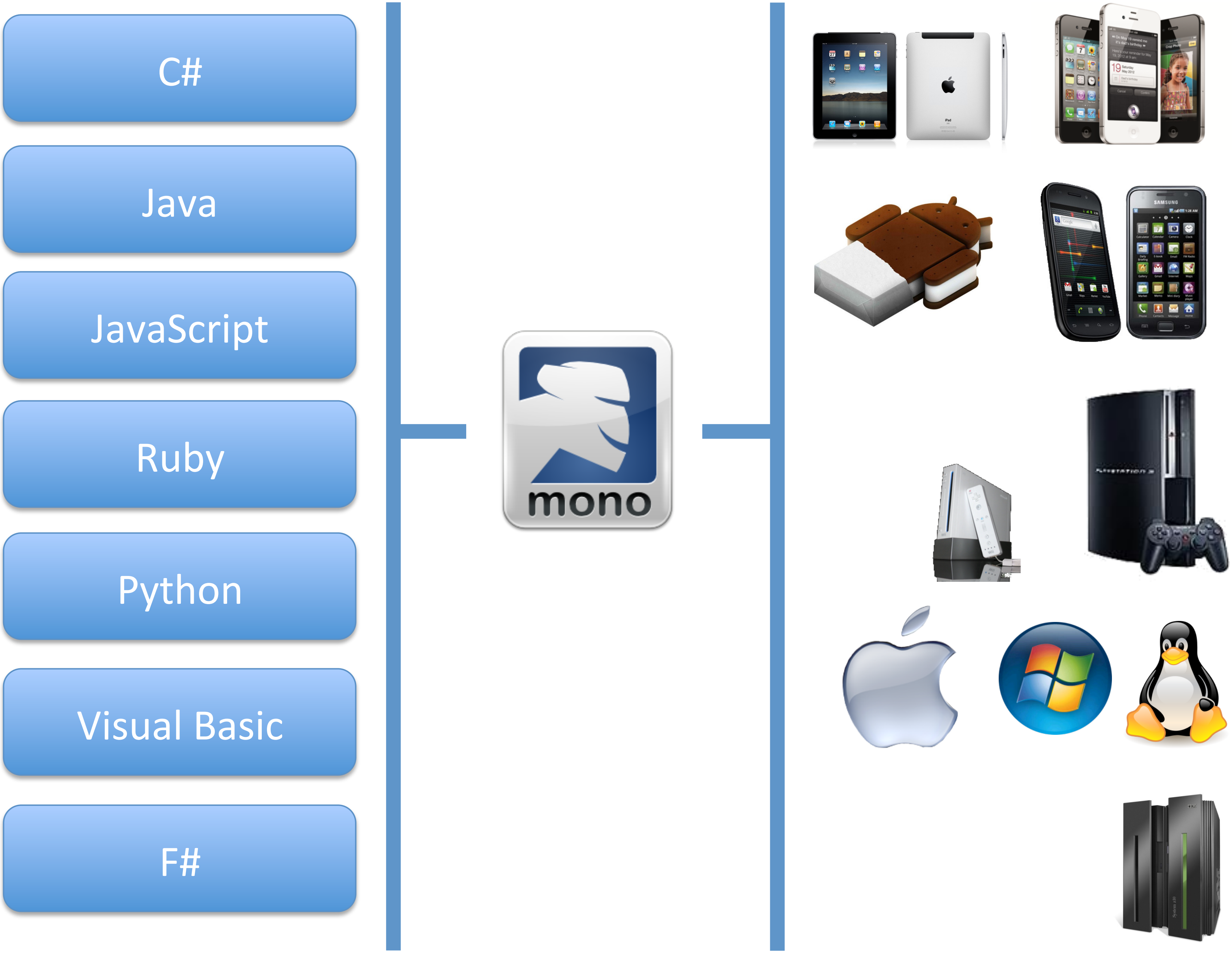
Xamarin Inc

Agenda

- Mono in Games
- Using Mono for Games
- Performance
- Garbage Collection
- Co-routines, Asynchronous Programming

MONO IN GAMES



C#

Java

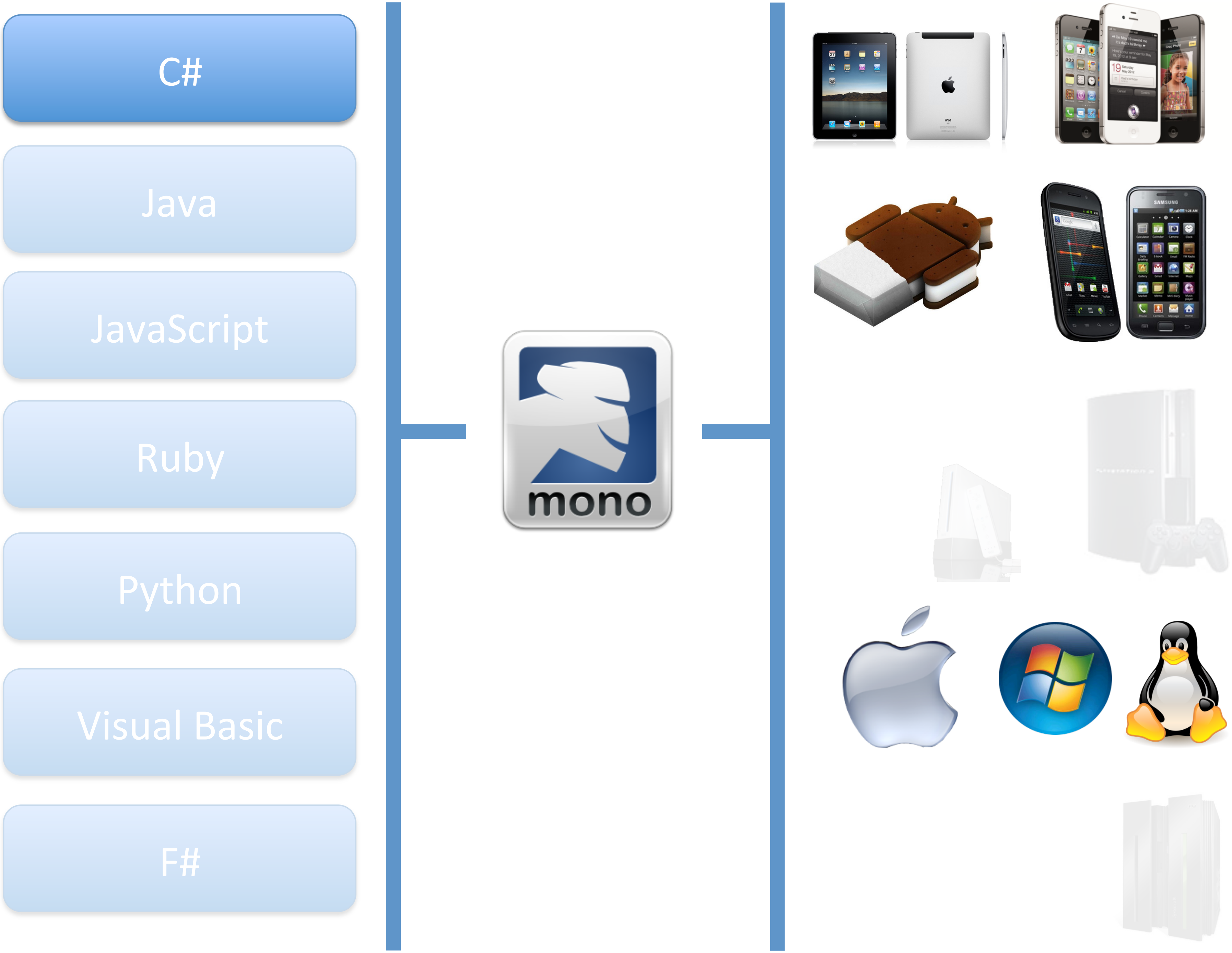
JavaScript

Ruby

Python

Visual Basic

F#



C#

Java

JavaScript

Ruby

Python

Visual Basic

F#

Sims 3

- Mixed Code:
  - C/C++ engine
  - C# scripting/AI
  - C# high-level
- Visual Studio + Mono
- X86, PS3, Xbox360

Credit: www.thesims3facts.webs.com

Bastion – on Google Chrome NaCl

- C# XNA codebase
- Originally on Xbox
- Ported to NativeClient
  - Mono
  - MonoGame (XNA)
- Mac, Windows, Linux

Pure C# - SoulCraft

- DeltaEngine
  - Pure C# engine
  - Open source
  - Android, iOS, Mac, Win

Unity 3D

- Unity Engine
  - C/C++ game engine
  - Embedded Mono
- User code
  - C# or UnityScript
  - Extends Unity itself

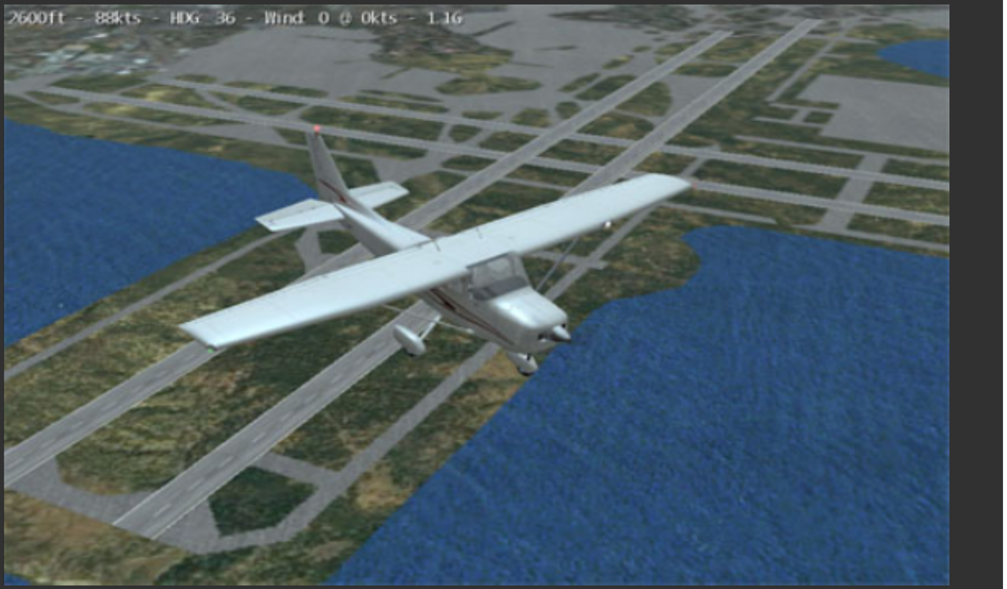
Shadow Gun, built with Unity

SecondLife

- Mono on the server
- Powers LSL scripts
- Nice 200x perf boost
- Code Injection

Infinite Flight

- Subject of the second part of this session



```
2600ft - 88kts - HDG 36 - Wind 0 @ 0kts - 1.1G
```

WHY MONO?

Because Life is too Short

- To debug another memory leak
- To track another memory corruption bug
- Because you deserve better

The Quest for Productivity

System Languages

Pros:

- Low-level
- Good control of hardware
- Typed
- Fast code

Cons:

- Easy to corrupt state
- Low productivity
- Crash often
- Complex for newcomers

Scripting Languages

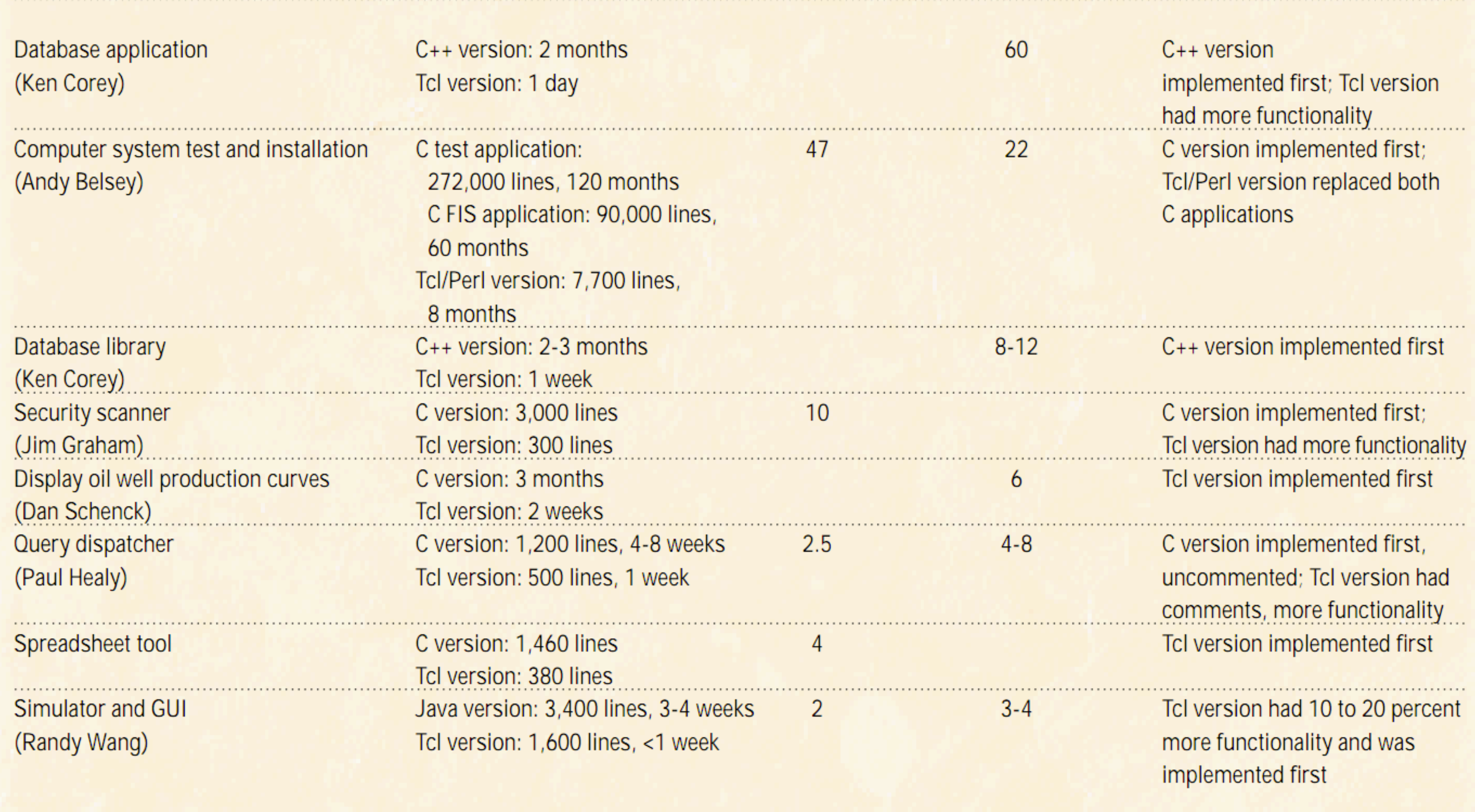
Pros:

