Single 3D frame

0) Initialize libraries, register callbacks, …
1) Set OpenGL params
   1) Recompute app state values
      (player health, positions, …)
   2) Frame start → Clear canvas
   3) Draw scene → Vertices attributes
   4) Finish frame → Display
   5) Poll OS events
2) End program

GLFW Functionality Overview (third party library used in labs)

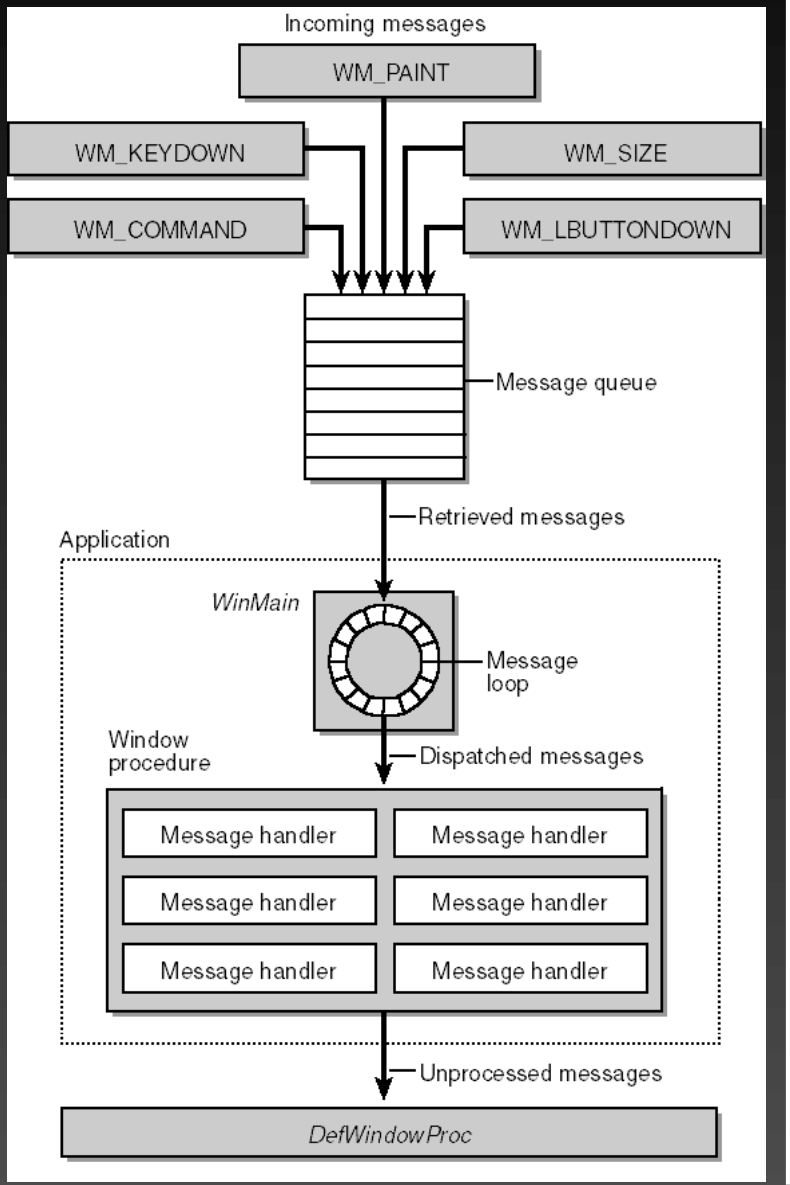
- library for OpenGL, OpenGL ES, Vulkan apps
- multiplatform, multilanguage
- Z-Buffer, stencil, alpha settings
- Camera settings
- Callbacks for OS events
  - mouse, keyboard, timer, windows resize, window redraw, ...

