```
// ********************************************************************************
***************
// This is a program for teaching Vulkan
// As such, it is deliberately verbose so that it is obvious (as possible, at least) wh
at is being done
//
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//
// The class notes for which this program was written can be found here:
//      http://cs.oregonstate.edu/~mjb/cs519v
//
// Keyboard commands:
//      'i', 'I': Toggle using the mouse for object rotation
//      'm', 'M': Toggle display mode (textures vs. colors, for now)
//      'p', 'P': Pause the animation
//      'q', 'Q', Esc: exit the program
//
// Latest update: January 9, 2018
// ********************************************************************************
***************



// *********
// INCLUDES:
// *********

#ifdef _WIN32
#include <io.h>
#endif
#include <stdlib.h>
#include <stdio.h>
//#include <unistd.h>
#include <math.h>
#ifndef M_PI
#define M_PI  3.14159265f
#endif
#include <stdarg.h>
#include <string.h>
#include <string>
#include <stdbool.h>
#include <assert.h>
#include <signal.h>

#ifndef _WIN32
typedef int errno_t;
int     fopen_s( FILE**, const char *, const char * );
#endif

#define GLFW_INCLUDE_VULKAN
#include "glfw3.h"

#define GLM_FORCE_RADIANS
#define GLM_FORCE_DEPTH_ZERO_TO_ONE
#include "glm/vec2.hpp"
#include "glm/vec3.hpp"
#include "glm/mat4x4.hpp"
#include "glm/gtc/matrix_transform.hpp"
#include "glm/gtc/matrix_inverse.hpp"
//#include "glm/gtc/type_ptr.hpp"

#ifdef _WIN32
#pragma comment(linker, "/subsystem:windows")
#define APP_NAME_STR_LEN 80
```

```
#endif

#include "vulkan.h"
#include "vk_sdk_platform.h"

// these are here to flag why addresses are being passed into a vulkan function --
// 1. is it because the function wants to consume the contents of that tructure or arra
y (IN)?
// or, 2. is it because that function is going to fill that staructure or array (OUT)?
#define IN
#define OUT
#define INOUT



// ******************
// DEFINED CONSTANTS:
// ******************

// useful stuff:

#define DEBUGFILE               "VulkanDebug.txt"
#define nullptr                 (void *)NULL
#define MILLION                 1000000L
#define BILLION                 1000000000L
#define TEXTURE_COUNT           1
#define APP_SHORT_NAME          "cube"
#define APP_LONG_NAME           "Vulkan Cube Demo Program"

#define SECONDS_PER_CYCLE       3.f
#define FRAME_LAG               2
#define SWAPCHAINIMAGECOUNT     2


// multiplication factors for input interaction:
// //  (these are known from previous experience)

const float ANGFACT = { M_PI/180.f };
const float SCLFACT = { 0.005f };


// minimum allowable scale factor:

const float MINSCALE = { 0.05f };


// active mouse buttons (or them together):

const int LEFT   = { 4 };
const int MIDDLE = { 2 };
const int RIGHT  = { 1 };


// the allocation callbacks could look like this:
//typedef struct VkAllocationCallbacks {
//void*                                   pUserData;
//PFN_vkAllocationFunction                pfnAllocation;
//PFN_vkReallocationFunction              pfnReallocation;
//PFN_vkFreeFunction                      pfnFree;
//PFN_vkInternalAllocationNotification    pfnInternalAllocation;
//PFN_vkInternalFreeNotification          pfnInternalFree;
//} VkAllocationCallbacks;
// but we are not going to use them for now:
#define PALLOCATOR              (VkAllocationCallbacks *)nullptr
```

```
// report on a result return:

#define REPORT(s)               { PrintVkError( result, s );  fflush(FpDebug); }
#define HERE_I_AM(s)            if( Verbose )  { fprintf( FpDebug, "\n***** %s *****\n"
, s );  fflush(FpDebug); }


// graphics parameters:

const double FOV =              glm::radians(60.);      // field-of-view angle
const float EYEDIST =           3.;                     // eye distance
const float OMEGA =             2.*M_PI;                // angular velocity, radians/se
c

#define SPIRV_MAGIC             0x07230203
// if you do an od -x, the magic number looks like this:
// 0000000 0203 0723 . . .

#define NUM_QUEUES_WANTED       1

#define ARRAY_SIZE(a)           (sizeof(a) / sizeof(a[0]))

// these are here for convenience and readability:
#define VK_FORMAT_VEC4          VK_FORMAT_R32G32B32A32_SFLOAT
#define VK_FORMAT_XYZW          VK_FORMAT_R32G32B32A32_SFLOAT
#define VK_FORMAT_VEC3          VK_FORMAT_R32G32B32_SFLOAT
#define VK_FORMAT_STP           VK_FORMAT_R32G32B32_SFLOAT
#define VK_FORMAT_XYZ           VK_FORMAT_R32G32B32_SFLOAT
#define VK_FORMAT_VEC2          VK_FORMAT_R32G32_SFLOAT
#define VK_FORMAT_ST            VK_FORMAT_R32G32_SFLOAT
#define VK_FORMAT_XY            VK_FORMAT_R32G32_SFLOAT
#define VK_FORMAT_FLOAT         VK_FORMAT_R32_SFLOAT
#define VK_FORMAT_S             VK_FORMAT_R32_SFLOAT
#define VK_FORMAT_X             VK_FORMAT_R32_SFLOAT

// my own error codes:
#define VK_FAILURE              (VkResult)( -2000000000 )
#define VK_SHOULD_EXIT          (VkResult)( -2000000001 )
#define VK_ERROR_SOMETHING_ELSE (VkResult)( -2000000002 )
```

```
// ***********************************************
// MY HELPER TYPEDEFS AND STRUCTS FOR VULKAN WORK:
// ***********************************************

typedef VkBuffer                VkDataBuffer;
typedef VkDevice                VkLogicalDevice;
typedef VkDeviceCreateInfo      VkLogicalDeviceCreateInfo;
#define vkCreateLogicalDevice   vkCreateDevice


// holds all the information about a data buffer so it can be encapsulated in one varia
ble:

typedef struct MyBuffer
{
        VkDataBuffer            buffer;
        VkDeviceMemory          vdm;
        VkDeviceSize            size;
} MyBuffer;


typedef struct MyTexture
{
        uint32_t                        width;
        uint32_t                        height;
        unsigned char *                 pixels;
        VkImage                         texImage;
        VkImageView                     texImageView;
        VkSampler                       texSampler;
        VkDeviceMemory                  vdm;
} MyTexture;



// bmp file headers:
struct bmfh
{
        short bfType;
        int bfSize;
        short bfReserved1;
        short bfReserved2;
        int bfOffBits;
} FileHeader;


struct bmih
{
        int biSize;
        int biWidth;
        int biHeight;
        short biPlanes;
        short biBitCount;
        int biCompression;
        int biSizeImage;
        int biXPelsPerMeter;
        int biYPelsPerMeter;
        int biClrUsed;
        int biClrImportant;
} InfoHeader;



// ****************************
```

```
// STRUCTS FOR THIS APPLICATION:
// ****************************

// uniform variable block:

struct matBuf
{
        glm::mat4 uModelMatrix;
        glm::mat4 uViewMatrix;
        glm::mat4 uProjectionMatrix;
        glm::mat3 uNormalMatrix;
};


// uniform variable block:

struct lightBuf
{
        glm::vec4 uLightPos;
};


// uniform variable block:

struct miscBuf
{
        float uTime;
        int   uMode;
};


// an array of this struct will hold all vertex information:

struct vertex
{
        glm::vec3       position;
        glm::vec3       normal;
        glm::vec3       color;
        glm::vec2       texCoord;
};
```

```
// ********************************
// VULKAN-RELATED GLOBAL VARIABLES:
// ********************************

VkCommandBuffer                 CommandBuffers[2];                      // 2, because o
f double-buffering
VkCommandPool                   CommandPool;
VkPipeline                      ComputePipeline;
VkPipelineCache                 ComputePipelineCache;
VkPipelineLayout                ComputePipelineLayout;
VkDataBuffer                    DataBuffer;
VkImage                         DepthImage;
VkImageView                     DepthImageView;
VkDescriptorSetLayout           DescriptorSetLayouts[4];
VkDescriptorSet                 DescriptorSets[4];
VkDebugReportCallbackEXT        ErrorCallback = VK_NULL_HANDLE;
VkEvent                         Event;
VkFence                         Fence;
VkDescriptorPool                DescriptorPool;
VkFramebuffer                   Framebuffers[2];
VkPipeline                      GraphicsPipeline;
VkPipelineCache                 GraphicsPipelineCache;
VkPipelineLayout                GraphicsPipelineLayout;
uint32_t                        Height;
VkInstance                      Instance;
VkExtensionProperties *         InstanceExtensions;
VkLayerProperties *             InstanceLayers;
VkLogicalDevice                 LogicalDevice;
GLFWwindow *                    MainWindow;
VkPhysicalDevice                PhysicalDevice;
VkPhysicalDeviceProperties      PhysicalDeviceProperties;
uint32_t                        PhysicalDeviceCount;
VkPhysicalDeviceFeatures        PhysicalDeviceFeatures;
VkImage *                       PresentImages;
VkImageView *                   PresentImageViews;      // the swap chain image views
VkQueue                         Queue;
VkRect2D                        RenderArea;
VkRenderPass                    RenderPass;
VkSemaphore                     SemaphoreImageAvailable;
VkSemaphore                     SemaphoreRenderFinished;
VkShaderModule                  ShaderModuleFragment;
VkShaderModule                  ShaderModuleVertex;
VkBuffer                        StagingBuffer;
VkDeviceMemory                  StagingBufferMemory;
VkSurfaceKHR                    Surface;
VkSwapchainKHR                  SwapChain;
VkCommandBuffer                 TextureCommandBuffer;   // used for transfering texture
 from staging buffer to actual texture buffer
VkImage                         TextureImage;
VkDeviceMemory                  TextureImageMemory;
VkDebugReportCallbackEXT        WarningCallback;
uint32_t                        Width;


#include "SampleVertexData.cpp"



// ************************************
// APPLICATION-RELATED GLOBAL VARIABLES:
// ************************************

int                             ActiveButton;                   // current button that
is down
```

```
FILE *                          FpDebug;                        // where to send debugg
ing messages
struct lightBuf                 Light;                          // cpu struct to hold l
ight information
struct matBuf                   Matrices;                       // cpu struct to hold m
atrix information
struct miscBuf                  Misc;                           // cpu struct to hold m
iscellaneous information information
int                             Mode;                           // 0 = use colors, 1 =
use textures, ...
MyBuffer                        MyLightUniformBuffer;
MyTexture                       MyPuppyTexture;                 // the cute puppy textu
re struct
MyBuffer                        MyMatrixUniformBuffer;
MyBuffer                        MyMiscUniformBuffer;
MyBuffer                        MyVertexDataBuffer;
bool                            NeedToExit;                     // true means the progr
am should exit
int                             NumRenders;                     // how many times the r
ender loop has been called
bool                            Paused;                         // true means don't ani
mate
float                           Scale;                          // scaling factor
double                          Time;
bool                            Verbose;                        // true = write message
s into a file
int                             Xmouse, Ymouse;                 // mouse values
float                           Xrot, Yrot;                     // rotation angles in d
egrees
bool                            UseMouse;                       // true = use mouse for
 interaction, false = animate
```

```
// ********************
// FUNCTION PROTOTYPES:
// ********************

VkResult                        DestroyAllVulkan( );

//VkBool32                      ErrorCallback( VkDebugReportFlagsEXT, VkDebugReportObje
ctTypeEXT, uint64_t, size_t, int32_t, const char *, const char *, void * );

int                             FindMemoryThatIsDeviceLocal( );
int                             FindMemoryThatIsHostVisible( );
int                             FindMemoryWithTypeBits( uint32_t );

void                            InitGraphics( );

VkResult                        Init01Instance( );

VkResult                        Init02CreateDebugCallbacks( );

VkResult                        Init03PhysicalDeviceAndGetQueueFamilyProperties( );

VkResult                        Init04LogicalDeviceAndQueue( );

VkResult                        Init05DataBuffer( VkDeviceSize, VkBufferUsageFlags, OUT
 MyBuffer * );
VkResult                        Init05UniformBuffer( VkDeviceSize, OUT MyBuffer * );
VkResult                        Init05MyVertexDataBuffer( VkDeviceSize, OUT MyBuffer *
);
VkResult                        Fill05DataBuffer( IN MyBuffer, IN void * );

VkResult                        Init06CommandPool( );
VkResult                        Init06CommandBuffers( );

VkResult                        Init07TextureSampler( OUT MyTexture * );
VkResult                        Init07TextureBuffer( INOUT MyTexture * );

VkResult                        Init07TextureBufferAndFillFromBmpFile( IN std::string,
OUT MyTexture * );

VkResult                        Init08Swapchain( );

VkResult                        Init09DepthStencilImage( );

VkResult                        Init10RenderPasses( );

VkResult                        Init11Framebuffers( );

VkResult                        Init12SpirvShader( std::string, OUT VkShaderModule * );

VkResult                        Init13DescriptorSetPool( );
VkResult                        Init13DescriptorSetLayouts( );
VkResult                        Init13DescriptorSets( );

VkResult                        Init14GraphicsPipelineLayout( );
VkResult                        Init14GraphicsVertexFragmentPipeline( VkShaderModule, V
kShaderModule, VkPrimitiveTopology, OUT VkPipeline * );
VkResult                        Init14ComputePipeline( VkShaderModule, OUT VkPipeline *
 );


VkResult                        RenderScene( );
void                            UpdateScene( );
//VkBool32                      WarningCallback( VkDebugReportFlagsEXT, VkDebugReportOb
jectTypeEXT, uint64_t, size_t, int32_t, const char *, const char *, void * );
```

```
void                            PrintVkError( VkResult, std::string = "" );
void                            Reset( );

void                            InitGLFW( );
void                            GLFWErrorCallback( int, const char * );
void                            GLFWKeyboard( GLFWwindow *, int, int, int, int );
void                            GLFWMouseButton( GLFWwindow *, int, int, int );
void                            GLFWMouseMotion( GLFWwindow *, double, double );
double                          GLFWGetTime( );

int                             ReadInt( FILE * );
short                           ReadShort( FILE * );
```

```
// *************
// MAIN PROGRAM:
// *************


int
main( int argc, char * argv[ ] )
{
        Width  = 1024;
        Height = 1024;

        //FpDebug = stderr;
        errno_t err = fopen_s( &FpDebug, DEBUGFILE, "w" );
        if( err != 0 )
        {
                fprintf( stderr, "Cannot open debug print file '%s'\n", DEBUGFILE );
                FpDebug = stderr;
        }
        else
        {
                //int old = _dup(2);
                //_dup2( _fileno(FpDebug), 2 );
        }
        fprintf(stderr,  "stderr:  Width = %d ; Height = %d\n", Width, Height);
        fprintf(FpDebug, "FpDebug: Width = %d ; Height = %d\n", Width, Height);

        Reset( );
        InitGraphics( );


        // loop until the user closes the window:

        while( glfwWindowShouldClose( MainWindow ) == 0 )
        {
                glfwPollEvents( );
                Time = glfwGetTime( );          // elapsed time, in double-precision se
conds
                UpdateScene( );
                RenderScene( );
                if( NeedToExit )
                        break;
        }

        fprintf(FpDebug, "Closing the GLFW window\n");

        vkQueueWaitIdle( Queue );
        vkDeviceWaitIdle( LogicalDevice );
        DestroyAllVulkan( );
        glfwDestroyWindow( MainWindow );
        glfwTerminate( );
        return 0;
}
```

```
void
InitGraphics( )
{
	HERE_I_AM( "InitGraphics" );

	VkResult result = VK_SUCCESS;

	Init01Instance( );

	InitGLFW( );

	Init02CreateDebugCallbacks( );

	Init03PhysicalDeviceAndGetQueueFamilyProperties( );

	Init04LogicalDeviceAndQueue( );

	Init05UniformBuffer( sizeof(Matrices),   &MyMatrixUniformBuffer );
	Fill05DataBuffer( MyMatrixUniformBuffer,(void *) &Matrices );

	Init05UniformBuffer( sizeof(Light),      &MyLightUniformBuffer );
	Fill05DataBuffer( MyLightUniformBuffer, (void *) &Light );

	Init05UniformBuffer( sizeof(Misc),      &MyMiscUniformBuffer );
	Fill05DataBuffer( MyMiscUniformBuffer,  (void *) &Misc );

	Init05MyVertexDataBuffer(  sizeof(VertexData), &MyVertexDataBuffer );
	Fill05DataBuffer( MyVertexDataBuffer,                  (void *) VertexData );

	Init06CommandPool();
	Init06CommandBuffers();

	Init07TextureSampler( &MyPuppyTexture );
	Init07TextureBufferAndFillFromBmpFile("puppy.bmp", &MyPuppyTexture);

