Distributed Computing

Lecture 4: Asynchronous Communication

Last updated: 11 August 2023

This Week

- Last week, we discussed Multi-tier architecture and started the discussion on Asynchronous communication
- This week we will explore deeper into Asynchronous communication
- We will illustrate with .NET
  - the underlying concepts apply to any language/framework

Blocking Calls and Distributed Computing

- When a function is called, the caller typically must wait (block) until the function completes & returns
- In a distributed computing system, blocking for a remote call can easily be a waste of resources
  - Especially if it is a call that could take a while
  - eg: Client waits while server performs a long job
  - Not utilising resources properly/efficiently there!

Synchronous vs Aynchronous

- Synchronous invocation = blocking call
  - Serial processing
  - Control is passed to called function
  - Caller cannot continue until called function returns
- Asynchronous invocation = non-blocking call
  - Parallel processing (or at least one way to implement it)
  - Control is returned immediately to the caller
  - Called function carries on in the background
  - At some later time, caller retrieves function’s return value

Asynchronous Calls

- Reasons for using asynchronous calls
  - Maintain GUI responsiveness
  - Utilise resources of caller more efficiently
    (eg: continue doing other work during a long-running call)
- Asynchronity traditionally implemented with threads
  - Spin off a worker thread to perform call 'in the background'

An Interlude: Threads

– Thread: an independent line of code execution within a process
  - A single process can have one or many threads within it
    - » The first thread starts at `main()`
    - » Subsequent threads can be created and start at a given function
  - All threads share the same code and memory (process space)
    - » A thread can run any function and access any data in the process
  - Each thread is scheduled independently by the O/S
    - » Thus they run concurrently (in parallel)
    - » Different threads can be updating the same data at the same time
    - » This leads to the possibility of data corruption: lost updates, etc

Threads to Asynchronous Calls

- The problem with threads is that they are hard to get working bug-free
  - The main way threads 'communicate' with each other is via updating shared data
  - But do this wrong and the data will get corrupted
    - …and be too conservative and lose all parallel performance
- Microsoft created .NET-specific approaches to (largely) take care of the threads for the user
  - Event-based: notifications sent on call completion
  - Threads still used, but hidden from the user

When to use Asynchronous Calls?

- Naïve answer: for any potentially long-running call
- But *every* RPC call is potentially long-running
  - Network/server failure only detected after timeouts expire
  - Making every RPC call asynchronous increases code complexity, just on the *chance* a network failure occurs
- So use asynchronous calls only on functions that are *expected* to take a long time
  - eg: heavy processing tasks, intensive disk I/O tasks, etc
  - For GUI clients, responsiveness is also a key issue

.NET Asynchronous Call Methods

- Blocking/polling with delegates (a special .NET concept)
  - Fairly unsophisticated: Call-DoOtherWork-WaitForReturn
  - But also simple and threads fully taken care of for you
- Completion callbacks with delegates
  - Have .NET callback your own method on completion
  - Very useful, but thread syncing is needed
- Background (worker) thread + function call
  - Manual method - create thread, do call in background
  - Flexible, but must deal directly with threads yourself

Delegates

- .NET delegates used extensively for notifications:
  - Callbacks (eg: for asynchronous completion callbacks)
  - Events (eg: OnClick event handler for Buttons)
- Delegates are like a function pointer in C/C++
  - Define a delegate, like declaring a function prototype
  - Create a variable whose type is the delegate
  - Then 'point' this variable at a real function and call the function through the delegate variable
    - » Passing this variable around is then like passing the function
- Java has no equivalent

Delegate Example

```
namespace MyExample {
public class Calculator ← Can be remote but this example won't use RPC
    {
       public int Add(int num1, int num2) { return num1 + num2; }
       public int Subtract(int num1, int num2) { return num1 - num2; }
       public int Multiply(int num1, int num2) { return num1 * num2; }
    }
}
------------------------------------------------------------------------------------------

public delegate int BinaryOperation(int operand1, int operand2); ← Delegate definition

public class DelegateTester
{
   public static void Main() {
       BinaryOperation binOp;                               ← Declare a variable of delegate type
       Calculator calc;

       calc = new Calculator();
       binOp = calc.Add;                  ← Point at Add() function of calc (the object, NOT the class!)
       System.Console.WriteLine("1 + 2 = " + binOp(1, 2)); ← binOp substitutes for calc.Add
       binOp = calc.Subtract;                              ← Point at calc.Subtract()
       System.Console.WriteLine("1 - 2 = " + binOp(1, 2)); ← binOp now substitutes for calc.Subtract
    }
}
```

Asynchronity with Blocking/Polling

- Each delegate has a BeginInvoke( ) and EndInvoke( )
  - Generated by compiler to match delegate prototype
- Use BeginInvoke( ) to start an asynchronous call
  - Call is started on a new thread
- Use EndInvoke( ) to retrieve results
  - Blocks if call hasn't completed yet
    - » NOTE: It is *still* an async call: block only occurs on EndInvoke()
  - Thread creation/syncing is done for you by .NET
- Can check if call completed before calling EndInvoke
  - In other words, can do polling – can be inefficient
  - asyncObj.IsCompleted in loop (waste processing power)

Async Call w/Blocking Example

– An example of running two calls in parallel (not RPC):

```
public delegate int BinaryOperation(int operand1, int operand2);

public class CalcClient
{
   public static void Main() {
      BinaryOperation addDel;
      Calculator calc = new Calculator();          ← Could have set up an RPC for this - has no effect on async calls
      IAsyncResult asyncObj1, asyncObj2;           ← Each IAsyncResult object tracks info for a single async call
      int iAddResult1, iAddResult2;

      addDel = calc.Add;                           ← Point delegate at function to be called asynchronously

      asyncObj1 = addDel.BeginInvoke(1, 2, null, null);      ← Start worker threads
      asyncObj2 = addDel.BeginInvoke(3, 4, null, null);        for async calls in parallel

      // Block, waiting for all async calls to complete
      iAddResult1 = addDel.EndInvoke(asyncObj1);   ← Retrieve return value from each async call tracked by the
      iAddResult2 = addDel.EndInvoke(asyncObj2);     appropriate asyncObjX

      asyncObj1.AsyncWaitHandle.Close();           ← Clean up
      asyncObj2.AsyncWaitHandle.Close();

      System.Console.WriteLine("1 + 2 = " + iAddResult1);
      System.Console.WriteLine("3 + 4 = " + iAddResult2);
   }
}
```

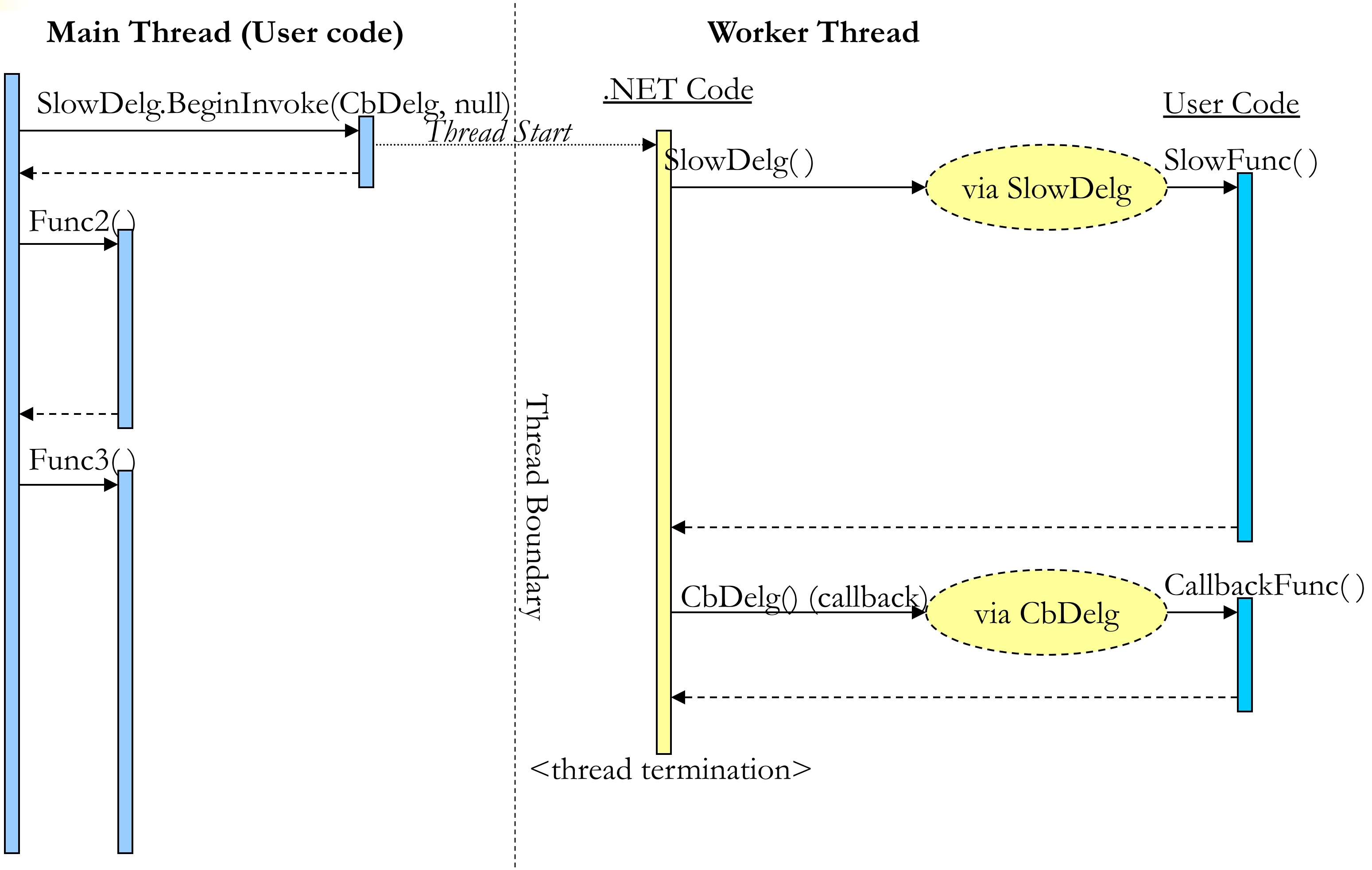
Blocking/Polling Uses

- Block/polling is 'half-synchronous'
  - Need to 'guess' when async call completes
  - But much simpler than async completion-callbacks
  - And don't have to mess with thread synchronisation
- Blocking/polling has its uses
  - Blocking is good for firing off several calls where you must wait for all calls to complete before continuing
    - » eg: for executing a task in parallel – blocking async calls are one of the few relatively elegant methods to facilitate this
  - Polling can be used to facilitate similar scenarios that have greater complexity/interplay between parallel calls