- High-level, good productivity
- Easy to write
- Safe, prevent crashes
- Loosely typed

Cons:

- Poor control of hardware
- Slow (interpreted)

John Ousterhout Scripting Quest
IEEE 1998 Summary Paper



Database application (Ken Corey)	C++ version: 2 months Tcl version: 1 day		60	C++ version implemented first; Tcl version had more functionality
Computer system test and installation (Andy Belsey)	C test application: 272,000 lines, 120 months C FIS application: 90,000 lines, 60 months Tcl/Perl version: 7,700 lines, 8 months	47	22	C version implemented first; Tcl/Perl version replaced both C applications
Database library (Ken Corey)	C++ version: 2-3 months Tcl version: 1 week		8-12	C++ version implemented first
Security scanner (Jim Graham)	C version: 3,000 lines Tcl version: 300 lines	10		C version implemented first; Tcl version had more functionality
Display oil well production curves (Dan Schenck)	C version: 3 months Tcl version: 2 weeks		6	Tcl version implemented first
Query dispatcher (Paul Healy)	C version: 1,200 lines, 4-8 weeks Tcl version: 500 lines, 1 week	2.5	4-8	C version implemented first, uncommented; Tcl version had comments, more functionality
Spreadsheet tool	C version: 1,460 lines Tcl version: 380 lines	4		Tcl version implemented first
Simulator and GUI (Randy Wang)	Java version: 3,400 lines, 3-4 weeks Tcl version: 1,600 lines, <1 week	2	3-4	Tcl version had 10 to 20 percent more functionality and was implemented first

http://www.stanford.edu/~ouster/cgi-bin/papers/scripting.pdf

John was always ahead of his time

- Professional workstations in 1998
  - SPARC, HP-PA
- Not achievable on PCs of the time

2000 – Desktop Development

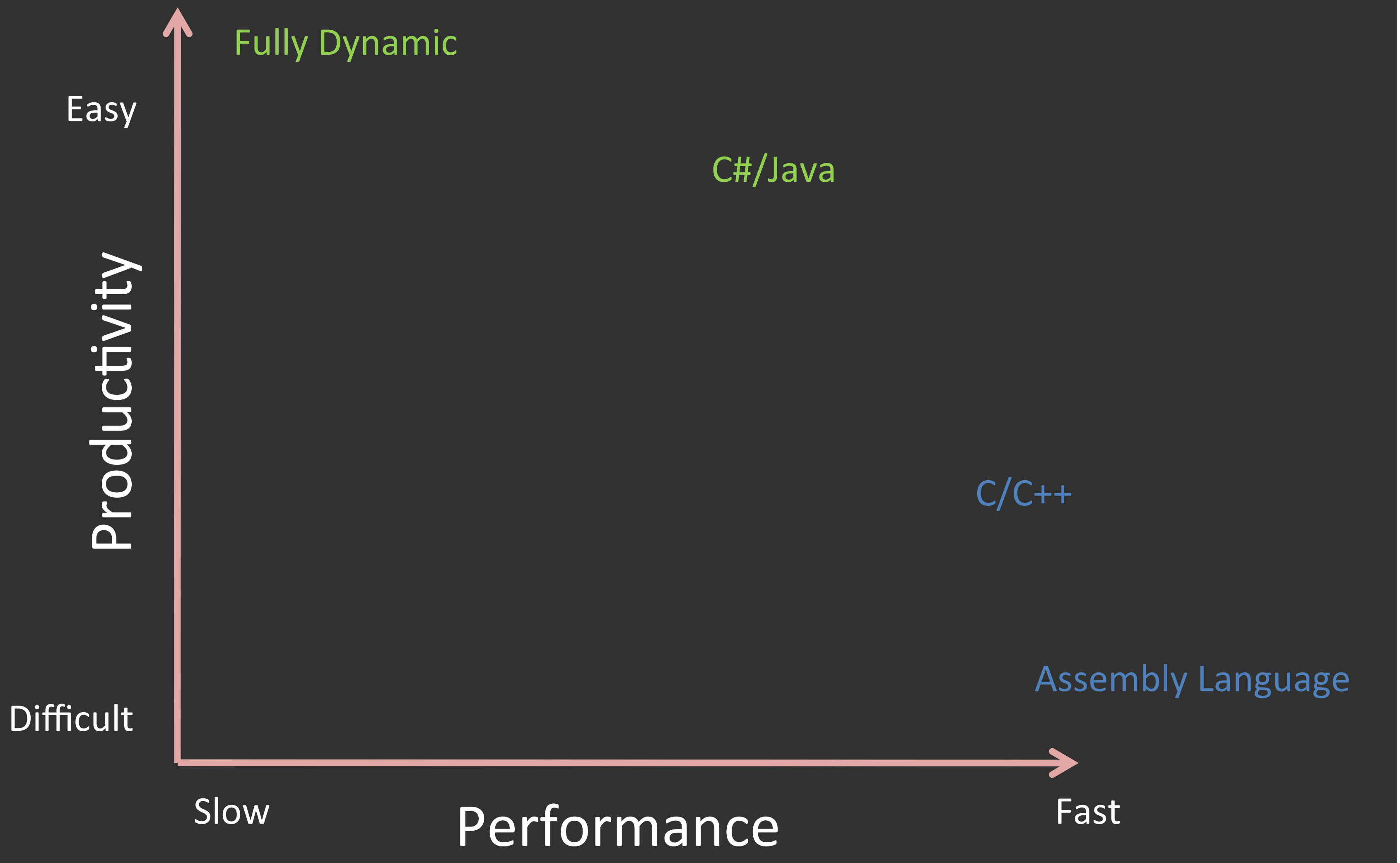
- Building desktop apps with C and C++
  - Slow progress, error prone, frequent crashes
- Windows 2000 Requirements:
  - 133 Mhz or more
  - 64 megs for desktop, 256 for server
- Windows XP Requirements (one year later)
  - 233Mhz or more
  - 128 megs for desktop
- Development desktops at the time:
  - ~1Ghz speed
  - ~1 GB of memory

C# Introduced in 2000

- C# 1.0 was a Java-like system

- With many design fixes
  - 10 years of experience
  - Change defaults (all virtual, vs opt-in virtual)
  - Introduce structs (help GC, no boxing)
  - Direct access to native libraries (P/Invoke)
  - Delegates (foundation for lambdas)

Language Choices



Fully Dynamic

Easy

C#/Java

Productivity

C/C++

Assembly Language

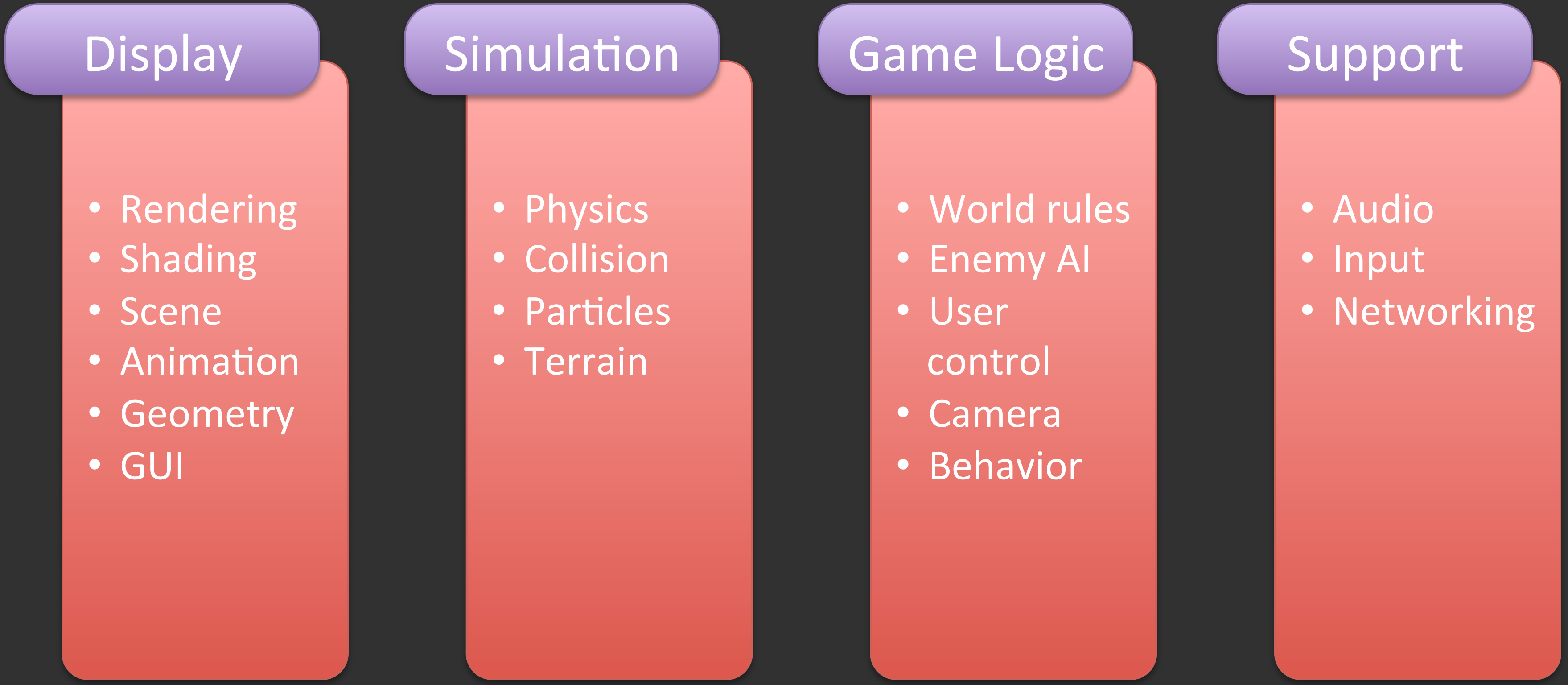
Difficult

Slow

Performance

Fast

Game Software Components



Display

- Rendering
- Shading
- Scene
- Animation
- Geometry
- GUI

Simulation

- Physics
- Collision
- Particles
- Terrain

Game Logic

- World rules
- Enemy AI
- User control
- Camera
- Behavior

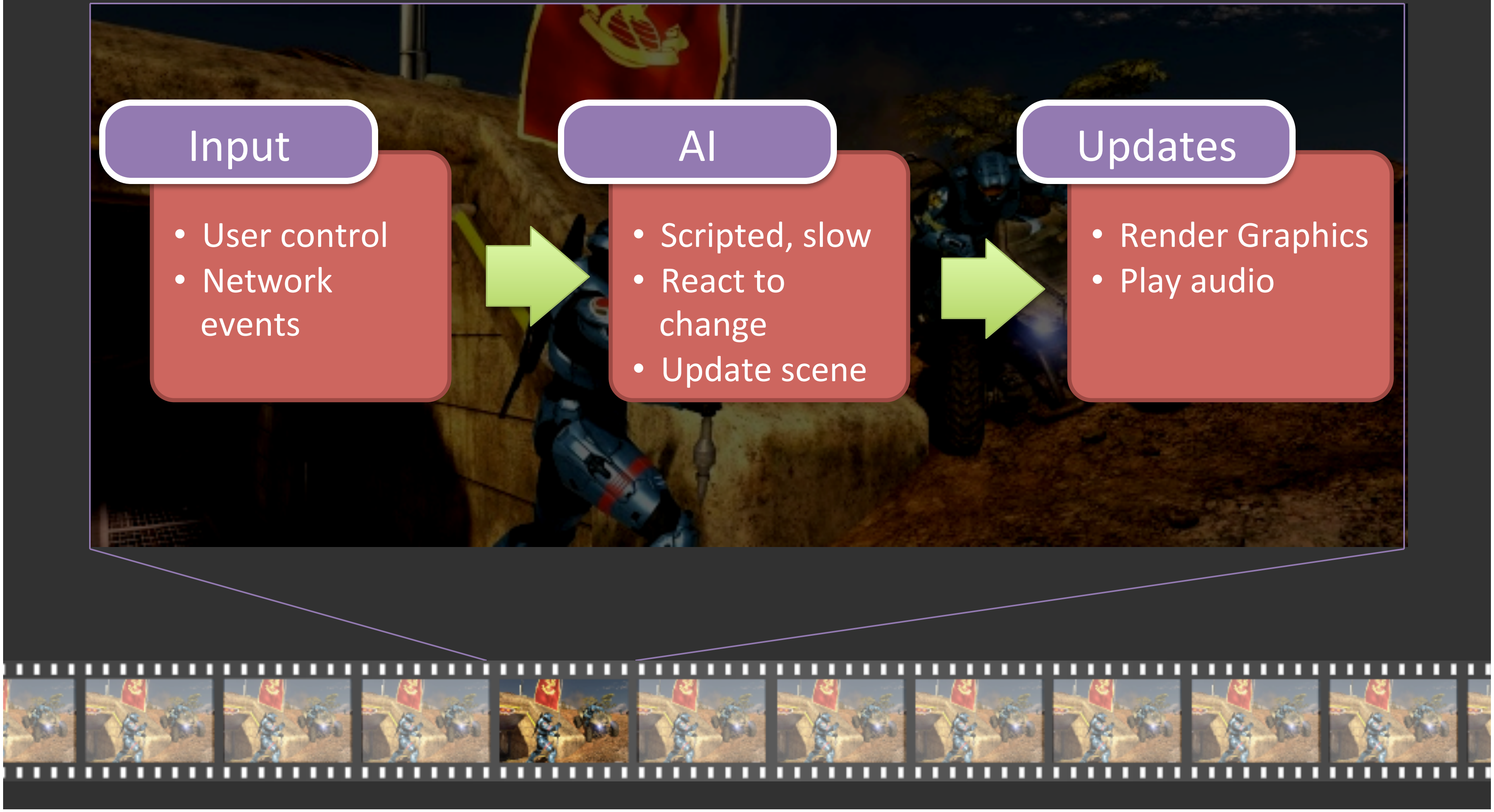
Support

- Audio
- Input
- Networking

The Problem

Games are real-time programs

- 30 to 60 frames per second (0.016 seconds)