	Init08Swapchain( );

	Init09DepthStencilImage( );

	Init10RenderPasses( );

	Init11Framebuffers( );

	Init12SpirvShader( "sample-vert.spv", &ShaderModuleVertex );
	Init12SpirvShader( "sample-frag.spv", &ShaderModuleFragment );

	Init13DescriptorSetPool( );
	Init13DescriptorSetLayouts();
	Init13DescriptorSets( );

	Init14GraphicsVertexFragmentPipeline( ShaderModuleVertex, ShaderModuleFragment,
 VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST, &GraphicsPipeline  );
}
```

```
// **********************
// CREATING THE INSTANCE:
// **********************

VkResult
Init01Instance( )
{
	HERE_I_AM( "Init01Instance" );

	VkResult result = VK_SUCCESS;

	VkApplicationInfo vai;
		vai.sType = VK_STRUCTURE_TYPE_APPLICATION_INFO;
		vai.pNext = nullptr;
		vai.pApplicationName = "Vulkan Sample";
		vai.applicationVersion = 100;
		vai.pEngineName = "";
		vai.engineVersion = 1;
		vai.apiVersion = VK_MAKE_VERSION(1, 0, 0);


	// these are the layers and extensions we would like to have:

	const char * instanceLayers[ ] =
	{
		////"VK_LAYER_LUNARG_api_dump",
		////"VK_LAYER_LUNARG_core_validation",
		//"VK_LAYER_LUNARG_image",
		"VK_LAYER_LUNARG_object_tracker",
		"VK_LAYER_LUNARG_parameter_validation",
		//"VK_LAYER_NV_optimus"
	};

	const char * instanceExtensions[ ] =
	{
		"VK_KHR_surface",
		"VK_KHR_win32_surface",
		"VK_EXT_debug_report"
		//"VK_KHR_swapchains"
	};

	// see what layers are available:

	uint32_t count;
	vkEnumerateInstanceLayerProperties( &count, (VkLayerProperties *)nullptr );
	InstanceLayers = new VkLayerProperties[ count ];
	result = vkEnumerateInstanceLayerProperties( &count, InstanceLayers );
	REPORT( "vkEnumerateInstanceLayerProperties" );
	if( result != VK_SUCCESS )
	{
		return result;
	}

	fprintf( FpDebug, "\n%d instance layers enumerated:\n", count );
	for( unsigned int i = 0; i < count; i++ )
	{
		fprintf( FpDebug, "0x%08x  %2d  '%s'  '%s'\n",
			InstanceLayers[i].specVersion,
			InstanceLayers[i].implementationVersion,
			InstanceLayers[i].layerName,
			InstanceLayers[i].description );
	}

	// see what extensions are available:
```

```
	vkEnumerateInstanceExtensionProperties( (char *)nullptr, &count, (VkExtensionPr
operties *)nullptr );
	InstanceExtensions = new VkExtensionProperties[ count ];
	result = vkEnumerateInstanceExtensionProperties( (char *)nullptr, &count, Insta
nceExtensions );
	REPORT( "vkEnumerateInstanceExtensionProperties" );
	if( result != VK_SUCCESS )
	{
		return result;
	}

	fprintf( FpDebug, "\n%d extensions enumerated:\n", count );
	for( unsigned int i = 0; i < count; i++ )
	{
		fprintf( FpDebug, "0x%08x  '%s'\n",
			InstanceExtensions[i].specVersion,
			InstanceExtensions[i].extensionName );
	}


	// create the instance, asking for the layers and extensions:

	VkInstanceCreateInfo vici;
		vici.sType = VK_STRUCTURE_TYPE_INSTANCE_CREATE_INFO;
		vici.pNext = nullptr;
		vici.flags = 0;
		vici.pApplicationInfo = &vai;
		vici.enabledLayerCount = sizeof(instanceLayers) / sizeof(char *);
		vici.ppEnabledLayerNames = instanceLayers;
		vici.enabledExtensionCount = sizeof(instanceExtensions) / sizeof(char *
);
		vici.ppEnabledExtensionNames = instanceExtensions;

	result = vkCreateInstance( IN &vici, PALLOCATOR, OUT &Instance );
	REPORT( "vkCreateInstance" );
	return result;
}



// ***************************
// CREATE THE DEBUG CALLBACKS:
// ***************************

VkResult
Init02CreateDebugCallbacks( )
{
	HERE_I_AM( "Init02CreateDebugCallbacks" );

	VkResult result = VK_SUCCESS;

	PFN_vkCreateDebugReportCallbackEXT vkCreateDebugReportCallbackEXT = (PFN_vkCrea
teDebugReportCallbackEXT)nullptr;
	*(void **) &vkCreateDebugReportCallbackEXT = vkGetInstanceProcAddr( Instance, "
vkCreateDebugReportCallbackEXT" );

#ifdef NOTDEF
	VkDebugReportCallbackCreateInfoEXT		vdrcci;
		vdrcci.sType = VK_STRUCTURE_TYPE_DEBUG_REPORT_CREATE_INFO_EXT;
		vdrcci.pNext = nullptr;
		vdrcci.flags = VK_DEBUG_REPORT_ERROR_BIT_EXT;
		vdrcci.pfnCallback = (PFN_vkDebugReportCallbackEXT) &DebugReportCallbac
k;
		vdrcci.pUserData = nullptr;
```

```
        result = vkCreateDebugReportCallbackEXT( Instance, IN &vdrcci, PALLOCATOR, OUT
&ErrorCallback );
        REPORT( "vkCreateDebugReportCallbackEXT - 1" );

                vdrcci.flags = VK_DEBUG_REPORT_WARNING_BIT_EXT | VK_DEBUG_REPORT_PERFOR
MANCE_WARNING_BIT_EXT;

        result = vkCreateDebugReportCallbackEXT( Instance, IN &vdrcci, PALLOCATOR, OUT
&WarningCallback );
        REPORT( "vkCreateDebugReportCallbackEXT - 2" );
#endif

        return result;
}



#ifdef NOTYET
PFN_vkDebugReportCallbackEXT
DebugReportCallback(VkDebugReportFlagsEXT flags, VkDebugReportObjectTypeEXT objectType,
        uint64_t object, size_t location, int32_t messageCode,
        const char *  pLayerPrefix, const char *  pMessage, void * pUserData)
{
}



VkBool32
ErrorCallback(  VkDebugReportFlagsEXT flags, VkDebugReportObjectTypeEXT objectType,
                        uint64_t object, size_t location, int32_t messageCode,
                        const char *  pLayerPrefix, const char *  pMessage, void * pUse
rData )
{
        fprintf( FpDebug, "ErrorCallback: ObjectType = 0x%0x ; object = %ld ; LayerPref
ix = '%s' ; Message = '%s'\n", objectType, object, pLayerPrefix, pMessage );
        return VK_TRUE;
}


VkBool32
WarningCallback( VkDebugReportFlagsEXT flags, VkDebugReportObjectTypeEXT objectType,
                        uint64_t object, size_t location, int32_t messageCode,
                        const char *  pLayerPrefix, const char *  pMessage, void * pUse
rData )
{
        fprintf( FpDebug, "WarningCallback: ObjectType = 0x%0x ; object = %ld ; LayerPr
efix = '%s' ; Message = '%s'\n", objectType, object, pLayerPrefix, pMessage );
        return VK_TRUE;
}
#endif
```

```
// ************************************************************
// FINDING THE PHYSICAL DEVICES AND GET QUEUE FAMILY PROPERTIES:
// ************************************************************

VkResult
Init03PhysicalDeviceAndGetQueueFamilyProperties( )
{
	HERE_I_AM( "Init03PhysicalDeviceAndGetQueueFamilyProperties" );

	VkResult result = VK_SUCCESS;

	result = vkEnumeratePhysicalDevices( Instance, OUT &PhysicalDeviceCount, (VkPhy
sicalDevice *)nullptr );
	REPORT( "vkEnumeratePhysicalDevices - 1" );
	if( result != VK_SUCCESS || PhysicalDeviceCount <= 0 )
	{
		fprintf( FpDebug, "Could not count the physical devices\n" );
		return VK_SHOULD_EXIT;
	}

	fprintf(FpDebug, "\n%d physical devices found.\n", PhysicalDeviceCount);

	VkPhysicalDevice * physicalDevices = new VkPhysicalDevice[ PhysicalDeviceCount
];
	result = vkEnumeratePhysicalDevices( Instance, OUT &PhysicalDeviceCount, OUT ph
ysicalDevices  );
	REPORT( "vkEnumeratePhysicalDevices - 2" );
	if( result != VK_SUCCESS )
	{
		fprintf( FpDebug, "Could not enumerate the %d physical devices\n", Phys
icalDeviceCount );
		return VK_SHOULD_EXIT;
	}

	int discreteSelect   = -1;
	int integratedSelect = -1;
	for( unsigned int i = 0; i < PhysicalDeviceCount; i++ )
	{
		VkPhysicalDeviceProperties vpdp;
		vkGetPhysicalDeviceProperties( IN physicalDevices[i], OUT &vpdp );
		if( result != VK_SUCCESS )
		{
			fprintf( FpDebug, "Could not get the physical device properties
 of device %d\n", i );
			return VK_SHOULD_EXIT;
		}

		fprintf( FpDebug, " \n\nDevice %2d:\n", i );
		fprintf( FpDebug, "\tAPI version: %d\n", vpdp.apiVersion );
		fprintf( FpDebug, "\tDriver version: %d\n", vpdp.apiVersion );
		fprintf( FpDebug, "\tVendor ID: 0x%04x\n", vpdp.vendorID );
		fprintf( FpDebug, "\tDevice ID: 0x%04x\n", vpdp.deviceID );
		fprintf( FpDebug, "\tPhysical Device Type: %d =", vpdp.deviceType );
		if( vpdp.deviceType == VK_PHYSICAL_DEVICE_TYPE_DISCRETE_GPU )   fprintf
( FpDebug, " (Discrete GPU)\n" );
		if( vpdp.deviceType == VK_PHYSICAL_DEVICE_TYPE_INTEGRATED_GPU ) fprintf
( FpDebug, " (Integrated GPU)\n" );
		if( vpdp.deviceType == VK_PHYSICAL_DEVICE_TYPE_VIRTUAL_GPU )    fprintf
( FpDebug, " (Virtual GPU)\n" );
		if( vpdp.deviceType == VK_PHYSICAL_DEVICE_TYPE_CPU )            fprintf
( FpDebug, " (CPU)\n" );
		fprintf( FpDebug, "\tDevice Name: %s\n", vpdp.deviceName );
		fprintf( FpDebug, "\tPipeline Cache Size: %d\n", vpdp.pipelineCacheUUID
[0] );
```

```
                //fprintf( FpDebug, "?", vpdp.limits );
                //fprintf( FpDebug, "?", vpdp.sparseProperties );

                // need some logical here to decide which physical device to select:

                if( vpdp.deviceType == VK_PHYSICAL_DEVICE_TYPE_DISCRETE_GPU )
                        discreteSelect = i;

                if( vpdp.deviceType == VK_PHYSICAL_DEVICE_TYPE_INTEGRATED_GPU )
                        integratedSelect = i;
        }

        int which = -1;
        if( discreteSelect >= 0 )
        {
                which = discreteSelect;
                PhysicalDevice = physicalDevices[which];
        }
        else if( integratedSelect >= 0 )
        {
                which = integratedSelect;
                PhysicalDevice = physicalDevices[which];
        }
        else
        {
                fprintf( FpDebug, "Could not select a Physical Device\n" );
                return VK_SHOULD_EXIT;
        }

        vkGetPhysicalDeviceProperties( PhysicalDevice, OUT &PhysicalDeviceProperties );
        fprintf( FpDebug, "Device #%d selected ('%s')\n", which, PhysicalDeviceProperti
es.deviceName );

        vkGetPhysicalDeviceFeatures( IN PhysicalDevice, OUT &PhysicalDeviceFeatures );

        fprintf( FpDebug, "\nPhysical Device Features:\n");
        fprintf( FpDebug, "geometryShader = %2d\n", PhysicalDeviceFeatures.geometryShad
er);
        fprintf( FpDebug, "tessellationShader = %2d\n", PhysicalDeviceFeatures.tessella
tionShader );
        fprintf( FpDebug, "multiDrawIndirect = %2d\n", PhysicalDeviceFeatures.multiDraw
Indirect );
        fprintf( FpDebug, "wideLines = %2d\n", PhysicalDeviceFeatures.wideLines );
        fprintf( FpDebug, "largePoints = %2d\n", PhysicalDeviceFeatures.largePoints );
        fprintf( FpDebug, "multiViewport = %2d\n", PhysicalDeviceFeatures.multiViewport
 );
        fprintf( FpDebug, "occlusionQueryPrecise = %2d\n", PhysicalDeviceFeatures.occlu
sionQueryPrecise );
        fprintf( FpDebug, "pipelineStatisticsQuery = %2d\n", PhysicalDeviceFeatures.pip
elineStatisticsQuery );
        fprintf( FpDebug, "shaderFloat64 = %2d\n", PhysicalDeviceFeatures.shaderFloat64
 );
        fprintf( FpDebug, "shaderInt64 = %2d\n", PhysicalDeviceFeatures.shaderInt64 );
        fprintf( FpDebug, "shaderInt16 = %2d\n", PhysicalDeviceFeatures.shaderInt16 );

#ifdef COMMENT
        All of these VkPhysicalDeviceFeatures are VkBool32s:
robustBufferAccess;
fullDrawIndexUint32;
imageCubeArray;
independentBlend;
geometryShader;
tessellationShader;
sampleRateShading;
dualSrcBlend;
```

```
logicOp;
multiDrawIndirect;
drawIndirectFirstInstance;
depthClamp;
depthBiasClamp;
fillModeNonSolid;
depthBounds;
wideLines;
largePoints;
alphaToOne;
multiViewport;
samplerAnisotropy;
textureCompressionETC2;
textureCompressionASTC_LDR;
textureCompressionBC;
occlusionQueryPrecise;
pipelineStatisticsQuery;
vertexPipelineStoresAndAtomics;
fragmentStoresAndAtomics;
shaderTessellationAndGeometryPointSize;
shaderImageGatherExtended;
shaderStorageImageExtendedFormats;
shaderStorageImageMultisample;
shaderStorageImageReadWithoutFormat;
shaderStorageImageWriteWithoutFormat;
shaderUniformBufferArrayDynamicIndexing;
shaderSampledImageArrayDynamicIndexing;
shaderStorageBufferArrayDynamicIndexing;
shaderStorageImageArrayDynamicIndexing;
shaderClipDistance;
shaderCullDistance;
shaderFloat64;
shaderInt64;
shaderInt16;
shaderResourceResidency;
shaderResourceMinLod;
sparseBinding;
sparseResidencyBuffer;
sparseResidencyImage2D;
sparseResidencyImage3D;
sparseResidency2Samples;
sparseResidency4Samples;
sparseResidency8Samples;
sparseResidency16Samples;
sparseResidencyAliased;
variableMultisampleRate;
inheritedQueries;
#endif

        VkFormatProperties                                          vfp;
#ifdef CHOICES
VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT = 0x00000001,
VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT = 0x00000002,
VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT = 0x00000004,
VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT = 0x00000008,
VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT = 0x00000010,
VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT = 0x00000020,
VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT = 0x00000040,
VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT = 0x00000080,
VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT = 0x00000100,
VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT = 0x00000200,
VK_FORMAT_FEATURE_BLIT_SRC_BIT = 0x00000400,
VK_FORMAT_FEATURE_BLIT_DST_BIT = 0x00000800,
VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT = 0x00001000,
VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_IMG = 0x00002000,
```

```
#endif

        fprintf( FpDebug, "\nImage Formats Checked:\n" );
        vkGetPhysicalDeviceFormatProperties( PhysicalDevice, IN VK_FORMAT_R32G32B32A32_
SFLOAT, &vfp );
        fprintf( FpDebug, "Format VK_FORMAT_R32G32B32A32_SFLOAT: 0x%08x 0x%08x  0x%08x\
n",
                                vfp.linearTilingFeatures, vfp.optimalTilingFeatures, vf
p.bufferFeatures );
        vkGetPhysicalDeviceFormatProperties( PhysicalDevice, IN VK_FORMAT_R8G8B8A8_UNOR
M, &vfp );
        fprintf( FpDebug, "Format VK_FORMAT_R8G8B8A8_UNORM: 0x%08x 0x%08x  0x%08x\n",
                                vfp.linearTilingFeatures, vfp.optimalTilingFeatures, vf
p.bufferFeatures );
        vkGetPhysicalDeviceFormatProperties( PhysicalDevice, IN VK_FORMAT_B8G8R8A8_UNOR
M, &vfp );
        fprintf( FpDebug, "Format VK_FORMAT_B8G8R8A8_UNORM: 0x%08x 0x%08x  0x%08x\n",
                                vfp.linearTilingFeatures, vfp.optimalTilingFeatures, vf
p.bufferFeatures );

        VkPhysicalDeviceMemoryProperties                        vpdmp;
        vkGetPhysicalDeviceMemoryProperties( PhysicalDevice, OUT &vpdmp );

        fprintf( FpDebug, "\n%d Memory Types:\n", vpdmp.memoryTypeCount );
        for( unsigned int i = 0; i < vpdmp.memoryTypeCount; i++ )
        {
                VkMemoryType vmt = vpdmp.memoryTypes[i];
                fprintf( FpDebug, "Memory %2d: ", i );
                if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT       ) !
= 0 )   fprintf( FpDebug, " DeviceLocal" );
                if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT       ) !
= 0 )   fprintf( FpDebug, " HostVisible" );
                if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_HOST_COHERENT_BIT      ) !
= 0 )   fprintf( FpDebug, " HostCoherent" );
                if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_HOST_CACHED_BIT        ) !
= 0 )   fprintf( FpDebug, " HostCached" );
                if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT   ) !
= 0 )   fprintf( FpDebug, " LazilyAllocated" );
                fprintf(FpDebug, "\n");
        }

        fprintf( FpDebug, "\n%d Memory Heaps:\n", vpdmp.memoryHeapCount );
        for( unsigned int  i = 0; i < vpdmp.memoryHeapCount; i++ )
        {
                fprintf(FpDebug, "Heap %d: ", i);
                VkMemoryHeap vmh = vpdmp.memoryHeaps[i];
                fprintf( FpDebug, " size = 0x%08lx", (unsigned long int)vmh.size );
                if( ( vmh.flags & VK_MEMORY_HEAP_DEVICE_LOCAL_BIT  ) != 0 )     fprintf
( FpDebug, " DeviceLocal" );    // only one in use
                fprintf(FpDebug, "\n");
        }

        uint32_t count = -1;
        vkGetPhysicalDeviceQueueFamilyProperties( IN PhysicalDevice, &count, OUT (VkQue
ueFamilyProperties *)nullptr );
        fprintf( FpDebug, "\nFound %d Queue Families:\n", count );

        VkQueueFamilyProperties *vqfp = new VkQueueFamilyProperties[ count ];
        vkGetPhysicalDeviceQueueFamilyProperties( IN PhysicalDevice, &count, OUT vqfp )
;
        for( unsigned int i = 0; i < count; i++ )
        {
                fprintf( FpDebug, "\t%d: queueCount = %2d  ;   ", i, vqfp[i].queueCount
 );
                if( ( vqfp[i].queueFlags & VK_QUEUE_GRAPHICS_BIT ) != 0 )       fprintf
```

```
( FpDebug, " Graphics" );
                if( ( vqfp[i].queueFlags & VK_QUEUE_COMPUTE_BIT  ) != 0 )       fprintf
( FpDebug, " Compute " );
                if( ( vqfp[i].queueFlags & VK_QUEUE_TRANSFER_BIT ) != 0 )       fprintf
( FpDebug, " Transfer" );
                fprintf(FpDebug, "\n");
        }

        return result;
}
```

```
// ************************************
// CREATE THE LOGICAL DEVICE AND QUEUE:
// ************************************

VkResult
Init04LogicalDeviceAndQueue( )
{
	HERE_I_AM( "Init04LogicalDeviceAndQueue" );

	VkResult result = VK_SUCCESS;

	float   queuePriorities[NUM_QUEUES_WANTED] =
	{
		1.
	};

	VkDeviceQueueCreateInfo                         vdqci[NUM_QUEUES_WANTED];
		vdqci[0].sType = VK_STRUCTURE_TYPE_DEVICE_QUEUE_CREATE_INFO;
		vdqci[0].pNext = nullptr;
		vdqci[0].flags = 0;
		vdqci[0].queueFamilyIndex = 0;          // which queue family
		vdqci[0].queueCount = 1;                // how many queues to create
		vdqci[0].pQueuePriorities = queuePriorities;    // array of queue prior
ities [0.,1.]