Asynchronity with Completion Callbacks

- A callback is where one of your own methods is called in response to a call that you made earlier
- .NET *completion callbacks* are callbacks designed to notify you when an asynchronous call has *completed*:
  - Approach: Define *two* delegates:
    - » A: points at the function to run asynchronously via BeginInvoke
    - » C: points at the function that is to be called *on completion* of X
  - Normal async call, but pass C as well:
    - » A.BeginInvoke(…, C, null) tells .NET to callback on C when A is done
  - When call completes, .NET notifies your method via C
    - » On the same *background worker thread* that the call executed in
    - » Use EndInvoke( ) in callback fn C to retrieve return value

Asynchronity with Completion Callbacks



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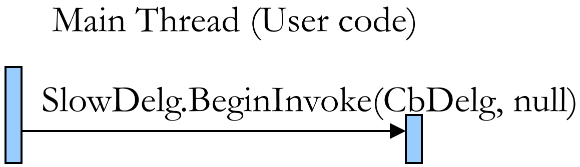
Asynchronity with Completion Callbacks



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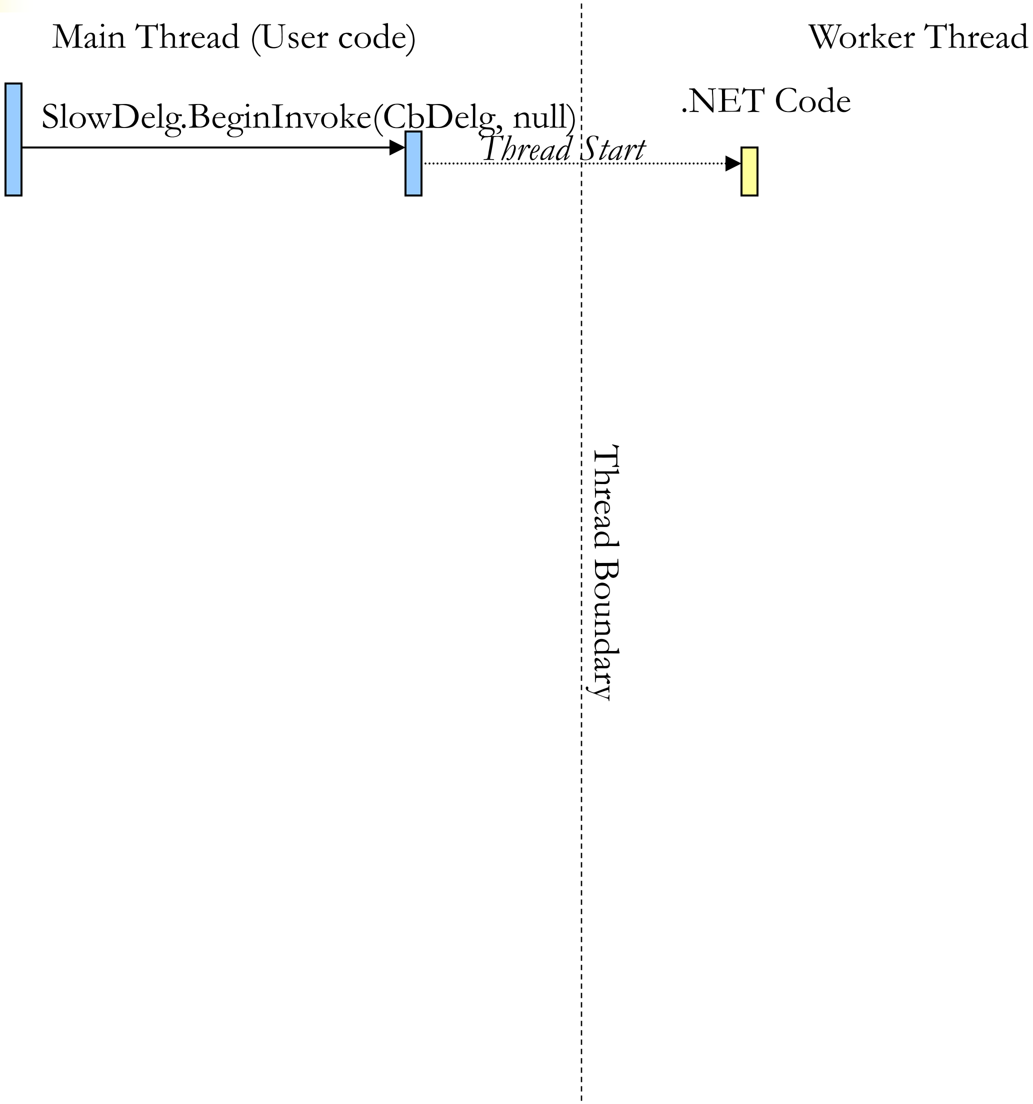

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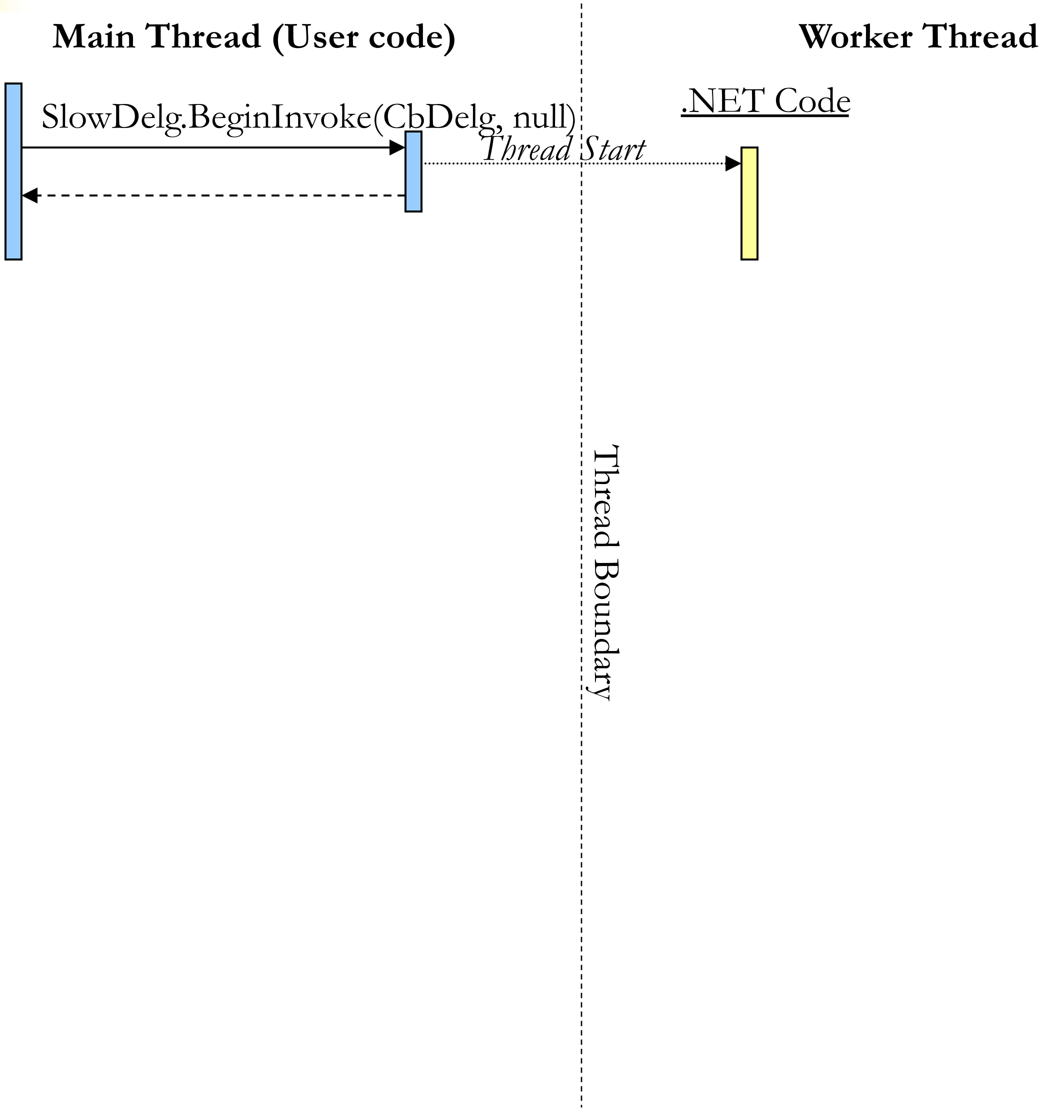