Input

- User control
- Network events

AI

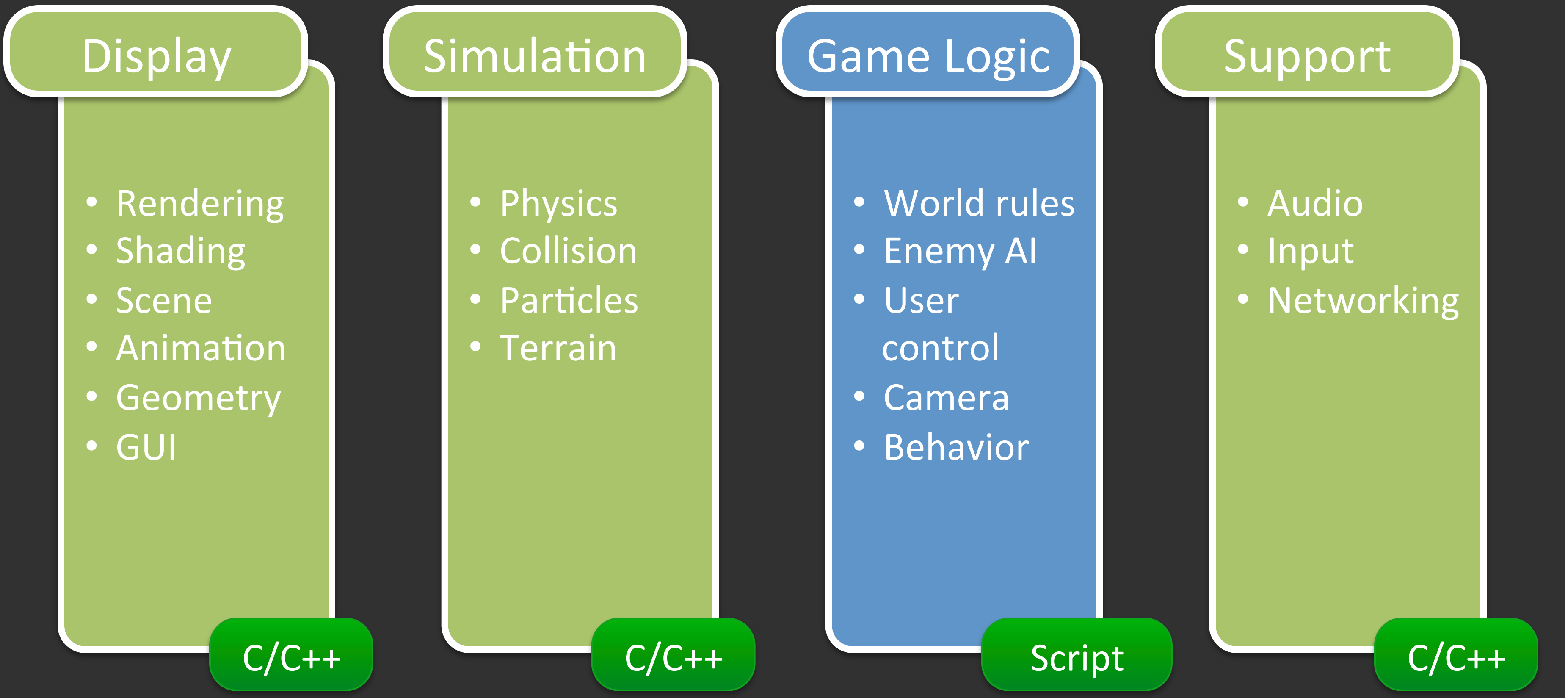
- Scripted, slow
- React to change
- Update scene

Updates

- Render Graphics
- Play audio

Problem: Scripting Is A Bottleneck

Gaming's Achilles' Heel



Display

- Rendering
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C/C++

Simulation

- Physics
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C/C++

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- World rules
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Script

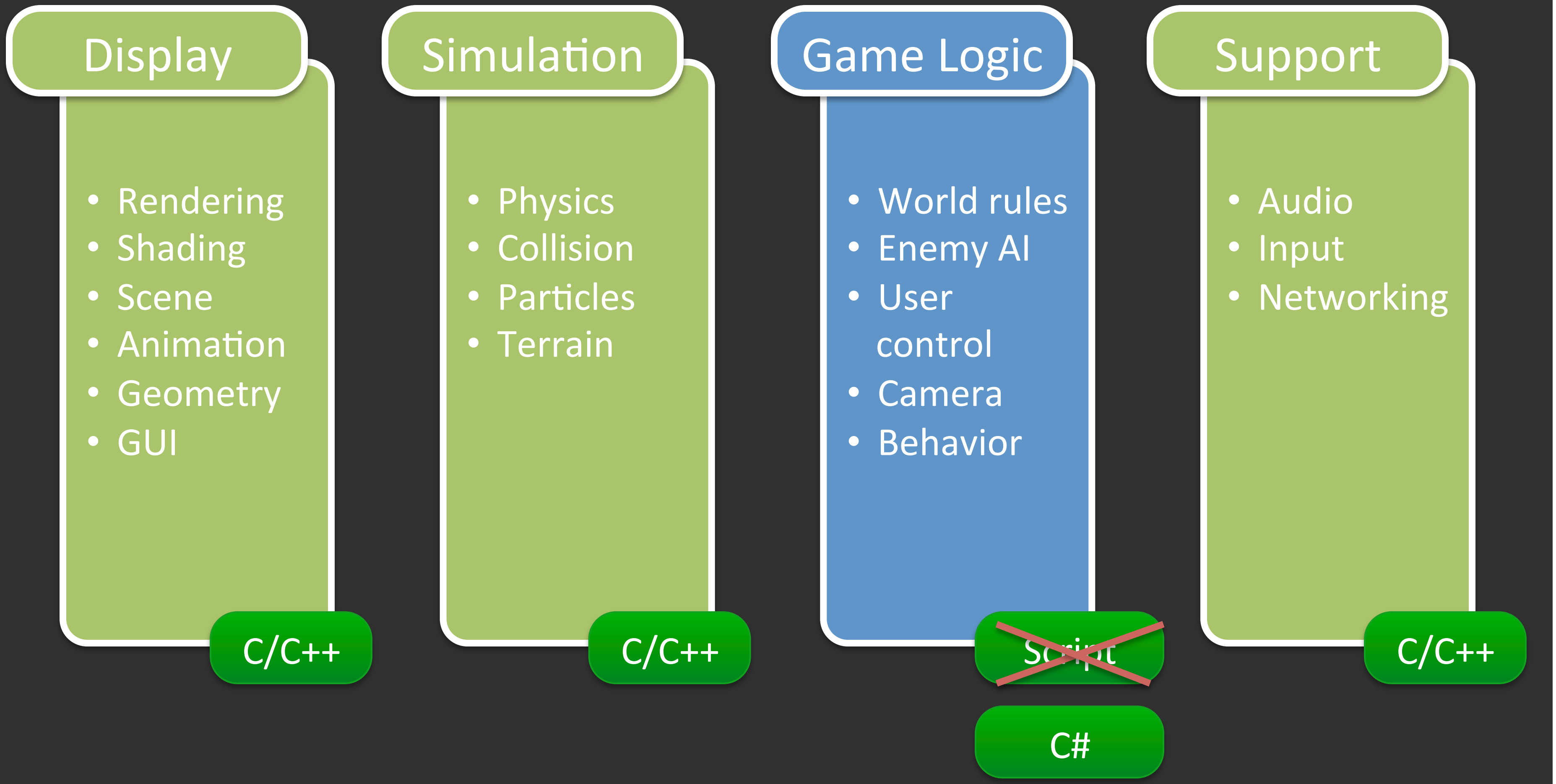
Support

- Audio
- Input
- Networking

C/C++

Problem: Scripting Is A Bottleneck

Gaming's Achilles' Heel



Display

- Rendering
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C/C++

Simulation

- Physics
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C/C++

Game Logic

- World rules
- Enemy AI
- User control
- Camera
- Behavior

~~Script~~

C#

Support

- Audio
- Input
- Networking

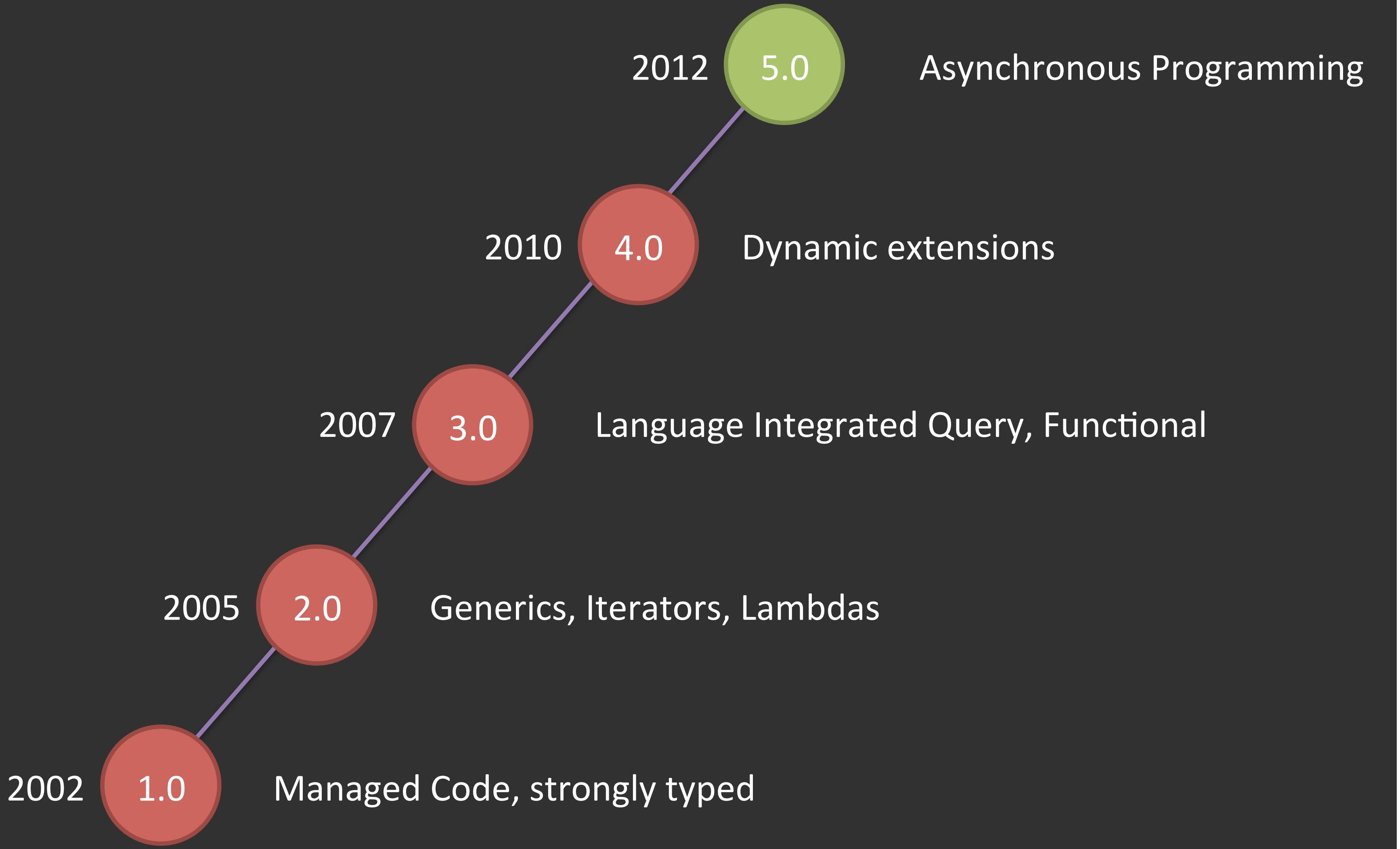
C/C++

What C# Offers

- Close to native performance
  - 50%-90% of native performance

- Safe Execution Environment
  - With optional support to shoot yourself in the foot.

