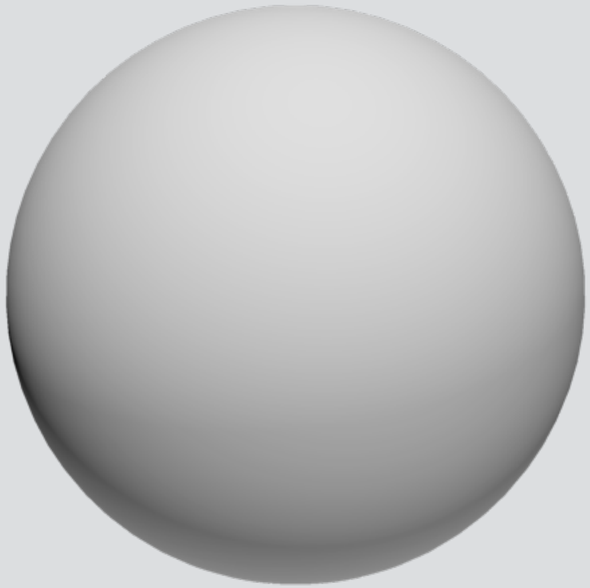
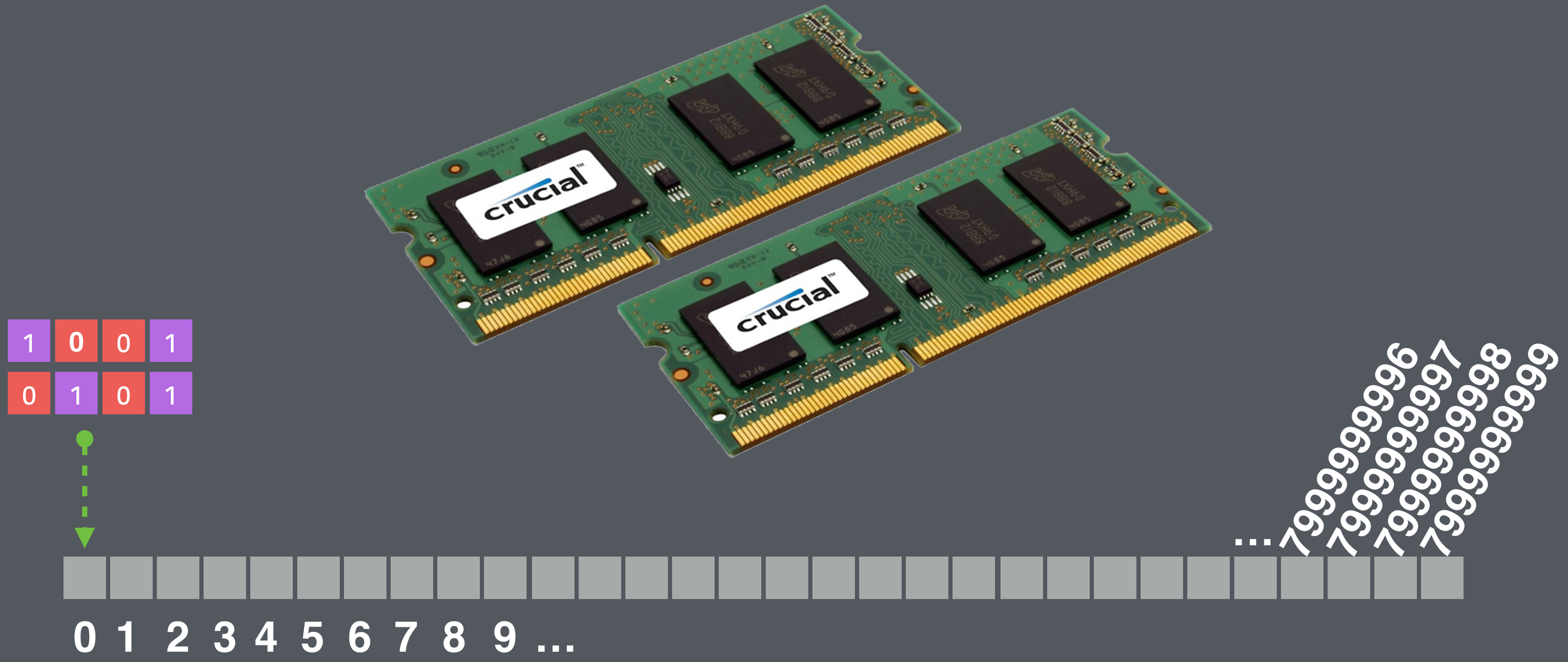
Graphics Foundations



CS 3113

Quick **pointer** refresher


1 0 0 1
0 1 0 1
crucial
crucial
...7999999996
7999999997
7999999998
7999999999
0 1 2 3 4 5 6 7 8 9 ...

```
char myVar = ‘a’; // char is an 8-bit variable
```

```
float myVar = 1.0f; // float is a 32-bit variable
```

```
double myVar = 1.0; // double is a 64-bit variable
```

```
float myVar = 16.0f;
```

```
float *myVarPtr = &myVar;

cout << myVarPtr << endl; // prints 3
```

```
float myVar = 16.0f;

float *myVarPtr = &myVar;

cout << myVarPtr << endl; // prints 3

cout << *myVarPtr << endl; // prints 16

cout << &myVar << endl; // prints 3
```

