Visual Studio LIVE!
EXPERT SOLUTIONS FOR ENTERPRISE DEVELOPERS

TRAINING SEMINAR

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Level: Intermediate

Schedule

• Days	Tuesday & Wednesday
• Class Hours	9:00 a.m. – 5:00 p.m.
• Breaks	throughout the day
• Lunch	12:30 p.m. – 1:30 p.m.

Q&A throughout the day

All Times are Central Daylight Time

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Materials

https://github.com/jeremybytes/async-virtual-seminar-2025

Agenda Part 1

- Running Asynchronous Code
  - Task and await
  - Desktop and Web
- Where Continuations Run
  - TaskScheduler
  - ConfigureAwait
- Useful Properties & Methods
  - Continuation parameters
  - .IsFaulted
  - Exception Handling
  - Cancellation
- Writing Asynchronous Methods
  - Return or await
  - async void
- Task vs. ValueTask
- Progress Reporting
- IAsyncEnumerable<T>
  - yield return
  - Task.WhenEach
  - Cancellation

Agenda Part 2

- Nerd Break: IL
  - Compiling Task vs. await
- Breaking Async
  - .Result
  - .Wait()
  - JoinableTaskFactory
  - Constructors
- Parallel Programming
  - Tasks
  - Channels
  - Parallel.ForEachAsync
- Parallel Exception Handling
- Parallel Considerations
  - Thread-safe Operations
  - Degrees of Parallelism

Topics (in no particular order)

- .NET Framework vs .NET 8/9
- TaskContinuationOptions
- CancellationToken.None
- ThrowIfCancellationRequested
- Action
- Lambda expressions
- Task.Run()
- Context vs. no context
- BlockingCollection
- Task.Result
- AggregateException
- OperationCanceledException
- CancellationTokenSource
- Linked Token Source
- async MVC Controllers
- IProgress<T> vs. Progress<T>
- .GetAwaiter().GetResult()
- SemaphoreSlim

Running Asynchronous Code

Async Revolves Around Task

Use **Task** directly

- Extremely powerful
- Lots of options
- Very complex

await Task

- Looks like other code
- Limited functionality
- Fits the "95% scenario"

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Task<T>

- Method Returns a Task
  - Task<T> GetDataAsync()
  - “T” = type for the result
- Task
  - Represents a concurrent operation
  - May or may not operate on a separate thread
  - Can be chained and combined

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Desktop App Sample: Using Task

```
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
peopleTask.ContinueWith(
    task =>
    {
        List<Person> people = task.Result;
        foreach (var person in people)
            PersonListBox.Items.Add(person);
    },
    TaskScheduler.FromCurrentSynchronizationContext());
```

Web App Sample: Using Task

```
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
Task<ViewResult> result = peopleTask.ContinueWith(
    task =>
    {
        List<Person> people = task.Result;
        return View("Index", people);
    });
return result;
```

async & await

- Syntactic Wrapper Around Task
  - “await” pauses the current method until Task is complete.
  - Looks like a blocking operation
  - Does not block current thread
- “async” modifier
  - Tells the compiler to treat “await” as noted above
  - The compiled method is turned into a state machine

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Desktop App Sample: Using await

```
List<Person> people = await reader.GetPeopleAsync();
foreach (var person in people)
{
    PersonListBox.Items.Add(person);
}
```

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Web App Sample: Using await

```
List<Person> people = await reader.GetPeopleAsync();
return View("Index", people);
```

Return Value with await

Whenever you “await” a Task in a method, the return value is wrapped in a Task.

No ‘await’

```
public Person GetPerson(int id)
{
    List<Person> people = People.GetPeopleNoAsync();
    Person selectedPerson = people.Single(p => p.Id == id);
    return selectedPerson; // Person
}
```

Return types match

With 'await'

```
public async Task<Person> GetPersonAsync(int id)
{
    List<Person> people = await GetPeopleAsync();
    Person selectedPerson = people.Single(p => p.Id == id);
    return selectedPerson; // Person
}
```

Return types do not match

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With Task

```
public Task<Person> GetPersonAsync(int id)
{
    Task<List<Person>> peopleTask = GetPeopleAsync();
    Task<Person> result = peopleTask.ContinueWith(task =>
    {
        List<Person> people = task.Result;
        Person selectedPerson = people.Single(p => p.Id == id);
        return selectedPerson; // Person
    });
    return result; // Task<Person>
}
```

Return types match

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Return Value with await

- Whenever you “await” a Task in a method, the return value is wrapped in a Task.
  - This makes more sense if we think of “await” as wrapping and hiding a Task.
  - We do not need to deal with the complexity of the continuation task directly, but the Task is still there.

Task.Result

.Result

- Should only be used inside a continuation.
- If ".Result" is used outside of a continuation, then the operation will block (and possibly deadlock).
- If ".Result" is accessed on a faulted task, it will raise an AggregateException.

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.GetAwaiter().GetResult()

.GetAwaiter().GetResult()

- It is sometimes used because it returns an Exception (not an AggregateException).
- Blocking effects are the same as with .Result.

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.GetAwaiter().GetResult()

DANGER

.GetAwaiter().GetResult() was designed for internal use only.

Remarks

This method is intended for compiler use rather than use directly in code.

https://learn.microsoft.com/en-us/dotnet/api/system.threading.tasks.task.getawaiter

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Task.Result

Advice

Avoid using .Result or .GetAwaiter().GetResult() to break asynchrony.

Where Continuations Run

Default Task Behavior

- By default, a Task continuation does *not* run on the current context (thread).

- This means if you need to access resources from the current context (thread), you cannot do it by default.

