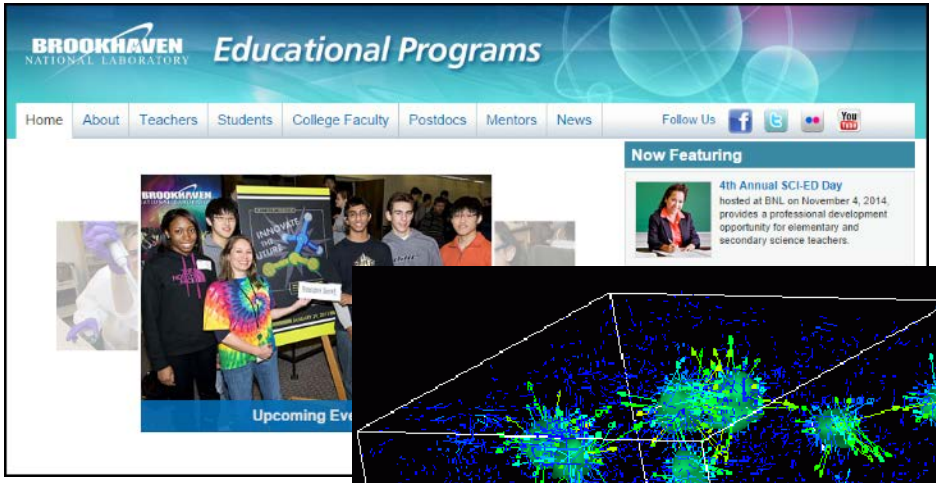

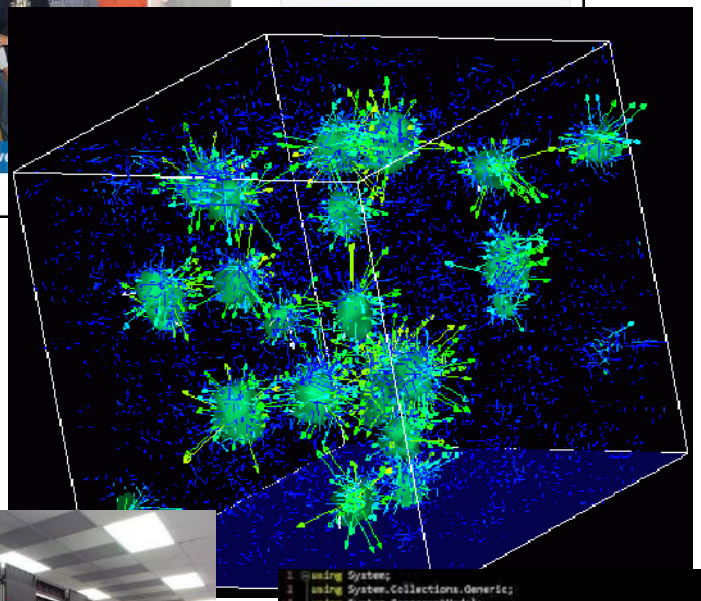

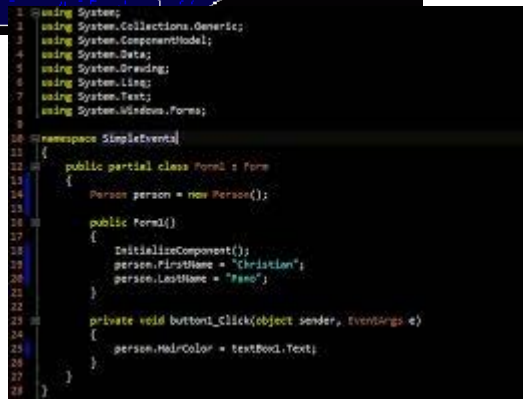

Survey of Scientific Computing (SciComp 301)

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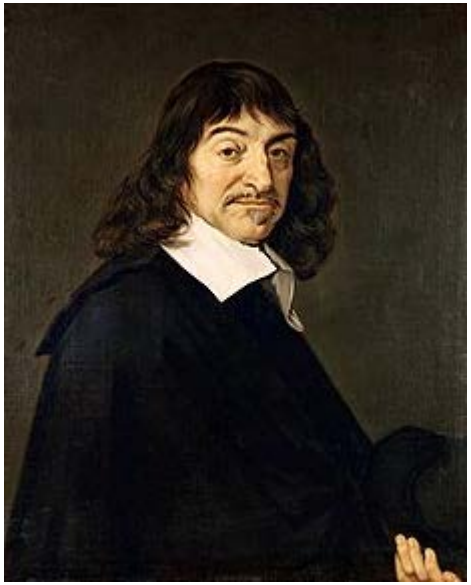
Session 05
2D Graphics,
Polar Coordinates

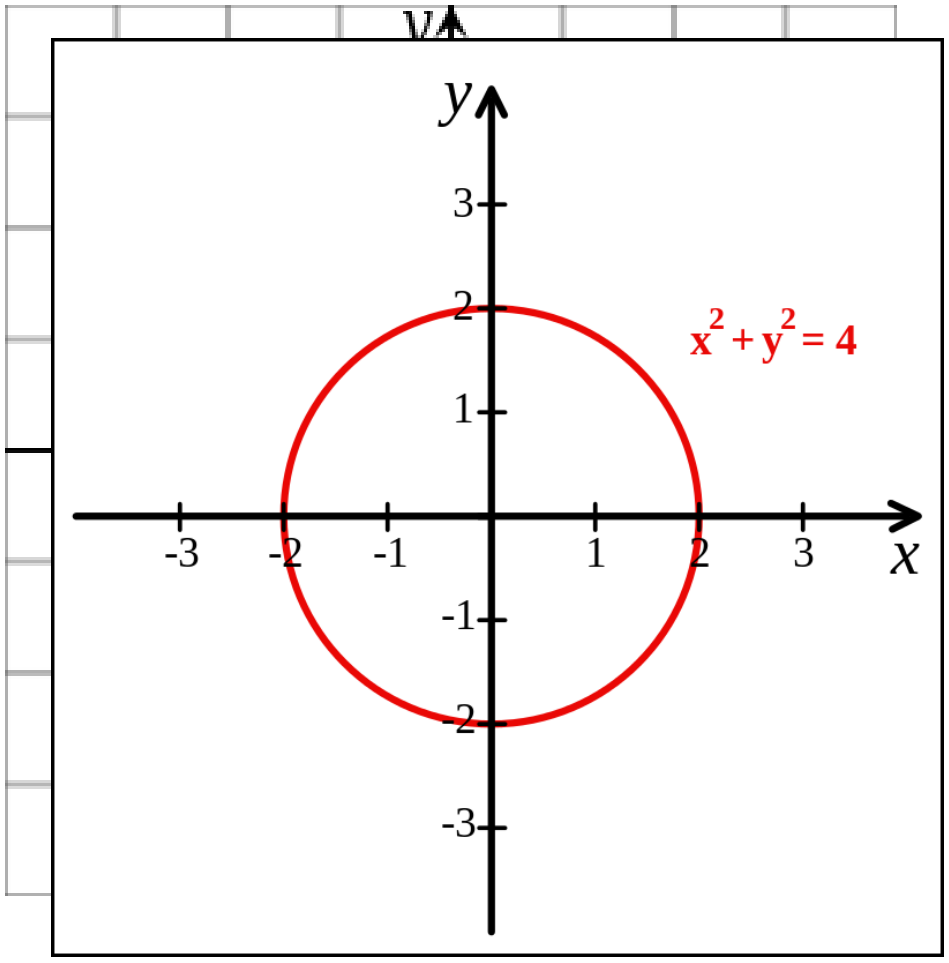
Session Goals

- Learn the **SimpleScreen** custom class to draw graphics
- Understand the World **bounding rectangle**
- Use **Cartesian** coordinates to draw 2D lines
- Use **polar** coordinates to draw 2D circles
- Approximate circles by dividing 2π **radians** into ***intervals***
- Use a **delay** count to watch each interval being drawn
- Appreciate *the hidden geometry* of the **Olympic Rings**
- Draw fancy curves using **parametric equations**

Cartesian Coordinates

Created by
René Descartes
in 1637



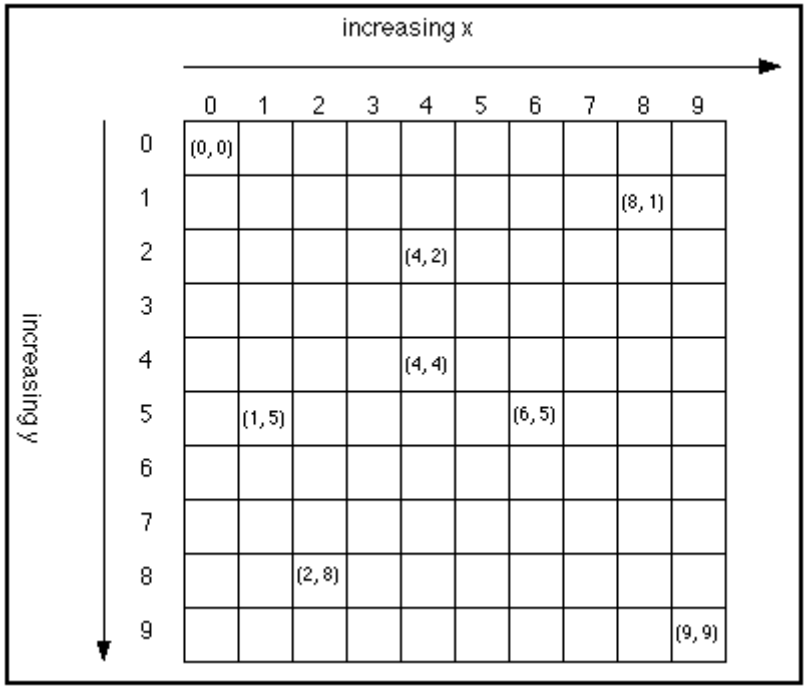


Screen Pixels

- A computer screen is divided into **2D array** of small rectangles called **pixels**
- Every pixels has both an **X** and a **Y** coordinate
- Each pixel is set to a specific **color**
- The number of pixels in each dimension is the resolution
- Modern screens have resolutions greater than 1920 x 1080
- The **top left** screen pixel has coordinates **(0,0)** and there are no negative pixel coordinates
- Unfortunately there is an even greater **discrepancy** between Cartesian coordinates and pixel coordinates…

