Basic Direct3D 9.0 The Managed Way

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Table Of Contents:

Introduction

This tutorial will introduce you to Microsoft's 3D-graphics programming library – Direct3D 9. For quite some time now, Microsoft has been particularly active in developing their gaming/multimedia development tools – DirectX being their flagship software library. Many of you will know that at least 75% of games shipped currently require a version of DirectX to be installed on the system, thus it is an incredibly important system to 1000's of developers and 100's of companies across the planet.

For the last 2 years I've been active in the community – writing tutorials, running my website and generally spending too much time talking on MSN/ICQ/web forums etc… My website is one of the biggest in the community, sporting over 120 tutorials/articles/reviews. In March/April 2002 I was accepted onto the beta-team for the next release of DirectX9 – my job was to test the new programming libraries and provide feedback to the developers at Microsoft and point out any problems, bugs or errors. That was over 6 months ago now – and as I sit down to write this article I am drawing on my experience with this library over the last 3 beta's and 3 release candidates; along with my experience's with versions 5,6,7 and 8. Over the next few pages I hope to give you push in the right direction to using Direct3D9.

This document is aimed at absolute beginners to intermediate games/multimedia programmers. However, it is NOT aimed at beginner programmers – I will take the time to explain a few of the general programming concepts I use, but you do need to be familiar with the .Net / managed languages AND be a confident general programmer.

Those with a solid understanding of Direct3D 7 or 8 can probably jump past the first few pages and get straight to the code – for those of you with little/no experience of the wonderful world that is Direct3D I suggest you start by turning the page…

What are 3D graphics, and where does Direct3D fit in?

3D graphics are the latest major advance in computer-generated imagery. To put it simply, the world we interact with is 3 dimensional all objects have height, width and depth. However, the computer screen is 2 dimensional – it has height and width, but no perceivable depth. 3D graphics, as we're going to look at them, is the process of taking a 3D representation of the world (stored in memory) and presenting it on a computer screen.

Traditional (and the still the majority) of computer graphics are 2D, the text you are reading now, the windows-operating system, the photo's you take on a digital camera and manipulate using Paintshop-Pro or Photoshop – all are 2D. We have been able to – for quite a long time – render 3D images using PC technology. However, they have often taken many, many hours to render the complete image – Ray Tracing, one of the long-standing rendering methods is still an area of research and can still take several minutes (at least) to render a single image of a 3D scene.

Consumer-level hardware has accelerated exponentially in the last 5 years, such that the processing power required for these 3D graphics is now in the hands of 'normal' people – not those with significant research budgets/corporate funding. The Pentium-4 3ghz processors, the GeForce FX's – provide us with more than enough power to render these 3D images at interactive/real-time speeds. This is the area we will be working with.

For all the hardware, and for all the mathematics involved in this level of programming, we still need a low-level set of libraries that allows us to communicate with this hardware. To be honest, it is a little more complicated than I make out – but if you're new to this field I don't want to confuse you too quickly! Microsoft, as we all know, have their primary business in Operating Systems – Windows. However, this OS has never been particularly fast when it comes to the huge processing power required by 3D graphics – there are too many parts of the OS that get in the way. So, Microsoft developed DirectX – more specifically for this case, Direct3D.

Direct3D exists between the hardware (your expensive 3D card) and us (the programmers). We tell Direct3D to do something (draw for example) and it will tell the hardware what we want. The key to it's importance is that Direct3D is a hardware-abstraction-layer (HAL), we use the same code to interface with ATI cards, Matrox cards and Nvidia cards – Direct3D (and the hardware drivers) deal with the finer differences between vendors. Anyone who's been around long enough to remember old-skool DOS programming (luckily I've not!) will know the problems caused by getting a hardware-dependent program running on multiple hardware configurations.

Combine all of these factors together and we have:
1. An abstract way of "talking" to any PC's graphics hardware
2. A very fast way to draw complex 3D images.
3. A way to render interactive, animated, 3D scenes.

Let the fun begin…

Basic 3D Theory

Okay, I lie. The fun doesn't begin yet – we've got 3D theory to cover first. You can't get very far without a reasonable understanding of how 3D graphics are constructed.

It helps, at this point, to be familiar with geometrical maths – planes, vectors, matrices, linear equations etc… However, if you're not too keen on this then you'll survive – but you might wish to dig-out old text books, or even buy a new one (see the references section for some suggestions).

The *real* mathematics behind 3D graphics gets stupidly complicated very quickly. For anyone but the most advanced graphics programmers it really isn't worth getting into it too deeply. Over time you may get more familiar with the core concepts – but for now I'm going to try and explain only the parts you really need to know in order to get started…

The 3D World Space

This is the most important concept to understand. Our 2D screen has width and height: X and Y dimensions. 3D adds depth: the Z dimension. We create a representation in memory of our world using 3D coordinates (3 numbers representing x, y & z), we then let D3D and the graphics hardware apply various algorithms to turn it into a 2D coordinate that can be drawn on the screen.

X,Y and Z – Once you get into D3D properly, these coordinates won't always match up as you might expect – i.e. the 'z' coordinate you give a point won't always translate into *depth* when drawn on the screen. As you move the camera around and translate geometry it could correspond with an up/down movement on the screen.

World space is defined in an un-specified measuring system – it's not directly feet/inches or metes/kilometres. However, it does fit best to a metric system. You can (and CAD/engineering packages will do this) set it up so that 1 world unit equals 1 metric meter, but it does get quite complicated.

Angles are always specified in radians, never degrees. It is very easy to get this muddled up and pass a function a *valid* parameter, but one that doesn't really make any sense when displayed on screen.

Simple Geometry

Everything we render on the screen can be traced back to simple geometry – triangles. All objects and meshes are made up of triangles (modern games use many thousands for a single model). A triangle is made up of 3 vertices and is always convex and planar – 2 very useful properties when it comes to rendering the final image to the screen.

A vertex (plural: vertices) is the simplest, and most primitive piece of geometric data used by 3D graphics. At the simplest level they are just a position [x,y,z] in 3D space. We will extend this later on by including information for lights, textures and colour at that particular position.

For example, a cube has 6 faces (each square). A square face will need to be made from 2 triangles, thus the whole cube will be made from 12 triangles. At best, you can describe this with 8 vertices (one for each corner of the cube), the triangles will be made by (in layman's terms) joining up 3 of these vertices.

Textures

Geometry on it's own can only look so good – regardless of the detail or the complex lighting algorithms you can design. Textures provide the missing element – material, texture, detail, pattern etc…

A texture is a two-dimensional image (stored as a bitmap) that is then pasted (like wallpaper) onto a triangle, or group of triangles. Graphics cards are currently extremely powerful and can output incredibly detailed geometry – but they are still far from powerful enough to display fine details (in geometry alone) that you can represent using textures.

Textures are quite an advanced topic, such that I'll cover them in more detail later.

Transformations

This is the first really tricky piece of 3D theory; I've lost count of how many times people email me with questions regarding this topic. As I've mentioned a couple of times already – the 3D world you represent in memory has to, at some point, be converted into a 2D representation that can be displayed on screen. This process is known as the transformation pipeline. A 3D vertex gets sent to be rendered, it's transformed, and out-pops a 2D representation of the vertex on the screen.

Matrices primarily handle 3D transformations, although Quaternion's have some uses. In Direct3D we'll be manipulating 4x4 world, camera and projection matrices – the mathematics behind this can get quite scary, but luckily we have a series of helper-functions to make things much simpler for us.

World Transforms

Take an example where we want to render 5 cubes, all in different places, on the screen in the same frame. How do we do this? We can create 5 cubes – specifying the correct coordinates for all 40 vertices, then telling D3D to render them all. This does work. However, if all 5 cubes are identical we will be storing 5 copies of the same thing – for a cube, this doesn't matter much, but what if we had a mesh with 50,000 vertices?

The common solution, is to store one copy of the model created around the origin (the coordinate [0,0,0]). This is our master copy. We can then use a world transform to move the geometry around. We can then render the same model 5,10,100,1000 times each frame without having to store the same number of copies in memory. It is therefore very useful to remember this when creating your own geometry/models for your applications. A quick bit of terminology: when you create your geometry around a local origin it is considered to be in *model space*, the world transform effectively transforms geometry from *model* to *world* space.

The world transform can handle any type of object-transformation that you can represent with a 4x4 matrix; however, for the immediate future you'll only come across rotation, scaling and translation.

Camera Transforms

Once you've positioned all of your geometry in the world, we need a way to determine what is on the screen – what we will eventually see. A camera handles this. Think of it as a movie set… the world transform is the method used to position all the props, actors etc… and the camera transform determines where the camera will be positioned in order to record/watch the film.

The camera is probably the simplest of the matrix-transforms to get your head around, I'll discuss it in more detail a bit later on.

Projection Transforms

By this point we have all of our objects, actors and scenery positioned in the world, and we know where the camera is and what it's looking at. Unfortunately this isn't everything that we need to know in order to render our final image.

This final part of the transformation-pipeline deals with *how* the camera sees what we're pointing it at. It's only so good to say "stand here, and look over there" – we need to tell it information about the aspect ratio, the view-distance, the frustum size. It is possible, using this matrix to specify a wide-angle lens (to get panoramic views) or a narrow-angle lens (to get zoomed in, very localised views).

Meshes and Models

These aren't strictly a part of 3D-theory; however, you do need to know what they are and why you'll want to use them. The terms mesh and model are often used interchangeably; technically a mesh refers to the geometry (vertices, indices, triangles etc…) and a model refers to the mesh *and* any textures, materials or other properties necessary.

A mesh is a structured group of triangles/geometry that make up a more complex object. Meshes are rarely created inside your program (simple objects like cubes, spheres etc… often are), instead artists will use powerful 3D modelling software to create a mesh and export it to a file – so that your program can load it at a later date. 3DS Max, trueSpace, lightwave and Maya are all popular 3D modelling tools.

A human character is a good example of a structured mesh – each part can be made up from various deformed/sculpted primitives (each one a part of the hierarchy/structure), and when put together they create a very complex object. All of the cubes/spheres etc… have relatively simple mathematics behind them – but the end result would either be impossible for a mathematical equation to represent or very, very complicated.

The Managed-code interfaces for Direct3D9

There are two ways to communicate with Direct3D 9 from high-level languages: native API calls (C++) or managed-code interfaces (all the .Net languages). This tutorial (and others I write) will be based on the latter.

Managed code has plenty of advantages and weaknesses – I could fill pages with arguments and counter-arguments. Before I get a 100 emails complaining – the code / methods I present in this tutorial are **one** way of writing D3D9 applications – it's not necessarily the best (and it's not the worst).

Managed-Code is Microsoft's latest step forward in programming language development, I don't have the time to explain it fully – but it basically uses a Common Language Runtime (CLR) with a JIT (Just In Time) compiler to generate potentially cross-platform and cross-OS compatible code. It is considerably higher level than C/C++ like languages – the CLR implements very efficient memory allocation and garbage collection such that you don't have to worry so much about the finer points of memory management and class/object lifetimes.

As a quick side-note, if/when the .Net framework appears on linux/Mac it will in theory mean that all pure managed-code applications will run on those respective operating systems. This WILL NOT be the case for DirectX based applications. DirectX is very system-dependent and is very tightly integrated into the Windows operating system, such that it would not be easy for Microsoft to 'port' it over to linux/mac based systems.

How to set up your computer to program with D3D9

The first technical step that we're going to take is getting your computer set up to allow you to write DirectX 9 (and more particularly Direct3D 9) applications. The first few steps are generic for getting DX9 apps working, the latter steps are required for D3D9 only.

1. Programming Tools

If you want a nice IDE for programming, then you'll need Microsoft's latest Visual Studio .Net 2002 programming tools. This is a fairly pricey piece of software, so it's not necessary to buy the whole lot – you can get away with only buying the tools for the language you want to use: C# or VB for example.

It is possible to download and use the .NET CLR compilers for free from Microsoft – but you'll have to get familiar with using it at a command-line, which can be tricky. If you do this, make sure that you've downloaded and installed the latest .Net framework on your system (VStudio .Net will do this for you).

2. The DirectX9 SDK

Microsoft ships two versions of DirectX9: the end-user package and the Software Development Kit (SDK). You'll need to download this from Microsoft.com – it'll probably be in the region of 200-250mb. Once you've downloaded this, install it – but make sure you have the .Net frameworks installed first. If you don't have the .Net frameworks installed then the DX9 installer WONT install the managed-code components, and you'll only be able to develop C/C++ applications.

3. Drivers and Hardware

This part is where it can get complicated. For Direct3D9 you'll need graphics hardware that is AT LEAST DDI-7 compatible. To normal people this means a Direct3D7 of higher graphics card. You can get away with some older graphics cards IF they have newer drivers. In all cases, your best bet will be to download the absolute latest drivers from your hardware vendor and hope it works. If no newer drivers exist, allow the manufacturer a few weeks/months to get up to speed – it can take them a while to release new drivers for hardware.

By the very nature of D3D9, you'll need the highest-level graphics cards in order to use all the features it exposes. At the time of writing, even the Radeon 9700's and GeForceFX's don't support a full D3D9 feature set. I'll make a guess that mid-2003 will see the first cards that support every major feature of DX9. Having said this, A GeForce (nVIDIA), or Radeon (ATI) graphics card will be more than sufficient for the code presented in this tutorial.

Setting up an end-user's computer to run a D3D9 app

This isn't as complicated as setting up your own computer, but it still creates more than enough *interesting* challenges.

I won't go into too much detail on this subject, instead, there are a couple of points that I need to make – and you can work out the rest!

Firstly, the end user's system MUST have the .Net framework installed – otherwise your program won't work at all. There is a freely distributable package for the .Net framework you can include on set up disks or as parts of downloads if necessary.

Secondly, the end user's system MUST have DirectX 9.0 runtimes installed (they do not require the SDK). Based on point #2 in the previous section, the .Net framework must be installed BEFORE DirectX is.

These two points may seem blindingly obvious – but you'd be surprised how many people forget this and then get into no-end of trouble when it comes to distributing their application to 100's of different computers.

Introduction To The Source Code

I've now finished the pre-code waffle; hopefully it was useful. At the end of this section I'll start with the source code, and relevant explanations.