	const char * myDeviceLayers[ ] =
	{
		////"VK_LAYER_LUNARG_api_dump",
		////"VK_LAYER_LUNARG_core_validation",
		//"VK_LAYER_LUNARG_image",
		"VK_LAYER_LUNARG_object_tracker",
		"VK_LAYER_LUNARG_parameter_validation",
		//"VK_LAYER_NV_optimus"
	};

	const char * myDeviceExtensions[ ] =
	{
		"VK_KHR_surface",
		"VK_KHR_win32_surface",
		"VK_EXT_debug_report"
		//"VK_KHR_swapchains"
	};


	// see what device layers are available:

	uint32_t layerCount;
	vkEnumerateDeviceLayerProperties(PhysicalDevice, &layerCount, (VkLayerPropertie
s *)nullptr);
	VkLayerProperties * deviceLayers = new VkLayerProperties[layerCount];
	result = vkEnumerateDeviceLayerProperties( PhysicalDevice, &layerCount, deviceL
ayers);
	REPORT("vkEnumerateDeviceLayerProperties");
	if (result != VK_SUCCESS)
	{
		return result;
	}

	fprintf(FpDebug, "\n%d physical device layers enumerated:\n", layerCount);
	for (unsigned int i = 0; i < layerCount; i++)
	{
		fprintf(FpDebug, "0x%08x  %2d  '%s'  '%s'\n",
			deviceLayers[i].specVersion,
```

```
                        deviceLayers[i].implementationVersion,
                        deviceLayers[i].layerName,
                        deviceLayers[i].description);


                // see what device extensions are available:

                uint32_t extensionCount;
                vkEnumerateDeviceExtensionProperties(PhysicalDevice, deviceLayers[i].la
yerName, &extensionCount, (VkExtensionProperties *)nullptr);
                VkExtensionProperties * deviceExtensions = new VkExtensionProperties[ex
tensionCount];
                result = vkEnumerateDeviceExtensionProperties(PhysicalDevice, deviceLay
ers[i].layerName, &extensionCount, deviceExtensions);
                //REPORT("vkEnumerateDeviceExtensionProperties");
                if (result != VK_SUCCESS)
                {
                        return result;
                }

                fprintf(FpDebug, "\t%d device extensions enumerated for '%s':\n", exten
sionCount, deviceLayers[i].layerName );
                for (unsigned int ii = 0; ii < extensionCount; ii++)
                {
                        fprintf(FpDebug, "\t0x%08x  '%s'\n",
                                deviceExtensions[ii].specVersion,
                                deviceExtensions[ii].extensionName);
                }
                fprintf(FpDebug, "\n");
        }


        VkDeviceCreateInfo   vdci;
                vdci.sType = VK_STRUCTURE_TYPE_DEVICE_CREATE_INFO;
                vdci.pNext = nullptr;
                vdci.flags = 0;
                vdci.queueCreateInfoCount = NUM_QUEUES_WANTED;          // # of device
queues, each of which can create multiple queues
                vdci.pQueueCreateInfos = IN vdqci;                              // arra
y of VkDeviceQueueCreateInfo's
                vdci.enabledLayerCount = sizeof(myDeviceLayers) / sizeof(char *);
                //vdci.enabledLayerCount = 0;
                vdci.ppEnabledLayerNames = myDeviceLayers;
                vdci.enabledExtensionCount = 0;
                vdci.ppEnabledExtensionNames = (const char **)nullptr;
        // no extensons
                //vdci.enabledExtensionCount = sizeof(myDeviceExtensions) / sizeof(char
 *);
                //vdci.ppEnabledExtensionNames = myDeviceExtensions;
                vdci.pEnabledFeatures = IN &PhysicalDeviceFeatures;     // already crea
ted

        result = vkCreateLogicalDevice( PhysicalDevice, IN &vdci, PALLOCATOR, OUT &Logi
calDevice );
        REPORT( "vkCreateLogicalDevice" );


        // get the queue for this logical device:

        vkGetDeviceQueue( LogicalDevice, 0, 0,  OUT &Queue );
                                // queueFamilyIndex, queueIndex
        return result;
}
```

```
// **********************
// CREATE A DATA BUFFER:
// **********************

// This just creates the data buffer -- filling it with data uses the Fill05DataBuffer
function
// Use this for vertex buffers, index buffers, uniform buffers, and textures

VkResult
Init05DataBuffer( VkDeviceSize size, VkBufferUsageFlags usage, OUT MyBuffer * pMyBuffer
 )
{
        HERE_I_AM( "Init05DataBuffer" );

        VkResult result = VK_SUCCESS;

        VkBufferCreateInfo  vbci;
                vbci.sType = VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO;
                vbci.pNext = nullptr;
                vbci.flags = 0;
                vbci.size = size;
                vbci.usage = usage;
#ifdef CHOICES
VK_USAGE_TRANSFER_SRC_BIT
VK_USAGE_TRANSFER_DST_BIT
VK_USAGE_UNIFORM_TEXEL_BUFFER_BIT
VK_USAGE_STORAGE_TEXEL_BUFFER_BIT
VK_USAGE_UNIFORM_BUFFER_BIT
VK_USAGE_STORAGE_BUFFER_BIT
VK_USAGE_INDEX_BUFFER_BIT
VK_USAGE_VERTEX_BUFFER_BIT
VK_USAGE_INDIRECT_BUFFER_BIT
#endif
                vbci.sharingMode = VK_SHARING_MODE_CONCURRENT;
#ifdef CHOICES
VK_SHARING_MODE_EXCLUSIVE
VK_SHARING_MODE_CONCURRENT
#endif
                vbci.queueFamilyIndexCount = 0;
                vbci.pQueueFamilyIndices = (const uint32_t *)nullptr;

        pMyBuffer->size = size;
        result = vkCreateBuffer ( LogicalDevice, IN &vbci, PALLOCATOR,  OUT &pMyBuffer-
>buffer );
        REPORT( "vkCreateBuffer" );

        VkMemoryRequirements                    vmr;
        vkGetBufferMemoryRequirements( LogicalDevice, IN pMyBuffer->buffer, OUT &vmr );
                // fills vmr
        if( Verbose )
        {
                fprintf( FpDebug, "Buffer vmr.size = %lld\n", vmr.size );
                fprintf( FpDebug, "Buffer vmr.alignment = %lld\n", vmr.alignment );
                fprintf( FpDebug, "Buffer vmr.memoryTypeBits = 0x%08x\n", vmr.memoryTyp
eBits );
                fflush( FpDebug );
        }

        VkMemoryAllocateInfo                    vmai;
                vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
                vmai.pNext = nullptr;
                vmai.allocationSize = vmr.size;
                vmai.memoryTypeIndex = FindMemoryThatIsHostVisible( );
```

```
        VkDeviceMemory                          vdm;
        result = vkAllocateMemory( LogicalDevice, IN &vmai, PALLOCATOR, OUT &vdm );
        REPORT( "vkAllocateMemory" );
        pMyBuffer->vdm = vdm;

        result = vkBindBufferMemory( LogicalDevice, pMyBuffer->buffer, IN vdm, 0 );
                // 0 is the offset
        REPORT( "vkBindBufferMemory" );

        return result;
}



// ************************
// CREATE A VERTEX BUFFER:
// ************************
// this allocates space for a data buffer, but doesn't yet fill it:

VkResult
Init05MyVertexDataBuffer( IN VkDeviceSize size, OUT MyBuffer * pMyBuffer )
{
        VkResult result = Init05DataBuffer( size, VK_BUFFER_USAGE_VERTEX_BUFFER_BIT, pM
yBuffer );              // fills pMyBuffer
        REPORT( "InitDataBuffer" );
        return result;
}



// ************************
// CREATE A UNIFORM BUFFER:
// ************************
// this allocates space for a data buffer, but doesn't yet fill it:

VkResult
Init05UniformBuffer( VkDeviceSize size, MyBuffer * pMyBuffer )
{
        VkResult result = Init05DataBuffer( size, VK_BUFFER_USAGE_UNIFORM_BUFFER_BIT, O
UT pMyBuffer ); // fills pMyBuffer
        return result;
}


// ********************
// FILL A DATA BUFFER:
// ********************

VkResult
Fill05DataBuffer( IN MyBuffer myBuffer, IN void * data )
{
        // the size of the data had better match the size that was used to Init the buf
fer!

        void * pGpuMemory;
        vkMapMemory( LogicalDevice, IN myBuffer.vdm, 0, VK_WHOLE_SIZE, 0, &pGpuMemory )
;       // 0 and 0 are offset and flags
        memcpy( pGpuMemory, data, (size_t)myBuffer.size );
        vkUnmapMemory( LogicalDevice, IN myBuffer.vdm );
        return VK_SUCCESS;
}
```

```
// *************************
// CREATE A TEXTURE SAMPLER:
// *************************

VkResult
Init07TextureSampler( MyTexture * pMyTexture )
{
        HERE_I_AM( "Init07TextureSampler" );

        VkResult result = VK_SUCCESS;

        VkSamplerCreateInfo                                     vsci;
                vsci.sType = VK_STRUCTURE_TYPE_SAMPLER_CREATE_INFO;
                vsci.pNext = nullptr;
                vsci.flags = 0;
                vsci.magFilter = VK_FILTER_LINEAR;
                vsci.minFilter = VK_FILTER_LINEAR;
                vsci.mipmapMode = VK_SAMPLER_MIPMAP_MODE_LINEAR;
                vsci.addressModeU = VK_SAMPLER_ADDRESS_MODE_REPEAT;
                vsci.addressModeV = VK_SAMPLER_ADDRESS_MODE_REPEAT;
                vsci.addressModeW = VK_SAMPLER_ADDRESS_MODE_REPEAT;
#ifdef CHOICES
VK_SAMPLER_ADDRESS_MODE_REPEAT
VK_SAMPLER_ADDRESS_MODE_MIRRORED_REPEAT
VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE
VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER
VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE
#endif
                vsci.mipLodBias = 0.;
                vsci.anisotropyEnable = VK_FALSE;
                vsci.maxAnisotropy = 1.;
                vsci.compareEnable = VK_FALSE;
                vsci.compareOp = VK_COMPARE_OP_NEVER;
#ifdef CHOICES
VK_COMPARE_OP_NEVER
VK_COMPARE_OP_LESS
VK_COMPARE_OP_EQUAL
VK_COMPARE_OP_LESS_OR_EQUAL
VK_COMPARE_OP_GREATER
VK_COMPARE_OP_NOT_EQUAL
VK_COMPARE_OP_GREATER_OR_EQUAL
VK_COMPARE_OP_ALWAYS
#endif
                vsci.minLod = 0.;
                vsci.maxLod = 0.;
                vsci.borderColor = VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK;
#ifdef CHOICES
VK_BORDER_COLOR_FLOAT_TRANSPARENT_BLACK
VK_BORDER_COLOR_INT_TRANSPARENT_BLACK
VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK
VK_BORDER_COLOR_INT_OPAQUE_BLACK
VK_BORDER_COLOR_FLOAT_OPAQUE_WHITE
VK_BORDER_COLOR_INT_OPAQUE_WHITE
#endif
                vsci.unnormalizedCoordinates = VK_FALSE;        // VK_TRUE means we are
 use raw texels as the index
                                                                // VK_FALSE means we ar
e uing the usual 0. - 1.

        result = vkCreateSampler( LogicalDevice, IN &vsci, PALLOCATOR, OUT &pMyTexture-
>texSampler );
        REPORT( "vkCreateSampler" );
        return result;
}
```

```
// ************************
// CREATE A TEXTURE BUFFER:
// ************************

// assume we get to here and have in a MyTexture struct:
//      * an unsigned char array, holding the pixel rgba
//      * width  is the number of texels in s
//      * height is the number of texels in t

VkResult
Init07TextureBuffer( INOUT MyTexture * pMyTexture)
{
        HERE_I_AM( "Init07TextureBuffer" );

        VkResult result = VK_SUCCESS;

        uint32_t texWidth = pMyTexture->width;;
        uint32_t texHeight = pMyTexture->height;
        unsigned char *texture = pMyTexture->pixels;
        VkDeviceSize textureSize = texWidth * texHeight * 4;            // rgba, 1 byte
 each

        VkImage  stagingImage;
        VkImage  textureImage;


        // ********************************************************************************
***
        // this first {...} is to create the staging image:
        // ********************************************************************************
***
        {
                VkImageCreateInfo                       vici;
                        vici.sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO;
                        vici.pNext = nullptr;
                        vici.flags = 0;
#ifdef CHOICES
VK_IMAGE_CREATE_SPARSE_BINDING_BIT
VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT
VK_IMAGE_CREATE_SPARSE_ALIASED_BIT
VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT
VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT
VK_IMAGE_CREATE_BIND_SFR_BIT_KHX
VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT_KHR
#endif
                        vici.imageType = VK_IMAGE_TYPE_2D;
                        vici.format = VK_FORMAT_R8G8B8A8_UNORM;
                        vici.extent.width = texWidth;
                        vici.extent.height = texHeight;
                        vici.extent.depth = 1;
                        vici.mipLevels = 1;
                        vici.arrayLayers = 1;
                        vici.samples = VK_SAMPLE_COUNT_1_BIT;
                        vici.tiling = VK_IMAGE_TILING_LINEAR;
#ifdef CHOICES
VK_IMAGE_TILING_OPTIMAL
VK_IMAGE_TILING_LINEAR
#endif
                        vici.usage = VK_IMAGE_USAGE_TRANSFER_SRC_BIT;
#ifdef CHOICES
VK_IMAGE_USAGE_TRANSFER_SRC_BIT
VK_IMAGE_USAGE_TRANSFER_DST_BIT
```

```
VK_IMAGE_USAGE_SAMPLED_BIT
VK_IMAGE_USAGE_STORAGE_BIT
VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT
VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT
VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT
#endif
                        vici.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
                        vici.initialLayout = VK_IMAGE_LAYOUT_PREINITIALIZED;
#ifdef CHOICES
VK_IMAGE_LAYOUT_UNDEFINED
VK_IMAGE_LAYOUT_PREINITIALIZED
#endif
                        vici.queueFamilyIndexCount = 0;
                        vici.pQueueFamilyIndices = (const uint32_t *)nullptr;

                result = vkCreateImage(LogicalDevice, IN &vici, PALLOCATOR, OUT &stagin
gImage);        // allocated, but not filled
                REPORT("vkCreateImage");

                VkMemoryRequirements                    vmr;
                vkGetImageMemoryRequirements(LogicalDevice, IN stagingImage, OUT &vmr);

                if (Verbose)
                {
                        fprintf(FpDebug, "Image vmr.size = %lld\n", vmr.size);
                        fprintf(FpDebug, "Image vmr.alignment = %lld\n", vmr.alignment)
;
                        fprintf(FpDebug, "Image vmr.memoryTypeBits = 0x%08x\n", vmr.mem
oryTypeBits);
                        fflush(FpDebug);
                }

                VkMemoryAllocateInfo                    vmai;
                        vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
                        vmai.pNext = nullptr;
                        vmai.allocationSize = vmr.size;
                        vmai.memoryTypeIndex = FindMemoryThatIsHostVisible();   // beca
use we want to mmap it

                VkDeviceMemory                          vdm;
                result = vkAllocateMemory(LogicalDevice, IN &vmai, PALLOCATOR, OUT &vdm
);
                REPORT("vkAllocateMemory");
                pMyTexture->vdm = vdm;

                result = vkBindImageMemory(LogicalDevice, IN stagingImage, IN vdm, 0);
        // 0 = offset
                REPORT("vkBindImageMemory");


                // we have now created the staging image -- fill it with the pixel data
:

                VkImageSubresource                      vis;
                        vis.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
                        vis.mipLevel = 0;
                        vis.arrayLayer = 0;

                VkSubresourceLayout                     vsl;
                vkGetImageSubresourceLayout(LogicalDevice, stagingImage, IN &vis, OUT &
vsl);

                if (Verbose)
                {
```

```
                        fprintf(FpDebug, "Subresource Layout:\n");
                        fprintf(FpDebug, "\toffset = %lld\n", vsl.offset);
                        fprintf(FpDebug, "\tsize = %lld\n", vsl.size);
                        fprintf(FpDebug, "\trowPitch = %lld\n", vsl.rowPitch);
                        fprintf(FpDebug, "\tarrayPitch = %lld\n", vsl.arrayPitch);
                        fprintf(FpDebug, "\tdepthPitch = %lld\n", vsl.depthPitch);
                        fflush(FpDebug);
                }

                void * gpuMemory;
                vkMapMemory(LogicalDevice, vdm, 0, VK_WHOLE_SIZE, 0, OUT &gpuMemory);
                                                        // 0 and 0 = offset and memory
map flags

                if (vsl.rowPitch = 4 * texWidth)
                {
                        memcpy(gpuMemory, (void *)texture, (size_t)textureSize);
                }
                else
                {
                        unsigned char *gpuBytes = (unsigned char *)gpuMemory;
                        for (unsigned int y = 0; y < texHeight; y++)
                        {
                                memcpy(&gpuBytes[y * vsl.rowPitch], &texture[4 * y * te
xWidth], (size_t)(4*texWidth) );
                        }
                }

                vkUnmapMemory(LogicalDevice, vdm);

        }
        // ********************************************************************
***


        // ********************************************************************
***
        // this second {...} is to create the actual texture image:
        // ********************************************************************
***
        {
                VkImageCreateInfo                       vici;
                        vici.sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO;
                        vici.pNext = nullptr;
                        vici.flags = 0;
                        vici.imageType = VK_IMAGE_TYPE_2D;
                        vici.format = VK_FORMAT_R8G8B8A8_UNORM;
                        vici.extent.width  = texWidth;
                        vici.extent.height = texHeight;
                        vici.extent.depth = 1;
                        vici.mipLevels = 1;
                        vici.arrayLayers = 1;
                        vici.samples = VK_SAMPLE_COUNT_1_BIT;
                        vici.tiling = VK_IMAGE_TILING_OPTIMAL;
                        vici.usage = VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_S
AMPLED_BIT;
                                                // because we are transfering into it and will
eventual sample from it
                        vici.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
                        vici.initialLayout = VK_IMAGE_LAYOUT_PREINITIALIZED;
                        vici.queueFamilyIndexCount = 0;
                        vici.pQueueFamilyIndices = (const uint32_t *)nullptr;

                result = vkCreateImage(LogicalDevice, IN &vici, PALLOCATOR, OUT &textur
eImage);        // allocated, but not filled
```

```
		REPORT("vkCreateImage");

		VkMemoryRequirements			vmr;
		vkGetImageMemoryRequirements(LogicalDevice, IN textureImage, OUT &vmr);

		if( Verbose )
		{
			fprintf( FpDebug, "Texture vmr.size = %lld\n", vmr.size );
			fprintf( FpDebug, "Texture vmr.alignment = %lld\n", vmr.alignme
nt );
			fprintf( FpDebug, "Texture vmr.memoryTypeBits = 0x%08x\n", vmr.