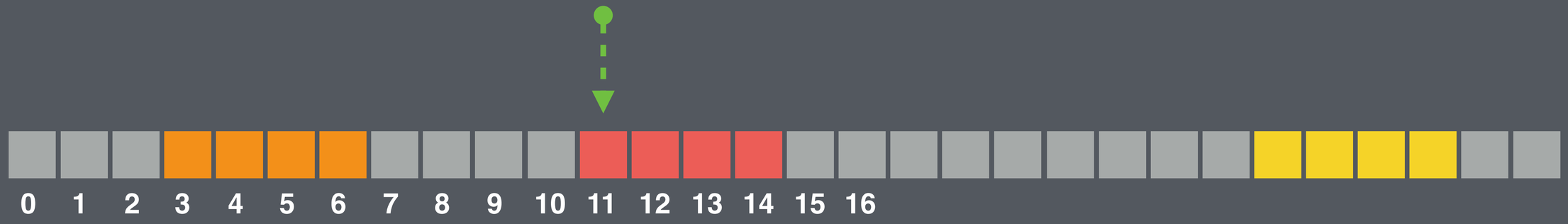
Reference

Dereference

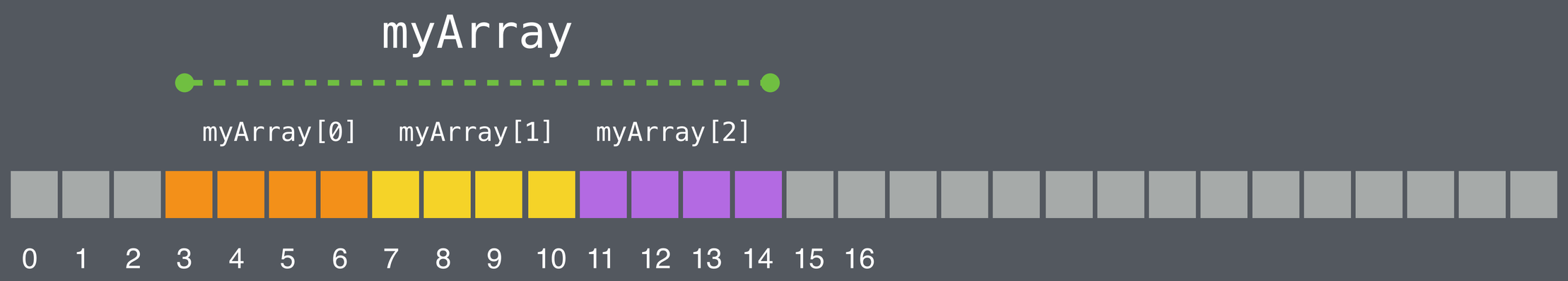
```
float myVar = 16.0f;

float *myVarPtr = &myVar;

cout << myVarPtr; // prints 3

cout << *myVarPtr; // prints 16

cout << &myVar; // prints 3

float **myVarPtrPtr = &myVarPtr;

cout << myVarPtrPtr; // prints 11
```