I strongly suggest you download the accompanying source code for this tutorial – and take 10 minutes to get familiar with it. I shall in-line piece of code in the tutorial text, but it is best to have the source code available at the same time as reading. I've had to format the source code that it fits an A4 page layout; as such it might look a little odd. Some trivial things like error messages have been shortened to "…" – the full version can be found in the actual source files.

The basic premise for this tutorial is to create a demo with two 3D cubes rotating on screen, and a simple 2D read-out of text and frame rate.

The pace is about to pick up – we have a huge amount of code, and huge amount of explanation to cover…

The basic framework for a D3D9 application

Designing a powerful 3D engine for your application can be a very complicated task – the engines that power the most advanced games in available today (Unreal-2, Doom-3 to name two) took many developers many months to design, implement and complete. The engine we'll be working through should take no more than an hour to complete.

For good OO design, I'm going to be wrapping up all D3D9 code in a single class `CSampleGraphicsEngine`, this way we *could* put the class in an external library and link it to any number of other applications. I've also left it to be fairly open-ended, such that you can extend it for your own experimentation.

As a side note, the samples in the SDK use a very elaborate class hierarchy that you're free to use. For quick examples/samples and prototyping they are very useful, but I don't rate them too highly for learning D3D9 basics. For this reason, I've developed (and will show you) my own greatly simplified system.

```
CSampleGraphicsEngine
--- PUBLIC
------ New()
------ Finalize()
------ isDisplayModeOkay()
------ oneFrameRender()
------ oneFrameUpdate()
--- PRIVATE
------ initialiseDevice()
------ loadTextures()
------ loadGeometry()
--- PROPERTIES
------ wireframe()
------ useTextures()
------ backFaceCulling()
------ drawFrameRate()
```

I'll be using a standard windows form to interact with this class – to provide D3D with a place to draw, and a way for the user to provide input.

On the following three pages is the completed outline for the `CSampleGraphicsEngine` class:

```
'[----------------------------------------------------------]
'
'   NAME: CSampleGraphicsEngine
'   AUTHOR: Jack Hoxley
'   CONTACT: mailto:Jack.Hoxley@DirectX4VB.com
'            http://www.DirectX4VB.com
'
'   DATE: 16th December 2002 (started)
'         21st December 2002 (finished)
'
'   NOTES:
'       This is a relatively simple graphics library designed
'       for learning from - it'll work fine for small-medium
'       projects, but it's far from a complete solution.
'
'       You're free to use/disect this class for your own
'       projects, although a little credit for the original
'       work wouldn't hurt!
'
'[----------------------------------------------------------]

Public Class CSampleGraphicsEngine

    '[----------------------------------------------------------]
    '   CONSTRUCTOR #1
    '   Creates a windowed application based on the current
    '   display properties and that of the Target specified
    '[----------------------------------------------------------]
    Public Sub New(ByVal Target As System.Windows.Forms.Control)

    End Sub

    '[----------------------------------------------------------]
    '   CONSTRUCTOR #2
    '   Creates a fullscreen application based on the display properties
    '   specified. Throws an exception if the parameters are not valid.
    '[----------------------------------------------------------]
    Public Sub New(ByVal Target As System.Windows.Forms.Control, _
                   ByVal iWidth As Integer, _
                   ByVal iHeight As Integer, _
                   ByVal iDepth As Integer _
                   )

    End Sub

    '[----------------------------------------------------------]
    '   DESTRUCTOR #1
    '   Makes sure that all objects that were used are terminated if
    '   necessary.
    '[----------------------------------------------------------]
    Protected Overrides Sub Finalize()

    End Sub

    '[----------------------------------------------------------]
    '   isDisplayModeOkay()
    '   Checks the specified display mode parameters against
    '   the hardware to see if the requested mode is acceptable
    '[----------------------------------------------------------]
    Public Shared Function isDisplayModeOkay(ByVal iWidth As Integer, _
                                             ByVal iHeight As Integer, _
                                             ByVal iDepth As Integer _
                                             ) As Boolean

    End Function
```

```
'[------------------------------------------------------------]
'   oneFrameUpdate()
'   this updates all the math, physics and any other
'   per-frame calculations necessary.
'[------------------------------------------------------------]
Public Sub oneFrameUpdate()

End Sub

'[------------------------------------------------------------]
'   oneFrameRender()
'   this handles rendering all of the graphics. it
'   shouldn't have to deal with updating any variables
'   or objects.
'[------------------------------------------------------------]
Public Sub oneFrameRender()

End Sub

'[------------------------------------------------------------]
'   initialiseDevice()
'   once the constructor has filled out the PresentParameters
'   we can use this method to finish off all device
'   initialisation
'[------------------------------------------------------------]
Private Sub initialiseDevice(ByVal Target As System.Windows.Forms.Control, _
                             ByVal win As PresentParameters)

End Sub

'[------------------------------------------------------------]
'   loadTextures()
'   this loads all the required textures from disk
'   into memory
'[------------------------------------------------------------]
Private Sub loadTextures()

End Sub

'[------------------------------------------------------------]
'   loadGeometry()
'   this will create and/or load any geometry that we're
'   going to be using throughout the application.
'[------------------------------------------------------------]
Private Sub loadGeometry()

End Sub

'[------------------------------------------------------------]
'   wireframe()
'   allows the host to specify if we want
'   to render in wireframe or not.
'[------------------------------------------------------------]
Public Property wireframe() As Boolean
    Get

    End Get
    Set(ByVal Value As Boolean)

    End Set
End Property

'[------------------------------------------------------------]
'   useTextures()
'   allows the host to tell the engine
'   to render with/without textures applied
'   to the surfaces.
'[------------------------------------------------------------]
Public Property useTextures() As Boolean
    Get

    End Get
    Set(ByVal Value As Boolean)

    End Set
End Property
```

```
    '[-------------------------------------------------------------]
    '   backFaceCulling()
    '   turns back face culling on or off.
    '[-------------------------------------------------------------]
    Public Property backFaceCulling() As Boolean
        Get

        End Get
        Set(ByVal Value As Boolean)

        End Set
    End Property


    '[-------------------------------------------------------------]
    '   drawFrameRate()
    '   do we draw the frame rate on the screen?
    '[-------------------------------------------------------------]
    Public Property drawFrameRate() As Boolean
        Get

        End Get
        Set(ByVal Value As Boolean)

        End Set
    End Property

End Class
```

I've left out all of the actual code that makes up this class so that you can see what the actual outline for the class is. Over the next few sections I'll discuss the finer points of each piece of code.

Imports and Global Declarations

Before you can begin typing DirectX-related code, you'll need to add references to the relevant libraries. This is the same for all languages, managed or unmanaged. In Visual Studio .Net you need to click 'Project' > 'Add Reference'. Give it a few seconds to load the information and you'll see a window that lists all of the possible references (by default under the .Net tab).

Select:
`Microsoft.DirectX`
`Microsoft.DirectX.Direct3D`
`Microsoft.DirectX.Direct3DX`

They should appear in the second list box, once done, click okay.

You have to have these libraries selected, or the compiler (and of a lesser importance, intellisense) won't know what to do with the DirectX calls you include in your source code. It is these libraries (and the other Microsoft.DirectX.*** ones) that are installed when you install the DirectX 9 runtimes, and they're also the files that *could* be missing if the end-user hasn't setup his/her computer properly.

The final part to do, to finish all the links between your application and the DirectX libraries is import them into the relevant source files. For every class, form or module you use DirectX functions in, you must include the relevant libraries at the top of the file:

```
Imports Microsoft.DirectX
Imports Microsoft.DirectX.Direct3D

Imports System.Math
```

I've added System.Math in there – 3D graphics make regular use of the math library, so it's easiest to just (by default) include it in any graphics modules.

The next step is to complete the private variables used by the graphics engine. The most important ones are, obviously, the D3D related variables; but there are also quite a few supporting variables to maintain the engine.

```
'core objects
Private D3DRoot As Manager
Private D3DDev As Device
Private D3DHelp As D3DX

'transformation matrices
Private matCube1 As Matrix
Private matCube2 As Matrix
Private matView As Matrix
Private matProj As Matrix

'textures
Private texCube1 As Texture
Private texCube2 As Texture
Private texMenu As Texture

'geometry
Private vbCube As VertexBuffer
Private vbMenu As VertexBuffer

'fonts
Private fntOut As Font
```

The first three (`D3DRoot`, `D3DDev` and `D3DHelp`) are the most important. `D3DRoot` represents Direct3D – which in turn represents everything that we can do with

the library. It manages the devices and exposes the various methods by which we can "get" a device. The `D3DDev` object represents a device.

So what's a `Device`? The device object represents the actual hardware that we use – your GeForce4, your Radeon8500 or whatever it is you're using. If we tell a Device object to do something, we will effectively be communicating with the hardware itself (or as near as it ever gets).

`D3DHelp` represents the D3DX helper library – a set of utility functions that's accompanied every release of DirectX for quite some time now. It is possible to work with D3D without using D3DX, but it makes it needlessly complicated – given that it comes for free, it makes sense to use it wherever possible.

The remaining variables will be examined in further detail later on in this tutorial – it doesn't take much to make a pretty good guess as to what they are!

```
'per-frame variables
Private lastFrameUpdate As Int32
Private cube1Angle As Single
Private cube2Angle As Single
Private Const cube1Speed As Single = 50.0F
Private Const cube2Speed As Single = 75.0F
Private Const cube1Size As Single = 2.0F
Private Const cube2Size As Single = 4.0F

'misc variables
Private bInitOkay As Boolean = False
Private iLastFPSCheck As Int32
Private Const iFPSProfileSpeed As Integer = 200
Private iCurrCnt As Integer
Private iFrameRate As Integer
Private sDevInfo As String
Private sDispInfo As String

'control variables:
Private bRenderWireframe As Boolean = False
Private bRenderTextures As Boolean = True
Private bBackFaceCulling As Boolean = True
Private bDrawFPS As Boolean = True
Private bShowFrameRate As Boolean = True

'reference variables:
Private rTarget As System.Windows.Forms.Form
Private bWindowed As Boolean
Private iFontSize As Integer
```

This last batch of global variables is nothing particularly special – they just handle various persistent variables that the engine needs. The first group are the only ones that you need to pay particular attention to; these dictate from a programming level how the demo will actually behave when running.

Initialising Direct3D9

Now we're onto the first complicated piece of Direct3D programming. We're also going to be using the class constructors in an interesting way. First, a bit of theory:

Firstly; there are two ways to create a device in Direct3D – *windowed* mode or *fullscreen* mode. The names are straight-forward enough, windowed mode will render to a window-like area and fullscreen mode renders to the entire screen.

Windowed mode is for use when you want to use other windows controls, or want to be able to see other parts of windows in the background. A good example of windowed rendering is that of graphics packages – where you have the workspace and then toolbars and controls visible around it.

Fullscreen mode is best for games – you control the entire graphics output of the computer, such that you can't see any other programs "behind" yours. Because you're taking over so much of the graphics subsystem you'll get a considerable speed increase. It also makes for a far more immersive environment when used in the context of gaming.

Secondly; we have to give thought to what 'size' we create our Render Target – for windowed mode it doesn't matter too much as long as it isn't bigger than the current screen (not a technical limitation, but it makes little point rendering where you'll never see it). For fullscreen it matter a great deal. You should be familiar with the fact that you can change the resolution of the screen you're looking at now – using the display properties in control panel. The options that appear here vary according to the hardware attached to the system.

Because it varies, we need a way to check if the requested display mode is valid for the current system. This branches into an area of DirectX that many people ignore – Enumeration. Because Direct3D is an abstract API (discussed earlier), it is necessary to query the drivers about the capabilities of the hardware attached – this process is called enumeration.

The following code fits into the class outline defined earlier, and will return true/false depending on whether the current adapter supports a particular display mode:

```
'[------------------------------------------------------------]
'   isDisplayModeOkay()
'   Checks the specified display mode parameters against
'   the hardware to see if the requested mode is acceptable
'[------------------------------------------------------------]
Public Shared Function isDisplayModeOkay(ByVal iWidth As Integer, _
                                         ByVal iHeight As Integer, _
                                         ByVal iDepth As Integer _
                                         ) As Boolean
    Try
        'this covers the most commonly used display modes
        'only. others exist and are used for more specific cases
        Dim AdapterInfo As AdapterInformation
        Dim DispMode As DisplayMode
        Dim fmt As Format
        Dim D3Dr As Manager

        Select Case iDepth
            Case 16
                fmt = Format.R5G6B5
            Case 32
                fmt = Format.X8R8G8B8
        End Select

        For Each AdapterInfo In D3Dr.Adapters
            For Each DispMode In AdapterInfo.SupportedDisplayModes(fmt)
                If DispMode.Width = iWidth Then
                    If DispMode.Height = iHeight Then
                        Return True
                    End If
                End If
            Next
        Next

        Throw New Exception("No compatable resolution was found")

        'errors are caught silently, no real need
        'to inform the user as to whether the resolution
        'is supported or not. The caller can do that.
    Catch DXErr As DirectXException
        Return False
    Catch Err As Exception
        Return False
    End Try
End Function
```

As long as the DirectX libraries are included in the project and then imported at the top of this source file this function is a completely self-sufficient function and doesn't rely on any other part of the library.

Back to the original plot… if we use this function we can work out what display modes the host computer supports. Size is only one aspect – depth is another issue. Direct3D9 introduces many new formats for colour information in a render-target, most notably the inclusion of floating-point numbers (expect this to be quite a big thing in the near future) and 64/128 bit formats.

For the purposes of learning Direct3D, you'll want to decide between either 16bits or 32bits of colour information per pixel. This means that for every pixel on the screen the hardware will allocate 16 or 32 bits of memory to storing the colour at that location. Colour is stored either with either 3 or 4 channels: always Red, Green and Blue with an optional Alpha component.

There are only 2 formats that you need to concern yourself with at the moment:

R5G5B5 – 16 bit RGB
RRRRRGGGGGGBBBBB

X8R8G8B8 – 32 bit RGB
XXXXXXXXRRRRRRRRGGGGGGGGBBBBBBBB (the X's indicate unused memory)

As a quick bit of math – a 1024x768 display with 32bits per pixel will require 1024x768x32 bits of memory = 3.0mb

The basic trade off is this: higher bit depths give a better image but take up more memory, lower bit depths don't look so good but take up less memory.