memoryTypeBits );
			fflush( FpDebug );
		}

		VkMemoryAllocateInfo			vmai;
			vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
			vmai.pNext = nullptr;
			vmai.allocationSize = vmr.size;
			vmai.memoryTypeIndex = FindMemoryThatIsDeviceLocal( );  // beca
use we want to sample from it

		VkDeviceMemory				vdm;
		result = vkAllocateMemory(LogicalDevice, IN &vmai, PALLOCATOR, OUT &vdm
);
		REPORT("vkAllocateMemory");

		result = vkBindImageMemory( LogicalDevice, IN textureImage, IN vdm, 0 )
;	// 0 = offset
		REPORT( "vkBindImageMemory" );
	}
	// ****************************************************************************
***


	// copy pixels from the staging image to the texture:

	VkCommandBufferBeginInfo		vcbbi;
		vcbbi.sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_BEGIN_INFO;
		vcbbi.pNext = nullptr;
		vcbbi.flags = VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT;
		vcbbi.pInheritanceInfo = (VkCommandBufferInheritanceInfo *)nullptr;

	result = vkBeginCommandBuffer( TextureCommandBuffer, IN &vcbbi);
	REPORT( "Init07TextureBuffer -- vkBeginCommandBuffer" );


	// ****************************************************************************
***
	// transition the staging buffer layout:
	// ****************************************************************************
***
	{
		VkImageSubresourceRange			visr;
			visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
			visr.baseMipLevel = 0;
			visr.levelCount = 1;
			visr.baseArrayLayer = 0;
			visr.layerCount = 1;

		VkImageMemoryBarrier			vimb;
			vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
			vimb.pNext = nullptr;
			vimb.oldLayout = VK_IMAGE_LAYOUT_PREINITIALIZED;
			vimb.newLayout = VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL;
```

```
                        vimb.srcQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
                        vimb.dstQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
                        vimb.image = stagingImage;
                        vimb.srcAccessMask = VK_ACCESS_HOST_WRITE_BIT;
                        vimb.dstAccessMask = VK_ACCESS_TRANSFER_READ_BIT;
                        vimb.subresourceRange = visr;


                vkCmdPipelineBarrier( TextureCommandBuffer,
                                VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT, VK_PIPELINE_STAGE_TR
ANSFER_BIT, 0,
                                0, (VkMemoryBarrier *)nullptr,
                                0, (VkBufferMemoryBarrier *)nullptr,
                                1, IN &vimb );
        }
        // ****************************************************************************
***



        // ****************************************************************************
***
        // transition the texture buffer layout:
        // ****************************************************************************
***
        {
                VkImageSubresourceRange                 visr;
                        visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
                        visr.baseMipLevel = 0;
                        visr.levelCount = 1;
                        visr.baseArrayLayer = 0;
                        visr.layerCount = 1;

                VkImageMemoryBarrier                    vimb;
                        vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
                        vimb.pNext = nullptr;
                        vimb.oldLayout = VK_IMAGE_LAYOUT_PREINITIALIZED;
                        vimb.newLayout = VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL;
                        vimb.srcQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
                        vimb.dstQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
                        vimb.image = textureImage;
                        vimb.srcAccessMask = VK_ACCESS_TRANSFER_READ_BIT;
                        vimb.dstAccessMask = VK_ACCESS_TRANSFER_WRITE_BIT;
                        vimb.subresourceRange = visr;

                vkCmdPipelineBarrier(TextureCommandBuffer,
                        VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT, VK_PIPELINE_STAGE_FRAGMENT_S
HADER_BIT, 0,
                        0, (VkMemoryBarrier *)nullptr,
                        0, (VkBufferMemoryBarrier *)nullptr,
                        1, IN &vimb);

                // now do the final image transfer:

                VkImageSubresourceLayers                visl;
                        visl.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
                        visl.baseArrayLayer = 0;
                        visl.mipLevel = 0;
                        visl.layerCount = 1;

                VkOffset3D                              vo3;
                        vo3.x = 0;
                        vo3.y = 0;
                        vo3.z = 0;
```

```
		VkExtent3D				ve3;
			ve3.width = texWidth;
			ve3.height = texHeight;
			ve3.depth = 1;

		VkImageCopy				vic;
			vic.srcSubresource = visl;
			vic.srcOffset = vo3;
			vic.dstSubresource = visl;
			vic.dstOffset = vo3;
			vic.extent = ve3;

		vkCmdCopyImage(TextureCommandBuffer,
			stagingImage, VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL,
			textureImage, VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL,
			1, IN &vic);
	}
// ****************************************************************************


// ****************************************************************************
// transition the texture buffer layout a second time:
// ****************************************************************************
	{
		VkImageSubresourceRange			visr;
			visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
			visr.baseMipLevel = 0;
			visr.levelCount = 1;
			visr.baseArrayLayer = 0;
			visr.layerCount = 1;

		VkImageMemoryBarrier			vimb;
			vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
			vimb.pNext = nullptr;
			vimb.oldLayout = VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL;
			vimb.newLayout = VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL;
			vimb.srcQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
			vimb.dstQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
			vimb.image = textureImage;
			vimb.srcAccessMask = VK_ACCESS_TRANSFER_READ_BIT;
			vimb.dstAccessMask = VK_ACCESS_SHADER_READ_BIT | VK_ACCESS_INPU
T_ATTACHMENT_READ_BIT;
			vimb.subresourceRange = visr;

		vkCmdPipelineBarrier(TextureCommandBuffer,
			VK_PIPELINE_STAGE_TRANSFER_BIT, VK_PIPELINE_STAGE_FRAGMENT_SHAD
ER_BIT, 0,
			0, (VkMemoryBarrier *)nullptr,
			0, (VkBufferMemoryBarrier *)nullptr,
			1, IN &vimb);
	}
	// ****************************************************************************
***

	result = vkEndCommandBuffer( TextureCommandBuffer );
	REPORT("Init07TextureBuffer -- vkEndCommandBuffer");

	VkSubmitInfo				vsi;
		vsi.sType = VK_STRUCTURE_TYPE_SUBMIT_INFO;
		vsi.pNext = nullptr;
		vsi.commandBufferCount = 1;
		vsi.pCommandBuffers = &TextureCommandBuffer;
		vsi.waitSemaphoreCount = 0;
		vsi.pWaitSemaphores = (VkSemaphore *)nullptr;
		vsi.signalSemaphoreCount = 0;
```

```
		vsi.pSignalSemaphores = (VkSemaphore *)nullptr;
		vsi.pWaitDstStageMask = (VkPipelineStageFlags *)nullptr;

	result = vkQueueSubmit( Queue, 1, IN &vsi, VK_NULL_HANDLE );
	if (Verbose)		REPORT("vkQueueSubmit");

	result = vkQueueWaitIdle( Queue );
	if (Verbose)		REPORT("vkQueueWaitIdle");


	// create an image view for the texture image:

	VkImageSubresourceRange			visr;
		visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
		visr.baseMipLevel = 0;
		visr.levelCount = 1;
		visr.baseArrayLayer = 0;
		visr.layerCount = 1;

	VkImageViewCreateInfo			vivci;
		vivci.sType = VK_STRUCTURE_TYPE_IMAGE_VIEW_CREATE_INFO;
		vivci.pNext = nullptr;
		vivci.flags = 0;
		vivci.image = textureImage;
		vivci.viewType = VK_IMAGE_VIEW_TYPE_2D;
		vivci.format = VK_FORMAT_R8G8B8A8_UNORM;
		vivci.components.r = VK_COMPONENT_SWIZZLE_R;
		vivci.components.g = VK_COMPONENT_SWIZZLE_G;
		vivci.components.b = VK_COMPONENT_SWIZZLE_B;
		vivci.components.a = VK_COMPONENT_SWIZZLE_A;
		vivci.subresourceRange = visr;

	result = vkCreateImageView(LogicalDevice, IN &vivci, PALLOCATOR, OUT &pMyTextur
e->texImageView);
	REPORT("vkCreateImageView");

	return result;
}



// ****************************************
// CREATE A TEXTURE IMAGE FROM A BMP FILE:
// ****************************************

VkResult
Init07TextureBufferAndFillFromBmpFile( IN std::string filename, OUT MyTexture * pMyText
ure )
{
	HERE_I_AM( "Init07TextureBufferAndFillFromBmpFile" );

	VkResult result = VK_SUCCESS;

	const int birgb = { 0 };

	FILE * fp;
	(void) fopen_s( &fp, filename.c_str(), "rb");
	if( fp == NULL )
	{
		fprintf( FpDebug, "Cannot open Bmp file '%s'\n", filename.c_str() );
		return VK_FAILURE;
	}

	FileHeader.bfType = ReadShort( fp );
```

```
	// if bfType is not 0x4d42, the file is not a bmp:

	if( FileHeader.bfType != 0x4d42 )
	{
		fprintf( FpDebug, "Wrong type of file: 0x%0x\n", FileHeader.bfType );
		fclose( fp );
		return VK_FAILURE;
	}


	FileHeader.bfSize = ReadInt( fp );
	FileHeader.bfReserved1 = ReadShort( fp );
	FileHeader.bfReserved2 = ReadShort( fp );
	FileHeader.bfOffBits = ReadInt( fp );

	InfoHeader.biSize = ReadInt( fp );
	InfoHeader.biWidth = ReadInt( fp );
	InfoHeader.biHeight = ReadInt( fp );

	uint32_t texWidth  = InfoHeader.biWidth;
	uint32_t texHeight = InfoHeader.biHeight;

	InfoHeader.biPlanes = ReadShort( fp );
	InfoHeader.biBitCount = ReadShort( fp );
	InfoHeader.biCompression = ReadInt( fp );
	InfoHeader.biSizeImage = ReadInt( fp );
	InfoHeader.biXPelsPerMeter = ReadInt( fp );
	InfoHeader.biYPelsPerMeter = ReadInt( fp );
	InfoHeader.biClrUsed = ReadInt( fp );
	InfoHeader.biClrImportant = ReadInt( fp );

	fprintf( FpDebug, "Image size found: %d x %d\n", texWidth, texHeight );

	unsigned char * texture = new unsigned char[ 4 * texWidth * texHeight ];

	// extra padding bytes:

	int numExtra =  4*(( (3*InfoHeader.biWidth)+3)/4) - 3*InfoHeader.biWidth;

	// we do not support compression:

	if( InfoHeader.biCompression != birgb )
	{
		fprintf( FpDebug, "Wrong type of image compression: %d\n", InfoHeader.b
iCompression );
		fclose( fp );
		return VK_FAILURE;
	}

	rewind( fp );
	fseek( fp, 14+40, SEEK_SET );

	if( InfoHeader.biBitCount == 24 )
	{
		unsigned char *tp = texture;
		for( unsigned int t = 0; t < texHeight; t++ )
		{
			for( unsigned int s = 0; s < texWidth; s++, tp += 4 )
			{
				*(tp+3) = 255;			// a
				*(tp+2) = fgetc( fp );		// b
				*(tp+1) = fgetc( fp );		// g
				*(tp+0) = fgetc( fp );		// r
			}
```

```
                        for( int e = 0; e < numExtra; e++ )
                        {
                                fgetc( fp );
                        }
                }
        }
        fclose( fp );

        pMyTexture->width = texWidth;
        pMyTexture->height = texHeight;
        pMyTexture->pixels = texture;

        result = Init07TextureBuffer( INOUT pMyTexture );
        REPORT( "Init07TextureBuffer" );

        return result;
}



int
ReadInt( FILE *fp )
{
        unsigned char b3, b2, b1, b0;
        b0 = fgetc( fp );
        b1 = fgetc( fp );
        b2 = fgetc( fp );
        b3 = fgetc( fp );
        return ( b3 << 24 )  |  ( b2 << 16 )  |  ( b1 << 8 )  |  b0;
}


short
ReadShort( FILE *fp )
{
        unsigned char b1, b0;
        b0 = fgetc( fp );
        b1 = fgetc( fp );
        return ( b1 << 8 )  |  b0;
}
```

```
// ************************
// CREATING THE SWAP CHAIN:
// ************************

VkResult
Init08Swapchain( )
{
	HERE_I_AM( "Init08Swapchain" );

	VkResult result = VK_SUCCESS;

	VkSurfaceCapabilitiesKHR		vsc;

	vkGetPhysicalDeviceSurfaceCapabilitiesKHR( PhysicalDevice, Surface, OUT &vsc );
#ifdef ELEMENTS
vsc.uint32_t			minImageCount;
vsc.uint32_t			maxImageCount;
vsc.VkExtent2D			currentExtent;
vsc.VkExtent2D			minImageExtent;
vsc.VkExtent2D			maxImageExtent;
vsc.uint32_t			maxImageArrayLayers;
vsc.VkSurfaceTransformFlagsKHR	supportedTransforms;
vsc.VkSurfaceTransformFlagBitsKHR	currentTransform;
vsc.VkCompositeAlphaFlagsKHR	supportedCompositeAlpha;
vsc.VkImageUsageFlags		supportedUsageFlags;
#endif

	VkExtent2D surfaceRes = vsc.currentExtent;
	fprintf( FpDebug, "\nSurface resolution for swap chain = %d, %d\n",
		surfaceRes.width, surfaceRes.height );

#ifdef ELEMENTS
surfaceRes.width
surfaceRes.height;
#endif

	VkSwapchainCreateInfoKHR		vscci;
		vscci.sType = VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR;
		vscci.pNext = nullptr;
		vscci.flags = 0;
		vscci.surface = Surface;				// ???
		vscci.minImageCount = 2;				// double buffering
		vscci.imageFormat = VK_FORMAT_B8G8R8A8_UNORM;
		vscci.imageColorSpace = VK_COLORSPACE_SRGB_NONLINEAR_KHR;
		vscci.imageExtent.width = surfaceRes.width;
		vscci.imageExtent.height = surfaceRes.height;
		vscci.imageUsage = VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT;
		vscci.preTransform = VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR;
		vscci.compositeAlpha = VK_COMPOSITE_ALPHA_OPAQUE_BIT_KHR;
		vscci.imageArrayLayers = 1;
		vscci.imageSharingMode = VK_SHARING_MODE_EXCLUSIVE;
		vscci.queueFamilyIndexCount = 0;
		vscci.pQueueFamilyIndices = (const uint32_t *)nullptr;
		vscci.presentMode = VK_PRESENT_MODE_MAILBOX_KHR;
		//vscci.oldSwapchain = (VkSwapchainKHR *)nullptr;	// what if ther
e is no old swapchain? ???
		vscci.oldSwapchain = VK_NULL_HANDLE;			// what if ther
e is no old swapchain? ???