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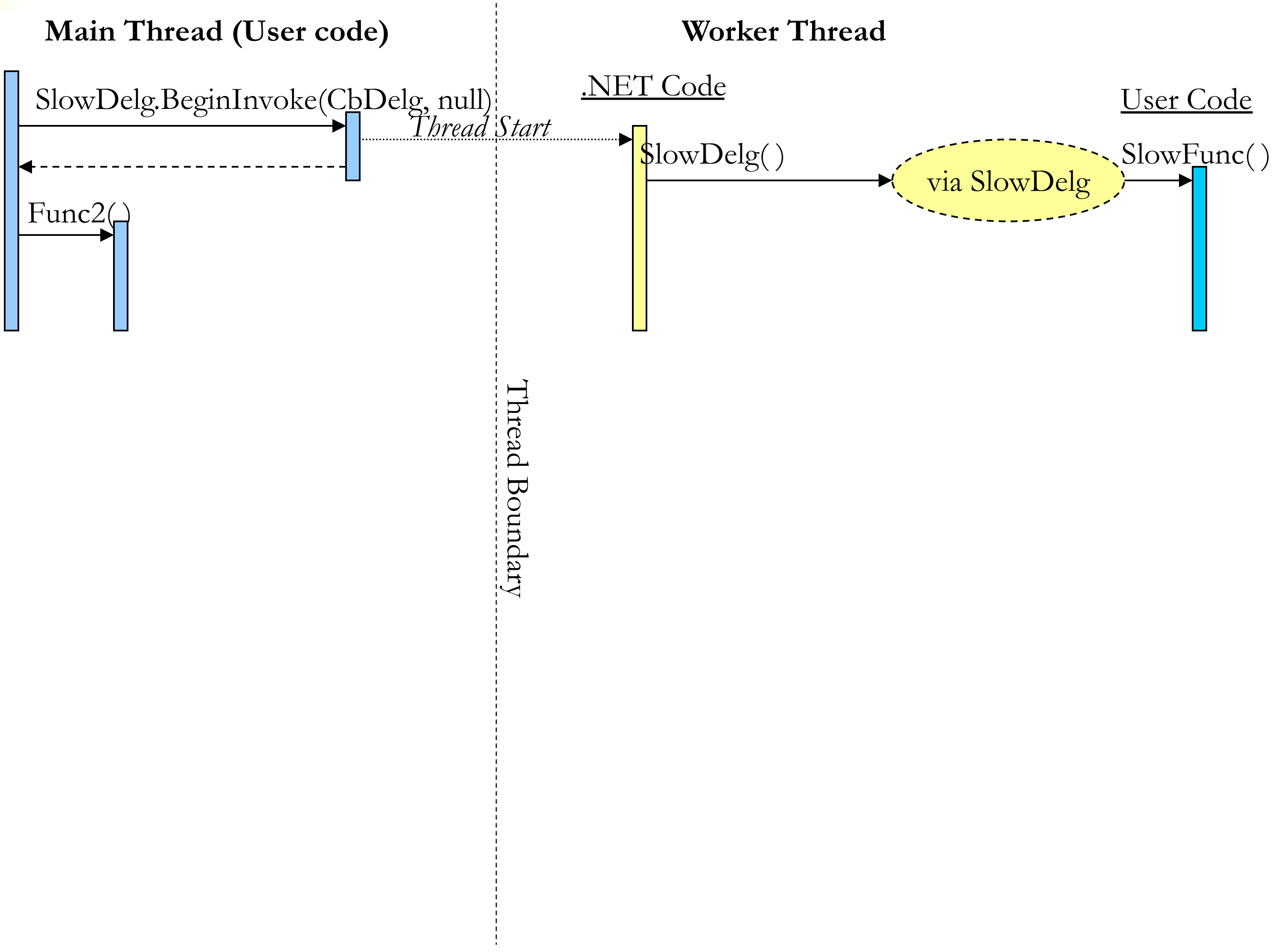

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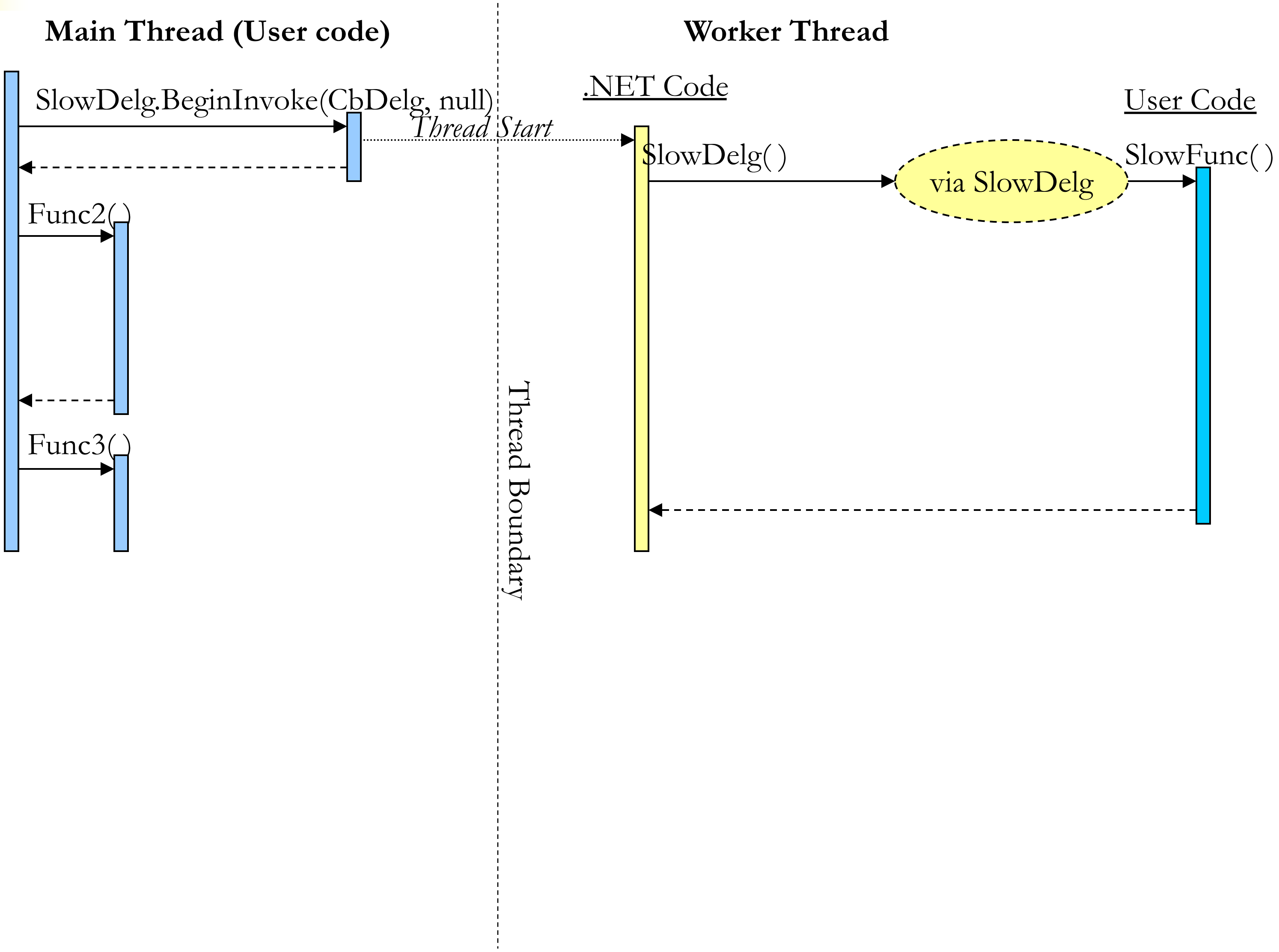

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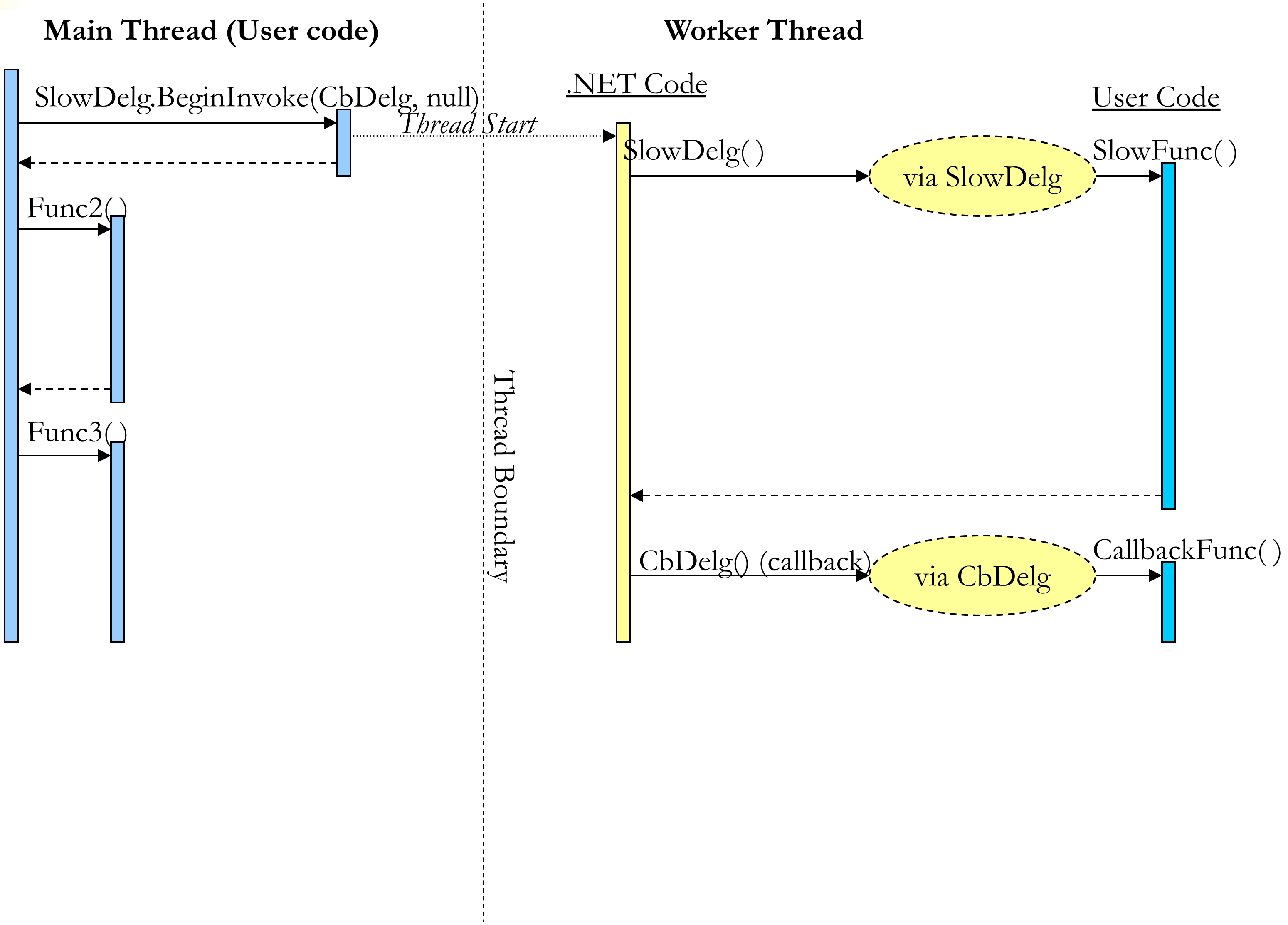