Now that we can decide what resolution and depth, and screen type (full or windowed), we need some code that actually does the job.

I've designed the class to have two overloaded constructors – one where you specify a target and NO display mode information, the other where you specify a target and display mode information. My logic being that if you specify no information you want a windowed-mode renderer, and if you specify information about the screen size you'll want a fullscreen renderer.

First up – the windowed mode constructor:

```
Public Sub New(ByVal Target As System.Windows.Forms.Form)
    Try
        Dim d3dPP As New PresentParameters()

        d3dPP.Windowed = True : bWindowed = True
        d3dPP.SwapEffect = SwapEffect.Discard
        d3dPP.BackBufferCount = 1
        d3dPP.BackBufferFormat = D3DRoot.Adapters(0).CurrentDisplayMode.Format
        d3dPP.BackBufferWidth = Target.ClientSize.Width()
        d3dPP.BackBufferHeight = Target.ClientSize.Height()

        sDispInfo = "[WINDOWED] " + _
                    Target.ClientSize.Width.ToString + "x" + _
                    Target.ClientSize.Height.ToString + " " + _
                    d3dPP.BackBufferFormat.ToString()

        rTarget = Target

        initialiseDevice(CType(Target, System.Windows.Forms.Control), d3dPP)
    Catch err As Exception
        bInitOkay = False
        Throw New Exception("Could not initialise graphics engine.")
    End Try
End Sub
```

As we'll see a bit later on (in the initialiseDevice() function), we have to pass Direct3D a structure describing the render target, that is, we pass a `PresentParameters` structure.

At this point in time we only need to pay attention to the BackBuffer related parameters. I've already discussed the render target – in previous versions of DirectX this was called the front buffer. In order to avoid flickering and to stop the user seeing objects actually being drawn it is necessary to render the current frame to a hidden render-target and then let the user see the final product. As a simple analogy, it would be like an artist hiding their canvas while painting and only revealing it when they were completely finished.

When hidden, the backbuffer is used. You won't need to "mess" with this for most of your work with Direct3D. The basic idea is that you create it using the same format and dimensions as you would the real render-target.

Now onto full-screen mode:

```
Public Sub New(ByVal Target As System.Windows.Forms.Form, _
                  ByVal iWidth As Integer, _
                  ByVal iHeight As Integer, _
                  ByVal iDepth As Integer _
                  )
    Try
        Dim d3dPP As New PresentParameters()
        If Not isDisplayModeOkay(iWidth, iHeight, iDepth) Then
            Throw New Exception("…")
        End If
        bWindowed = False
        d3dPP.BackBufferWidth = iWidth
        d3dPP.BackBufferHeight = iHeight
        d3dPP.BackBufferCount = 1
        d3dPP.SwapEffect = SwapEffect.Copy
        d3dPP.PresentationInterval = PresentInterval.Immediate
        Select Case iDepth
            Case 16
                d3dPP.BackBufferFormat = Format.R5G6B5
            Case 32
                d3dPP.BackBufferFormat = Format.X8R8G8B8
            Case Else
                Throw New Exception("…")
        End Select

        rTarget = Target

        initialiseDevice(CType(Target, System.Windows.Forms.Control), d3dPP)
    Catch err As Exception
        bInitOkay = False
        Throw New Exception("Could not initialise graphics engine")
    End Try
End Sub
```

There are only two major differences between this and windowed-mode initialization. Firstly, instead of using the Target's height/width we first verify the parameters and if they're valid we use those. Secondly, I've set the `PresentationInterval` member of d3dPP. D3D has parameters indicating when it will actually display the image onto the screen, this parameter forces D3D to show it on screen as soon as we've finished rendering it. Alternatives are to wait until a VSync occurs.

Once either of the constructors has been called we continue execution with the initialiseDevice() function. I designed the class this way, because regardless of windowed or fullscreen configuration only the first part changes – the latter part always remains the same.

```
Private Sub initialiseDevice(ByVal Target As System.Windows.Forms.Control, _
                             ByVal win As PresentParameters)
    Try
        '0. declare useful variables:
        Dim D3DCaps As Caps
        Dim DevCreate As Integer

        '1. check for, and specify, depth buffer
        If D3DRoot.CheckDepthStencilMatch(0, DeviceType.Hardware, _
                                          win.BackBufferFormat, _
                                          win.BackBufferFormat, _
                                          DepthFormat.D16) Then
            'support exists.
            win.AutoDepthStencilFormat = DepthFormat.D16
            win.EnableAutoDepthStencil = True
        Else
            'support does not exist!
            Throw New Exception("…")
        End If

        '2. examine the device capabilities
        D3DCaps = D3DRoot.GetDeviceCaps(0, DeviceType.Hardware)

        'allow this engine to take advantage of hw tnl where available
        If D3DCaps.DeviceCaps.SupportsHardwareTransformAndLight Then
            DevCreate = CreateFlags.HardwareVertexProcessing Or _
                        CreateFlags.MultiThreaded
        Else
            DevCreate = CreateFlags.SoftwareVertexProcessing Or _
                        CreateFlags.MultiThreaded
        End If

        '3. attempt to create the device interface.
        D3DDev = New Device(0, DeviceType.Hardware, Target, DevCreate, win)
        If D3DDev Is Nothing Then Throw New Exception("…")


        '4. Configure render states and other parameters
        'we need to tell D3D we want it to use the depth buffer
        D3DDev.RenderState.ZBufferEnable = True

        'we don't want to use lighting in this sample
        D3DDev.RenderState.Lighting = False

        'allow texture transparencies
        D3DDev.RenderState.SourceBlend = Blend.SourceAlpha
        D3DDev.RenderState.DestinationBlend = Blend.InvSourceAlpha

        'set up texture blending
        D3DDev.SamplerState(0).MinFilter = TextureFilter.Linear
        D3DDev.SamplerState(0).MagFilter = TextureFilter.Linear

        '5. load textures.
        loadTextures(win.BackBufferFormat)

        '6. create the necessary geometry.
        loadGeometry()

        '7. Setup the matrices.
        'view matrix: describes the properties of the camera.
        D3DDev.Transform.View = Matrix.LookAtLH(New Vector3(0, 0, -15), _
                                                New Vector3(0, 0, 0), _
                                                New Vector3(0, 1, 0))

        'projection matrix: describes the properties of the cameras lens.
        D3DDev.Transform.Projection = Matrix.PerspectiveFovLH(Math.PI / 4, _
                                                              4 / 3, _
                                                              1, _
                                                              100)

        'world matrix: how all the geometry is altered in world space.
        D3DDev.Transform.World = Matrix.Identity()

        '8. sort out fonts for on-screen rendering
        iFontSize = 11
        fntOut = New Font(D3DDev, _
                 New Drawing.Font("Arial", iFontSize, FontStyle.Bold))
```

```
        '9. Condigure any misc. or general variables

        'if we dont do this then the initial angle calculations
        'go pear shaped.
        lastFrameUpdate = Environment.TickCount()

        'store the name of the graphics card as the driver reports it
        sDevInfo = D3DRoot.Adapters(0).Information.Description

        'if we've got this far then we can assume it was a successful
        'initialisation.
        bInitOkay = True

    Catch err As Exception
        bInitOkay = False
        Throw New Exception("Could not initialise graphics engine.")
    End Try
End Sub
```

Initialisation of Direct3D generally follows the same trends every time:

1. determine display mode / format
2. configure depth buffer
3. enumerate any additional options
4. actually create the device, and retrieve a valid reference
5. configure render states
6. configure initial transformation matrices

Other pieces of code (of which there are a few in the above listing) often fit quite well "mixed" in. Loading of geometry and textures, for example, is often a distinctly separate part of initialisation – for a real world application it is often a much lengthier process than that of a tutorial.

A few new terms have just appeared – fear not! I shall explain:

Firstly, a depth buffer is an extremely useful piece of "silent" technology built into all commercial graphics cards. The final render target, as mentioned, is a 2D image – it has no third dimension. What appears on screen is therefore draw-order dependent; if you render an object it will be placed on the render target, if you render another object it will also be placed on the render target – but if it overlaps any existing part of the image it will overwrite it. This doesn't make our job very easy at all – you'd have to explicitly make sure you rendered everything from the back (furthest from the camera) to the front (closest to the camera). The depth buffer adds a third dimension to the render target (it is also known as a Z-Buffer), this invisible data buffer stores the depth of EVERY pixel rendered. Before any subsequent pixels are rendered it checks the depth of the new pixel against the depth of the pixel that's already been rendered – if the new pixel is deemed as "behind" the existing one it WONT be rendered.

In practical terms, we can set up a depth buffer and then get on with rendering objects in any order and it will appear on screen as you would expect it (the foreground is rendered in front of the background). There are many additional properties and factors regarding depth buffers, but it's not necessary to complicate the issue at this stage.

Secondly – device options; in particular the ability to use one of 4 types of hardware device: software, mixed, hardware or pure. All of these flags determine the type of vertex processing your device will use; In the last few generations of 3D cards we've gotten familiar with "hardware transform & lighting" engines – vastly accelerating the rendering pipeline and allowing for far more detailed geometry. Software vertex processing states that the CPU (your AMD/Intel chip) will do the transform & lighting; Mixed vertex processing states that you'll be

using a bit of both (by default it's hardware, but you can toggle software on so that you can run vertex shaders on older hardware); hardware vertex processing states that you'll be letting the GPU do the work (your G-Force / Radeon); finally, pure device processing states that the hardware gets as much control of rendering as is possible.

Ideally you want to aim for hardware vertex processing, pure-device if available and mixed-processing if you have to. Software processing should be your last option. Before you use one of these options, you must enumerate for support (as done in the code listing above). One last note on this topic – in the above code I've appended the `MultiThreaded` flag. This isn't required, and does slow the program down a little bit but I decided to add it after seeing several warnings from the debug runtimes regarding multiple threads accessing the device object.

The last major part to note from the above code is the usage of render-states and samplers. The device represents our actual hardware graphics card, and as you might expect, they have 100's (if not 1000's) of different options, modes and settings. Some are very subtle and rarely need to be used, others you will get very familiar with, very quickly. The `RenderState` control structure allows us access to the majority of these options – it is beyond the scope of this tutorial to discuss all of the finer points of each render state. Accept that you'll learn what they are as and when you need to use them, as you become more skilled with 3D graphics effects and concepts you will find uses for the settings and will come to appreciate the differences they can make. The `SampleState` structure is similar to the `RenderState` structure, but is more specialized to the control and configuration of texture rendering.

Terminating Direct3D9

Terminating Direct3D used to be an involved task – you could often let DirectX handle it and hope for the best, but it was always advised that you made sure you released all textures, meshes and devices. With the managed code version of Direct3D Microsoft have made good use of their new .Net object-oriented strategy. All classes have both constructors and destructors, it is the destructors job (along with the garbage collector) to clear up the references, free up memory and generally clean up after you. Such as it is you can simply let your graphics engine object go out of scope and let the destructor kick in. The other method is to set objects to nothing and then either quit or re-start. I have built in a destructor (called `Finalize`) into the `CSampleGraphicsEngine` should you need to add any application-specific termination code (the tutorial code doesn't).

Setting the properties for the engine

It is necessary to wrap up all of D3D9 in our class, in order to save confusion (at the programming level, not in your head) we'll maintain our interface as the only way to access 3D graphics. Notice that if you use the `CSampleGraphicsEngine` class from an external library you wouldn't easily see that it relied on Direct3D to render 3D graphics – the host application need not worry itself with how the interface does the job.

However, the host application might want to set various properties to control how the graphics engine works. In fact, it is quite likely that this will be the case. Our engine will do this by altering various `RenderState` options (as one example), but we don't want our host to have direct access to Direct3D, thus we must wrap this

up in properties for the engine. The .Net framework allows us to do this using it's built in get/set property structure. An example of which follows:

```
Public Property wireframe() As Boolean
    Get
        Return bRenderWireframe
    End Get
    Set(ByVal Value As Boolean)
        'error check, then change the state.
        If Not bInitOkay Then Throw New Exception("…")

        bRenderWireframe = Value

        If Value Then
            D3DDev.RenderState.FillMode = FillMode.WireFrame
        Else
            D3DDev.RenderState.FillMode = FillMode.Solid
        End If
    End Set
End Property
```

Fairly simple really, this allows the host to use the wireframe() member in order to specify whether they want the graphics rendered as a wire-frame mesh or a solid rendering.

In More Depth: Geometry

Geometry is the next area of discussion. We should now be able to initialise a simple instance of Direct3D 9. This is all wonderful, but we need to generate geometry that we will then learn to render on the screen. This geometry (be it 2D or 3D) makes up the worlds that we can interact with – it is a huge topic extending all the way to advanced animation and view-culling algorithms. This section will give you a crash course in geometry basics.

How Geometry is Stored

I've already introduced triangles and vertices as being the most primitive building blocks for geometry. The next step is to realise how they are stored.

All geometry will be stored as a list of vertices and/or indices, the order in which they are stored in memory will be discussed in the next sub-section, but the method of storage is only one of two possibilities.

You can either store your geometry in vertex buffers – effectively an array that Direct3D will handle for you, or you can store your geometry in system memory as a traditional array. The former is by far the preferred approach – its faster and more flexible; you can let Direct3D manage whether it is stored in system memory, or on the graphics card. If your vertex buffer does get pushed into video memory (the drivers will often make this the case) you get the added performance of not having to transmit geometry across the AGP bus each time you want to render it; that is, for the latest graphics cards it can access it at the 10's of gigabytes per second bandwidth speed. The only real advantage to storing geometry in a system memory array is to allow your program fast access to the data (should you need to quickly and regularly change vertex data), changing the contents of vertex buffer's can sometimes be quite slow.

The general rule-of-thumb is to use a vertex buffer for an object with 100-5000 vertices. For more vertices you should create multiple vertex buffers, for less vertices you can consider grouping many smaller sets of data together (say 20 quads) into one *master* vertex buffer.

