Thread Safety

DEVELOPMENTOR
DEVELOPING PEOPLE WHO DEVELOP SOFTWARE

Agenda

- **Highlight issues with multi threaded programming**
- **Introduce thread synchronization primitives**
- **Introduce thread safe collections**

Need for Synchronization

- **Creating threads is easy**
- **When threads share data problems can occur**
  - Inconsistent reads
  - State corruption
- **Synchronization fixes these problems, but potentially creates a new problem**
  - Over synchronization reduces scalability
- **Lots of techniques to implement synchronization**
  - Each have cost and benefit
- **Developers role is to write an application that scales and is thread safe, by selecting the best synchronization technique**

Simple Increment

- **Two threads**
  - Sharing an instance of Counter.
  - Both are calling **Increment** 1000 times
- **Question**
  - What is the value of count after both threads have completed?

```
public class Counter
{
  protected int count;

  public virtual void Increment()
  {
    count++;
  }
  public int Value { get { return count; }  }
}
```

Simple Increment, NOT Atomic

- **Even a simple count++ is not an atomic operation.**
  - Multiple CPU instructions that could be interweaved.
- **Consider the possible execution below of two threads (T0, T1)**
  - Assuming count=0 at the start
  - At the end of execution i would be 1 and not the desired 2.
- **If two threads don't attempt to increment count at the same time not a problem. Spotting these kind of errors is hard**

time

```
T0: MOV R0,count
T0: ADD R0,1          T1: MOV R0,count
T0: MOV count,R0      T1: ADD R0,1
                      T1: MOV count,R0
```

Interlocked

- **Modern CPU’s expose special instruction set to perform various operations atomically**
  - Cost more than non atomic variants.
- **Access to these instructions via Interlocked class**
  - Interlocked.Increment
  - Interlocked.Decrement
  - Interlocked.Add
  - Interlocked.Exchange, Interlocked.CompareAndExchange
    - Useful for building Spin locks

```
public class InterlockedCounter : Counter
{
  public override void Increment()
  {
    // Atomic count++
    Interlocked.Increment(ref count);
  }
}
```

Multi step state transition

- **What happens if**
  – Thread A is inside ReceivePayment
  – Thread B is inside NetWorth
- **Can Interlocked help ?**

```
 class SmallBusiness {
   decimal Cash = 0;
   decimal Receivables = 1000;

   public void ReceivePayment(decimal amount){
     Cash += amount;
     Receivables -= amount;
   }

   public decimal NetWorth {
     get { return Cash + Receivables; }
   }
}
```

Sequential access

- **To fix the problem**
  - Sequentialise access to the object state
- **How**
  - Each instance of a reference type has a Monitor
  - CLR guarantees that only one thread can own the monitor
  - If a thread can’t acquire the monitor it enters a wait state
  - When the monitor is available it is woken up and proceeds
- **Critical areas of code can therefore be protected by using a monitor.**

Monitor based solution

- Only one thread in any critical region at any point in time

```
private object _lock = new object();

public void ReceivePayment(decimal amount)
{
  Monitor.Enter(_lock);
    Cash += amount;
    Receivables -= amount;
  Monitor.Exit(_lock);
}
```

Could be an issue with exceptions

```
public decimal NetWorth
{  get {
   Monitor.Enter(_lock);
   try { return Cash + Receivables; }
   finally { Monitor.Exit(_lock);
   }
  }
}
```

Deals better with exceptions

Lock keyword

- **Enter, try, finally , Exit common pattern**
  - C# language offers lock keyword to assist
  - Compiler emits try, finally logic
- **Use of Monitor.Enter and lock can lead to deadlocks**
  - Prefer Montior.TryEnter which takes a timeout
- **Avoid using lock(this) and lock(typeof(X))**
  - Less control over objects use for synchronization.
  - Prefer creation of object for sole purpose of synchronization

```
public void ReceivePayment(decimal amount){
 lock (_lock)
 {
   Cash += amount;
   Receivables -= amount;
 }
}
```

