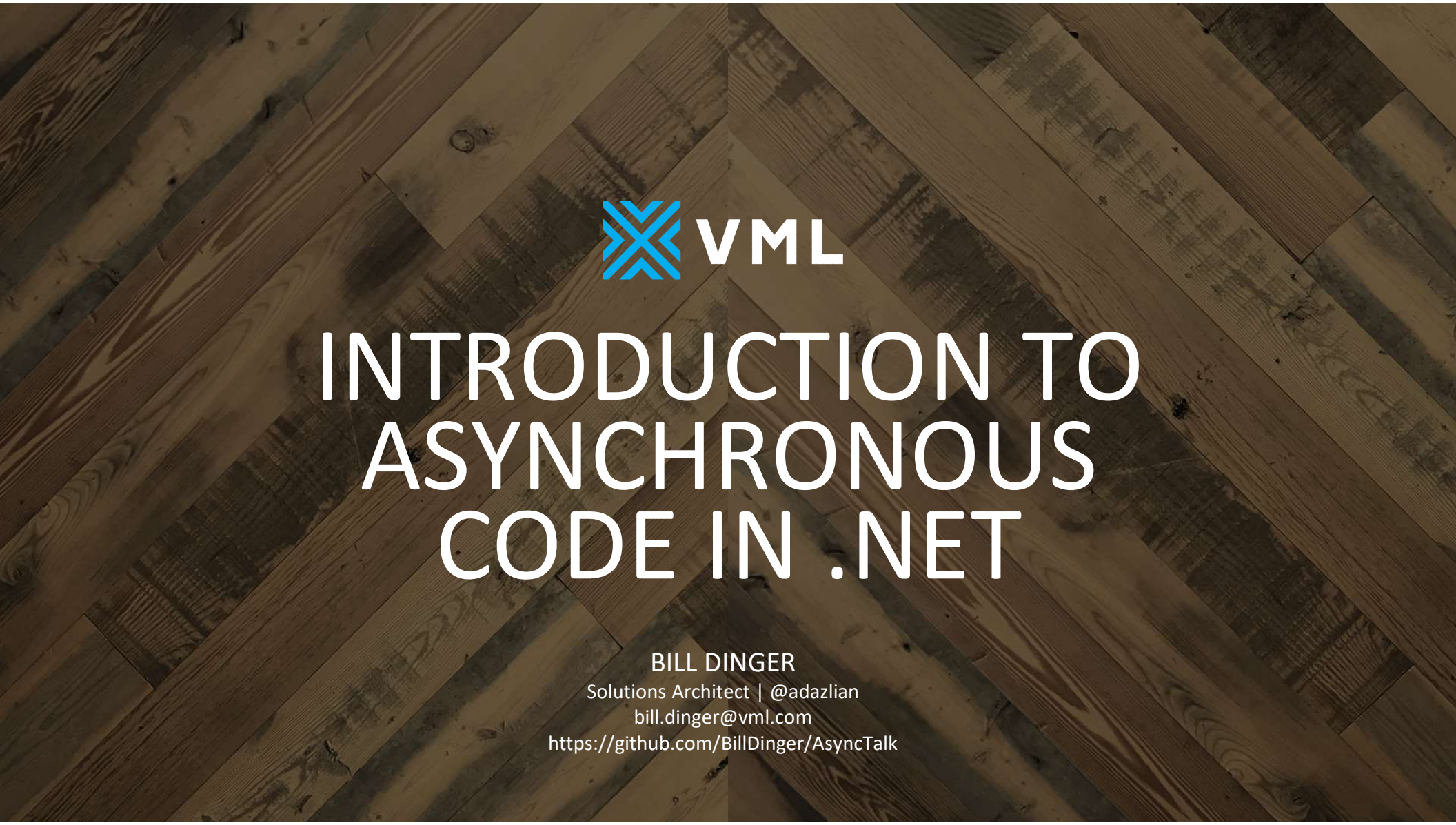

INTRODUCTION TO ASYNCHRONOUS CODE IN .NET

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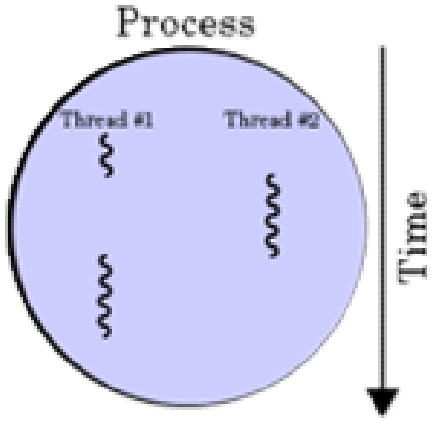
WHAT PROBLEM ARE WE SOLVING HERE?

SPEED OF THE APPLICATION

- **TPL** (Task Parallel Library)
  - Introduced in .NET 4.0
- **Async/Await**
  - Introduced in .NET 4.5
- **PLINQ** (Parallel LINQ)
  - Introduced in .NET 4.0

THE BASICS OF THREADING

- A **thread** is the smallest series of computer instructions that can be managed by a scheduler (typically the operating system).
- A **process** comprises one or more threads.
- A CPU core can typically execute only one thread simultaneously.



DEMO OF A SINGLE THREADED APP VERSUS A MULTITHREAD APP

TASK PARALLEL LIBRARY DESIGN GOALS

Make parallel programming easier on developers.

- Manually maintaining mutexes and thread primitives is not fun.

Make multithreading more efficient.

- Thread creation, destruction and synchronization are difficult to manage correctly and efficiently.

Give developers control to easily schedule task workflows.

- Allow continuation, result and task scheduling.

TASK PARALLEL LIBRARY

- Introduced with .NET 4.0, uses tasks to schedule operations that are performed on a background thread pool managed by the .NET CLR
- Removes complexities of managing and synchronizing threads
- Supports exception handling, continuation and return values
- Most suitable to CPU-intensive operations that can be decomposed
- Automatically scales itself to meet processing demand and patterns

.NET THREAD POOL BASICS