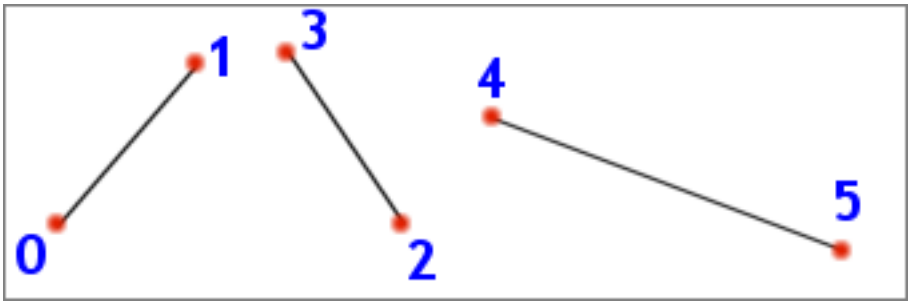
How Geometry is Rendered

This is where geometry rendering really gets interesting – and complicated. This is where people start to get stuck – hang in there! Essentially it is only one issue you need to get your head around, but it has a sting in its tail. First up: the simple stuff…

As briefly mentioned above, the order you store vertices in memory affects how they will be interpreted and rendered by Direct3D later on. If you store geometry as a Triangle list, and render it as a triangle strip no end of odd things will start happening. There are 6 formats for ordering your vertex data all described over the next 2 pages.

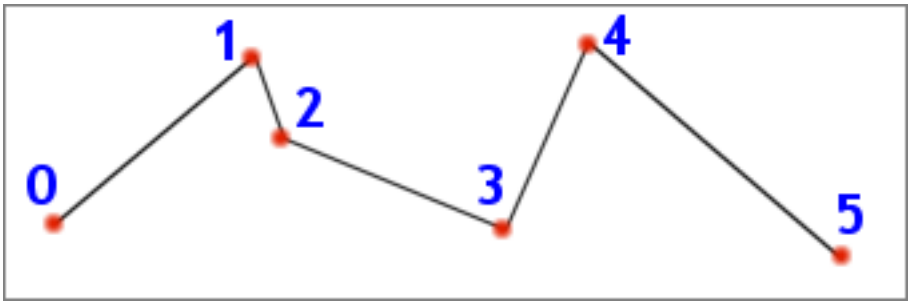
1. Line List

This is simple. Direct3D will draw a straight 1-pixel thick line between each pair of vertices it finds in the stream. 0 & 1, 2 & 3, 4 & 5…



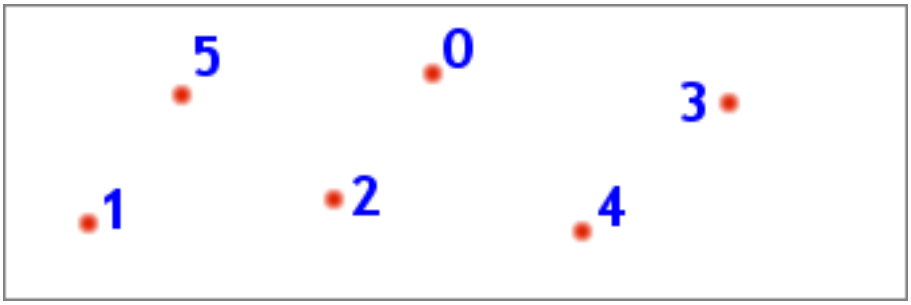
2. Line Strip

This is similar to the line list arrangement, but instead Direct3D will draw a 1-pixel thick line between the current vertex and the previous vertex. So instead of a set of unconnected lines you get a long "snake" of lines where each one is joined together. 0 & 1, 1 & 2, 2 & 3, 3 & 4, 4 & 5…



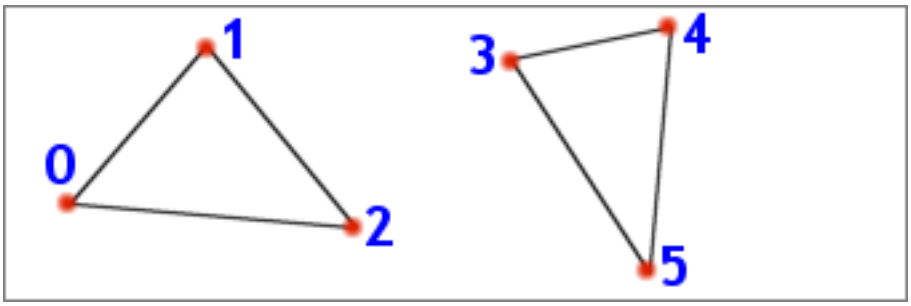
3. Point List

This is as simple as geometry comes. It takes every vertex and renders it as a 1-pixel 'dot' on the screen. Effectively it'll work out to being a pixel plotter for now, later on you can extend this to amazing effects with "point sprites" – smoke, water, fire and other particle effects.



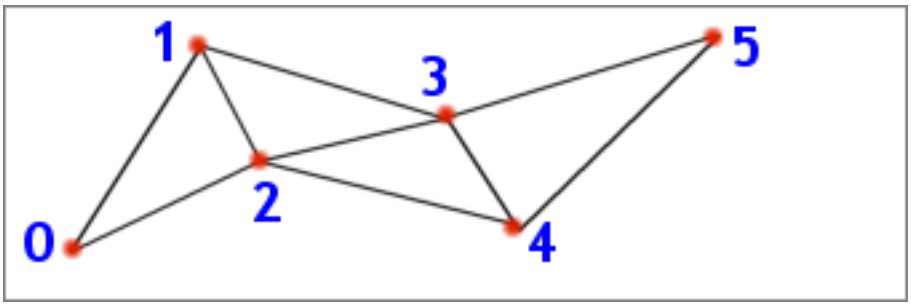
4. Triangle List

We shall be using this for the cube in the following sample code. Direct3D interprets every triplet of vertices as describing a triangle and renders them accordingly. No triangles are connected together. 0 & 1 & 2, 3 & 4 & 5



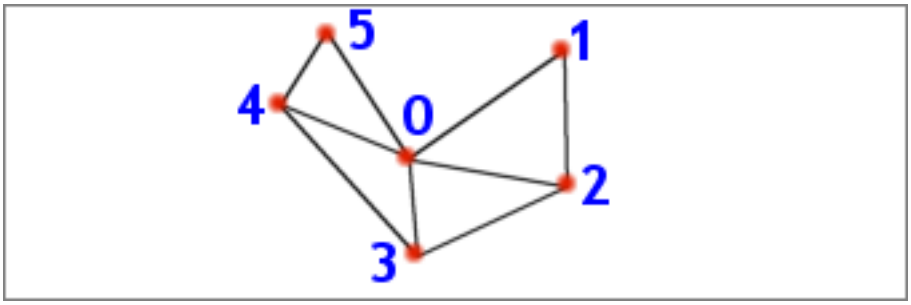
5. Triangle Strip

An extension of triangle lists, each triangle will now share the two previous vertices of the previous triangle. The resultant effect is that all pairs of triangles are joined together along a common edge – they appear as a strip. This arrangement is a very useful optimisation, partly because fewer vertices need to be stored but mostly because it allows the graphics cards to implement optimisations regarding the number of vertices transformed, lit and clipped. 0 & 1 & 2, 1 & 2 & 3, 2 & 3 & 4, 3 & 4 & 5



6. Triangle Fan

This is similar to the Triangle Strip, but instead of sharing the previous 2 vertices all triangles share the first vertex (0). This arrangement is particularly useful for geometry that follows a common focus (a cone, a circle, a hexagon etc…). 0 & 1 & 2, 0 & 2 & 3, 0 & 3 & 4, 0 & 4 & 5



You need to get all 6 of these in your head – you'll probably only ever use #4 and #5, but it pays off to be at least remember that the other 4 exist.

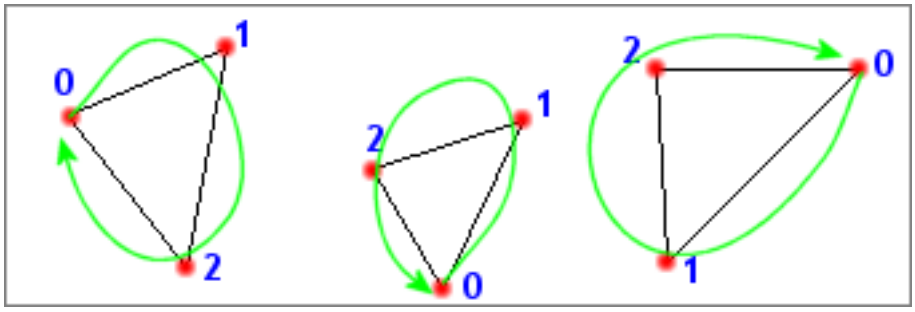
Vertex Ordering in an Individual Triangle

Depending on which of the above arrangements you use, you'll need to pay particular attention to the order in which you store vertices. Sure, A triangle is made up of 3 vertices – why does it matter which order the 3 are in? (it wouldn't matter if you drew it on paper) Direct3D adds an additional optimisation to the rendering pipeline – back face culling.

As you're probably aware, complex 3D scenes are made up of 100,000 triangles or more, and it is quite likely that when rendered we won't know if they're facing the camera or not (some are *back facing*). Take a cube for example, it has 6 sides, but we can only ever see 3 at a time: the other 3 are back facing. To save drawing time (the process of plotting pixels) Direct3D cleverly removes the faces we shouldn't be able to see – saving on drawing them (and then drawing over them) and saving on depth-buffer comparisons.

Because of this clever Direct3D optimisation, it is necessary to understand how it works – so you can create your geometry accordingly. As you'll see in the sample code, you can use the `Device.RenderState.CullMode` to change to 1 of 3 culling modes, the default being `Cull.CounterClockwise` – meaning it removes all counter-clockwise faces.

If you transform the 3 points of a triangle into screen-space (ie, they have their 2D coordinates as they'd be rendered on the screen), and you then draw a line from vertex 0->1->2 (in the order arranged in memory) you'll be able to make it a clockwise or counter-clockwise pattern. If you have the culling set to counter clockwise you'll remove all those triangles that have a counter clockwise pattern, if you have clockwise culling you'll remove clockwise triangles. See the following 2 diagrams for an example:



The left-most diagram is clockwise – drawing a circle from 0->1->2 results in a clockwise arrow. The Middle diagram is counter-clockwise and the right-most diagram is clockwise.

It is usual to stick with counter-clockwise culling (in the above example, the middle triangle would not be rendered) and design your models accordingly. Industry-standard modelling packages (such as 3DS Max and trueSpace) export their models with clockwise 'winding' such that they easily fit into a Direct3D engine. It may be necessary (depending on the tools you use) to specify clockwise culling.

No culling has its uses – particularly for some advanced effects (Such as those involving semi-transparent surfaces), but for normal 'solid' geometry you shouldn't use it. It may seem like the easy way out – setting no-culling would allow you to completely ignore this issue of geometry creation. However, in past

experience you can loose at least 40% of your rendering performance by choosing this route. A drop from 200 to 120 frames per second isn't that amazing, but a drop from 40 to 26 frames per second will make a noticeable difference (for lower-end systems).

Completing the Engine: loadGeometry()

Now that we've covered the specifics of geometry storage and rendering I'll cover the actual specifics – how to implement this in code. The code shown next looks far more complicated than it actually is – I had to write out some of this on paper before coding it to get it in the correct order.