- NO fonts, GUI, sound, texture load, threads, …

GLFW
Hello world

```c
#include <GLFW/glfw3.h>

int main(void)
{
    GLFWwindow* window;

    /* Initialize the library */
    if (!glfwInit())
        return -1;

    /* Create a windowed mode window and its OpenGL context */
    window = glfwCreateWindow(640, 480, "Hello World", NULL, NULL);
    if (!window)
    {
        glfwTerminate();
        return -1;
    }

    /* Make the window's context current */
    glfwMakeContextCurrent(window);

    /* Loop until the user closes the window */
    while (!glfwWindowShouldClose(window))
    {
        /* Render here */
        glClear(GL_COLOR_BUFFER_BIT);

        /* ... more draw-calls ... */

        /* Swap front and back buffers */
        glfwSwapBuffers(window);

        /* Poll for and process events */
        glfwPollEvents();
    }

    glfwTerminate();
    return 0;
}
```

Event Loop




```
void key_callback(GLFWwindow* window, int key, int scancode, int action, int mods) {
	if (key == GLFW_KEY_E && action == GLFW_PRESS) // handle keys...
		activate_airship();
}

void cursor_position_callback(GLFWwindow* window, double xpos, double ypos) {
	// handle mouse movement...
}

init() {
	//...
	GLFWwindow* window =
		glfwCreateWindow(640, 480, "My Title", NULL, NULL);
	//...
	glfwSetKeyCallback(window, key_callback);
	//...
}

int main(int argc, char* argv[]) {
	init();
	while (!glfwWindowShouldClose(window)) {
		update_physics(); // update positions, animations etc.
		draw_scene(); // GL draw calls to create the scene

		if (i_want_to_quit) // player quit, zero lives, etc.
			glfwSetWindowShouldClose(window, GLFW_TRUE);

		glfwSwapBuffers(window);
		glfwPollEvents();   // pick events from the queue and call
				    // proper callback
	}
}
```

Event Loop (bare vs. class)

```
GLFWwindow* window;

void key_callback(GLFWwindow* window, int key, int scancode,
                  int action, int mods) {
    if (key == GLFW_KEY_E && action == GLFW_PRESS)
        activate_airship();
}

void cursor_position_callback(GLFWwindow* window, double
xpos, double ypos) {
    // handle mouse movement...
}

init() {
    //...
    window =
        glfwCreateWindow(640, 480, "MyTitle", NULL, NULL);
    //...
    glfwSetKeyCallback(window, key_callback);
    //...
}

int main(int argc, char* argv[]) {
    init();
    while (!glfwWindowShouldClose(window)) {
        update_physics(); // update positions, animations
etc.
        draw_scene(); // GL draw calls to create the scene

        if (i_want_to_quit) // player quit, zero lives, etc.
            glfwSetWindowShouldClose(window, GLFW_TRUE);

        glfwSwapBuffers(window);
        glfwPollEvents();  // pick events from the queue
                           // and call proper callback
    }
}
```

```
class App {
public:
    init();
    run();
private:
    static void key_callback(...);
    static void cursor_position_callback(...);
    activate_airship();
    int my_counter = 0;
    GLFWwindow* window;
}

void App::key_callback(GLFWwindow* window,int key,int scancode,int action,int mods){
    // get App instance
    auto this_inst = static_cast<App*>(glfwGetWindowUserPointer(window));

    if (key == GLFW_KEY_E && action == GLFW_PRESS)
        this_inst->activate_airship();
    this_inst->my_counter++;
}

void App::cursor_position_callback(GLFWwindow* window, double xpos, double ypos) {
}

App::init() {
    // init glfw...
    window = glfwCreateWindow(640, 480, "MyTitle", NULL, NULL);
    // init glew, set context, ...
    glfwSetWindowUserPointer(window, this);
    glfwSetKeyCallback(window, key_callback);
}

App::run() {
    while (!glfwWindowShouldClose(window)) {
        update_physics(); // update positions, animations etc.
        draw_scene(); // GL draw calls to create the scene

        if (i_want_to_quit) // player quit, zero lives, etc.
            glfwSetWindowShouldClose(window, GLFW_TRUE);

        glfwSwapBuffers(window);
        glfwPollEvents();    // pick events from the queue
                             // and call proper callback
    }
}

int main(int argc, char* argv[]) {
       App app;
       app.init();
       app.run();
}
```