- When the CLR starts an application, it creates a pool of threads an application can use.
- Creating and destroying threads is computationally intensive. In addition, a thread has a minimum memory size of 1MB.
- .NET will manage this thread pool for you, queuing tasks as necessary and assigning threads to process them.

TASKS

BASICS

- Tasks are queued onto the .NET thread pool and executed in parallel.
- Tasks are not guaranteed to execute in any particular order.
- Tasks support exception handling, cancellation, workflow, returning results, child tasks and continuation.
- Task constructors take a System.Action (usually as a lambda expression) to execute.

TASKS

BASICS

A small unit of work takes a System.Action delegate. At its most basic:

```
public void RunATask()
{
    Task.Run(() => { Console.WriteLine("I'm a task!"); });
}
```

It can also be created as a Task to run later:

```
public void StartATask()
{
    int i = 0;
    var aTask = new Task(() =>
    {
        i = 17 + 23;
    });
    aTask.Start();
    Console.WriteLine(i);
}
```

TASKS

BASICS

What are Tasks?

- Tasks are small discrete blocks of code that execute asynchronously.
- They can be created by using new Task<T>, Task.Run or Task.Factory.StartNew().
- Best practice uses the Task.Factory.StartNew pattern that creates and starts the task in one call, which is slightly more efficient.

```
public void RunATaskFactory()
{
    var someTask =
        Task.Factory.StartNew(
            () => { return "I'm a task factory!"; }
    Console.WriteLine(someTask.Result);
}
```

