COMP3421/9415 Computer Graphics

Introduction

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Administriva

- Who: Robert Clifton-Everest (lecturer), Ali Darejeh (admin)
- Where: http://www.cse.unsw.edu.au/~cs3421
    - Same website for COMP9415
- What: See the course outline

Lectures

- Lecture videos are linked from the course website
- Timetable is a bit complicated
- Lecture starter code is released before each lecture
    - Code along if you want

Lab

- Optional lab this week (not marked)
- Attend any session you like
- Opportunity to get your laptop setup for the practical components of the course
- Thursday 3-4PM or Friday 2-3PM in piano lab (K14, behind physics theatre)

Tutorials

- Tutorials start this week!
  - Reenforce what we cover in the Lectures
  - You’ll need to pick an assignment partner for the second assignment, so it’s a good idea to get to know people!

Assignments

- Assignment 1
  - Individual
  - 2D graphics
  - Due at the end of week 4
- Assignment 2
  - Pairs
  - 3D graphics
  - Milestone 1 due at end of week 7
  - Milestone 2 due at the end of week 10
  - Demonstrate in week 11

Quizzes

- 5 online quizzes throughout the course
- Released in weeks 1,3,5,7 and 9
- Due at the end of weeks 2,4,6,8, and 10

Assumed knowledge

- Java
  - Don’t be afraid to ask questions
- Basic linear algebra
  - Vectors, matrices
  - We will revise this

Gained knowledge

- Computer graphics (obviously)
- We also touch on many other areas
    - Linear algebra
    - Geometry
    - High-performance computing
    - Parallelism
    - Software engineering

Why Graphics?

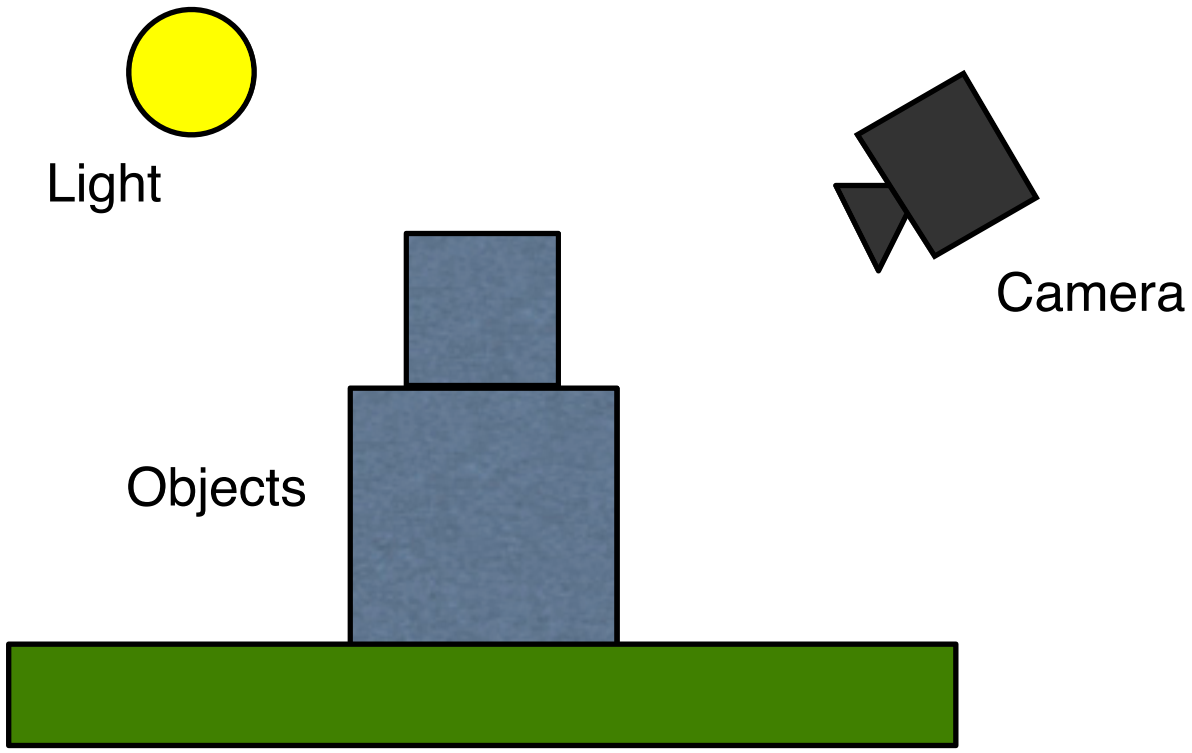
- Games
- Movies and TV
- Visualisations
- Something else?

Assignment 2 example

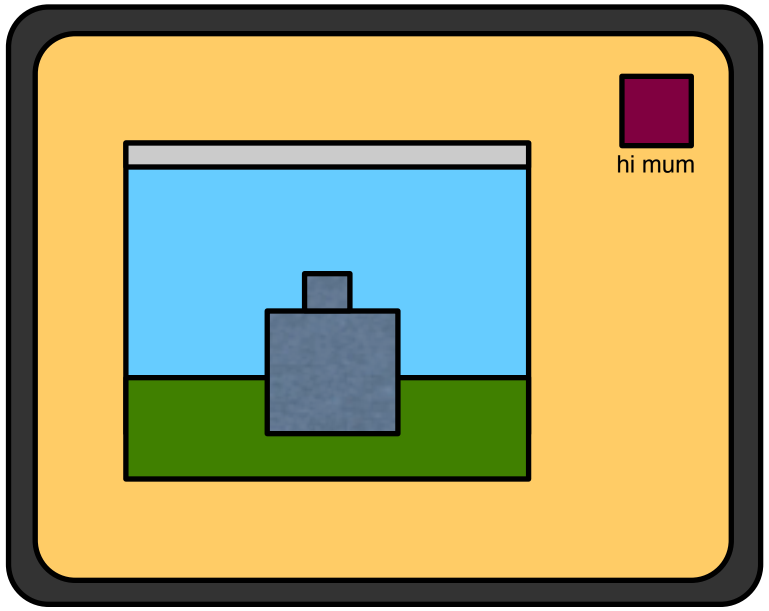
What will you create?

How?

- Algorithms to automatically render images from models.



model

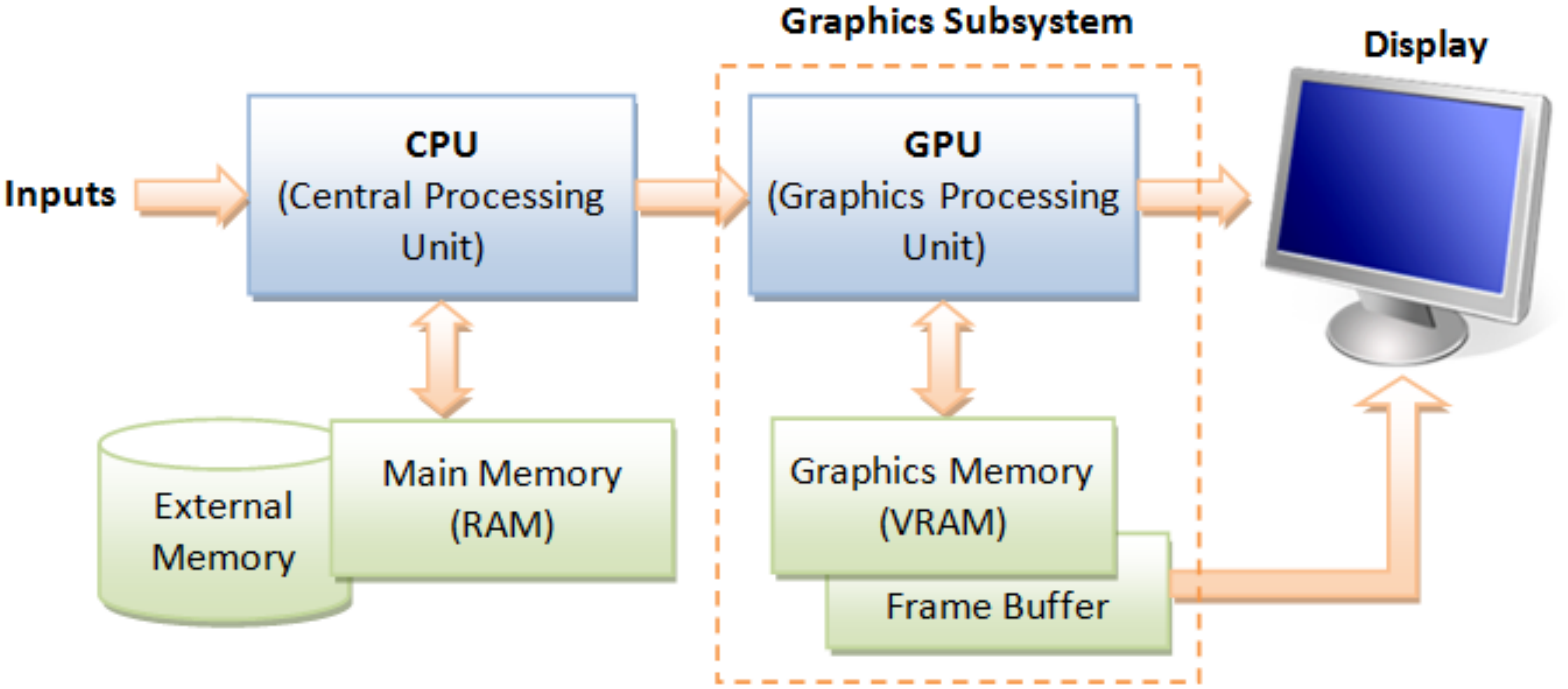


image

How?

- Based on:
  - Geometry
  - Physics
  - Physiology/Neurology/Psychology
- A lot of simplifications and hacks to make it tractable and look good.

Hardware


Graphics Subsystem

Display

Inputs

CPU
(Central Processing
Unit)

GPU
(Graphics Processing
Unit)

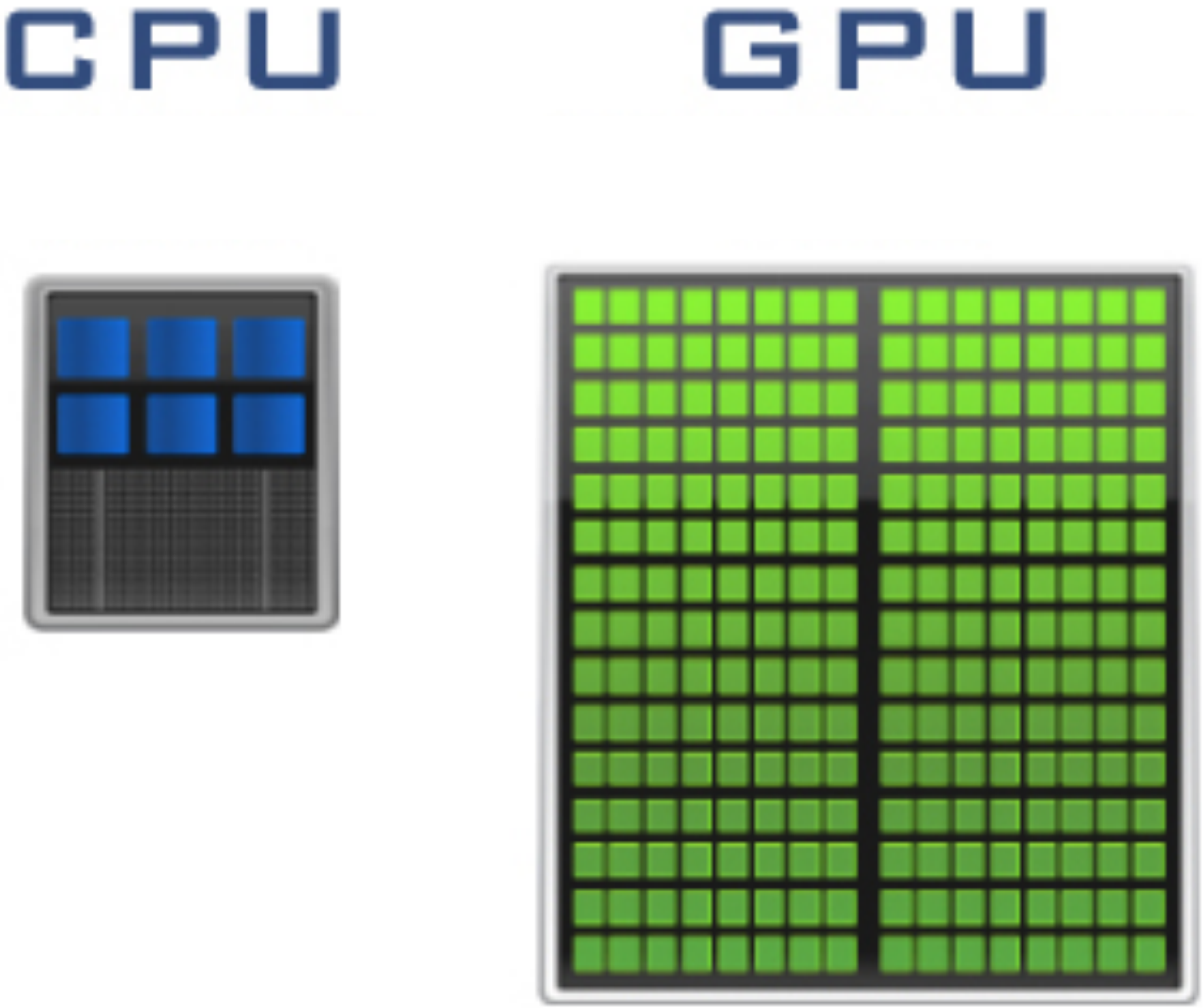
External
Memory

Main Memory
(RAM)

Graphics Memory
(VRAM)

Frame Buffer

CPU vs GPU



CPU vs GPU

- CPU consists of a few cores optimized for sequential serial processing

- GPU has a massively parallel architecture (SIMT/Single Instruction Multiple Thread) consisting of smaller special purpose cores designed for parallel work.