GLFW Init, callback

glfwSetErrorCallback

- error can occur during initialization

```
//============================================================================================
//callback definition for GLFW
void error_callback(int error, const char* description)
{
    std::cerr << "Error no: " << error << " : " << description << std::endl;
}

//============================================================================================

void init_glfw(void)
{
     // set error callback first
    glfwSetErrorCallback(error_callback);

    //initialize GLFW library
    int glfw_ret = glfwInit();
    if (!glfw_ret) {
        std::cerr << "GLFW init failed." << std::endl;
        exit(EXIT_FAILURE);
    }

    window = glfwCreateWindow(800, 600, "OpenGL context", NULL, NULL);
    if (!window) {
        std::cerr << "GLFW window creation error." << std::endl;
        exit(EXIT_FAILURE);
    }

    // Set current window.
    glfwMakeContextCurrent(window);
}
```

Querying basic info

glfwGetVersion
glfwGetVersionString

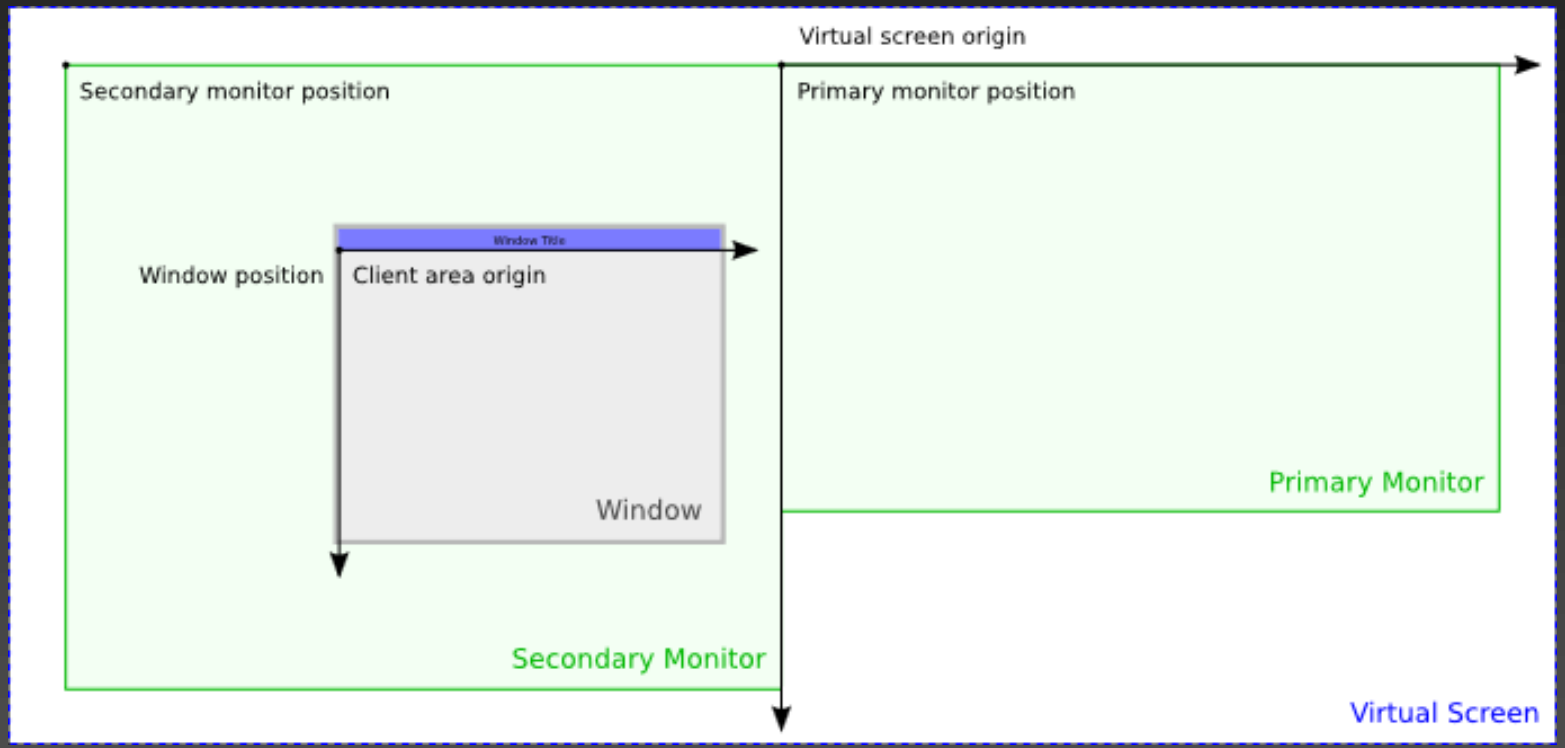
```
// Get some GLFW info.
{
    int major, minor, revision;

    glfwGetVersion(&major, &minor, &revision);
    std::cout << "Running GLFW " << major << '.' << minor << '.' << revision << '\n';
    std::cout << "Compiled against GLFW "
     << GLFW_VERSION_MAJOR << '.' << GLFW_VERSION_MINOR << '.' << GLFW_VERSION_REVISION
         << '\n';
}
```