TASKS

STARTING AND WAITING FOR MULTIPLE

Use WaitAll to start a group of tasks and block the calling thread until finished:

```
public void RunABunchOfTasks()
{
    var watch = Stopwatch.StartNew();
    var taskA = Task.Factory.StartNew(() => SpinWait(11));
    var taskB = Task.Factory.StartNew(() => SpinWait(4));
    var taskC = Task.Factory.StartNew(() => SpinWait(22));
    var taskD = Task.Factory.StartNew(() => SpinWait(7));
    var tasks = new[] { taskA, taskB, taskC, taskD };
    Task.WaitAll(tasks);
    watch.Stop();
    Console.WriteLine($"Finished in {watch.Elapsed.Seconds}
}
```

TASKS

STARTING AND WAITING FOR MULTIPLE

Use WhenAll to start a group of tasks and await the result.

```
await Examples.AwaitRunABunchOfTasks();
```

```
public async Task AwaitRunABunchOfTasks()
{
    var taskA = Task.Factory.StartNew(() => SpinWait(11));
    var taskB = Task.Factory.StartNew(() => SpinWait(4));
    var taskC = Task.Factory.StartNew(() => SpinWait(22));
    var taskD = Task.Factory.StartNew(() => SpinWait(7));
    var tasks = new[] { taskA, taskB, taskC, taskD };
    await Task.WhenAll(tasks);
}
```

TASKS

RETURNING VALUES

Closures can be used to return values, but beware that this is not inherently thread-safe! The result below might return 117 or it might return 200.

```
public void UnsafeClosures()
{
    int i = 0;
    var taskA = new Task(() => i = 17 + 100);
    var taskB = new Task(() => i = 100 + 100);
    taskA.Start();
    taskB.Start();
    Console.WriteLine(i);
}
```

TASKS

RETURNING VALUES

Best practice — use the Result<T> task property to view the result.

```
public void ReturnAValue()
{

    var someTask = Task.Run(() => { return "a string"; });
    Console.WriteLine(someTask.Result);
}
public void ReturnTask()
{
    var taskA = new Task<int>(() => 17 + 100);
    var taskB = new Task<int>(() => 100 + 100);
    taskA.Start();
    taskB.Start();
    Console.WriteLine($"TaskA: {taskA} ");
    Console.WriteLine($"TaskB: {taskB} ");
}
```

TASKS

RETURNING VALUES

To return multiple results and process them, we can use WhenAny. This allows us to observe the first processed result off the stack.

```
public void ReturnResultsFromMany()
{
    var taskA = Task.Factory.StartNew(SomeWork);
    var taskB = Task.Factory.StartNew(SomeWork);
    var taskC = Task.Factory.StartNew(SomeWork);
    var taskD = Task.Factory.StartNew(SomeWork);

    var tasks = new List<Task<int>>() { taskA, taskB, taskC, taskD };
    while (tasks.Count > 0)
    {
        var completedIndex = Task.WaitAny(tasks.ToArray());
        var completedTask = tasks[completedIndex];
        Console.WriteLine(completedTask.Result);
        tasks.RemoveAt(completedIndex);
    }
}
```

TASKS

ADDING WORKFLOW

TPL natively supports continuation tasks that run after another task.

```
public void ContinueTask()
{
    var task =
        Task.Factory.StartNew(() => 100 + 30)
        .ContinueWith(antecedent => antecedent.Result + 17);
    Console.WriteLine(task.Result);
}
```

TASKS

ADDING WORKFLOW

ContinueWith has enumeration options (TaskContinuationOptions) that let you specify under what conditions to run it (i.e., the task has “faulted”).

```
public void ContinueTaskWithOptions()
{
    Task.Factory.StartNew(() => throw new Exception("Stuff"))
        .ContinueWith(
        antecedent =>
        Console.WriteLine(antecedent.Exception.Flatten().InnerExce
        TaskContinuationOptions.OnlyOnFaulted);
}
```