Reference

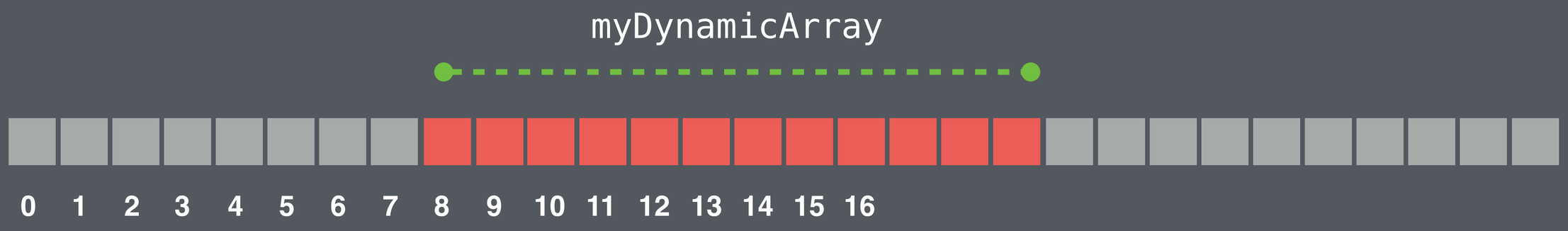
Dereference



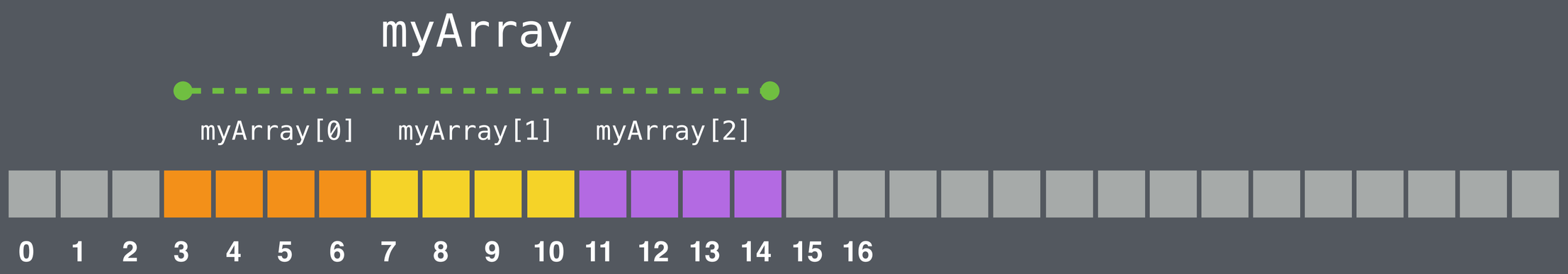
```
float myArray[3] = {13.5f, 2.3f, 5.4f};

cout << myArray[0]; // prints 13.5
cout << myArray; // prints 3
cout << &myArray[0]; // prints 3

float *myArrayAsAPointer = myArray;
cout << myArrayAsAPointer; // prints 3

cout << myArrayAsAPointer[0]; // prints 13.5
cout << myArrayAsAPointer[1]; // prints 2.3
```



```
float *myDynamicArray;

cout << myDynamicArray; // 0x0 or some uninitialized location
cout << myDynamicArray[0]; // crash or garbage!

myDynamicArray = new float[3];

cout << myDynamicArray; // prints 8
cout << myDynamicArray[0]; no crash!

delete myDynamicArray;
```



```
float *myArray = new float[3];
```




```
char *myCharArray = (char*) myArray;
```