SIMT

```
nums[i] = nums[i]*nums[i];

if (nums[i] % 2 == 0) {
    nums[i] = nums[i] + 1;
} else {
    nums[i] = 0;
}
```

…

`nums =`

0	1	2	3	4	5	6	7	8	9

`i` is different for each thread

SIMT

```
▶ nums[i] = nums[i]*nums[i];

  if (nums[i] % 2 == 0) {
      nums[i] = nums[i] + 1;
  } else {
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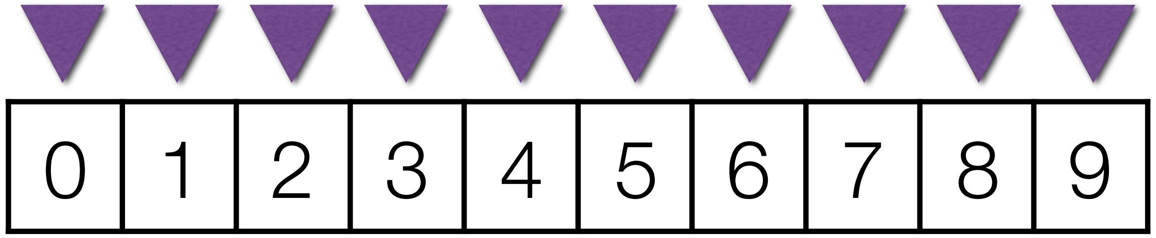
  }
  …
```



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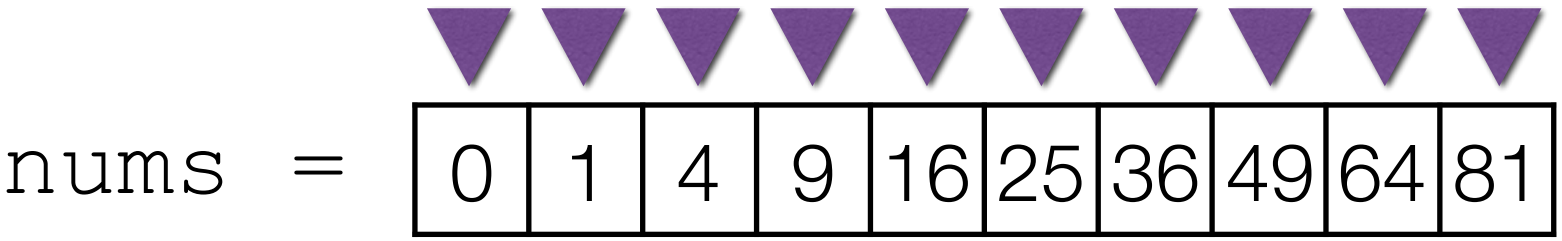
```



nums =

0	1	4	9	16	25	36	49	64	81

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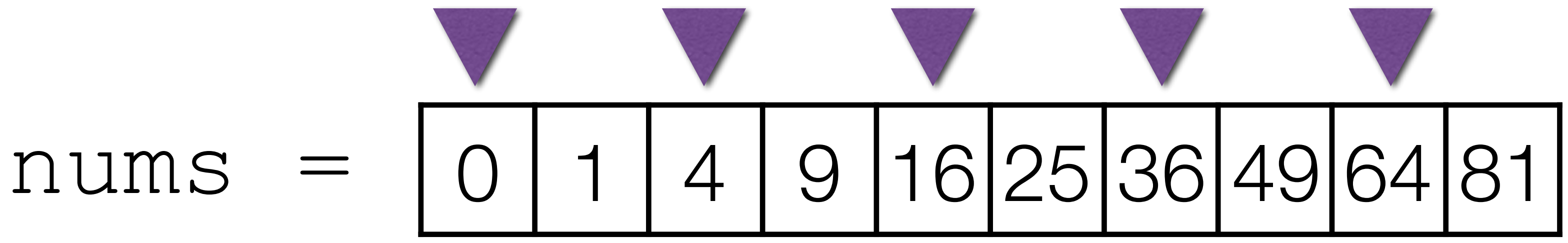

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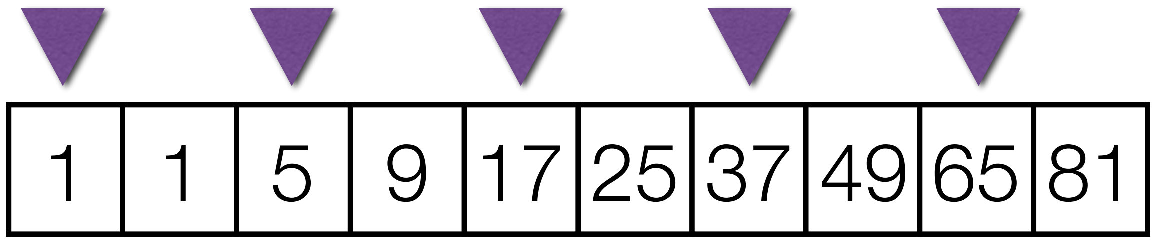
  …
```



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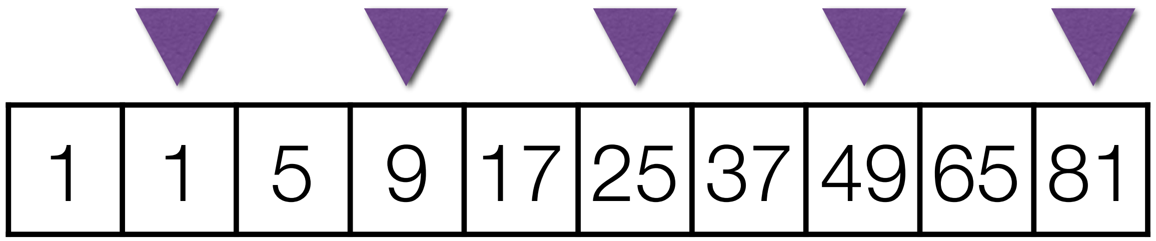

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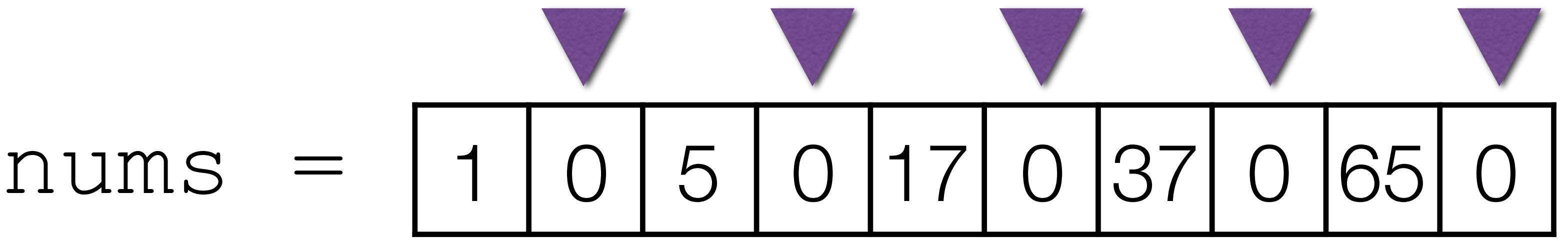