Screen Y vs. World Y Coordinates

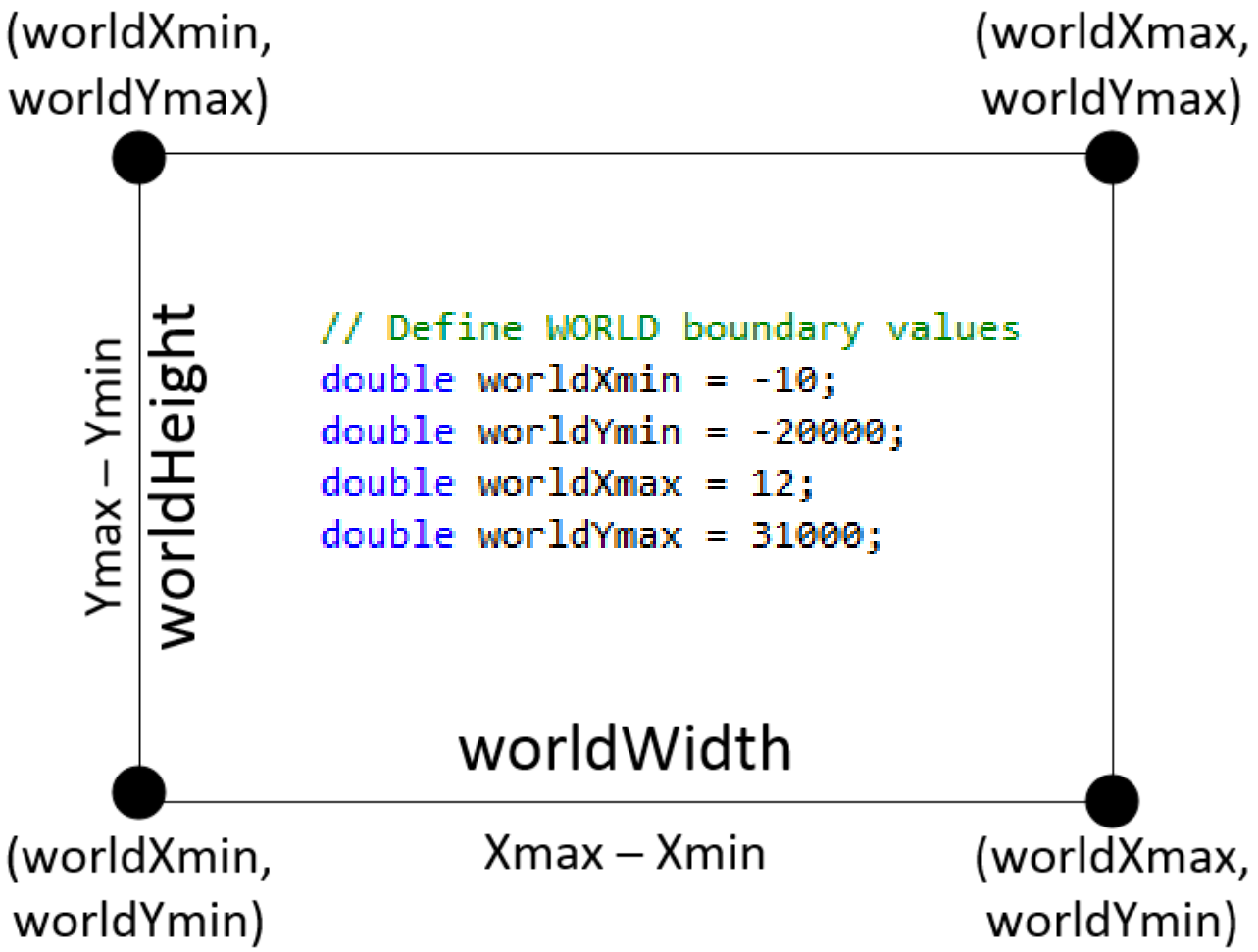
- In screen coordinates, as you move from the **top** of the screen *towards* the **bottom**, **the Y coordinate increases!**
- This is the exact opposite of world (Cartesian) coordinates
- Fortunately, the X axis behaves the as expected between the **screen** and **world** coordinate system
- This discrepancy will drive you nuts!



World Bounding Rectangle

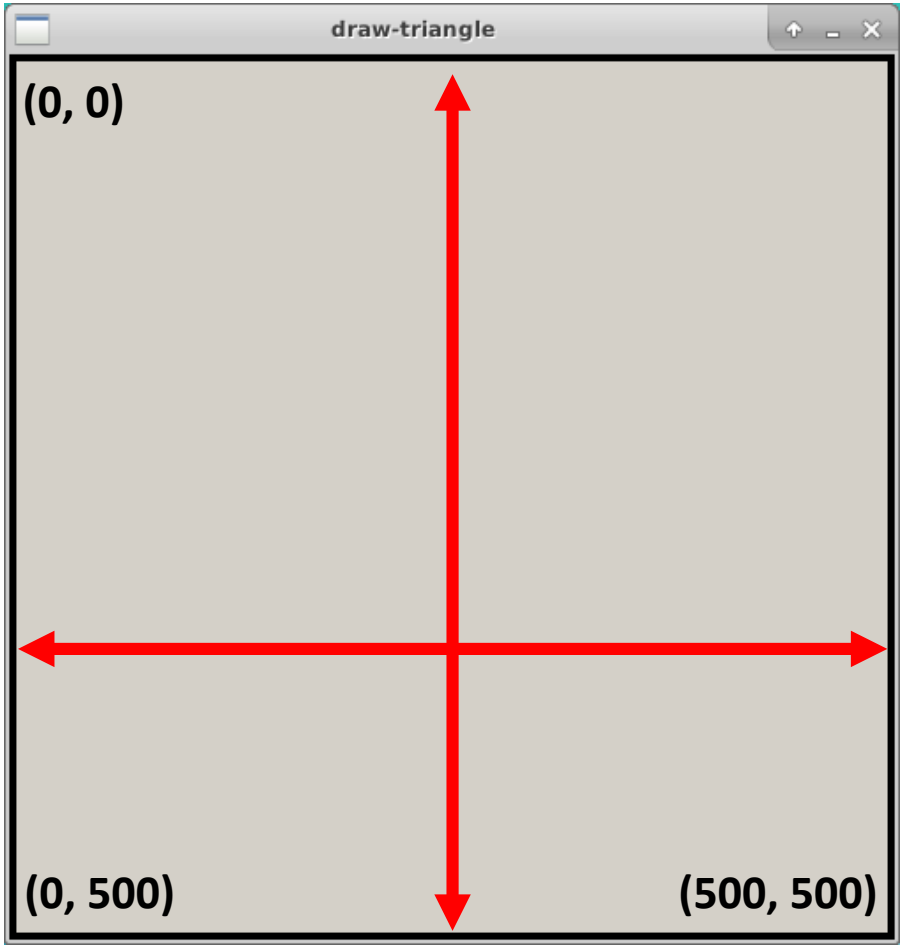
- World coordinates are what we use when doing pure math
- Screen coordinates are what we have to use when drawing
- We need a way to *map* **World** X,Y to **Screen** X,Y
- The world is framed by a "**bounding rectangle**" which is comprised of four variables of type **double**
  - **worldXmin**, **worldYmin**
  - **worldXmax**, **worldYmax**
- The values for all four World variables are **our choice** – they can be as big or as small as we want them

World Bounding Rectangle

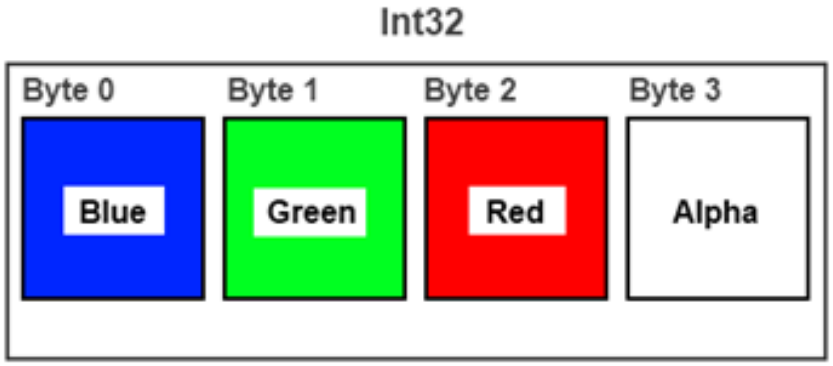


Screen Bounding Rectangle

- The Screen bounding rectangle is the size of the **Allegro** display bitmap
- Due to your smaller laptop screens, we set the size to be **501 x 501**
- Remember Screen Y coordinates are **inverted** as **(0,0)** is in the **top** left

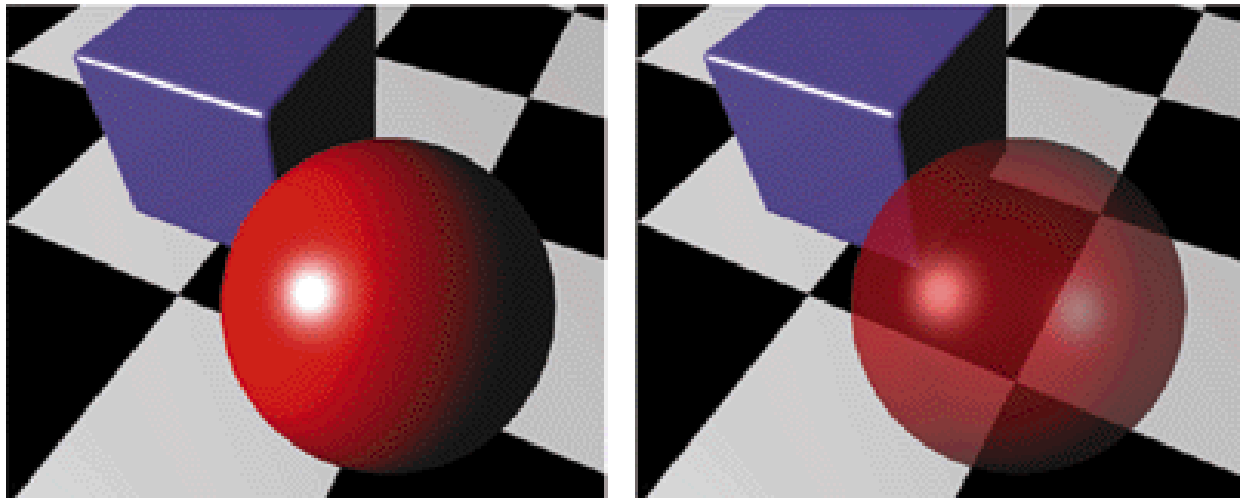


Argb Color Encoding




```
ALLEGRO_COLOR clrRed = al_map_rgb(255, 0, 0);   // Red
ALLEGRO_COLOR clrGreen = al_map_rgb(0, 255, 0); // Green
ALLEGRO_COLOR clrBlue = al_map_rgb(0, 0, 255);  // Blue
```

