

.NET Framework 4.7 and C# 8.0

Lesson 13 : Parallel and
Async programming
with C#



Lesson Objectives

- Parallel Programming
- Async Keyword





CLR and DLR enhancements

- Increased usability with features like Optional parameters & Named arguments
- Provides dynamic programming
- Introduced Late binding support in C#, while it still remains a statically typed language
- Provides support for interaction with dynamic languages like Python & Ruby etc
- Improved COM Interop using Optional parameters (Omit ref on COM calls)
- 'dynamic' keyword allows C# to defer method invocation at runtime i.e Dynamic method Invocation
- Co-Variance and Contra-Variance



Co-Variance and Contra-Variance

- .NET Framework has introduced Co-variance and Contra-variance
 - to generic interfaces and delegates
- Suppose there is a class hierarchy, say Employee type and a Manager type that derives from it, then what will the following code do :

```
IEnumerable<Manager> ms = GetManagers();
```

```
IEnumerable<Employee> es = ms;
```

- In this example, we are trying to treat the sequence of managers as if they were the sequence of employees, but this will fail in C# 3.0 and the compiler will tell you that there is no conversion.
- In C# 4.0 this assignment works fine, because `IEnumerable<T>`, along with few other interfaces has changed, due to Co-variance of type parameters.



Co-Variance and Contra-Variance

- Covariance means think “out”

E.g. :

```
public interface IEnumerable<out T> : IEnumerable
{
    IEnumerator<T> GetEnumerator();
}
```

- Here the 'out' keyword, actually modifies the definition of type parameter, T. Compiler sees this and marks type T as covariant
- The out keyword signifies that the generic type parameter, T can appear only in output positions like, as method return value and read-only properties
- Here the interface becomes covariant in 'T'.
- It means that `IEnumerable<A>` is implicitly reference convertible to `IEnumerable`, if A has an implicit reference conversion to B,



Co-Variance and Contra-Variance

- In case of Employee and Manager classes, since there is a relationship between these classes, there is an implicit reference conversion from Manager to Employee :
 - Manager -> Employee
- Also because now type T in IEnumerable is out i.e. IEnumerable<out T> ,
- there is also an implicit reference conversion from IEnumerable<Manager> to IEnumerable<Employee> :
 - IEnumerable<Manager> -> IEnumerable<Employee>
- Here these new types convert the same way as the old ones.



Co-Variance and Contra-Variance

- Contra-Variance means think “in”
- In this case, ‘in’ keyword signifies that the generic type parameters can only be used at input positions like, as method parameters and write-only properties
- E.g. :- .NET framework has an interface `IComparable<T>`, which has a single method called `CompareTo` :

```
public interface IComparable<in T> {  
    bool CompareTo(T other); }
```

- Here the ‘in’ keyword, actually modifies the definition of type parameter, T. Compiler sees this and marks type T as contravariant
- Now, the following code :

```
IComparable<Employee> ec = GetEmployeeComparer();  
IComparable<Manager> mc = ec;
```



Co-Variance and Contra-Variance

- Because a manager is an employee, putting manager in works due to contra-variance.
- In case of Employee and Manager classes, since there is a relationship between these classes, there is an implicit reference conversion from Manager to Employee :

Manager -> Employee

- Also because type T in Comparable is in i.e. Comparable<in T> ,
- there is also an reference conversion from
- Comparable<Employee> to Comparable<Manager> :
 - Comparable<Manager> <- Comparable<Employee>



Limitations

- Covariant and contravariant type parameters can be applied only on generic interfaces and delegates.
- Covariance and contravariance only applies when there is a reference (or identity) conversion between type arguments
- For instance, an `IEnumerable<int>` is not an `IEnumerable<object>` because the conversion from `int` to `object` is a boxing conversion, not a reference conversion