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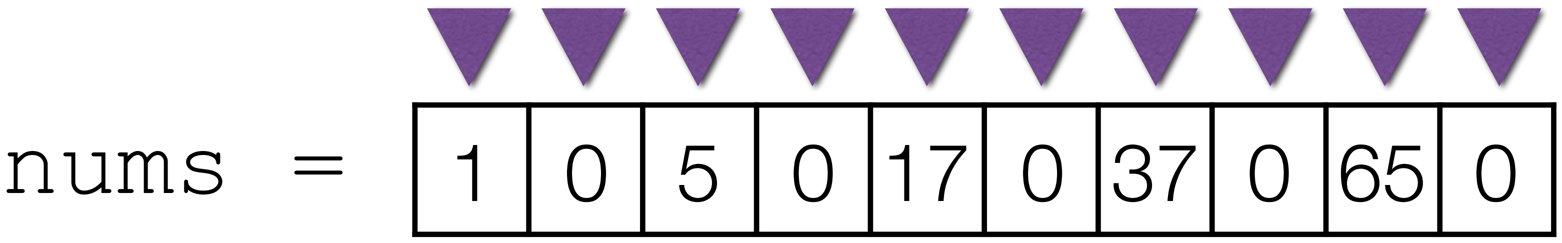
```



nums =										
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`i` is different for each thread

OpenGL

- A low-level 2D/3D graphics API.
    - Free, Open source
    - Cross platform (incl. web and mobile)
    - Highly optimised
    - Designed to use GPUs
    - We will be using OpenGL

DirectX

- Direct3D
    - Microsoft proprietary
    - Only on MS platforms or through emulation (Wine, VMWare)
    - Roughly equivalent features

Vulcan

- Next generation graphics API
  - Still fairly new
  - Even more low-level than OpenGL
  - Only limited support on some platforms (e.g. Mac)
  - Not quite ready for teaching yet, but hopefully soon

Do it yourself

- Generally a bad idea:
  - Reinventing the wheel
  - Numerical accuracy is hard
  - Efficiency is also hard
  - Hardware variations

Low-level graphics

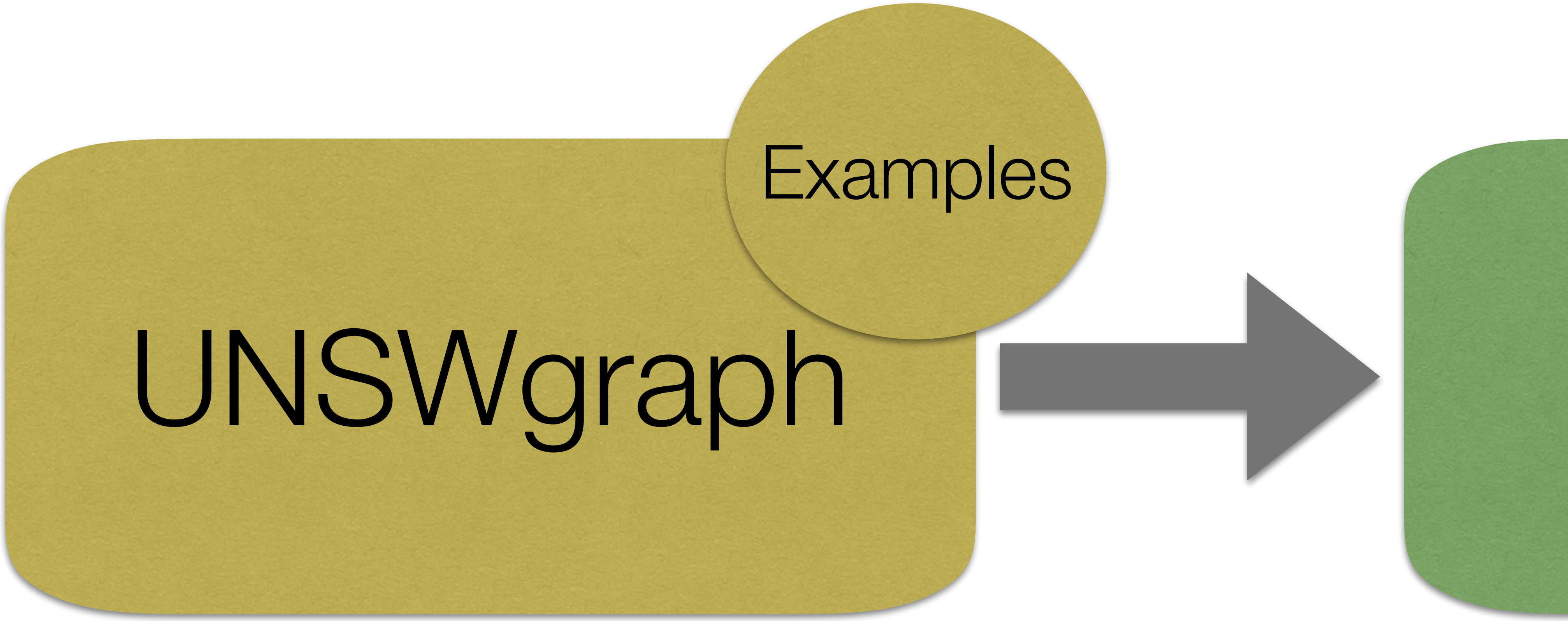
- OpenGL is used to:
  - transfer data to the graphics memory
  - draw primitive shapes (points, lines, triangles, …) using that data
- More complex things like curves, composite shapes, etc. we have to implement ourselves
  - Composing primitives
  - Running programs (shaders) on the GPU

High-level graphics

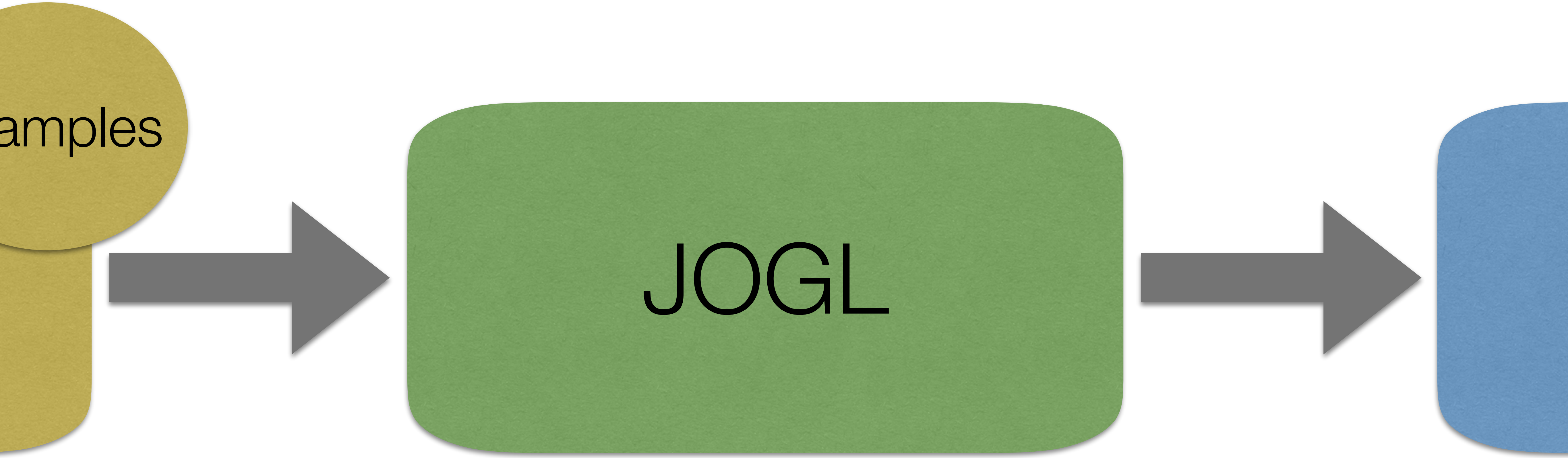
- Game engines - Unity, Unreal engine
- Modelling - Maya, Blender, 3DS Max
- CAD
- Microsoft Paint?

The plan

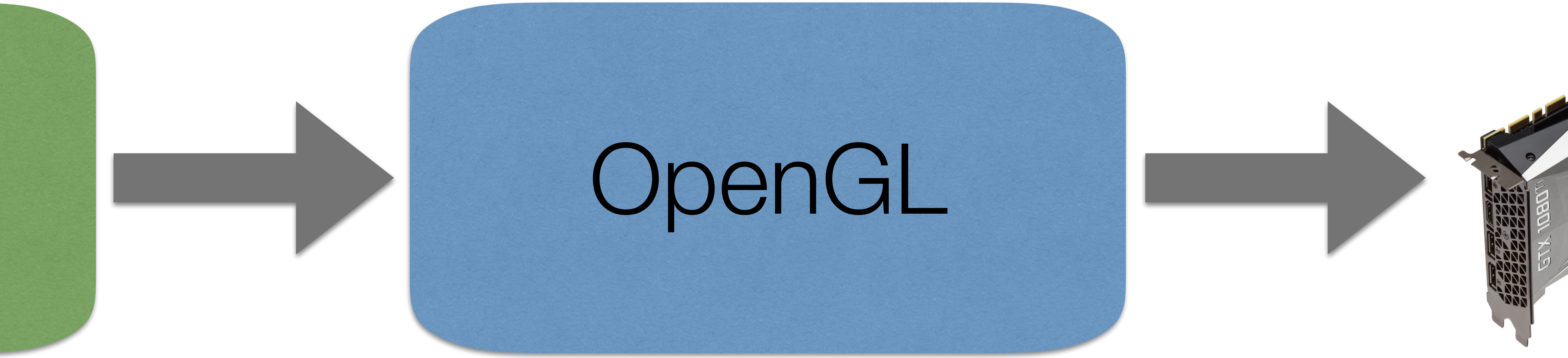
- Learn about techniques, concepts and algorithms relating to computer graphics.
- Use them to implement a high-level graphics library
    - In lectures, tutes, assignments
    - Using OpenGL for the low-level components



- A small high-level graphics library
  - Only VERY basic features (week 1)
  - We will explore and extend it throughout the course
  - Contains some example programs

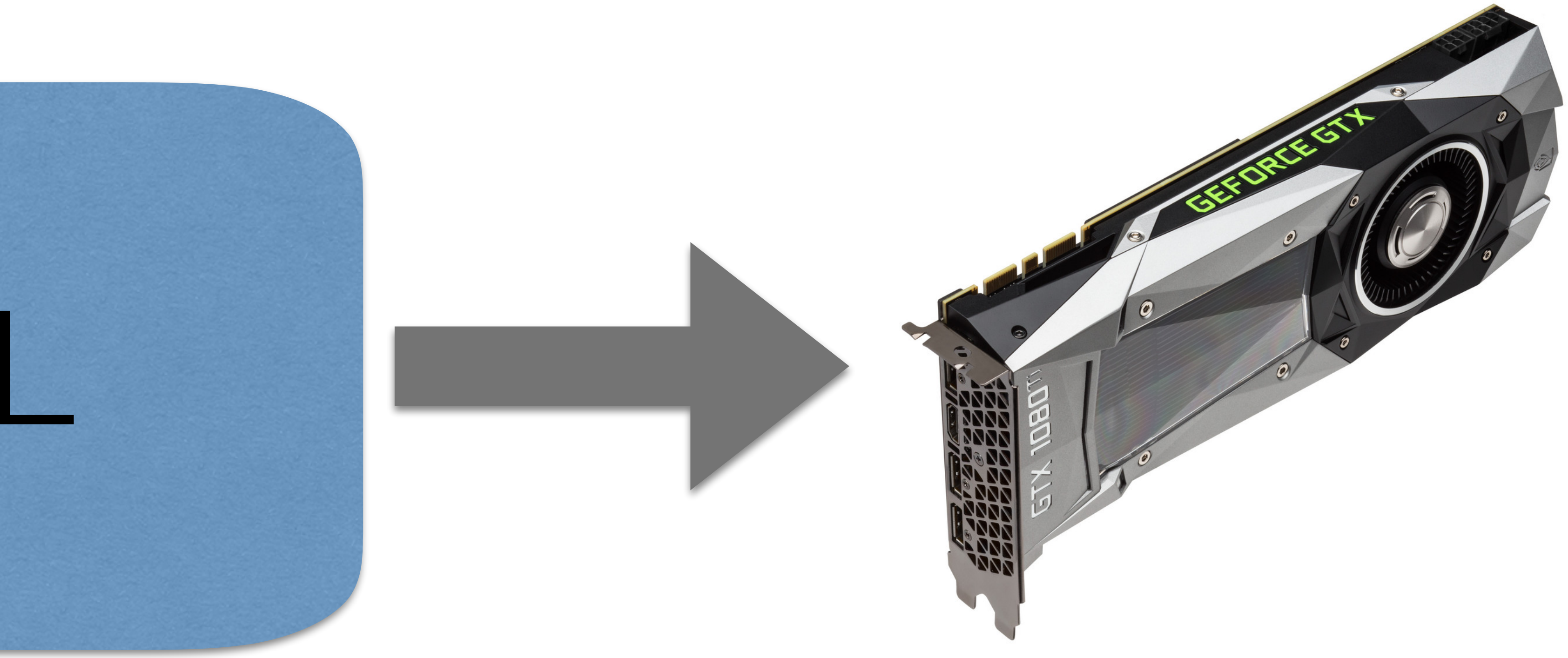


- A Java library
- A wrapper around OpenGL (a C library)
- Contains NEWT, a basic windowing toolkit
- http://jogamp.org/jogl/www/



OpenGL

- Implementation of the API provided by the GPU driver
- We don’t *know* how it works internally



- For this course we will focus on how to use it, not the hardware architecture

Pipeline

L

UNSWgraph

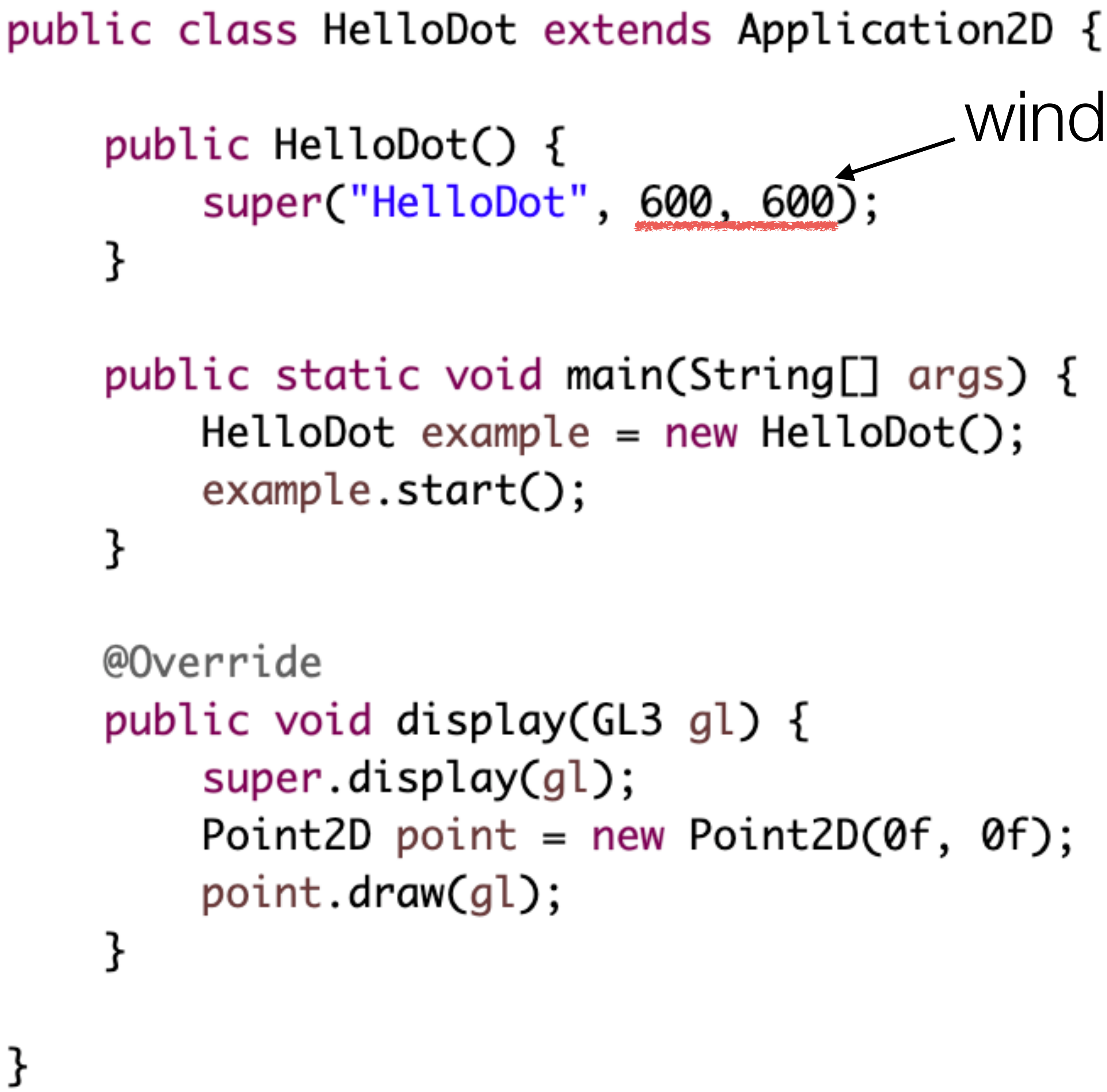
- The lab contains instructions for setting up UNSWgraph and running an example program.
- Short version: It is packaged as an eclipse project, so can be directly imported into eclipse with minimal hassle
- NOTE: Doesn’t work on VLAB

My first graphics program

- See HelloDot.java
- Shows ALL features of UNSWgraph version 0.1

Application

- Applications have a single NEWT window
- 2D applications give a simple 2D canvas to draw on.
- The size of the window is given to the constructor.