Note: "Context" and "thread" are not technically equivalent. There are some async operations that do not use thread resources. But for most situations, we can think of these as interchangeable.

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Default Task Behavior

Runs in Main Context **Runs somewhere else**

```
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
peopleTask.ContinueWith(
    task =>
```

Runs somewhere else

```
    {
        List<Person> people = task.Result;
        foreach (var person in people)
            PersonListBox.Items.Add(person);
    },
);
```

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Task Scheduler

- TaskScheduler.FromCurrentSynchronizationContext will return to the prior context.
- For web applications, this means going back to the request thread.
- This may be needed for WebForms or applications that require Session or similar information.

Task Continuation in Main Context

Runs in Main Context

Runs somewhere else

```
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
peopleTask.ContinueWith(
    task =>
    {
        List<Person> people = task.Result;
        foreach (var person in people)
            PersonListBox.Items.Add(person);
    },
    TaskScheduler.FromCurrentSynchronizationContext());
```

Runs in Main Context

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Default await Behavior

- By default, code after "await" *does* run on the current context (thread).

- This means that you can safely access resources from that context (thread) – such as UI elements (desktop/mobile) or Session information (web).

Default await Behavior

Runs in Main Context

Runs somewhere else

```
ClearListBox();
List<Person> people = await reader.GetPeopleAsync();
foreach (var person in people)
{
    PersonListBox.Items.Add(person);
}
```

Runs in Main Context

ConfigureAwait

Code running after "await" returns to the current context.

This is fine for most situations, but using ConfigureAwait(false) can optimize performance.

Note: ASP.NET Core does not have a synchronization context. So ConfigureAwait has no effect.

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ConfigureAwait

ConfigureAwait determines whether processing needs to go back to the current context (thread) after awaiting an operation.

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ConfigureAwait

- ConfigureAwait(true) returns to the current context.
  - This is the default
- ConfigureAwait(false) uses whatever context is readily available.

ConfigureAwait(false) is preferred for optimization purposes.

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await with ConfigureAwait(false)

Runs in Main Context

```
ClearListBox();
List<Person> people = await reader.GetPeopleAsync()
        .ConfigureAwait(false);
foreach (var person in people)
{
    PersonListBox.Items.Add(person);
}
```

Runs somewhere else

Runs somewhere else

Runs somewhere else

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Importance of Asynchronous Code

Reminder:

Web servers have a limited number of threads to handle incoming requests.

Getting off of these threads (with async code) frees them up to take additional requests.

ConfigureAwait

General Guideline:

- ConfigureAwait(false) for library code
- ConfigureAwait(true) for UI code

Exception:

- ASP.NET Core applications do *not* have a current context, so this setting will be ignored.
- .NET Framework ASP.NET applications *do* have a context. You may need to go back to the prior context if you need Session or similar information.

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ConfigureAwait

More Options in .NET 8 and .NET 9:

- ConfigureAwait(ConfigureAwaitOptions)
  - Lets you fine tune behavior
  - Generally for more complex situations

- Check Stephen Cleary’s article for details:

  https://blog.stephencleary.com/2023/11/configureawait-in-net-8.html

Lab

Lab 01 – Recommended Practices and Continuations

https://github.com/jeremybytes/async-virtual-seminar-2025

Useful Properties and Methods

.ContinueWith() Parameters

- Action<Task>
  - A delegate to run when the task is complete.

- TaskScheduler
  - TaskSchedule.FromCurrentSynchronizationContext will return to the prior context (e.g. to run the continuation on the UI thread).

.ContinueWith() Parameters

- CancellationToken
  - A canceled token prevents the continuation running.
  - CancellationToken.None can be used as a placeholder.

- TaskContinuationOptions
  - OnlyOn… and NotOn… values set conditions on whether the continuation will run.

Task Properties (.NET 8 / 9)

- Task Properties
  - IsFaulted
  - IsCanceled
  - IsCompleted*
  - IsCompletedSuccessfully

**Note: Means "no longer running" not "completed successfully"*

IsCompletedSuccessfully

- .NET 8 / 9
- .NET Standard 2.1

- NOT .NET Standard 2.0
- NOT .NET Framework

Task Properties (.NET Framework)

- Task Properties
  - IsFaulted
  - IsCanceled
  - IsCompleted*
  - **Status**

**Note: Means "no longer running" not "completed successfully"*

- TaskStatus
  - ***Canceled***
  - Created
  - ***Faulted***
  - ***RanToCompletion***
  - Running
  - WaitingForActivation
  - WaitingForChildrenToComplete
  - WaitingToRun

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async void

- async void
- Only for true "fire and forget"
- Disadvantages
  - Cannot tell when (or if) the operation completes
  - Cannot tell whether the operation was successful
  - Cannot see exceptions that occur

- Reminder: Exceptions stay on their own thread unless we go looking for them. Using "await" with a Task is one way to show them.

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async void

Advice

Avoid writing
async void method.

- Exception: Event handlers must return void. Be sure proper error handling is in place inside the event handler (or in a global exception handler)

Exception Handling

- AggregateException
  - Tree structure of exceptions
- Flatten()
  - Flattens the tree structure to a single level of InnerExceptions

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Cancellation

- CancellationToken is ReadOnly when created directly
  - new CancellationToken(true)
  - new CancellationToken(false)

- CancellationTokenSource
  - IDisposable → "using" or call "Dispose"
  - cts.Token → CancellationToken
  - cts.Cancel() → Sets "IsCancellationRequested" to true

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Cancellation

- ThrowIfCancellationRequested
  - Sets Task Status property
  - Sets IsCompleted, IsCanceled, etc. properties
  - Throws OperationCanceledException (needed for "await")

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Web Cancellation

- MVC Controller Actions, Controller APIs and Minimal APIs can have a CancellationToken parameter.
- If the request is canceled (for example, by clicking the “Stop” button in a browser), the token is put into a cancellation requested state.