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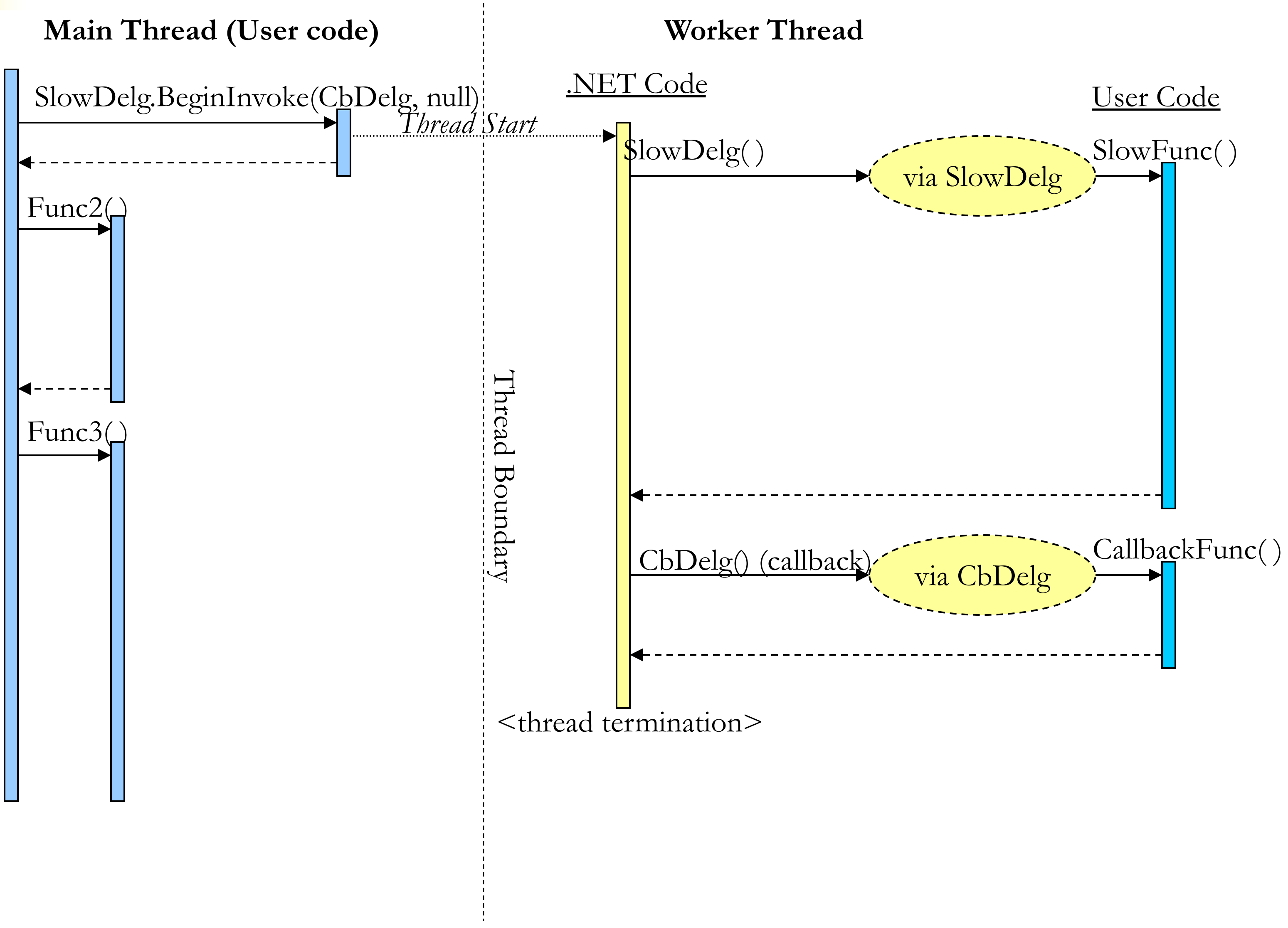


Completion Callback Example

```
public delegate int BinaryOperation(int operand1, int operand2);

public class CalcClient
{
   public static void Main() {
      BinaryOperation addDel;
      AsyncCallback callbackDel;                ← AsyncCallback is defined by .NET for BeginInvoke()
      Calculator calc = new Calculator();       ← Could have set up an RPC for this - has no effect on callbacks

      addDel = calc.Add;
      callbackDel = this.OnAddCompletion;       ← Point callback delegate at callback function
      addDel.BeginInvoke(1, 2, callbackDel, null);         ← Start worker thread (*callbackDel note*)

      System.Console.WriteLine("Waiting for completion.");  ← Race condition with result output below
      System.Console.ReadLine();
   }
   private void OnAddCompletion(IAsyncResult asyncResult) {  ← Must be same signature as AsyncCallback
      int iAddResult;
      BinaryOperation addDel;
      AsyncResult asyncObj = (AsyncResult)asyncResult;      ← So that we can get the AsyncDelegate

      if (asyncObj.EndInvokeCalled == false) {    ← Must not call EndInvoke more than once!
         addDel = (BinaryOperation)asyncObj.AsyncDelegate;  ← Gain access to delegate for EndInvoke
         iAddResult = addDel.EndInvoke(asyncObj);          ← Would retrieve ref or out params here too
         System.Console.WriteLine("1 + 2 = " + iAddResult); ← Race condition with result output in Main()
      }
      asyncObj.AsyncWaitHandle.Close();  ← Clean up
   }
}
```

Blocking/Polling vs Completion Callback

- Blocking advantages
  - ☑ All thread synchronisation performed for you by .NET
  - ☑ Very little extra coding over a normal synchronous call
  - ☑ Simple: no callback function involved
- Blocking disadvantages
  - ☒ Will block calling thread if async call hasn't finished by the time EndInvoke() is called
    - » May cause GUI to freeze if the thread is the event loop thread

Blocking/Polling vs Completion Callback

- Polling advantages
  - ☑ All thread synchronisation performed for you by .NET
  - ☑ Simple: no callback function involved
- Polling disadvantages
  - ☒ Inefficient use of CPU to repeatedly check if call is complete – takes CPU time away from useful processing
  - ☒ Requires coding to periodically check (poll) if complete

Blocking/Polling vs Completion Callback

- Completion Callback advantages
  - ☑ Will be notified as soon as async call is finished
    - » This avoids unnecessary waiting on the thread (blocking) and resource wasting (polling)
- Completion Callback disadvantages
  - ☒ Complex: requires a second function as the callback
  - ☒ Callback occurs on a different thread, so user must perform thread synchronisation themselves

Thread-Safety

- One problem with completion callbacks is that the callback is made on the worker thread
  - Whereas the original call was made on the main thread
  - Need some way to safely pass data between threads
    - » Using shared data is efficient, but data can be corrupted if multiple threads access/update it at the same time
  - This is the problem of thread synchronisation
    - » Coordinating two or more threads so as to avoid corrupting data
- Concept of thread-safety / re-entrancy
  - A thread-safe function guarantees that it will not corrupt data even if it is called simultaneously by multiple threads
    - » Re-entrancy is an older term for a similar concept

Need for Thread-Safety

- If you just avoid using asynchronous calls or threads, why worry about thread-safety?
  - Calls to server objects *always* run on their own thread
    - » Two simultaneous client calls = two server threads
  - Thus if server objects have any shared resources (eg: global variables), thread-safety becomes an issue
    - » eg: Say the server host has a GUI showing how many clients are connected. Server objects updating this form must synchronise or else risk corrupting the connection count.
- Moreover, most GUI clients use worker threads or asynchronous calls to keep the GUI responsive
  - I won't require this, but your employer ***definitely*** will!

Thread Synchronisation in .NET

- Two ways to perform thread synchronisation
- ‘Automatic’ (via .NET-specific attribute keywords)
  - SynchronizationContext (controlled by UseSynchronizationContext)
    - » Essentially forces single-threaded access to a *synchronisation domain* (a set of objects that were all created on same thread)
  - Synchronised methods (your likely mainstay)
    - » Calling a synchronised method of an object locks all other threads from accessing any other *synchronised* method of the obj
- Manual: locks, mutexs, waits/signals (underpins auto methods)
  - We won’t explore these in this unit
  - Fairly easy to use, but hard to keep bug-free!

.NET Thread Synchronisation Example

```
public class CalculatorEx : Calculator
{
   private int m_iNumOperationsCompleted;  ← A bit contrived, but we need some kind of shared data

   public CalculatorEx() {
      m_iNumOperationsCompleted = 0;
   }

   public int GetNumOperationsCompleted() {
      return m_iNumOperationsCompleted;     ← Read only: no need to synchronise this
   }

   [MethodImpl(MethodImplOptions.Synchronized)]     ← Synchronise access to member var(s)
   public int Add(int operand1, int operand2) {
      m_iNumOperationsCompleted++;
      return operand1 + operand2;
   }

   [MethodImpl(MethodImplOptions.Synchronized)]     ← Synchronise access to member var(s)
   public int Subtract(int operand1, int operand2) {
      m_iNumOperationsCompleted++;
      return operand1 - operand2;
   }
}
```

.NET Thread Syncing with Lock

– Locking in the previous example could have been done manually with the lock keyword too (not recommended):

```
public int Add(int operand1, int operand2) {
    lock(m_iNumOperationsCompleted) {   ← Synchronise access to var m_iNumOpsCompleted
        m_iNumOperationsCompleted++;
    }
    return operand1 + operand2;
}
```

– The fact that we only locked on a single variable increases the risk of accidentally creating race conditions or deadlocks
  - Must be careful that you lock the right variable(s) in the right order
  - `lock(this)` is safer, but same as a Synchronized MethodImpl
    - » Locking the whole object means locking access to *any* shared variable (safer)
  - It can be more efficient to use lock(), but at the cost of more bugs
    - » And there is no harder bug to find than a threading bug