Alpha Blending = Opacity



Alpha = 0 means fully transparent (see through)
Alpha = 255 means fully opaque

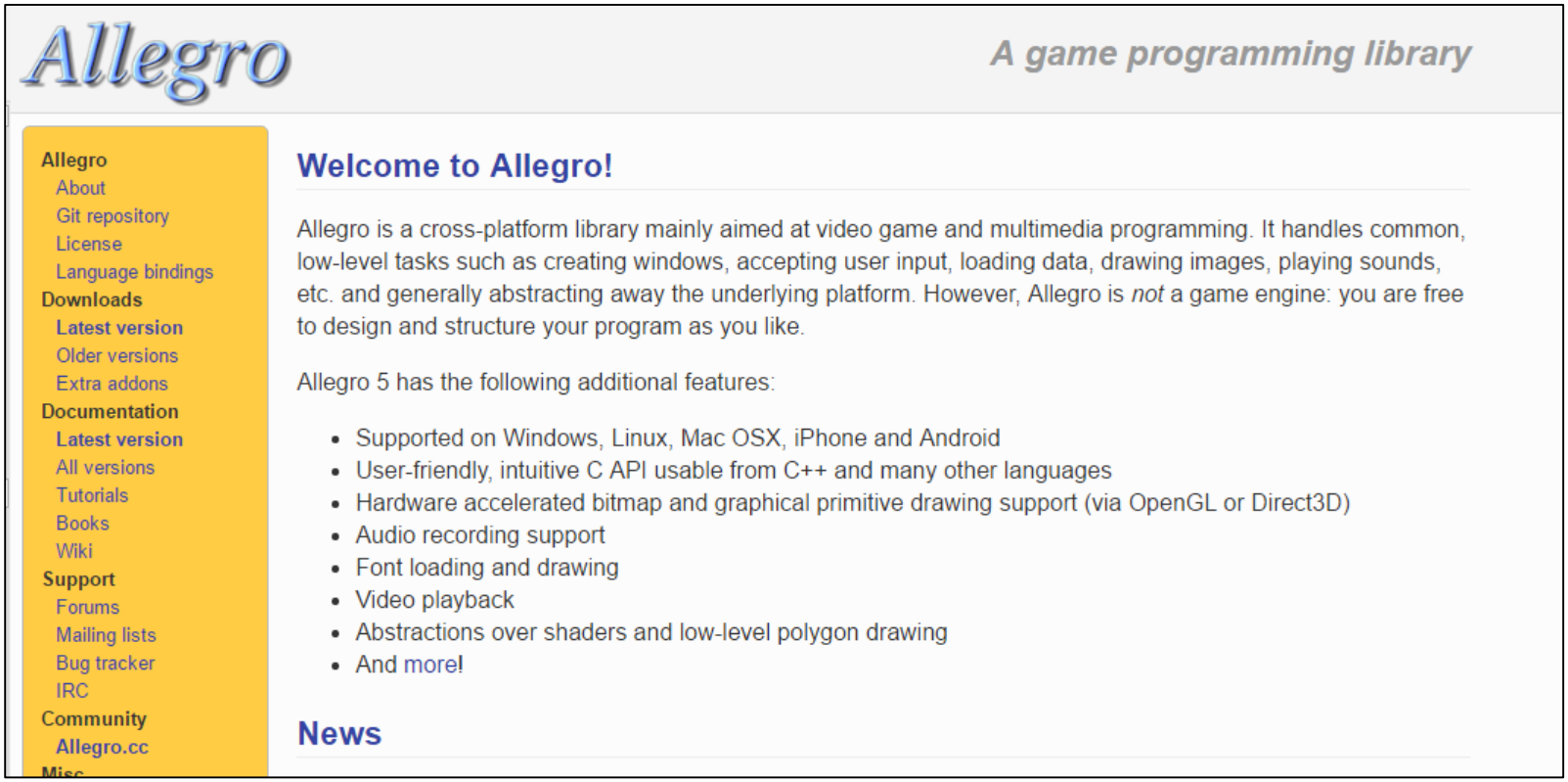
We will be using **Alpha = 255** in our code

Various Colors in **RGB** Values

Predefined Color “Names”

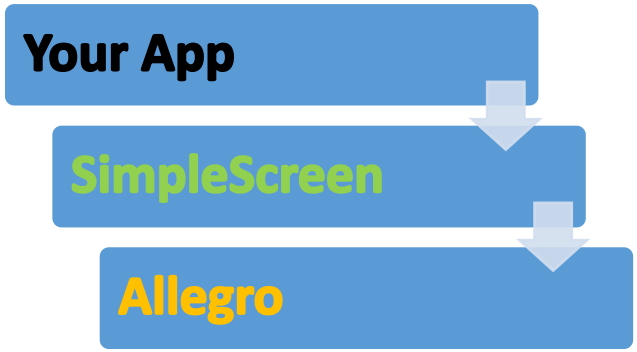
Allegro Graphics Library

http://liballeg.org



```
// SimpleScreen
class SimpleScreen
{
public:
    SimpleScreen(void(*draw)(SimpleScreen& ss) = nullptr,
        void(*eventHandler)(SimpleScreen& ss, ALLEGRO_EVENT& ev)= nullptr);

    ~SimpleScreen();

    void SetWorldRect(double xMin, double yMin,
        double xMax, double yMax);

    void GetWorldRect();

    void SetProjection(double degrees = 45, double correction = 1);

    void SetCameraLocation(double x, double y, double z);

    void SetZoomFrame(string clr, double width = 2);

    void LockDisplay();

    void UnlockDisplay();

    void Clear();

    void Update();

    void Redraw();

    void Exit();

    void HandleEvents();

    bool Contains(double x, double y);

    void DrawAxes(string clr = "black", float width = 1);

    void DrawLine(Point2D &a, Point2D &b,
        string clr = "black", float width = 1);

    void DrawLines(PointSet* ps, string clr, float width = 1,
        bool close = true, bool fill = false, long delay = 0);

    void DrawLines(FacetSet* facets, string clr, float width = 1,
        bool fill = false, long delay = 0);
```

The SimpleScreen Class



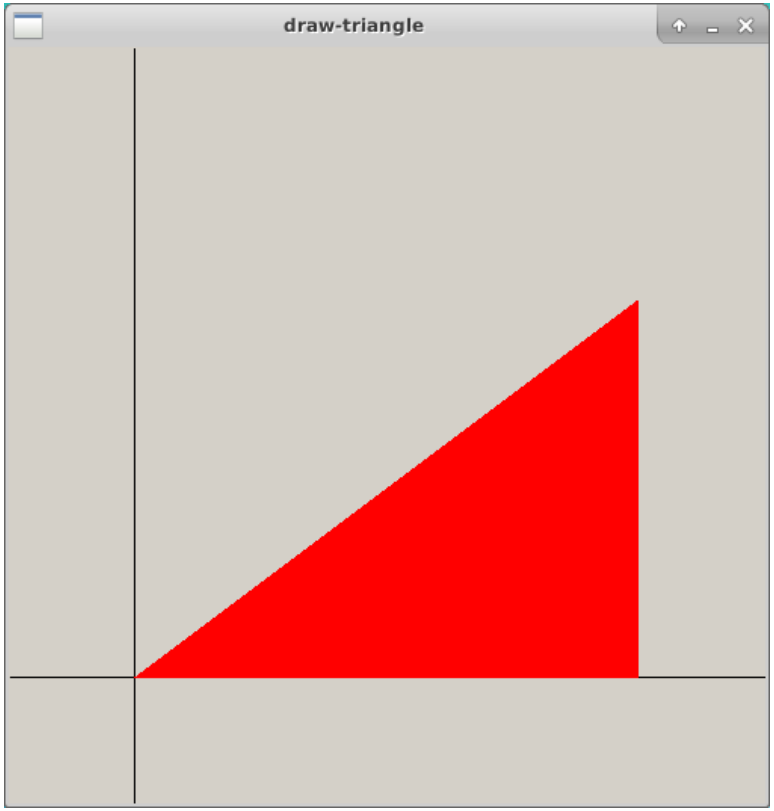
The **PointSet** Class

```
// PointSet
class PointSet
{
public:
    PointSet();
    ~PointSet();
    Point2D* at(size_t i);
    void clear();
    void add(double x, double y);
    size_t size();
private:
    vector<Point2D*>* points;
};
```

Open Lab 1 – Draw Triangle

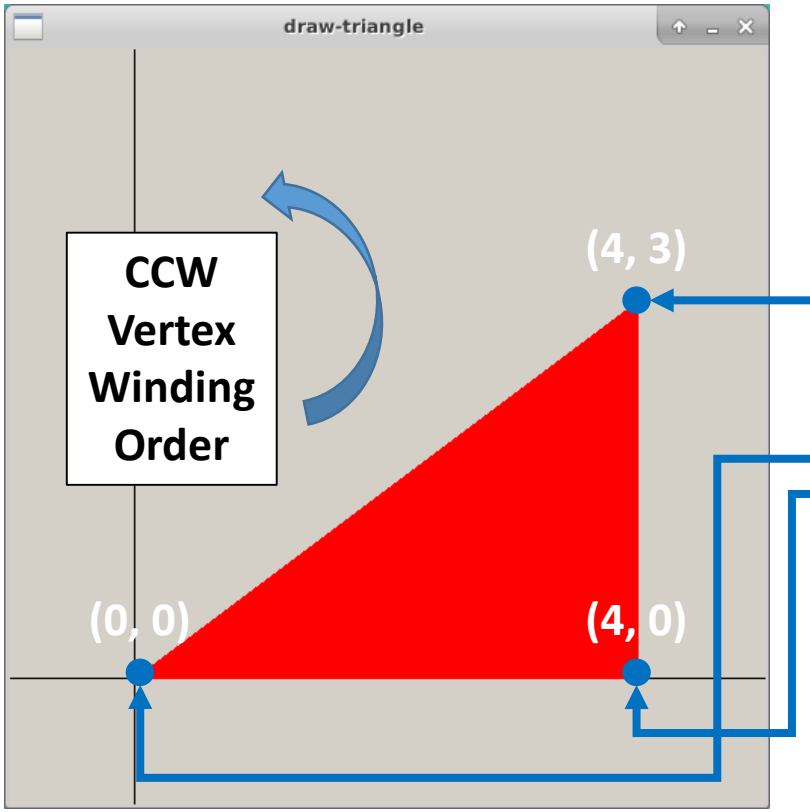
- **No coding required – just follow along** **main()**
- Draw a **3-4-5** right triangle in the *first* quadrant
- Paint the entire triangle **RED** including the interior
- Set the correct ***world rectangle*** dimensions

View Lab 1 – Draw Triangle




```
#include "stdafx.h"
#include "simplescreen.h"

using namespace std;

int main()
{
    SimpleScreen ss;
    ss.SetWorldRect(-1, -1, 5, 5);
    ss.DrawAxes();

    PointSet ps;
    ps.add(0, 0);
    ps.add(4, 0);
    ps.add(4, 3);

    ss.DrawLines(&ps, "red", 1, true, true);

    ss.HandleEvents();

    return 0;
}
```

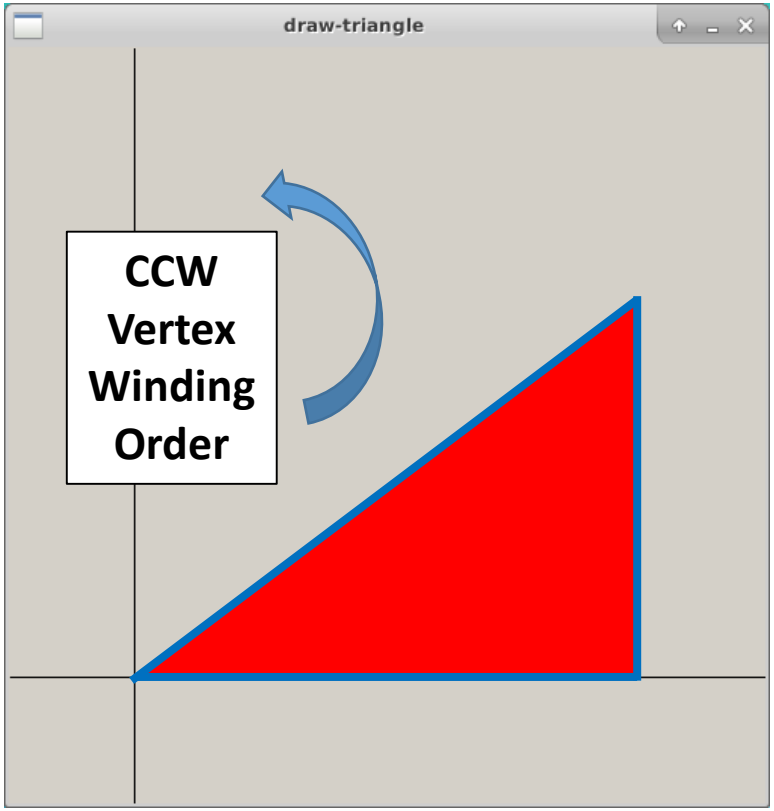
View Lab 1 – Draw Triangle




```
#include "stdafx.h"
#include "simplescreen.h"

using namespace std;

int main()
{
    SimpleScreen ss;
    ss.SetWorldRect(-1, -1, 5, 5);
    ss.DrawAxes();

    PointSet ps;
    ps.add(0, 0);
    ps.add(4, 0);
    ps.add(4, 3);

    ss.DrawLines(&ps, "red", 1, true, true);

    ss.HandleEvents();

    return 0;
}
```