Web Cancellation

- The cancellation token can be used in the Action method or API.
- Reminder: Awaiting a canceled task throws an OperationCanceledException, so your Action/API code should be prepared to handle that.

Cancellation and Continuations

- ContinueWith CancellationToken parameter
  - When "IsCancellationRequested" is true,
    the continuation **will not run**.
  - An option is to use "CancellationToken.None" as a dummy token.

Cancellation and Continuations

- If canceled, continuation will not run

```
personTask.ContinueWith(task =>
{
    if (task.IsFaulted) ...
    if (task.IsCanceled) ...
    if (task.IsCompletedSuccessfully) ...
}, tokenSource.Token);
```

Cancellation and Continuations

Advice

Be careful when passing a cancellation token to a continuation as a parameter.

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Linked Token Source

- Token sources can be linked together.

```
var parentCts = new CancellationTokenSource();
var childCts = CancellationTokenSource
               .CreateLinkedTokenSource(parentCts.Token);
```

- If the parent token is canceled, the child token is also canceled.
- The child token can be canceled independently.

Writing Asynchronous Methods

Writing Asynchronous Methods

- Directly return a Task
- Sample:

```
public Task<Person> GetPersonAsync(int id)
{
    Task<Person> personTask = Task.Run(() => GetPerson(id));
    return personTask;
}
```

Writing Asynchronous Methods

- If you "await" something in your method, then the return value is automatically wrapped in a Task.
- Sample:

```
public async Task<Person> GetPersonAsync(int id)
{
    Person person = await Task.Run(() => GetPerson(id));
    return person;
}
```

await or Not?

ADVICE

Prefer async/await
over directly returning Task

David Fowler's Async Guide

https://github.com/davidfowl/AspNetCoreDiagnosticScenarios/blob/master/AsyncGuidance.md#prefer-asyncawait-over-directly-returning-task

await and IDisposable

- It is important to await Tasks with IDisposable elements.

- If a Task is not awaited, an object may be disposed before the Task has a chance to complete.

await and IDisposable

- Sample (bad)

```
public Task<IReadOnlyCollection<Person>> GetPeople()
{
    using SQLReader reader = new(sqlFileName);
    return reader.GetPeople();
}
```

- The `reader` is disposed when this method exits (which may be before the reader.GetPeople task is complete.

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await and IDisposable

- Sample (good)

```
public async Task<IReadOnlyCollection<Person>> GetPeople()
{
    using SQLReader reader = new(sqlFileName);
    return await reader.GetPeople();
}
```

- `await` pauses the operation, so the reader object will not be disposed until after the reader.GetPeople task is complete.

async void

- async void
- Only for true "fire and forget"
- Disadvantages
  - Cannot tell when (or if) the operation completes
  - Cannot tell whether the operation was successful
  - Cannot see exceptions that occur

- Reminder: Exceptions stay on their own thread unless we go looking for them. Using "await" with a Task is one way to show them.

async void and ASP.NET Core

"The use of async void in ASP.NET Core
applications is **ALWAYS** bad.
Avoid it, never do it... Async void methods
will crash the process if an exception is thrown."

David Fowler's Async Guide

https://github.com/davidfowl/AspNetCoreDiagnosticScenarios/blob/master/AsyncGuidance.md#async-void

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Advice

Avoid writing async void method.

- Exception: Event handlers must return void. Be sure proper error handling is in place inside the event handler (or in a global exception handler)

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ConfigureAwait

General Guideline:

- ConfigureAwait(false) for library code
- ConfigureAwait(true) for UI code

Exception:

- ASP.NET Core applications do *not* have a current context, so this setting will be ignored.
- .NET Framework ASP.NET applications *do* have a context. You may need to go back to the prior context if you need Session or similar information.

Task vs. ValueTask

Task vs. ValueTask

Advice

Use “Task” unless you have specific performance or memory issues.

ValueTask

- ValueTask is a struct (no Task allocation unless it is required).

- Can be useful for methods that have both async and non-async paths (where the non-async path is used more frequently).

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ValueTask

```
public async ValueTask<Person> GetPersonAsync(int id)
{
    if (!cacheValid)
    {
        cachedPerson = await reader.GetPersonAsync(id);
        return cachedPerson;
    }
    else
    {
        return cachedPerson;
    }
}
```

Async path

Non-async path

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ValueTask Restrictions

- DO NOT await multiple times.

```
ValueTask<Person> personTask = GetPersonAsync(3);
Person selectedPerson = await personTask;
Person personCopy = await personTask;
```

- The ValueTask may already be recycled on the second "await".

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ValueTask Restrictions

- DO NOT await concurrently.

```
ValueTask<Person> personTask = GetPersonAsync(3);
Task.Run(async() => await personTask);
Task.Run(async() => await personTask);
```

- This has the effect of awaiting the ValueTask multiple times.

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ValueTask Restrictions

- DO NOT use GetAwaiter().GetResult().

```
ValueTask<Person> personTask = GetPersonAsync(3);
Person selectedPerson =
    personTask.GetAwaiter().GetResult();
```

This should go without saying, but it is specifically called out by Stephen Toub
https://devblogs.microsoft.com/dotnet/understanding-the-whys-whats-and-whens-of-valuetask/

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Task vs. ValueTask

Advice

Use “Task” unless you have specific performance or memory issues.

