

# Asynchronous and Parallel Programming in C#

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Level: Intermediate



# Materials

[https://github.com/jeremybytes/  
vslive2023-orlando](https://github.com/jeremybytes/vslive2023-orlando)

# Schedule

- Class Hours 9:00 a.m. – 6:00 p.m.
- Coffee Break 11:00 a.m. – 11:15 a.m.
- Lunch 1:00 p.m. – 2:00 p.m.
- Snack Break 4:00 p.m. – 4:15 p.m.

Additional breaks and Q&A throughout the day

All Times are Eastern Standard Time

# Agenda 1

- Calling async methods with Task
- "await"ing async methods
- Getting Results
- Continuing after async is complete
- Dealing with Exceptions
- Cancellation



# Agenda 2

- Writing async methods
  - Task.Run()
  - "await" inside async methods
  - Return values
  - Cancellation
- Running code in Parallel
  - Using Tasks directly
  - Using Channels
  - Using Parallel.ForEachAsync

# Topics (in no particular order)

- `ConfigureAwait()`
- `Action`
- Lambda expressions
- `TaskContinuationOptions`
- `async/await`
- `CancellationToken.None`
- `ThrowIfCancellationRequested`
- `async void`
- `Task.Run()`
- `Task.Result`
- `GetAwaiter().GetResult()`
- `IsFaulted`, `IsCanceled`, `IsCompleted`
- `AggregateException`
- `OperationCanceledException`
- `CancellationTokenSource`
- `async MVC Controllers`
- `Task` vs. `ValueTask`

# Running Asynchronous Code

# Asynchronous Patterns

- Asynchronous Programming Model (APM)
- Event Asynchronous Pattern (EAP)
- Task Asynchronous Pattern (TAP)



# Asynchronous Programming Model (APM)

- Method-Based
- Methods
  - `IAsyncResult BeginGetData()`
  - `EndGetData(IAsyncResult ...)`
- `IAsyncResult`

# Event Asynchronous Pattern (EAP)

- Method/Event-Based
- Method
  - GetDataAsync()
- Event
  - GetDataCompleted
  - Results in EventArgs

# Task Asynchronous Pattern (TAP)

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

# 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);  
    })
```

# Web App Sample: Using Task

```
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
Task<ViewResult> resultTask = peopleTask.ContinueWith(
    task =>
    {
        List<Person> people = task.Result;
        ViewData["RequestEnd"] = DateTime.Now;
        return View("Index", people);
    });
return resultTask;
```



# 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” is just a Hint
  - Does not make a method run asynchronously
  - Tells the compiler to treat “await” as noted above

# Desktop App Sample: Using await

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

# Web App Sample: Using await

```
List<Person> people = await reader.GetPeopleAsync();  
ViewData["RequestEnd"] = DateTime.Now;  
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 = GetPeople();
    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

# Using Task

```
public Task<Person> GetPersonAsyncWithTask(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

# 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 Tasks are still there.

# Task.Result 1

## .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.

## Task.Result 2

### .GetAwaiter().GetResult()

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





Task.Result 3

## 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.

# 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);  
}
```

```
);
```

# 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 => **Runs in Main Context**

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

```
TaskScheduler.FromCurrentSynchronizationContext());
```

# 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

```
ClearListBox();
```

```
List<Person> people = await reader.GetPeopleAsync();
```

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

## Runs somewhere else

## Runs in Main Context

# ConfigureAwait 1

By default, code running after "await" returns to the current context.

This is fine for many situations (and won't break anything), but using `ConfigureAwait(false)` can optimize performance.

# ConfigureAwait 2

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

## ConfigureAwait 3

- `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.

# await with ConfigureAwait(false)

## Runs in Main Context

```
ClearListBox();
```

```
List<Person> people = await reader.GetPeopleAsync()
```

**Runs somewhere else**

**Runs somewhere else**

```
.ConfigureAwait(false);
```

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

**Runs somewhere else**



# 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 4

## 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.

# ConfigureAwait 5

## More Options in .NET 8:

- `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/  
vslive2023-orlando](https://github.com/jeremybytes/vslive2023-orlando)



# Useful Properties and Methods

# .ContinueWith() Parameters 1

- Action<Task>
  - A delegate to run when the task is complete.
- TaskScheduler
  - TaskSchedule.FromCurrentSynchronizationContext will return to the prior thread (e.g. to run the continuation on the UI thread).