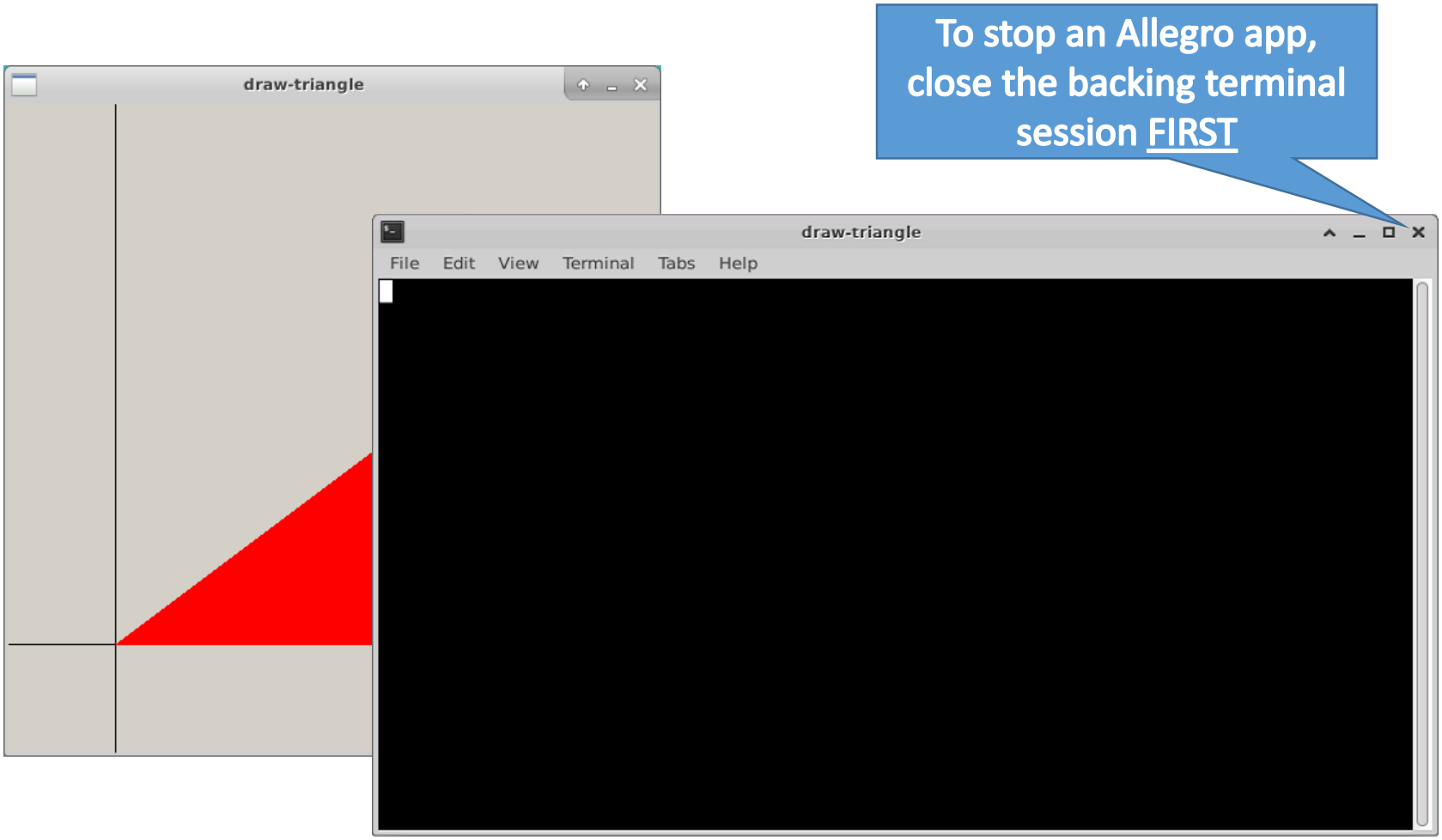
Add vertices in a counter-clockwise "winding order"

View Lab 1 – Draw Triangle




```
#include "stdafx.h"
#include "simplescreen.h"

using namespace std;

int main()
{
    SimpleScreen ss;
    ss.SetWorldRect(-1, -1, 5, 5);
    ss.DrawAxes();

    PointSet ps;
    ps.add(0, 0);
    ps.add(4, 0);
    ps.add(4, 3);

    ss.DrawLines(&ps, "red", 1, true, true);

    ss.HandleEvents();

    return 0;
}
```

Run Lab 1 – Draw Triangle



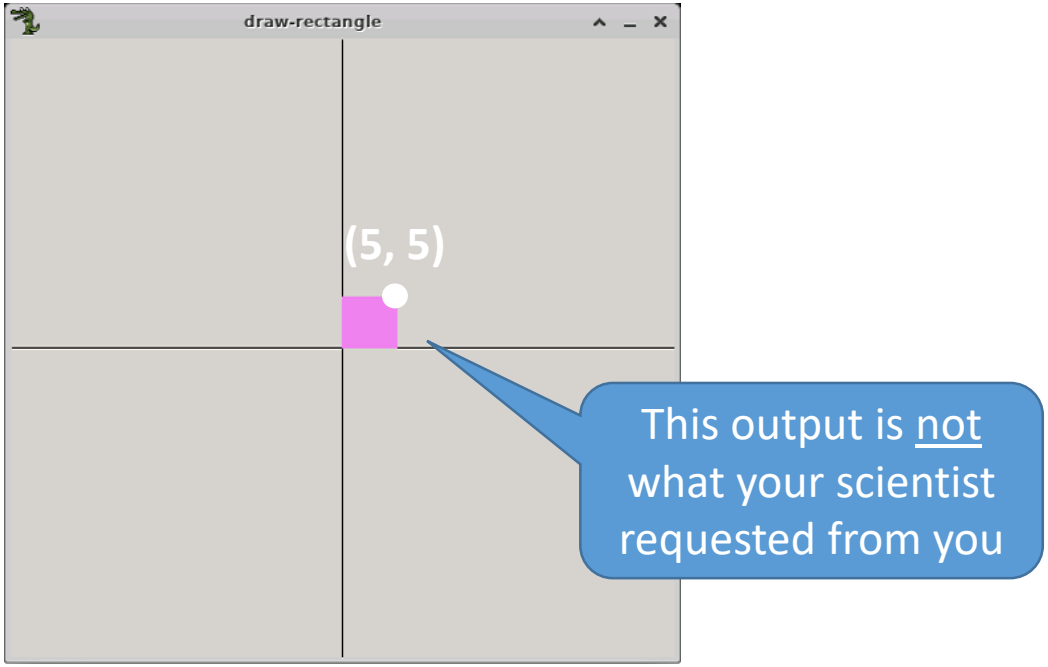
Open Lab 2 – Draw Rectangle

- Draw a violet rectangle in the first quadrant with the bottom left corner located at (0,0) and the longest side on the x-axis
- The dimensions are: **Area = 210** and **Perimeter = 62**
- Assume the world coordinates are (-30,-30) to (30,30)

```
int main()
{
    SimpleScreen ss;
    ss.SetWorldRect(-30, -30, 30, 30);
    ss.DrawAxes();

    PointSet ps;
    ps.add(0, 0);
    ps.add(5, 0);
    ps.add(5, 5);
    ps.add(0, 5);

    ss.DrawLines(&ps, "violet", 1, true, true);

    ss.HandleEvents();

    return 0;
}
```

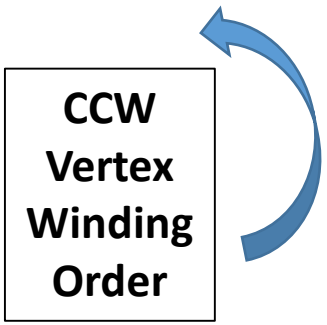
Run Lab 2 – Draw Rectangle

- Draw a **violet** rectangle in the first quadrant with the bottom left corner located at (0,0) and the longest side on the x-axis
- The dimensions are: **Area = 210** and **Perimeter = 62**
- Assume the world coordinates are (-30,-30) to (30,30)



Edit Lab 2 – Draw Rectangle

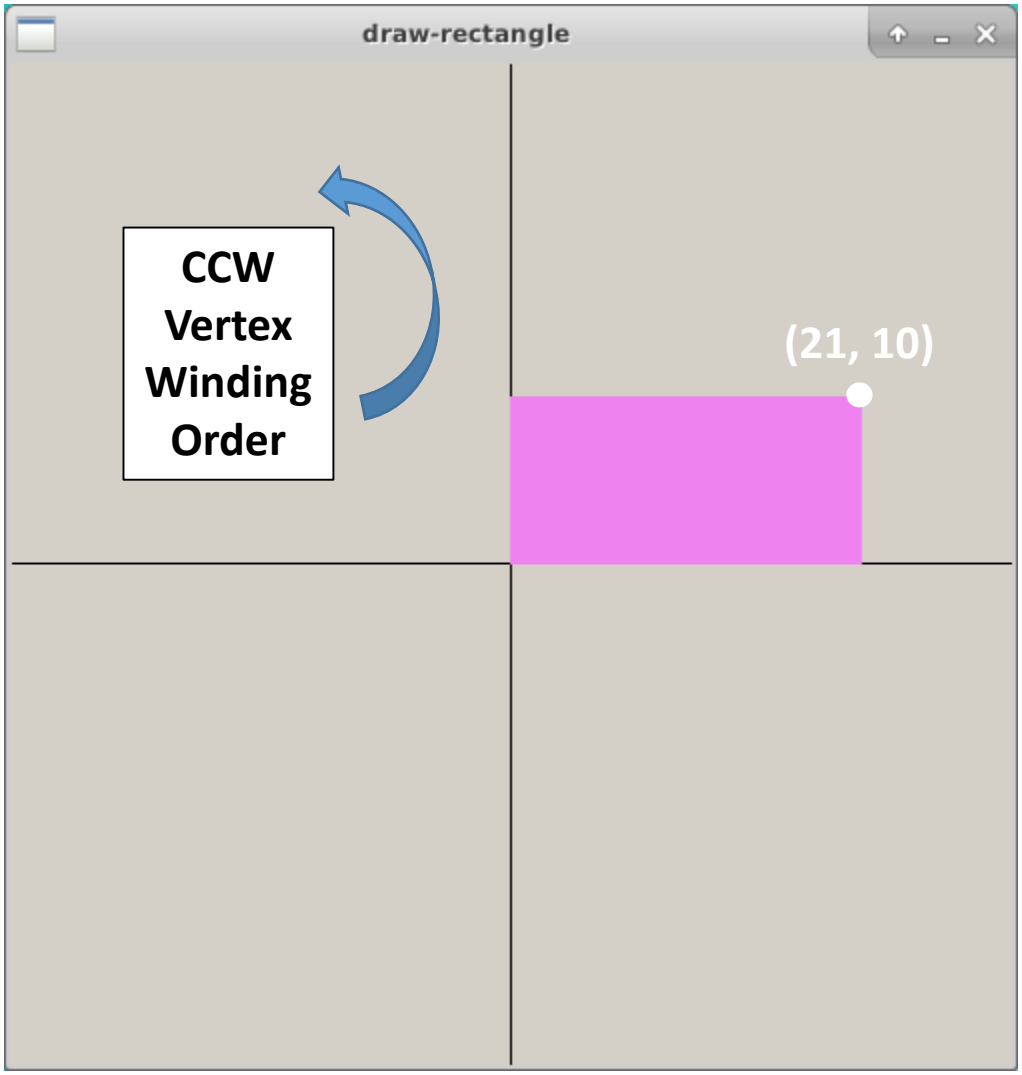
- Draw a **violet** rectangle in the first quadrant with the bottom left corner located at (0,0) and the longest side on the x-axis
- The dimensions are: **Area = 210** and **Perimeter = 62**
- Assume the world coordinates are (-30,-30) to (30,30)
- Edit the coordinates of the **three remaining** corner points with the correct values