Lab

Lab 02 – Adding Async to an Existing Application

https://github.com/jeremybytes/async-virtual-seminar-2025

Progress Reporting

Progress Reporting

- IProgress<T>
  - Good for a parameter of an async method.

- Progress<T>
  - Built-in type for creating an IProgress<T> object.

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Reporting Progress from an Async Method

```
public async Task<List<Person>> GetPeopleAsync(IProgress<int> progress)
{
    for (int i = 0; i < ids.Count; i++)
    {   // Other work here
        int percentComplete = CalculatePercentComplete();
        progress.Report(percentComplete);
    }
    return people;
}
```

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Configuring Progress<T>

- Action<T> callback in constructor

```
Progress<int> progress = new(p => ProgressBar.Value = p);
```

- ProgressChanged event handler

```
Progress<int> progress = new();
progress.ProgressChanged +=
    (_, e) => ProgressBar.Value = e;
```

Note: If the callback and event handlers are configured, they all run.

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Reporting Types

The reporting type can be simple or complex.

- Single Value (simple)

```
Progress<int> progress = new();
```

- Custom Type (complex)

```
Progress<ProgressMessage> progress = new();
```

- Tuple (complex)

```
Progress<(int, string)> progress = new();
```

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Tuple Sample

```
complexProgress.ProgressChanged += (_, e) =>
{
    (int progress, string message) = e;
    ProgressBar.Value = progress;
    ProgressText.Text = progress switch
    {
        0 => "",
        100 => "",
        _ => $"Current Item: {message}",
    };
};
```

Lab

Lab 03 – Progress Reporting

https://github.com/jeremybytes/async-virtual-seminar-2025

IAsyncEnumerable<T>

IAsyncEnunumerable<T>

- Similar to IEnumerable<T>, but it is asynchronous.

- `foreach` can be used to iterate over IEnumerable<T>
- `await foreach` can be used to iterate over IAsyncEnumerable<T>

- Available in .NET 8 & .NET 9 (not .NET Framework)

IEnunumerable<T> Sample

```
public IEnumerator<int> GetEnumerator()
{
    var value = (current: 0, next: 1);
    while (true)
    {
        value = NextFibonacci(value);
        yield return value.current;
    }
}
```

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Using IEnunumerable<T>

```
FibonacciSequence fibs = new();
foreach (int fib in fibs)
{
    Console.WriteLine(fib);
}
```

IAsyncEnunumerable<T> Sample

```
public async IAsyncEnumerator<int> GetAsyncEnumerator(...)
{
    var value = (current: 0, next: 1);
    while (true)
    {
        value = await NextFibonacciAsync(value);
        yield return value.current;
    }
}
```

Using IAsyncEnunumerable<T>

```
AsyncFibonacciSequence asyncFibs = new();
await foreach (int fib in fibs)
{
    Console.WriteLine(fib);
}
```

Task.WhenEach

New in .NET 9

- Task.WhenEach() takes a collection of tasks and returns an IAsyncEnumerable<Task>
- `await foreach` will run the body of the loop as each Task completes.

IAsyncEnunumerable<T> Cancellation

- A method that returns IAsyncEnumerable<T> must attribute a cancellation token parameter with [EnumeratorCancellation]

```
public async IAsyncEnumerable<Person> GetPeopleAsyncEnumerable(
    IProgress<int> progress,
    [EnumeratorCancellation] CancellationToken cancelToken){ }
```

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Nerd Break: IL

Intermediate Language & ILDasm

- IL (Intermediate Language)
  - C# (and other .NET languages) compile to an assembly-like intermediate language.
  - The .NET Runtime turns the IL into native machine code.

Note: Another option is Native AOT (Ahead-of-Time) Compilation. This compiles to native machine code (and not IL).

Intermediate Language & ILDasm

- ILDasm (Intermediate Language Disassembler)
  - A .NET tool that shows the IL inside of an assembly.
  - Included with Visual Studio (and the .NET SDK).

https://github.com/jeremybytes/ildasm-setup

Sample IL

```
static void Main(string[] args)
{
    Console.WriteLine("Hello, World!");
}
```

HelloWorld.Program::Main : void(string[])

Find Find Next

```
.method private hidebysig static void  Main(string[] args) cil managed
{
  .entrypoint
  .custom instance void [System.Runtime]System.Runtime.CompilerServices.Nullable
  // Code size       13 (0xd)
  .maxstack  8
  IL_0000:  nop
  IL_0001:  ldstr      "Hello, World!"
  IL_0006:  call       void [System.Console]System.Console::WriteLine(string)
  IL_000b:  nop
  IL_000c:  ret
} // end of method Program::Main
```

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Why? Curiosity!

```csharp
foreach (var person in people)
{
    PersonListBox.Items.Add(
        person);
}
```

```csharp
using var enumerator =
    people.GetEnumerator();

while(enumerator.MoveNext())
{
    PersonListBox.Items.Add(
        enumerator.Current);
}
```