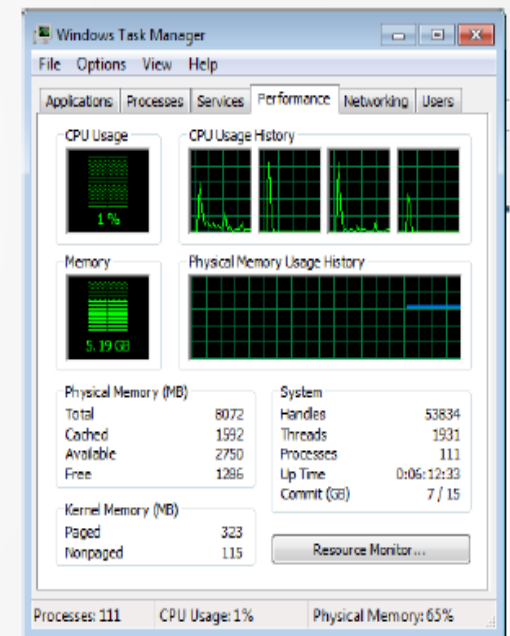
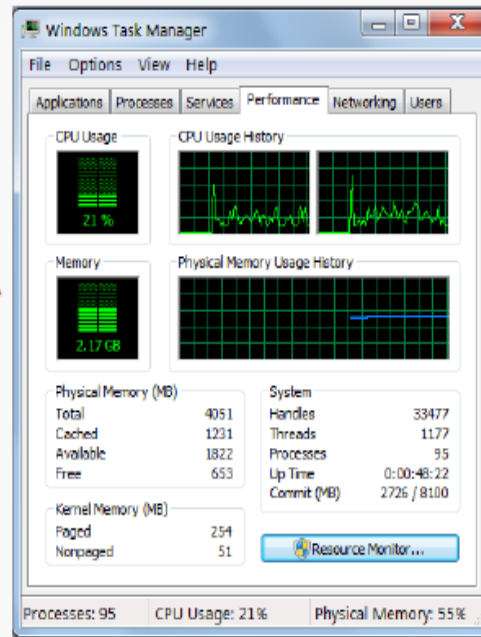
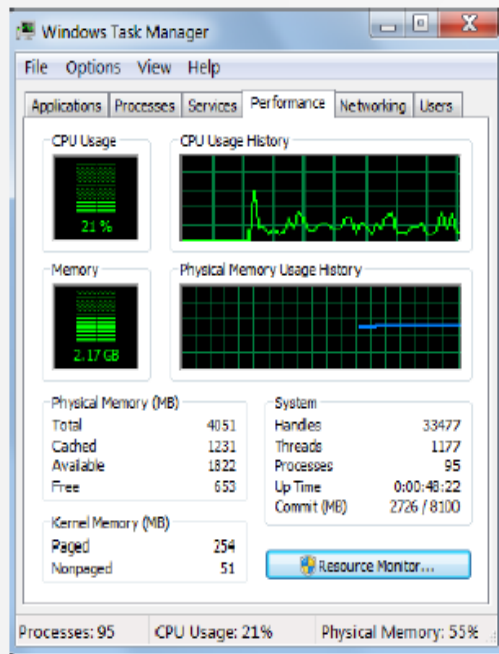


Demo

➤ Covariance and Contravariance



Evolution of Processors: The Multi Core Shift





The Multi Core Shift

- New model for increasing hardware processing power
- Focus shifted from increasing PC CPU Clock speed
- Overall processing power increased due to additional CPUs, or “cores” on a single chip
- Most desktop and laptop systems now ship with multi-core microprocessors
- Developers should leverage these multi cores in the programs



Parallelization Overview

➤ Business Need

- Need Continuous and Higher Performance to support Complex Processing & Larger Data sets
- Manage Computational and Data Intensive Applications
- Develop More Responsive applications

➤ IT Solution

- Leverage Multi-Core CPU(s)
- Paradigm Shift - Move from Sequential to Parallel Execution
- Develop asynchronous applications