High Read to Write Ratio

- **Monitor provides mutual exclusion behaviour**
  - Excluding readers and writers
- **Thread safety not an issue if all threads read.**
- **Better throughput may be achieved with a Synchronization primitive that ensures**
  - There can be Many Readers, Zero Writer
  - Or One Writer, Zero Readers
- **This is known as a ReaderWriterLock**
  - .NET 3.5 and above prefer ReaderWriterLockSlim
  - Pre 3.5, ReaderWriterLock
    - Not well implemented, can result in writer being denied access for long periods of time.
- **Often used for caching, where most of the time is spent reading with occasional updates.**

Reader Writer Lock

```
public class SimpleCache
{
 private Dictionary<int, string> cache=
              new Dictionary<int, string>();
 private ReaderWriterLockSlim _lock = new ReaderWriterLockSlim();

 public string Get(int key) {
   _lock.EnterReadLock();
    try { return cache[key]; }
    finally { _lock.ExitReadLock(); }
}

 public void Set(int key, string val)
 {
   _lock.EnterWriteLock();
   try { cache.Add(key,val) }
   finally { _lock.ExitWriteLock(); }
 }
}
```

Many threads can can read from the cache

When one thread has the write lock no other thread can obtain read or write lock.

Concurrent Collections

- **Standard Collections not thread safe**
  - List<T>,Dictionary<K,V>,Queue<T>,Stack<T>
- **.NET 4 introduces Concurrent variants**
  - ConcurrentQueue<T>
  - ConcurrentStack<T>
  - ConcurrentDictionary<K,V>
  - ConcurrentBag<T>
- **Designed to**
  - When possible to run lock free.
  - Operations don’t block, TryXXXX

Example of Concurrent Collection

- **Dictionary.Add throws exception if key already present**
  - To prevent exception check if key is present, if not add item
  - Checking for key and then adding is two steps would require locking in a multithreaded environment
- **ConcurrentDictionary.TryAdd will return false if key already exists. Negating the need for a lock**

```
public class SimpleCache{
 private ConcurrentDictionary<int, string> cache = new
        ConcurrentDictionary<int, string>();

 public string Get(int key) {
   return cache[key];
 }
 public void Set(int key, string val) {
   cache.TryAdd(key, val);
 }
}
```

Rendezvous

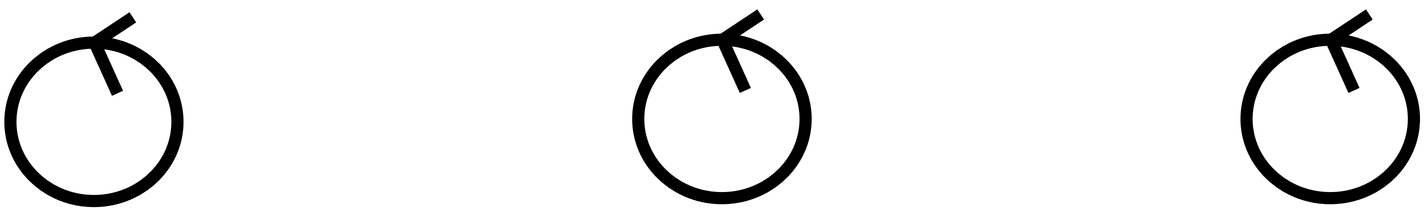
- **Co-operating tasks sometime need to synchronize with each other before proceeding.**
  - Exchange results.
  - Wait for all tasks to initialise before commencing.
- **Barrier**

```
Barrier phase = new Barrier(3);
```

```
phase.SignalAndWait();
```

```
phase.SignalAndWait();
```