These blocks of code compile to the same IL

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Task vs. await

- Task compiles to a standard method

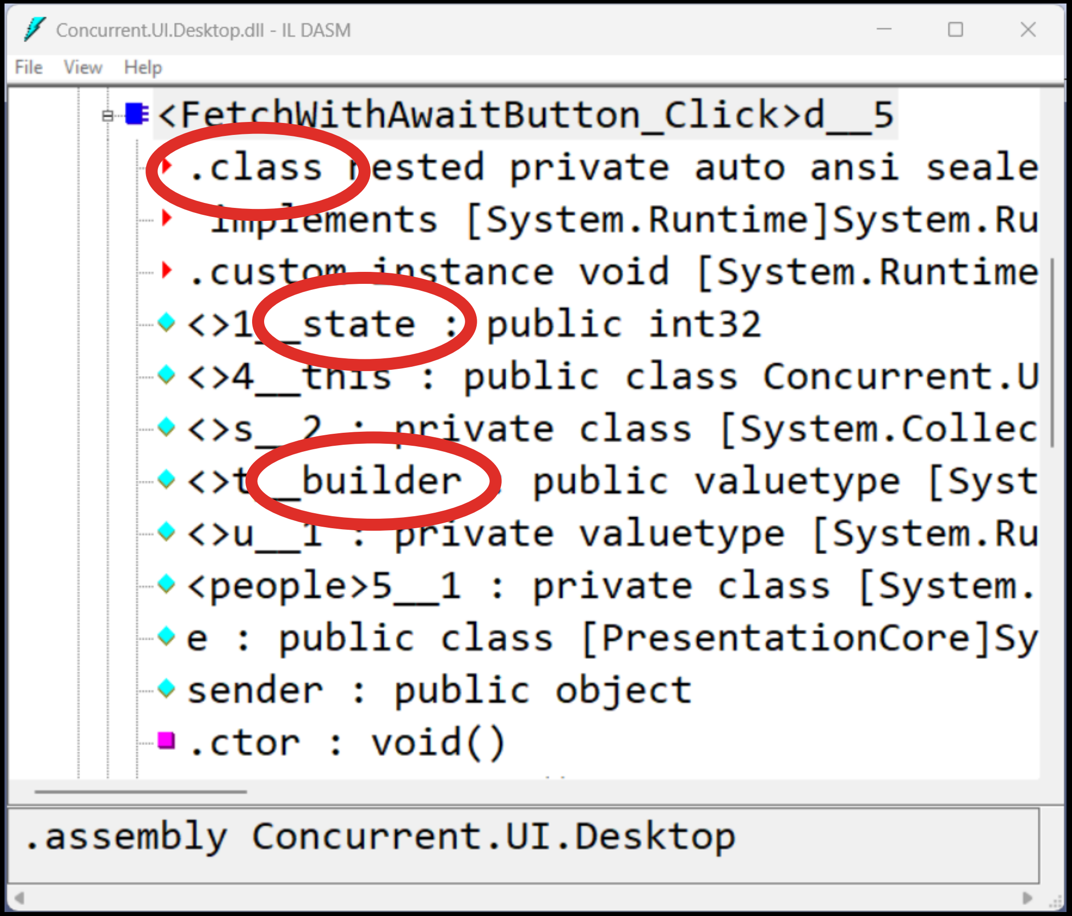
Concurrent.UI.MainWindow::FetchWithTaskButton_Click : void(object,class [PresentationCore]System.Windows.RoutedEventArgs)

Find   Find Next

```
.locals init (class [System.Runtime]System.Threading.Tasks.Task`1<class [System.Col
         valuetype [System.Runtime]System.Threading.CancellationToken V_1)
IL_0000:  nop
IL_0001:  ldarg.0
IL_0002:  call       instance void Concurrent.UI.MainWindow::ClearListBox()
IL_0007:  nop
IL_0008:  ldarg.0
IL_0009:  ldfld      class [TaskAwait.Library]TaskAwait.Library.PersonReader Concur
IL_000e:  ldloca.s   V_1
IL_0010:  initobj    [System.Runtime]System.Threading.CancellationToken
IL_0016:  ldloc.1
IL_0017:  callvirt   instance class [System.Runtime]System.Threading.Tasks.Task`1<c
IL_001c:  stloc.0
IL_001d:  ldloc.0
IL_001e:  ldarg.0
IL_001f:  ldftn      instance void Concurrent.UI.MainWindow::PopulateListBox(class
IL_0025:  newobj     instance void class [System.Runtime]System.Action`1<class [Sys
```

Task vs. await

- await compiles to a state machine



Breaking Async

Breaking Async

- Blocking / Potential Deadlock
  - .Result
  - .GetAwaiter().GetResult()
  - .Wait()
  - Task.WaitAll()

- Blocking / No Deadlock
  - JoinableTaskFactory

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.Result

- Using .Result blocks until the result is populated.
- May result in a deadlock.

```
PersonReader reader = new();
return reader.GetPeopleAsync().Result;
```

.GetAwaiter().GetResult()

- Using .GetAwaiter().GetResult() blocks until the result is populated.
- May result in a deadlock.

```
PersonReader reader = new();
return reader.GetPeopleAsync().GetAwaiter().GetResult();
```

.GetAwaiter().GetResult()

DANGER

.GetAwaiter().GetResult() was designed for internal use only.

Remarks

This method is intended for compiler use rather than use directly in code.

https://learn.microsoft.com/en-us/dotnet/api/system.threading.tasks.task.getawaiter

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.Wait()

- Using .Wait() blocks until the async process is done.
- May result in a deadlock.

```
PersonReader reader = new();
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
peopleTask.Wait();
return peopleTask.Result;
```

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Task.WaitAll()

- Using Task.WaitAll() blocks until the async process is done.
- May result in a deadlock.

```
PersonReader reader = new();
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
Task.WaitAll([peopleTask]);
return peopleTask.Result;
```

.ConfigureAwait(false)

- .Result
- .GetAwaiter().GetResult()
- .Wait()
- Task.WhenAll()

- All of the above processes block, but if the async code uses .ConfigureAwait(false), they may not deadlock.

JoinableTaskFactory

- Using JoinableTaskFactory will block, but will not deadlock.