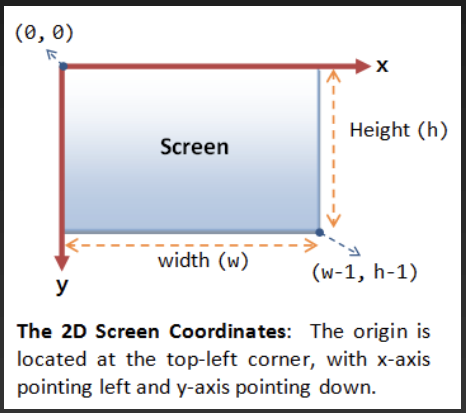
END of application loop with GLFW

```
void window_close_callback(GLFWwindow* window)
{
     if (!time_to_close)
          glfwSetWindowShouldClose(window, GLFW_FALSE); // You can cancel the request.
}


int main(void)
{

     glfwSetWindowCloseCallback(window, window_close_callback);

     while (!glfwWindowShouldClose(window)) // APP loop
     {
          recompute_physics_etc();

          do_my_render(window);

          if (i_want_to_quit)
                    glfwSetWindowShouldClose(window, GLFW_TRUE);

          glfwSwapBuffers(window);
          glfwPollEvents();
     }

     // Close OpenGL window if opened and terminate GLFW
     if (window)
          glfwDestroyWindow(window);

}
```

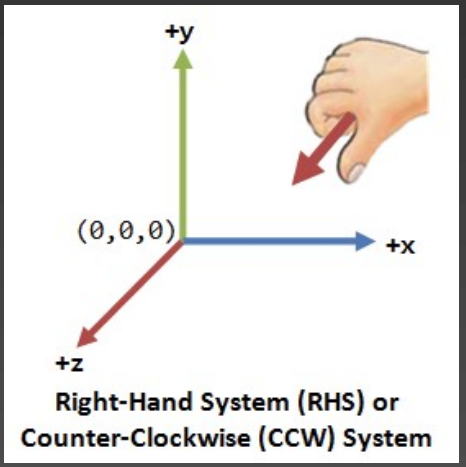
GLFW coordinates

- Virtual screen coordinates and client area
  - may map 1:1 to pixels
  - eg. not on Mac with a Retina display etc.





The 2D Screen Coordinates: The origin is located at the top-left corner, with x-axis pointing left and y-axis pointing down.



Right-Hand System (RHS) or Counter-Clockwise (CCW) System

GLFW and threads

- All callbacks and event processing must be called in main thread!
- Rendering may be done on any single thread.
- Event processing and obj. destruction are NOT reentrant → must not call these in callbacks:

  glfwDestroyWindow
  glfwDestroyCursor
  glfwPollEvents
  glfwWaitEvents
  glfwWaitEventsTimeout
  glfwTerminate