➤ Microsoft Provides Task Parallel Library (TPL) to implement parallelism

➤ Tasks are the new model for asynchronous programming



Asynchronous Defined

➤ Concurrent

- Several things happening at once

➤ Multithreaded

- Multiple execution contexts

➤ Parallel

- Multiple simultaneous Computations

➤ Asynchronous

- Not having to wait

➤ Parallel => divide workload so that you can finish sooner
(Performance)

➤ Async => start an operation and then return to UI
(responsiveness)



Async and Parallel

"Async" programming

Responsiveness

— hide latency of potentially long-running or blocking operations (such as I/O) by executing in background

Performance

— reduce time of CPU-bound computations by dividing workload & executing simultaneously

"Parallel" programming



Task Parallel Library

- The Task Parallel Library (TPL), as its name implies, is based on the concept of the task.
- Tasks are a new abstraction in .NET 4 to represent units of asynchronous work
- Tasks were not available in earlier versions of .NET, and developers would instead use ThreadPool work items for this purpose
- The term task parallelism refers to one or more independent tasks running concurrently.
- A task represents an asynchronous operation, and in some ways, it resembles the creation of a ThreadPool work item, but at a higher level of abstraction.
- Tasks provide two primary benefits:
 - More efficient and more scalable use of system resources
 - More programmatic control than is possible with a thread or work item



Task Parallel Library

- The Task Parallel Library (TPL) is a set of APIs in the `System.Threading` and `System.Threading.Tasks` namespaces in the .NET Framework version 4.
- The TPL scales the degree of concurrency dynamically to most efficiently use all the processors that are available.
- In addition, the TPL handles the partitioning of the work, the scheduling of threads on the `ThreadPool`, cancellation support, state management, and other low-level details.
- By using TPL, you can maximize the performance of your code while focusing on the work that your program is designed to accomplish



Task Parallel Library

- Parallel Extensions in .NET 4.0 provides a set of libraries and tools which
 - Makes concurrent programming easier where developers need not care much details of threads and locks
 - Makes profiling and debugging concurrent applications easier
 - Enables the applications to scale up without any code as number of cores increases
 - Allows existing applications to be easily parallelized



Threads Vs. Tasks

Threads



- ☐ High on Memory
- ☐ Run on Single Core
- ☐ Context Switching
- ☐ Fire and Forget