# .ContinueWith() Parameters 2

- 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 6 / 8)

- Task Properties

- IsFaulted
- IsCanceled
- IsCompleted\*
- IsCompletedSuccessfully

## IsCompletedSuccessfully

- .NET 6 / 8
- .NET Standard 2.1
- NOT .NET Standard 2.0
- NOT .NET Framework

*\*Note: Means “no longer running”  
not “completed successfully”*

# 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

# 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.

# Exception Handling

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

# Cancellation 1

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

# Cancellation 2

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

# 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.



# Writing Asynchronous Methods

# Writing Asynchronous Methods 1

- Directly return a Task
- Ex:

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

# Writing Asynchronous Methods 2

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

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

# 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

Default to using “Task”  
unless you have  
specific performance  
or memory issues.

# ValueTask 1

- 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).



# ValueTask 2

```
public async ValueTask<Person> GetPersonAsync(int id)
{
    if (!cacheValid)
    {
        Async path
        cachedPerson = await GetPersonAsync(id);
        return cachedPerson;
    }
    else
    {
        Non-async path
        return cachedPerson;
    }
}
```

# ValueTask Restrictions 1

- 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”.

# ValueTask Restrictions 2

- 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.

# ValueTask Restrictions 3

- 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/>

# Task vs. ValueTask

## Advice

Default to using “Task”  
unless you have  
specific performance  
or memory issues.



Lab

Lab 02 – Adding Async to an Existing Application

[https://github.com/jeremybytes/  
vslive2023-orlando](https://github.com/jeremybytes/vslive2023-orlando)

# Parallel Programming

# Sequential Programming

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

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

CallService2Async will not run until after CallService1 Async is complete.  
CallService3Async will not run until after CallService2Async is complete.



# Parallel with Task 1

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

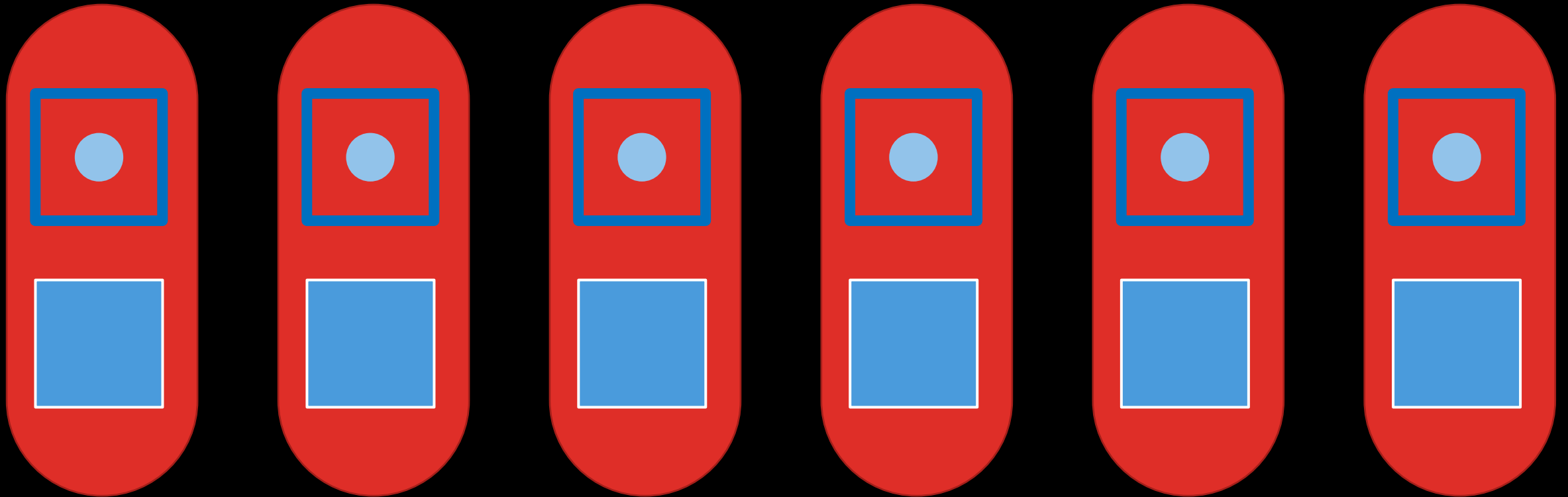
```
Task.Run( () => CallService1 ).ContinueWith(...)
```

```
Task.Run( () => CallService2 ).ContinueWith(...)
```

```
Task.Run( () => CallService3 ).ContinueWith(...)
```

CallService1, CallService2, and CallService3 all run at the same time.