loadGeometry() is the function in our class that is designed to handle all the geometry loading and creation, by the time this function completes we should have a complete set of geometry ready to be rendered.

```
Private Sub loadGeometry()
    Try
        'in this sample, we dont actually LOAD geometry from a file,
        'rather we LOAD it into memory.
        '[-----------------------------------]
        '   LOAD 2D GEOMETRY INTO VBUFFERS
        '[-----------------------------------]
        vbMenu = New VertexBuffer(GetType(CustomVertex.TransformedTextured), _
                                  4, D3DDev, 0, _
                                  CustomVertex.TransformedTextured.Format, _
                                  Pool.Default)

        Dim v As CustomVertex.TransformedTextured() = CType(vbMenu.Lock(0, 0), _
                                                CustomVertex.TransformedTextured())

        Const iMBWidth As Integer = 158
        Const iMBHeight As Integer = 93

        'use the constructors to fill the data.
        'laid out such that first line = coordinate (x,y,z,rhw)
        'and second line = texcoord (u,v)
        v(0) = New CustomVertex.TransformedTextured(0, 86, 0, 1, _
                                                    0, 2 / 127)
        v(1) = New CustomVertex.TransformedTextured(iMBWidth, 86, 0, 1, _
                                                    iMBWidth / 255, 2 / 127)
        v(2) = New CustomVertex.TransformedTextured(0, 86 + iMBHeight, 0, 1, _
                                                    0, iMBHeight / 127)
        v(3) = New CustomVertex.TransformedTextured(iMBWidth, 86 + iMBHeight, 0, 1, _
                                                    iMBWidth / 255, iMBHeight / 127)

        vbMenu.Unlock()

        '[-----------------------------------]
        '   LOAD 3D GEOMETRY INTO VBUFFERS
        '[-----------------------------------]
        vbCube = New VertexBuffer(GetType(CustomVertex.PositionTextured), _
                                  36, D3DDev, 0, CustomVertex.PositionTextured.Format, _
                                  Pool.Managed)

        'use CType() to typecast a pointer to the
        'memory into an array of position&textured vertices
        Dim vCube As CustomVertex.PositionTextured() = CType(vbCube.Lock(0, 0), _
                                                CustomVertex.PositionTextured())

        '2a. Generate top plane
        vCube(0) = New CustomVertex.PositionTextured(-0.5, 0.5, 0.5, 0, 0)
        vCube(1) = New CustomVertex.PositionTextured(0.5, 0.5, 0.5, 1, 0)
        vCube(2) = New CustomVertex.PositionTextured(-0.5, 0.5, -0.5, 0, 1)

        vCube(3) = New CustomVertex.PositionTextured(0.5, 0.5, -0.5, 1, 1)
        vCube(4) = New CustomVertex.PositionTextured(-0.5, 0.5, -0.5, 0, 1)
        vCube(5) = New CustomVertex.PositionTextured(0.5, 0.5, 0.5, 1, 0)

        '2b. Generate bottom plane
        vCube(6) = New CustomVertex.PositionTextured(-0.5, -0.5, -0.5, 1, 0)
```

```
        vCube(7) = New CustomVertex.PositionTextured(0.5, -0.5, 0.5, 0, 1)
        vCube(8) = New CustomVertex.PositionTextured(-0.5, -0.5, 0.5, 0, 0)

        vCube(9) = New CustomVertex.PositionTextured(0.5, -0.5, 0.5, 0, 1)
        vCube(10) = New CustomVertex.PositionTextured(-0.5, -0.5, -0.5, 1, 0)
        vCube(11) = New CustomVertex.PositionTextured(0.5, -0.5, -0.5, 1, 1)

        '2c. Generate 'left' plane
        vCube(12) = New CustomVertex.PositionTextured(-0.5, 0.5, -0.5, 0, 0)
        vCube(13) = New CustomVertex.PositionTextured(-0.5, -0.5, -0.5, 1, 0)
        vCube(14) = New CustomVertex.PositionTextured(-0.5, 0.5, 0.5, 0, 1)

        vCube(15) = New CustomVertex.PositionTextured(-0.5, 0.5, 0.5, 0, 1)
        vCube(16) = New CustomVertex.PositionTextured(-0.5, -0.5, -0.5, 1, 0)
        vCube(17) = New CustomVertex.PositionTextured(-0.5, -0.5, 0.5, 1, 1)

        '2d. Generate 'right' plane
        vCube(18) = New CustomVertex.PositionTextured(0.5, 0.5, -0.5, 0, 0)
        vCube(19) = New CustomVertex.PositionTextured(0.5, 0.5, 0.5, 1, 0)
        vCube(20) = New CustomVertex.PositionTextured(0.5, -0.5, -0.5, 0, 1)

        vCube(21) = New CustomVertex.PositionTextured(0.5, -0.5, 0.5, 1, 1)
        vCube(22) = New CustomVertex.PositionTextured(0.5, -0.5, -0.5, 0, 1)
        vCube(23) = New CustomVertex.PositionTextured(0.5, 0.5, 0.5, 1, 0)

        '2e. Generate 'Back' plane
        vCube(24) = New CustomVertex.PositionTextured(-0.5, 0.5, -0.5, 0, 0)
        vCube(25) = New CustomVertex.PositionTextured(0.5, 0.5, -0.5, 1, 0)
        vCube(26) = New CustomVertex.PositionTextured(-0.5, -0.5, -0.5, 0, 1)

        vCube(27) = New CustomVertex.PositionTextured(0.5, -0.5, -0.5, 1, 1)
        vCube(28) = New CustomVertex.PositionTextured(-0.5, -0.5, -0.5, 0, 1)
        vCube(29) = New CustomVertex.PositionTextured(0.5, 0.5, -0.5, 1, 0)

        '2f. Generate 'Front' plane
        vCube(30) = New CustomVertex.PositionTextured(0.5, 0.5, 0.5, 1, 0)
        vCube(31) = New CustomVertex.PositionTextured(-0.5, 0.5, 0.5, 0, 0)
        vCube(32) = New CustomVertex.PositionTextured(-0.5, -0.5, 0.5, 0, 1)

        vCube(33) = New CustomVertex.PositionTextured(-0.5, -0.5, 0.5, 0, 1)
        vCube(34) = New CustomVertex.PositionTextured(0.5, -0.5, 0.5, 1, 1)
        vCube(35) = New CustomVertex.PositionTextured(0.5, 0.5, 0.5, 1, 0)

        vbCube.Unlock()


    Catch err As Exception
        MsgBox("loadGeometry(): " + Chr(13) + Chr(13) + err.ToString())
        Throw New Exception("could not complete loadGeometry()")
    End Try
End Sub
```

The above code sample is considerably more complicated and 'scary' than it really is. There are actually only 4 parts of this code that you need to pay attention to – the rest are specific to this sample application, and to the process of creating a cube.

The above function is split into two parts – firstly where we create a simple 2D menu-bar, and the second where we create the cube. Both give different results, yet both follow exactly the same programming.

Firstly, we need to create the vertex buffer – we have to tell Direct3D that we want a new vertex buffer, we want it to store a specific type of vertex (vertex buffers can only store one type of vertex at a time) and how many vertices (which equates to how big the buffer will be).

```
vbCube = New VertexBuffer(GetType(CustomVertex.PositionTextured), 36, D3DDev, 0, _
                          CustomVertex.PositionTextured.Format, Pool.Managed)
```

We use the VertexBuffer class' constructor to create a reference for our new vertex buffer. The above line states: I want to create a buffer where all vertices

have a position and a texture coordinate, I want to store 36 of these vertices and I want Direct3D to handle it's position in memory for me. The `GetType()` command tells the function what type of vertex we'll be storing, the second parameter '36' is the number of vertices we'll be storing, `Pool.Managed` indicates that we want Direct3D to move our buffer from/to system memory and video-memory accordingly. The `CustomVertex` class holds all the common types of vertex – so that we don't need to define them manually, have a look at it in the object browser – there are quite a few different ones. It also holds the Flexible Vertex Format (FVF) value for the vertex type, a number that we'll need to use later on.

Secondly, we lock the vertex buffer and retrieve a pointer to the vertex buffer's data. This will become a common theme in Direct3D – the process of locking a resource, filling it with data, and then unlocking it. To lock the vertex buffer we use this line of code:

```
Dim vCube As CustomVertex.PositionTextured() = CType(vbCube.Lock(0, 0), _
                                               CustomVertex.PositionTextured())
```

`CType()` is VB's odd way of type-casting variables, but basically, we use the `Lock(0,0)` call to lock the vertex buffer at the start (ie, index 0) and with no special parameters. Whilst it's not obviously subscript-checked, we can access vCube(0) to vCube(35) as being the 36 available vertex-storage locations.

The third stage of geometry creation is to fill in this array of vertices with meaningful data. In the sample code we'll be making it a cube – out of 36 vertices. This is completely up to you – and it is where your choice of rendering technique will first apply. The arrangement I'm using for the sample code is a triangle-list – the simplest possible, it is more optimal to use triangle-strips and potentially two triangle fans.

The final stage is possibly the simplest – an unlock command. If we lock the vertex buffer, and acquire a pointer to its memory we must at some point free this pointer. It makes good sense to free it as soon as we're finished using it, but more importantly we have to free it before we render. If we attempt to render the vertex buffer while it's locked you'll find Direct3D throwing you a nasty `DirectXException`.

In More Depth: Textures

Now we've covered geometry, we need to cover the basics of textures; as mentioned earlier – geometry only really comes alive when you make clever use of textures. It will be many, many years from now before we can render realistic 3D models with geometry alone (and no textures).

One useful thing to note before we work with textures; optimally textures are stored with dimensions of 2^n. The width and the height are powers of 2. 128x128, 256x256, 512x1024, 256x128 etc… This allows the hardware to use a few optimizations to further speed up rendering of texture surfaces. Modern hardware doesn't always have this requirement (it will allow "non 2-to-the-power-n" textures), but if you opt to use such a texture you should expect it NOT to perform as well as one that is 2^n. You don't need to store your textures as 2^n sizes, but they will (unless you specify otherwise) be converted to a 2^n size by Direct3D – so it generally helps to get used to this scheme early on. It is also necessary to enumerate support for texture sizes – most hardware beyond the GeForce-2 will allow textures up to and beyond 1024x1024 (big enough for most situations) but it is still best to enumerate. Direct3D 9 is restricted to DDI 7 level drivers, but there are a few (such as the popular 'voodoo' series) that have rather odd texture requirements (256x256 maximum size).

How is a Texture Represented On-Disk

Textures on disk are nothing but standard image files – something you've probably come across 1000's of times. Typically they'll be represented as two-dimensional arrays of pixels – bitmaps. Many modern formats use lossy (or non-lossy) compression schemes to reduce the size stored on disk. A perfect copy of a printable photo would normally occupy around 24mb, however digital cameras often store them in around $1/50^{th}$ of this size – 400kb.

With Direct3DX – the helper library that ships with Direct3D, you don't need to worry too much about the format of the texture; as long as you stick to a common format (BMP, TGA, GIF, JPG etc…) it'll probably be able to load it. With this in mind, the only compromise is regarding the quality and the size on the disk (note, size in memory is not involved here). If you intend to ship your product on a CD, you can very easily fill up 650mb with 3,500 medium-low resolution textures alone (it's not as difficult as you might think for a complete 3D world / game).

There is one additional format to be aware of – Direct Draw Surface (DDS) format. These files store (on disk) the same data as would be stored in memory by the graphics card. This is a surprisingly powerful method – if the data is stored on disk the same as it is stored in memory it can be loaded extremely quickly. It also allows the artists to specify exactly how Direct3D will represent the color; if the alpha channel has 2-bit accuracy, you can design it for 2-bit accuracy from the start (rather than let Direct3DX sample an 8bit alpha channel down to 2bit as is the case for TGA files). If you want to create DDS files, it is best to use the 'DXTex' tool shipped with the SDK; there are plugins for photoshop and other graphics packages that allow you to directly export from these tools – but you'll have to search for these.

How is a Texture Represented in Memory

How textures are stored on disk is similar, but subtly different to how they are stored in memory. It is important to appreciate this difference and it's consequences.

The first important difference – almost all textures will be stored in bitmap format in memory. For a rendering system that attempts to give the greatest performance possible it can't be required to decompress often complex compression schemes just to render a few 100 triangles. There are 5 texture formats that are compressed – DXT1…5. They still offer good performance, and DXT1 also offers 6:1 compression, which can be extremely useful when you want to fit 256mb of textures onto a 64mb graphics card.

Texture formats are represented by the `Format` enumeration, which has over 40 possible textures formats defined. Direct3D9 introduces a few complications to what used to be a relatively simple rule – but for simple applications like ours these need not bother us. All of the formats described by this enumeration are divided into the follow names:

<tag 1><bits 1><tag 2><bits 2> … <tag *n*><bits *n*>

Where *tag* is the single-letter name for the channel (A, R, G, B, Y, U, V and X) and *bits* is the number of bits-per-pixel allocated to store the amount of that channel required for that pixel.

X8R8G8B8

Is a good example – one that you'll probably become familiar with quite quickly. It states: 8 bits for the 'X' channel, 8 bits for the 'R' channel, 8 bits for the 'G' Channel and 8 bits for the 'B' channel. Where X is an unused component, R is Red, G is Green and B is blue. The number of bits indicates the space, stored as an integer, allocated for that channel – thus in the above example there are 8 bits for the blue channel – 2^8 possible colors (256). It therefore follows that if you add up all the numbers in the format descriptor you'll get the number of bits per pixel – in this case it's 32bits. You'll generally find common formats follow the 2^n rule – 8,16,32,64 or 128 bits per pixel.

Direct3D9 has added 6 new formats that differ from this rule:

```
A16R16G16B16F
A32R32G32B32F
G16R16F
G32R32F
R16F
R32F
```

They all have the same naming scheme – except they have an 'F' appended to the end. These six formats are all floating-point numbers. The `A32R32G32B32F` format stores 4 Singles (in normal programming terms) per pixel – 1 float per channel; this allows for much higher color fidelity and generally much better color for rendered images – something that I hope developers make good use of in the near future. You won't need to use these in anything but the most advanced graphics engines.

As a summary: when you create a texture in memory you'll assign it a format (as discussed above) and it'll be stored accordingly. If you have a 32mb card you'll

probably have around 20-25mb of memory available for textures, you'll need to decide how many textures of a given size and format you can fit into this space. If you can fit an entire level/world's textures in at the same time you'll have to devise an algorithm to load only the most important ones at any given time.

Texture Coordinate Theory

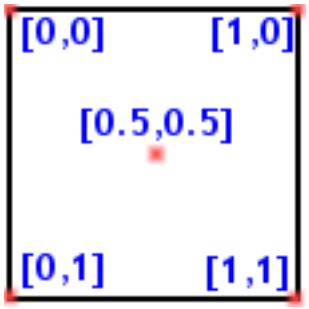
Now that we understand the way that data is stored both on disk and in memory, we have to understand how Direct3D will be using these textures when applied to geometry.

We have covered the idea of vertices – and the way that they are the fundamental building block for all geometry rendered by Direct3D. Every vertex has a set of properties – position, color, lighting values and texture coordinates. It is texture coordinates that are important for our work in this section. A texture is defined in two dimensions, so we'll have a 2D coordinate for each vertex associated with the texture we'll be rendering on it – these coordinates are known as the U and V coordinates (*NOT* X and Y).

As mentioned, a triangle, even if we define it in 3D-space, is still a planar two-dimensional object (it is flat). If we take the 3 vertices that make up a triangle, and examine the associated texture coordinates we can work out an area of the texture (stored in memory) that we will map onto the triangle when it is displayed on the screen. The area specified by the coordinates can be 500 square pixels of 2 square pixels – it doesn't matter. Direct3D will filter the texture accordingly so that you get the correct piece of texture displayed on the triangle.

The surprising part about texture coordinates (if you've never come across them before!) is that they're not measured in pixels. Instead, they're measured as single-precision floating-point numbers in the range 0.0 to 1.0 (you *can* use values outside this range, but that's beyond the current level). This system of measuring texture coordinates works as a scalar – if you specify 0.0 you'll reference the top or left of the texture, if you specify 1.0 you'll specify the bottom or right of the texture (the maximum width/height), if you specify 0.5 you'll reference the middle of one dimension of the texture.

U , V	
0.0 , 0.0	= top left
1.0 , 0.0	= top right
0.0 , 1.0	= bottom left
1.0 , 1.0	= bottom right
0.5, 0.5	= absolute middle



It may seem odd that you don't use pixel-measurements to specify texture coordinates, but if you think about it (and appreciate 3D graphics concepts) it does make a lot of sense. Textures when you load them, will be of the size you expect – but there may also be several identical copies of the texture at lower resolutions in memory. This has been a common feature for some time – Mip Mapping (Latin for 'much in little'); if you create a texture of size 256x256 Direct3D will silently create smaller, identical, textures of 128x128, 64x64, 32x32, 16x16, 8x8, 4x4, 2x2, 1x1. The reason for this is that when a triangle gets further from the camera the area it occupies in the final image is significantly smaller – so there's no point in trying to map a very high-detail texture to a very

small space on-screen. Direct3D will dynamically choose which "level" of the mip-map should be used based on the size of the triangle on the screen. This may seem odd, but it works out as giving a much higher final-image quality. It also allows you to change the texture size (at load-time) and not worry about altering texture coordinates – you can store a 1024x1024 texture on the disk, but if the system can't handle it you can load it in as a smaller size and the texture coordinates will behave as if nothing has changed and the end result will be almost identical (although probably more blurred due to lower resolution data).