C# - An Evolving Language



2012 5.0 Asynchronous Programming

2010 4.0 Dynamic extensions

2007 3.0 Language Integrated Query, Functional

2005 2.0 Generics, Iterators, Lambdas

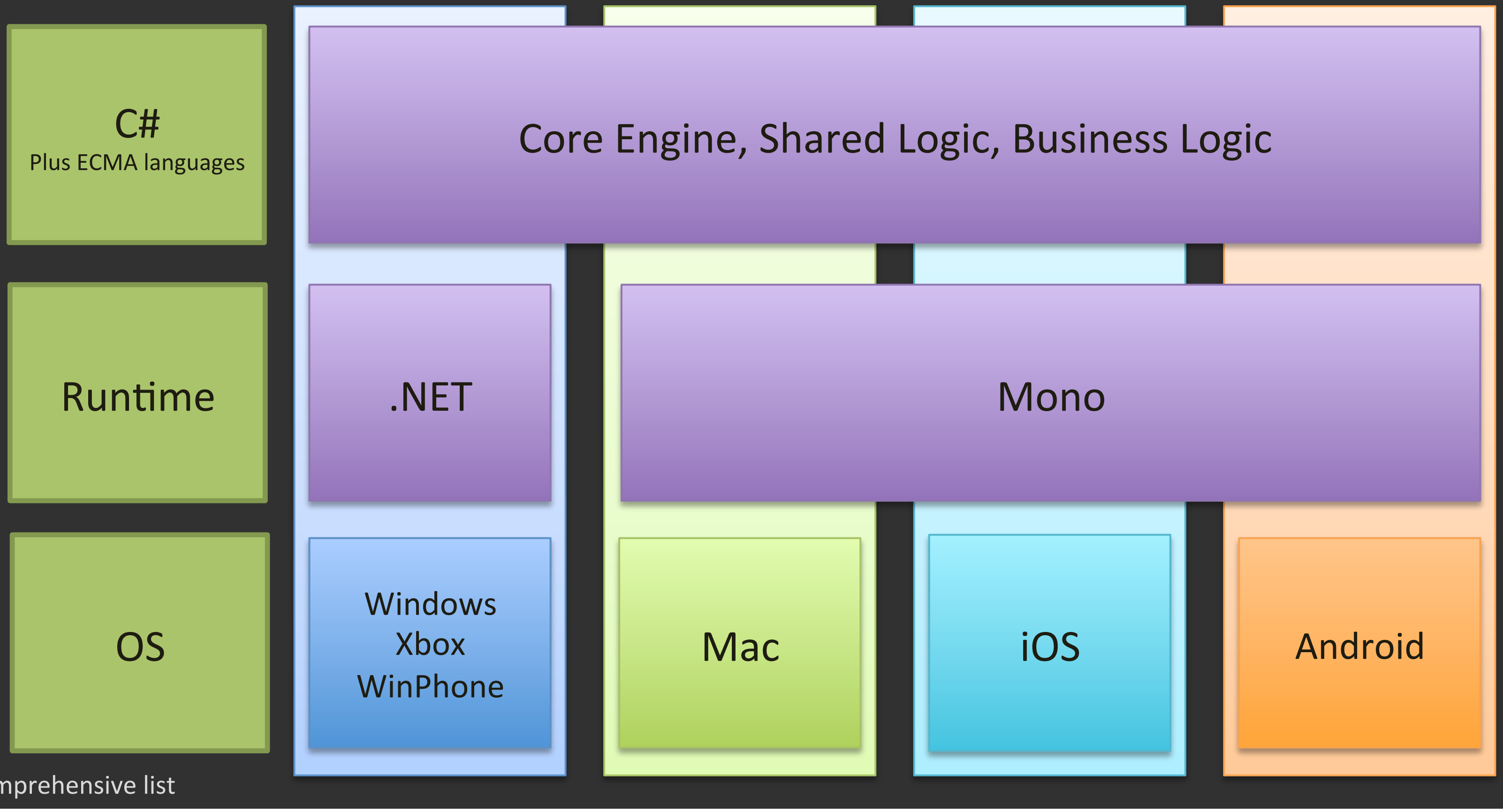
2002 1.0 Managed Code, strongly typed

USING MONO

Designing Mono Applications

- Provided:
  - C# Language
  - Base Class Libraries
- Not Provided:
  - User Interface, Graphics, Audio
  - These are all platform specific

Code Sharing and Native Experience



C#
Plus ECMA languages

Runtime

OS

Core Engine, Shared Logic, Business Logic

.NET

Mono

Windows
Xbox
WinPhone

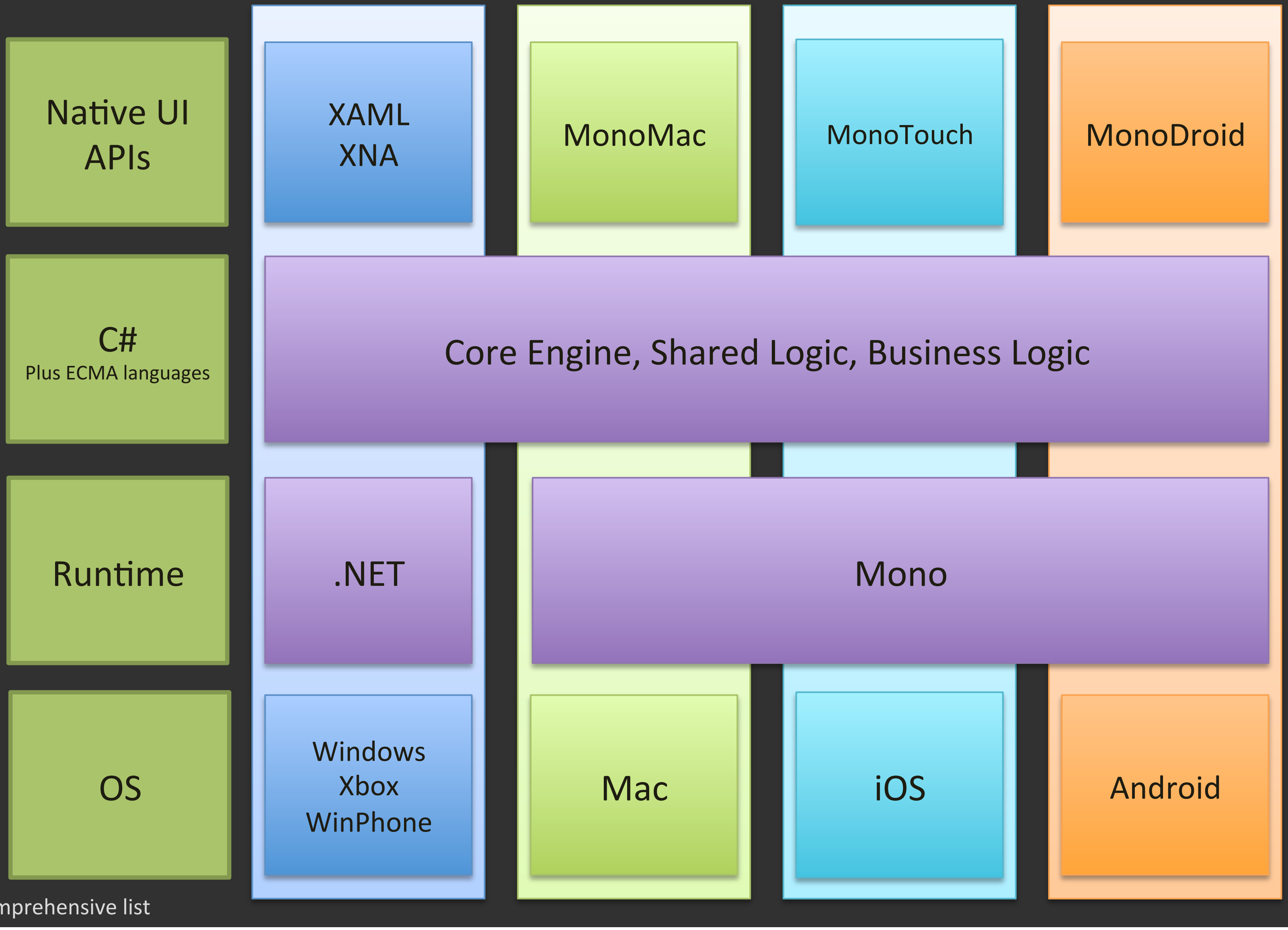
Mac

iOS

Android

Not a comprehensive list

Code Sharing and Native Experience



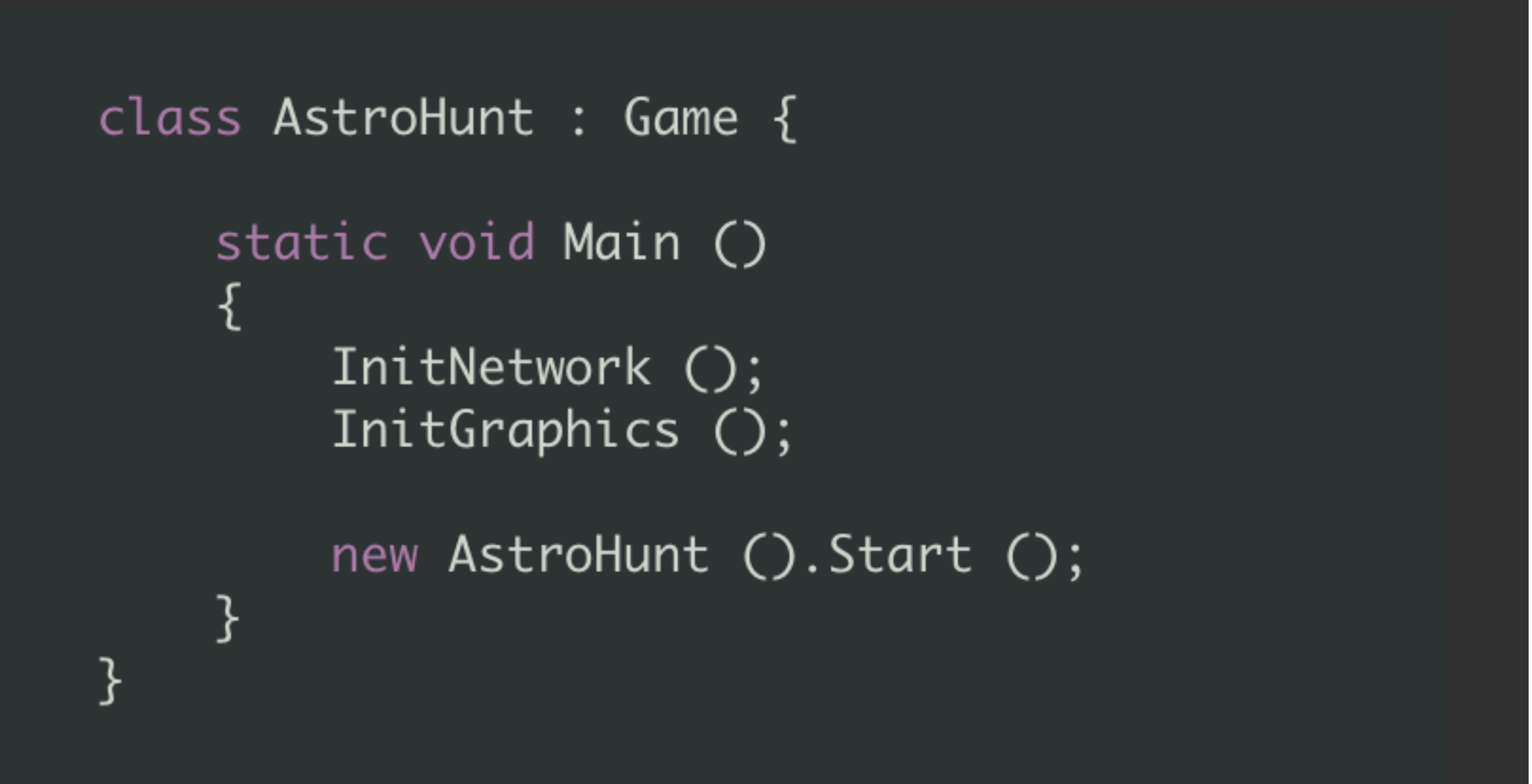
Native UI APIs	XAML XNA	MonoMac	MonoTouch	MonoDroid
C# Plus ECMA languages	Core Engine, Shared Logic, Business Logic			
Runtime	.NET	Mono		
OS	Windows Xbox WinPhone	Mac	iOS	Android