Automatic vs Manual Syncing

- Automatic
  - ☑ Very easy - just add a line of code
    - » Easier to see what is thread-safe too
  - ☒ Inefficient for objects that have many methods used by many threads, especially if they use different private data
    - » A call to one method locks *all* methods of that object
- Manual
  - ☑ Fine control - can lock at the variable level (or lower)
    - » ie: can be more efficient (IF you do it properly)
  - ☒ More coding - must lock wherever variable is used
  - ☒ Much more prone to errors

WARNING

- Never underestimate thread concurrency issues
  - **IF YOU DO NOT FEAR THREADS, YOU DO NOT KNOW THREADS**
    - » It's like plutonium: *never ever* be less than cautious!
    - » Debugging race conditions is the stuff of nightmares
- Race conditions:
  - when two threads are in a race to update shared resources
- Types of errors from race conditions
  - Lost update – one thread overwrites the change another thread made
  - Out-of-date data
    - » eg: Memory access errors: one thread deletes data another uses
  - Inconsistent state
    - » Two threads interleave their updates on related member vars

How to Approach Thread Safety

- Avoid mixing auto and manual syncing in one class
  - Auto-syncing won't be aware of your manual syncing
- Components should be (externally) thread-safe
  - Data integrity: Can't assume clients will ensure thread-safe access
- Minimise number of potentially-shared variables
  - Use local variables, or use arrays with one entry for each thread
- Better safe than sorry: err on the side of inefficiency
  - eg: lock entire object rather than one variable
- BUT: Don't just synchronise everything
  - Frequent thread [b]locking = slower than single-threaded
  - Synchronise at the business logic level, not the low level classes like Lists (Java learned this the hard way with Vector, hence ArrayList)
  - No need to lock read-only accesses to shared variables (usually)

Oneway Calls

- What if we just need to quickly fire off a message to the remote end but don't need anything back?
  - Blocking would be a waste of time: there's no return val
  - An async RPC call wouldn't block, but it adds MT issues
- One solution is to use oneway calls
  - Introduced back in CORBA (and probably earlier)
  - Still a synchronous (non-threaded) call, but the client only blocks long enough to ensure the call started on the server
  - As soon as the server ACKs the initial call, the client continues even though the server has not completed

Oneway Calls

- Oneway calls must be void and with no out/ref parameters
  - ie: no returned values
- In .NET, a oneway call is defined by marking it with a parameter on the OperationContract attribute:
  - [OperationContract(IsOneWay=true)]
- Their behaviour is such that they are a much simpler substitute for full-blown asynchronous calls

Oneway Calls vs Async Calls

- However, oneway calls aren't *quite* immediate return
  - Will block until server ACKs the call
  - This could be a while if the server is down and times out
  - Still, it would be rare to have a oneway call last a noticeable amount of time
- Hence network exceptions can occur on the call
  - Network errors, timeout errors
- In comparison, async calls return *before* the RPC call is made
  - A thread is spun off to deal with the call

Remote Callbacks

- The concept of callbacks is broader than just their use as completion callbacks in asynchronous calls
  - Callback refers to the idea of calling back (or on behalf of) the caller via the function they provided to you
- Callback are frequently used in distributed computing
- Examples:
  - Progress updates from server to client
  - Publisher/subscriber systems
  - Peer-to-peer applications, where there is no server/client
    - » or more accurately, both sides act as both client and server

Remote Callbacks

- Typical case is that server needs to notify the client
  - eg: when the server is processing a long job and must periodically update the client on its progress
- In most RPC frameworks (but not WCF) the approach is to have the *client* implement a server object
  - Client passes this object to the server when starting the job
    - » The object is passed by reference (as a kind of 'network pointer')
  - Server does callback by invoking on the passed object ref
    - » Object knows where it came from; no need to set up connection
    - » Server must have been compiled with the client's interface

Remote Callbacks

- However, WCF tries to be *service*-oriented, not O-O
  - Hence passing object references around is not allowed
  - Instead, server objects have an optional *callback channel* that can be defined and associated with an interface
    - » Set up on connection initialisation
    - » This callback channel is requested by the *client*
      - – Called a duplex channel; duplex = two-way communication
  - On the client, we then have a class that implements the callback interface
    - » This class is effectively acting as a server object for the true server to call back on

Remote Callbacks – Duplex Channels

- Duplex channels are an explicit callback mechanism
  - As opposed to other frameworks that allow you to pass object references across the network, where callbacks are just invocations on a pointer to the client's 'server' object
- There are a few limitations of this approach:
  - Only one callback interface per server interface
    - » Although can have an inheritance hierarchy for your callbacks, so that the client can choose the base interface that fits it needs
  - .NET only provides access to the client's callback impl object during the server's RPC handling of a client
    - » You must save or pass this reference around to use it later
    - » (since it is a reference to a proxy, it is just a normal pointer)

Remote Callbacks – Server Side

```
// IServer.cs
[ServiceContract]
public interface IServerCallback {                ← Callback interface
   [OperationContract(IsOneWay=true)]              ← Callbacks are often a good candidate for oneway methods
   void ProgressUpdate(int iteration);
}
[ServiceContract(CallbackContract=typeof(IServerCallback)]   ← Define the associated callback
public interface IServer {                                        ← Server interface
   [OperationContract]
   void LongRunningJob();
}
-------------------------------------------------------------------------------------------
// ServerImpl.cs
[ServiceBehavior(ConcurrencyMode=ConcurrencyMode.Multiple,
                 UseSynchronizationContext=false)]
internal class ServerImpl : IServer {
   public void LongRunningJob() {
      // Get a reference to the client-side callback object
      IServerCallback cb = OperationContext.Current.GetCallbackChannel<IServerCallback>();
                        ← The cb ref can only be obtained in LongRunningJob (but can be stored)
      // Do server processing of the long-running job
      int ii = 0;
      while (DoProcessing() == true) {
         ii++;
         cb.ProgressUpdate(ii);                    ← Callback: let the client know of the progress
      }
   }
}
```

Remote Callbacks – Server Side

```
--------------------------------------------------------------------------------
// ServerHost.cs is the same as usual - see Week 2 lecture notes
// The use of a duplex channel is defined on the client side
--------------------------------------------------------------------------------
```

Remote Callbacks – Client Side

```
// ClientObj.cs
using IServer;                                                  ← For definition of IServerCallback
[CallbackBehavior(ConcurrencyMode=ConcurrencyMode.Multiple,      ← Same as ServiceBehaviour
                  UseSynchronizationContext=false)]
internal class ClientObj : IServerCallback {                    ← Implementation class for callback
   public void ConnectToServer() {
      DuplexChannelFactory<IServer> serverFactory;               ← Note Duplex, to allow for callbacks
      IServer theServer;
      NetTcpBinding tcpBinding = new NetTcpBinding()
      string sURL = "net.tcp://localhost:8005/Server";
      serverFactory = new DuplexChannelFactory<IServer>(this, tcpBinding, sURL);
                                                                 ← Pass ourselves to be callback handler
      theServer = serverFactory.CreateChannel();
      theServer.LongRunningJob()                                 ← Will do callbacks to ProgressUpdate
   }
   public void ProgressUpdate() {
      MessageBox.Show("Progress is occurring.");
   }
}
------------------------------------------------------------------------------------------
// ClientMain.cs
public class TheClient {
   public static void Main() {
      ClientObj client = new ClientObj();
      client.ConnectToServer
   }
}
```

Remote Callbacks - Notes

– Things to note:
  - We made the callback a oneway call
    - » This means that the server will not be blocked by the client
    - » Important since the server is probably doing processing, so waiting for the client to tell the user is a waste of server time
    - » And *much* simpler than writing an async call for the callback!
  - We marked the impl class with `[CallbackBehavior(...)]`
    - » Force .NET to be multi-threaded and that <u>we</u> handle synch-ing
    - » If the client is a GUI, then in truth a single-threaded, .NET-synchronised callback is actually a good idea
      - – GUIs run on an event loop, so the callback will just add itself to the event queue and act like any other fired event – convenient!
    - » But since we are learning, we'll stick with the harder MT option

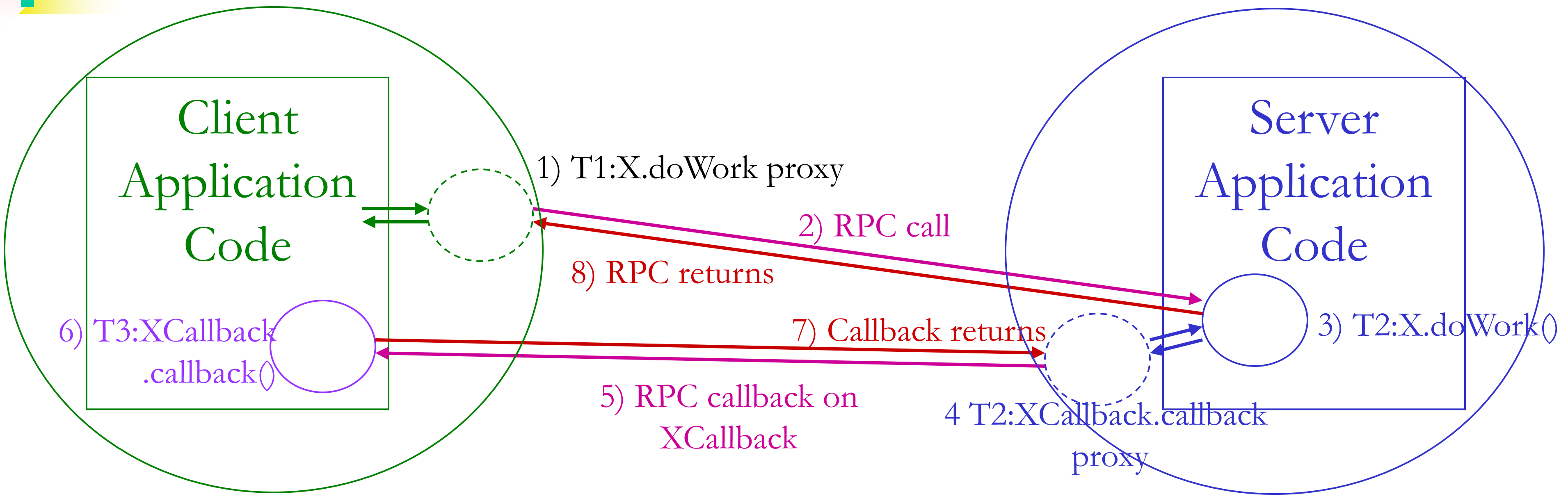
Remote Callbacks - Duplex

- The duplex channel setup is nearly identical to the normal channel setup
  - Just change ChannelFactory to DuplexChannelFactory, AND pass in a reference to the callback handler object
- Note that the callback class can be *any* class that implements IServerCallback
  - It didn't have to be the ClientObj, that was just convenient
    - » It reduced the number of classes and keeps the callback code in the same class as where the original call was made
    - » In the pracs, we will make the MainWindow (a GUI class!) to be our handler