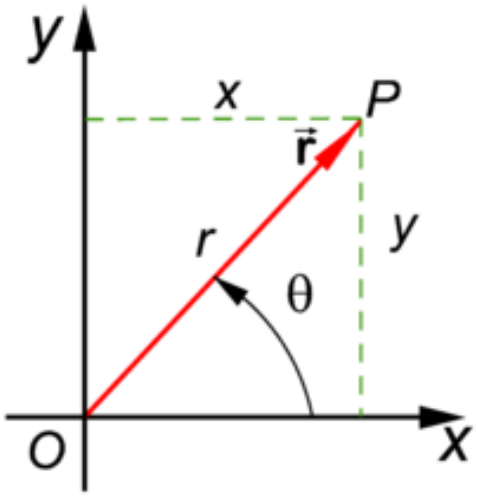

```
PointSet ps;
ps.add(0, 0);
ps.add(5, 0);
ps.add(5, 5);
ps.add(0, 5);
```

Fix these
last 3 points

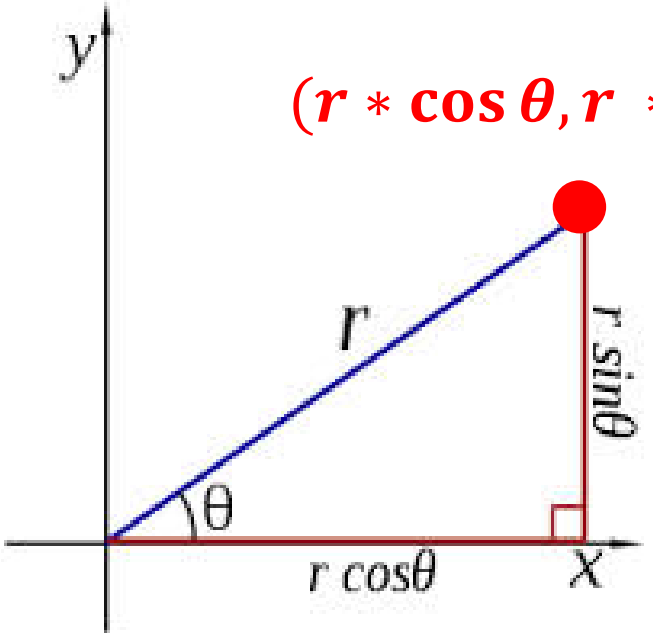
Check Lab 2 – Draw Rectangle



Polar Coordinates

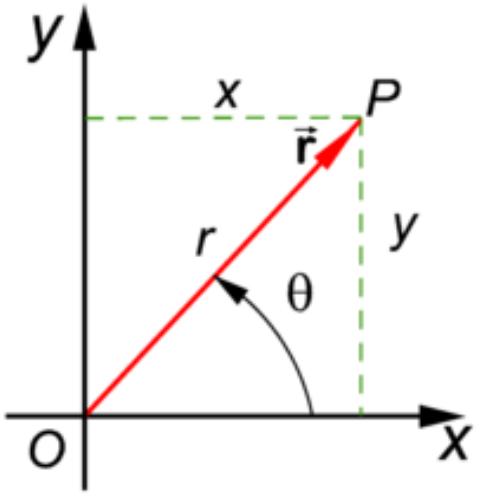


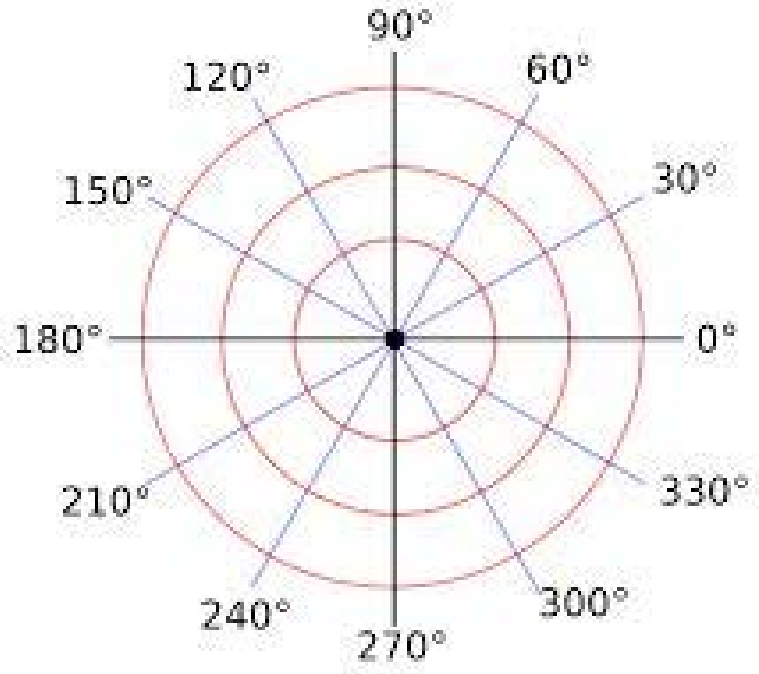
A radius and an angle (theta) make a 2D polar coordinate