GLFW window management

```
	// Create in windowed mode
	GLFWwindow* window = glfwCreateWindow(640, 480, "My Title", NULL, NULL);

	// Create in fullscreen mode
	GLFWwindow* window = glfwCreateWindow(640, 480, "My Title", glfwGetPrimaryMonitor(), NULL);


	// Switch windowed and fullscreen
	// Get primary monitor
	GLFWmonitor * monitor = glfwGetPrimaryMonitor();
	// Get resolution of monitor
	const GLFWvidmode * mode = glfwGetVideoMode(monitor);
	// Switch to full screen
	glfwSetWindowMonitor(window, monitor, 0, 0, mode->width, mode->height, mode->refreshRate);

	// Switch back to windowed mode (use glfwGetWindowFrameSize(…) to get pos&size)
	glfwSetWindowMonitor(window, nullptr, xpos, ypos, width, height, 0);

void window_iconify_callback(GLFWwindow* window, int iconified)
{
	if (iconified)  {
		// The window was iconified
	}    else {
		// The window was restored
	}
}

	// minimize
	glfwIconifyWindow(window);

	// restore
	glfwRestoreWindow(window);

	// set callback
	glfwSetWindowIconifyCallback(window, window_iconify_callback);
```

GLFW window size limits

- Get

```
glfwGetWindowSize(window, &width, &height);
```

- Set minimum & maximum

```
glfwSetWindowSizeLimits(window, 200, 200, 400, 400);
```

- Set only minimum

```
glfwSetWindowSizeLimits(window, 640, 480, GLFW_DONT_CARE, GLFW_DONT_CARE);
```

- Force aspect ratio

```
glfwSetWindowAspectRatio(window, 16, 9);
```

GLFW window size

- Do not pass the window size to glViewport() or other pixel-based OpenGL calls. The window size is in screen coordinates, not pixels. Use the framebuffer size, which is in pixels, for pixel-based calls.

```
void window_size_callback(GLFWwindow* window, int width, int height)
{
}

void framebuffer_size_callback(GLFWwindow* window, int width, int height)
{
    glViewport(0, 0, width, height);
}

main ()
{
    int width, height;
    glfwSetWindowSizeCallback(window, window_size_callback);
    glfwSetFramebufferSizeCallback(window, framebuffer_size_callback);

    glfwGetWindowSize(window, &width, &height);
    glfwSetWindowSize(window, 640, 480);

    glfwGetFramebufferSize(window, &width, &height);
}
```

GLFW – other functions

- set window focus

  glfwFocusWindow(window);

- Window title, window icon, position, show & hide, scaling…
- Multi-monitor: positions, resolution, scale, area...

```
void window_focus_callback(GLFWwindow* window, int focused)
{
    if (focused)  {
        // The window gained input focus
    }   else {
        // The window lost input focus
    }
}

main ()
{
    glfwSetWindowFocusCallback(window, window_focus_callback);

    int focused = glfwGetWindowAttrib(window, GLFW_FOCUSED);
}
```

GLFW event processing

- continuous (games)

  glfwPollEvents();

- only on input (force thread to sleep)

  glfwWaitEvents();

- on input with timeout in seconds

  glfwWaitEventsTimeout(0.7);

- wake main thread sleeping on glfwWaitEvents() from another thread

  glfwPostEmptyEvent();

- Swaps the front and back buffers of the window

  glfwSwapBuffers (window)

GLFW keyboard input

- key codes – defined for portability
  - GLFW_KEY_0 .. GLFW_KEY_9, GLFW_KEY_A .. GLFW_KEY_Z
  - GLFW_KEY_APOSTROPHE, GLFW_KEY_COMMA, GLFW_KEY_MINUS, …
- standard key action
  - GLFW_PRESS, GLFW_REPEAT, GLFW_RELEASE
- unknown key action (multimedia keyboard – play, email, …)

  GLFW_KEY_UNKNOWN
- modifiers

  GLFW_MOD_ALT, GLFW_MOD_CONTROL, GLFW_MOD_SHIFT, GLFW_MOD_SUPER
- Also sticky keys

```
void key_callback(GLFWwindow* window, int key, int scancode, int action, int mods)
{
    if (key == GLFW_KEY_E && action == GLFW_PRESS)
        activate_airship();
}

main ()
{
    glfwSetKeyCallback(window, key_callback);

    // or poll state manually
    int state = glfwGetKey(window, GLFW_KEY_E);
    if (state == GLFW_PRESS)
        activate_airship();
}
```