```java
public class HelloDot extends Application2D {

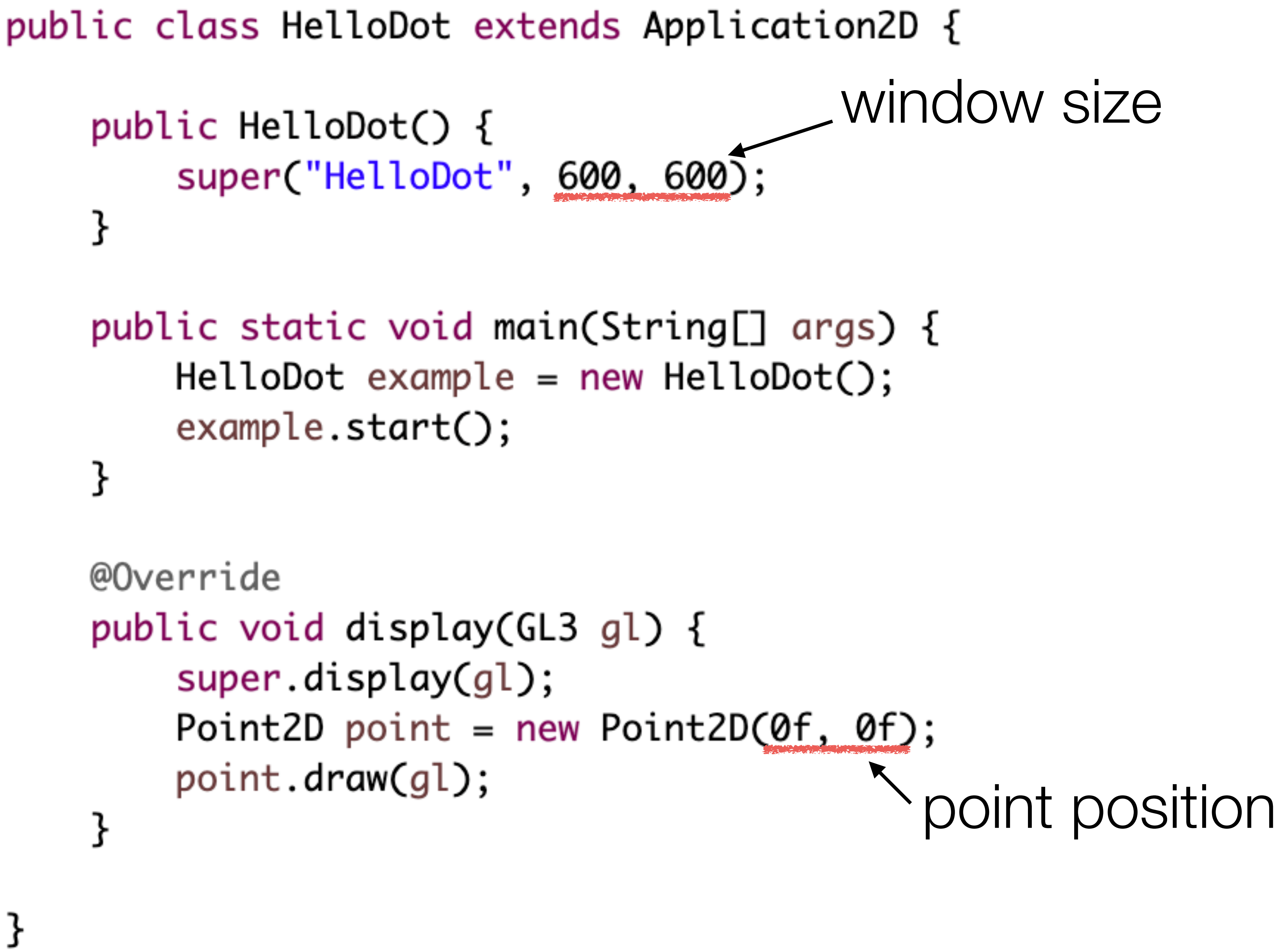
    public HelloDot() {
        super("HelloDot", 600, 600);
    }

    public static void main(String[] args) {
        HelloDot example = new HelloDot();
        example.start();
    }

    @Override
    public void display(GL3 gl) {
        super.display(gl);
        Point2D point = new Point2D(0f, 0f);
        point.draw(gl);
    }

}
```

window size



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```

window size

point position

Viewport

- We talk in general about the viewport as the piece of the screen we are drawing on.

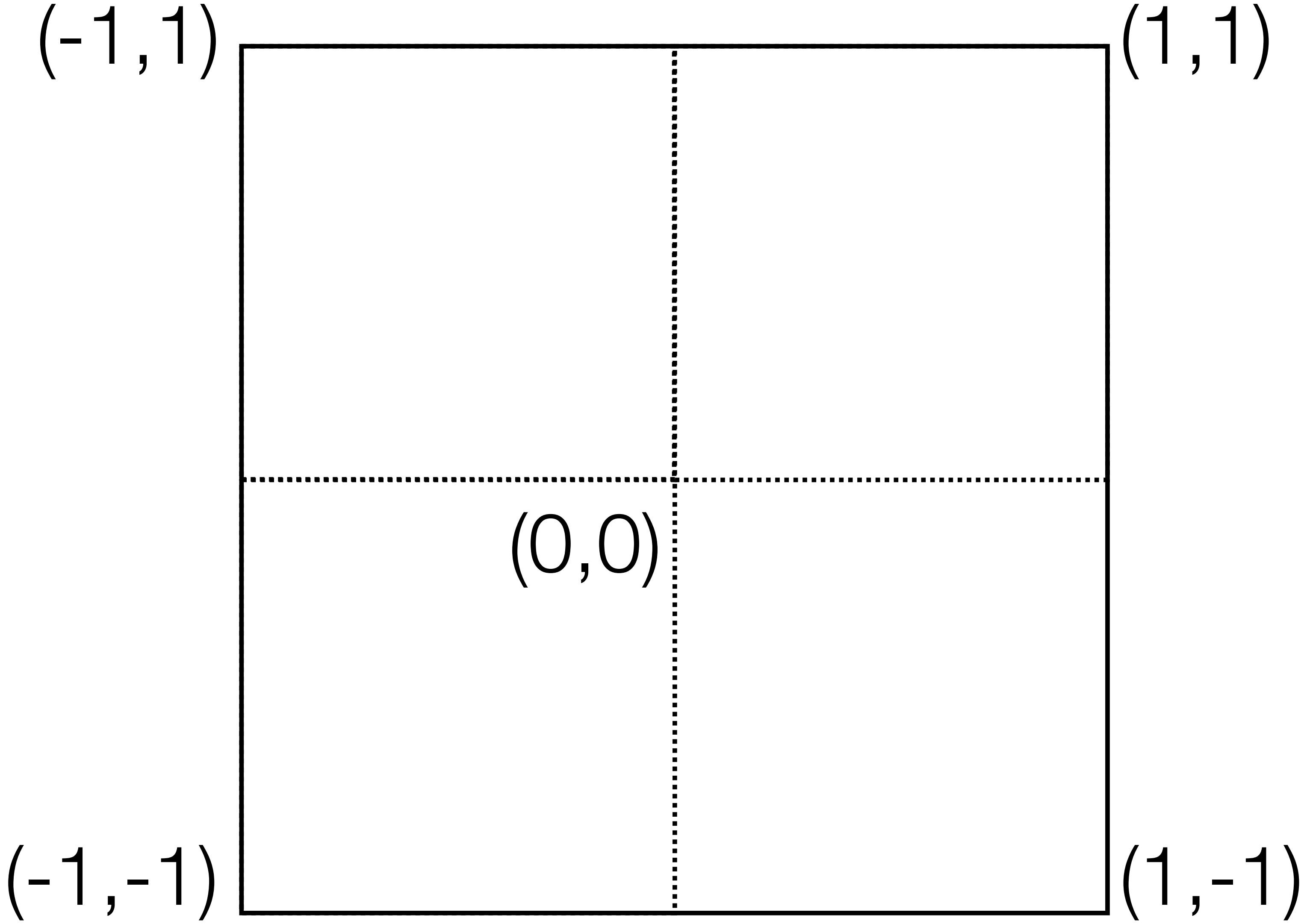
- It may be a window, part of a window, or the whole screen. (In UNSWgraph by default it is the whole window – minus the border)

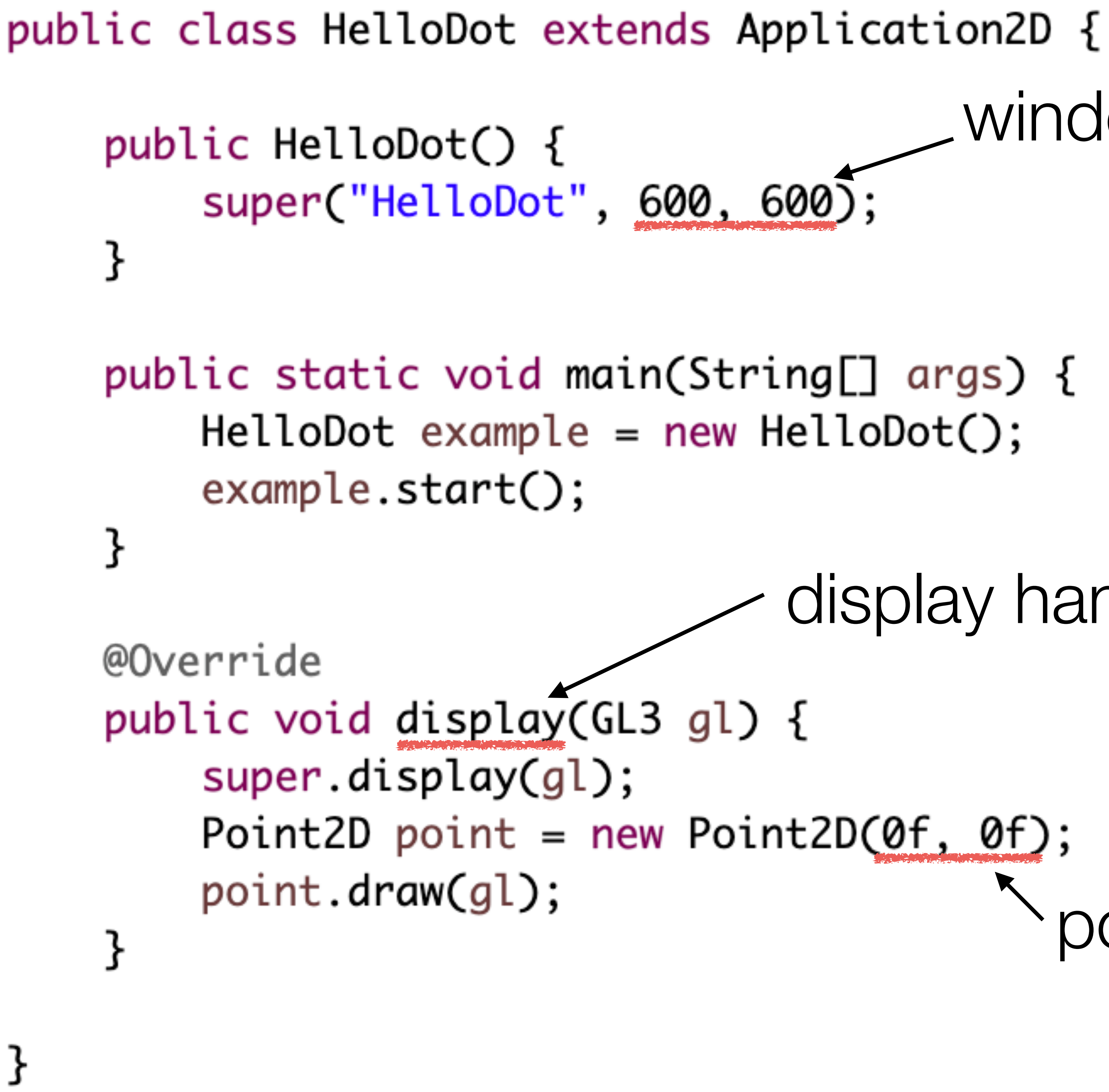
- It can be any size but we assume it is always a rectangle.

- It has its own coordinate system

Coordinate system

- By default the viewport is centred at (0,0). The left boundary is at x=-1, the right at x=1, the bottom at y=-1 and the top at y=1.





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}
```

window size

display handler

point position

Event-based Programming

- UNSWgraph and NEWT are event-driven.
- This requires a different approach to procedural programming:
  - The main() method create an instance of the application and calls start(), which doesn't terminate.
  - Events are dispatched by the event loop.
  - Handlers are called when events occur.
    - e.g. display() is called 60 times a second