TASKS

HANDLING CANCELLATION

Cancellation is a cooperative model — the task being canceled must support it.
Tasks monitor tokens; if cancellation is detected, tasks clean up and throw exceptions. This will set the task status" to canceled.

```
private void CheckIfCancel(CancellationToken ct)
{
    while (ct.IsCancellationRequested == false)
    {
        if (ct.IsCancellationRequested)
        {
            ct.ThrowIfCancellationRequested();
        }
        var waitTime = Rando.Next(0, 10);
        Console.WriteLine($"Not Cancelled waiting {waitTime}
        Thread.Sleep(Rando.Next(0, 10));
    }
```

TASKS

HANDLING CANCELLATION

We can cancel multiple tasks by deriving from a single CancellationTokenSource.

```
public void TaskCancellation()
{
    var cts = new CancellationTokenSource();
    var taskA = Task.Factory.StartNew(SomeWork, cts.Token);
    var taskB = Task.Factory.StartNew(SomeWork, cts.Token);
    Task.WaitAll(new Task[] { taskA, taskB });
    cts.Cancel();
}
```

TASKS

HANDLING ERRORS

In general, unhandled exceptions are propagated back to the calling thread when waiting on tasks or checking their results.

```
public void UnhandledExceptions()
{
    var taskA =
        Task.Factory.StartNew(() => throw new Exception("Stuff"));
    var taskB =
        Task.Factory.StartNew(() => throw new Exception("new"));
    var tasks = new []{taskA, taskB};

    // will bubble up exception here:
    Task.WaitAll(tasks);
}
```

TASKS

HANDLING ERRORS

Tasks will bubble up an AggregateException, which contains a list of all the exceptions.

```
public void UnhandledExceptions()
{
    var taskA =
        Task.Factory.StartNew(() => throw new Exception("Stuff"));
    var taskB =
        Task.Factory.StartNew(() => throw new Exception("new"));
    var tasks = new []{taskA, taskB};

    // will bubble up exception here:
    Task.WaitAll(tasks);
}
```

TASKS

PITFALLS

Deadlocks are possible – **never** wrap asynchronous code in S

ASYNC/AWAIT

BASICS

Use async to mark a method as awaitable. By convention, the method name should end in async.

- Awaiting a method yields control back to the calling thread
- Reliant upon tasks
- Built-in support on most popular frameworks (EntityFramework, StreamReader classes, HttpClient, Web API, etc.)
- Use for I/O heavy code

ASYNC/AWAIT

HOW TO MAKE A METHOD *AWAITABLE*

Your method signature returns a Task<T> and you await one resource in your method body. You then return type T.

```
public async Task<int> GetAReturnCodeAsync()
{
    using (var httpclient = new HttpClient())
    {
        using (var result =
            await httpclient.GetAsync("https://detroitcode.amegala.com"))
        {
            return (int)result.StatusCode;
        }
    }
}
```

ASYNC/AWAIT

HOW TO MAKE A METHOD *AWAITABLE*

Your method signature returns a task and you await one or more resources. You do not specify a return value.

```
public async Task GetAWebsiteContentAsync()
{
    using (var httpclient = new HttpClient())
    {
        using (var result =
            await httpclient.GetAsync("https://detroitcode.amegala.com"))
        {
            // implicitly returned:
                await result.Content.ReadAsStringAsync();
        }
    }
}
```

ASYNC/AWAIT

HOW TO MAKE A METHOD *AWAITABLE*

Your method signature returns void and you await a task. Only use for event handlers.

```
public async void GetAWebsiteOnClick(object sender, EventArgs e)
{
    await GetAWebsiteAsync();
}
```

ASYNC/AWAIT

BEHIND THE SCENES

- Async/Await doesn't cause allocation of a new thread; instead, work is handed off to a background thread while we wait for the results.
- Because of this, it's best to use Async/Await when dealing with I/O heavy tasks in client and server applications.
- Keep using TPL and PLINQ for CPU-intensive tasks.

ASYNC/AWAIT

DOWN THE ENTIRE STACK

Do not mix blocking and asynchronous code, because it can lead to deadlocks.