Not a comprehensive list

Modes of Use

- Drive the application
- Scripting engine
  - Sandboxed
  - Full access

Run on Mono

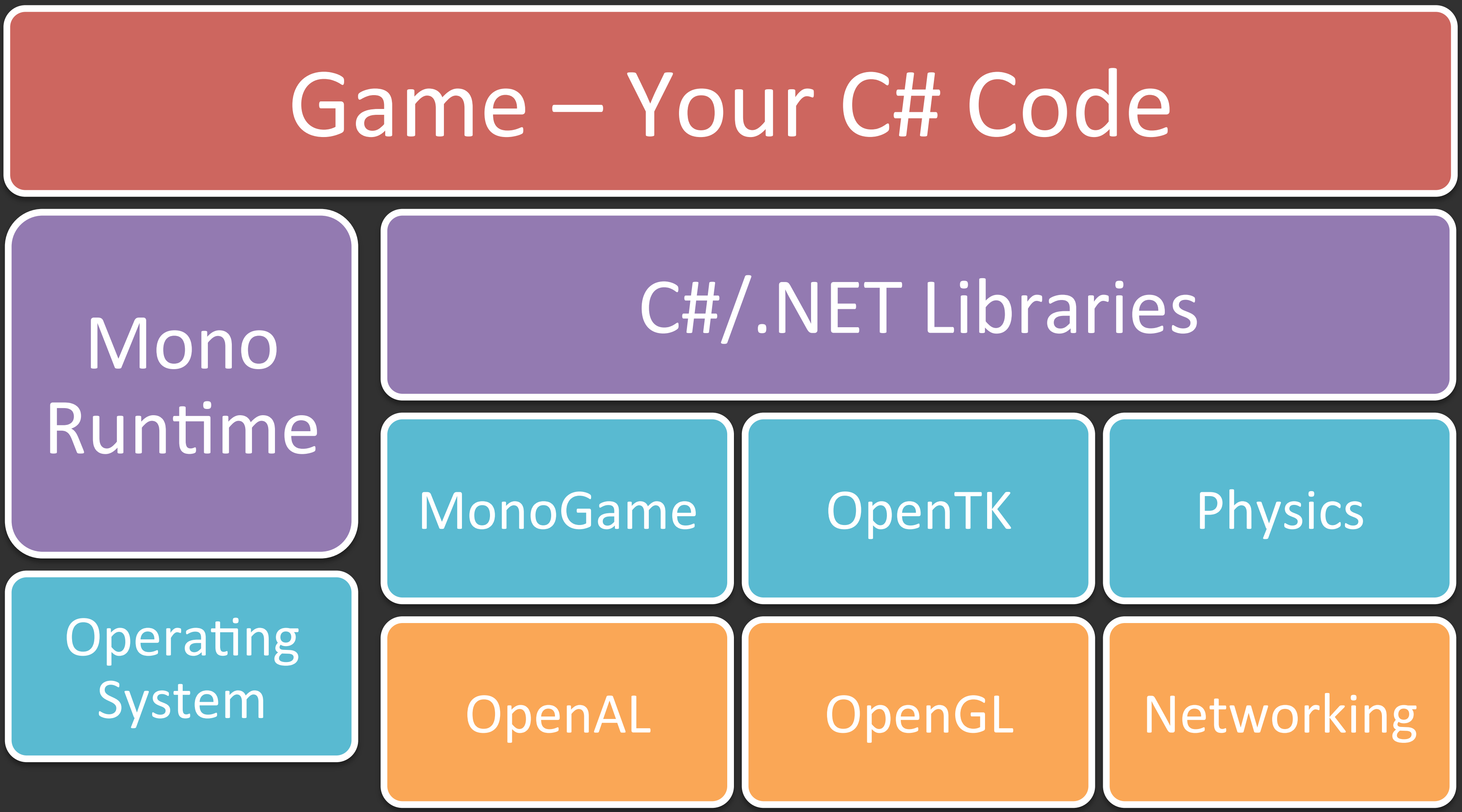


```
class AstroHunt : Game {

    static void Main ()
    {
        InitNetwork ();
        InitGraphics ();

        new AstroHunt ().Start ();
    }
}
```

Run on Mono



Game – Your C# Code

Mono Runtime

C#/.NET Libraries

MonoGame

OpenTK

Physics

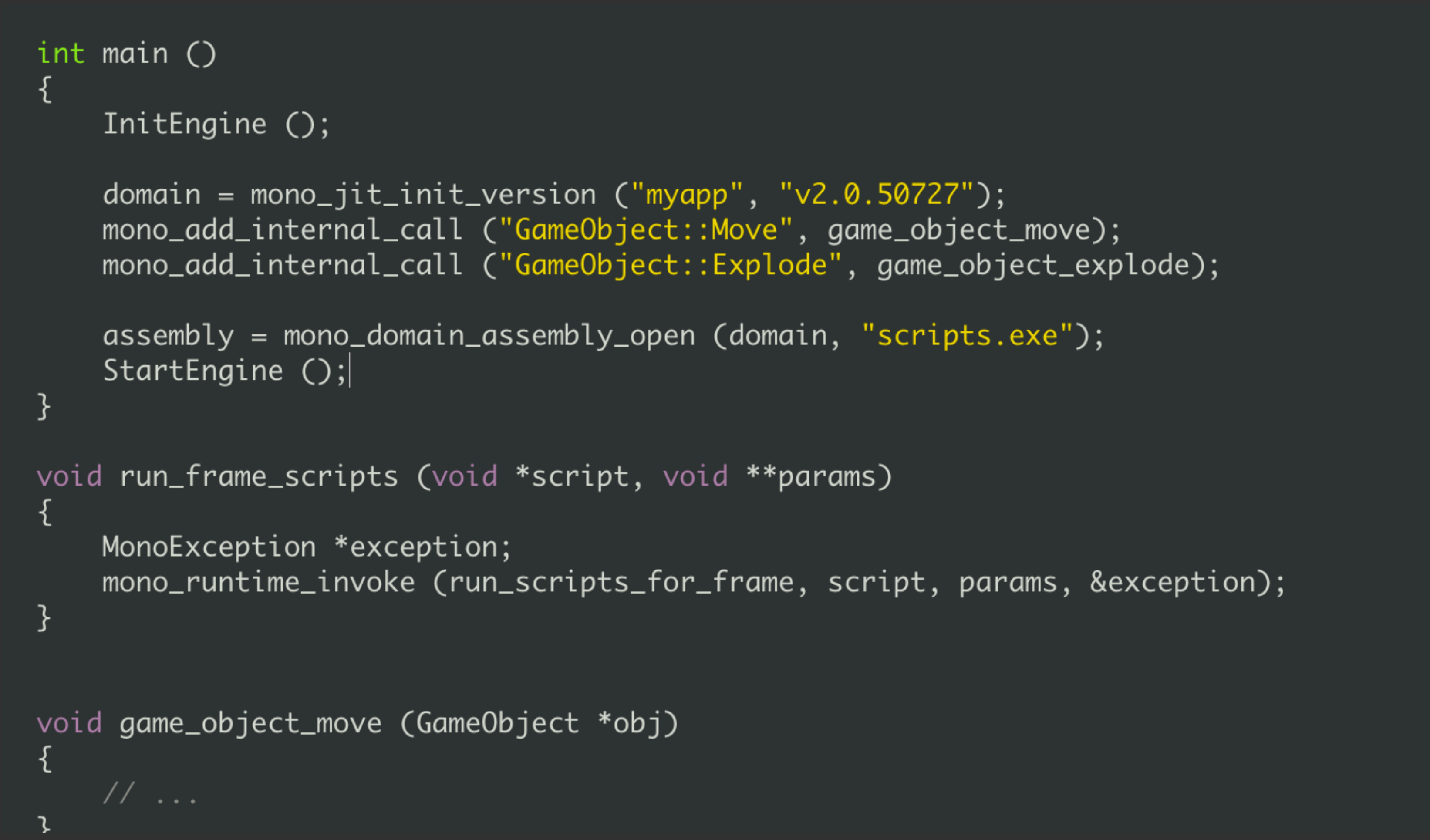
Operating System

OpenAL

OpenGL

Networking

Using Mono as a Library



```
int main ()
{
    InitEngine ();

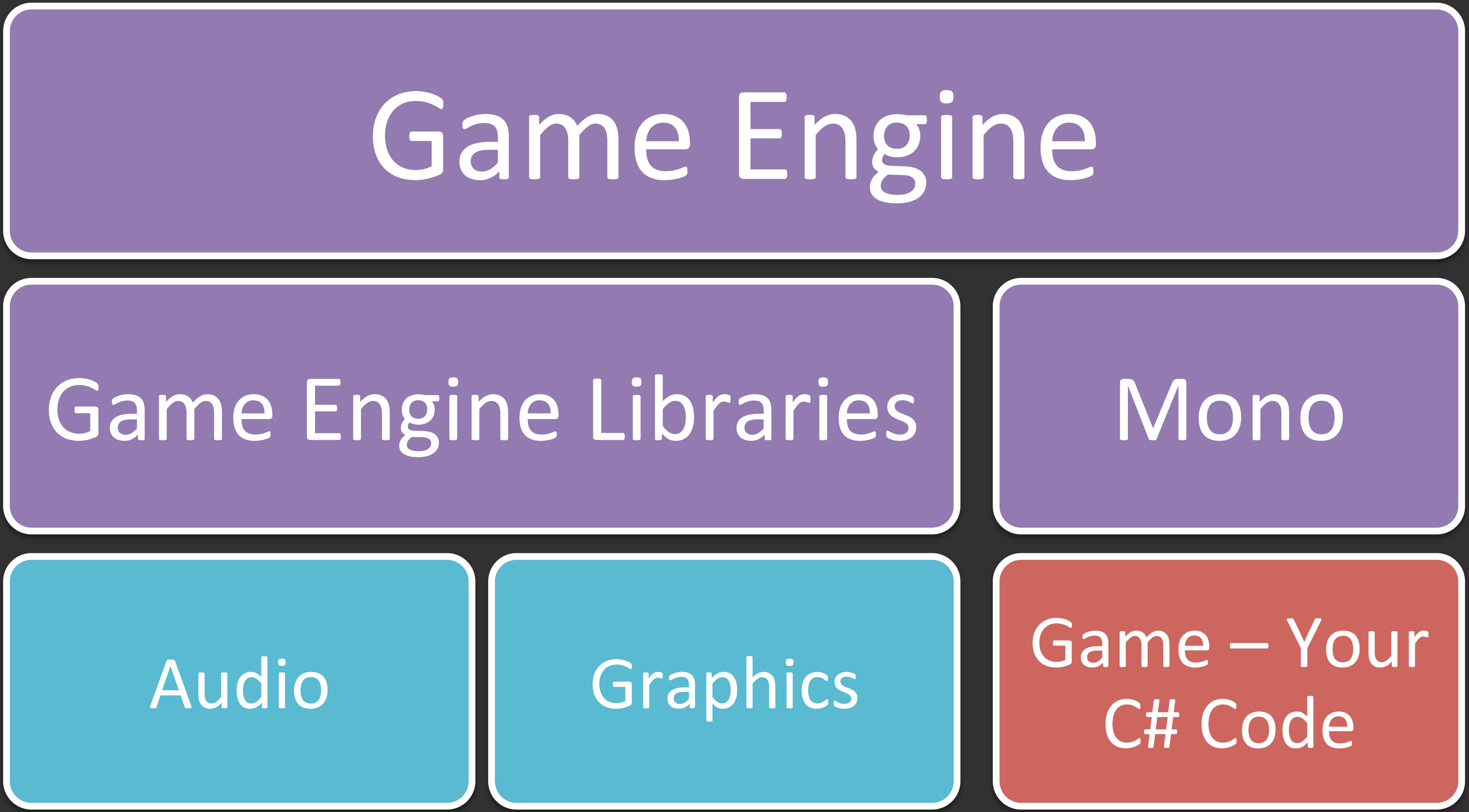
    domain = mono_jit_init_version ("myapp", "v2.0.50727");
    mono_add_internal_call ("GameObject::Move", game_object_move);
    mono_add_internal_call ("GameObject::Explode", game_object_explode);

    assembly = mono_domain_assembly_open (domain, "scripts.exe");
    StartEngine ();
}

void run_frame_scripts (void *script, void **params)
{
    MonoException *exception;
    mono_runtime_invoke (run_scripts_for_frame, script, params, &exception);
}


void game_object_move (GameObject *obj)
{
    // ...
}
```

Use Mono as a Library



Game Engine

Game Engine Libraries

Mono

Audio

Graphics

Game – Your C# Code

TIPS ON USING MONO

Two Code Generation Backends

Mono’s Native Backend

- Very fast codegen
  - .3 seconds bootstrap
- Not great code output
- JIT’s default engine

LLVM Backend

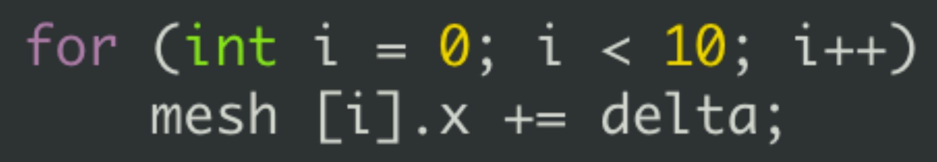
- Very slow codegen
  - 7 second bootstrap
- Great output quality
- Opt-in:
  - `mono --llvm`

Just in Time vs Ahead of Time

- Just in Time Compilation
  - Default Mode of Operation
  - Very fast at compiling code
  - Not great quality of code generation

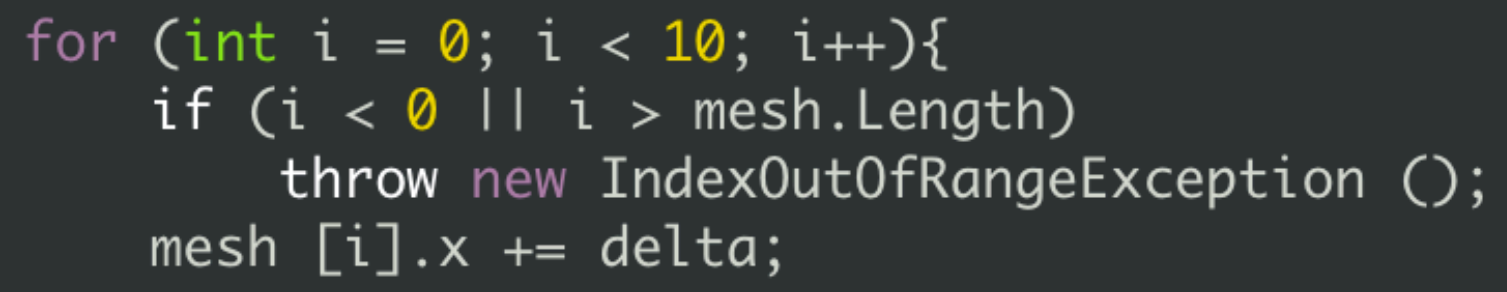
- Ahead of Time Compilation
  - Mandatory on some platforms
    - PS3, XBox360, iOS
  - Can afford expensive compiler optimizations

Arrays Bounds Checking



```
for (int i = 0; i < 10; i++)
    mesh [i].x += delta;
```

Mono Runtime translates this to:



```
for (int i = 0; i < 10; i++){
    if (i < 0 || i > mesh.Length)
        throw new IndexOutOfRangeException ();
    mesh [i].x += delta;
```