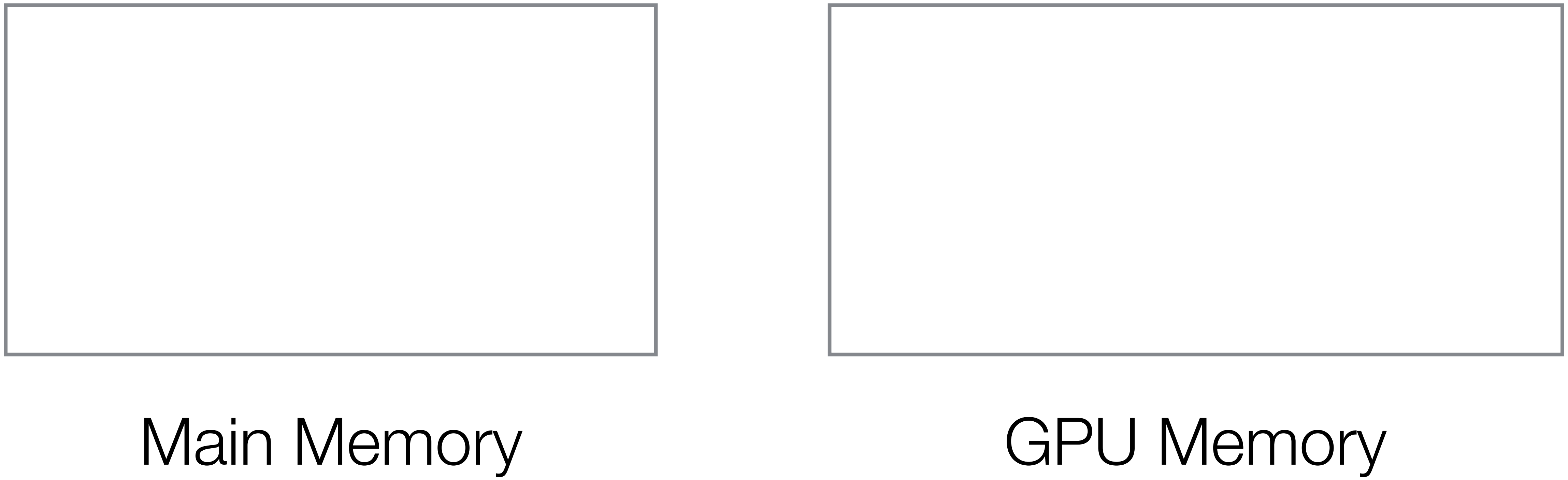
But what's really going on?

- See Point2D.draw()
- In the draw method for point we have to do 4 main things
    - Create a buffer in main memory containing the point coordinates
    - Transfer that buffer to GPU memory
    - Tell the GPU to draw that buffer as a point
    - Free the buffer in GPU memory

GL3

- GL3 provides access to all the normal OpenGL methods and constants.
- http://jogamp.org/deployment/v2.2.4/javadoc/jogl/javadoc/javax/media/opengl/GL3.html
- A GL3 object can’t be constructed, cloned or copied in any way
- We have to pass it through to the methods that need it

We have two memory spaces

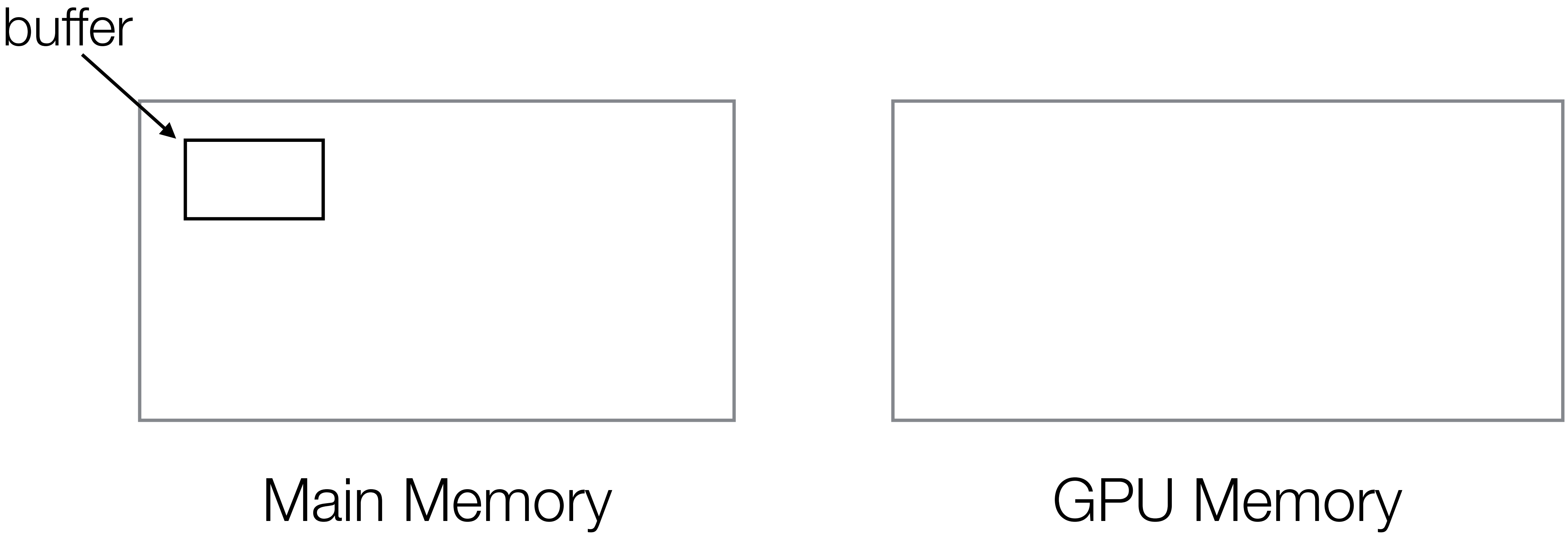


Main Memory

GPU Memory

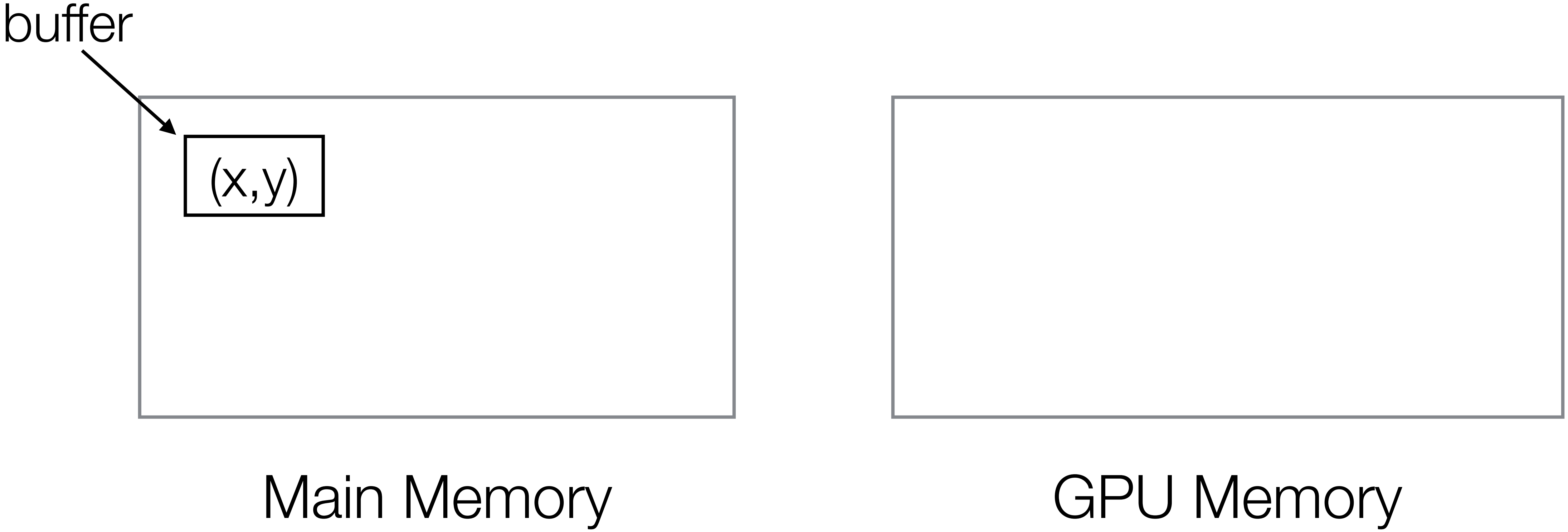
```
Point2DBuffer buffer = new Point2DBuffer(1);
```

Create a buffer that can store 1 point
The buffer is pinned in main memory.



```
buffer.put(0, this);
```

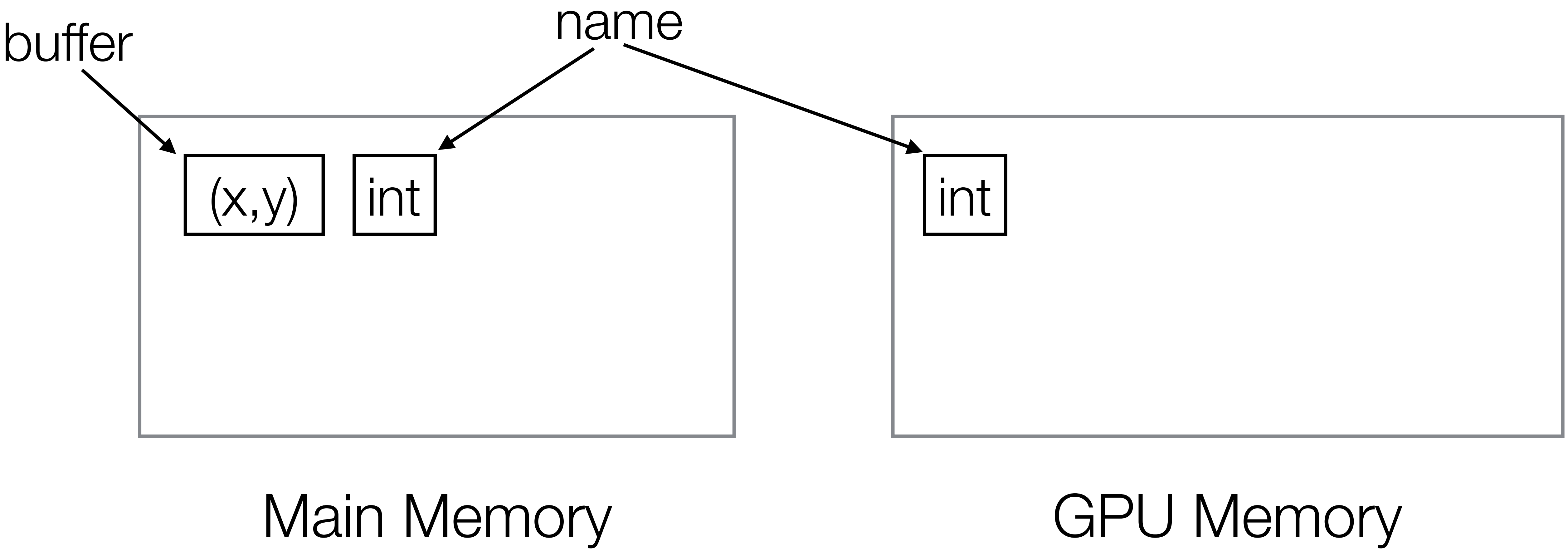
Store the value of this point at index 0 in the buffer



http://docs.gl/gl3/glGenBuffers

```
int[] names = new int[1];
gl.glGenBuffers(1, names, 0);
```