Tasks

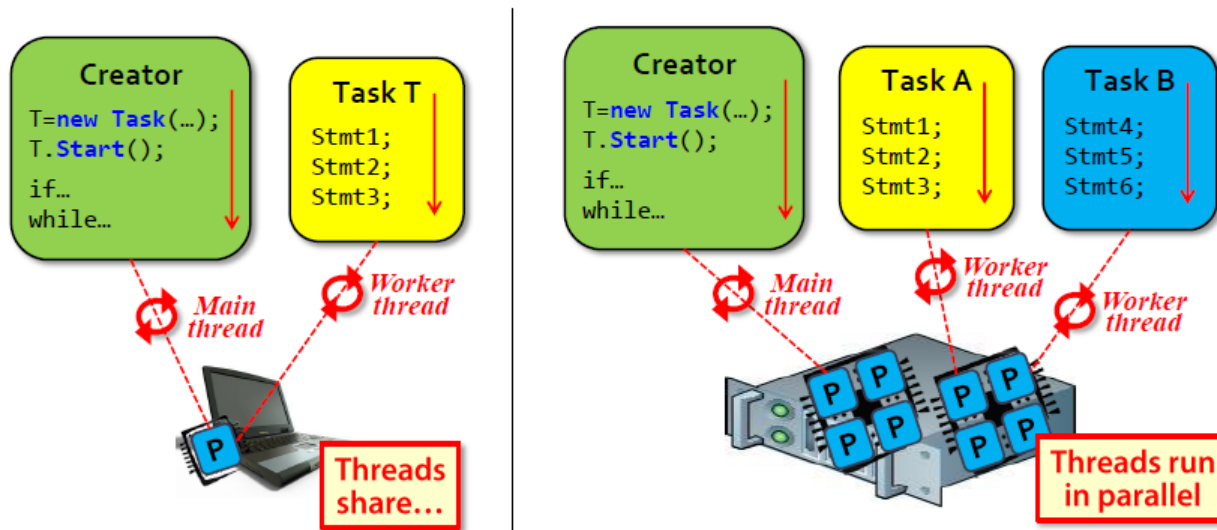


- ☐ Light Weight
- ☐ Multi Core Aware
- ☐ Asynchronous Operations
- ☐ Can return a value



Threads Vs. Tasks

- Code based tasks are executed by a thread on some processor
- Thread is dedicated to task until task completes





Parallel Extensions in .NET

➤ Data Parallelism

- This refers to dividing the data across multiple processors for parallel execution. e.g. we are processing an array of 1000 elements we can distribute the data between two processors say 500 each.
- Using Parallel Foreach, For, Invoke, PLINQ

➤ Task Parallelism

- This breaks down the program into multiple tasks which can be parallelized and are executed on different processors.
- This is supported by Task Parallel Library (TPL) in .NET and the Task class
- Implement the "Task Asynchronous Pattern" TAP



Data Parallelism

- When a parallel loop runs, the TPL partitions the data source so that the loop can operate on multiple parts concurrently.
- Behind the scenes, the Task Scheduler partitions the task based on system resources and workload.

```
// Sequential version  
foreach (var item in sourceCollection)  
{  
    Process(item);  
}
```

```
// Parallel equivalent  
Parallel.ForEach(sourceCollection, item => Process(item));
```



Task Parallelism

- The term task parallelism refers to one or more independent tasks running concurrently.

```
// Create a task and supply a user delegate by using a lambda expression.  
var taskA = new Task(() => Console.WriteLine("Hello from taskA."));  
  
// Start the task.  
taskA.Start();  
  
// Output a message from the joining thread.  
Console.WriteLine("Hello from the calling thread.");
```

```
/* Output:  
* Hello from the joining thread.  
* Hello from taskA.  
*/
```



Using lock Statement

- lock Statement Acquires the Mutual-Exclusion Lock
 - Used the mutual-exclusion lock for a given object, executes a statement block, and then releases the lock
 - Used in multithreaded applications to ensure that the current thread executes a block of code to completion without interruption by other threads
- At the same time No Any other Threads Can Acquire the lock
 - Any other thread is blocked from acquiring the lock and waits until the lock is released.
- Provides Synchronized Access to Shared Resources in Multithreaded Application
 - locking construct used to ensure synchronized access to shared data in multithreaded applications.
 - It helps to protect the integrity of a mutable resource that is shared by multiple threads without creating interference between those threads
- lock Statement Holds reference to an object which may be “Acquired” by a thread
 - Object hold by lock statement is know as monitor
 - Only one thread may acquire a particular monitor at one time