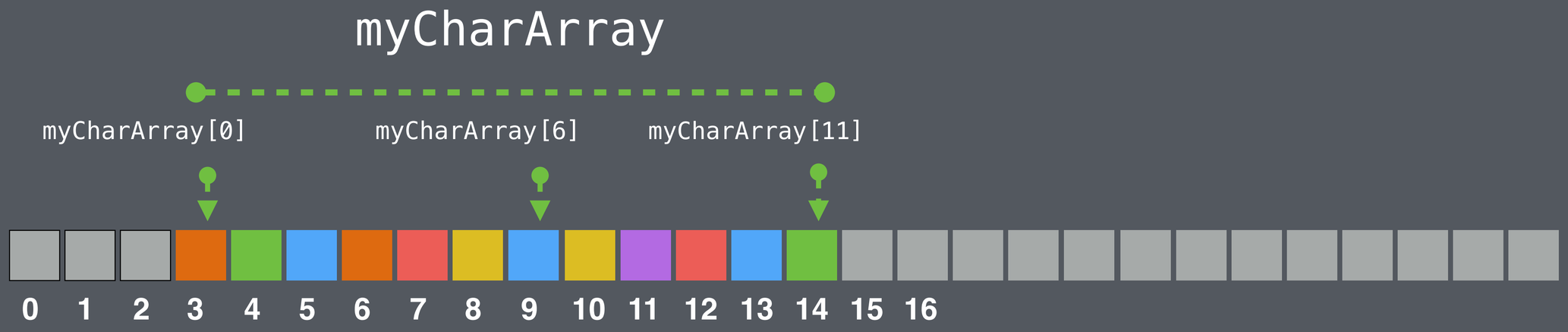


Image on the screen

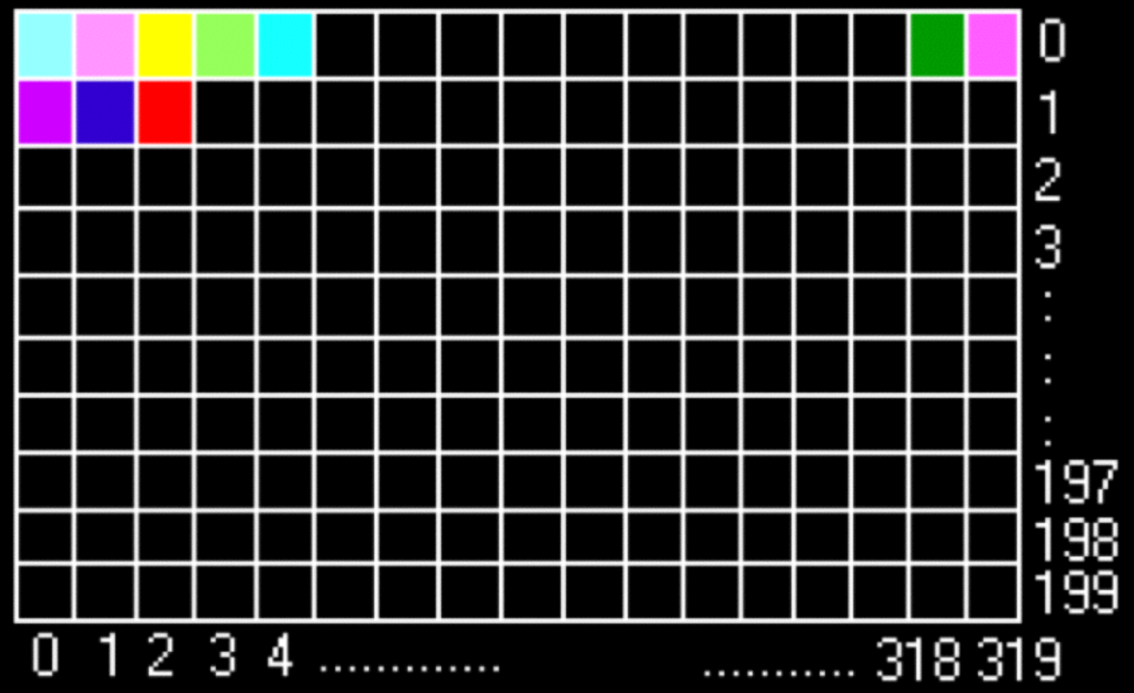