Get Data / Use Data

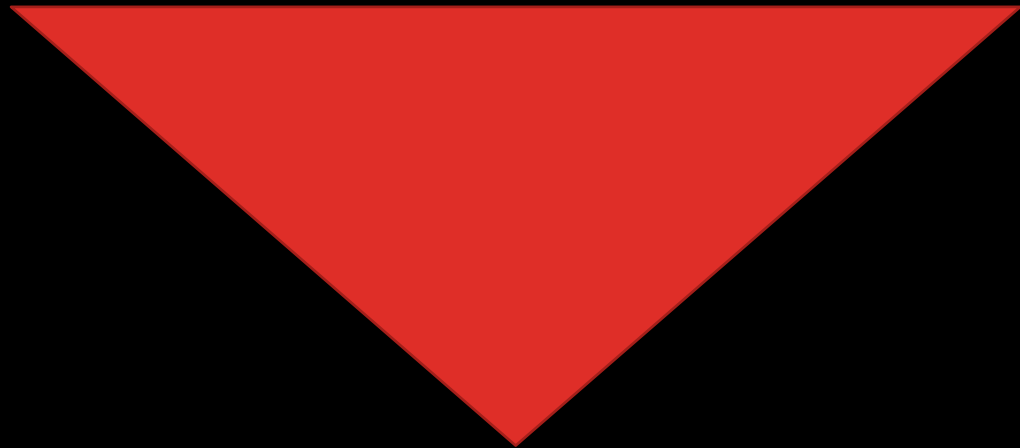
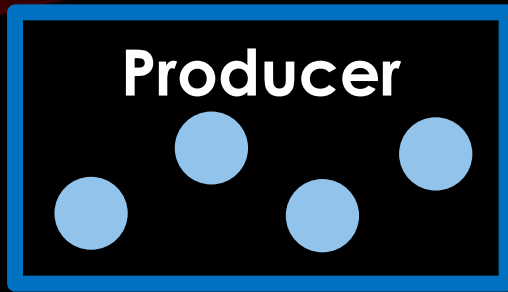
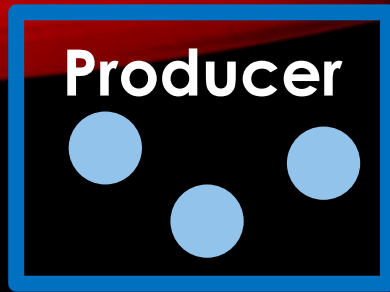


## Parallel with Task 2

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

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

# Producer / Consumer



# 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(item);
```

# Reading from a Channel

- `reader.ReadAllAsync()`
  - Returns an `IEnumerable<T>`

```
await foreach (var item 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.



# 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)

# Parallel.ForEachAsync

**Waits for all iterations to finish**

```
await Parallel.ForEachAsync(
    ids, ← The items to iterate over
    new ParallelOptions() { MaxDegreeOfParallelism = 7 },
    async(id, _) =>
    {
        var result = await reader.CallService(id);
        DisplayResult(result);
    });
```

**The method to run in parallel**

# Comparing Loops

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

# 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 03 – Parallel Practices

[https://github.com/jeremybytes/  
vslive2023-orlando](https://github.com/jeremybytes/vslive2023-orlando)

# Wrap Up



# Task Asynchronous Pattern (TAP)

- Task-Based
- Method Returns a Task
  - `Task<T> GetDataAsync()`
- Task
  - Represents a concurrent operation
  - May or may not operate on a separate thread
  - Can be chained and combined

# 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” is just a Hint
  - Does not make a method run asynchronously
  - Tells the compiler to treat “await” as noted above



Thank You!

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