Remote Callbacks

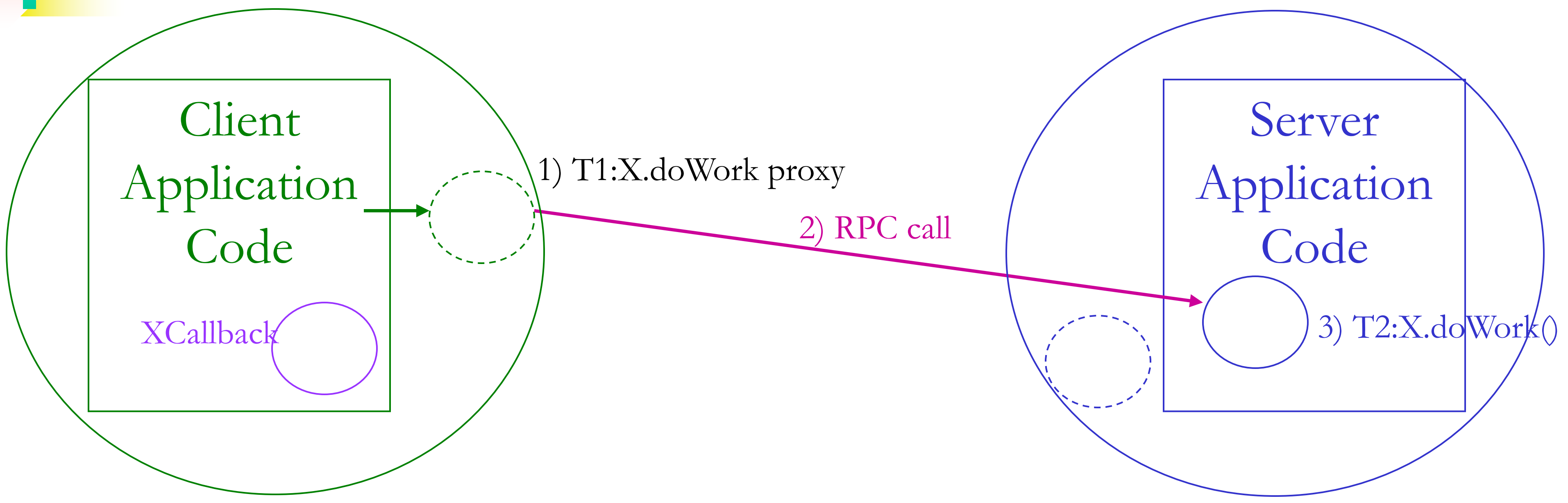
- Moreover, the callback ref can be stored by the server
      - » eg: in a member field
  - Would allow the server to call the client *at any time*, not just when handling the client's call
      - » In other words, the client becomes like a server
      - » Good for peer-to-peer applications where both sides can initiate new calls to the remote end depending on their respective users
- In any case, thread synchronisation is still needed
  - An RPC callback on a client object will be run in a new thread, just like an RPC call to a server object
      - » It can't just interrupt the client's main thread!
  - Most callbacks will need to update shared resources
      - » eg: update a progress bar
      - » Hence thread synchronisation becomes an issue

Example Remote Callback



– We'll do it in animation over the next few slides

Example Remote Callback



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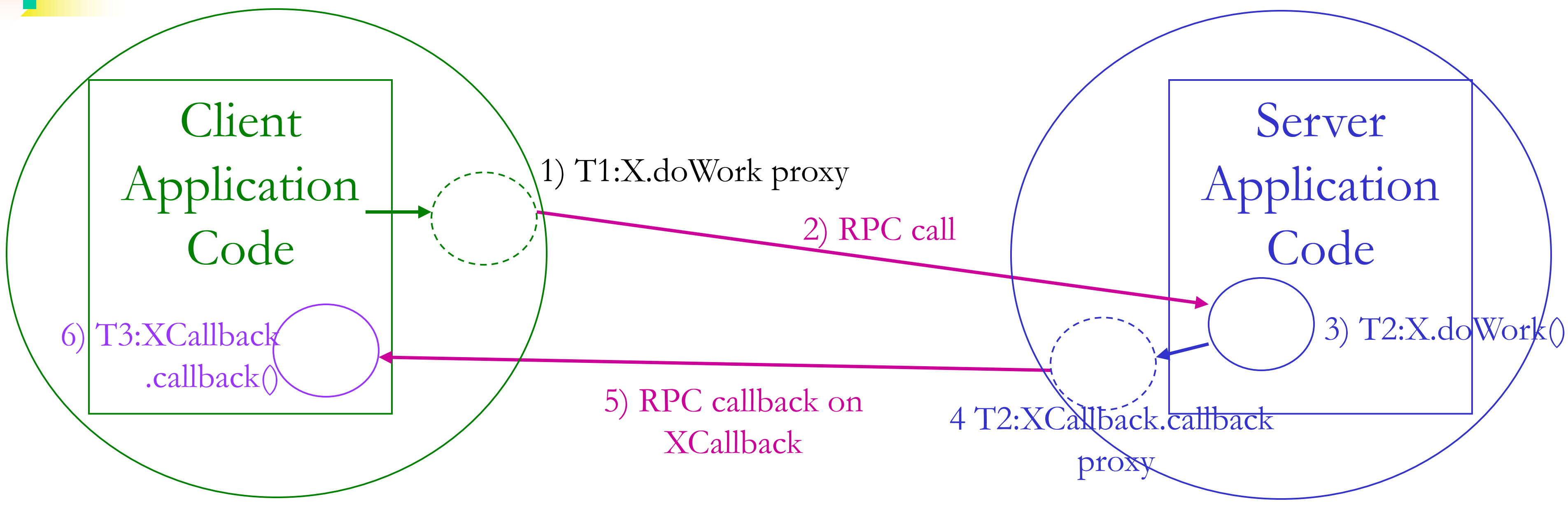

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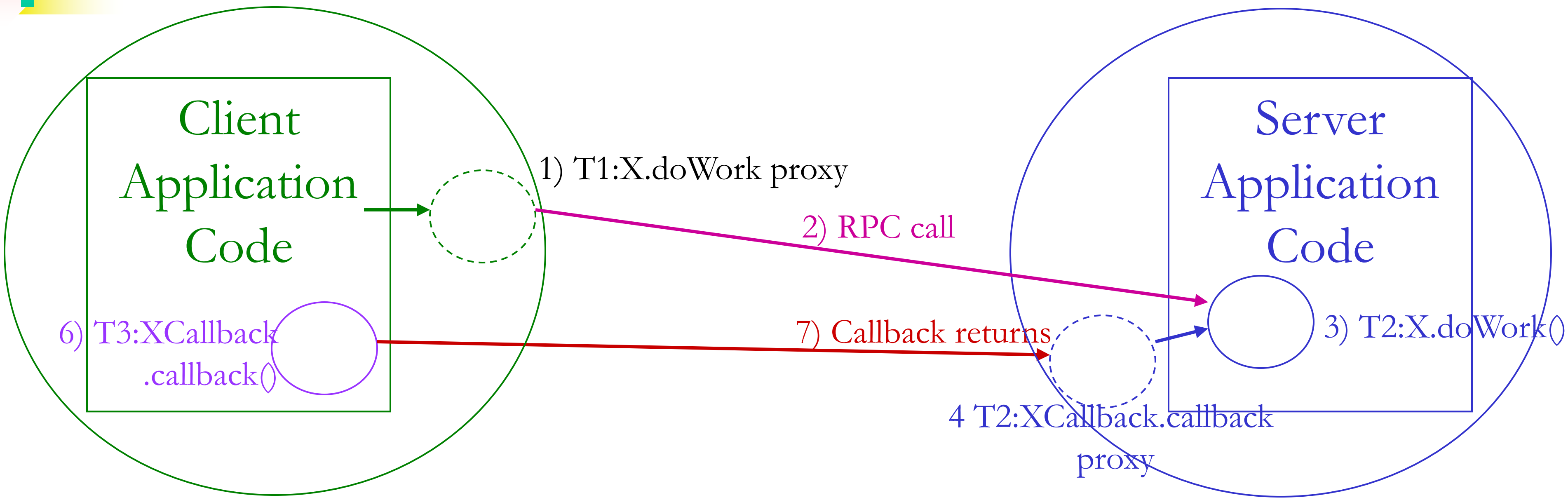
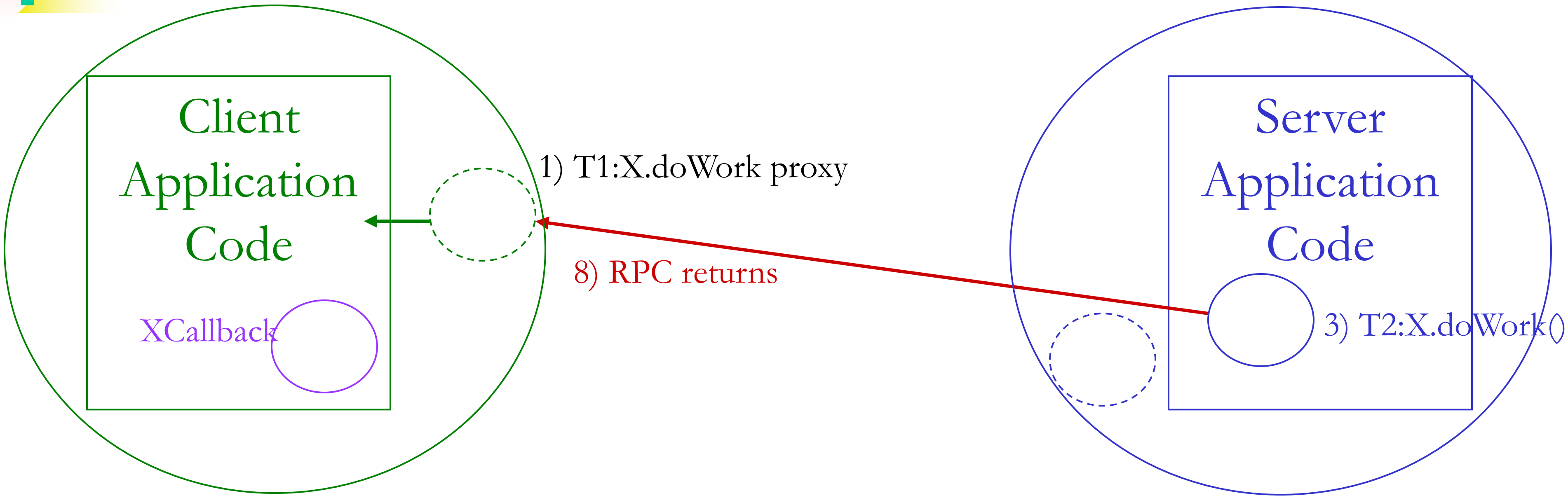