So, in summary, for every texture we'll specify a U and a V coordinate for the piece of texture we want to use. The code shown (for creating a cube) in the geometry section earlier actually included texture coordinates. The last two parameters of the vertex-constructor were the U and V coordinates.

Get your head around this… for its now going to get complicated again. It is perfectly possible to have more than 1 texture per triangle. In fact, it's possible to have 8 textures per triangle. In practice, you'll be unlikely to use more than 3 textures (and that's for quite advanced graphics). You can ignore this for the meantime – but it is useful to know that it is possible to have more than one set of texture coordinates per texture, and that it's also possible to have no texture coordinates for a vertex.

Completing the Engine: loadTextures()

loadTextures() is actually quite a simple piece of code – the real 'genius' is in using the textures – not loading them. It is interesting to note that Direct3D doesn't actually load the texture for you – Direct3DX (the helper library) does everything related to moving/converting the data stored on the disk to the location in memory.

The only 'tricky' part is the inclusion of enumeration for texture formats. The `Format` class exposes 40+ possible texture formats to use, but this is no guarantee that the target hardware will actually be able to use data in this format. Before loading a texture into memory with a particular format it is best to check to see if the device will later be able to render from it.

`CheckDeviceFormat( )` is the function that we can use to decide if a texture format is suitable for the current device. There is the odd exception whereby a device *does* support 16bit textures but won't allow us to use them with a 32bit display mode – this will also be exposed by this function.

```
Public Shared Function CheckDeviceFormat( _
    ByVal adapter As Integer, _
    ByVal deviceType As DeviceType, _
    ByVal adapterFormat As Format, _
    ByVal usage As Usage, _
    ByVal resourceType As ResourceType, _
    ByVal checkFormat As Format _
) As Boolean
```

Is the actual function prototype. `adapter` is almost always 0 (signifying the primary display hardware). `devicetype` is going to be '`Hardware`'; `adapterformat` will be the display mode that you selected at the start (and was stored in the back buffer format member of `PresentParameters`). `usage` will be '0' for default (and indicating no special usage), `resourcetype` will be '`Textures`' and `checkformat` is the format that we actually want information regarding.

The function will return true or false depending on whether `checkformat` is `compatible` with the specified adapter and display mode. Simple as that.

The sample code only uses 3 textures – one for each cube, and one for a menu. They are stored as 2^n-sized 24bit .bmp textures. The code for loading them is as follows on the next page:

```
Private Sub loadTextures(ByVal AdapterFmt As Format)
    'attempt to load the menu texture
    If D3DRoot.CheckDeviceFormat(0, _
                                 DeviceType.Hardware, _
                                 AdapterFmt, _
                                 0, _
                                 ResourceType.Textures, _
                                 Format.A8R8G8B8 _
                                 ) Then
        texMenu = TextureLoader.FromFile(D3DDev, _
                                         Application.StartupPath + "\menubar.bmp", _
                                         256, 128, 1, 0, _
                                         Format.A8R8G8B8, Pool.Managed, _
                                         Filter.None, Filter.None, _
                                         Drawing.Color.Magenta.ToArgb())

    ElseIf D3DRoot.CheckDeviceFormat(0, _
                                     DeviceType.Hardware, _
                                     AdapterFmt, _
                                     0, _
                                     ResourceType.Textures, _
                                     Format.A1R5G5B5 _
                                     ) Then
        texMenu = TextureLoader.FromFile(D3DDev, _
                                         Application.StartupPath + "\menubar.bmp", _
                                         256, 128, 1, 0, _
                                         Format.A1R5G5B5, Pool.Managed, _
                                         Filter.None, Filter.None, _
                                         Drawing.Color.Magenta.ToArgb())

    Else
        Throw New Exception("…")
    End If

    'attempt to load the cube textures
    If D3DRoot.CheckDeviceFormat(0, _
                                 DeviceType.Hardware, _
                                 AdapterFmt, _
                                 0, _
                                 ResourceType.Textures, _
                                 Format.X8R8G8B8 _
                                 ) Then
        texCube1 = TextureLoader.FromFile(D3DDev, _
                                          Application.StartupPath + "\cube1.bmp", _
                                          256, 256, 1, 0, _
                                          Format.X8R8G8B8, Pool.Managed, _
                                          Filter.Linear, Filter.Linear, 0)
        texCube2 = TextureLoader.FromFile(D3DDev, _
                                          Application.StartupPath + "\cube2.bmp", _
                                          256, 256, 1, 0, _
                                          Format.X8R8G8B8, Pool.Managed, _
                                          Filter.Linear, Filter.Linear, 0)

    ElseIf D3DRoot.CheckDeviceFormat(0, _
                                     DeviceType.Hardware, _
                                     AdapterFmt, _
                                     0, _
                                     ResourceType.Textures, _
                                     Format.R5G6B5 _
                                     ) Then
        texCube1 = TextureLoader.FromFile(D3DDev, _
                                          Application.StartupPath + "\cube1.bmp", _
                                          256, 256, 1, 0, _
                                          Format.R5G6B5, Pool.Managed, _
                                          Filter.Linear, Filter.Linear, 0)
        texCube2 = TextureLoader.FromFile(D3DDev, _
                                          Application.StartupPath + "\cube2.bmp", _
                                          256, 256, 1, 0, _
                                          Format.R5G6B5, Pool.Managed, _
                                          Filter.Linear, Filter.Linear, 0)

    Else
        Throw New Exception("…")
    End If
End Sub
```

The source code is actually divided into two sections only because there is a subtle difference for 1 of the 3 textures that we'll be loading. Transparencies.

As you may have noticed – all textures so far have been described as either square or rectangular grids of pixels. This is fine for most situations, but there are a number of cases where this is not entirely useful. Some complex patterns (such as leaves on a plant) would require an incredibly high polygon count if all textures were mapped as a solid image. It would make much more sense to render a slightly larger (and simpler) polygon and 'skip' a certain number of pixels so that only a portion of the texture was actually visible giving the illusion of a much higher-detailed mesh than that being used.

I've mentioned earlier in this section the 'A' channel in textures – the alpha channel. This channel never directly contributes to the final color rendered on the screen, rather it is fundamental in a set of equations that can be performed on every pixel rendered – alpha blending operations. These allow for a number of subtle per-pixel effects – color fades and alterations, and topically, optional transparency.

We can specify values in the 'A' component to indicate whether a pixel is transparent or not. If it is deemed as transparent Direct3D won't render it to the screen. If you look back to the previous page, the first set of If ... End If statements examine two formats: `A8R8G8B8` and `A1R5G5B5` – 32bit and 16bit (respectively) texture formats that allow at least one bit of alpha precision. 1 bit allows for two states – on/off yes/no. For transparencies we need only two states – transparent or opaque. Thus we create a texture with at least 1 bit of alpha precision, if we can't do this then we deem the operation a failure. The 32bit format has 8bits of precision, but this is necessary – the only common 32bit format with an alpha channel allocates it 8bits (the `A2R10G10B10` format is new and not widely supported).

We also need to specify a color value for the last parameter in the FromFile() function. Note that for the first texture it is magenta, and for the remaining two textures it is 0. This last parameter tells Direct3DX to examine every pixel loaded – if it's color is the same as the color key (magenta) we make it transparent, otherwise we make it opaque. If you open up "menubar.bmp" in an image editor you'll see that the majority of the texture is magenta in color – if we were to render any of this to the screen it would not appear because the loader has deemed it transparent.

Two lines in the `initialiseDevice()` function configure the transparent rendering:

```
D3DDev.RenderState.SourceBlend = Blend.SourceAlpha
D3DDev.RenderState.DestinationBlend = Blend.InvSourceAlpha
```

We'll discuss the actual rendering of these textures in the next-but-one section.

The remaining two textures that we load don't need an alpha channel –they're solid textures. As such we can stick to the common 32bit and 16bit textures: X888 and 565 formats.

The `TextureLoader` class is the part of the Direct3DX library that allows us to create a Texture object from either a stream (data already in memory) or from a file on the disk. The FromFile() function is overloaded 5 times to allow us various ways of creating files. In the above sample code I've used on of the more complex overloads – it was necessary to explicitly state what options I wanted to

use for textures (this will continue to be necessary for any special formats, including alpha-channel textures). I could have made the loadTextures() function considerably simpler by using the 5th overload:

```
Public Shared Function FromFile( _
    ByVal device As Device, _
    ByVal srcFile As String _
) As Texture
```

```
texMenu = TextureLoader.FromFile(D3Ddev, Application.StartupPath + "\menubar.bmp")
texCube1 = TextureLoader.FromFile(D3Ddev, Application.StartupPath + "\cube1.bmp")
texCube2 = TextureLoader.FromFile(D3Ddev, Application.StartupPath + "\cube2.bmp")
```

However, by using this trivial loading mechanism I would not be allowed to specify an alpha channel and color key for `texMenu`.

Matrices Revisited

Matrices, as mentioned earlier in this tutorial area a way of using a single set of geometry mutliple times to appear as though it were a completely different entity. You can use a transformation matrix to render, what appears to the user, as three different models from the same original source data.

However, it's not (as you might have guessed) as simple as it seems. Matrix operations in D3D follow pretty-much exactly the same rules as they do for pure mathematics. If you're not familiar with these rules, you'll very quickly get used to them.

Order Counts

The first fact about matrices that you need to appreciate is this:

```
A*B is not equal to B*A
```

Unlike the majority of pure mathematics, the multiplication operation is not commutative. You have to pay attention to the order that you multiply matrices.

This is particularly important because to create a final transformation matrix we will use several smaller (and simpler) matrix transformations multiplied together. The above example could be:

```
Rotation_X*Translation is not equal to Translation*Rotation_x
```

If you think about it, if you rotate an object and then translate it you'll be left with (at the translation point) a rotated object. If you translate then rotate you'll get an object that is rotated a given distance from the origin. In animated terms, Rotation then translation will give you a spinning object at any given point in 3D space. Translation then rotation will give you an object that rotates around the origin at the distance specified by the translation matrix.

This subtle difference is extremely important. It matters a great deal which order you specify the various transformation matrices. We'll be dealing with (and you're unlikely to need to bother with) world transformation matrices – view and projection matrices can be formed in one step (and thus don't need any multiplication). In general, for a world transformation you'll use the following formula:

1) Scale
2) rotation (x,y,z)
3) translation

There is no reason that you need to stick to this pattern, but it does (75% of the time) yield the result that you'd expect. Swapping number 2 and 3 on the above list can give interesting results.

The sample code that you'll see in a minute offers two different ways of translating the same geometry. It is well worth your time to experiment with these methods – and the order in which they are applied.

The D3D Math Helper Library

Matrix math is an ugly subject – there's no other way to describe it. The theory is understandable, but in practice it's either plain confusing or requires too many calculations to be possible on paper. The three transformations: scaling, rotation and translation are all different and respectably complicated – it is far beyond the scope of this tutorial to explain them. We shall, however, use the Direct3DX math library to do all the hard work for us.

The `Matrix` structure has over 25 functions that we can use to create a transformation matrix. Of which, only 7 are of particular use:

`Multiply()`	- puts two different matrices together
`Identity()`	- the most basic transformation matrix
`RotateX()`	- rotates the matrix around the X-axis
`RotateY()`	- rotates the matrix around the Y-axis
`RotateZ()`	- rotates the matrix around the Z-axis
`Scaling()`	- scales the matrix by a given factor
`Translation()`	- translates the matrix a given distance

The above are all fairly self-explanatory, and where 'matrix' is involved you *can* read it as being the object/geometry you're about to render. I.e. "rotates the matrix around the y-axis" is effectively the same as "rotates the geometry around the y-axis".

Most of the functions listed above have overloads – you can specify 3 singles or a 3-part vector – both are acceptable. A useful mechanic to remember, when putting several matrices together is:

```
matCube1 = Matrix.Multiply(matCube1, Matrix.Scaling(3, 3, 3))
```

Using this system, you don't need a temporary matrix to store the scaling factor. More importantly, you can put many of these lines together (where the 2nd parameter is the new modifier) and keep very clean and readable code.

Completing the Engine: oneFrameUpdate()

Before we get stuck in, it's important to appreciate how the world transformation is applied to the geometry that you render. All transformation matrices are set using the `Device.Transform` interface – world, view and projection matrices as well as a few others. Once a matrix has been "set" to the device, all subsequent geometry is affected by it – if you set a rotation matrix for the world matrix ALL geometry from that point onwards is rotated. This somehow seems to get people very confused – they don't seem to see how you can render multiple objects with different transformations. The key is to appreciate that you can change the transformation matrix as many times in a frame as you want, and as soon as it's changed all geometry will be affected by the new matrix and not the old one. To outline this further, take this piece of pseudo-code:

```
<Begin the frame>

<Set matrix 1>
<Render object 1>

<Set matrix 2>
<Render object 2>

…
```

```
<Set matrix n>
<Render object n>

<End the frame>
```

For this reason I added two cubes to the sample code – both using different matrices. Follow the code structure used by the sample and you can easily see how to render multiple pieces of geometry with different transformations.