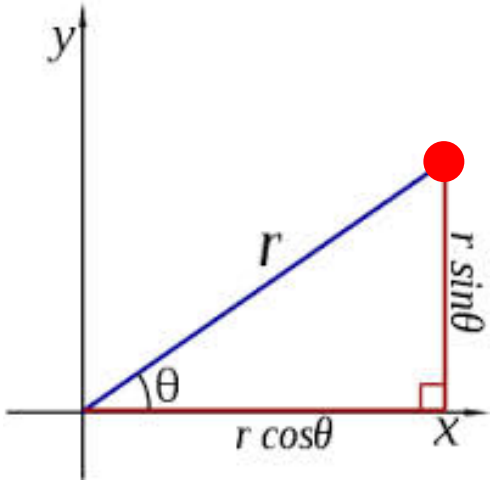
$(r * \cos\theta, r * \sin\theta)$

Polar Coordinates



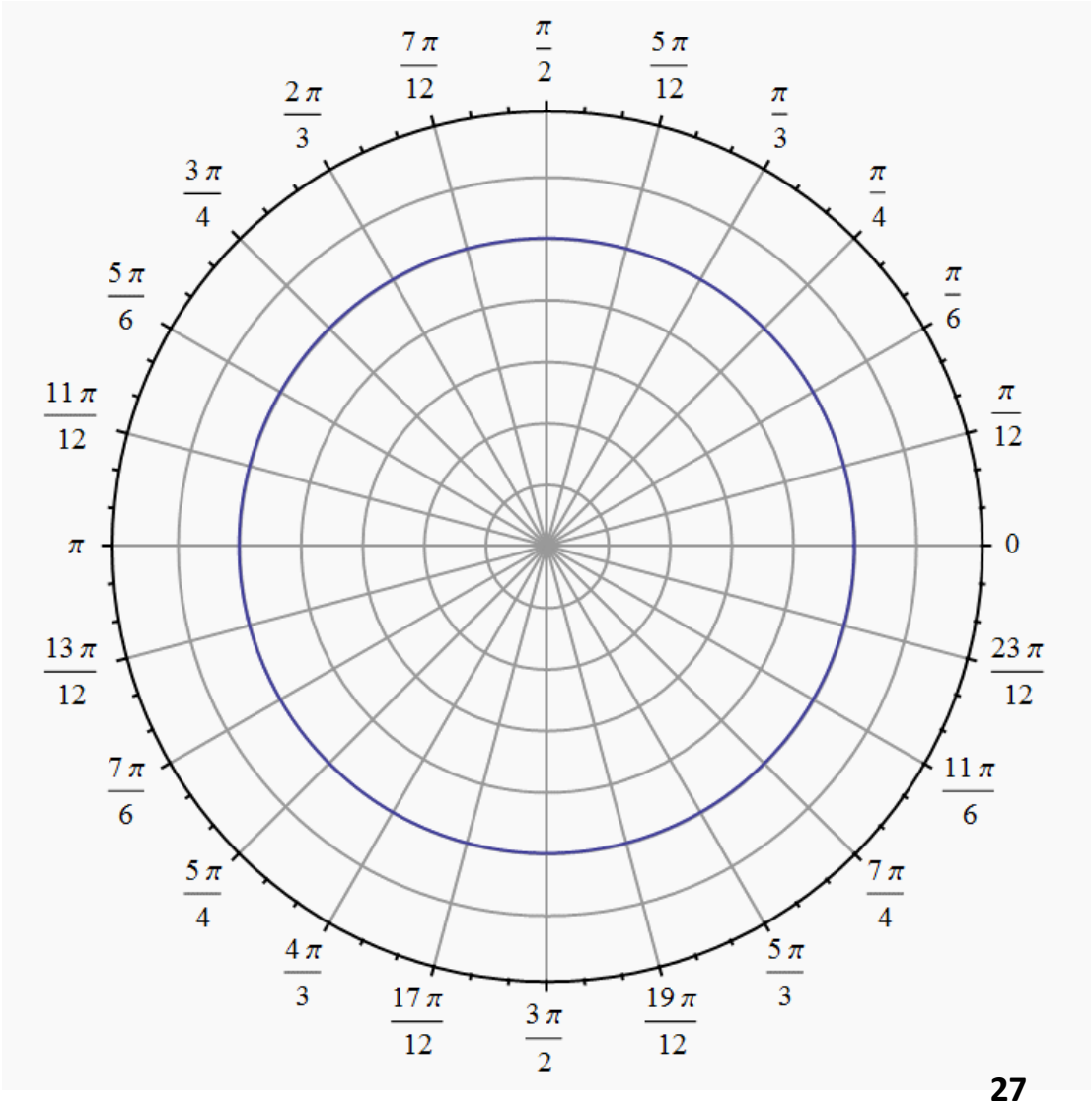


Polar Coordinates



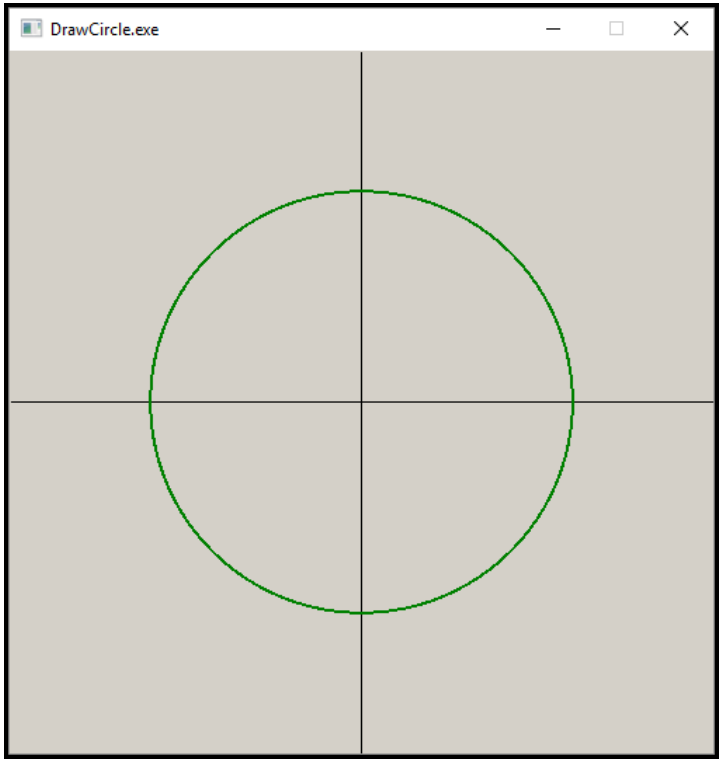
Angles are measured in **radians**

$(0 \le \theta \le 2\pi)$



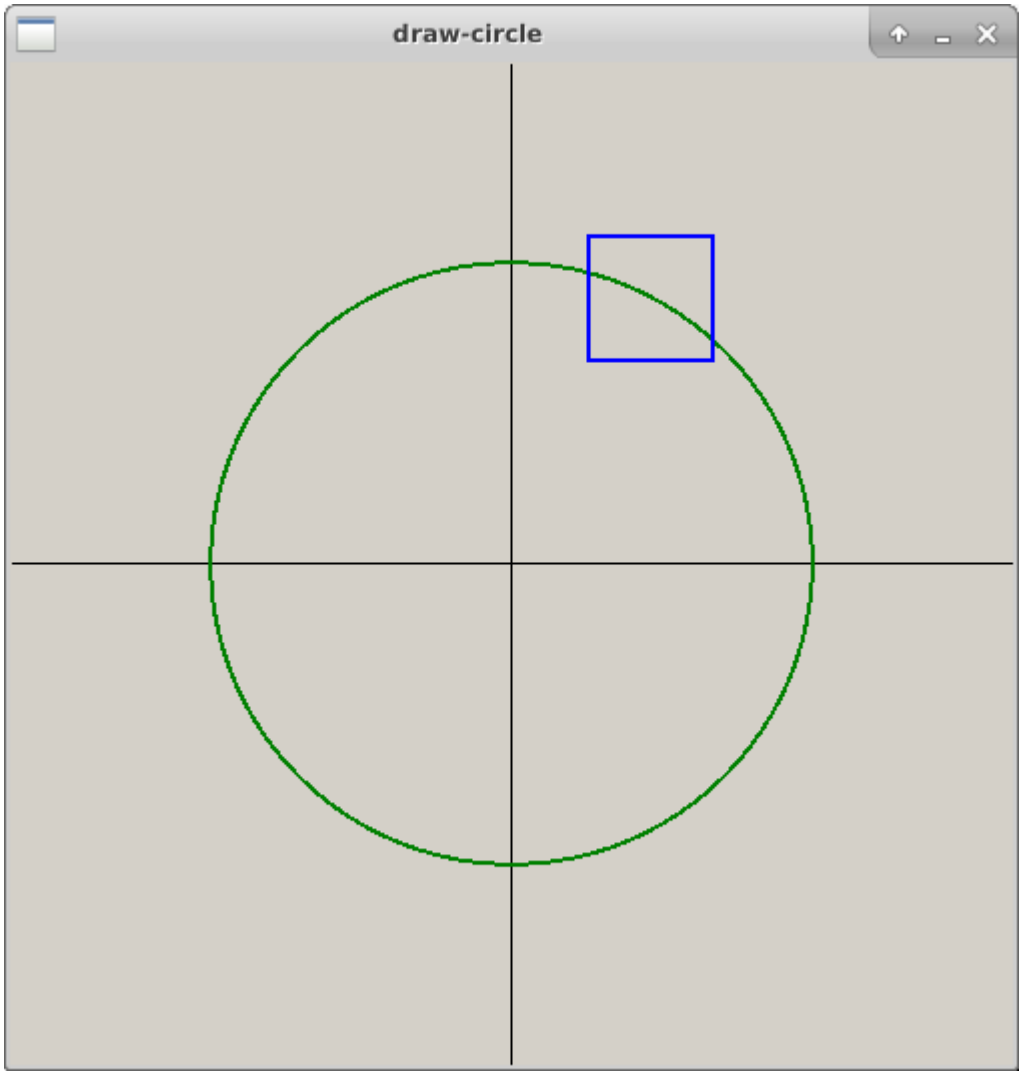
Open Lab 3 – Draw Circle

```
void draw(SimpleScreen& ss) {
    ss.DrawAxes();

    double radius{ 3 };

    int intervals{ 97 };

    double deltaTheta{ 2.0 * M_PI / intervals };

    PointSet psCircle;

    for (int i{}; i < intervals; ++i) {
        double theta = deltaTheta * i;
        double x = radius * cos(theta);
        double y = radius * sin(theta);
        psCircle.add(x, y);
    }

    ss.DrawLines(&psCircle, "green", 2);
}

int main()
{
    SimpleScreen ss(draw);
    ss.SetWorldRect(-5, -5, 5, 5);
    ss.HandleEvents();
    return 0;
}
```



draw() is a "callback function"
It is your custom drawing code that is called by the **SimpleScreen** object

Run Lab 3 – Draw Circle



By using the callback pattern, the framework can call your custom **draw()** function whenever it needs to repaint the screen. This enables features like **zooming**

You can **left click and drag** on the canvas to outline a zoom frame. When you release the left mouse button it will set the new **world rectangle** to the coordinates of the zoom frame and redraw the image

A **single right click** will restore each of the prior zoom levels

Edit Lab 3 – Draw Circle

- First, change intervals to **8**, run the app, then leave it at 8 for the next steps – **what shape do you see?**
- Then change the existing call to **ss.DrawLines()** as follows – be sure to run the app **each time** after making these individual changes:

```
ss.DrawLines(psCircle, "blue", 2, false);

ss.DrawLines(psCircle, "red", 2, true, true);
```

```
void DrawLines(PointSet* ps, string clr, float width = 1,
    bool close = true, bool fill = false, long delay = 0);
```

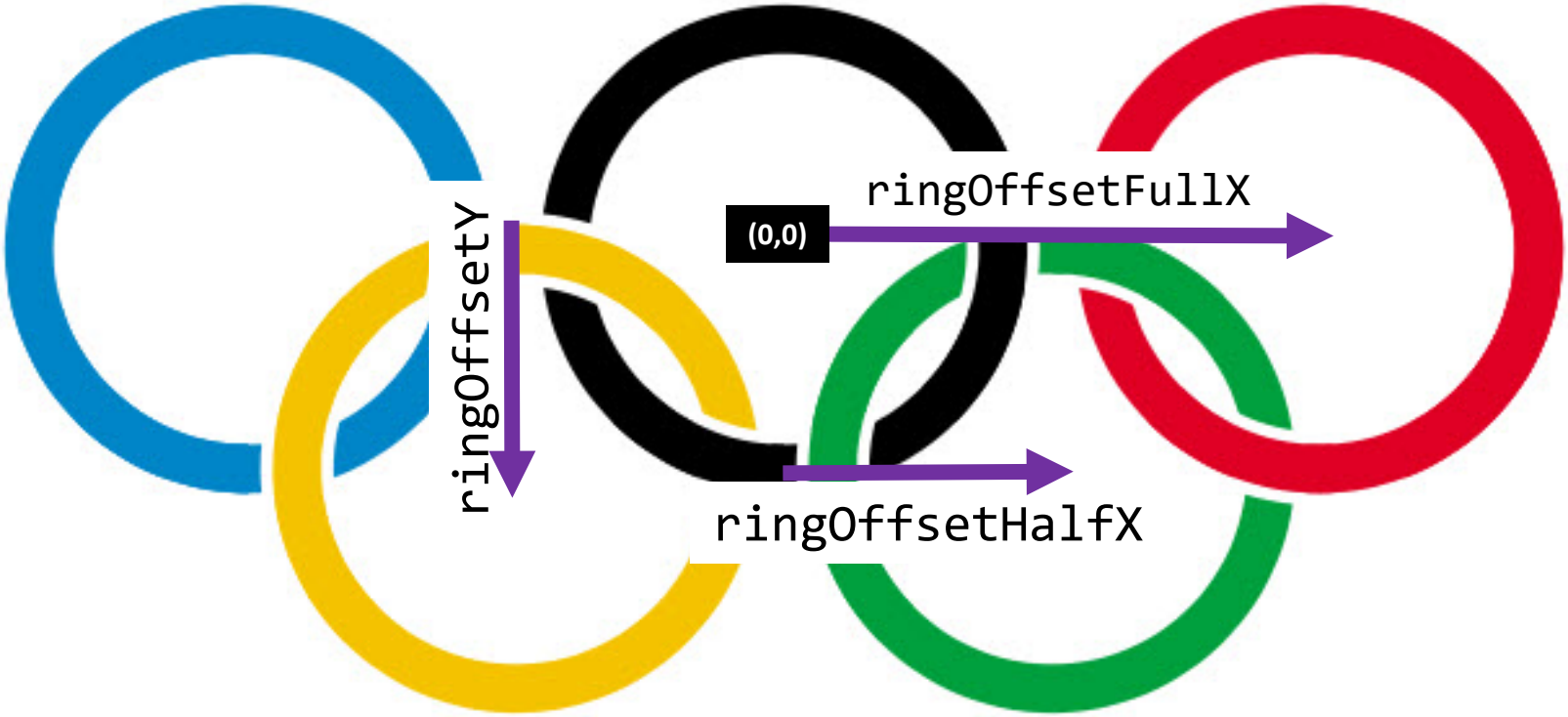
Creating a New **Primitive**

```
void SimpleScreen::DrawCircle(double centerX, double centerY,
                              double radius, string clr, int width)
{
    PointSet* psCircle = new PointSet();
    const int intervals = 97;
    const double deltaTheta = 2.0 * M_PI / intervals;
    for (int i{}; i < intervals; ++i)
    {
        double theta = deltaTheta * i;
        double x = centerX + radius * cos(theta);
        double y = centerY + radius * sin(theta);
        psCircle->add(x, y);
    }
    DrawLines(psCircle, clr, width);
}
```

Note:

- Circle **radius** is given in world coordinates
- Border **width** is given in *screen* coordinates