		vscci.clipped = true;

	result = vkCreateSwapchainKHR( LogicalDevice, IN &vscci, PALLOCATOR, OUT &SwapC
hain );
	REPORT( "vkCreateSwapchainKHR" );
```

```
	uint32_t imageCount;
	result = vkGetSwapchainImagesKHR( LogicalDevice, IN SwapChain, OUT &imageCount,
 (VkImage *)nullptr );  // 0
	REPORT( "vkGetSwapchainImagesKHR - 0" );
	if( imageCount != 2 )
	{
		fprintf( FpDebug, "imageCount return from vkGetSwapchainImages = %d; sh
ould have been 2\n", imageCount );
		return result;
	}

	PresentImages = new VkImage[ imageCount ];
	result = vkGetSwapchainImagesKHR( LogicalDevice, SwapChain, OUT &imageCount, Pr
esentImages );  // 0
	REPORT( "vkGetSwapchainImagesKHR - 1" );


	// present views for the double-buffering:

	PresentImageViews = new VkImageView[ imageCount ];	// better be 2
	for( unsigned int i = 0; i < imageCount; i++ )
	{
		VkImageViewCreateInfo		vivci;
		vivci.sType = VK_STRUCTURE_TYPE_IMAGE_VIEW_CREATE_INFO;
		vivci.pNext = nullptr;
		vivci.flags = 0;
		vivci.viewType = VK_IMAGE_VIEW_TYPE_2D;
		vivci.format = VK_FORMAT_B8G8R8A8_UNORM;
		vivci.components.r = VK_COMPONENT_SWIZZLE_R;
		vivci.components.g = VK_COMPONENT_SWIZZLE_G;
		vivci.components.b = VK_COMPONENT_SWIZZLE_B;
		vivci.components.a = VK_COMPONENT_SWIZZLE_A;
		vivci.subresourceRange.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
		vivci.subresourceRange.baseMipLevel = 0;
		vivci.subresourceRange.levelCount = 1;
		vivci.subresourceRange.baseArrayLayer = 0;
		vivci.subresourceRange.layerCount = 1;
		vivci.image = PresentImages[i];

		result = vkCreateImageView( LogicalDevice, IN &vivci, PALLOCATOR, OUT &
PresentImageViews[i] );
		REPORT( "vkCreateImageView" );
	}

	return result;
}
```

```
// ************************************
// CREATING THE DEPTH AND STENCIL IMAGE:
// ************************************

VkResult
Init09DepthStencilImage( )
{
	HERE_I_AM( "Init09DepthStencilImage" );

	VkResult result = VK_SUCCESS;

	VkExtent3D ve3d = { Width, Height, 1 };

	VkImageCreateInfo			vici;
		vici.sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO;
		vici.pNext = nullptr;
		vici.flags = 0;
		vici.imageType = VK_IMAGE_TYPE_2D;
		vici.format = VK_FORMAT_D32_SFLOAT_S8_UINT;
		vici.extent = ve3d;
		vici.mipLevels = 1;
		vici.arrayLayers = 1;
		vici.samples = VK_SAMPLE_COUNT_1_BIT;
		vici.tiling = VK_IMAGE_TILING_OPTIMAL;
		vici.usage = VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT;
		vici.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
		vici.queueFamilyIndexCount = 0;
		vici.pQueueFamilyIndices = (const uint32_t *)nullptr;
		vici.initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;

	result = vkCreateImage( LogicalDevice, IN &vici, PALLOCATOR, &DepthImage );
	REPORT( "vkCreateImage" );

	VkMemoryRequirements			vmr;
	vkGetImageMemoryRequirements( LogicalDevice, IN DepthImage, OUT &vmr );

	VkMemoryAllocateInfo			vmai;
		vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
		vmai.pNext = nullptr;
		vmai.allocationSize = vmr.size;
		vmai.memoryTypeIndex = FindMemoryThatIsDeviceLocal( );

	VkDeviceMemory imageMemory;
	result = vkAllocateMemory( LogicalDevice, IN &vmai, PALLOCATOR, OUT &imageMemor
y );
	REPORT( "vkAllocateMemory" );

	result = vkBindImageMemory( LogicalDevice, DepthImage, imageMemory, 0 );
	// 0 is the offset
	REPORT( "vkBindImageMemory" );

	VkImageViewCreateInfo			vivci;
		vivci.sType = VK_STRUCTURE_TYPE_IMAGE_VIEW_CREATE_INFO;
		vivci.pNext = nullptr;
		vivci.flags = 0;
		vivci.image = DepthImage;
		vivci.viewType = VK_IMAGE_VIEW_TYPE_2D;
		vivci.format = vici.format;
		vivci.components.r = VK_COMPONENT_SWIZZLE_IDENTITY;
		vivci.components.g = VK_COMPONENT_SWIZZLE_IDENTITY;
		vivci.components.b = VK_COMPONENT_SWIZZLE_IDENTITY;
		vivci.components.a = VK_COMPONENT_SWIZZLE_IDENTITY;
		vivci.subresourceRange.aspectMask = VK_IMAGE_ASPECT_DEPTH_BIT;
		vivci.subresourceRange.baseMipLevel = 0;
```

```
                vivci.subresourceRange.levelCount = 1;
                vivci.subresourceRange.baseArrayLayer = 0;
                vivci.subresourceRange.layerCount = 1;

                result = vkCreateImageView( LogicalDevice, IN &vivci, PALLOCATOR, OUT &
DepthImageView );
                REPORT("vkCreateImageView");
                return result;
}
```

```
// *************************
// CREATING THE RENDERPASSES:
// *************************

VkResult
Init10RenderPasses( )
{
	HERE_I_AM( "Init10RenderPasses" );

	VkResult result = VK_SUCCESS;

	// need 2 - one for the color and one for the depth/stencil
	VkAttachmentDescription				vad[2];
		vad[0].format = VK_FORMAT_B8G8R8A8_UNORM;;
		vad[0].samples = VK_SAMPLE_COUNT_1_BIT;
		vad[0].loadOp = VK_ATTACHMENT_LOAD_OP_CLEAR;
		vad[0].storeOp = VK_ATTACHMENT_STORE_OP_STORE;
		vad[0].stencilLoadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
		vad[0].stencilStoreOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
		vad[0].initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;
		vad[0].finalLayout = VK_IMAGE_LAYOUT_PRESENT_SRC_KHR;
		//vad[0].flags = VK_ATTACHMENT_DESCRIPTION_MAT_ALIAS_BIT;
		//vad[0].flags = VK_ATTACHMENT_DESCRIPTION_MAT_ALIAS_BIT;

		vad[1].format = VK_FORMAT_D32_SFLOAT_S8_UINT;
		vad[1].samples = VK_SAMPLE_COUNT_1_BIT;
		vad[1].loadOp = VK_ATTACHMENT_LOAD_OP_CLEAR;
		vad[1].storeOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
		vad[1].stencilLoadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
		vad[1].stencilStoreOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
		vad[1].initialLayout = VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL
;
		vad[1].finalLayout = VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL;
		//vad[1].flags = VK_ATTACHMENT_DESCRIPTION_MAT_ALIAS_BIT;

	VkAttachmentReference				colorReference;
		colorReference.attachment = 0;
		colorReference.layout = VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL;

	VkAttachmentReference				depthReference;
		depthReference.attachment = 1;
		depthReference.layout = VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMA
L;

	VkSubpassDescription				vsd;
		vsd.flags = 0;
		vsd.pipelineBindPoint = VK_PIPELINE_BIND_POINT_GRAPHICS;
		vsd.inputAttachmentCount = 0;
		vsd.pInputAttachments = (VkAttachmentReference *)nullptr;
		vsd.colorAttachmentCount = 1;
		vsd.pColorAttachments = &colorReference;
		vsd.pResolveAttachments = (VkAttachmentReference *)nullptr;
		vsd.pDepthStencilAttachment = &depthReference;
		vsd.preserveAttachmentCount = 0;
		vsd.pPreserveAttachments = (uint32_t *)nullptr;

	VkRenderPassCreateInfo				vrpci;
		vrpci.sType = VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO;
		vrpci.pNext = nullptr;
		vrpci.flags = 0;
		vrpci.attachmentCount = 2;			// color and depth/stencil
		vrpci.pAttachments = vad;
		vrpci.subpassCount = 1;
		vrpci.pSubpasses = &vsd;
```

```
		vrpci.dependencyCount = 0;			// ********************
* ERROR ?
		vrpci.pDependencies = (VkSubpassDependency *)nullptr;

	result = vkCreateRenderPass( LogicalDevice, IN &vrpci, PALLOCATOR, OUT &RenderP
ass );
	REPORT( "vkCreateRenderPass" );
		//vgpci.renderPass = RenderPass;

	return result;
}


// ************************
// CREATE THE FRAMEBUFFERS:
// ************************

VkResult
Init11Framebuffers( )
{
	HERE_I_AM( "Init11Framebuffers" );

	VkResult result = VK_SUCCESS;
	VkImageView frameBufferAttachments[2];		// color + depth/stencil

	VkFramebufferCreateInfo				vfbci;
		vfbci.sType = VK_STRUCTURE_TYPE_FRAMEBUFFER_CREATE_INFO;
		vfbci.pNext = nullptr;
		vfbci.flags = 0;
		vfbci.renderPass = RenderPass;
		vfbci.attachmentCount = 2;
		vfbci.pAttachments =  frameBufferAttachments;
		vfbci.width = Width;
		vfbci.height = Height;
		vfbci.layers = 1;

	frameBufferAttachments[0] = PresentImageViews[0];
	frameBufferAttachments[1] = DepthImageView;
	result = vkCreateFramebuffer( LogicalDevice, IN &vfbci, PALLOCATOR, OUT &Frameb
uffers[0] );
	REPORT( "vkCreateFrameBuffer - 0" );

	frameBufferAttachments[0] = PresentImageViews[1];
	frameBufferAttachments[1] = DepthImageView;
	result = vkCreateFramebuffer( LogicalDevice, IN &vfbci, PALLOCATOR, OUT &Frameb
uffers[1] );
	REPORT( "vkCreateFrameBuffer - 1" );

	return result;
}
```

```
// ******************************
// CREATE THE COMMAND BUFFER POOL:
// ******************************

// Note: need a separate command buffer for each thread!

VkResult
Init06CommandPool( )
{
	HERE_I_AM( "Init06CommandPool" );

	VkResult result = VK_SUCCESS;

	VkCommandPoolCreateInfo				vcpci;
		vcpci.sType = VK_STRUCTURE_TYPE_COMMAND_POOL_CREATE_INFO;
		vcpci.pNext = nullptr;
		vcpci.flags = VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT;
#ifdef CHOICES
VK_COMMAND_POOL_CREATE_TRANSIENT_BIT
VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT
#endif
		vcpci.queueFamilyIndex = 0;		// had better be part of the gr
aphics family

	result = vkCreateCommandPool( LogicalDevice, IN &vcpci, PALLOCATOR, OUT &Comman
dPool );
	REPORT( "vkCreateCommandPool" );
	return result;
}



// ***************************
// CREATE THE COMMAND BUFFERS:
// ***************************

VkResult
Init06CommandBuffers( )
{
	HERE_I_AM( "Init06CommandBuffers" );

	VkResult result = VK_SUCCESS;

	// allocate 2 command buffers for the double-buffered rendering:

	{
		VkCommandBufferAllocateInfo			vcbai;
			vcbai.sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_ALLOCATE_INFO;
			vcbai.pNext = nullptr;
			vcbai.commandPool = CommandPool;
			vcbai.level = VK_COMMAND_BUFFER_LEVEL_PRIMARY;
			vcbai.commandBufferCount = 2;		// 2, because of double
-buffering

		result = vkAllocateCommandBuffers( LogicalDevice, IN &vcbai, OUT &Comma
ndBuffers[0] );
		REPORT( "vkAllocateCommandBuffers - 1" );
	}


	// allocate 1 command buffer for the transfering pixels from a staging buffer t
o a texture buffer:

	{
```

```
                VkCommandBufferAllocateInfo                     vcbai;
                        vcbai.sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_ALLOCATE_INFO;
                        vcbai.pNext = nullptr;
                        vcbai.commandPool = CommandPool;
                        vcbai.level = VK_COMMAND_BUFFER_LEVEL_PRIMARY;
                        vcbai.commandBufferCount = 1;

                result = vkAllocateCommandBuffers( LogicalDevice, IN &vcbai, OUT &Textu
reCommandBuffer );
                REPORT( "vkAllocateCommandBuffers - 2" );
        }

        return result;
}
```

```
// ***************************************
// READ A SPIR-V SHADER MODULE FROM A FILE:
// ***************************************

VkResult
Init12SpirvShader( std::string filename, VkShaderModule * pShaderModule )
{
	HERE_I_AM( "Init12SpirvShader" );

	FILE *fp;
	(void) fopen_s( &fp, filename.c_str(), "rb");
	if( fp == NULL )
	{
		fprintf( FpDebug, "Cannot open shader file '%s'\n", filename.c_str( ) )
;
		return VK_SHOULD_EXIT;
	}
	uint32_t magic;
	fread( &magic, 4, 1, fp );
	if( magic != SPIRV_MAGIC )
	{
		fprintf( FpDebug, "Magic number for spir-v file '%s is 0x%08x -- should
 be 0x%08x\n", filename.c_str( ), magic, SPIRV_MAGIC );
		return VK_SHOULD_EXIT;
	}

	fseek( fp, 0L, SEEK_END );
	int size = ftell( fp );
	rewind( fp );
	unsigned char *code = new unsigned char [size];
	fread( code, size, 1, fp );
	fclose( fp );

	VkShaderModuleCreateInfo		vsmci;
		vsmci.sType = VK_STRUCTURE_TYPE_SHADER_MODULE_CREATE_INFO;
		vsmci.pNext = nullptr;
		vsmci.flags = 0;
		vsmci.codeSize = size;
		vsmci.pCode = (uint32_t *)code;

	VkResult result = vkCreateShaderModule( LogicalDevice, &vsmci, PALLOCATOR, pSha
derModule );
	REPORT( "vkCreateShaderModule" );
	fprintf(FpDebug, "Shader Module '%s' successfully loaded\n", filename.c_str());
	delete [ ] code;
	return result;
}
```

```
// ****************************
// CREATE A DESCRIPTOR SET POOL:
// ****************************

VkResult
Init13DescriptorSetPool()
{
	HERE_I_AM( "Init13DescriptorSetPool" );

	VkResult result = VK_SUCCESS;

	VkDescriptorPoolSize				vdps[4];
		vdps[0].type = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		vdps[0].descriptorCount = 1;
		vdps[1].type = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		vdps[1].descriptorCount = 1;
		vdps[2].type = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		vdps[2].descriptorCount = 1;
		vdps[3].type = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER;
		vdps[3].descriptorCount = 1;
#ifdef CHOICES
VkDescriptorType:
VK_DESCRIPTOR_TYPE_SAMPLER
VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE
VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER
VK_DESCRIPTOR_TYPE_STORAGE_IMAGE
VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER
VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER
VK_DESCRIPTOR_TYPE_STORAGE_BUFFER
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC
VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC
VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT
#endif

	VkDescriptorPoolCreateInfo				vdpci;
		vdpci.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_CREATE_INFO;
		vdpci.pNext = nullptr;
		vdpci.flags = 0;
#ifdef CHOICES
0
VK_DESCRIPTOR_POOL_CREATE_FREE_DESCRIPTOR_SET_BIT
#endif
		vdpci.maxSets = 4;
		vdpci.poolSizeCount = 4;
		vdpci.pPoolSizes = &vdps[0];

	result = vkCreateDescriptorPool(LogicalDevice, IN &vdpci, PALLOCATOR, OUT &Desc
riptorPool);
	REPORT("vkCreateDescriptorPool");

	return result;
}



// ********************************
// CREATING A DESCRIPTOR SET LAYOUT:
// ********************************

// A DS is a set of resources bound into the pipeline as a group.
// Multiple sets can be bound at one time.
// Each set has a layout, which describes the order and type of data in that set.
// The pipeline layout consists of multiple DS layouts.
```

```
#ifdef CODE_THAT_THIS_WILL_BE_DESCRIBING
layout( std140, set = 0, binding = 0 ) uniform matrixBuf
{
        mat4 uModelMatrix;
        mat4 uViewMatrix;
        mat4 uProjectionMatrix;
        mat3 uNormalMatrix;
} Matrices;

layout( std140, set = 1, binding = 0 ) uniform lightBVuf
{
        vec4 uLightPos;
} Light;

layout( std140, set = 2, binding = 0 ) uniform miscBuf
{
        float uTime;
        int   uMode;
} Misc;

layout ( set = 3, binding = 0 ) uniform sampler2D uSampler;
#endif



VkResult
Init13DescriptorSetLayouts( )
{
        HERE_I_AM( "Init13DescriptorSetLayouts" );

        VkResult result = VK_SUCCESS;

        // arrays of >= 1 layouts:
        //DS #0:
        VkDescriptorSetLayoutBinding            MatrixSet[1];
                MatrixSet[0].binding            = 0;
                MatrixSet[0].descriptorType     = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
                MatrixSet[0].descriptorCount    = 1;
                MatrixSet[0].stageFlags         = VK_SHADER_STAGE_VERTEX_BIT;
                MatrixSet[0].pImmutableSamplers = (VkSampler *)nullptr;

        // DS #1:
        VkDescriptorSetLayoutBinding            LightSet[1];
                LightSet[0].binding            = 0;
                LightSet[0].descriptorType     = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
                LightSet[0].descriptorCount    = 1;
                LightSet[0].stageFlags         = VK_SHADER_STAGE_VERTEX_BIT | VK_SHADER
_STAGE_FRAGMENT_BIT;
                LightSet[0].pImmutableSamplers = (VkSampler *)nullptr;

        //DS #2:
        VkDescriptorSetLayoutBinding            MiscSet[1];
                MiscSet[0].binding            = 0;
                MiscSet[0].descriptorType     = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
                MiscSet[0].descriptorCount    = 1;
                MiscSet[0].stageFlags         = VK_SHADER_STAGE_VERTEX_BIT | VK_SHADER_
STAGE_FRAGMENT_BIT;
                MiscSet[0].pImmutableSamplers = (VkSampler *)nullptr;

        // DS #3:
        VkDescriptorSetLayoutBinding            TexSamplerSet[1];
                TexSamplerSet[0].binding            = 0;
                TexSamplerSet[0].descriptorType     = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE
_SAMPLER;
```

```
                                                        // uniform sampler2D uSampler
                                                        // vec4 rgba = texture( uSample
r, vST );
                TexSamplerSet[0].descriptorCount    = 1;
                TexSamplerSet[0].stageFlags         = VK_SHADER_STAGE_FRAGMENT_BIT;
                TexSamplerSet[0].pImmutableSamplers = (VkSampler *)nullptr;

#ifdef CHOICES
VkDescriptorType:
VK_DESCRIPTOR_TYPE_SAMPLER
VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE
VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER
VK_DESCRIPTOR_TYPE_STORAGE_IMAGE
VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER
VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER
VK_DESCRIPTOR_TYPE_STORAGE_BUFFER
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC
VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC
VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT
#endif

        VkDescriptorSetLayoutCreateInfo                 vdslc0;
                vdslc0.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
                vdslc0.pNext = nullptr;
                vdslc0.flags = 0;
                vdslc0.bindingCount = 1;
                vdslc0.pBindings = &MatrixSet[0];

        VkDescriptorSetLayoutCreateInfo                 vdslc1;
                vdslc1.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
                vdslc1.pNext = nullptr;
                vdslc1.flags = 0;
                vdslc1.bindingCount = 1;
                vdslc1.pBindings = &LightSet[0];

        VkDescriptorSetLayoutCreateInfo                 vdslc2;
                vdslc2.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
                vdslc2.pNext = nullptr;
                vdslc2.flags = 0;
                vdslc2.bindingCount = 1;
                vdslc2.pBindings = &MiscSet[0];

        VkDescriptorSetLayoutCreateInfo                 vdslc3;
                vdslc3.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
                vdslc3.pNext = nullptr;
                vdslc3.flags = 0;
                vdslc3.bindingCount = 1;
                vdslc3.pBindings = &TexSamplerSet[0];

        result = vkCreateDescriptorSetLayout( LogicalDevice, &vdslc0, PALLOCATOR, OUT &
DescriptorSetLayouts[0] );
        REPORT( "vkCreateDescriptorSetLayout - 0" );

        result = vkCreateDescriptorSetLayout( LogicalDevice, &vdslc1, PALLOCATOR, OUT &
DescriptorSetLayouts[1] );
        REPORT( "vkCreateDescriptorSetLayout - 1" );

        result = vkCreateDescriptorSetLayout( LogicalDevice, &vdslc2, PALLOCATOR, OUT &
DescriptorSetLayouts[2] );
