LIVE! 360
TECH EVENTS WITH PERSPECTIVE

The Ultimate Education Destination
ORLANDO 2023

Asynchronous and Parallel Programming in C#

Jeremy Clark
Developer Betterer
jeremybytes.com

Level: Intermediate

Visual Studio LIVE! EXPERT SOLUTIONS FOR ENTERPRISE DEVELOPERS
SQL Server LIVE! TRAINING FOR DBAs AND IT PROS
TECHMENTOR IN-DEPTH TRAINING FOR IT PROS
Artificial Intelligence LIVE!
Cloud & Containers LIVE!
Cybersecurity & Ransomware LIVE!

Session Survey

- Your feedback is very important to us
- Please take a moment to complete the session survey found in the mobile app
- Use the QR code or search for “Converge360 Events” in your app store
- Find this session on the Agenda tab
- Click “Session Evaluation”
- Thank you!

LIVE! 360

TECH EVENTS WITH PERSPECTIVE

The Ultimate Education Destination

ORLANDO 2023

Asynchronous and Parallel Programming in C#

Jeremy Clark

Developer Betterer

jeremybytes.com

Level: Intermediate

Visual Studio LIVE! EXPERT SOLUTIONS FOR ENTERPRISE DEVELOPERS

SQL Server LIVE! TRAINING FOR DBAs AND IT PROS

TECHMENTOR IN-DEPTH TRAINING FOR IT PROS

Artificial Intelligence LIVE!

Cloud & Containers LIVE!

Cybersecurity & Ransomware LIVE!

Materials

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);
    });
```

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

```
try
{
    List<Person> people = await reader.GetPeopleAsync();
    return View("Index", people);
}
finally
{
    ViewData["RequestEnd"] = DateTime.Now;
}
```

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 on Main Thread — **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);
    }
);
```

Runs somewhere else

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 on Main Thread | **Runs somewhere else**

```
Task<List<Person>> peopleTask = reader.GetPeopleAsync();
peopleTask.ContinueWith(
    task =>     Runs on Main Thread
    {
        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 on Main Thread

Runs somewhere else

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

Runs on Main Thread

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 on Main Thread

```
ClearListBox();
```

Runs somewhere else

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

Runs somewhere else

```
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.

Lab

Lab 01 – Recommended Practices and Continuations

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 / 7)

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

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

IsCompletedSuccessfully

- .NET 6 / 7
- .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

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

- Ex:

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

Asyc path

Non-async path

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

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 CallService1Async is complete.

CallService3Async will not run until after CallService2Async is complete.