Drawing the Olympic Rings

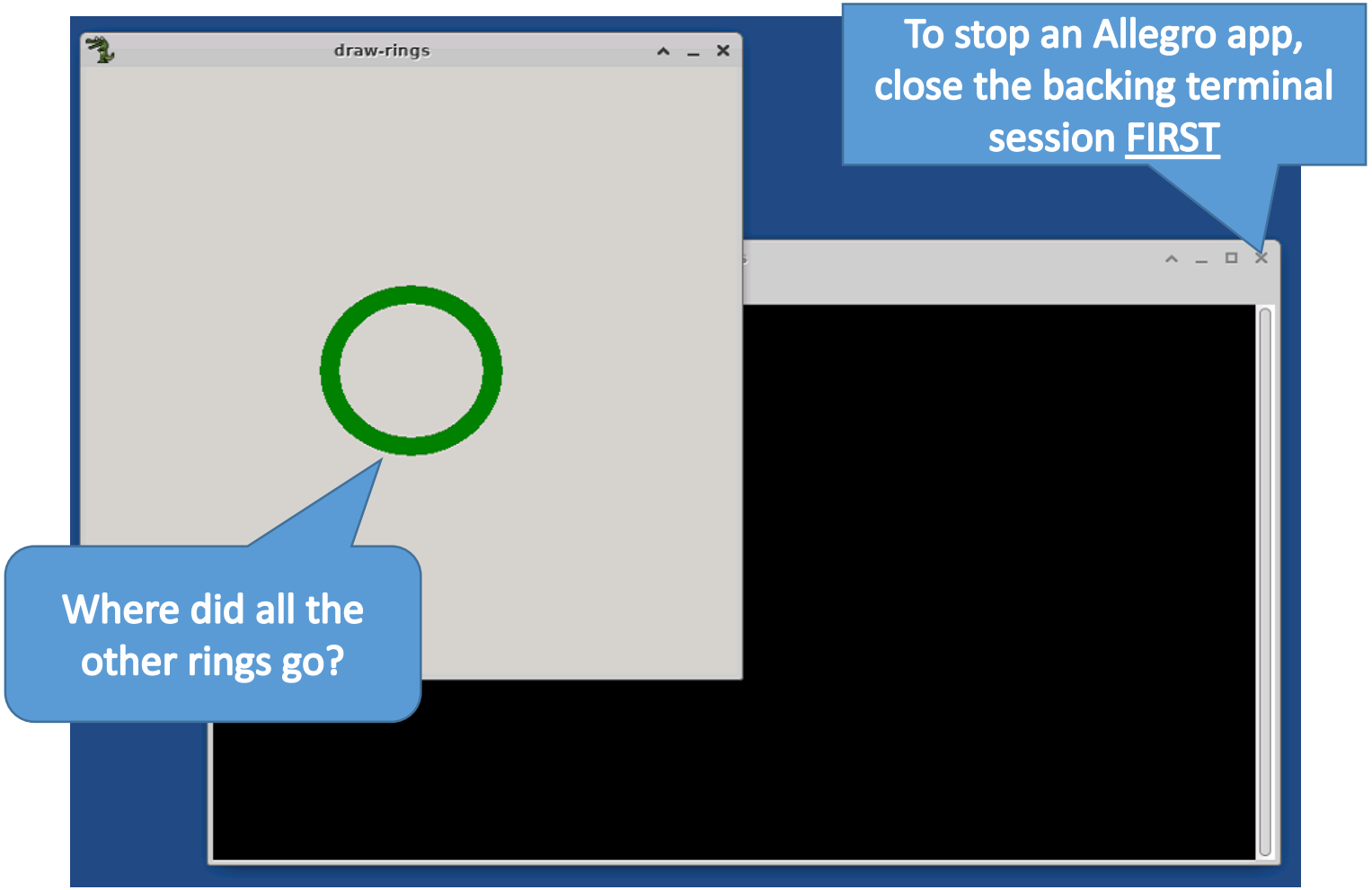


Open Lab 4 – Draw the Olympic Rings

```
void draw(SimpleScreen& ss)
{
    double radius{ 5 };
    int width{ 15 };

    // You must determine proper offsets
    double ringOffsetFullX{};
    double ringOffsetHalfX{};
    double ringOffsetY{};

    ss.DrawCircle(0, 0, radius, "black", width);
    ss.DrawCircle(-ringOffsetFullX, 0, radius, "blue", width);
    ss.DrawCircle(ringOffsetFullX, 0, radius, "red", width);
    ss.DrawCircle(-ringOffsetHalfX, -ringOffsetY, radius, "yellow", width);
    ss.DrawCircle(ringOffsetHalfX, -ringOffsetY, radius, "green", width);
}

int main()
{
    SimpleScreen ss(draw);
    ss.SetWorldRect(-20, -20, 20, 20);
    ss.HandleEvents();
    return 0;
}
```

- Circle **radius** is given in world coordinates
- Border **width** is given in *screen* coordinates

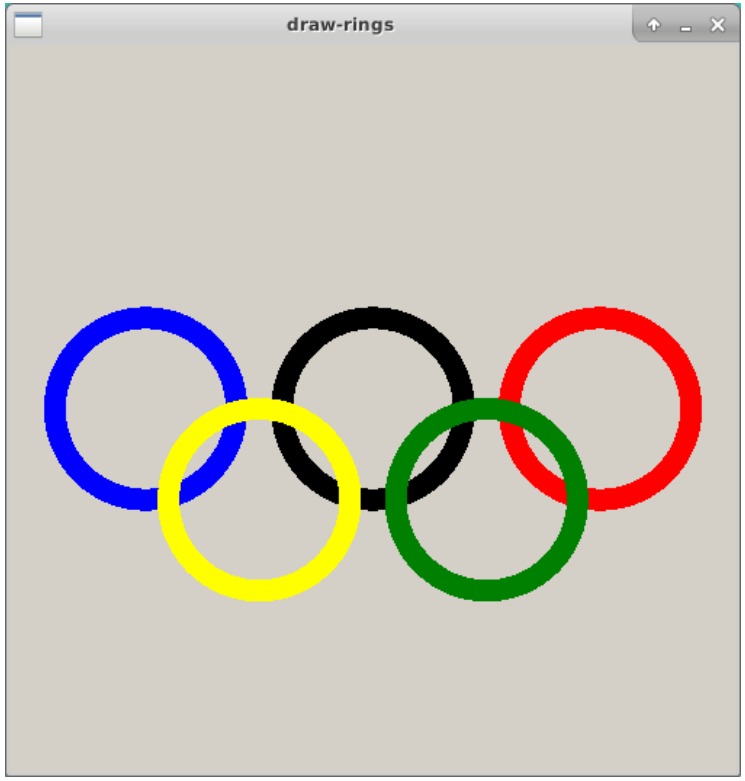
Run Lab 4 – Draw the Olympic Rings



Open Lab 4 – Draw the Olympic Rings

```
void draw(SimpleScreen& ss)
{
    double radius{ 5 };
    int width{ 15 };

    // You must determine proper offsets
    double ringOffsetFullX{};
    double ringOffsetHalfX{};
    double ringOffsetY{};

    ss.DrawCircle(0, 0, radius, "black", width);
    ss.DrawCircle(-ringOffsetFullX, 0, radius, "blue", width);
    ss.DrawCircle(ringOffsetFullX, 0, radius, "red", width);
    ss.DrawCircle(-ringOffsetHalfX, -ringOffsetY, radius, "yellow", width);
    ss.DrawCircle(ringOffsetHalfX, -ringOffsetY, radius, "green", width);
}

int main()
{
    SimpleScreen ss(draw);
    ss.SetWorldRect(-20, -20, 20, 20);
    ss.HandleEvents();
    return 0;
}
```

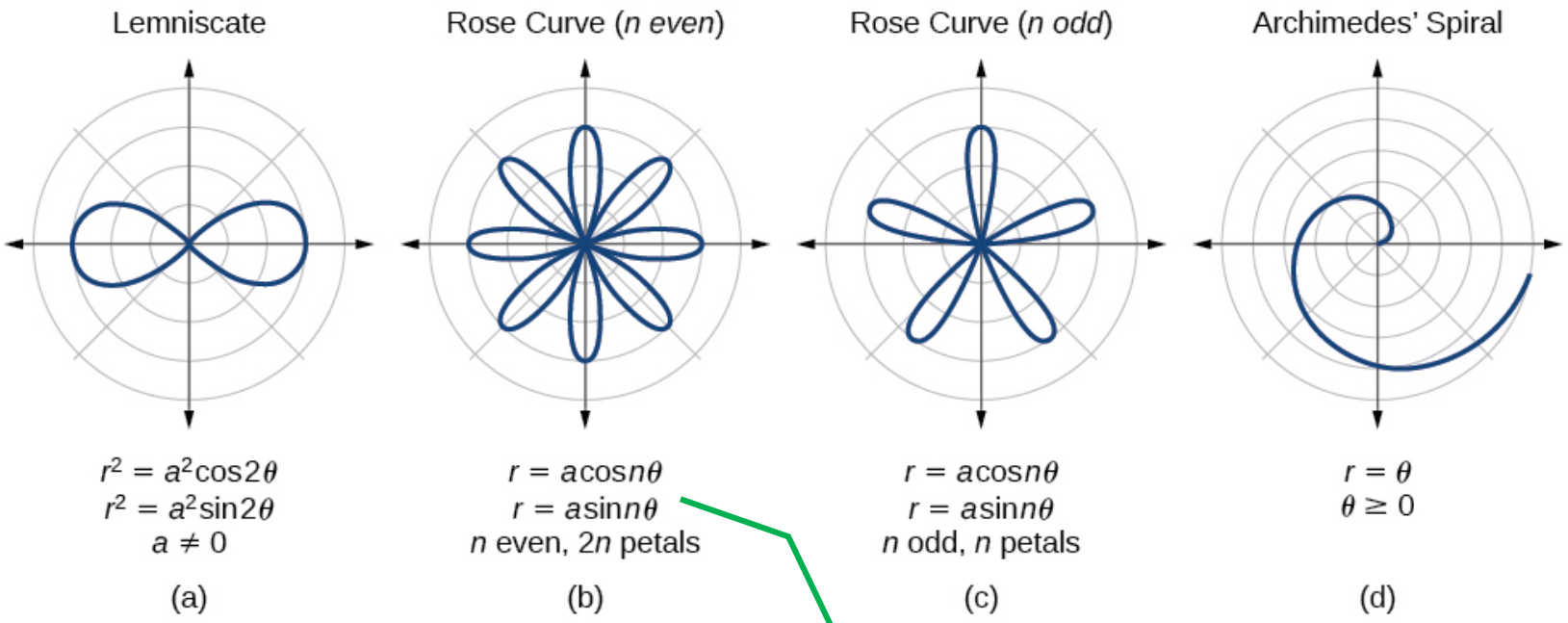
Check Lab 4 – Draw the Olympic Rings




```
// You must determine proper offsets
double ringOffsetFullX{radius * 5. / 2};
double ringOffsetHalfX{radius * 5. / 4};
double ringOffsetY{radius};
```

Parametric Curves

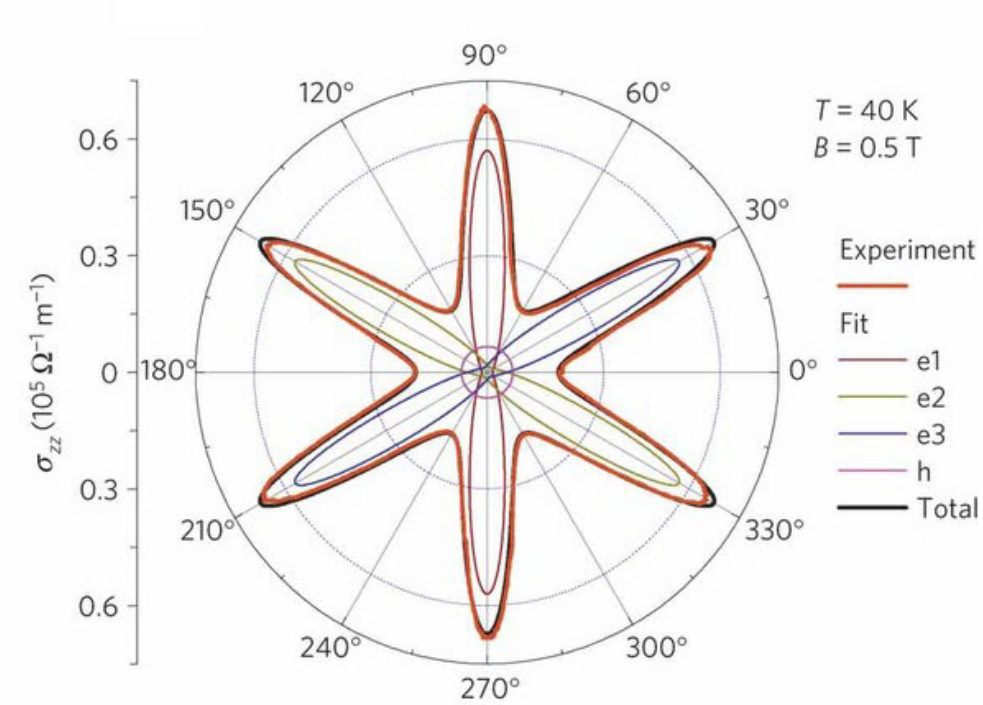
Parametric Curves



The two parameters **a, n** are used to calculate the current radius $\boldsymbol{r}$ as $\boldsymbol{\theta}$ sweeps the circle