        REPORT( "vkCreateDescriptorSetLayout - 2" );

        result = vkCreateDescriptorSetLayout( LogicalDevice, &vdslc3, PALLOCATOR, OUT &
DescriptorSetLayouts[3] );
        REPORT( "vkCreateDescriptorSetLayout - 3" );
```

```
	return result;
}



// *********************************
// ALLOCATE AND WRITE DESCRIPTOR SETS:
// *********************************

VkResult
Init13DescriptorSets( )
{
	HERE_I_AM( "Init13DescriptorSets" );

	VkResult result = VK_SUCCESS;

	VkDescriptorSetAllocateInfo			vdsai;
		vdsai.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_ALLOCATE_INFO;
		vdsai.pNext = nullptr;
		vdsai.descriptorPool = DescriptorPool;
		vdsai.descriptorSetCount = 4;
		vdsai.pSetLayouts = DescriptorSetLayouts;


	result = vkAllocateDescriptorSets( LogicalDevice, IN &vdsai, OUT &DescriptorSet
s[0] );
	REPORT( "vkAllocateDescriptorSets" );

	VkDescriptorBufferInfo				vdbi0;
		vdbi0.buffer = MyMatrixUniformBuffer.buffer;
		vdbi0.offset = 0;	// bytes
		vdbi0.range = sizeof(Matrices);

	VkDescriptorBufferInfo				vdbi1;
		vdbi1.buffer = MyLightUniformBuffer.buffer;
		vdbi1.offset = 0;	// bytes
		vdbi1.range = sizeof(Light);

	VkDescriptorBufferInfo				vdbi2;
		vdbi2.buffer = MyMiscUniformBuffer.buffer;
		vdbi2.offset = 0;	// bytes
		vdbi2.range = sizeof(Misc);

	VkDescriptorImageInfo				vdii;
		vdii.sampler   = MyPuppyTexture.texSampler;
		vdii.imageView = MyPuppyTexture.texImageView;
		vdii.imageLayout = VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL;

	VkWriteDescriptorSet				vwds0;
		// ds 0:
		vwds0.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
		vwds0.pNext = nullptr;
		vwds0.dstSet = DescriptorSets[0];
		vwds0.dstBinding = 0;
		vwds0.dstArrayElement = 0;
		vwds0.descriptorCount = 1;
		vwds0.descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		vwds0.pBufferInfo = &vdbi0;
		vwds0.pImageInfo = (VkDescriptorImageInfo *)nullptr;
		vwds0.pTexelBufferView = (VkBufferView *)nullptr;

		// ds 1:
	VkWriteDescriptorSet				vwds1;
```

```
                vwds1.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
                vwds1.pNext = nullptr;
                vwds1.dstSet = DescriptorSets[1];
                vwds1.dstBinding = 0;
                vwds1.dstArrayElement = 0;
                vwds1.descriptorCount = 1;
                vwds1.descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
                vwds1.pBufferInfo = &vdbi1;
                vwds1.pImageInfo = (VkDescriptorImageInfo *)nullptr;
                vwds1.pTexelBufferView = (VkBufferView *)nullptr;

        VkWriteDescriptorSet                            vwds2;
                // ds 2:
                vwds2.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
                vwds2.pNext = nullptr;
                vwds2.dstSet = DescriptorSets[2];
                vwds2.dstBinding = 0;
                vwds2.dstArrayElement = 0;
                vwds2.descriptorCount = 1;
                vwds2.descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
                vwds2.pBufferInfo = &vdbi2;
                vwds2.pImageInfo = (VkDescriptorImageInfo *)nullptr;
                vwds2.pTexelBufferView = (VkBufferView *)nullptr;

                // ds 3:
        VkWriteDescriptorSet                            vwds3;
                vwds3.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
                vwds3.pNext = nullptr;
                vwds3.dstSet = DescriptorSets[3];
                vwds3.dstBinding = 0;
                vwds3.dstArrayElement = 0;
                vwds3.descriptorCount = 1;
                vwds3.descriptorType = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER;
                vwds3.pBufferInfo = (VkDescriptorBufferInfo *)nullptr;
                vwds3.pImageInfo = &vdii;
                vwds3.pTexelBufferView = (VkBufferView *)nullptr;

        uint32_t copyCount = 0;

        // this could have been done with one call and an array of VkWriteDescriptorSet
s:

        vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds0, IN copyCount, (VkCopyDescr
iptorSet *)nullptr );
        vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds1, IN copyCount, (VkCopyDescr
iptorSet *)nullptr );
        vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds2, IN copyCount, (VkCopyDescr
iptorSet *)nullptr );
        vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds3, IN copyCount, (VkCopyDescr
iptorSet *)nullptr );

        return VK_SUCCESS;
}
```

```
// *************************
// CREATE A PIPELINE LAYOUT:
// *************************

VkResult
Init14GraphicsPipelineLayout( )
{
        HERE_I_AM( "Init14GraphicsPipelineLayout" );

        VkResult result = VK_SUCCESS;

        VkPipelineLayoutCreateInfo                      vplci;
                vplci.sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
                vplci.pNext = nullptr;
                vplci.flags = 0;
                vplci.setLayoutCount = 4;
                vplci.pSetLayouts = &DescriptorSetLayouts[0];
                vplci.pushConstantRangeCount = 0;
                vplci.pPushConstantRanges = (VkPushConstantRange *)nullptr;

        result = vkCreatePipelineLayout( LogicalDevice, IN &vplci, PALLOCATOR, OUT &Gra
phicsPipelineLayout );
        REPORT( "vkCreatePipelineLayout" );

        return result;
}



// ****************************
// CREATING A GRAPHICS PIPELINE:
// ****************************


#ifdef COMMENT
struct matBuf
{
        glm::mat4 uModelMatrix;
        glm::mat4 uViewMatrix;
        glm::mat4 uProjectionMatrix;
} Matrices;

struct lightBuf
{
        glm::vec4 uLightPos;
} Light;

struct miscBuf
{
        float uTime;
        int   uMode;
} Misc;

struct vertex
{
        glm::vec3       position;
        glm::vec3       normal;
        glm::vec3       color;
        glm::vec2       texCoord;
} Vertices;
#endif


VkResult
```

```
Init14GraphicsVertexFragmentPipeline( VkShaderModule vertexShader, VkShaderModule fragm
entShader, VkPrimitiveTopology topology, OUT VkPipeline *pGraphicsPipeline  )
{
#ifdef ASSUMPTIONS
                vvibd[0].inputRate = VK_VERTEX_INPUT_RATE_VERTEX;
                vprsci.depthClampEnable = VK_FALSE;
                vprsci.rasterizerDiscardEnable = VK_FALSE;
                vprsci.polygonMode = VK_POLYGON_MODE_FILL;
                vprsci.cullMode = VK_CULL_MODE_NONE;    // best to do this because of t
he projectionMatrix[1][1] *= -1.;
                vprsci.frontFace = VK_FRONT_FACE_COUNTER_CLOCKWISE;
                vpmsci.rasterizationSamples = VK_SAMPLE_COUNT_ONE_BIT;
                vpcbas.blendEnable = VK_FALSE;
                vpcbsci.logicOpEnable = VK_FALSE;
        VkDynamicState                                  vds[ ] = { VK_DYNAMIC_STATE_VIE
WPORT, VK_DYNAMIC_STATE_SCISSOR };
                vpdssci.depthTestEnable = VK_TRUE;
                vpdssci.depthWriteEnable = VK_TRUE;
                vpdssci.depthCompareOp = VK_COMPARE_OP_LESS;
#endif

                HERE_I_AM( "Init14GraphicsVertexFragmentPipeline" );

                VkResult result = VK_SUCCESS;

        VkPipelineLayoutCreateInfo                              vplci;
                vplci.sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
                vplci.pNext = nullptr;
                vplci.flags = 0;
                vplci.setLayoutCount = 4;
                vplci.pSetLayouts = DescriptorSetLayouts;
                vplci.pushConstantRangeCount = 0;
                vplci.pPushConstantRanges = (VkPushConstantRange *)nullptr;

        result = vkCreatePipelineLayout( LogicalDevice, IN &vplci, PALLOCATOR, OUT &Gra
phicsPipelineLayout );
        REPORT( "vkCreatePipelineLayout" );

        VkPipelineShaderStageCreateInfo                         vpssci[2];
                vpssci[0].sType = VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO;
                vpssci[0].pNext = nullptr;
                vpssci[0].flags = 0;
                vpssci[0].stage = VK_SHADER_STAGE_VERTEX_BIT;
#ifdef BITS
VK_SHADER_STAGE_VERTEX_BIT
VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT
VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT
VK_SHADER_STAGE_GEOMETRY_BIT
VK_SHADER_STAGE_FRAGMENT_BIT
VK_SHADER_STAGE_COMPUTE_BIT
VK_SHADER_STAGE_ALL_GRAPHICS
VK_SHADER_STAGE_ALL
#endif
                vpssci[0].module = vertexShader;
                vpssci[0].pName = "main";
                vpssci[0].pSpecializationInfo = (VkSpecializationInfo *)nullptr;

                vpssci[1].sType = VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO;
                vpssci[1].pNext = nullptr;
                vpssci[1].flags = 0;
                vpssci[1].stage = VK_SHADER_STAGE_FRAGMENT_BIT;
                vpssci[1].module = fragmentShader;
                vpssci[1].pName = "main";
                vpssci[1].pSpecializationInfo = (VkSpecializationInfo *)nullptr;
```

```
        VkVertexInputBindingDescription                 vvibd[1];       // an array con
taining one of these per buffer being used
                vvibd[0].binding = 0;           // which binding # this is
                vvibd[0].stride = sizeof( struct vertex );              // bytes betwee
n successive
                vvibd[0].inputRate = VK_VERTEX_INPUT_RATE_VERTEX;
#ifdef CHOICES
VK_VERTEX_INPUT_RATE_VERTEX
VK_VERTEX_INPUT_RATE_INSTANCE
#endif

#ifdef COMMENT
struct vertex
{
        glm::vec3       position;
        glm::vec3       normal;
        glm::vec3       color;
        glm::vec2       texCoord;
} Vertices;
#endif
        VkVertexInputAttributeDescription               vviad[4];               // an a
rray containing one of these per vertex attribute in all bindings
                // 4 = vertex, normal, color, texture coord
                vviad[0].location = 0;                  // location in the layout decor
ation
                vviad[0].binding = 0;                   // which binding description th
is is part of
                vviad[0].format = VK_FORMAT_VEC3;       // x, y, z
                vviad[0].offset = offsetof( struct vertex, position );
        // 0
#ifdef EXTRAS_DEFINED_AT_THE_TOP
VK_FORMAT_VEC4 = VK_FORMAT_R32G32B32A32_SFLOAT
VK_FORMAT_XYZW = VK_FORMAT_R32G32B32A32_SFLOAT
VK_FORMAT_VEC3 = VK_FORMAT_R32G32B32_SFLOAT
VK_FORMAT_STP = VK_FORMAT_R32G32B32_SFLOAT
VK_FORMAT_XYZ = VK_FORMAT_R32G32B32_SFLOAT
VK_FORMAT_VEC2 = VK_FORMAT_R32G32_SFLOAT
VK_FORMAT_ST = VK_FORMAT_R32G32_SFLOAT
VK_FORMAT_XY = VK_FORMAT_R32G32_SFLOAT
VK_FORMAT_FLOAT = VK_FORMAT_R32_SFLOAT
VK_FORMAT_S = VK_FORMAT_R32_SFLOAT
VK_FORMAT_X = VK_FORMAT_R32_SFLOAT
#endif

                vviad[1].location = 1;
                vviad[1].binding = 0;
                vviad[1].format = VK_FORMAT_VEC3;       // nx, ny, nz
                vviad[1].offset = offsetof( struct vertex, normal );
        // 12

                vviad[2].location = 2;
                vviad[2].binding = 0;
                vviad[2].format = VK_FORMAT_VEC3;       // r, g, b
                vviad[2].offset = offsetof( struct vertex, color );
        // 24

                vviad[3].location = 3;
                vviad[3].binding = 0;
                vviad[3].format = VK_FORMAT_VEC2;       // s, t
                vviad[3].offset = offsetof( struct vertex, texCoord );
        // 36


        VkPipelineVertexInputStateCreateInfo                    vpvisci;
                // used to describe the input vertex attributes
```

```
                vpvisci.sType = VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_STATE_CREATE_IN
FO;
                vpvisci.pNext = nullptr;
                vpvisci.flags = 0;
                vpvisci.vertexBindingDescriptionCount = 1;
                vpvisci.pVertexBindingDescriptions = vvibd;
                vpvisci.vertexAttributeDescriptionCount = 4;
                vpvisci.pVertexAttributeDescriptions = vviad;

        VkPipelineInputAssemblyStateCreateInfo                  vpiasci;
                vpiasci.sType = VK_STRUCTURE_TYPE_PIPELINE_INPUT_ASSEMBLY_STATE_CREATE_
INFO;
                vpiasci.pNext = nullptr;
                vpiasci.flags = 0;
                vpiasci.topology = VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST;;
#ifdef CHOICES
                        VK_PRIMITIVE_TOPOLOGY_POINT_LIST
                        VK_PRIMITIVE_TOPOLOGY_LINE_LIST
                        VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST
                        VK_PRIMITIVE_TOPOLOGY_LINE_STRIP
                        VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP
                        VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN
                        VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY
                        VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY
                        VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY
                        VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY
#endif
                vpiasci.primitiveRestartEnable = VK_FALSE;

        VkPipelineTessellationStateCreateInfo                   vptsci;
                vptsci.sType = VK_STRUCTURE_TYPE_PIPELINE_TESSELLATION_STATE_CREATE_INF
O;
                vptsci.pNext = nullptr;
                vptsci.flags = 0;
                vptsci.patchControlPoints = 0;          // number of patch control poin
ts

        // VkPipelineGeometryStateCreateInfo                    vpgsci;
                // vptsci.sType = VK_STRUCTURE_TYPE_PIPELINE_TESSELLATION_STATE_CREATE_
INFO;
                // vptsci.pNext = nullptr;
                // vptsci.flags = 0;

        VkViewport                                              vv;
                vv.x = 0;
                vv.y = 0;
                vv.width = (float)Width;
                vv.height = (float)Height;
                vv.minDepth = 0.0f;
                vv.maxDepth = 1.0f;

        // scissoring:
        VkRect2D                                                vr;
                vr.offset.x = 0;
                vr.offset.y = 0;
                vr.extent.width = Width;
                vr.extent.height = Height;

        VkPipelineViewportStateCreateInfo                       vpvsci;
                vpvsci.sType = VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_STATE_CREATE_INFO;
                vpvsci.pNext = nullptr;
                vpvsci.flags = 0;
                vpvsci.viewportCount = 1;
                vpvsci.pViewports = &vv;
                vpvsci.scissorCount = 1;
```

```
                vpvsci.pScissors = &vr;

        VkPipelineRasterizationStateCreateInfo                  vprsci;
                vprsci.sType = VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_CREATE_IN
FO;
                vprsci.pNext = nullptr;
                vprsci.flags = 0;
                vprsci.depthClampEnable = VK_FALSE;
                vprsci.rasterizerDiscardEnable = VK_FALSE;
                vprsci.polygonMode = VK_POLYGON_MODE_FILL;
#ifdef CHOICES
VK_POLYGON_MODE_FILL
VK_POLYGON_MODE_LINE
VK_POLYGON_MODE_POINT
#endif
                vprsci.cullMode = VK_CULL_MODE_NONE;    // recommend this because of th
e projMatrix[1][1] *= -1.;
#ifdef CHOICES
VK_CULL_MODE_NONE
VK_CULL_MODE_FRONT_BIT
VK_CULL_MODE_BACK_BIT
VK_CULL_MODE_FRONT_AND_BACK_BIT
#endif
                vprsci.frontFace = VK_FRONT_FACE_COUNTER_CLOCKWISE;
#ifdef CHOICES
VK_FRONT_FACE_COUNTER_CLOCKWISE
VK_FRONT_FACE_CLOCKWISE
#endif
                vprsci.depthBiasEnable = VK_FALSE;
                vprsci.depthBiasConstantFactor = 0.f;
                vprsci.depthBiasClamp = 0.f;
                vprsci.depthBiasSlopeFactor = 0.f;
                vprsci.lineWidth = 1.f;

        VkPipelineMultisampleStateCreateInfo                    vpmsci;
                vpmsci.sType = VK_STRUCTURE_TYPE_PIPELINE_MULTISAMPLE_STATE_CREATE_INFO
;
                vpmsci.pNext = nullptr;
                vpmsci.flags = 0;
                vpmsci.rasterizationSamples = VK_SAMPLE_COUNT_1_BIT;
                vpmsci.sampleShadingEnable = VK_FALSE;
                vpmsci.minSampleShading = 0;
                vpmsci.pSampleMask = (VkSampleMask *)nullptr;
                vpmsci.alphaToCoverageEnable = VK_FALSE;
                vpmsci.alphaToOneEnable = VK_FALSE;

        VkPipelineColorBlendAttachmentState                     vpcbas;
                vpcbas.colorWriteMask =         VK_COLOR_COMPONENT_R_BIT
                                              | VK_COLOR_COMPONENT_G_BIT
                                              | VK_COLOR_COMPONENT_B_BIT
                                              | VK_COLOR_COMPONENT_A_BIT;
                vpcbas.blendEnable = VK_FALSE;
                vpcbas.srcColorBlendFactor = VK_BLEND_FACTOR_SRC_COLOR;
                vpcbas.dstColorBlendFactor = VK_BLEND_FACTOR_ONE_MINUS_SRC_COLOR;
                vpcbas.colorBlendOp = VK_BLEND_OP_ADD;
                vpcbas.srcAlphaBlendFactor = VK_BLEND_FACTOR_ONE;
                vpcbas.dstAlphaBlendFactor = VK_BLEND_FACTOR_ZERO;
                vpcbas.alphaBlendOp = VK_BLEND_OP_ADD;

        VkPipelineColorBlendStateCreateInfo                     vpcbsci;
                vpcbsci.sType = VK_STRUCTURE_TYPE_PIPELINE_COLOR_BLEND_STATE_CREATE_INF
O;
                vpcbsci.pNext = nullptr;
                vpcbsci.flags = 0;
                vpcbsci.logicOpEnable = VK_FALSE;
```

```
                vpcbsci.logicOp = VK_LOGIC_OP_COPY;
#ifdef CHOICES
VK_LOGIC_OP_CLEAR
VK_LOGIC_OP_AND
VK_LOGIC_OP_AND_REVERSE
VK_LOGIC_OP_COPY
VK_LOGIC_OP_AND_INVERTED
VK_LOGIC_OP_NO_OP
VK_LOGIC_OP_XOR
VK_LOGIC_OP_OR
VK_LOGIC_OP_NOR
VK_LOGIC_OP_EQUIVALENT
VK_LOGIC_OP_INVERT
VK_LOGIC_OP_OR_REVERSE
VK_LOGIC_OP_COPY_INVERTED
VK_LOGIC_OP_OR_INVERTED
VK_LOGIC_OP_NAND
VK_LOGIC_OP_SET
#endif
                vpcbsci.attachmentCount = 1;
                vpcbsci.pAttachments = &vpcbas;
                vpcbsci.blendConstants[0] = 0;
                vpcbsci.blendConstants[1] = 0;
                vpcbsci.blendConstants[2] = 0;
                vpcbsci.blendConstants[3] = 0;

        VkDynamicState                          vds[ ] = { VK_DYNAMIC_STATE_VIEWPORT, V
K_DYNAMIC_STATE_SCISSOR };
#ifdef CHOICES
VK_DYNAMIC_STATE_VIEWPORT       --      vkCmdSetViewort( )
VK_DYNAMIC_STATE_SCISSOR        --      vkCmdSetScissor( )
VK_DYNAMIC_STATE_LINE_WIDTH     --      vkCmdSetLineWidth( )
VK_DYNAMIC_STATE_DEPTH_BIAS     --      vkCmdSetDepthBias( )
VK_DYNAMIC_STATE_BLEND_CONSTANTS        --      vkCmdSetBendConstants( )
VK_DYNAMIC_STATE_DEPTH_BOUNDS   --      vkCmdSetDepthZBounds( )
VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK   --      vkCmdSetStencilCompareMask( )