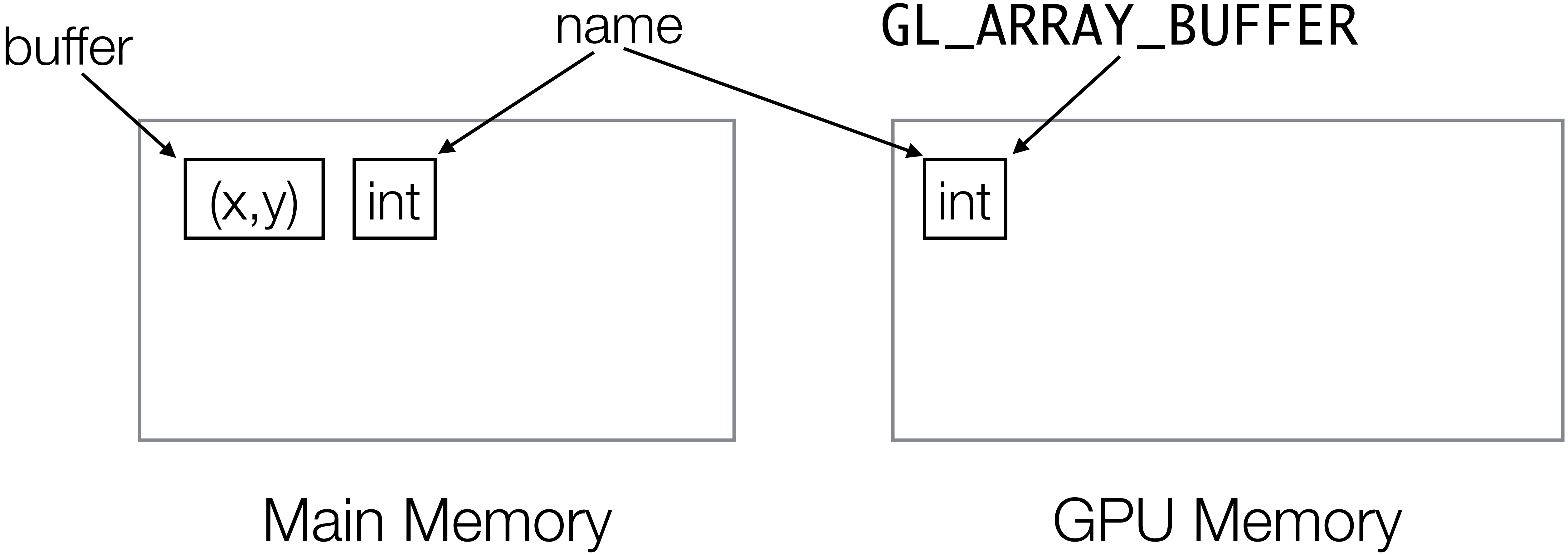
Create a new name for a buffer



http://docs.gl/gl3/glBindBuffer

```
gl.glBindBuffer(GL.GL_ARRAY_BUFFER, names[0]);
```

This is the buffer we want to use. All future buffer operations will be on this buffer.



```
void glBindBuffer(int target,  // Binding target
                  int buffer); // Name of buffer
```

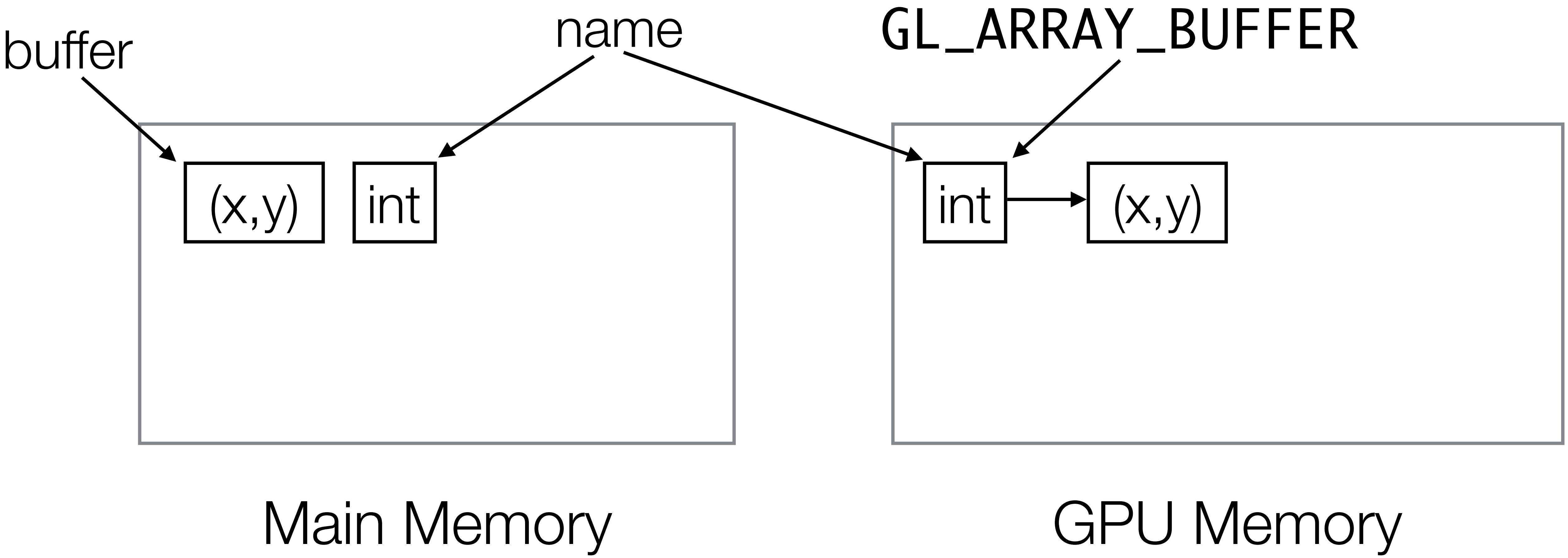
Buffer targets

- OpenGL can only have one active buffer of a particular target
- Binding a buffer to GL_ARRAY_BUFFER tells OpenGL that all future operations on the GL_ARRAY_BUFFER are for this buffer
- The GL_ARRAY_BUFFER target is a general purpose target
- Other buffer targets we will see in later weeks.

http://docs.gl/gl3/glBufferData

```
gl.glBufferData(GL.GL_ARRAY_BUFFER, 2 * Float.BYTES,
    buffer.getBuffer(), GL.GL_STATIC_DRAW);
```

This allocates the buffer in graphics memory and transfers the data from main memory into it



```
void glBufferData(
    int target,     // Destination
    long size,      // Transfer size (in bytes)
    Buffer data,    // Source
    int usage);     // How it is used
```

Buffer usage hints

- When allocating a buffer OpenGL lets you give a hint how it might be used.

- OpenGL is free to ignore this information but may use it to optimise how and where it stores the data.

- The most common hints are:

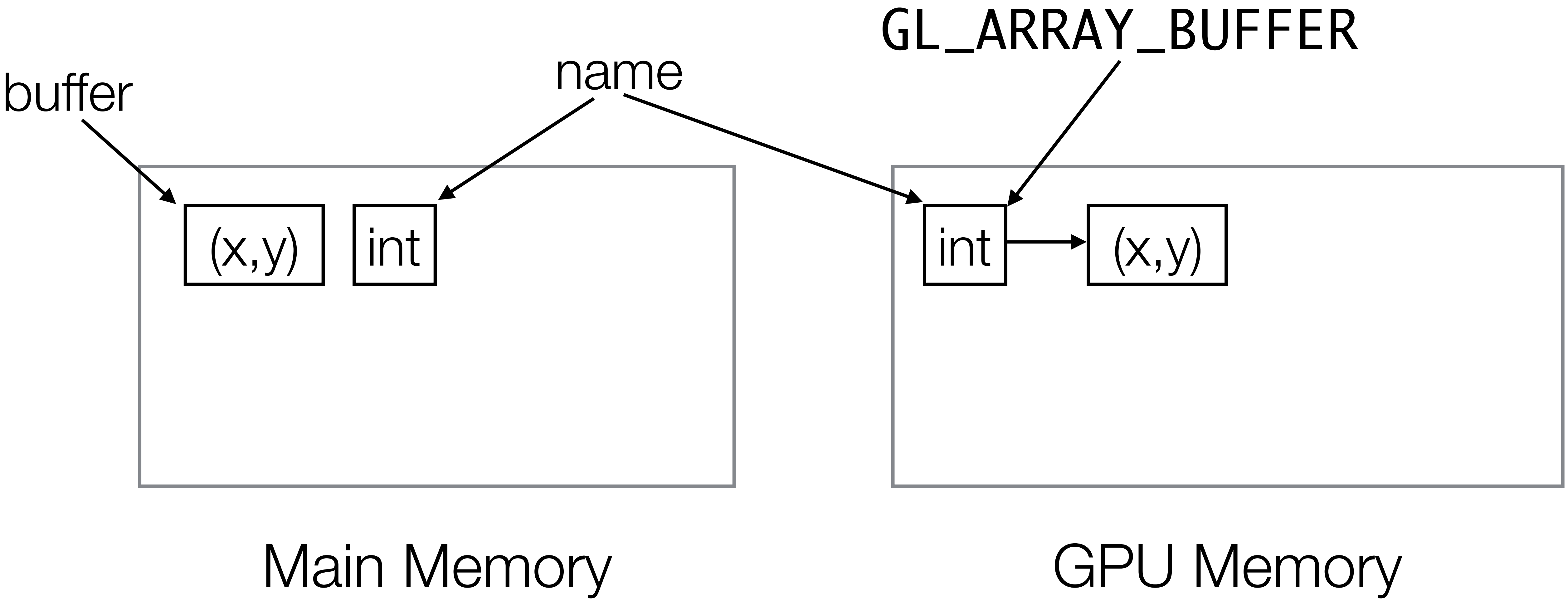
  - GL_STATIC_DRAW — Data will be modified once and used many times

  - GL_DYNAMIC_DRAW —Data will be modified repeatedly and used repeatedly

http://docs.gl/gl3/glBufferData

```
gl.glBufferData(GL.GL_ARRAY_BUFFER, 2 * Float.BYTES,
    buffer.getBuffer(), GL.GL_STATIC_DRAW);
```

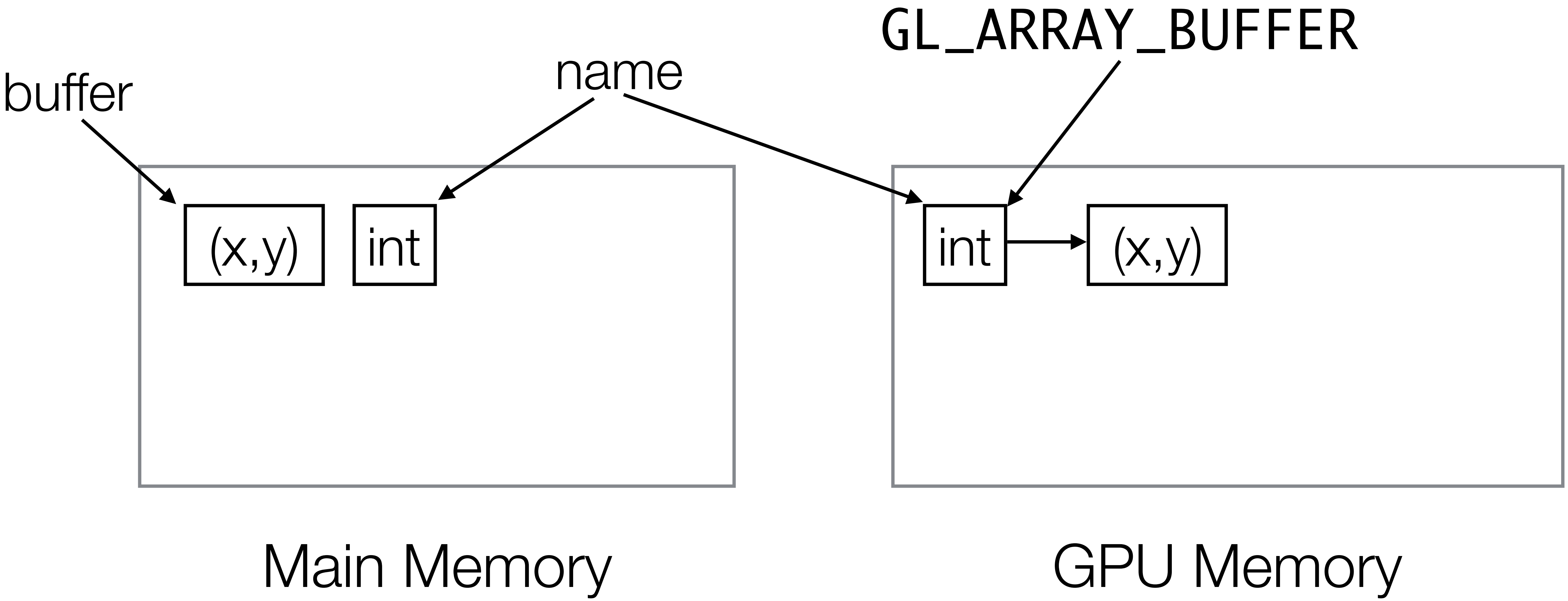
Transfer data into the current GL_ARRAY_BUFFER



http://docs.gl/gl3/glBufferData

```
gl.glBufferData(GL.GL_ARRAY_BUFFER, 2 * Float.BYTES,
    buffer.getBuffer(), GL.GL_STATIC_DRAW);
```