- Available from NuGet:
    - Microsoft.VisualStudio.Threading

JoinableTaskFactory Sample

```
JoinableTaskContext context = new();
JoinableTaskFactory factory = new(context);

List<Person> people = factory.Run(async () =>
    await reader.GetPeopleAsync());
return people;
```

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.ConfigureAwait(false)

JoinableTaskFactory does not deadlock regardless of whether the async code uses .ConfigureAwait(false) or not.

Async Constructor?

- Constructors cannot be asynchronous.

```
public AsyncConstructorReader()
{
    PersonReader reader = new();

    // NOT ALLOWED
    people = await reader.GetPeopleAsync();
}
```

Static Factory Method

- Static factory methods can be asynchronous.

```
private AsyncConstructorReader() { }

public static async Task<AsyncConstructorReader>
    CreateReaderAsync()
{
    AsyncConstructorReader myself = new();
    PersonReader taskLibraryReader = new();
    people = await taskLibraryReader.GetPeopleAsync();
    return myself;
}
```

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Using a Static Factory Method

```
private async void AsyncConstructorButton_Click(
    object sender, RoutedEventArgs e)
{
    ClearListBox();
    IPersonReader reader =
        await AsyncConstructorReader.CreateReaderAsync();
    FetchData(reader);
}
```

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Parallel Programming

Sequential Programming

- Multiple "await"'s run in sequence (one at a time)
- Sample: multiple service calls

```
await CallService1Async();
await CallService2Async();
await CallService3Async();
```

CallService2Async will not run until after CallService1Async is complete.
CallService3Async will not run until after CallService2Async is complete.

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Parallel with Task

- Multiple Tasks can run in parallel (at the same time)
- Ex: multiple service calls

```
CallService1Async().ContinueWith(…);
CallService2Async().ContinueWith(…);
CallService3Async().ContinueWith(…);
```

CallService1Async, CallService2Async, and CallService3Async all run at the same time.

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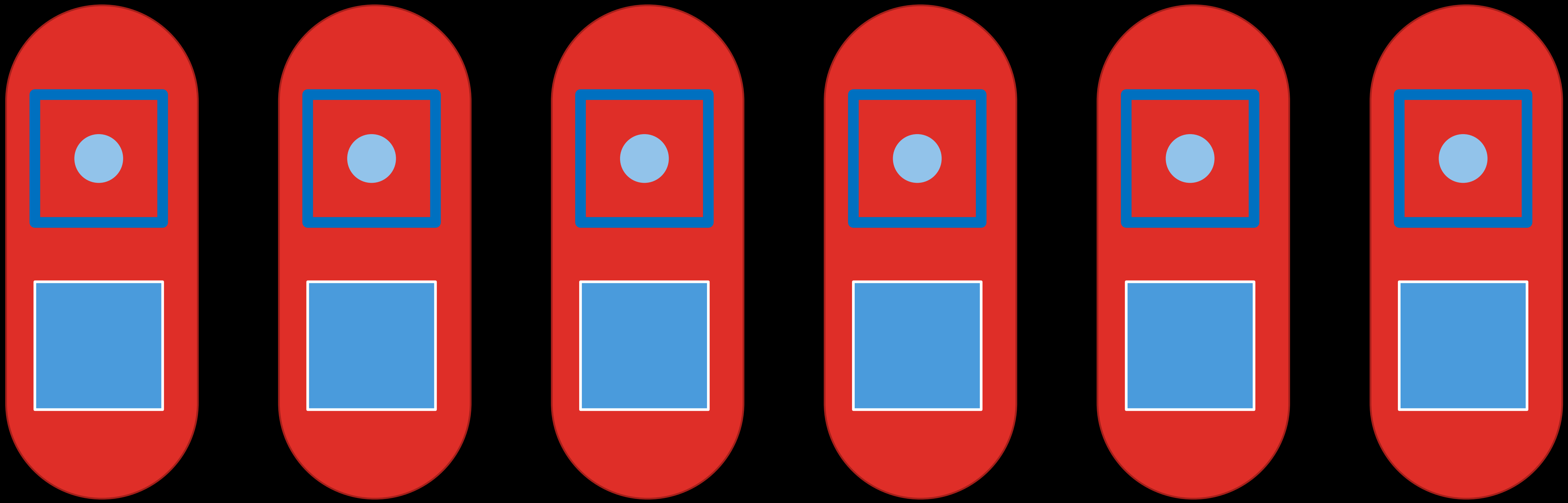
Get Data / Use Data