VK_DYNAMIC_STATE_STENCIL_WRITE_MASK     --      vkCmdSetStencilWriteMask( )
VK_DYNAMIC_STATE_STENCIL_REFERENCE      --      vkCmdSetStencilReferences( )
#endif
        VkPipelineDynamicStateCreateInfo                                vpdsci;
                vpdsci.sType = VK_STRUCTURE_TYPE_PIPELINE_DYNAMIC_STATE_CREATE_INFO;
                vpdsci.pNext = nullptr;
                vpdsci.flags = 0;
                vpdsci.dynamicStateCount = 0;                   // leave turned off for
 now
                vpdsci.pDynamicStates = vds;

        VkStencilOpState                                        vsosf;  // front
                vsosf.failOp = VK_STENCIL_OP_KEEP;
                vsosf.passOp = VK_STENCIL_OP_KEEP;
                vsosf.depthFailOp = VK_STENCIL_OP_KEEP;
#ifdef CHOICES
VK_STENCIL_OP_KEEP
VK_STENCIL_OP_ZERO
VK_STENCIL_OP_REPLACE
VK_STENCIL_OP_INCREMENT_AND_CLAMP
VK_STENCIL_OP_DECREMENT_AND_CLAMP
VK_STENCIL_OP_INVERT
VK_STENCIL_OP_INCREMENT_AND_WRAP
VK_STENCIL_OP_DECREMENT_AND_WRAP
#endif
                vsosf.compareOp = VK_COMPARE_OP_NEVER;
#ifdef CHOICES
VK_COMPARE_OP_NEVER
VK_COMPARE_OP_LESS
```

```
VK_COMPARE_OP_EQUAL
VK_COMPARE_OP_LESS_OR_EQUAL
VK_COMPARE_OP_GREATER
VK_COMPARE_OP_NOT_EQUAL
VK_COMPARE_OP_GREATER_OR_EQUAL
VK_COMPARE_OP_ALWAYS
#endif
                vsosf.compareMask = ~0;
                vsosf.writeMask = ~0;
                vsosf.reference = 0;

        VkStencilOpState                                        vsosb;  // back
                vsosb.failOp = VK_STENCIL_OP_KEEP;
                vsosb.passOp = VK_STENCIL_OP_KEEP;
                vsosb.depthFailOp = VK_STENCIL_OP_KEEP;
                vsosb.compareOp = VK_COMPARE_OP_NEVER;
                vsosb.compareMask = ~0;
                vsosb.writeMask = ~0;
                vsosb.reference = 0;

        VkPipelineDepthStencilStateCreateInfo                   vpdssci;
                vpdssci.sType = VK_STRUCTURE_TYPE_PIPELINE_DEPTH_STENCIL_STATE_CREATE_I
NFO;
                vpdssci.pNext = nullptr;
                vpdssci.flags = 0;
                vpdssci.depthTestEnable = VK_TRUE;
                vpdssci.depthWriteEnable = VK_TRUE;
                vpdssci.depthCompareOp = VK_COMPARE_OP_LESS;
#ifdef CHOICES
VK_COMPARE_OP_NEVER
VK_COMPARE_OP_LESS
VK_COMPARE_OP_EQUAL
VK_COMPARE_OP_LESS_OR_EQUAL
VK_COMPARE_OP_GREATER
VK_COMPARE_OP_NOT_EQUAL
VK_COMPARE_OP_GREATER_OR_EQUAL
VK_COMPARE_OP_ALWAYS
#endif
                vpdssci.depthBoundsTestEnable = VK_FALSE;
                vpdssci.front = vsosf;
                vpdssci.back  = vsosb;
                vpdssci.minDepthBounds = 0.;
                vpdssci.maxDepthBounds = 1.;
                vpdssci.stencilTestEnable = VK_FALSE;



        VkGraphicsPipelineCreateInfo                            vgpci;
                vgpci.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;
                vgpci.pNext = nullptr;
                vgpci.flags = 0;
#ifdef CHOICES
VK_PIPELINE_CREATE_DISABLE_OPTIMIZATION_BIT
VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT
VK_PIPELINE_CREATE_DERIVATIVE_BIT
#endif
                vgpci.stageCount = 2;                           // number of stages in
this pipeline
                vgpci.pStages = vpssci;
                vgpci.pVertexInputState = &vpvisci;
                vgpci.pInputAssemblyState = &vpiasci;
                vgpci.pTessellationState = (VkPipelineTessellationStateCreateInfo *)nul
lptr;           // &vptsci
                vgpci.pViewportState = &vpvsci;
                vgpci.pRasterizationState = &vprsci;
```

```
                vgpci.pMultisampleState = &vpmsci;
                vgpci.pDepthStencilState = &vpdssci;
                vgpci.pColorBlendState = &vpcbsci;
                vgpci.pDynamicState = &vpdsci;
                vgpci.layout = IN GraphicsPipelineLayout;
                vgpci.renderPass = IN RenderPass;
                vgpci.subpass = 0;                                  // subpass number
                vgpci.basePipelineHandle = (VkPipeline) VK_NULL_HANDLE;
                vgpci.basePipelineIndex = 0;

        result = vkCreateGraphicsPipelines( LogicalDevice, VK_NULL_HANDLE, 1, IN &vgpci
, PALLOCATOR, OUT pGraphicsPipeline );
        REPORT( "vkCreateGraphicsPipelines" );

        return result;
}
```

```
// *************************
// SETUP A COMPUTE PIPELINE:
// *************************

VkResult
Init14ComputePipeline( VkShaderModule computeShader, OUT VkPipeline * pComputePipeline
 )
{
        HERE_I_AM( "Init14ComputePipeline" );

        VkResult result = VK_SUCCESS;

        VkPipelineShaderStageCreateInfo                 vpssci;
                vpssci.sType = VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO;
                vpssci.pNext = nullptr;
                vpssci.flags = 0;
                vpssci.stage = VK_SHADER_STAGE_COMPUTE_BIT;
                vpssci.module = computeShader;
                vpssci.pName = "main";
                vpssci.pSpecializationInfo = (VkSpecializationInfo *)nullptr;

        VkPipelineLayoutCreateInfo                              vplci;
                vplci.sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
                vplci.pNext = nullptr;
                vplci.flags = 0;
                vplci.setLayoutCount = 1;
                vplci.pSetLayouts = DescriptorSetLayouts;
                vplci.pushConstantRangeCount = 0;
                vplci.pPushConstantRanges = (VkPushConstantRange *)nullptr;

        result = vkCreatePipelineLayout( LogicalDevice, IN &vplci, PALLOCATOR, OUT &Com
putePipelineLayout );
        REPORT( "vkCreatePipelineLayout" );

        VkComputePipelineCreateInfo                     vcpci[1];
                vcpci[0].sType = VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_CREATE_INFO;
                vcpci[0].pNext = nullptr;
                vcpci[0].flags = 0;
                vcpci[0].stage = vpssci;
                vcpci[0].layout = ComputePipelineLayout;
                vcpci[0].basePipelineHandle = VK_NULL_HANDLE;
                vcpci[0].basePipelineIndex = 0;

        result = vkCreateComputePipelines( LogicalDevice, VK_NULL_HANDLE, 1, &vcpci[0],
 PALLOCATOR, pComputePipeline );
        REPORT( "vkCreateComputePipelines" );
        return result;
}

#ifdef SAMPLE_CODE
vkBeginRenderPass( );
vkCmdBindPipeline( CommandBuffer, VK_PIPELINE_BIND_POINT_COMPUTE, ComputePipelines[0] )
;
vkCmdDispatch( CommandBuffer, numWGx, numWGy, numWQz );
vkEndRenderPass( );
#endif
```

```
// *********************************
// CREATING AND SUBMITTING THE FENCE:
// *********************************

VkResult
InitFence( )
{
	VkFenceCreateInfo			vfci;
		vfci.sType = VK_STRUCTURE_TYPE_FENCE_CREATE_INFO;
		vfci.pNext = nullptr;
		vfci.flags = 0;

	vkCreateFence( LogicalDevice, &vfci, PALLOCATOR, &Fence );


	VkSubmitInfo				vsi;
		vsi.sType = VK_STRUCTURE_TYPE_SUBMIT_INFO;
		vsi.pNext = nullptr;
		vsi.waitSemaphoreCount = 0;					// ???
uint32_t
		vsi.pWaitSemaphores = (VkSemaphore *)nullptr;			// ????
??
		vsi.pWaitDstStageMask = (VkPipelineStageFlags *)nullptr;	// ????
?
		vsi.commandBufferCount = 1;
		vsi.pCommandBuffers = CommandBuffers;
		vsi.signalSemaphoreCount = 0;					// ????
?
		vsi.pSignalSemaphores = (VkSemaphore *)nullptr;			// ????
?

	VkResult result = vkQueueSubmit( Queue, 1, IN &vsi, IN Fence );
		// Fence can be VK_NULL_HANDLE if have no fence
	REPORT( "vkQueueSubmit" );

#ifdef SAMPLE_CODE
	result = vkWaitForFences( LogicalDevice, 1, pFences, VK_TRUE, timeout );
	REPORT( "vkWaitForFences" );
#endif

	return result;
}

#ifdef SAMPLE_CODE
	vkDestroyFence( LogicalDevice, Fence, nullptr );
#endif



// ***************
// PUSH CONSTANTS:
// ***************
//
// Push Constants are uniform variables in a shader.
// There is one Push Constant block per pipeline.
// Push Constants are "injected" into the pipeline.
// They are not necessarily backed by device memory, although they could be.

#ifdef COMMENT
layout( push_constant ) uniform myPushConstants_t
{
	int a;
	float b;
```

```
        int c;
} MyPushConstants;
#endif

#ifdef SAMPLE_CODE
        VkPushConstantRange                             vpcr[1];
                vpcr.stageFlags = VK_SHADER_STAGE_ALL;
                vpcr.offset = 0;
                vpcr.size = << in bytes >>

        VkPipelineLayoutCreateInfo              vplci;
                vplci.sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
                vplci.pNext = nullptr;
                vplci.flags = 0;
                vplci.setLayoutCount = << length of array .pSetLayouts >>
                vplci.pSetLayouts = << array of type VkDescriptorSetLayout >>
                vplci.pushConstantRangeCount = << length of array pPushConstantRanges >
>
                vplci.pPushConstantRanges = << array of type VkPushConstantRange >>

        result = vkCreatePipelineLayout( LogicalDevice, &vplci, PALLOCATOR, &PipelineLa
yout );
#endif

#ifdef SAMPLE_CODE
        vkCmdPushConstants( CommandBuffer, PipelineLayout, VK_SHADER_STAGE_ALL, offset,
 size, void *values );
#endif



// *************************
// SPECIALIZATION CONSTANTS:
// *************************
//
// Specialization Constants "specialize" a shader.
// I.e., these constants get compiled-in.
// Typically, the final code generation comes late, with calls to
//      vkCreateComputePipelines( )
//      vkCreateGraphicsPipelines( )
// The compiler can make code-generation decisions based on Specialization Constants.
// Specialization constants are good for:
//      branching (~ #ifdef)
//      switch
//      loop unrolling
//      constant folding
//      operator simplification

#ifdef SAMPLE_CODE
layout( constant_id = 1 ) const bool  USE_HALF_ANGLE = true;
layout( constant_id = 2 ) const float G = -9.8f;


        VkSpecializationMapEntity                       vsme[1];
                vsme[0].constantId = << the constant_id in the layout line, uint32_t >>
                vsme[0].offset = << how far into the raw data this constant is, bytes >
>
                vsme[0].size = << size of this SC in the raw data >>

        VkSpecializationInfo                            vsi;
                vsi.mapEntryCount = << number of SCs to be set >>
                vsi.pmapEntries = << array of VkSpecializationMapEntry elements >>
                vsi.dataSize = << in bytes >>
                vsi.pData = << the raw data, void * >>
#endif
```

```
// ******************************
// HANDLING A VULKAN ERROR RETURN:
// ******************************

struct errorcode
{
	VkResult	resultCode;
	std::string	meaning;
}
ErrorCodes[ ] =
{
	{ VK_NOT_READY,				"Not Ready"			},
	{ VK_TIMEOUT,				"Timeout"			},
	{ VK_EVENT_SET,				"Event Set"			},
	{ VK_EVENT_RESET,			"Event Reset"			},
	{ VK_INCOMPLETE,			"Incomplete"			},
	{ VK_ERROR_OUT_OF_HOST_MEMORY,		"Out of Host Memory"		},
	{ VK_ERROR_OUT_OF_DEVICE_MEMORY,	"Out of Device Memory"		},
	{ VK_ERROR_INITIALIZATION_FAILED,	"Initialization Failed"		},
	{ VK_ERROR_DEVICE_LOST,			"Device Lost"			},
	{ VK_ERROR_MEMORY_MAP_FAILED,		"Memory Map Failed"		},
	{ VK_ERROR_LAYER_NOT_PRESENT,		"Layer Not Present"		},
	{ VK_ERROR_EXTENSION_NOT_PRESENT,	"Extension Not Present"		},
	{ VK_ERROR_FEATURE_NOT_PRESENT,		"Feature Not Present"		},
	{ VK_ERROR_INCOMPATIBLE_DRIVER,		"Incompatible Driver"		},
	{ VK_ERROR_TOO_MANY_OBJECTS,		"Too Many Objects"		},
	{ VK_ERROR_FORMAT_NOT_SUPPORTED,	"Format Not Supported"		},
	{ VK_ERROR_FRAGMENTED_POOL,		"Fragmented Pool"		},
	{ VK_ERROR_SURFACE_LOST_KHR,		"Surface Lost"			},
	{ VK_ERROR_NATIVE_WINDOW_IN_USE_KHR,	"Native Window in Use"		},
	{ VK_SUBOPTIMAL_KHR,			"Suboptimal"			},
	{ VK_ERROR_OUT_OF_DATE_KHR,		"Error Out of Date"		},
	{ VK_ERROR_INCOMPATIBLE_DISPLAY_KHR,	"Incompatible Display"		},
	{ VK_ERROR_VALIDATION_FAILED_EXT,	"Valuidation Failed"		},
	{ VK_ERROR_INVALID_SHADER_NV,		"Invalid Shader"		},
	{ VK_ERROR_OUT_OF_POOL_MEMORY_KHR,	"Out of Pool Memory"		},
	{ VK_ERROR_INVALID_EXTERNAL_HANDLE_KHX,	"Invalid External Handle"	},
};

void
PrintVkError( VkResult result, std::string prefix )
{
	if (Verbose  &&  result == VK_SUCCESS)
	{
		fprintf(FpDebug, "%s: %s\n", prefix.c_str(), "Successful");
		fflush(FpDebug);
		return;
	}

	const int numErrorCodes = sizeof( ErrorCodes ) / sizeof( struct errorcode );
	std::string meaning = "";
	for( int i = 0; i < numErrorCodes; i++ )
	{
		if( result == ErrorCodes[i].resultCode )
		{
			meaning = ErrorCodes[i].meaning;
			break;
		}
	}

	fprintf( FpDebug, "\n%s: %s\n", prefix.c_str(), meaning.c_str() );
	fflush(FpDebug);
}
```

```
// *******
// FENCES:
// *******

#ifdef SAMPLE_CODE
VkResult
InitFence( )
{
	VkResult result;

	VkFenceCreateInfo                                vfci;
		vfci.sType = VK_STRUCTURE_TYPE_FENCE_CREATE_INFO;
		vfci.pNext = nullptr;
		vfci.flags = VK_FENCE_CREATE_SIGNALED_BIT;      // the only option

	result = vkCreateFence( LogicalDevice, IN &vfci, PALLOCATOR, &Fence );
	REPORT( "vkCreateFence" );


	result = vkGetFenceStatus( LogicalDevice, IN Fence );
#ifdef RESULT
		VK_SUCCESS:     its signaled
		VK_NOT_READY:   its not signaled
#endif
	REPORT( "vkGetFenceStatus" );


	result = vkWaitForFence( LogicalDevice, fenceCount, pFences, waitForAll, timeou
t );
#ifdef CHOICES
		waitForAll: VK_TRUE = wait for all fences
		          : VK_FALSE = wait for any fences
		timeout   : uint64_t, timeout in nanoseconds
#endif
#ifdef RESULT
		result:   : VK_SUCCESS = returned because a fence signaled
		          : VK_TIMEOUT = returned because the timeout was exceeded
#endif
	REPORT( "vkWaitForFence" );

	result = vkResetFences( LogicalDevice, count, pFemces );
	REPORT( "vkResetFences" );
}
#endif



// *******
// EVENTS:
// *******
#ifdef SAMPLE_CODE
VkResult
InitEvent( )
{
	VkResult result;

	VkEventCreateInfo                          veci;
		veci.sType = VK_STRUCTURE_TYPE_EVENT_CREATE_INFO;
		veci.pNext = nullptr;
		veci.flags = 0;

	VkResult result = vkCreateEvent( LogicalDevice, IN &veci, PALLOCATOR, OUT &Even
t );
	REPORT( "vkCreateEvent" );
```

```
        result = vkSetEvent( LogicalDevice, Event );
        REPORT( "vkSetEvent" );
        result = vkResetEvent( LogicalDevice, Event );
        REPORT( "vkResetEvent" );

        result = vkGetEventStatus( LogicalDevice, Event );
#ifdef RESULTS
                VK_EVENT_SET  : signaled
                VK_EVENT_RESET: not signaled
#endif
        REPORT( "vkGetEventStatus" );


        result = vkCmdSetEvent( CommandBuffer, Event, pipelineStageBits );
        REPORT( "vkCmdSetEvent" );
        result = vkCmdResetEvent( CommandBuffer, Event, pipelineStageBits );
        REPORT( "vkCmdResetEvent" );

        result = vkCmdWaitEvents( CommandBuffer, eventCount, pEvents, srcPipelineStageB
its, dstPipelineStageBits,
                memoryBarrierCount, pMemoryBarriers,
                bufferMemoryBarrierCount, pBufferMemoryBarriers,
                imageMemoryBarrierCount, pImageMemoryBarriers );
        REPORT( "vkCmdWaitEvents" );
#endif



// ***********
// SEMAPHORES:
// ***********

VkResult
InitSemaphore( )
{
        VkResult result = VK_SUCCESS;

        VkSemaphoreCreateInfo                   vsci;
                vsci.sType = VK_STRUCTURE_TYPE_SEMAPHORE_CREATE_INFO;
                vsci.pNext = nullptr;
                vsci.flags = 0;

        result = vkCreateSemaphore( LogicalDevice, IN &vsci, PALLOCATOR, OUT &Semaphore
ImageAvailable );
        REPORT( "vkCreateSemaphore -- image available" );

        result = vkCreateSemaphore( LogicalDevice, IN &vsci, PALLOCATOR, OUT &Semaphore
RenderFinished );
        REPORT( "vkCreateSemaphore -- render finished" );

                // vkQueueSubmit waits for one set of semaphores and signals another
                // Can have 2 queues, one for compute and one for graphics
                        // Graphics Queue can wait on signal from Compute Queue
                        // Then, Compute Queue can wait on signal from Graphics Queue

        return result;
}
```

```
VkResult
DestroyAllVulkan( )
{
	VkResult result = VK_SUCCESS;

	result = vkDeviceWaitIdle( LogicalDevice );
	REPORT( "vkWaitIdle" );

	vkDestroyPipelineLayout( LogicalDevice, GraphicsPipelineLayout, PALLOCATOR );
	vkDestroyDescriptorSetLayout( LogicalDevice, DescriptorSetLayouts[0], PALLOCATO
R );
	vkDestroyDescriptorSetLayout( LogicalDevice, DescriptorSetLayouts[1], PALLOCATO
R );
	vkDestroyDescriptorSetLayout( LogicalDevice, DescriptorSetLayouts[2], PALLOCATO
R );
	vkDestroyDevice( LogicalDevice, PALLOCATOR );
	vkDestroyInstance( Instance, PALLOCATOR );

	return result;
}


int
FindMemoryThatIsDeviceLocal( )
{
	VkPhysicalDeviceMemoryProperties	vpdmp;
	vkGetPhysicalDeviceMemoryProperties( PhysicalDevice, OUT &vpdmp );
	for( unsigned int i = 0; i < vpdmp.memoryTypeCount; i++ )
	{
		VkMemoryType vmt = vpdmp.memoryTypes[i];
		if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT ) != 0 )
		{
			return i;
		}
	}
	return 0;
}


int
FindMemoryThatIsHostVisible( )
{
	VkPhysicalDeviceMemoryProperties	vpdmp;
	vkGetPhysicalDeviceMemoryProperties( PhysicalDevice, OUT &vpdmp );
	for( unsigned int i = 0; i < vpdmp.memoryTypeCount; i++ )
	{
		VkMemoryType vmt = vpdmp.memoryTypes[i];
		if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT ) != 0 )
		{
			return i;
		}
	}
	return 0;
}


int
FindMemoryWithTypeBits( uint32_t memoryTypeBits )
{
	VkPhysicalDeviceMemoryProperties	vpdmp;
	vkGetPhysicalDeviceMemoryProperties( PhysicalDevice, OUT &vpdmp );
	for( unsigned int i = 0; i < vpdmp.memoryTypeCount; i++ )
```

```
        {
                VkMemoryType vmt = vpdmp.memoryTypes[i];
                if( ( vmt.propertyFlags & (1<<i) ) != 0 )
                {
                        return i;
                }
        }
        return 0;
}
```

```
// ********************************************
// EXECUTE THE CODE FOR THE RENDERING OPERATION:
// ********************************************

VkResult
RenderScene( )
{
	NumRenders++;
	if (NumRenders <= 2)
		HERE_I_AM( "RenderScene" );

	VkResult result = VK_SUCCESS;

	uint32_t nextImageIndex;
	vkAcquireNextImageKHR( LogicalDevice, IN SwapChain, IN UINT64_MAX, IN VK_NULL_H
ANDLE, IN VK_NULL_HANDLE, OUT &nextImageIndex );
	if( Verbose &&  NumRenders <= 2 )	fprintf(FpDebug, "nextImageIndex = %d\n
", nextImageIndex);

	VkCommandBufferBeginInfo		vcbbi;
		vcbbi.sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_BEGIN_INFO;
		vcbbi.pNext = nullptr;
		vcbbi.flags = VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT;
		//vcbbi.flags = VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT;   <-----
or could use this one??