GLFW keyboard input - UNICODE

- supports composing characters using dead keys
- translate default key position to language layout

```
void char_callback(GLFWwindow* window, unsigned int codepoint)
{

}

main ()
{
    glfwSetCharCallback(window, char_callback);

    // translate default key position to language layout
    const char* key_name = glfwGetKeyName(GLFW_KEY_W, 0);
    show_tutorial_hint("Press %s to move forward", key_name);
}
```

GLFW mouse input

- measured in screen coordinates
  - relative to the top-left corner of the window client area
- actions: GLFW_PRESS, GLFW_RELEASE
- buttons: GLFW_MOUSE_BUTTON_LEFT (1), GLFW_MOUSE_BUTTON_RIGHT (2), GLFW_MOUSE_BUTTON_MIDDLE (3), GLFW_MOUSE_BUTTON_(1..8)
- Also sticky mouse buttons

```
void cursor_position_callback(GLFWwindow* window, double xpos, double ypos)
{
}
void mouse_button_callback(GLFWwindow* window, int button, int action, int mods)
{
     if (button == GLFW_MOUSE_BUTTON_RIGHT && action == GLFW_PRESS)
          action();
}
void scroll_callback(GLFWwindow* window, double xoffset, double yoffset)
{
}
main ()
{
     glfwSetCursorPosCallback(window, cursor_pos_callback);
     glfwSetMouseButtonCallback(window, mouse_button_callback);
     glfwSetScrollCallback(window, scroll_callback);

     // or by polling
     double xpos, ypos;
     glfwGetCursorPos(window, &xpos, &ypos);
     // or by polling
     int state = glfwGetMouseButton(window, GLFW_MOUSE_BUTTON_LEFT);
     if (state == GLFW_PRESS)
          upgrade_cow();
}
```

GLFW cursor

- mouse motion based camera controls (fullscreen games)

  glfwSetInputMode(window, GLFW_CURSOR, GLFW_CURSOR_DISABLED);

- Raw mouse input: no acceleration etc.

  if (glfwRawMouseMotionSupported())

  glfwSetInputMode(window, GLFW_RAW_MOUSE_MOTION, GLFW_TRUE);

- other modes

  GLFW_CURSOR_NORMAL, GLFW_CURSOR_HIDDEN

- Custom cursor possible

```
void cursor_enter_callback(GLFWwindow* window, int entered)
{
	if (entered)	{
		// The cursor entered the client area of the window
	}	else {
		// The cursor left the client area of the window
	}
}

main ()
{
	glfwSetCursorEnterCallback(window, cursor_enter_callback);

	// change cursor shape
	//GLFW_ARROW_CURSOR, GLFW_CROSSHAIR_CURSOR, GLFW_HAND_CURSOR, GLFW_HRESIZE_CURSOR
	//GLFW_VRESIZE_CURSOR, GLFW_IBEAM_CURSOR
	GLFWcursor* cursor = glfwCreateStandardCursor(GLFW_HRESIZE_CURSOR);

	// set shape
	glfwSetCursor(window, cursor);
	// no cursor
	glfwSetCursor(window, NULL);

	glfwDestroyCursor(cursor);
}
```

GLFW – other functionality

- Time from glfwInit(…) call

  double seconds = glfwGetTime()

- Joystick

  int = glfwJoystickPresent(GLFW_JOYSTICK_1)
  char * = glfwGetJoystickName(GLFW_JOYSTICK_1)
  uchar * = glfwGetJoystickButtons(GLFW_JOYSTICK_1, &count)
  uchar * = glfwGetJoystickAxes(GLFW_JOYSTICK_1, &count)
  uchar * = glfwGetJoystickHats(GLFW_JOYSTICK_1, &count);