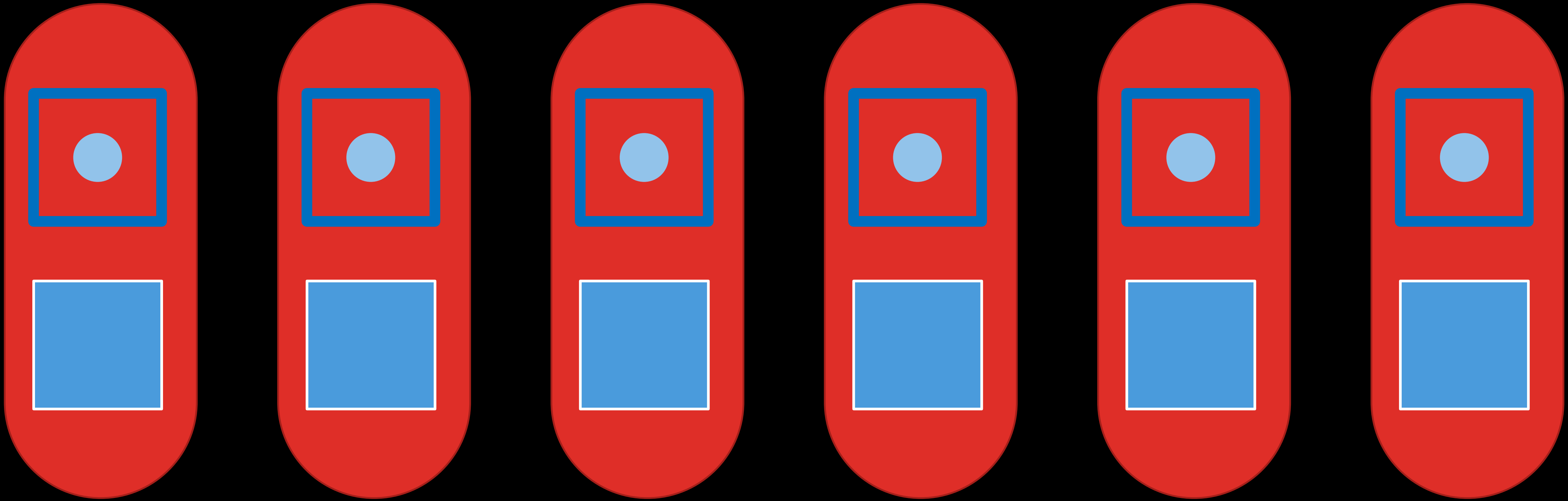
Parallel with Task 1

- 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

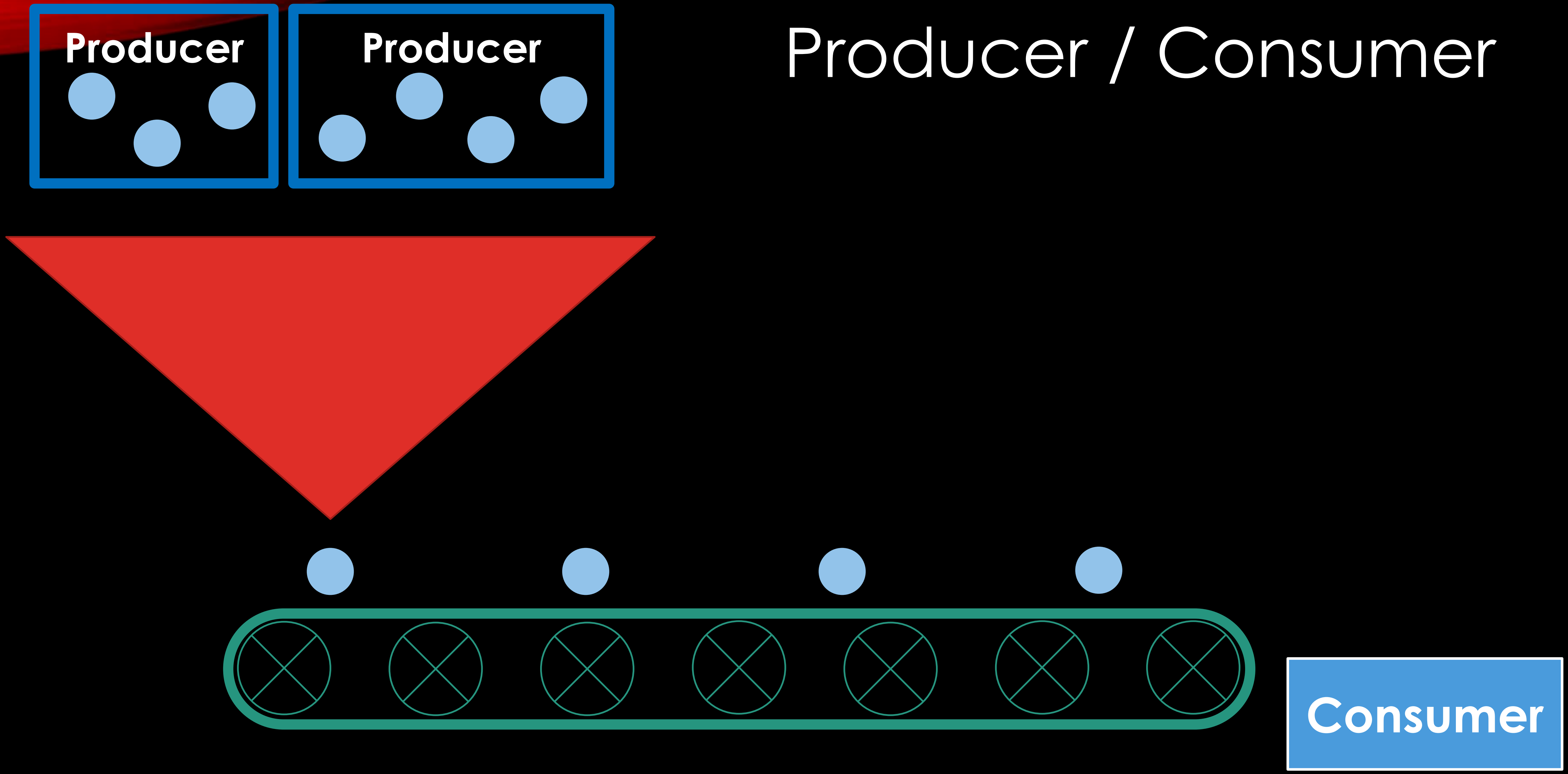


Parallel with Task 2

- 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 IAsyncEnumerable<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

	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**

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

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

Session Survey

- Your feedback is very important to us
- Please take a moment to complete the session survey found in the mobile app
- Use the QR code or search for “Converge360 Events” in your app store
- Find this session on the Agenda tab
- Click “Session Evaluation”
- Thank you!

Thank You!

Jeremy Clark

- www.jeremybytes.com
- github.com/jeremybytes
- youtube.com/jeremybytes
- @jeremybytes

https://github.com/jeremybytes/vslive2023-orlando