		vcbbi.pInheritanceInfo = (VkCommandBufferInheritanceInfo *)nullptr;

	result = vkBeginCommandBuffer( CommandBuffers[nextImageIndex], IN &vcbbi );
	//REPORT( "vkBeginCommandBuffer" );

	VkClearColorValue			vccv;
		vccv.float32[0] = 0.0;
		vccv.float32[1] = 0.0;
		vccv.float32[2] = 0.0;
		vccv.float32[3] = 1.0;

	VkClearDepthStencilValue		vcdsv;
		vcdsv.depth = 1.f;
		vcdsv.stencil = 0;

	VkClearValue				vcv[2];
		vcv[0].color = vccv;
		vcv[1].depthStencil = vcdsv;

	VkOffset2D o2d = { 0, 0 };
	VkExtent2D e2d = { Width, Height };
	VkRect2D r2d = { o2d, e2d };

	VkRenderPassBeginInfo				vrpbi;
		vrpbi.sType = VK_STRUCTURE_TYPE_RENDER_PASS_BEGIN_INFO;
		vrpbi.pNext = nullptr;
		vrpbi.renderPass = RenderPass;
		vrpbi.framebuffer = Framebuffers[ nextImageIndex ];
		vrpbi.renderArea = r2d;
		vrpbi.clearValueCount = 2;
		vrpbi.pClearValues = vcv;		// used for VK_ATTACHMENT_LOAD_
OP_CLEAR
	vkCmdBeginRenderPass( CommandBuffers[nextImageIndex], IN &vrpbi, IN VK_SUBPASS_
CONTENTS_INLINE );
	result = VK_SUCCESS;
	//REPORT("vkCmdBeginRenderPass");

	vkCmdBindPipeline( CommandBuffers[nextImageIndex], VK_PIPELINE_BIND_POINT_GRAPH
ICS, GraphicsPipeline );
```

```
        result = VK_SUCCESS;
        //REPORT("vkCmdBindPipeline");

        VkViewport viewport =
        {
                0.,                     // x
                0.,                     // y
                (float)Width,
                (float)Height,
                0.,                     // minDepth
                1.                      // maxDepth
        };

        vkCmdSetViewport( CommandBuffers[nextImageIndex], 0, 1, IN &viewport );
        // 0=firstViewport, 1=viewportCount
        result = VK_SUCCESS;
        //REPORT("vkCmdSetViewport");

        VkRect2D scissor =
        {
                0,
                0,
                Width,
                Height
        };

        vkCmdSetScissor( CommandBuffers[nextImageIndex], 0, 1, &scissor );
        result = VK_SUCCESS;
        //REPORT("vkCmdScissor");


        vkCmdBindDescriptorSets( CommandBuffers[nextImageIndex], VK_PIPELINE_BIND_POINT
_GRAPHICS, GraphicsPipelineLayout, 0, 4, DescriptorSets, 0, (uint32_t *)nullptr );

                                        // dynamic offset count, dynamic offsets
        result = VK_SUCCESS;
        //REPORT("vkCmdBindDescriptorSets");

        //vkCmdBindPushConstants( CommandBuffers[nextImageIndex], PipelineLayout, VK_SH
ADER_STAGE_ALL, offset, size, void *values );

        VkBuffer buffers[1] = { MyVertexDataBuffer.buffer };

        VkDeviceSize offsets[1] = { 0 };

        vkCmdBindVertexBuffers( CommandBuffers[nextImageIndex], 0, 1, buffers, offsets
);              // 0, 1 = firstBinding, bindingCount
        result = VK_SUCCESS;
        //REPORT("vkCmdBindVertexBuffers");

        const uint32_t vertexCount = sizeof(VertexData) / sizeof(VertexData[0]);
        const uint32_t instanceCount = 1;
        const uint32_t firstVertex = 0;
        const uint32_t firstInstance = 0;
        vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVer
tex, firstInstance );
        result = VK_SUCCESS;
        //REPORT("vkCmdDraw");

        vkCmdEndRenderPass( CommandBuffers[nextImageIndex] );
        result = VK_SUCCESS;
        //REPORT("vkEndRenderPass");

        vkEndCommandBuffer( CommandBuffers[nextImageIndex] );
        result = VK_SUCCESS;
```

```
        //REPORT("vkEndCommandBuffer");

        VkFenceCreateInfo                       vfci;
                vfci.sType = VK_STRUCTURE_TYPE_FENCE_CREATE_INFO;
                vfci.pNext = nullptr;
                vfci.flags = 0;

        VkFence renderFence;
        vkCreateFence( LogicalDevice, &vfci, PALLOCATOR, OUT &renderFence );
        result = VK_SUCCESS;
        //REPORT("vkCreateFence");

        VkPipelineStageFlags waitAtBottom = VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT;
#ifdef CHOICES
typedef enum VkPipelineStageFlagBits {
VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT = 0x00000001,
VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT = 0x00000002,
VK_PIPELINE_STAGE_VERTEX_INPUT_BIT = 0x00000004,
VK_PIPELINE_STAGE_VERTEX_SHADER_BIT = 0x00000008,
VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT = 0x00000010,
VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT = 0x00000020,
VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT = 0x00000040,
VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT = 0x00000080,
VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT = 0x00000100,
VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT = 0x00000200,
VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT = 0x00000400,
VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT = 0x00000800,
VK_PIPELINE_STAGE_TRANSFER_BIT = 0x00001000,
VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT = 0x00002000,
VK_PIPELINE_STAGE_HOST_BIT = 0x00004000,
VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT = 0x00008000,
VK_PIPELINE_STAGE_ALL_COMMANDS_BIT = 0x00010000,
VK_PIPELINE_STAGE_COMMAND_PROCESS_BIT_NVX = 0x00020000,
} VkPipelineStageFlagBits;
#endif
        VkQueue presentQueue;
        vkGetDeviceQueue( LogicalDevice, 0, 0, OUT &presentQueue );     // 0, 0 = queue
FamilyIndex, queueIndex
        result = VK_SUCCESS;
        //REPORT("vkGetDeviceQueue");

        VkSubmitInfo                            vsi;
                vsi.sType = VK_STRUCTURE_TYPE_SUBMIT_INFO;
                vsi.pNext = nullptr;
///             vsi.waitSemaphoreCount = 1;
                vsi.waitSemaphoreCount = 0;
                vsi.pWaitSemaphores = &SemaphoreImageAvailable;
                vsi.pWaitDstStageMask = &waitAtBottom;
                vsi.commandBufferCount = 1;
                vsi.pCommandBuffers = &CommandBuffers[nextImageIndex];
///             vsi.signalSemaphoreCount = 1;
                vsi.signalSemaphoreCount = 0;
                vsi.pSignalSemaphores = &SemaphoreRenderFinished;

        result = vkQueueSubmit( presentQueue, 1, IN &vsi, IN renderFence );     // 1 =
submitCount
        if( Verbose && NumRenders <= 2 )        REPORT("vkQueueSubmit");

        result = vkWaitForFences( LogicalDevice, 1, IN &renderFence, VK_TRUE, UINT64_MA
X );    // waitAll, timeout
        if (Verbose && NumRenders <= 2)         REPORT("vkWaitForFences");

        vkDestroyFence( LogicalDevice, renderFence, PALLOCATOR );
        result = VK_SUCCESS;
        //REPORT("vkDestroyFence");
```

```
        VkPresentInfoKHR                                    vpi;
                vpi.sType = VK_STRUCTURE_TYPE_PRESENT_INFO_KHR;
                vpi.pNext = nullptr;
                vpi.waitSemaphoreCount = 0;
                vpi.pWaitSemaphores = (VkSemaphore *)nullptr;
                vpi.swapchainCount = 1;
                vpi.pSwapchains = &SwapChain;
                vpi.pImageIndices = &nextImageIndex;
                vpi.pResults = (VkResult *)nullptr;

        result = vkQueuePresentKHR( presentQueue, IN &vpi );
        if (Verbose && NumRenders <= 2)         REPORT("vkQueuePresentKHR");

        return result;
}
```

```
// ***************************
// RESET THE GLOBAL VARIABLES:
// ***************************

void
Reset( )
{
        ActiveButton = 0;
        Mode = 0;
        NeedToExit = false;
        NumRenders = 0;
        Paused = false;
        Scale  = 1.0;
        UseMouse = false;
        Verbose = true;
        Xrot = Yrot = 0.;

        // initialize the matrices:

        glm::vec3  eye(0.,0.,EYEDIST);
        glm::vec3  look(0.,0.,0.);
        glm::vec3  up(0.,1.,0.);
        Matrices.uModelMatrix      = glm::mat4( );              // identity
        Matrices.uViewMatrix       = glm::lookAt( eye, look, up );
        Matrices.uProjectionMatrix = glm::perspective( FOV, (double)Width/(double)Heigh
t, 0.1, 1000. );
        Matrices.uProjectionMatrix[1][1] *= -1.;
        Matrices.uNormalMatrix = glm::inverseTranspose(  glm::mat3( Matrices.uModelMatr
ix )  );


        // initialize the light position:

        Light.uLightPos = glm::vec4( 0., 10., 0., 1. );


        // initialize the misc stuff:

        Misc.uTime = 0.;
        Misc.uMode = Mode;
}



// *****************
// UPDATE THE SCENE:
// *****************

void
UpdateScene( )
{
        // change the object orientation:

        if( UseMouse )
        {
                Matrices.uModelMatrix = glm::mat4( );           // identity
                Matrices.uModelMatrix = glm::rotate( Matrices.uModelMatrix, Yrot, glm::
vec3( 0.,1.,0.) );
                Matrices.uModelMatrix = glm::rotate( Matrices.uModelMatrix, Xrot, glm::
vec3( 1.,0.,0.) );

                if( Scale < MINSCALE )
                        Scale = MINSCALE;
                Matrices.uModelMatrix = glm::scale(  Matrices.uModelMatrix, glm::vec3(S
```

```
cale,Scale,Scale) );
        }
        else
        {
                if( ! Paused )
                {
                        const glm::vec3 axis = glm::vec3( 0., 1., 0. );
                        Matrices.uModelMatrix      = glm::rotate( glm::mat4( ),  (float
)glm::radians( 360.f*Time/SECONDS_PER_CYCLE ),   axis );
                }
        }


        // change the object projection:

        Matrices.uProjectionMatrix = glm::perspective( FOV, (double)Width/(double)Heigh
t, 0.1, 1000. );
                Matrices.uProjectionMatrix[1][1] *= -1.;


        // change the normal matrix:

        Matrices.uNormalMatrix = glm::inverseTranspose(  glm::mat3( Matrices.uModelMatr
ix )  );
        Fill05DataBuffer( MyMatrixUniformBuffer, (void *) &Matrices );


        // possibly change the light position:

        // Fill05DataBuffer( MyLightUniformBuffer, (void*) &Light );    // don't need t
his now:


        // change the miscellaneous stuff:

        Misc.uTime = (float)Time;
        Misc.uMode = Mode;
        Fill05DataBuffer( MyMiscUniformBuffer, (void *) &Misc );
}
```

```
//*********************************************************************
// GLFW WINDOW FUNCTIONS:
//*********************************************************************


void
InitGLFW( )
{
	glfwInit( );
	glfwWindowHint( GLFW_CLIENT_API, GLFW_NO_API );
	glfwWindowHint( GLFW_RESIZABLE, GLFW_FALSE );
	MainWindow = glfwCreateWindow( Width, Height, "Vulkan Sample", NULL, NULL );
	VkResult result = glfwCreateWindowSurface( Instance, MainWindow, NULL, &Surface
 );
	REPORT( "glfwCreateWindowSurface" );

	glfwSetErrorCallback( GLFWErrorCallback );
	glfwSetKeyCallback( MainWindow, GLFWKeyboard );
	glfwSetCursorPosCallback( MainWindow, GLFWMouseMotion );
	glfwSetMouseButtonCallback( MainWindow, GLFWMouseButton );
}



void
GLFWErrorCallback( int error, const char * description )
{
	fprintf( FpDebug, "GLFW Error = %d: '%s'\n", error, description );
}


void
GLFWKeyboard( GLFWwindow * window, int key, int scancode, int action, int mods )
{
	if( action == GLFW_PRESS )
	{
		switch( key )
		{

			case 'i':
			case 'I':
				UseMouse = ! UseMouse;
				break;

			case 'm':
			case 'M':
				Mode++;
				if( Mode >= 2 )
					Mode = 0;
				if (Verbose) {
					fprintf(FpDebug, "Mode = %d\n", Mode); fflush(F
pDebug);
				}
				break;

			case 'p':
			case 'P':
				Paused = ! Paused;
				break;

			case 'q':
			case 'Q':
			case GLFW_KEY_ESCAPE:
				NeedToExit = true;
```

```
                                break;

                        case 'v':
                        case 'V':
                                Verbose = ! Verbose;
                                break;

                        default:
                                fprintf( FpDebug, "Unknow key hit: 0x%04x = '%c'\n", ke
y, key );
                                fflush(FpDebug);
                }
        }
}


// ********************************
// PROCESS A MOUSE BUTTON UP OR DOWN:
// ********************************

void
GLFWMouseButton( GLFWwindow *window, int button, int action, int mods )
{
        if( Verbose )           fprintf( FpDebug, "Mouse button = %d; Action = %d\n", b
utton, action );

        int b = 0;              // LEFT, MIDDLE, or RIGHT


        // get the proper button bit mask:

        switch( button )
        {
                case GLFW_MOUSE_BUTTON_LEFT:
                        b = LEFT;               break;

                case GLFW_MOUSE_BUTTON_MIDDLE:
                        b = MIDDLE;             break;

                case GLFW_MOUSE_BUTTON_RIGHT:
                        b = RIGHT;              break;

                default:
                        b = 0;
                        fprintf( FpDebug, "Unknown mouse button: %d\n", button );
        }


        // button down sets the bit, up clears the bit:

        if( action == GLFW_PRESS )
        {
                double xpos, ypos;
                glfwGetCursorPos( window, &xpos, &ypos);
                Xmouse = (int)xpos;
                Ymouse = (int)ypos;
                ActiveButton |= b;              // set the proper bit
        }
        else
        {
                ActiveButton &= ~b;             // clear the proper bit
        }
}
```

```
// *************************
// PROCESS A MOUSE MOVEMENT:
// *************************

void
GLFWMouseMotion( GLFWwindow *window, double xpos, double ypos )
{
        if( Verbose )           fprintf( FpDebug, "Mouse position: %8.3lf, %8.3lf\n", x
pos, ypos );

        int dx = (int)xpos - Xmouse;            // change in mouse coords
        int dy = (int)ypos - Ymouse;

        if( ( ActiveButton & LEFT ) != 0 )
        {
                Xrot += ( ANGFACT*dy );
                Yrot += ( ANGFACT*dx );
        }


        if( ( ActiveButton & MIDDLE ) != 0 )
        {
                Scale += SCLFACT * (float) ( dx - dy );

                // keep object from turning inside-out or disappearing:

                if( Scale < MINSCALE )
                        Scale = MINSCALE;
        }

        Xmouse = (int)xpos;                     // new current position
        Ymouse = (int)ypos;
}
```