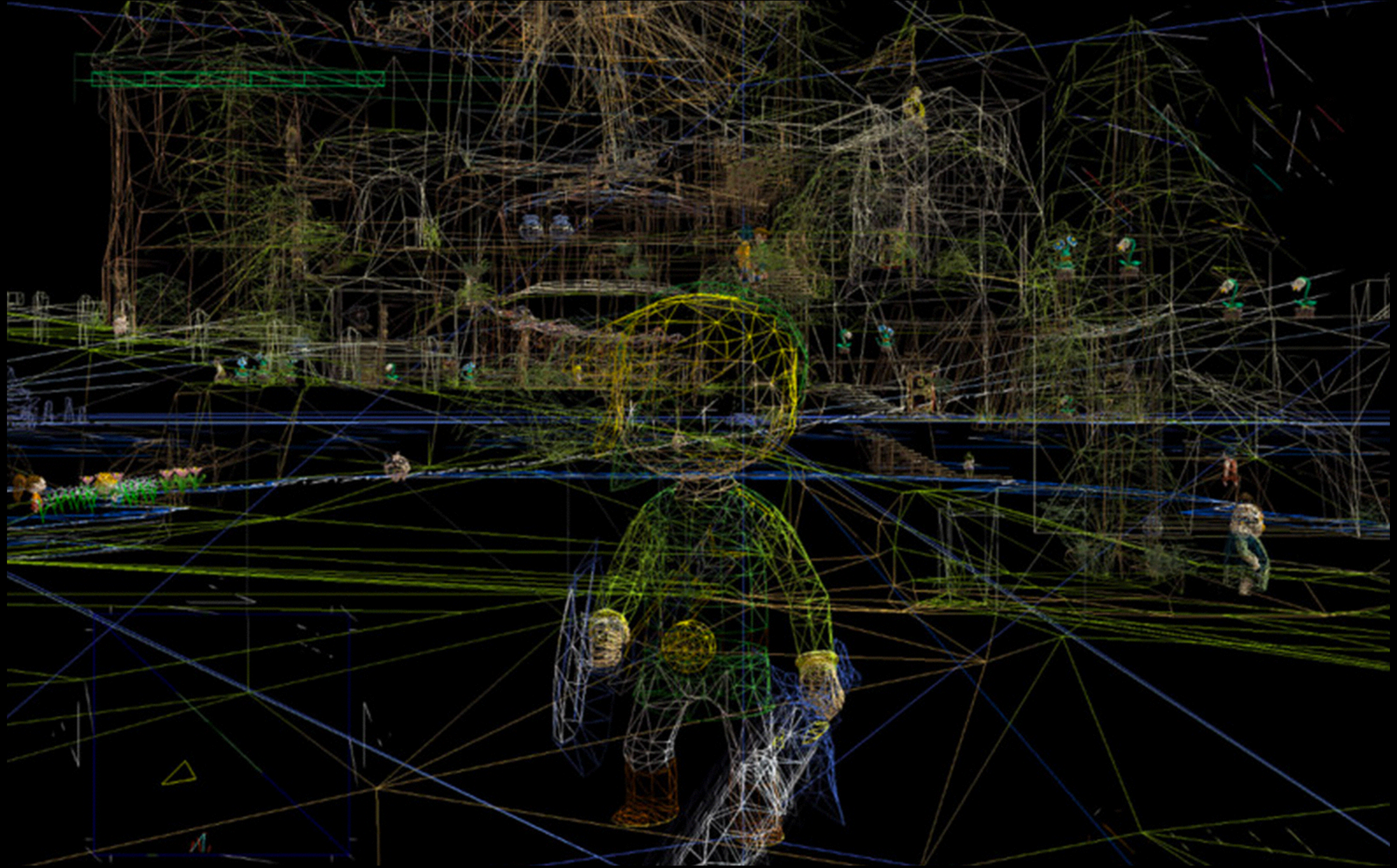
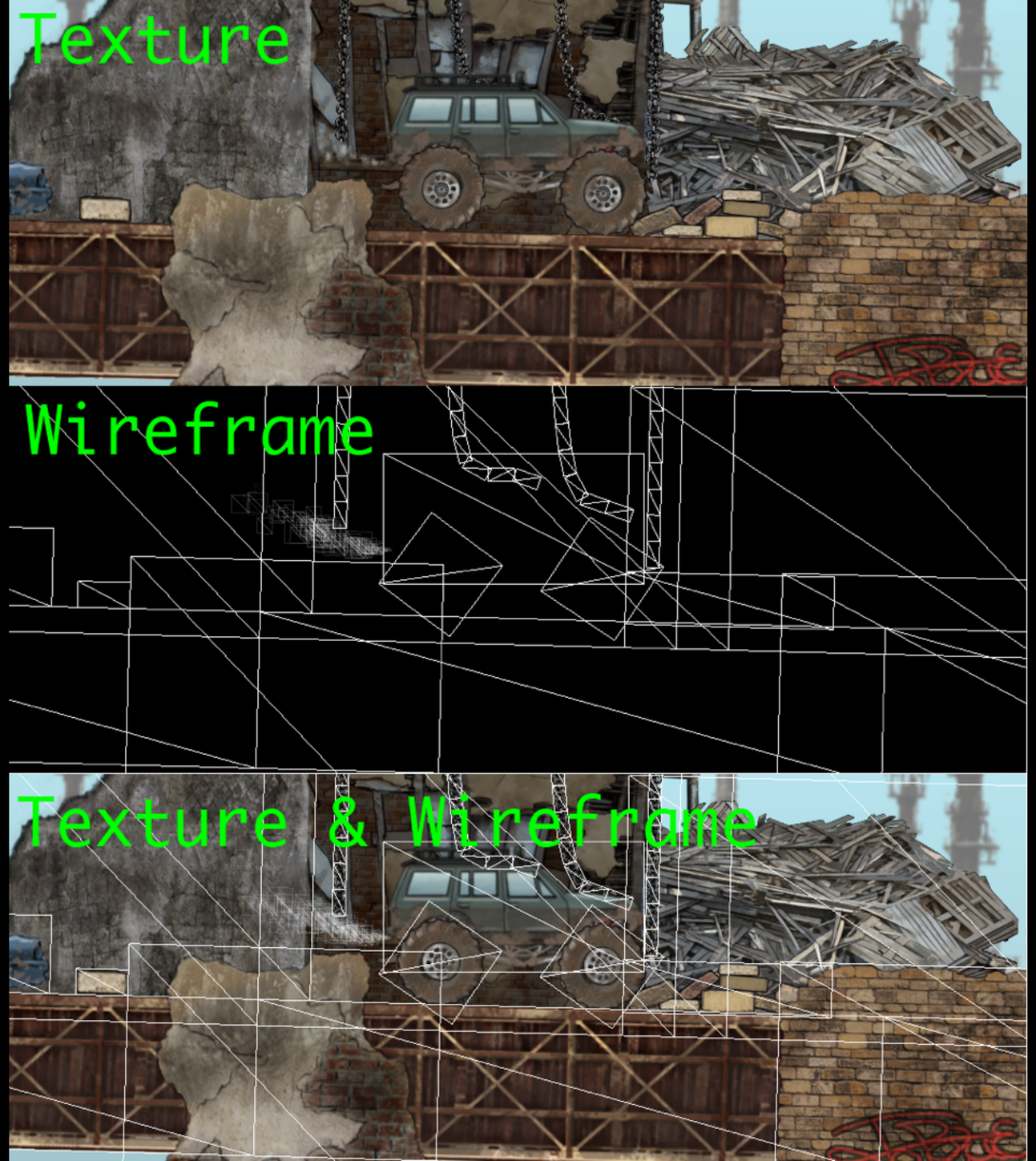