- Exception: console main windows

Avoid Async Void

- Exception: event handlers

Configure context: Use ConfigureAwait(False) when possible

- Exception: context is needed

ASYNC/AWAIT: DEMO IN A WEB APP

TECHNIQUE #3

PARALLEL LINQ (PLINQ)

- Added as part of .NET 3.5
- As easy as calling .AsParallel() on the data source in LINQ methods:

```
public void PlinqExample()
{
    var range = Enumerable.Range(1, 10000);
    var avg =
        (from x in range.AsParallel() select x).Average();
    Console.WriteLine(avg);
}
```

PLINQ

BASICS

- Most functionality is contained in the System.Linq.ParallelEnumerable namespace.
- The opt-in model is only used when invoked on the data source using .AsParallel keywords.
- At runtime, PLINQ will analyze the source and decide if its safe to parallelize.
- By default, PLINQ will use as many threads as cores that exist on the machine. We can override this by using WithDegreeOfParallelism().

```
public void DegreeOfParallelismExample()
{
    var range = Enumerable.Range(1, 10000);
    var avg =
        (from x in
             range.AsParallel().WithDegreeOfParallelism(10)
         select x).Average();
    Console.WriteLine(avg);
}
```

PLINQ

CANCELLATION

PLINQ uses cancellation tokens as do other parts of the threading namespace.

```
public void CancellationExample()
{
    var cts = new CancellationTokenSource();
    var token = cts.Token;
    var range = Enumerable.Range(1, 10000);
    var avg =
        (from x in
             range.AsParallel().WithCancellation(token)
         select x).Average();
    cts.Cancel();
    Console.WriteLine(avg);
}
```

PLINQ

PITFALLS

- Don’t assume parallel is always faster.
- Avoid reading/writing to shared variables (or use concurrent collections).
- Avoid calls to things that aren't thread-safe.
- Prefer ForAll to ForEach whenever possible.

PLINQ

FORALL

ForAll iterates over a collection as each thread completes, instead of iterating sequentially like ForEach.

```
public void ForAllExample()
{
    var range = Enumerable.Range(1, 10000);
    var query = from num in range.AsParallel()
        where num % 10 == 0
        select num;

    var bag = new ConcurrentBag<int>();
    query.ForAll(e => bag.Add(e));
}
```

CONCURRENT COLLECTIONS

Most .NET collections (arrays, lists, dictionarys) aren't thread-safe. Microsoft introduced the System.Collections.Concurrent namespace to offer thread-safe collections for use.

Five main collection types are provided:

- ConcurrentBag<T>
- ConcurrentStack<T>
- ConcurrentQueue<T>
- ConcurrentDictionary<Tkey, TValue>
- BlockingCollection<T>

QUESTIONS?

RESOURCES

Patterns of Parallel Programming in C#/VB.NET
https://www.microsoft.com/en-us/download/details.aspx?id=19222

MSDN Documentation on TPL
https://docs.microsoft.com/en-us/dotnet/standard/parallel-programming/task-parallel-library-tpl

Deadlocks in TPL & Async/Await
https://everydaylifein.net/netframework/task-parallel-library-taskscheduler-deadlocks-threads.html

Deadlocks in WPF
https://blogs.msdn.microsoft.com/pfxteam/2011/01/13/await-and-ui-and-deadlocks-oh-my/

RESOURCES CONT.

Async Best Practices for C# & Visual Basic
https://channel9.msdn.com/Events/TechEd/NorthAmerica/2014/DEV-B362

Async/Await Best Practices
https://msdn.microsoft.com/en-us/magazine/jj991977.aspx?f=255&MSPPError=-2147217396

Lambda Expressions in PLINQ/TPL
https://docs.microsoft.com/en-us/dotnet/standard/parallel-programming/lambda-expressions-in-plinq-and-tpl

Async or Not?
https://visualstudiomagazine.com/Blogs/Tool-Tracker/2014/07/To-Sync-or-Async.aspx

THANK YOU.