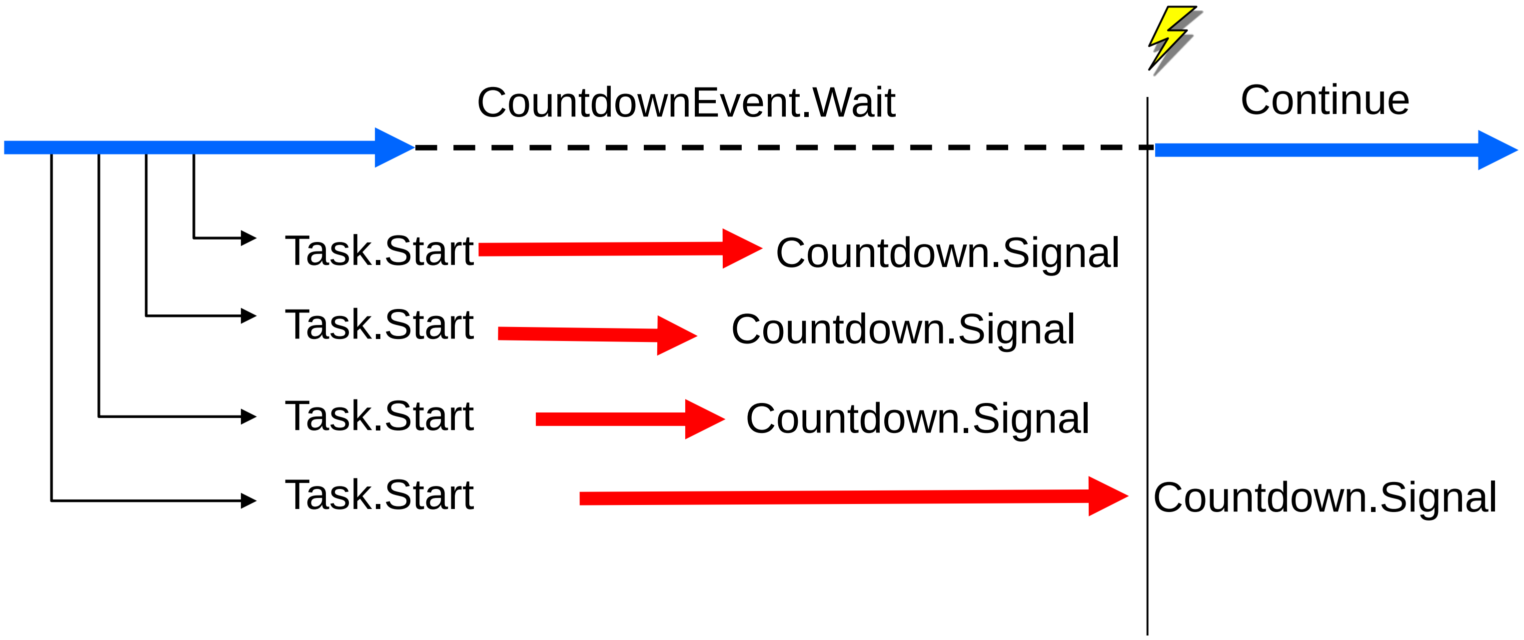
```
phase.SignalAndWait();
```



Threads block until all three have called SignalAndWait

Countdown Event

- **Primary task initiates N other tasks and wishes to wait for them all to have completed a series of steps.**
- **Creates an instance of a CountdownEvent initialised to the number of sub tasks.**



Synchronization across app domains

- **Managed synchronization primitives only allow synchronization inside a single app domain**
- **How to control access to a shared file ?**
  - Requires Kernel based synchronization
- **Kernel synchronization can be achieved via managed wrappers**
  - Mutex
  - Semaphore
  - AutoResetEvent
  - ManualResetEvent
- **These synchronization primitives are orders of magnitude more expensive than managed ones**

Summary

- **A variety of ways to perform synchronization, the skill is picking the correct one**
- **Concurrent collections make it simpler to write efficient thread safe code**
- **Only use kernel synchronization primitives when absolutely necessary**
- **Analyse code and imagine worse possible race conditions**