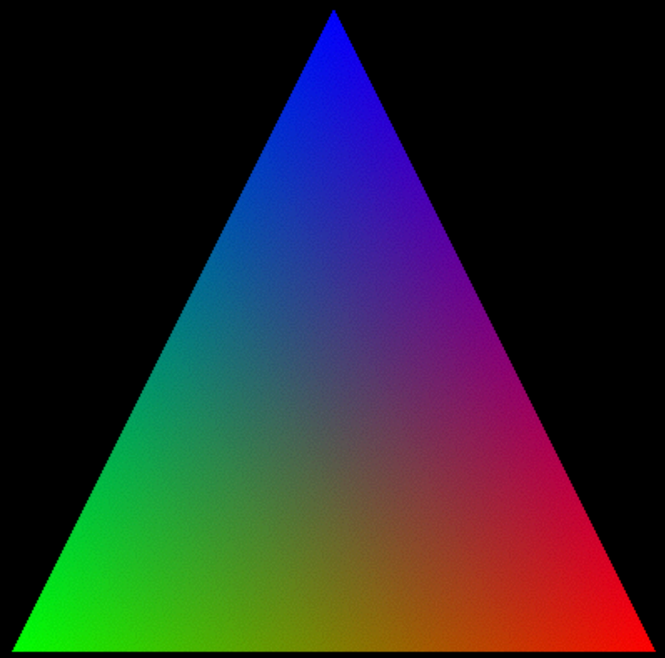
Image in memory

Graphics in games

Defend
Put Away
72
FREE
4168

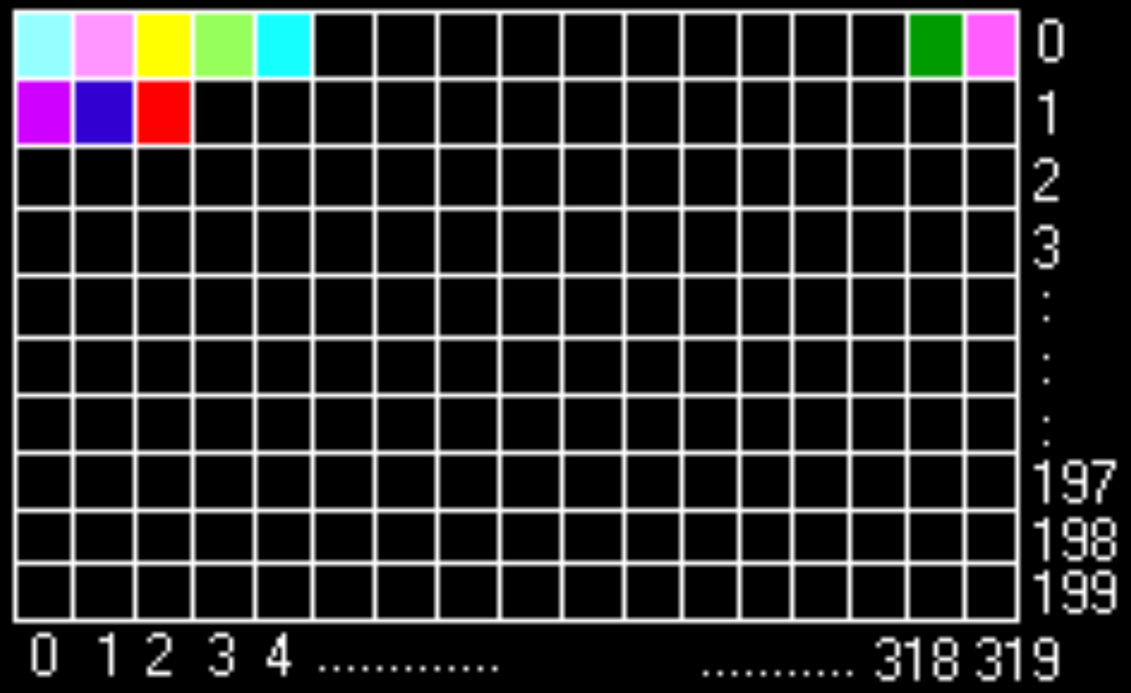



Texture
Wireframe
Texture & Wireframe



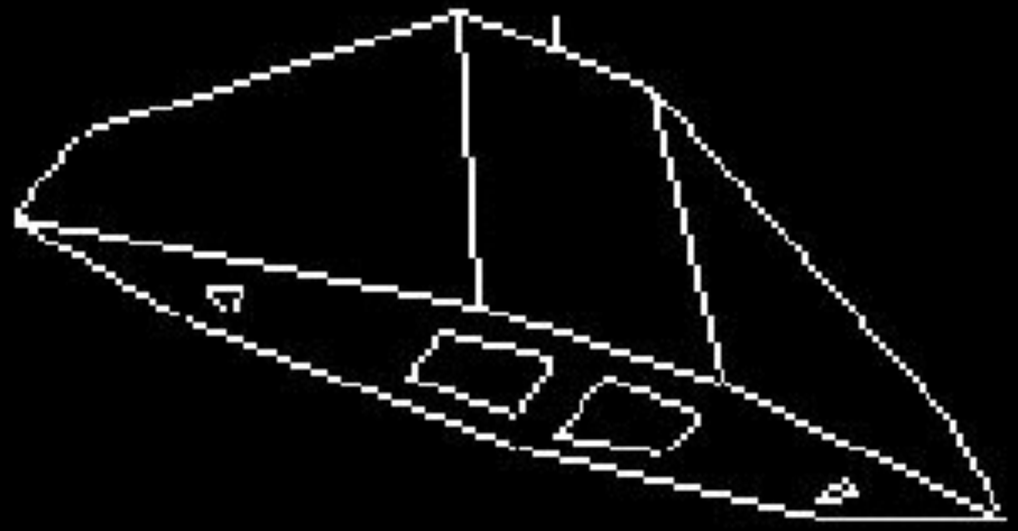
Why **triangles**?