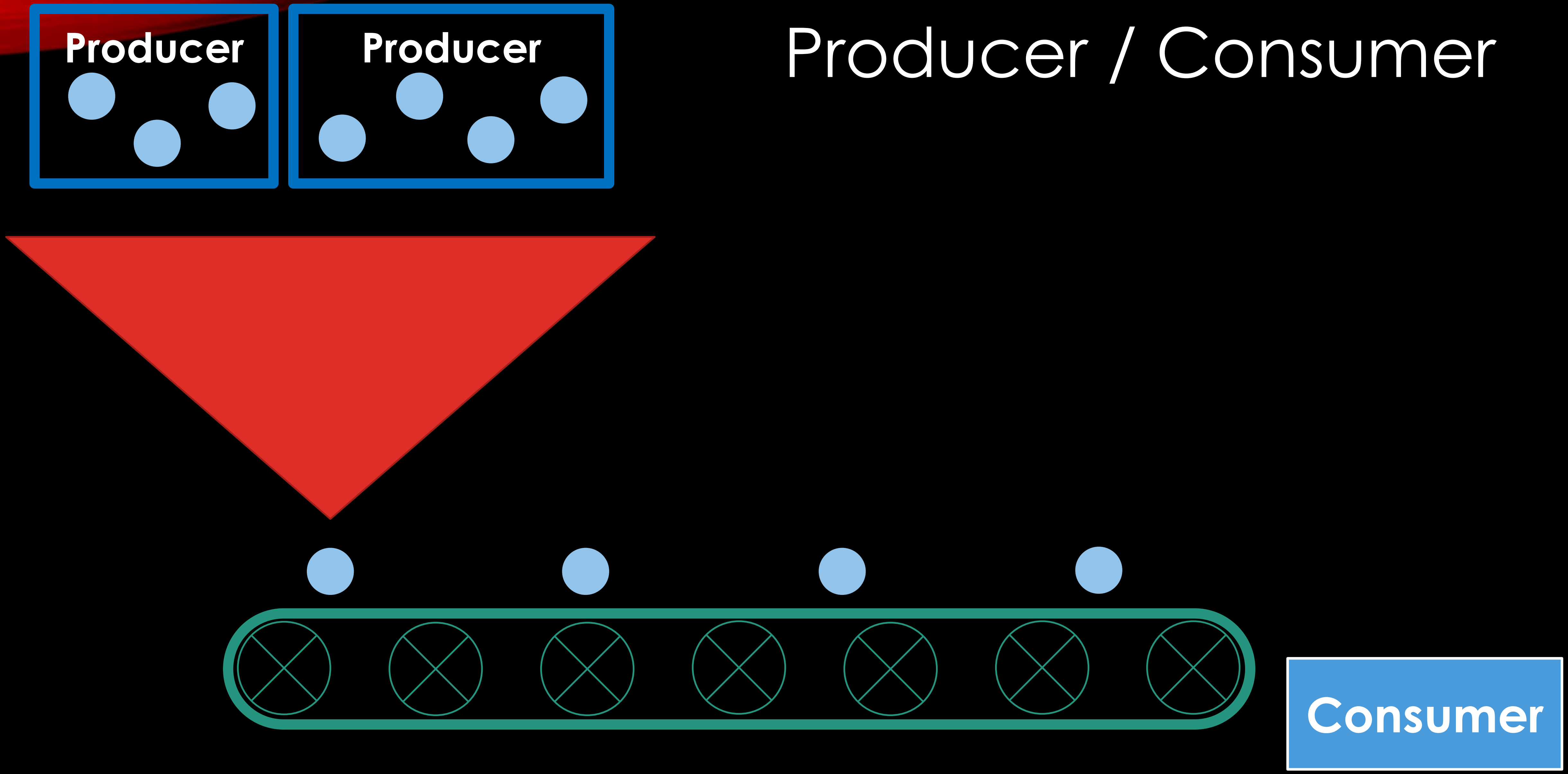


Parallel with Task

- await Task.WhenAll() can be used to determine when all tasks are complete
- Sample:

```
var taskList = new List<Task>();
taskList.Add(task1);
taskList.Add(task2);
taskList.Add(task3);
await Task.WhenAll(taskList);
```

Producer / Consumer



What are Channels?

- Similar to a concurrent queue.
  - Write items to the channel.
  - Read items from the channel in the same order they were added.
  - Items are removed as they are read.

- Concurrent means that you can safely write and read from multiple threads without worry of missed writes or duplicate reads.

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Where to Get Channels

- Built in to .NET 8 & .NET 9

- Available from NuGet for .NET Framework
  - System.Threading.Channels

Parallel with Channels

- Overall Steps
  - Create a channel
  - Write to a channel
  - Read from a channel
  - Mark the channel “complete”

Creating a Channel

- CreateBounded<T>
  - Creates a channel of a specific size
  - If the channel is full, writers are blocked until space is available

```
var channel = Channel.CreateBounded<Person>(10);
```

Writing to a Channel

- writer.WriteAsync()
  - Writes an item to the channel

```
await writer.WriteAsync(person);
```

Reading from a Channel (.NET 8/9)

- reader.ReadAllAsync()
  - Returns an IAsyncEnumerable<T>

```
await foreach(var person in reader.ReadAllAsync())
{
   // use item here
}
```

  - If the channel is empty, the loop will pause until an item is available.
  - If the channel is “complete”, the loop will exit.

Reading from a Channel (.NET Framework)

- WaitToReadAsync and TryRead can be used to retrieve items.

```
while (await reader.WaitToReadAsync())
{
    while (reader.TryRead(out Person person))
    {
        // use item here
    }
}
```

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Marking a Channel “Complete”

- writer.Complete()
  - Indicates that no further items will be written
  - Writing to a “complete” channel throws an exception
  - Reading from a “complete” channel will continue normally until the channel is empty

Parallel.ForEachAsync

- Loops over items and runs them in parallel
- “await” can be used safely inside the loop
  - Note: this is not true for “Parallel.ForEach”
- The entire loop can be “await”ed (this means all iterations will be complete)
- Available in .NET 8 & .NET 9 (not .NET Framework)

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Parallel.ForEachAsync

Waits for all iterations to finish

```
await Parallel.ForEachAsync(
      ids,
      new ParallelOptions { MaxDegreeOfParallelism = 10 },
        async (id, _) =>
        {
            var person = await reader.GetPersonAsync(id);
            DisplayPerson(person);
        });
```

← The items to iterate over

The method to run in parallel

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Comparing Loops

	Await	Task	Channel	ForEachAsync
Runs in Parallel	No	**Yes**	**Yes**	**Yes**
Continuation on Main Thread	**Yes**	**Yes** (optional)	**Yes**	No
Continuation in Parallel	No	**Yes**	No (optional)	**Yes**
Set Degrees of Parallelism	No	No	No	**Yes**

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Considerations

- For desktop / mobile, running continuations on the main thread is required to access UI elements.
- If continuations run in parallel, then they need to be thread-aware or surrounded by a “lock”
- Being able to specify degrees of parallelism gives control over resource usage
  - Limiting CPU resources to allow the UI to update
  - Limiting number of concurrent network connections

Lab

Lab 04 – Parallel Practices

https://github.com/jeremybytes/async-virtual-seminar-2025

Parallel Exception Handling

Parallel Exceptions

- Reminder, when you await a faulted Task, AggregateException is unwrapped an only 1 exception is thrown.