Demo



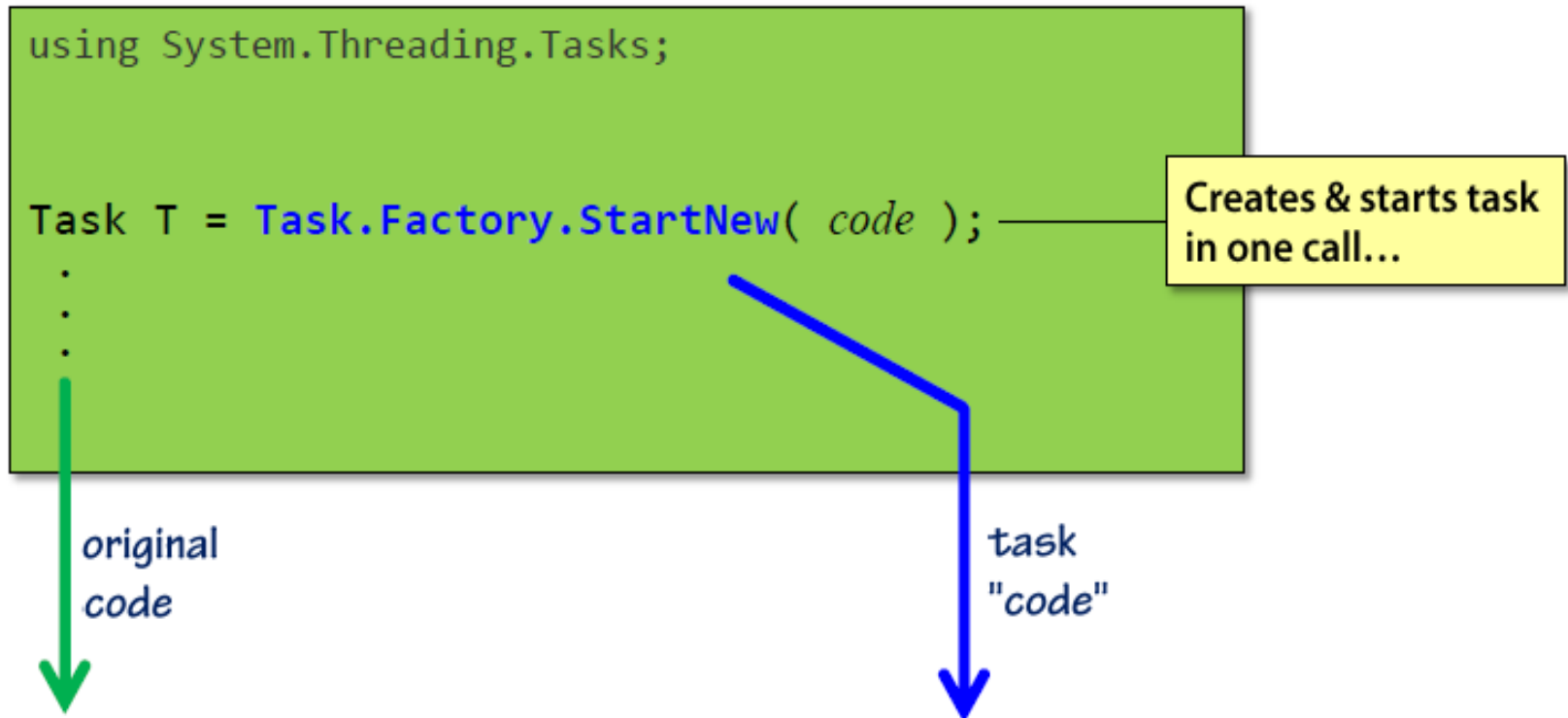
➤ Using lock Statement





Creating code Tasks – preferred approach

- More efficient way..





Lambda Expressions

- TPL accepts lambda expressions as parameters
 - Making it easy to create tasks..

// original code:

```
statement1;  
statement2;  
statement3;
```



// parallel code:

```
Task.Factory.StartNew( () =>  
    {  
        statement1;  
        statement2;  
        statement3;  
    }  
);
```



Parallel LINQ - PLINQ

- PLINQ provides a parallel implementation of LINQ and supports all the standard query operators.
- This is achieved by the `System.Linq.ParallelEnumerable` class which provides a set of extension methods on `IEnumerable` interface.
- Developers can opt-in for parallelism by invoking the `AsParallel` method of `ParallelEnumerable` class on the data source.
- Using PLINQ we can combine sequential and parallel queries

Task Based Asynchronous Model in .NET 4.5



- We can avoid performance bottlenecks and enhance the overall responsiveness of your application by using asynchronous programming.
- However, traditional techniques for writing asynchronous applications can be complicated, making them difficult to write, debug, and maintain.
- C# 5.0 introduced a simplified approach, async programming, that leverages asynchronous support in the .NET Framework 4.5 and the Windows Runtime