The screen



The video memory

Software rendering



Load New Commander (Y/N)?

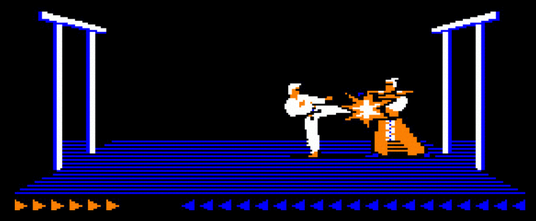
SPD: 0
VSI: 01.78
THR:90%
HDG:0
ALT:83

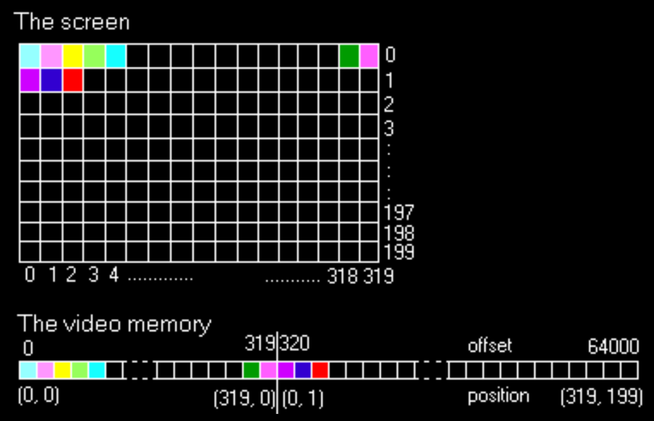
93
75
13
0
78
91
13

LEVEL UP
CHAR
QUESTS
MAP
MENU
1
2
3
4
5
6
7
8
RED STORM
TOTAL KILLS : 19
RESISTS : LIGHTNING