- In a Parallel.ForEachAsync loop, the loop short-circuit if an exception is thrown.

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Parallel Exceptions Issue #1

- Only 1 inner exception of the aggregate is thrown.

```
try
{
    await Task.WhenAll(continuations);
}
catch (Exception ex)
{
    DisplayException(ex); // Shows 1 inner exception
}
```

Show All Exceptions

- By adding a continuation, you can access the full AggregateException (and all of the inner exceptions)

```
await Task.WhenAll(continuations)
    .ContinueWith(task =>
    {
        // Task.Exception contains full AggregateException
        if (task.IsFaulted)
            DisplayException(task.Exception);
    });
```

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Parallel Exceptions Issue #2

- Loop short-circuits, i.e., stops processing.

```
try
{
    // Stops processing on exception
    await Parallel.ForEachAsync(...);
}
catch (Exception ex)
{
    DisplayException(ex);
}
```

Log and Continue

- Move the try/catch block inside the parallel loop.

```
await Parallel.ForEachAsync(ids, async (id, _) => {
    try
    { // Possible exception thrown here }
    catch (Exception ex)
    {
        // Each exception logged as it happens
        DisplayException(ex);
    }
});
```

ConfigureAwait

- ConfigureAwait has a SuppressThrowing parameter that will keep the await from throwing an exception even if the Task is faulted.
- This can be useful if you handle exceptions separately.
- .NET 8 & .NET 9 (not .NET Framework)

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SuppressThrowing Sample

```
await Task.WhenAll(continuations)
    .ConfigureAwait(ConfigureAwaitOptions.SuppressThrowing);
```

- Check Stephen Cleary's article for details:

  https://blog.stephencleary.com/2023/11/configureawait-in-net-8.html

Channel Exceptions

- Channels can be used for pipelines (meaning, sending items from one process to another).

- A separate error channel can be useful for retry and/or logging purposes.

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Writing to Exception Channel

```
await Parallel.ForEachAsync(ids, async (id, _) => {
    try {
        // Do stuff and write to success channel
        await writer.WriteAsync(item);
    }
    catch (Exception ex) {
        // Write to error channel
        await errorWriter.WriteAsync(ex);
    }
});
```

Reading from Exception Channel

```
private static async Task ProcessErrors(
    ChannelReader<Exception> errorReader)
{
    await foreach (var ex in errorReader.ReadAllAsync())
    {
        // Retry and/or log errors
        ExceptionReporter.LogException(ex);
    }
}
```

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Parallel Considerations

Parallel Considerations

- Thread-safe collections
- Thread-safe operations
- Continuing on the main thread
- Limit degrees of parallelism

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Thread-safe Collections

- List<T> is not thread-safe. If you call Add from concurrent processes, some items may not be added.
- When writing to a collection from concurrent processes (such as parallel code), use a concurrent collection.

- System.Collections.Concurrent
- BlockingCollection<T> is a good place to start.

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Thread-safe Increment

- Increment (++) and decrement (--) operators are not thread-safe.
- The Interlocked class has a useful set of thread-safe methods.
  - Increment
  - Decrement
  - Add
  - Several others

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Interlocked.Increment Sample

```
await Parallel.ForEachAsync(items, async (i, _) => {
    try {
        // Process Item
        Interlocked.Increment(ref TotalProcessed);
    }
    catch (Exception ex) {
        Interlocked.Increment(ref TotalExceptions);
        ExceptionReporter.ShowException(ex);
    }
});
```

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Comparing Loops

	Await	Task	Channel	ForEachAsync
Runs in Parallel	No	**Yes**	**Yes**	**Yes**
Continuation on Main Thread	**Yes**	**Yes** (optional)	**Yes**	No
Continuation in Parallel	No	**Yes**	No (optional)	**Yes**
Set Degrees of Parallelism	No	No	No	**Yes**

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Considerations

- For desktop / mobile, running continuations on the main thread is required to access UI elements.
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Continuations on Main Thread

- For Windows Desktop and MAUI applications, the Dispatcher class can be used to run a delegate on the UI thread.

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Dispatcher Samples

- Windows Desktop - Dispatcher.Invoke(Action)

```
Dispatcher.Invoke(() => CreateUIElements(result, DigitsBox));
```

- MAUI - Dispatcher.Dispatch()

```
Dispatcher.Dispatch(() => CreateUIElements(result, DigitsBox));
```

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Max Degrees of Parallelism

- SemaphoreSlim can be used to limit the number of concurrent processes.

- Steps
  - Create SemaphoreSlim with initial count.
  - Call WaitAsync to wait for entry.
  - Call Release when done.

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Semaphore Slim Sample

```
using SemaphoreSlim semaphore = new(10);
foreach (var imageData in rawData) {
    await semaphore.WaitAsync();
    var task = classifier.Predict(imageData);
    var continuation = task.ContinueWith(t => {
        CreateUIElements(t.Result, DigitsBox);
        semaphore.Release();
    });
}
```

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Lab

Lab 05 – Parallel Exception Handling

https://github.com/jeremybytes/async-virtual-seminar-2025

Wrap Up

Thank You!

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https://github.com/jeremybytes/async-virtual-seminar-2025