Async and Await - .NET 4.5

- Async programming is recommended in the following scenarios:
 - To keep your application responsive while waiting for something that is likely to take a long time to complete
 - To make your application as scalable as possible (particularly important for services and ASP.NET that have limited threads/resources to service requests)
- However, not all problems are suited to be run asynchronously
- Consider using async functionality in the following situations
 - You are waiting for a response from a remote service
 - The task you want to perform is computationally expensive and doesn't complete very quickly



Async

- `async`: This modifier indicates the method is now asynchronous.
- It provides a simpler way to perform potentially long-running operations without blocking the callers thread.
- The caller of this `async` method can resume its work without waiting for this asynchronous method to finish its job
- Reduces developer's efforts for writing an additional code
- The method with `async` modifier has at least one `await`
- This method now runs synchronously until the first `await` expression written in it



Await

- await: Typically, when a developer writes some code to perform an asynchronous operations using threads, then he/she has to explicitly write necessary code to perform wait operations to complete a task.
- In asynchronous methods, every operation which is getting performed is called a Task.
- The 'await' keyword is applied on the task in an asynchronous method and suspends the execution of the method, until the awaited task is not completed.
- During this time, the control is returned back to the caller of this asynchronous method



Await

- Most important behavior of the await keyword is it does not block the thread on which it is executing.
- What it does is that it signals to the compiler to continue with other async methods, till the task is in an await state.
- Once the task is completed, it resumes back where it left off from.



.NET 4.5 async and await

➤ Async

- Enables use of asynchronous features
- Applied to methods

➤ Await

```
void Work()
{
    Task<string> ts = Get();
    ts.ContinueWith(t =>
    {
        string result = t.Result;
        Console.WriteLine(result);
    });
}
```

```
async void Work()
{
    Task<string> ts = Get();
    string result = await ts;
    Console.WriteLine(result);
}
```



Async Rules

- The compiler will give you a warning for methods that contain async modifier but no await operator
- A method that isn't using the await operator will be run synchronously
- Microsoft suggests a convention of post-fixing an Async method with the words Async e.g. DoSomethingAsync
- Async methods can return any of the following:
 - **Void**
 - **Task**
 - **Task<T>**
- A number of BCL methods now have an Async version for you to use with the await keyword



The BCL Support for Async in .NET 4.5

```
public class Stream
{
    ...
    public Task WriteAsync(byte[] buffer, int offset, int count)
    public void Write(byte[] buffer, int offset, int count)
    ...
    public int Read(byte[] buffer, int offset, int count)
    public Task<int> ReadAsync(byte[] buffer, int offset, int count)
    ...
}
```



Task Based Asynchronous Model

```
async Task<string> AccessTheWebAsync()
{
    HttpClient client = new HttpClient();
    Task<string> getStringTask =
        client.GetStringAsync("http://msdn.microsoft.com");
    DoAnyOtherIndependentWork();
    string urlContents = await getStringTask;
    return urlContents;
}
```

Demo





Summary

- Increased usability with features like Optional parameters & Named arguments
- Provides dynamic programming
- Introduced Late binding support in C#, while it still remains a statically typed language
- Provides support for interaction with dynamic languages like Python & Ruby etc
- 'dynamic' keyword allows C# to defer method invocation at runtime i.e. Dynamic method Invocation
- Co-Variance and Contra-Variance
- Improved COM Interop using Optional parameters (Omit ref on COM calls)





Review Question

- Which feature of C# automatically generates temporary variables to pass them as reference to COM methods?
 - Linking of PIA
 - Omit REF
 - Indexed Properties
- C# 4.0 Compiler offers to embed definitions inside PIA in your application assembly
 - True/False
- _____ offers No-PIA option so that entire PIA need not be deployed along with your application setup.