Disabling Arrays Bounds Checking

- Very unsafe
  - GC depends on system integrity
  - But admissible if no error ever found on testing

- We give you the tools to shoot your feet
  - `mono -O=unsafe`

- Ask your QA team

GARBAGE COLLECTION

Mono’s Garbage Collectors

- Boehm GC:
  - Traditional Mono GC
  - Mostly-precise, stack conservative
  - Scans everything on each GC
- Generational Collector (SGen)
  - New (default on Android)
  - Generational (Old generation, nurseries)
  - Copying (plus mark+sweep for large objects)

SGen

Nursery

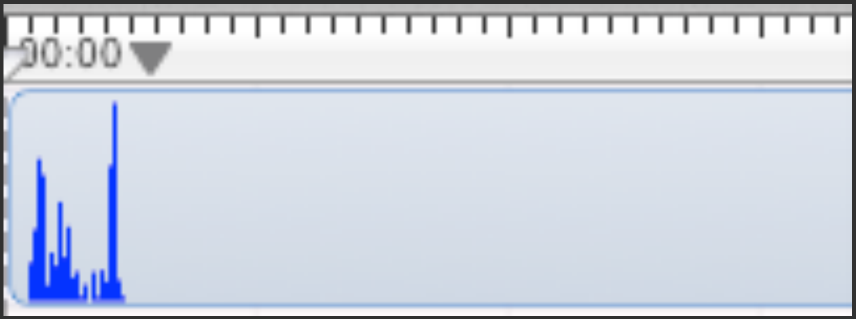
- New objects
- Small size (4MB)
- Per thread regions
- Very fast collection

Old Generation

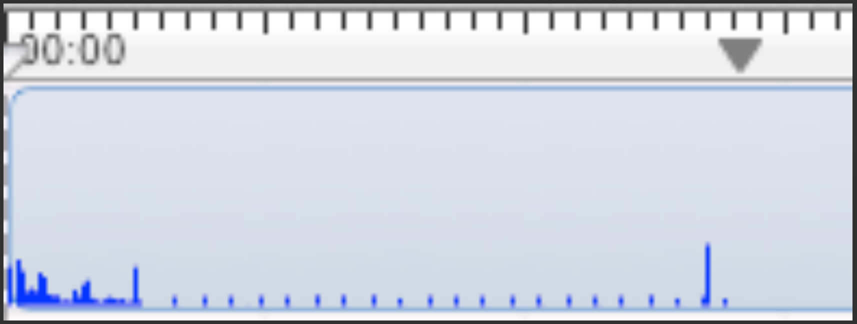
- Aged objects
- Slower collection
- Fixed or variable heaps
- Parallel collection

Garbage Collection

Memory Allocated



Released later



Garbage Collector determines when to run and release memory

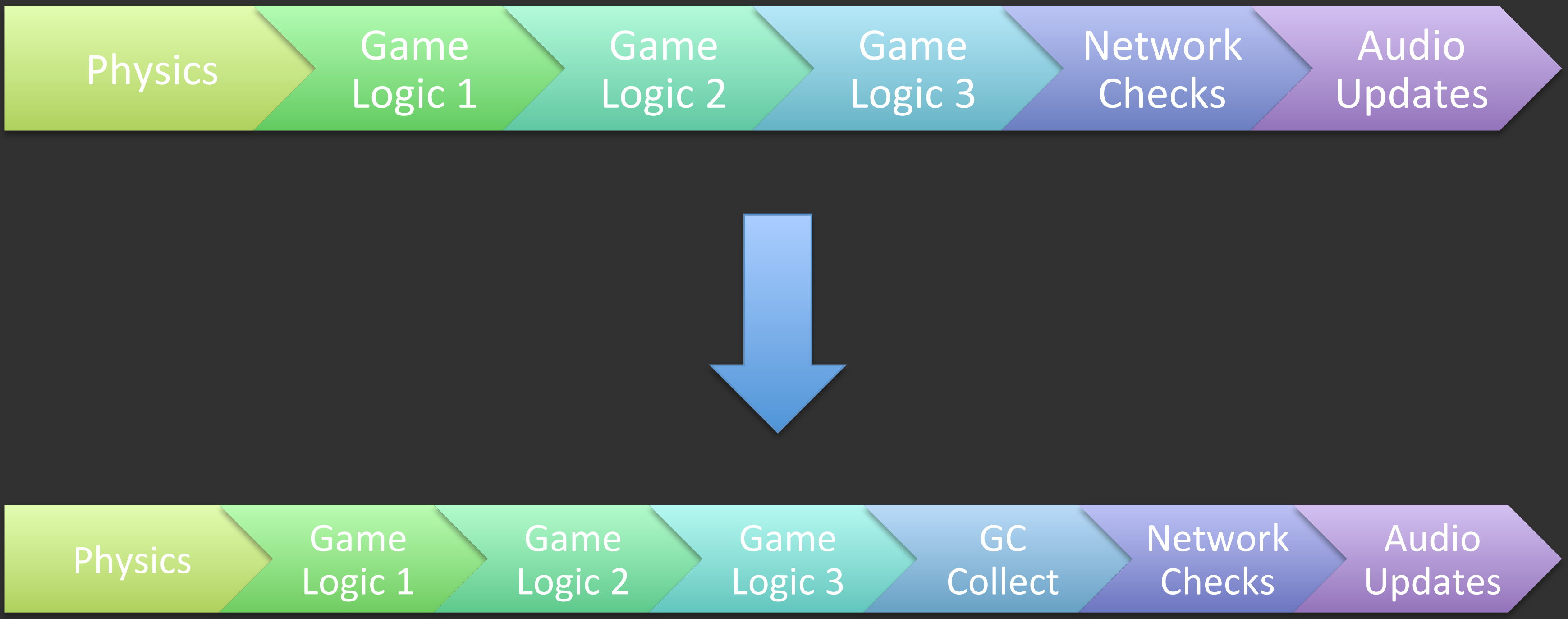
- Heuristics are platform-specific
- GC.Collect() is the only deterministic option

Best Practices

- Pre-allocate major objects before Game Loop
  - Managed objects
  - Or unmanaged buffers
  - Try to only use the nursery (stay under 4M)
  - If you must collect, only collect the nursery:
    - GC.Collect (0) – Performs only a nursery collection
    - GC.Collect () – Performs a complete GC on the heap

- On Main loop:
  - Use structs instead of classes

Schedule GC Collection

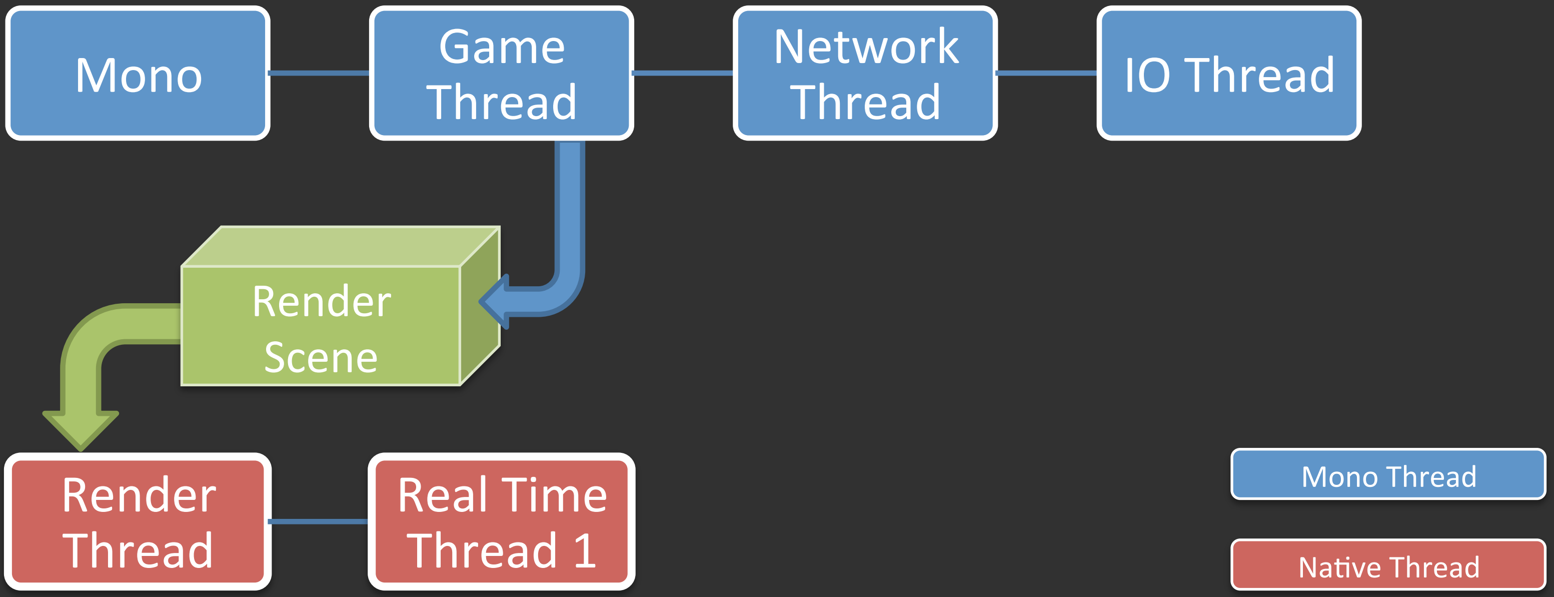


GC.Collect (0)
Limit Collection to Nursery

Mono's GC Thread Control

- Garbage Collection Stops all Mono Threads
- Non-Mono threads are not affected

- Alternative:
  - Use a Render Scene + Render Thread
  - Like Apple's CoreAnimation or Microsoft WPF



Mono

Game Thread

Network Thread

IO Thread

Render Scene

Render Thread

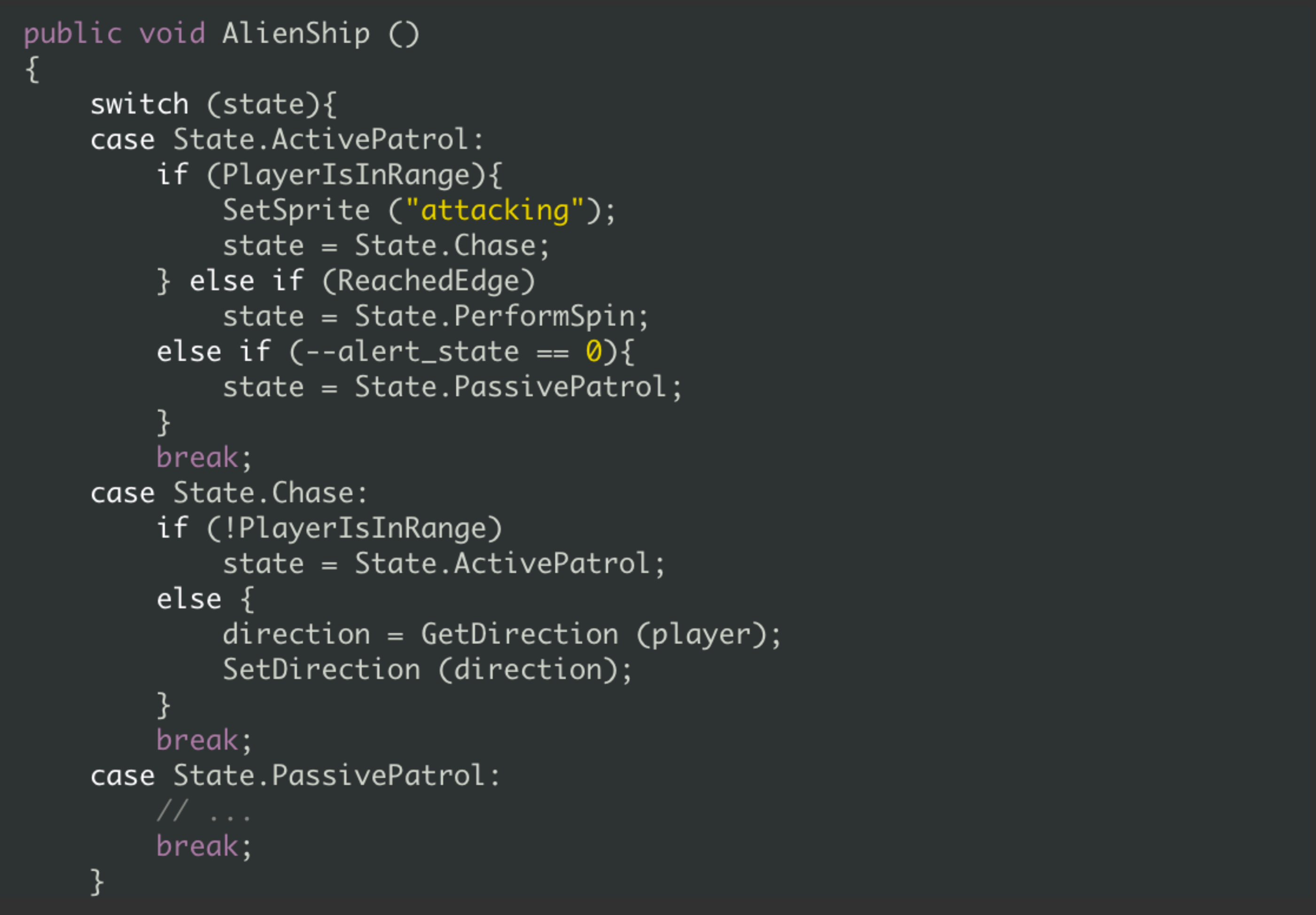
Real Time Thread 1

Mono Thread

Native Thread

COROUTINES

State-based programming



```
public void AlienShip ()
{
    switch (state){
    case State.ActivePatrol:
        if (PlayerIsInRange){
            SetSprite ("attacking");
            state = State.Chase;
        } else if (ReachedEdge)
            state = State.PerformSpin;
        else if (--alert_state == 0){
            state = State.PassivePatrol;
        }
        break;
    case State.Chase:
        if (!PlayerIsInRange)
            state = State.ActivePatrol;
        else {
            direction = GetDirection (player);
            SetDirection (direction);
        }
        break;
    case State.PassivePatrol:
        // ...
        break;
    }
```