We are transferring 2 * 4 = 8 bytes of data



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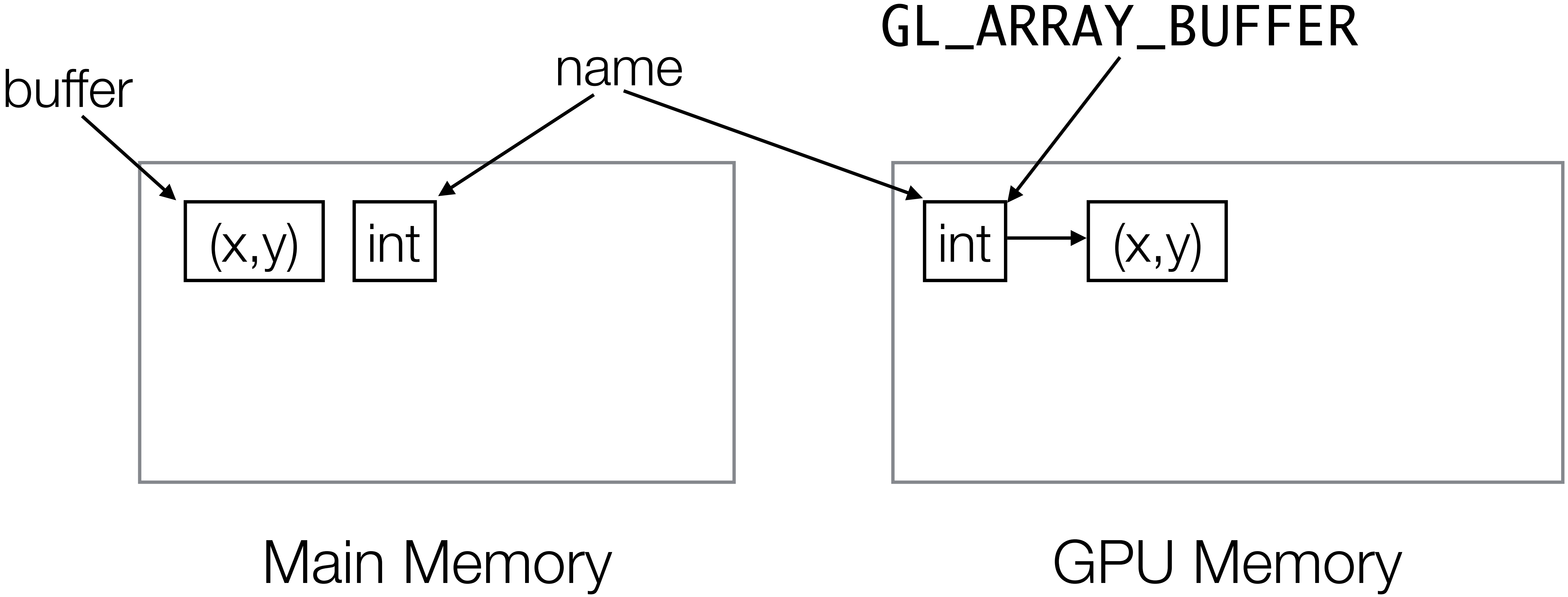
```

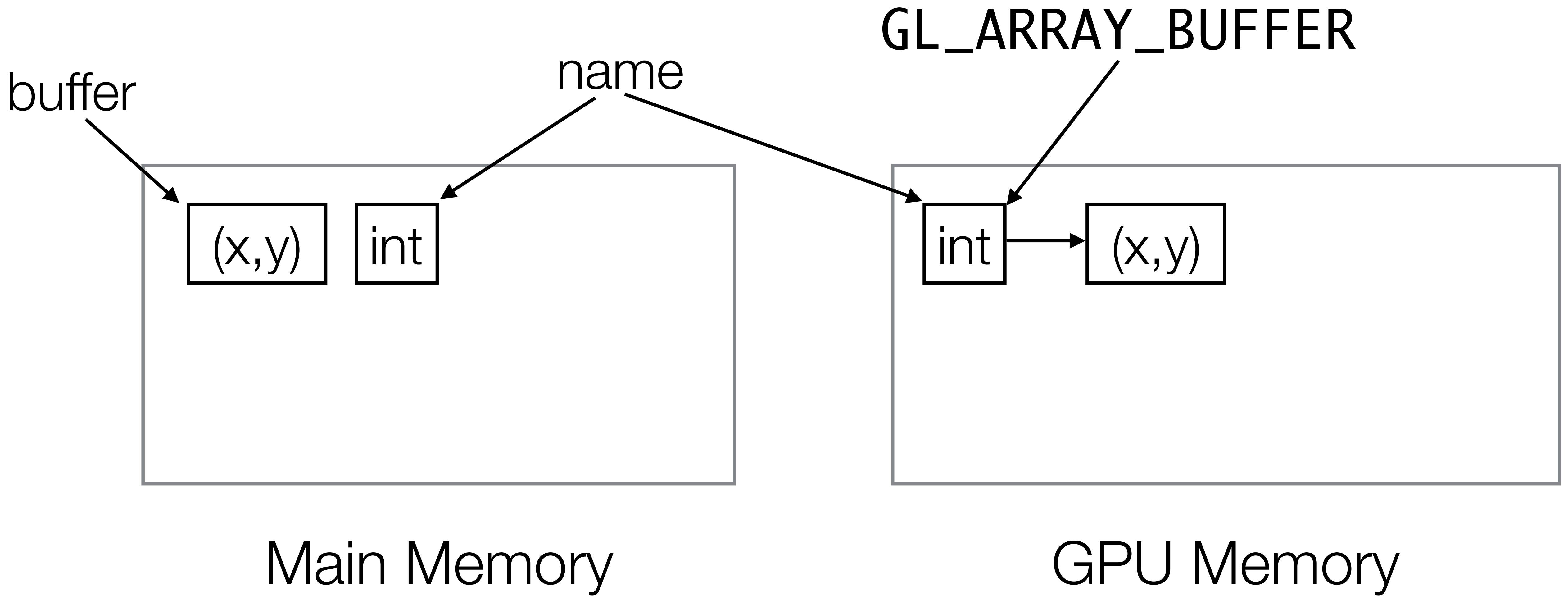
Using this buffer as a source



http://docs.gl/gl3/glBufferData

```
gl.glBufferData(GL.GL_ARRAY_BUFFER, 2 * Float.BYTES,
    buffer.getBuffer(), GL.GL_STATIC_DRAW);
```

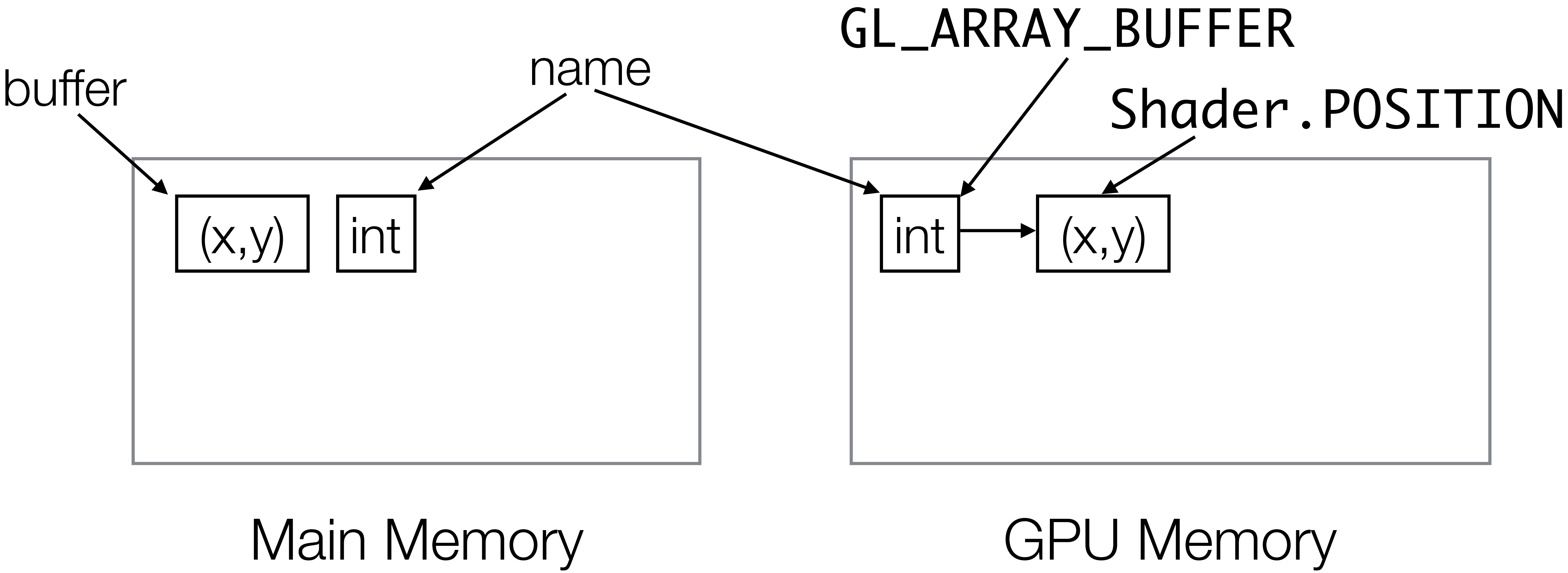
We aren’t going to update the buffer again and it will be used for drawing to the screen



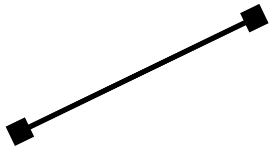
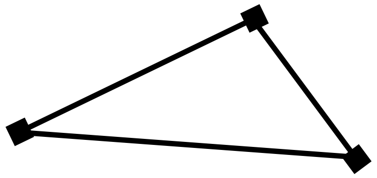
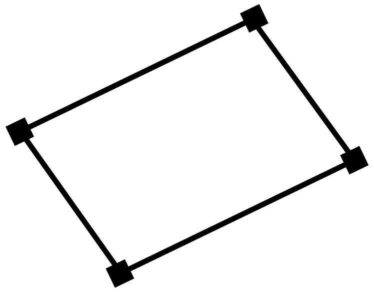
http://docs.gl/gl3/glVertexAttribPointer