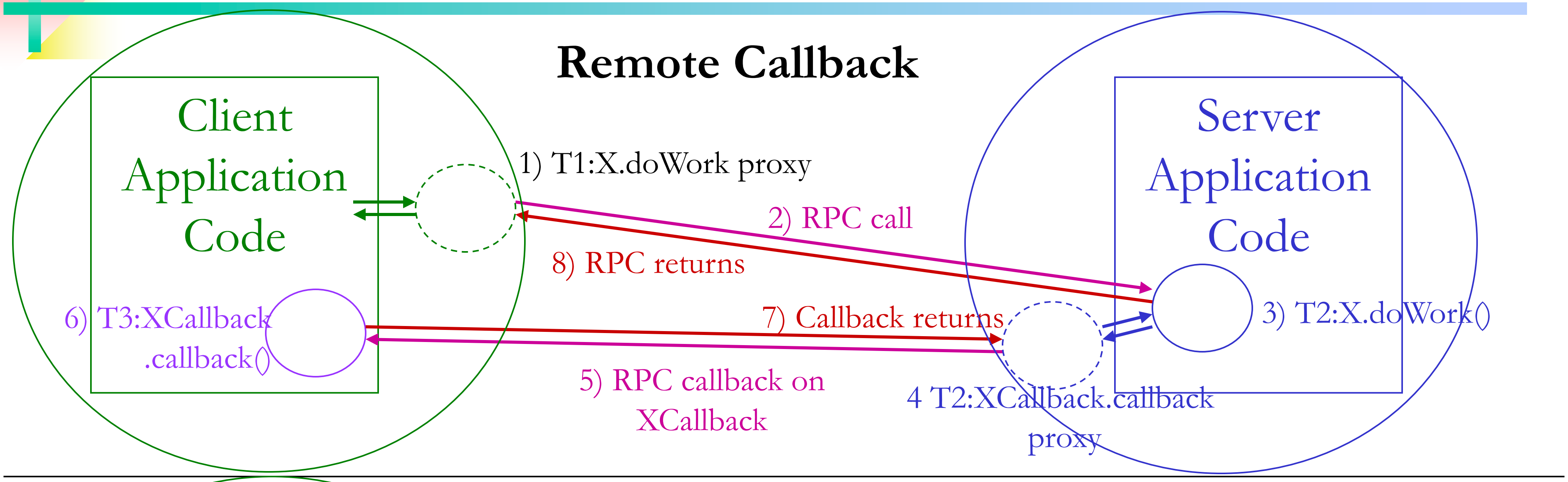
Example Remote Callback

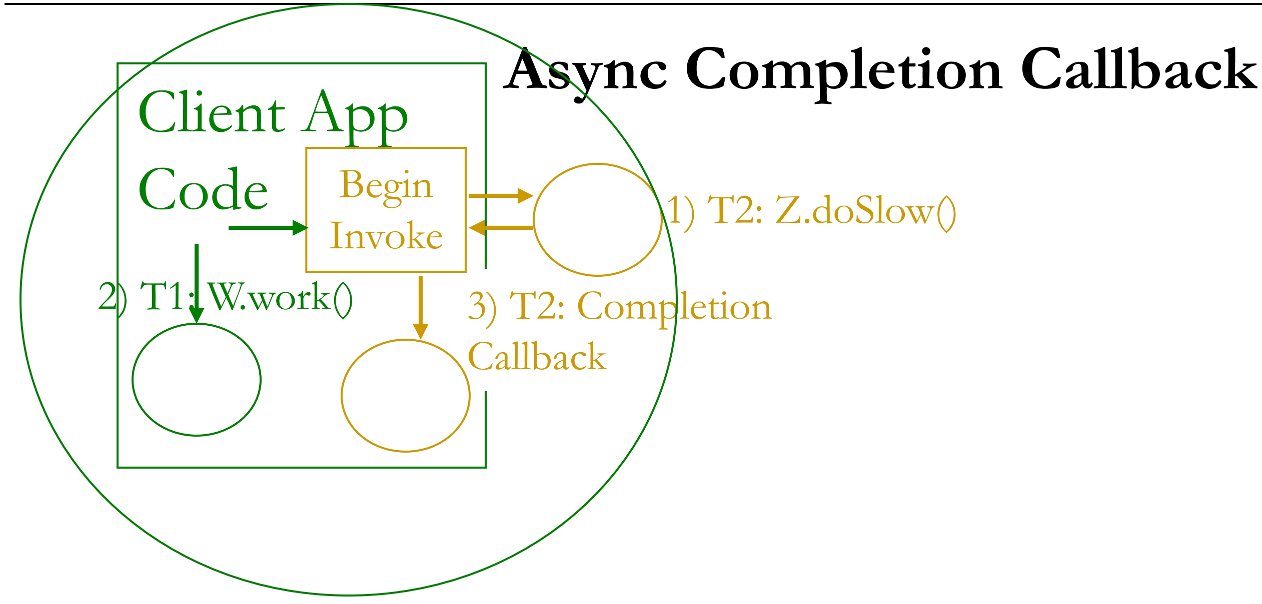


Remote Callback Example

- When X.doWork( ) is called on Duplex channel, the server is aware of the XCallback object
  - On the server, .NET silently creates a proxy to the XCallback object client object so that it can get RPC calls
- The server understands XCallback because it is an extended part of the interface definition of X
- Remote callbacks have nothing to do with async completion callbacks, even if it is a *remote* async call
  - The former is the server calling back to the client
  - The latter is .NET telling you an async call has *finished*