Problems with Callbacks and State-Machines Systems

- Repetitive
- Cumbersome
- Error Prone
- Poor Error Propagation protocols/practices
- Life is too short

Co-routines

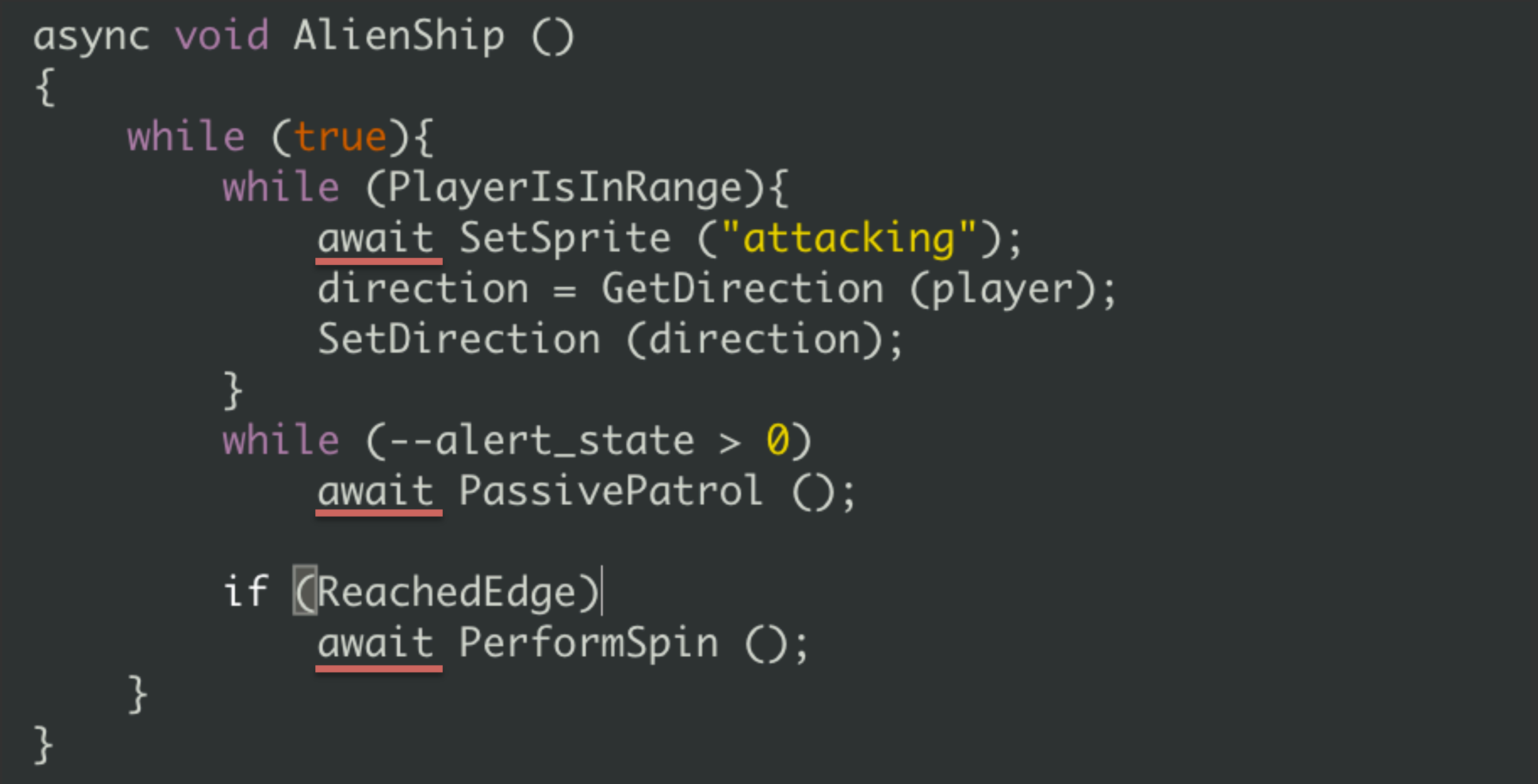
- Popular solution to simplify AI code
- Each Game Object has a script attached
  - Runs Game Logic
  - AI bits

- Many solutions
  - longjmp/setjmp for unmanaged code
  - Stack fiddling (Mono.Tasklets)
  - Interpreted languages with VM support

C# 5.0 and Async Programming

- Mono `master` has a complete C# 5 Compiler
- Turns repetitive callback-based async programming into linear programming
  - Compiler rewrites the code into a state machine
  - Tasks are scheduled on the main thread
  - Scheduling is customizable
- Originally designed for interactive UIs

Using Await



```
async void AlienShip ()
{
    while (true){
        while (PlayerIsInRange){
            await SetSprite ("attacking");
            direction = GetDirection (player);
            SetDirection (direction);
        }
        while (--alert_state > 0)
            await PassivePatrol ();

        if (ReachedEdge)
            await PerformSpin ();
    }
}
```

The Magic

- Await lets you write linear code

- Lets you focus on the problem
  - The compiler is at your service

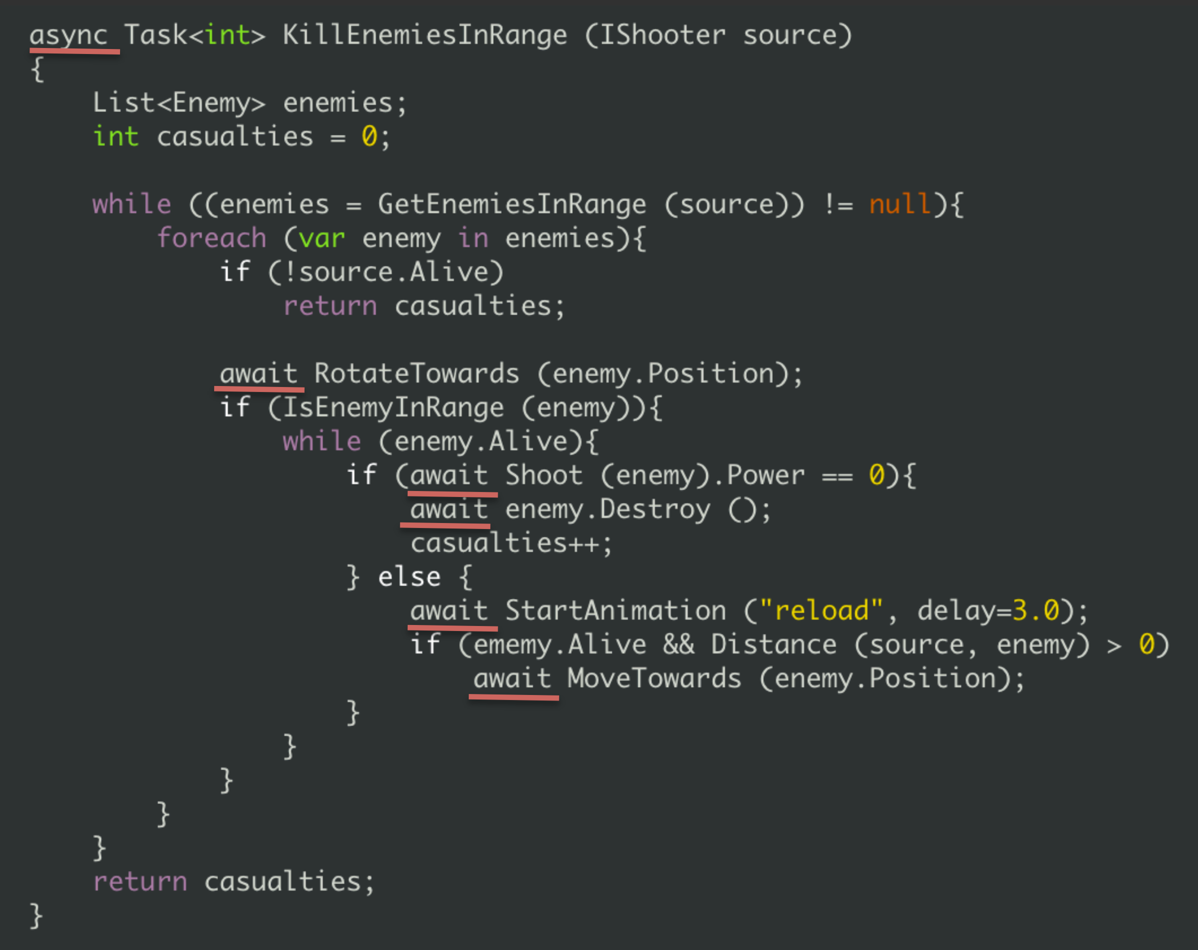
- Microsoft conventions for responsive UIs:
  - If it takes more than 50ms, make it async

More on `await`

- `await` introduces a suspension point
  - Code returns to caller
  - Execution resumes after “await” instruction
  - Very cheap memory-wise

- Works with IO, Networking stacks, slow code
  - System.IO, System.Net, Database access
  - Slow processing: XML, Json data
  - Blends transparently with Threads on multi-cores

Little more interesting



```
async Task<int> KillEnemiesInRange (IShooter source)
{
    List<Enemy> enemies;
    int casualties = 0;

    while ((enemies = GetEnemiesInRange (source)) != null){
        foreach (var enemy in enemies){
            if (!source.Alive)
                return casualties;

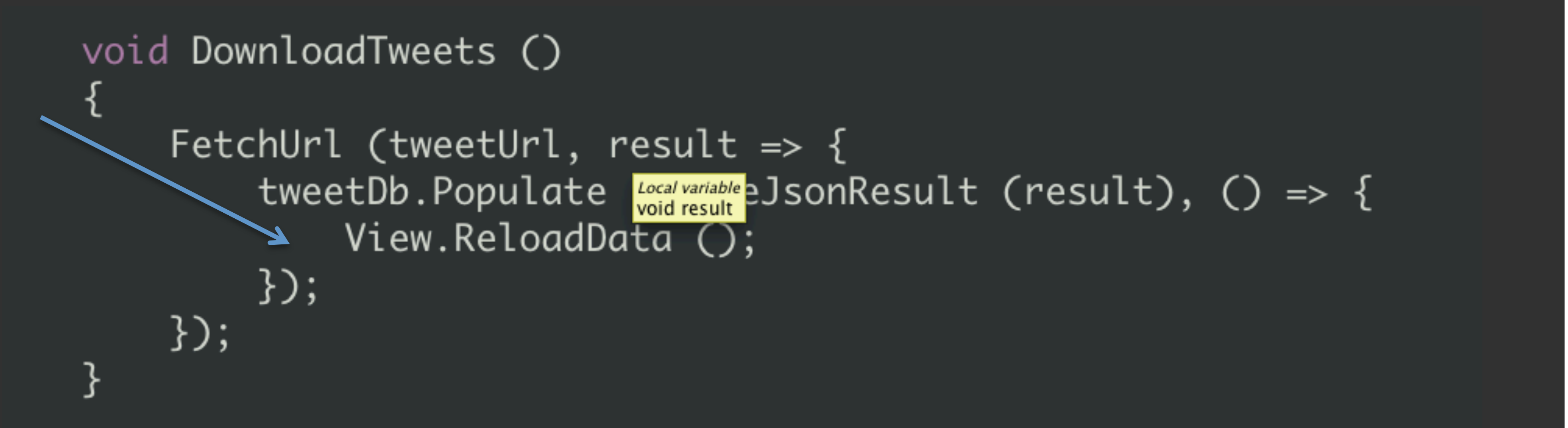
            await RotateTowards (enemy.Position);
            if (IsEnemyInRange (enemy)){
                while (enemy.Alive){
                    if (await Shoot (enemy).Power == 0){
                        await enemy.Destroy ();
                        casualties++;
                    } else {
                        await StartAnimation ("reload", delay=3.0);
                        if (ememy.Alive && Distance (source, enemy) > 0)
                            await MoveTowards (enemy.Position);
                    }
                }
            }
        }
    }
    return casualties;
}
```