Also to note is how I structured the graphics engine to handle transformation calculation. For the sample, both the view and projection matrices remain static – such that we can calculate that in `initialiseEngine()` and then ignore them. The world matrices (one for each cube) need to be calculated every frame. It makes for cleaner code if you split the rendering and the updating code apart; hence the `oneFrameUpdate()` and `oneFrameRender()` functions.

```
Public Sub oneFrameUpdate()
    If Not bInitOkay Then Throw New Exception("…")

    'general variables
    Dim matTmp As Matrix

    'calculate the current rotation angles for the two cubes
    cube1Angle += ((Environment.TickCount() - lastFrameUpdate) / 1000) * cube1Speed
    cube2Angle += ((Environment.TickCount() - lastFrameUpdate) / 1000) * cube2Speed
    lastFrameUpdate = Environment.TickCount()

    'calculate cube1's matrix
    matCube1 = Matrix.Identity()
    matCube1 = Matrix.Multiply(matCube1, _
                               Matrix.Scaling(3, 3, 3))
    matCube1 = Matrix.Multiply(matCube1, _
                               Matrix.RotationX(cube1Angle * (Math.PI / 180)))
    matCube1 = Matrix.Multiply(matCube1, _
                               Matrix.RotationY(cube1Angle * (Math.PI / 180)))

    'calculate cube2's matrix
    matCube2 = Matrix.Identity()
    matCube2 = Matrix.Multiply(matCube2, _
                               Matrix.Scaling(4, 5, 0.75))
    matCube2 = Matrix.Multiply(matCube2, _
                               Matrix.Translation(-8, -4, 0))
    matCube2 = Matrix.Multiply(matCube2, _
                               Matrix.RotationZ(cube2Angle * (Math.PI / 180)))

    'calculate the current framerate
    If (Environment.TickCount() - iLastFPSCheck >= iFPSProfileSpeed) Then
        iLastFPSCheck = Environment.TickCount()
        iFrameRate = iCurrCnt * (1000 / iFPSProfileSpeed)
        iCurrCnt = 0
    End If
    iCurrCnt += 1
End Sub
```

As you can see from the above code listing, `oneFrameUpdate()` is divided into 3 main parts, of which only the first two are concerned with matrices/transformations.

I've implemented a time-based modeling system for this sample which is slightly more complicated than some animation systems, but it pays off if you take the time to learn how the equation works. It, fairly simply, uses a couple of constants to increment the two angle variables at a constant rate – say 50 degrees every second. If the frame rate is extremely high or extremely low the matrix will still only ever rotate by 50 degrees in a second. The other animation methods involve adding a fixed amount per frame and then "capping" the frame rate. This way, if the application is capped to 45fps, you need at 1 to the angle each frame to get it moving at 45 degrees per second. This only works properly when the frame rate

is constant (I.e. never fluctuates from 45) and most importantly never falls below. For a fast computer this is quite possible, but there will still be moments when the frame rate drops and/or you're end user is not using a powerful-enough PC; in these cases the animation will go completely wrong – and you'll get no end of odd looking results and physics calculations/models can be completely thrown by this system.

The second and third parts actually construct the two matrices: `matCube1` and `matCube2`. We don't actually set either matrix to the device in this code – we just construct them and store them in memory for use later on.

Cube 1 is scaled first – such that it will be a cube of 3x3x3 units (if you look back at the `loadGeometry()` code you'll see that the cube is of size 1). It is then rotated about the X axis, and then the Y axis. There is no translation. The net result (as you'll see when you run the sample code) is a cube of equal dimensions rotating around one position (the origin).

Cube 2 is scaled first – except this time it isn't uniformly scaled, it's Z-size is smaller and the X & Y sizes are different. It is therefore more of a rectangular shape / flat cube. This object is then translated away from the origin by [-8,-4,0] and then rotated about the Z axis. This gives the interesting effect of the cube 'orbiting' around the first cube – rotations are always with respect to the world origin, so if you translate first it will still rotate around this point.

Finishing it all off

At this point in the tutorial we have covered almost all of the supporting code for a Direct3D graphics engine. We can initialise the graphics, load textures and create some simple geometry and we can configure a pair of transformation matrices. However, this is still merely the supporting code – the meat of any D3D engine is this next (and last) section.

If you play a commercial game, 99.9% of the *graphics* processing time will be spent rendering – not loading media or initialising objects. Thus we must spend the most time working on (and fine-tuning) the rendering functions. To fully utilize the power of modern graphics cards you have to be very careful how you design and implement your code – a slightly sloppy, or inefficient function can make the difference between interactive and non-interactive graphics or more importantly it can determine what the lowest-spec PC you can ship your product for. The teams that work on the famous graphics engines – Doom/Quake/Unreal (all FPS games) spend months working on algorithms to fine tune and optimize rendering performance.

The techniques that graphics programmers employ to squeeze every last drop out of your GeForce-4 are often well documented online; check out the references section for some starting places. I can't go into detail on any of these techniques – and for the purposes of learning they'll only serve to confuse.

Issues When Rendering to the Screen

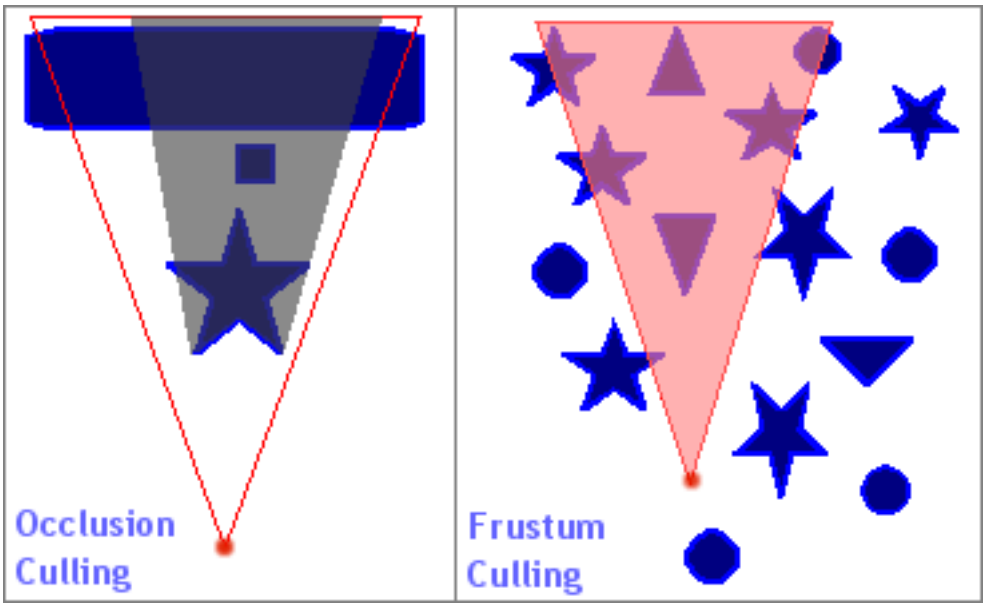
Draw order is one of the first problems that you can come across when you step into 3D graphics. I've mentioned draw order before – with respect to the depth buffer features. Whilst the depth buffer does a great job, it's far from perfect for all situations. There are two factors to be aware of.

Firstly, the Z-Buffer is only informed as far as what has *already* been rendered and has no knowledge regarding what will be rendered in the future; thus if you render a complex object and then render a simple cube in front of it (such that it blocks the camera's view of the complex object) *BOTH* objects will in fact be rendered – the depth buffer does not know (and hence will still allow rendering) that the first object will not be visible in the final image. This is known as overdraw – you can count overdraw for any pixel on the screen and you'll generally find that it's in the region of 2-3 (each pixel in the final image has been over drawn 2 or 3 times that frame). You can expect a certain degree of overdraw, but if forgotten about it can get out of control. Occlusion Culling/Queries have been introduced into D3D9 to allow some hardware to reduce this problem – but it's a fairly advanced topic.

The second factor to consider is that semi-transparent objects are very dependent on draw order, and the depth buffer cannot help them at all. If an object has a surface with semi-transparent textures or transparent areas (as discussed earlier in the texturing section) then it'll need to be drawn last. When the color is written to the screen using blending equations, it can only use the colors that already exist on the screen (objects rendered before). As a real-world example, if you render a window you need to render everything you can see through the window first. If you don't you'll end up with some objects being blurred/faded by the window, and some objects appearing completely normally (or not at all).

Another issue that you will come across as soon as you start creating large and/or complex worlds is that of invisible geometry. It's common-sense to realise that you only want to render objects that you'll actually see – any that are behind/beside the camera and can't be seen don't need to be rendered. If you do render these objects (commonly known as brute-force rendering) then you'll waste a huge amount of processing time. The objects will be 'removed' before any texturing, blending or shading operations are computed, but they will still be transformed, lit and clipped – and will also occupy a certain amount of memory bandwidth in the process. If you could avoid sending this geometry to be rendered you could cut out a lot of unnecessary work – which will make your application run much faster and/or can allow you to spend more time on the geometry that *does* appear on screen (more complex geometry, more textures, more special effects).

However, how do you tell which objects can/can't be rendered? This is quite a complicated area, and isn't included in this tutorial – but you can implement it fairly easily if you read through some sample code/tutorials available on the net. Frustum culling is a common technique and quite easy to understand, occlusion culling, portal culling, BSP Tree's, Quadtree's and Octree's are even more efficient but generally more complicated to understand and implement. The basic idea behind most of the algorithms is to 'reject' geometry at the application stage and before attempting any 3D-based rendering – any additional computing done by the application can be expensive but far outweighs the potential loss of rendering invisible geometry.

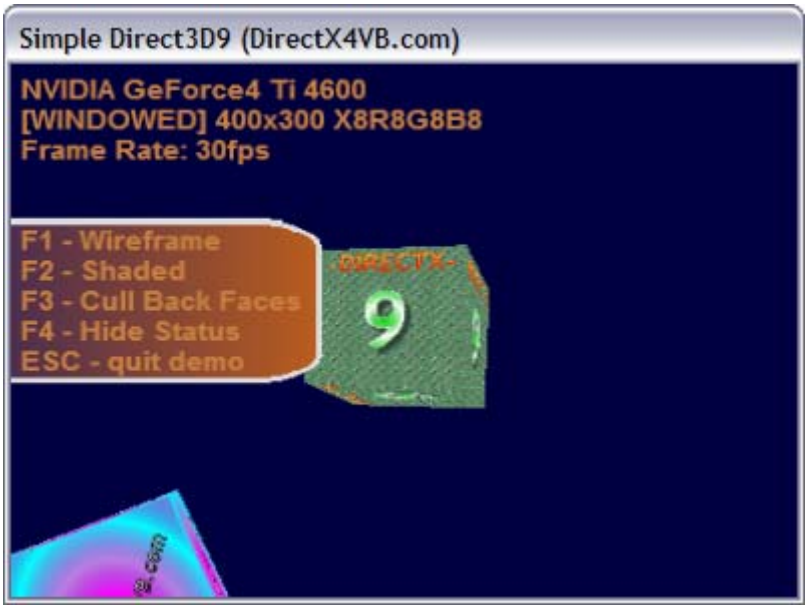


In the above image I've outlined (on the right) the most common type of culling and (on the left) one of the most advanced types of culling. Frustum culling works by testing all rendered objects (all of the blue stars, triangles and circles) against the visible area (the pink triangle); if an object is totally or partially in the pink area it is rendered, if it's outside the area it isn't rendered. In the above diagram 7 of the 15 objects will be rejected – reducing the number of objects transformed, lit and clipped by 47%. Occlusion culling works by taking each rendered object and creating an occluded zone (the dark gray area), almost like casting a shadow; all subsequent objects (such as the small blue square) are tested against this zone – if it's inside it is rejected, if it's outside it's rendered. This algorithm works best when you draw objects in a front-back order.

Completing the Engine: oneFrameRender()

Looking back to the original class definition we are left with only the `oneFrameRender()` function to handle all our rendering. `oneFrameUpdate()` did the necessary calculations, and now we just need to shift all the work over to the D3D runtimes/drivers/hardware. Based on the previous section, this is the place where you'd attempt early-rejection of invisible geometry and/or other optimization algorithms.

For the sample code we have only 4 piece of rendering to do – the 3D objects, a 2D menu and some text. The final result will look something like this:



The text is fairly obvious, the menu is the orange background with a white border and the 3D geometry is the two cubes you can see. One of the first things to notice in the image is the transparent area on the menu background. The right-most corners are both curved; and the areas outside the white border are transparent. This is shown up further by the fact you can see part of the green cube where the texture would normally be.

Before I show you the full code it is necessary to appreciate the most basic 3D rendering structure – the 4 D3D9 function calls that make up 99% of all rendering functions used on this planet:

```
Public Sub oneFrameRender()
    If Not bInitOkay Then Throw _
        New Exception("…")
    D3DDev.Clear(ClearFlags.Target Or ClearFlags.ZBuffer, _
                 Drawing.Color.FromArgb(255, 0, 0, 64), 1.0F, 0)

    D3DDev.BeginScene()

    D3DDev.EndScene()

    D3DDev.Present()
End Sub
```

The first line in the above framework just catches errors early – if the engine is not initalised properly then almost every D3D call made in this function will fail – so just to keep things simple: if the engine isn't initialised then we don't render.

The second line, `D3DDev.Clear(…)`, sets up the render target for us – clearing what was rendered in the last frame (although, it is likely to have been corrupted) and resets the depth buffer. You can achieve some interesting effects by altering this line (try removing Target or ZBuffer and see what happens) but in general you want to start each frame with a fresh canvas to work with. The first parameter tells D3D what parts of the rendering system you want cleared – Target, ZBuffer or Stencil. We're not using a stencil buffer so don't try to use that flag. The target refers to the color buffer (where the final image is stored) and the ZBuffer is the depth buffer. The second parameter indicates what color you want the target to be cleared to – this is the color that you'll see in any pixel that you haven't rendered over with geometry of some kind. In this example it's a dark blue color (alpha must be 255). The third parameter is the value to clear the ZBuffer to (you don't store any color information in the ZBuffer), this will always be a value in the range 0.0 to 1.0, and you will rarely need to use anything but 1.0F. The last parameter is the stencil clear value; we're not using stencil buffers so we can leave this as 0.

The third and fourth lines make a matching pair – you have to begin the scene (a scene is a single frame) and end it. All rendering (2D or 3D) should be done within this pair of lines. For more advanced tricks it is possible to use multiple begin/end scene calls, but you won't need to use this.

The final line, `Present()`, appears to be a very simple function call – but is incredibly important; without it you wont see anything on the screen. This function takes the image you've been rendering from the back buffer and displays it on the screen (as the front buffer) and then frees up the back buffer for you to use on the next frame. Direct3D doesn't actually copy the image that you've rendered (that would be to slow), instead it cycles a set of pointers around – effectively swapping the back-buffer and front-buffer over.