Remote Callback vs Completion Callback

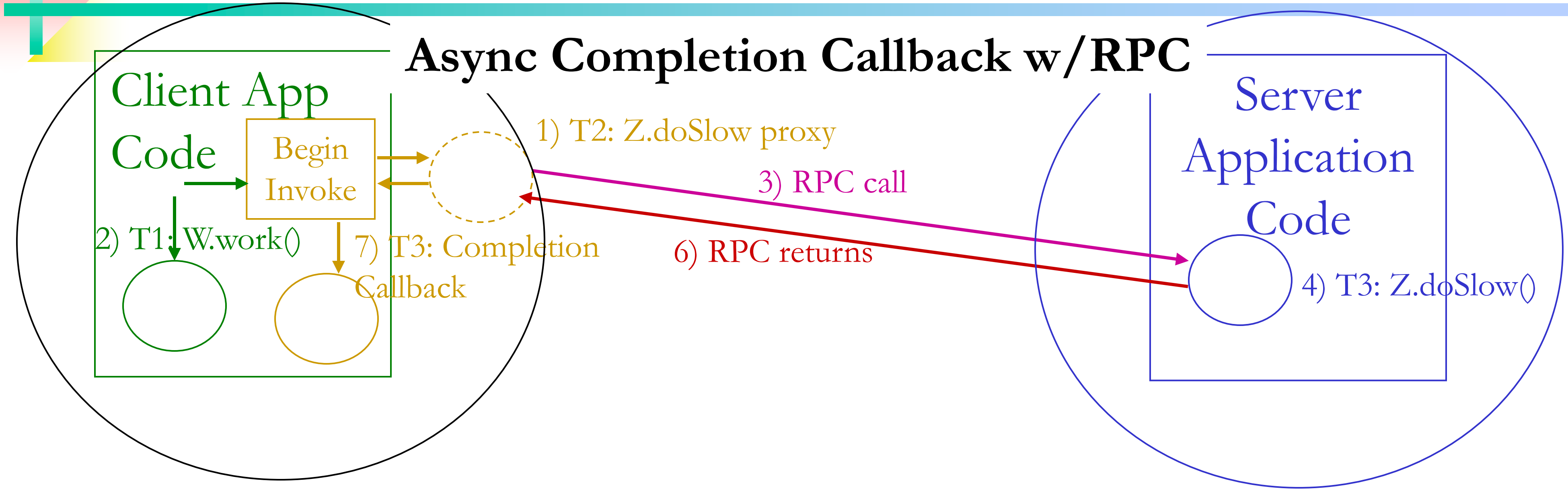


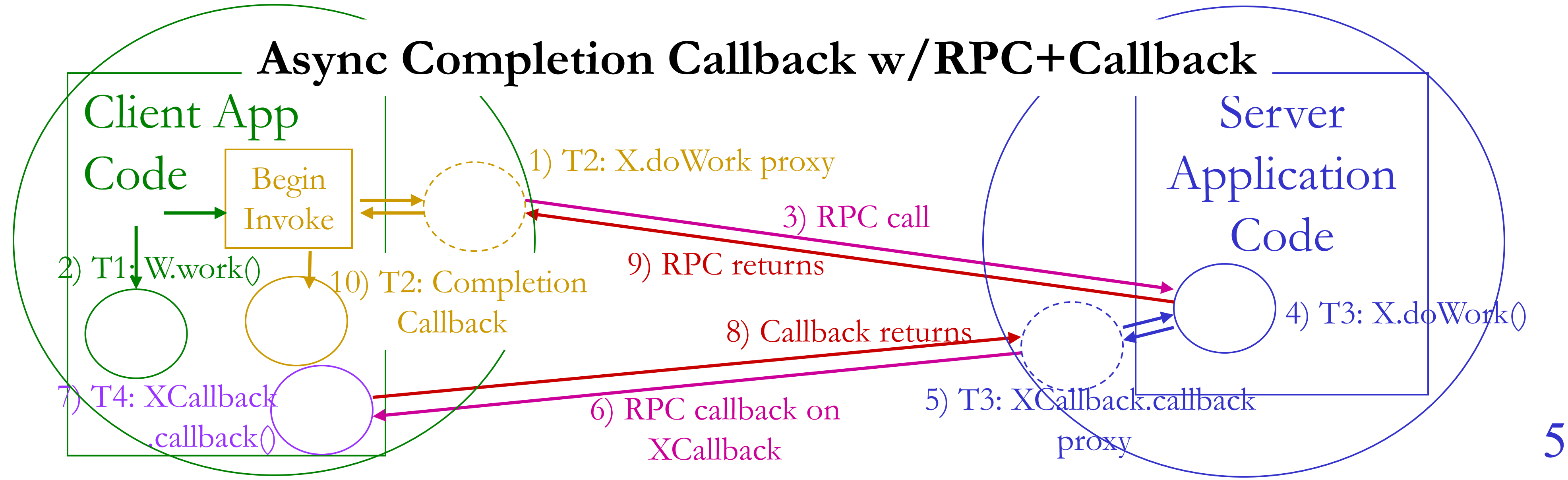


Remote Callback vs Completion Callback

- Note the two types *have nothing to do with each other*
  - The remote callback is about having the server callback to the client during its execution of X.doWork()
  - The completion callback is all about informing whoever called Z.doSlow() that the latter finished. Whether Z is remote or not is irrelevant
- Since the two are independent concepts, they can be used in combination
  - eg 1: Perform the async call to Z.doSlow as an RPC
  - eg 1: Perform the call to X.doWork asynchronously and have it do a callback
  - eg 3: Perform the *callback* asynchronously

Remote Callback vs Completion Callback





Cross-Thread Method Invocation

- Sometimes it's necessary for one thread to ask another thread to call a method
  - In particular, for methods of GUI controls - all updates to GUI controls must be done on the GUI event thread
    - » Ensures that the GUI will never be corrupted
  - .NET WPF uses delegates and the Dispatcher class for this
    - » In particular, by calling Application.Current.Dispatcher.Invoke() passing it a delegate to execute
  - Although it looks like you are invoking a function, you are in fact putting a message onto the GUI event queue
    - » This message will later be dispatched by the queue, thus 'calling' the method

GUI Event Loop

- Every GUI program executes an event loop
  - Most new languages (eg: Java) try to hide it from the coder
- The event loop iterates through a queue of events that need processing (called 'dispatching')
  - Events come from the operating system (eg: mouse click), or can be generated by the programmer
- An event is processed by calling the function(s) that have asked to be notified about a given event
  - eg: your own OnClick code for a Button

GUI Event Loop

- When an event is dispatched, the event handling method is given control *on the GUI event loop thread*
  - No other events can be processed until the method returns
    - » This includes painting the GUI or animating a button click
  - Thus a slow event will make the GUI appear to freeze
    - » Events still get buffered (queued), but not processed
- All updates of any GUI element *must* be processed via the event queue *and* on the event loop thread
  - Otherwise it is far too hard to guarantee thread-safety for the critical job of GUI event dispatching
  - Dispatcher is one way; there are a couple of others…

Dispatcher Invoke Example

```
partial public class wdwCalculatorGUI : Window
{
   // The following assumes there is a status bar called stbStatus on the Window...

   protected delegate void SetStatusDelg(string text);

   void SetStatus(string text) {
      ((StatusBarItem)stbStatus.Items[0]).Content = text;
   }

   [MethodImpl(MethodImplOptions.Synchronized)]      ← Let's say this function will be called from multiple threads
   public void SetMessage(string msg) {
      SetStatusDelg setSts = SetStatus;    ← Delegate for Dispatcher Invoke()

      object[] prms;                                 ← Set up params for SetStatusDelg()
      textParams = new object[1];
      textParams[0] = msg;

      Application.Current.Dispatcher.Invoke(setSts, prms);   ← Invoke SetStatus on GUI event thread
                                                               Blocks until invocation completes
                                                               (use BeginInvoke for async invocation)

   }
}
```

Anonymous Methods and Delegates

- The previous example can be simplified by the use of anonymous methods
  - The problem was that we had to define a separate SetStatus method and create an associated delegate type
  - Anonymous methods are methods which have no name and can be declared at any point *within* another method
    - » This allows you to put the update code close to where it is called
  - Can make the code *much* more compact and readable
- Anonymous methods also facilitate interesting tricks with using variables from outside the anon. method
  - From the concept of closures

Dispatcher w/Anon. Method

```
partial public class wdwCalculatorGUI : Window
{
   // The following assumes there is a status bar called stbStatus on the Window...

   [MethodImpl(MethodImplOptions.Synchronized)]
   public void SetMessage(string msg) {
      Action<string> a = delegate() {
         ((StatusBarItem)stbStatus.Items[0]).Content = msg;
      };

      Application.Current.Dispatcher.Invoke(a);
   }
}
```

← Let’s say this function will be called from multiple threads

← Define an anonymous function that takes no params and has no return val

← Can use outer variable! (‘closures’)

← No params needed: uses closure on msg variable

.NET Built-in Delegate Types

- Here, Action is a .NET built-in delegate type to point at methods with no parameters and no return value
  - ie .NET defines: `delegate void Action();`
- Other standard delegate types include:
  - Action<T>, Action<T1,T2>, Action<T1,T2,T3>
    - » Define void functions that receive one, two or three params whose types are defined by the generics
  - Func<TRes>, Func<T, TRes>, Func<T1,T2,TRes> …
    - » Similar to Action, but with a return value whose type is <TRes>
  - These are only provided for your convenience: you could easily have defined your own, but why not use these?

Closures

- Note that `msg` is made available to the anon method, via the concept of a 'closure' on that variable:
  - A closure is a compiler trick that 'captures' (keeps) variables for use in another method, even though those variables are not local or passed to that method
  - A complex topic with many subtleties in implementation

Lambda Expressions

- A related topic to anonymous methods and closures is the concept of Lambda Expressions
  - From functional programming, where everything is a function that transforms the results of other functions
  - Versus the more familiar imperative programming where data is state to be manipulated by statements
- A Lambda expression could be viewed as a kind of anonymous method
  - C# uses the => operator to define a lambda
    - » Define the parameter vars, then the =>, then the function
  - Data types are all inferred by the compiler (more tricks!)

Dispatcher w/Lambda Expression

```
partial public class wdwCalculatorGUI : Window
{
   // The following assumes there is a status bar called stbStatus on the Window...

   [MethodImpl(MethodImplOptions.Synchronized)]
   public void SetMessage(string msg) {
      Action<string> a = () => {
         ((StatusBarItem)stbStatus.Items[0]).Content = msg;
      };

      Application.Current.Dispatcher.Invoke(a);
   }
}
```

← Let's say this function will be called from multiple threads

← Define a lambda expression that has no parameters (the () =>)

← Can use outer variable! ('closures')

← No params needed: uses closure on msg variable

Lambda Expressions

- A different example where a parameter is passed:
  - `x => { 2.0 * x }`
  - From this, the compiler infers that x is a double and the function returns a double
- Lambdas are probably easiest to understand as a shorthand for defining an anonymous method
  - You can also define a lambda with multiple parameters, and even out or ref parameters
  - However, anything you can do with lambdas can also be done with the **`delegate()`** syntax explored earlier
    - » Or the long delegates-and-separate-methods for that matter!

Updating GUI – Deligate Example

```
private Search search; //reference to method

public MainWindow()
{…
}

private void GoButton_Click(object sender, RoutedEventArgs e)
{…
}

private void SearchButthon_Click(object sender, RoutedEventArgs e)
{
    search = SearchDB;
    AsyncCallback callback;
    callback = this.OnSearchCompletion;
    IAsyncResult result = search.BeginInvoke(SearchBox.Text, callback, null);

}
```

Updating GUI – Deligate Example

```
private Student SearchDB(string value)
{
    string name = null;
    int id = 0;
    string universityName = null;
    foob.GetValuesForSearch(value, out name, out id, out universityName);
    if (id != 0)
    {
        Student aStudent = new Student();
        aStudent.Name= name;
        aStudent.Id= id;
        aStudent.University = universityName;
        return aStudent;
    }
    return null;
}

private void OnSearchCompletion(IAsyncResult asyncResult)
{
    Student iStudent=null;
    Search search=null;
    AsyncResult asyncobj = (AsyncResult)asyncResult;
    if (asyncobj.EndInvokeCalled == false)
    {
        search = (Search)asyncobj.AsyncDelegate;
        iStudent = search.EndInvoke(asyncobj);
        UpdateGui(iStudent);
    }

    asyncobj.AsyncWaitHandle.Close();
```

Updating GUI – Delegate Example

```
private void UpdateGui(Student aStudent)
{
    SiD.Dispatcher.Invoke(new Action(() =>SiD.Text = aStudent.Id.ToString()));
    SName.Dispatcher.Invoke(new Action(() => SName.Text = aStudent.Name));
    SUni.Dispatcher.Invoke(new Action(() => SUni.Text = aStudent.University));

}
```

Updating GUI – Async Example

```
private async void SearchButthon_Click(object sender, RoutedEventArgs e)
{
    searchvalue = SearchBox.Text;
    Task<Student> task = new Task<Student>(SearchDB);
    task.Start();
    statusLabel.Content = "Searching starts.....";
    Student student = await task;
    UpdateGui(student);
    statusLabel.Content = "Searching ends.....";
}
```

```
private void UpdateGui(Student aStudent)
{
    SiD.Text = aStudent.Id.ToString();
    SName.Text = aStudent.Name;
    SUni.Text = aStudent.University;
}
```