```
gl.glVertexAttribPointer(Shader.POSITION,
    2, GL.GL_FLOAT, false, 0, 0);
```

Tell OpenGL that the buffer contains vertex positions.



Vertex

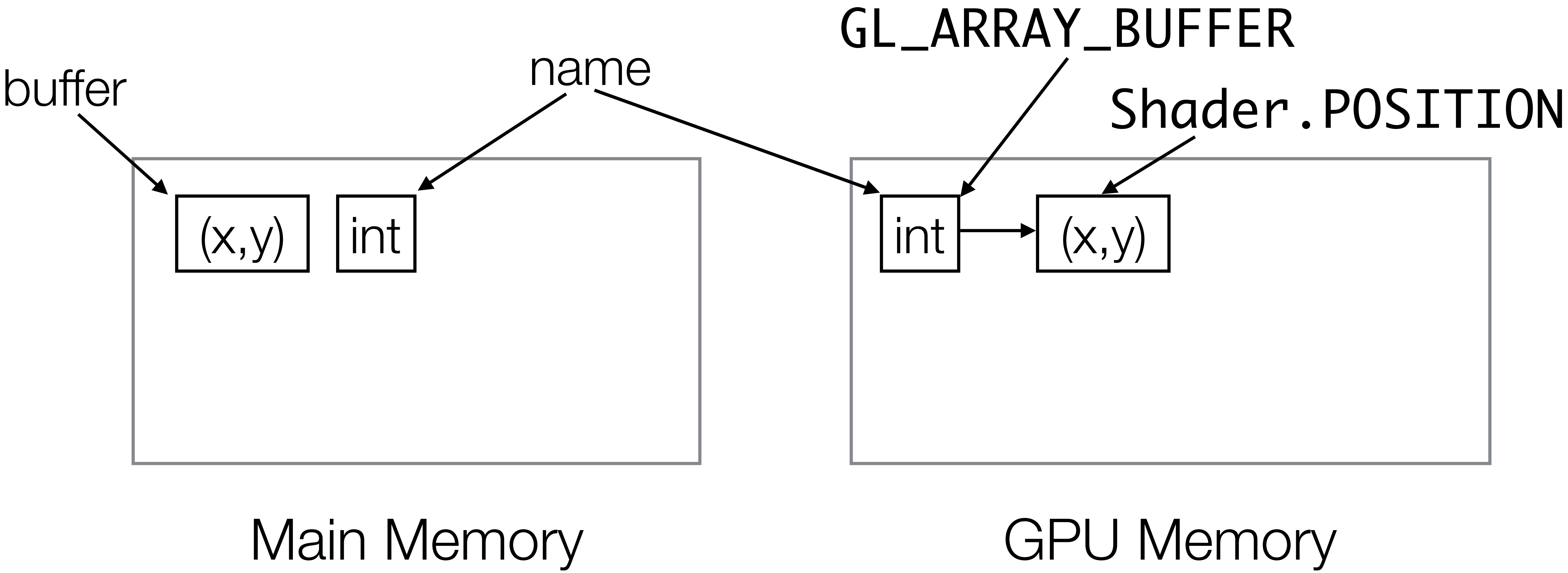
- In OpenGL a vertex (plural: vertices) is a point that forms part of the definition of a geometric shape. For example:
  - 1 vertex defines a point
  - 2 vertices define a line 
  - 3 vertices define a triangle 
  - 4 vertices *can* define a quadrilateral 
- Vertices can have attributes attached to them.

```
void glVertexAttribPointer(
    int index,                   // The attribute
    int size,                    // attribute size
    int type,                    // Primitive type
    boolean normalized,          // Normalize ints
    int stride,                  // Padding
    long pointer_buffer_offset); // Start
```

http://docs.gl/gl3/glVertexAttribPointer

```
gl.glVertexAttribPointer(Shader.POSITION,
    2, GL.GL_FLOAT, false, 0, 0);
```

The buffer contains the position of the vertices



http://docs.gl/gl3/glVertexAttribPointer

```
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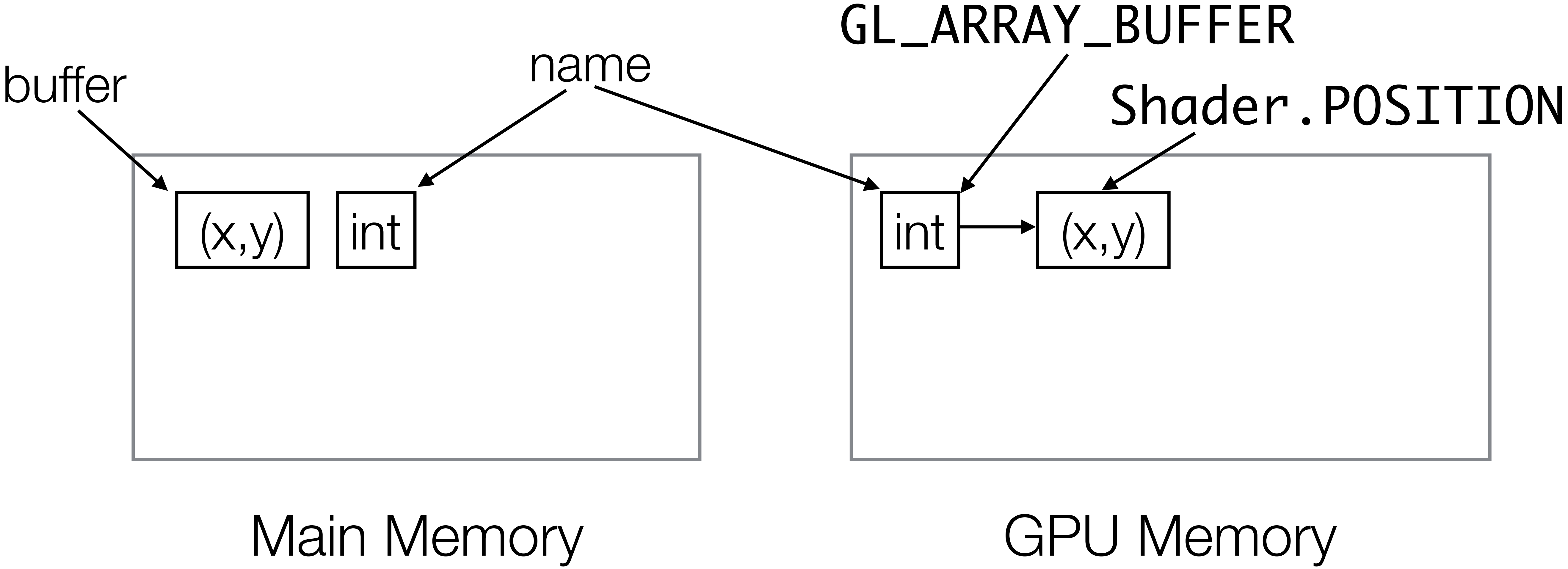
    2, GL.GL_FLOAT, false, 0, 0);
```

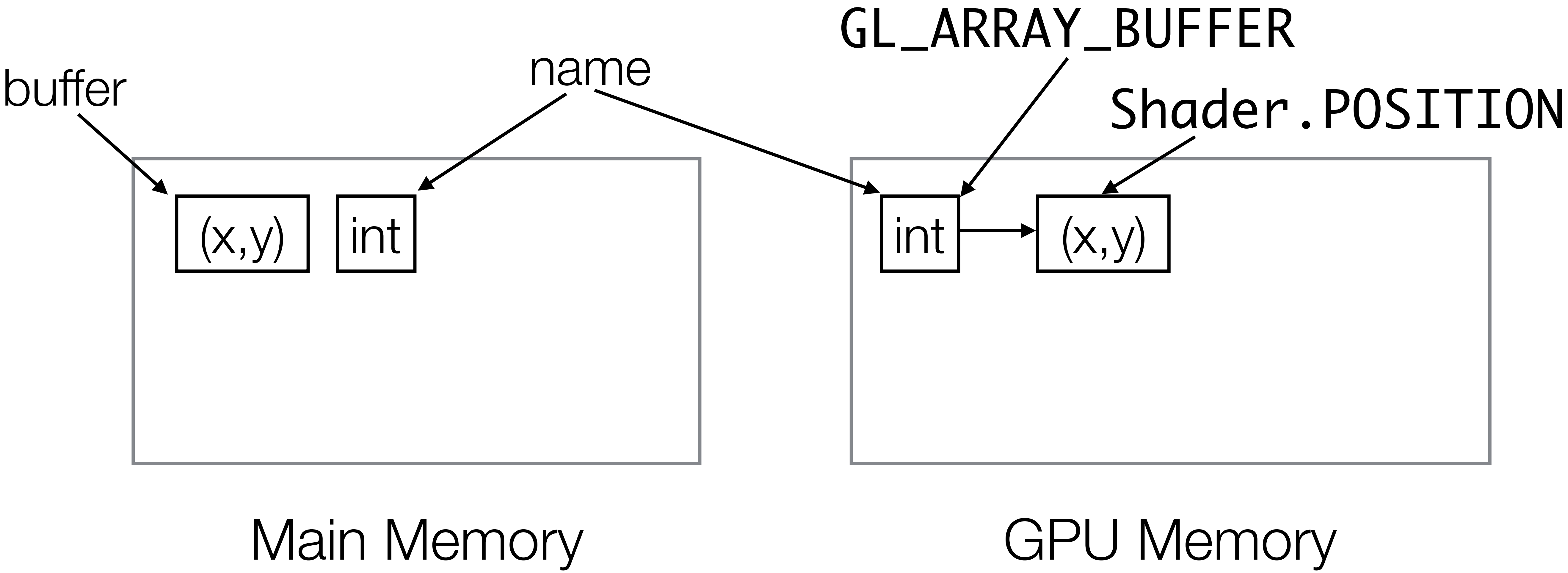
Each position has 2 floats associated with it.



http://docs.gl/gl3/glDrawArrays

```
gl.glDrawArrays(GL.GL_POINTS, 0, 1);
```

Draw the buffer as a point on the screen

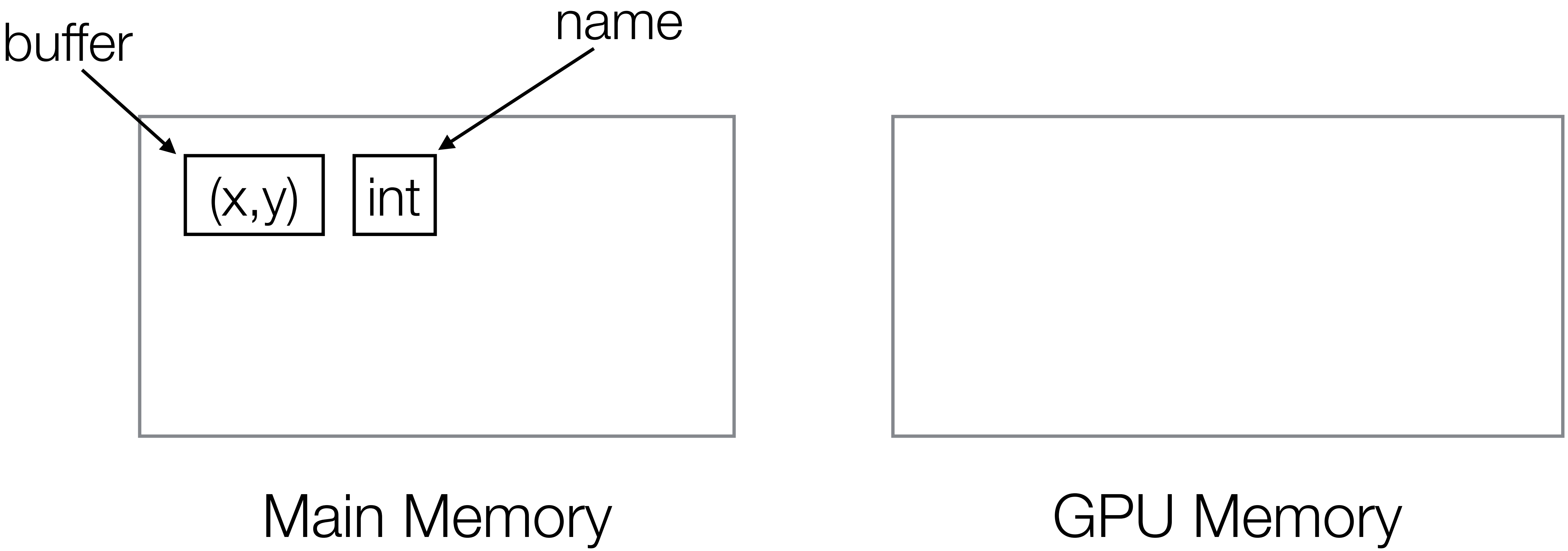


```
void glDrawArrays(int mode,   // Primitive to draw
                  int first,  // Starting vertex
                  int count); // Number of vertices
```

http://docs.gl/gl3/glDeleteBuffers

```
gl.glDeleteBuffers(1, names, 0);
```

Delete the buffer in graphics memory



```
void glDeleteBuffers(int n,
                     int[] buffers,
                     int buffers_offset);
```

OpenGL recap

- It is not Object-Oriented, despite us accessing it from Java
    - Use of ints instead of enums
    - Lots of effectively global state
- UNSWgraph is setup to try and report OpenGL errors, but in many cases failure is still silent (e.g. out of bounds errors)
- Error messages can be hard to decipher
- Need to rely on documentation

Questions

- What does it mean when we say OpenGL is low-level?
- Can you remember all the arguments to glVertexAttribPointer?
- Isn’t programming like this really tedious?

From points to lines

- See Line2D.java and HelloLine.java