Current Trends in Async Programming

Callback based

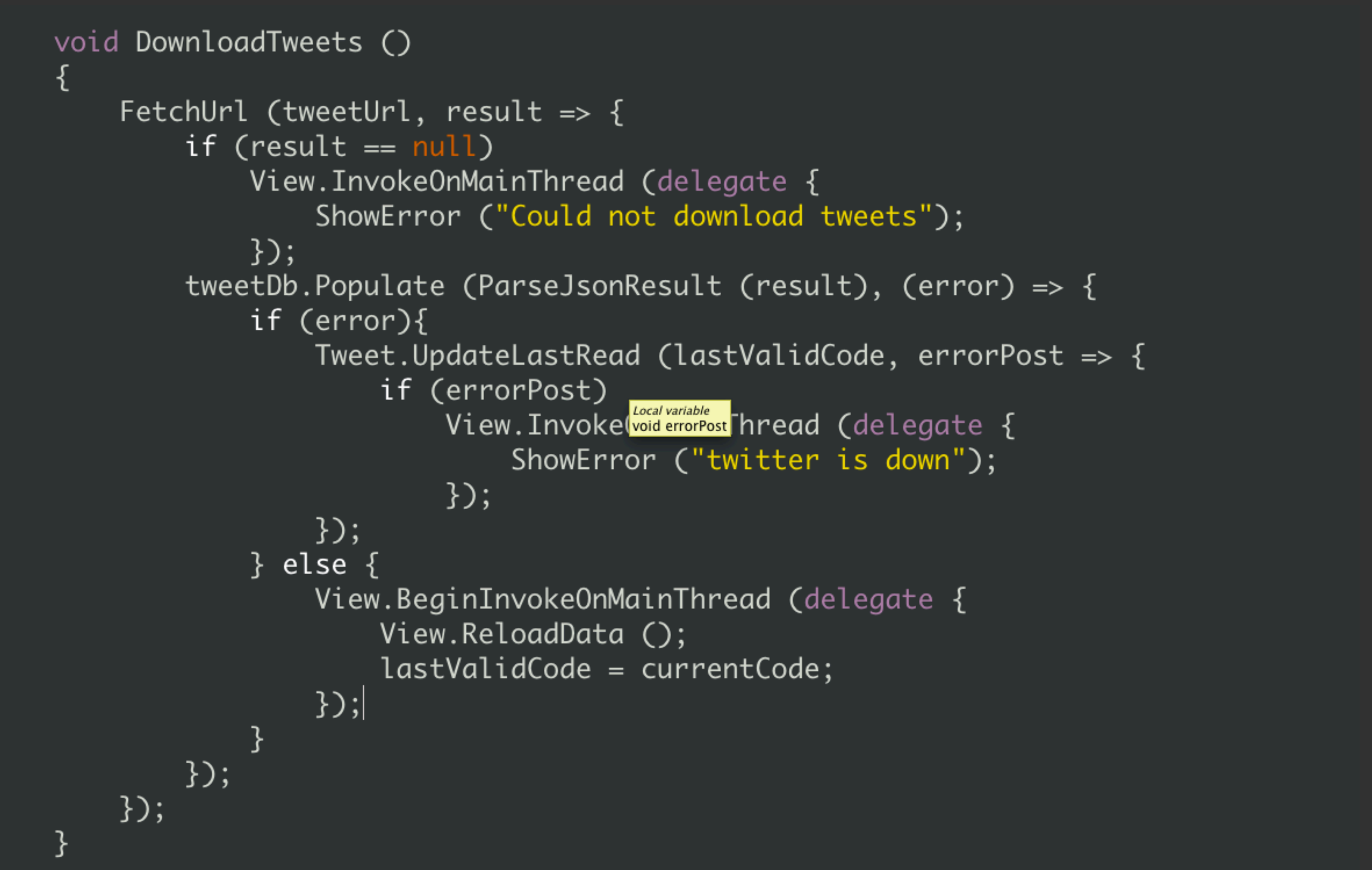
Where:

- GUI programming
- Scalable web servers
- Responsive mobile and desktop applications



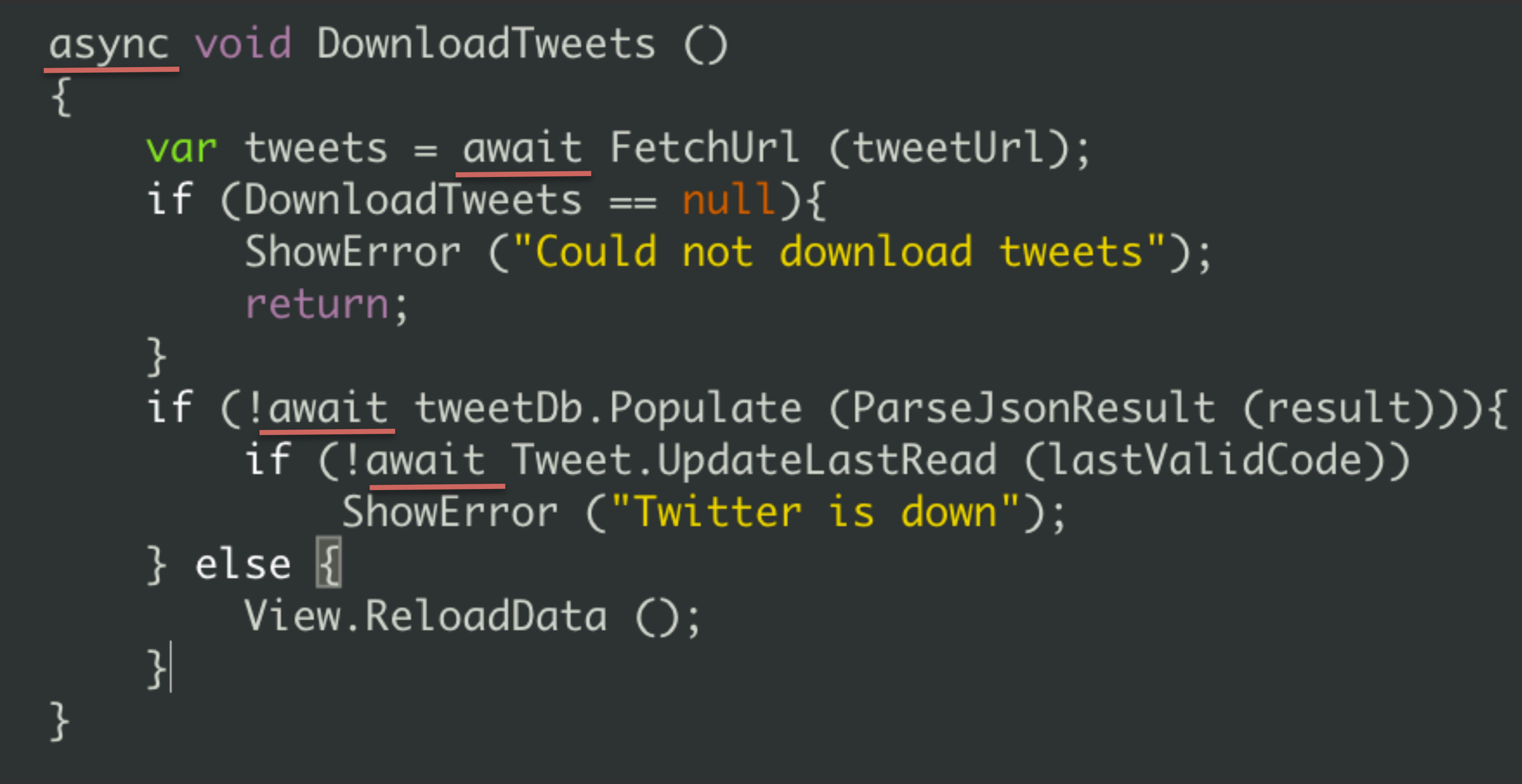
```
void DownloadTweets ()
{
    FetchUrl (tweetUrl, result => {
        tweetDb.Populate         eJsonResult (result), () => {
            View.ReloadData ();
        });
    });
}
```

With *some* error handling.



```
void DownloadTweets ()
{
    FetchUrl (tweetUrl, result => {
        if (result == null)
            View.InvokeOnMainThread (delegate {
                ShowError ("Could not download tweets");
            });
        tweetDb.Populate (ParseJsonResult (result), (error) => {
            if (error){
                Tweet.UpdateLastRead (lastValidCode, errorPost => {
                    if (errorPost)
                        View.InvokeOnMainThread (delegate {
                            ShowError ("twitter is down");
                        });
                });
            } else {
                View.BeginInvokeOnMainThread (delegate {
                    View.ReloadData ();
                    lastValidCode = currentCode;
                });
            }
        });
    });
}
```

C# 5.0 Async Support



```
async void DownloadTweets ()
{
    var tweets = await FetchUrl (tweetUrl);
    if (DownloadTweets == null){
        ShowError ("Could not download tweets");
        return;
    }
    if (!await tweetDb.Populate (ParseJsonResult (result))){
        if (!await Tweet.UpdateLastRead (lastValidCode))
            ShowError ("Twitter is down");
    } else {
        View.ReloadData ();
    }
}
```

Q&A

- Mono, ISO Standard, C# Async
  - http://www.mono-project.com
  - ISO Standard: http://bit.ly/cli-iso-standard
  - C# Async: http://msdn.microsoft.com/en-us/vstudio/gg316360

- Xamarin, Mono on iOS, Android:
  - Discount for AltDevConf attendees:
  - http://www.xamarin.com/altdevconf

- Contact:
  - miguel@xamarin.com, @migueldeicaza

- Resources:
  - @MonoGameTeam, @Unity3D

- Live Chat on IRC: irc.gnome.org
  - #mono, #monotouch, #monodroid, #monogame

BACKUP SLIDES

Iterators

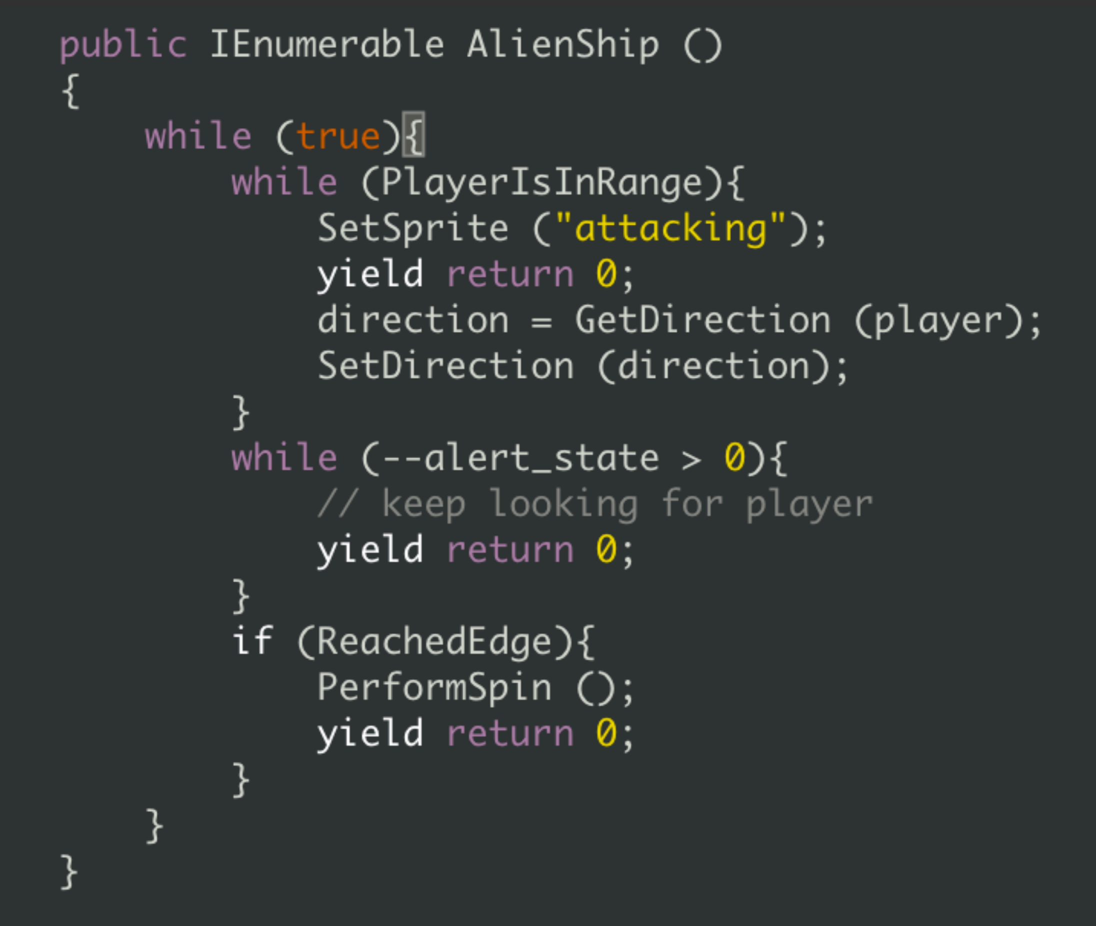
- C# compiler provided assistance
  - Built on top of C# IEnumerable
  - C# compiler rewrites iterators into state machines

- Developers build on top of conventions

- Unity3D uses this approach

- Open Source Iterator game framework:
  - http://mjhutchinson.com/journal/2010/02/01/iteratorbased_microthreading

Iterator based code



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public IEnumerable AlienShip ()
{
    while (true){
        while (PlayerIsInRange){
            SetSprite ("attacking");
            yield return 0;
            direction = GetDirection (player);
            SetDirection (direction);
        }
        while (--alert_state > 0){
            // keep looking for player
            yield return 0;
        }
        if (ReachedEdge){
            PerformSpin ();
            yield return 0;
        }
    }
}
```

Mono.Tasklets

- Pros:
  - No need to rewrite code
  - You can suspend execution/resume without new conventions.
- Cons:
  - Not available on every platform – Stack Fiddling
  - Does not work with Mono’s new Precise GC
  - In particular, wont work with Microsoft .NET

Not a comprehensive list

GAME ENGINES USING C#

unity^3

- Commercial Engine
- Very extensive support:
  - Consoles: XBox360, PS3, Wii
  - iOS, Android
  - Mac, Windows
  - Google Native Client
  - Flash target

MonoGame – Open Source XNA

- Open Source XNA implementation
  - Currently 2D-based
  - 3D support coming
- Runs on many platforms:
  - iOS (iPhone, iPad)
  - Android (phones and tablets)
  - Linux
  - Mac
  - Windows

Delta Engine

- Open Source Game Engine
- Written 100% in C#
- Runs on:
  - Android
  - Windows Phone
  - iOS
  - Mac
  - Windows

Axiom

- Open source
- Based on the OGRE C++ Engine
- Windows, Linux
- XNA, DirectX and OpenGL support

F# - Fascinating Language

- http://sharp-gamedev.blogspot.com/
  - Blog tracking the experiences of game development using F#

- F# introduced Async
  - Later adopted by C#

Architecture

- Computer Architecture – A Quantitative Approach

- Unix Systems for Modern Architectures
  - It says "Unix"
  - But applies to low-level systems engineering
  - Caches, MMUs, performance
  - Hardware Architectures design