Parametric Curves

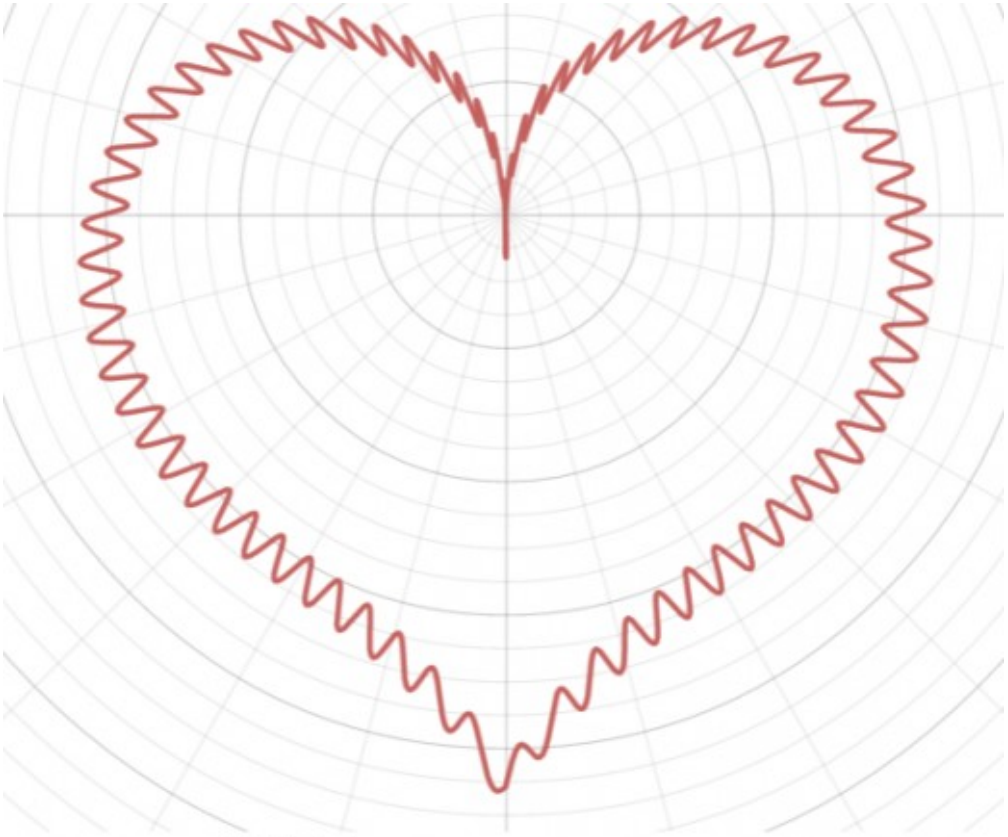
Field Induced Polarization of Dirac Valleys in Bismuth*



$$r = \sin^2\left(\frac{6}{5}\right) + \cos^2\left(\frac{6}{1}\right)$$

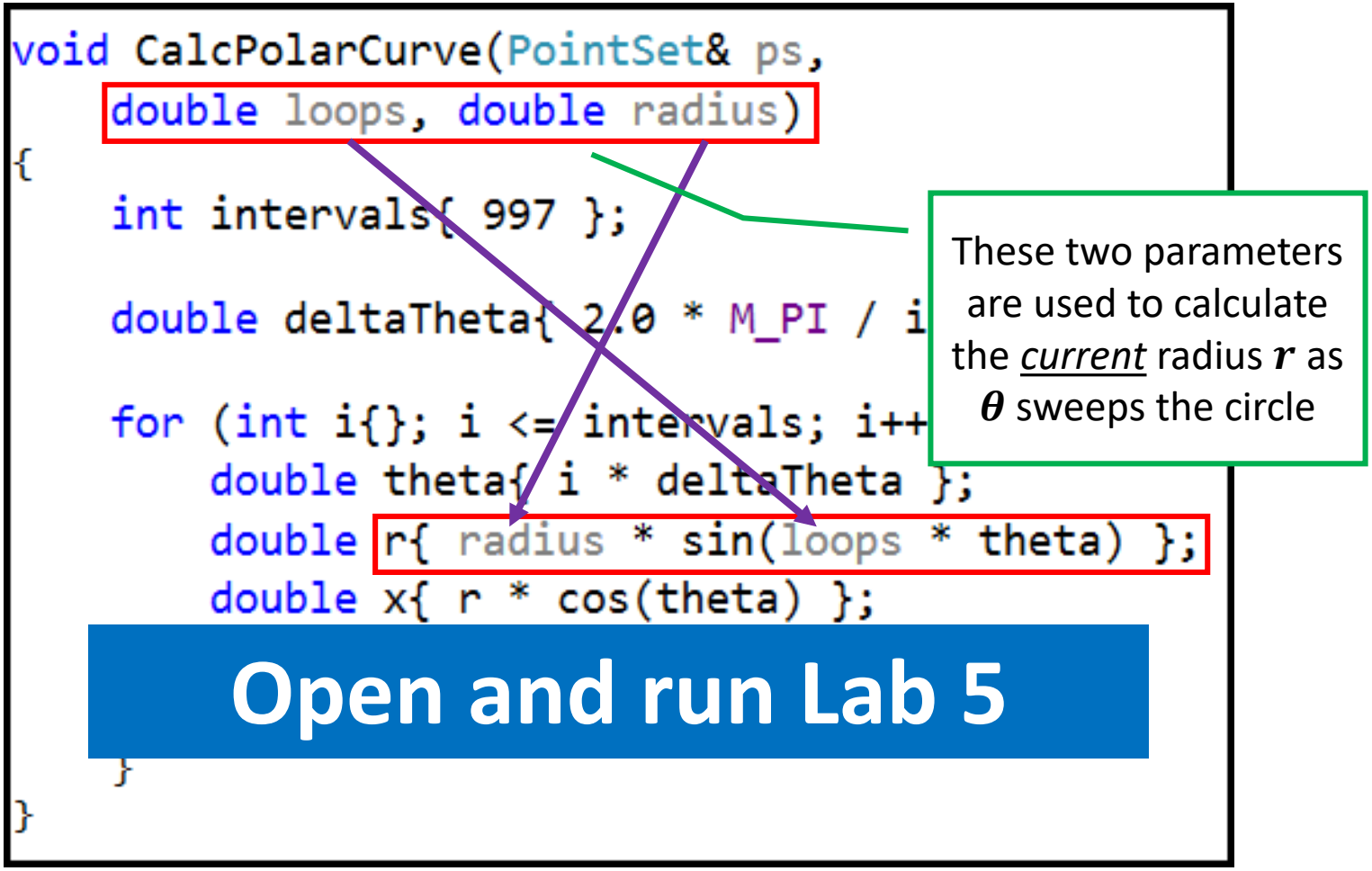
*Bismuth is the element with the **highest** atomic mass that is **stable**

Parametric Curves

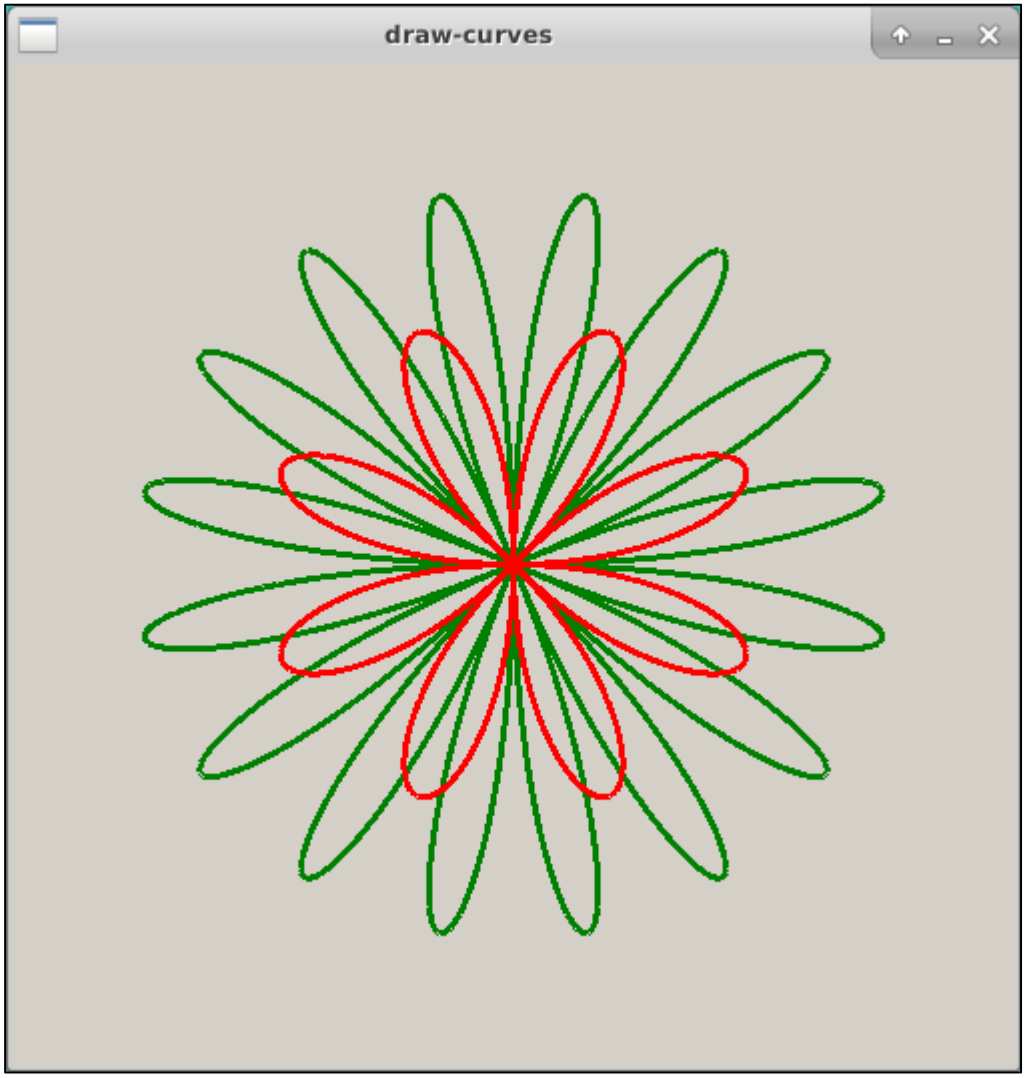


$$r = 5 - \frac{2.5\sin(\theta)}{\sqrt{0.2 + |\cos(\theta)|}} + \sin(\theta) + \cos(2\theta) + 0.3\sin(70\theta)$$

Parametric Curves



Check Lab 5 - Parametric Curves



The key points are:

- **The radius is changing while θ is changing**
- **The shape of the curve depends on two *parameters***

Now you know…

- **Allegro** is a free, open source, cross platform library for rendering 2D graphics
- A “bounding rectangle” is used to scale **world** (virtual) coordinates to **screen** (physical) coordinates
- How to create and populate elements of a **PointSet**
- How to “connect the dots” using **SimpleScreen.DrawLines()**
- How to use **polar coordinates** to draw 2D circles
- We approximate circles by drawing small **intervals**
- We can draw fancy curves by using **parametric equations**