Back to the actual code that we'll be using in the sample…

Because of the draw-order issues regarding transparent textures we'll be rendering the two cubes first, then the menu bar and then the text. This draw order guarantees that everything will appear correctly on screen.

```
D3DDev.SetStreamSource(0, vbCube, 0)
D3DDev.VertexFormat = CustomVertex.PositionTextured.Format
```

The above two lines will configure the device to use the vertex data for the cube. Both cubes work with the same original geometry such that this pair of lines needs only be executed once. The first line just tells Direct3D where to find the vertex data and the second line tells Direct3D what format the data will be in (and what data each vertex contains).

```
If bRenderTextures Then
    D3DDev.SetTexture(0, texCube1)
Else
    D3DDev.SetTexture(0, Nothing)
End If
D3DDev.Transform.World = matCube1
D3DDev.DrawPrimitives(PrimitiveType.TriangleList, 0, 12)
```

This next set of lines actually renders the first cube. Once these lines are complete the cube will be drawn on the back buffer. The first conditional is just for the sample – pressing F2 will allow you to toggle textures on/off. The next part applies the transformation matrix to the device, telling Direct3D that all incoming vertex data should be transformed by `matCube1`. The last line actually renders the data, the first parameter is necessary to tell D3D how the vertices are

organised (see the geometry rendering section) and the second and third parameters tell D3D which part of the vertex buffer we want rendered. In our case we're rendering a list of 12 triangles starting at the first vertex in the stream. The second cube is rendered in an identical fashion, except it uses `texCube2` and `matCube2`.

```
Dim bPrev As Boolean = wireframe()
wireframe = False
D3DDev.RenderState.AlphaBlendEnable = True

D3DDev.SetStreamSource(0, vbMenu, 0)
D3DDev.VertexFormat = CustomVertex.TransformedTextured.Format
D3DDev.SetTexture(0, texMenu)
D3DDev.DrawPrimitives(PrimitiveType.TriangleStrip, 0, 2)

D3DDev.RenderState.AlphaBlendEnable = False
wireframe = bPrev
```

This next part renders the 2D menu. It's very similar to the previous code, but with a couple of subtle differences.

Firstly, we disable wire-frame rendering, it is possible for the user to toggle solid/wireframe rendering, but we only want this to apply to the 3D geometry. However, to guarantee correctly operation we have to cache the previous wireframe status (on/off) before changing it.

Secondly, we enable alpha blending – this tells Direct3D to use the color key operations configured in `initialiseDevice()` and specified in `loadTextures()`. The net result is that all magenta colored pixels will *not* be rendered.

At this point we have finished rendering all the geometry. Take time to notice that whilst they give very different results on-screen they are not very different when written in code. You must tell D3D where the geometry is located, you must tell it what format you're using, and you have to set the texture (if you're using textures that is).

The last part of oneFrameRender() that we need to look at is text rendering. Text is an often-required part of graphics applications but the method we're using (and that built into D3D) is not particularly efficient. For the amount of text shown in the sample code it wont matter – but for a game that relies heavily on displaying large amounts of text you can find it chokes. A custom text rendering system is often far more efficient (you can fine tune it to do only the things you want it to).

```
fntOut.DrawText("Frame Rate: " + iFrameRate.ToString + "fps", _
                New Drawing.Rectangle(5, 5 + (2 * (iFontSize + 6)), 0, 0), _
                DrawTextFormat.Left Or DrawTextFormat.Top, _
                Drawing.Color.FromArgb(255, 200, 128, 64))
```

The above code is reasonably simple and powerful. You specify the text to be rendered and the rectangle you want it rendered to (note, it will be clipped), the text drawing operations (e.g. Left/center/right aligned) and the color. The only complicated part is determining the size of the rectangle to use; trial-and-error is often sufficient – but as a rule of thumb take the font size and add 2 for the height. It might seem simpler to specify the whole screen as the rectangle (or a very large area) but this works out to be quite inefficient (it has implications further down the D3D runtime when it draws the text).

Using The Engine

We've now completed the engine. If it has been designed correctly we can now use it – and hopefully use it without any detailed knowledge of *how* it works. It would require a little more work, but we should be able to store `CSampleGraphicsEngine` in it's own library and import it into any project wanting to use its features.

Linking the Class to the Form

We must link the engine to a control system and we must link Direct3D to a windows form. The control system is necessary to keep the main loop executing and to allow the user to specify options (such as those presented with the F1-F4 keys in this sample program), and Direct3D needs a form (or picture) object to fit its rendered images into.

Because Direct3D handles all of the graphics for our sample we don't need our windows form to do anything special – it needs only "sit" there and act as a container for our graphics engine. In windowed mode it is possible to add other (normal) windows controls into the application like normal; however this isn't going to work properly when you switch to fullscreen. Unless you really need to, try not to mix windows controls and Direct3D together too much – it is possible, but it's slightly tricky (the SDK contains a sample on how to do this).

For this sample I used the default form created by VisualStudio.Net when you add a form to the project; I changed the settings such that you can't minimize/maximize/resize the window and left everything else alone. The rest is all done using code.

```
Private c3DEngine As CSampleGraphicsEngine
Private bRunning As Boolean = False
#Const RENDER_WINDOWED = 1
```

I added a conditional compilation option to switch between windowed and fullscreen initialisation; it would have been fairly easy to allow the user to specify each time they started the application. Because of this, initialisation of the class varies depending on which value the `RENDER_WINDOWED` constant has.

```
c3DEngine = New CSampleGraphicsEngine(Me)
```

Above is the simple windowed mode intialisation. The 2nd line is the only one that actually does anything – the rest are error handling.

The next piece of code handles fullscreen initialisation; it makes particular use of the shared function `isDisplayModeOkay()` defined in the `CSampleGraphicsEngine` class.

```
dim iW as Integer = 0, iH as Integer = 0, iD as Integer = 0
If CSampleGraphicsEngine.isDisplayModeOkay(1024, 768, 32) Then
    iW = 1024 : iH = 768 : iD = 32
ElseIf (CSampleGraphicsEngine.isDisplayModeOkay(1024, 768, 16)) Then
    iW = 1024 : iH = 768 : iD = 16
ElseIf (CSampleGraphicsEngine.isDisplayModeOkay(640, 480, 32)) Then
    iW = 640 : iH = 480 : iD = 32
ElseIf (CSampleGraphicsEngine.isDisplayModeOkay(640, 480, 16)) Then
    iW = 640 : iH = 480 : iD = 16
Else
    'no modes supported?!
    Throw New Exception("No supported display modes found")
End If

c3DEngine = New CSampleGraphicsEngine(Me, iW, iH, iD)
```

The sample only attempts 2 resolutions at the two commonly supported display modes, a real application would allow the user to select any of the supported resolutions at any of the supported depths. I only implemented it this way for simplicity.

We don't actually need error checking around the graphics engine initialisation calls – the whole of the procedure is wrapped in a try…catch block such that they will pick up (and dispose of) the error.

Once we've created a valid reference to the `CSampleGraphicsEngine` class we can go about configuring it. This is where we access the public properties we created earlier to control how the 3D engine will work.

```
'set the initial properties for the engine
c3DEngine.backFaceCulling = False
c3DEngine.drawFrameRate = True
c3DEngine.useTextures = True
c3DEngine.wireframe = False

bRunning = True
```

All fairly simple really – the initial properties set above will yield what you'd expect to see from a 3D graphics engine.

The next part is the interesting part – the main application loop. High performance multimedia applications generally work by bolting through all relevant code as fast as is possible on the current hardware. In this sample we only have to worry about graphics, such that as soon as we finish one frame we start on the next frame. This is effectively an extremely tight loop:

```
Do While bRunning
    'these two functions do all the work,
    c3DEngine.oneFrameUpdate()
    c3DEngine.oneFrameRender()
    Application.DoEvents()
Loop
```

It is necessary to include the `DoEvents()` call – this allows the operating system time to breathe and do any maintenance jobs; without it the application *can* run faster but it wont process user input properly and can lead to an unstable system.

The loop will loop infinitely until the `bRunning` variable becomes false, we use this flag to control termination – class destructors and the .Net framework will

generally clean up if we allow the user to click on the close button, but it removes any control that we have over correctly unloading data.

The code mentioned thus far is all we need to get the graphics engine up and running, however there are a few loose ends left to tie up. User input is still not handled – we need to allow the user to press buttons and get results.

We can use the .Net frameworks built in keyboard handling functions for the windows form object to do this job:

```
Protected Overrides Sub OnKeyDown(ByVal e As System.Windows.Forms.KeyEventArgs)
    Select Case e.KeyCode
        Case Keys.Escape
            bRunning = False
        Case Keys.F1
            c3DEngine.wireframe = Not c3DEngine.wireframe
        Case Keys.F2
            c3DEngine.useTextures = Not c3DEngine.useTextures
        Case Keys.F3
            c3DEngine.backFaceCulling = Not c3DEngine.backFaceCulling
        Case Keys.F4
            c3DEngine.drawFrameRate = Not c3DEngine.drawFrameRate
    End Select
End Sub
```

With all this code in place, we have a complete and working Direct3D9 sample application!

Conclusion

Now that we've covered all the code and theory for this tutorial the only thing left is to conclude…

What you Should Have Learnt

In this tutorial you should have become familiar with:

1. basic 3D theory; how a scene is built up (vertices, triangles etc…) and most of the keywords associated with this field.
2. How Direct3D9 works and how it integrates with your system (drivers, hardware, OS configuration etc…)
3. How to set up a simple Direct3D9 interface ready for you to work with.
4. How to create geometry manually
5. How to load textures of varying configurations
6. How to set up a simple matrix transformation for 3D geometry and learnt the associated rules.
7. learnt the rules and theory of rendering geometry to the screen (in particular draw order and invisible geometry)

Hopefully the way that I divided this tutorial up allows you to isolate individual parts and re-read them if necessary.

What to do Next

Bare in mind that from the outset this tutorial could not (and did not intend to) teach you everything about Direct3D9 managed code. If this is your first taster of D3D then you're only a few steps down an extremely long path – there is a lot more to learn yet.

The next step is to make your own version of this tutorial code. Use my class outline as a template and try something a little more complicated; try creating a simple 3D world using simple 3D geometry.

However, the next step is ***not*** to start work on your own "simple quake-like game". I can't stress how many emails I get from people who've only just started with D3D and want to work on commercial-level projects. It isn't going to happen that quickly. The only way it will happen is if you're a veteran of a previous graphics-programming library (Direct3D, OpenGL, Glide or software).

Once you're familiar with the basics – branch out a bit; try something a little more complicated (a full, yet simple game). You need only try something a little more adventurous to add a huge number of new challenges. Real games require mathematics, physics and algorithms – make sure you're ready to meet their demands as and when they crop up.

Other Resources to Look at

Your key resource is the Internet. Books are great but they're quite expensive – there are a few books (see the references section below) that are worth the asking price, but they're often for the more advanced programmers. The internet has a great wealth of sites like mine that host tutorials for all types of developers trying to do all types of things. Web forums and newsgroups are also a key resource – finding a website that you can ask questions (and eventually answers other peoples questions) and get a good response is often worth more than an individual tutorial.

All told, I really hope you've enjoyed this tutorial. Feel free to drop me an email: Jack.Hoxley@DirectX4VB.com - I always like to hear from people who've made good use of the tutorials I write.

About Me

My name, as you've probably guessed is Jack Hoxley – I'm currently studying for my BSc. Computer Science degree at the University of Nottingham, England. Whilst I do work hard for my degree I still find myself with a substantial amount of spare time ☺ which, if not for sleeping/socializing/partying, is often spent reading further into the two areas of computer programming that interest me: Graphics and Artificial Intelligence.

For some years now I've been messing around with various types of graphics engines and AI systems – seeing if I can/can't implement certain types of algorithms and generally experimenting to see what happens. For the last year (at time of writing) I've been working with a team of dedicated Formula-1 racing fanatics to create the ultimate F1 management simulation – F1CM. Hopefully that'll be in the stores sometime in 2003.

I've also (as mentioned earlier) been participating in the DirectX9 beta program for the last 6 months, which has greatly advanced my knowledge of the API.

Acknowledgements

I'd like to mention the following people/groups of people and sources (in no particular order):

The Microsoft DirectX Developers
The DirectX9 beta developers
The Visual Basic gaming community
Any other developers I've come across in my travels.
The visitors to my website

References

The following list contains a few of the books and sources I've found useful in extending my knowledge of computer graphics.

Web resources

www.GameDev.Net - high quality articles and a reasonable forum (if only they'd ban anonymous posting!)

www.FlipCode.com - good for news and the image-of-the-day gallery.

www.Gamasutra.com - best source for games-industry news and articles.

www.mwgames.com/voodoovb/ - a good site with a great forum for meeting other VB multimedia programmers

www.rookscape.com/vbgaming/ - lucky's ever-popular site, no recent content but some great web forums.

www.DirectX4VB.com - how could I not mention my own website yet again? ☺

Books

None of these books directly contributed to the tutorial text, I've included them because they've proven to be useful to me on many occasions – they are my favorite/recommended books. All of these have been reviewed by myself and can be viewed here: http://www.DirectX4VB.com/reviews.asp

Real-Time Rendering 2nd Edition
Tomas Akenine-Möller & Eric Haines
ISBN: 1-56881-182-9

Mathematics for 3D Game Programming & Computer Graphics
Eric Lengyel
ISBN: 1-58450-037-9

Visual Basic Game Programming with DirectX
Jonathon S. Harbour
ISBN: 1-931841-25-X

Real-Time Rendering Tricks and Techniques in DirectX
Kelly Dempski
ISBN: 1-931841-27-6

Special Effects Game Programming with DirectX
Mason McCuskey
ISBN: 1-931841-06-3

Disclaimer

This tutorial was written entirely by me – including the source code. It's draws together some of the ideas I've highlighted in other tutorials on my site, but where I've quoted from (or used) content from other sites I've mentioned it.

The bottom line is: I don't get paid for this (or make any money), I do this in my spare time (of which I don't have a huge amount, this tutorial took me almost 20hrs to write), please don't give me too much grief regarding little errors – I try my best! Feel free to email me regarding any little bugs/mistakes, but I cant guarantee I'll get a chance to update the text. The source code was tested on as many systems as possible and is known to work on compatible systems – this doesn't necessarily mean it'll work on your system.

Distribution

I don't mind if you distribute this pdf document or the source code, but they must remain intact and I wish to retain full credit for the work contained within. If you are going to host this document on your website/server please send me an email – just so I can keep track of who has a copy…