- Gamepad

  if (glfwJoystickIsGamepad(GLFW_JOYSTICK_2)) { /* Use as gamepad */ }

- Clipboard

  glfwGetClipboardString, glfwSetClipboardString

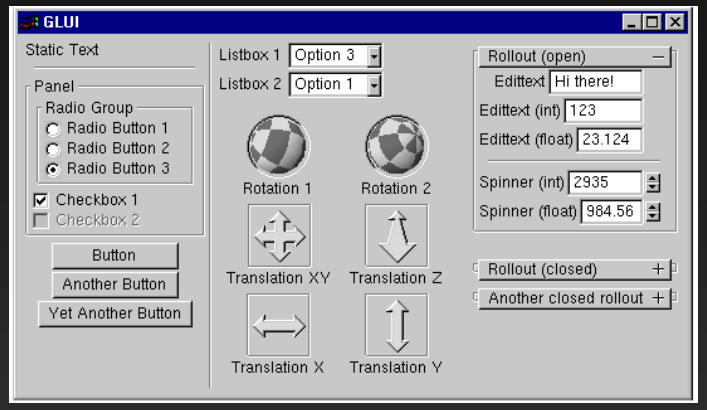
- File object drop

  glfwSetDropCallback

- Vulkan support, platform dependent calls

How about GUI?

- GLFW library allows simple I/O and setting
  - no GUI, text, etc.
- More libraries needed!
  - ImGUI
  - GLUI (github)
  - Nuklear (github)



Single 3D frame draw

Single 3D frame

0) Initialize libraries, register callbacks, …

1) Set initial projection, lights, camera, …

   1)Recompute app state values (health, positions, …)

   2)Frame start → Clear canvas

   3)Draw scene → Vertices with attributes

   4)Finish frame → Display

   5)Poll OS events

2) End program

Drawing Single Frame – Start

- At init – set clear color

  glClearColor(RGBA)

- Each frame – clear canvas

  glClear(BIT_MASK) // what to clear

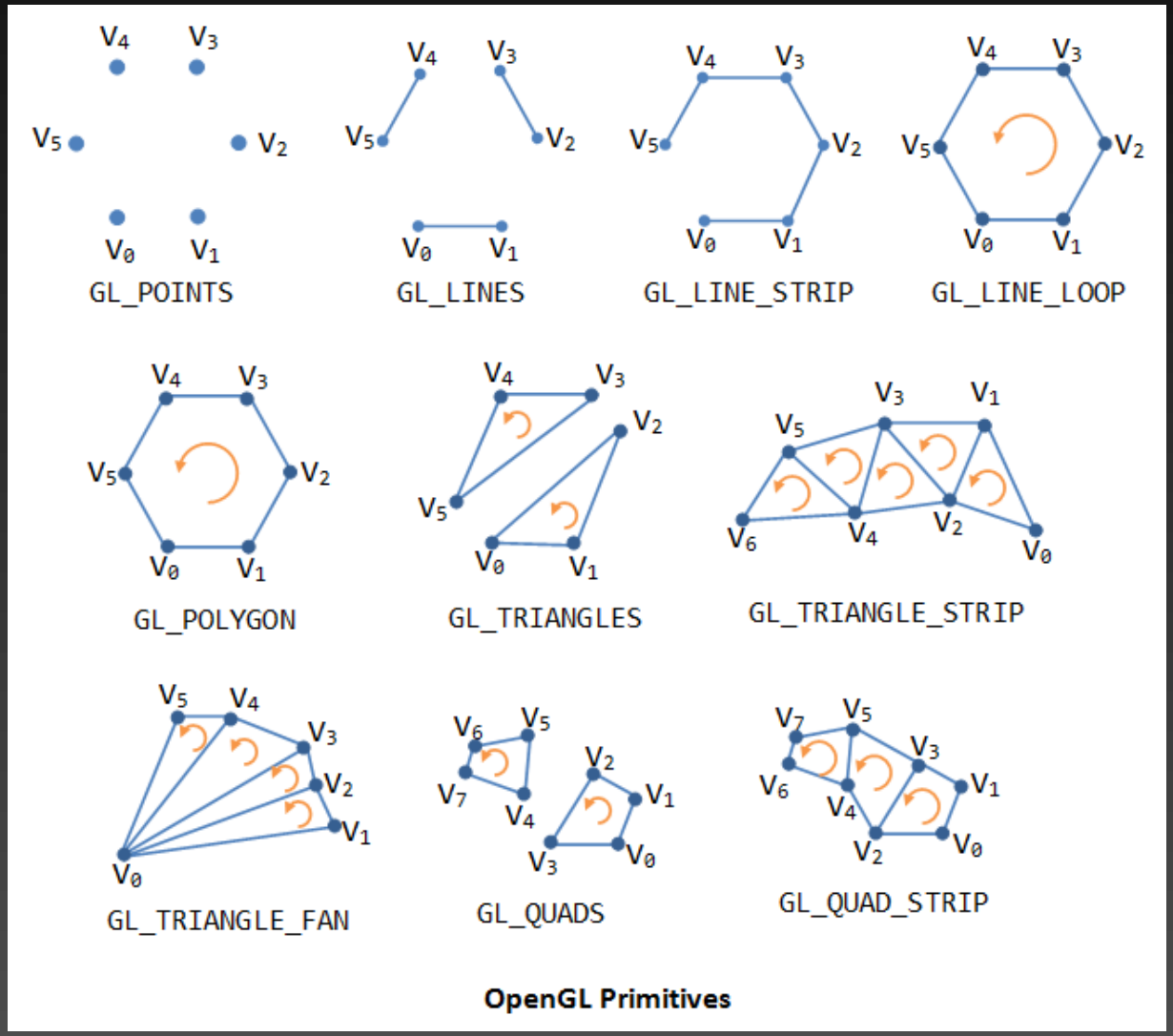
  - Bitmask tells, what will be cleared

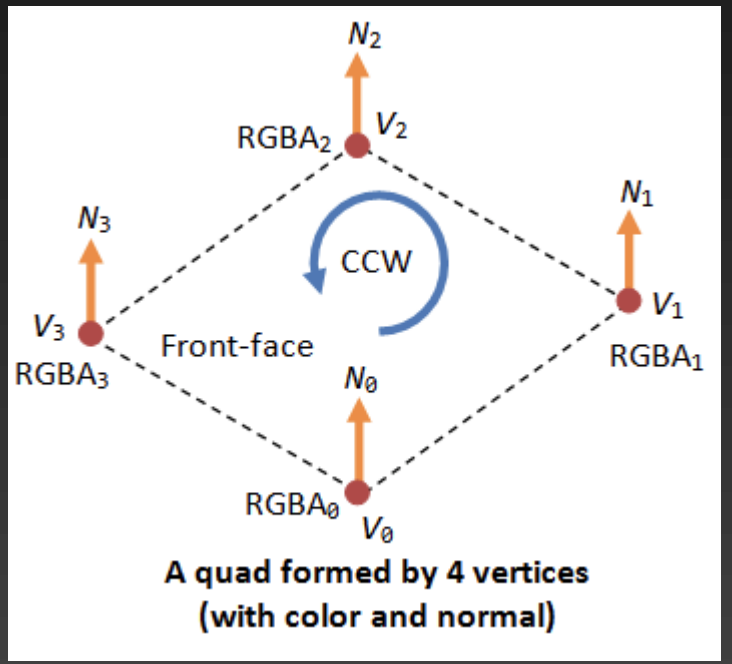
    1)frame buffer (color buffer)
    2)Z-buffer (depth buffer)
    3)accumulation buffer
    4)stencil buffer

```
glClearColor(0.0, 0.0, 0.0, 0.0);
glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)
```

OpenGL Graphical Primitives

- Use primitives to draw the whole scene





Drawing Single Frame – End

- All graphics primitives sent to GPU
- GO!
  - glFlush()
    - flush all buffers with primitives in driver etc., start draw immediately, do not wait till finish!
  - glFinish()
    - flush all buffers with primitives in driver etc., start draw immediately, do WAIT till finish!
    - whole application (thread) blocked

- Our program:

  glfwSwapBuffers(window);
  - perform glFlush() and swap front/back buffer

OpenGL Conventions

- Constants
  - Prefix GL_ and all capitals (eg. GL_TRUE)
- Functions
  - Prefix gl and CamelCase (eg. glClearColor)
  - Variations of parameters
    - glCommand{-,2,3,4}{b,s,i,f,d,...}{-,v}(x1, y1, x2, y2, ...)
- Data types

  1) GLbyte
  2) GLshort
  3) GLint
  4) GLfloat
  5) GLdouble

  ...