IMMUNE : MAGIC
INV
SPELLS

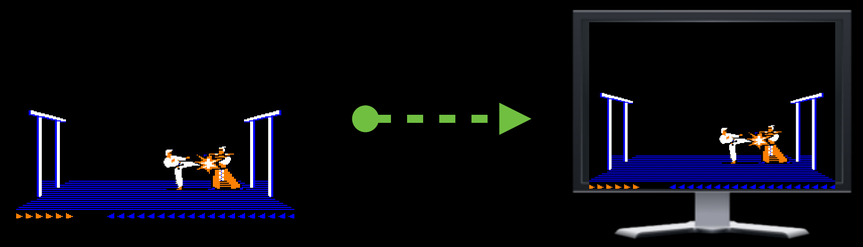
Software Rendering

RAM

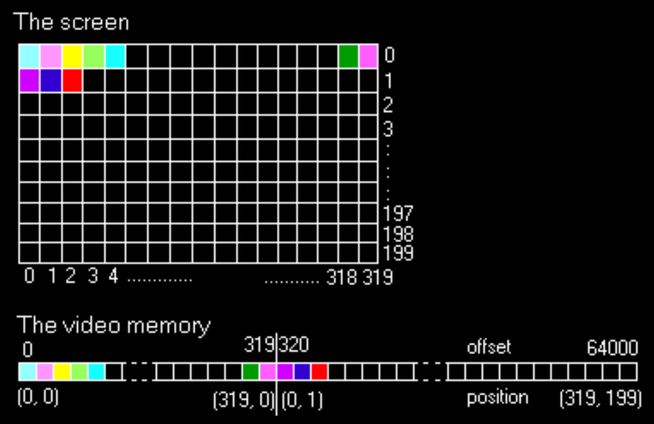




Video card



Software Rendering



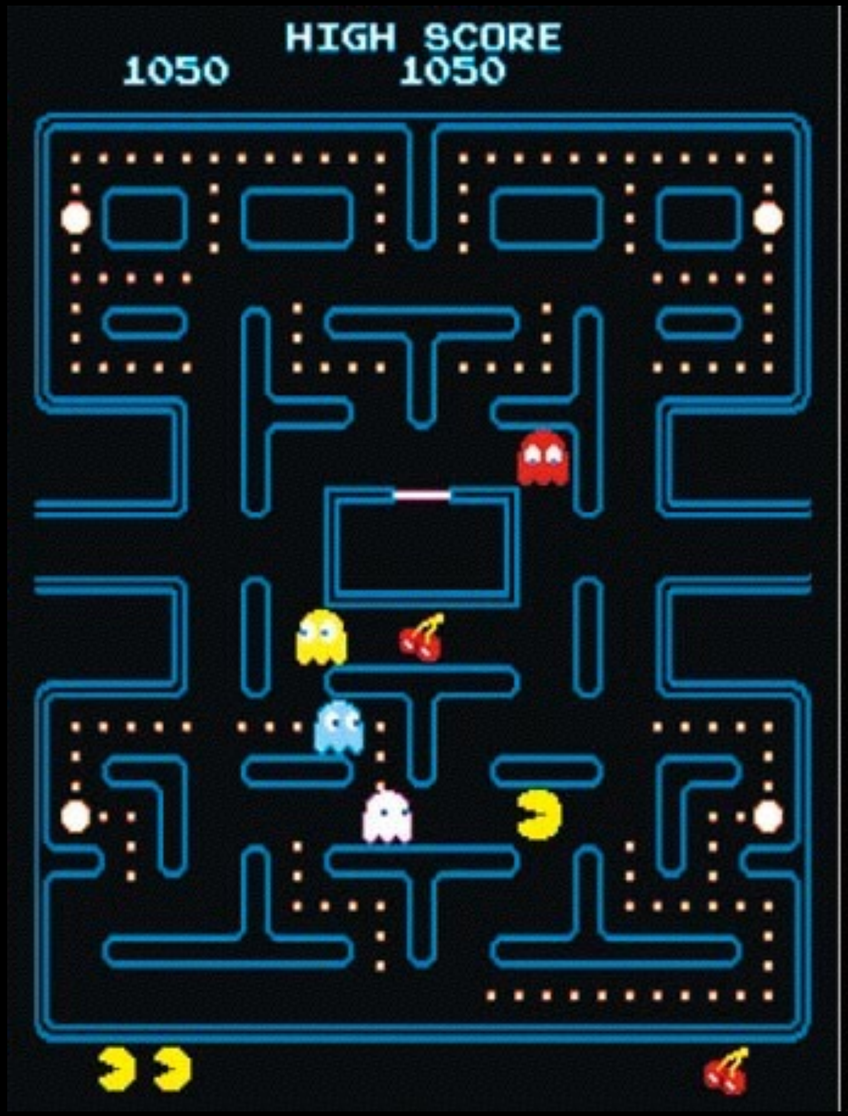
2560 * 1600 = **4,096,000** pixels

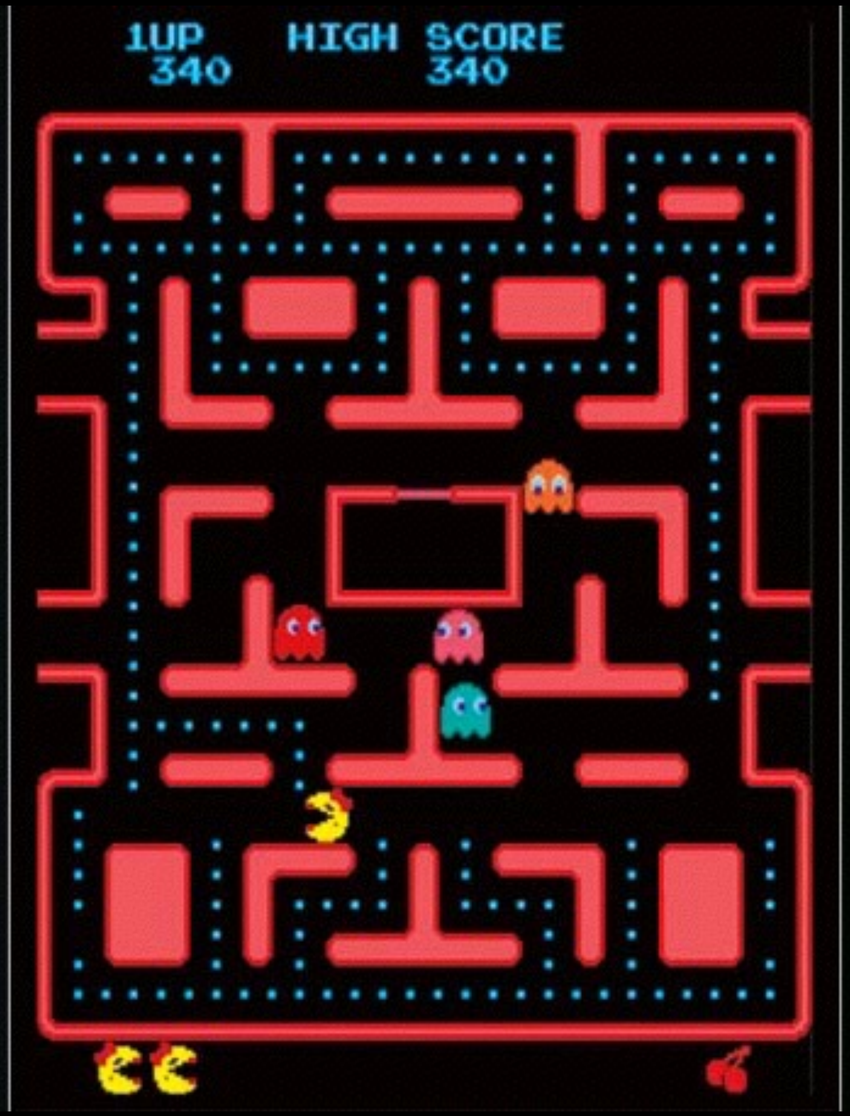
~12 MB== 4 * sizeof(**War and Peace**)

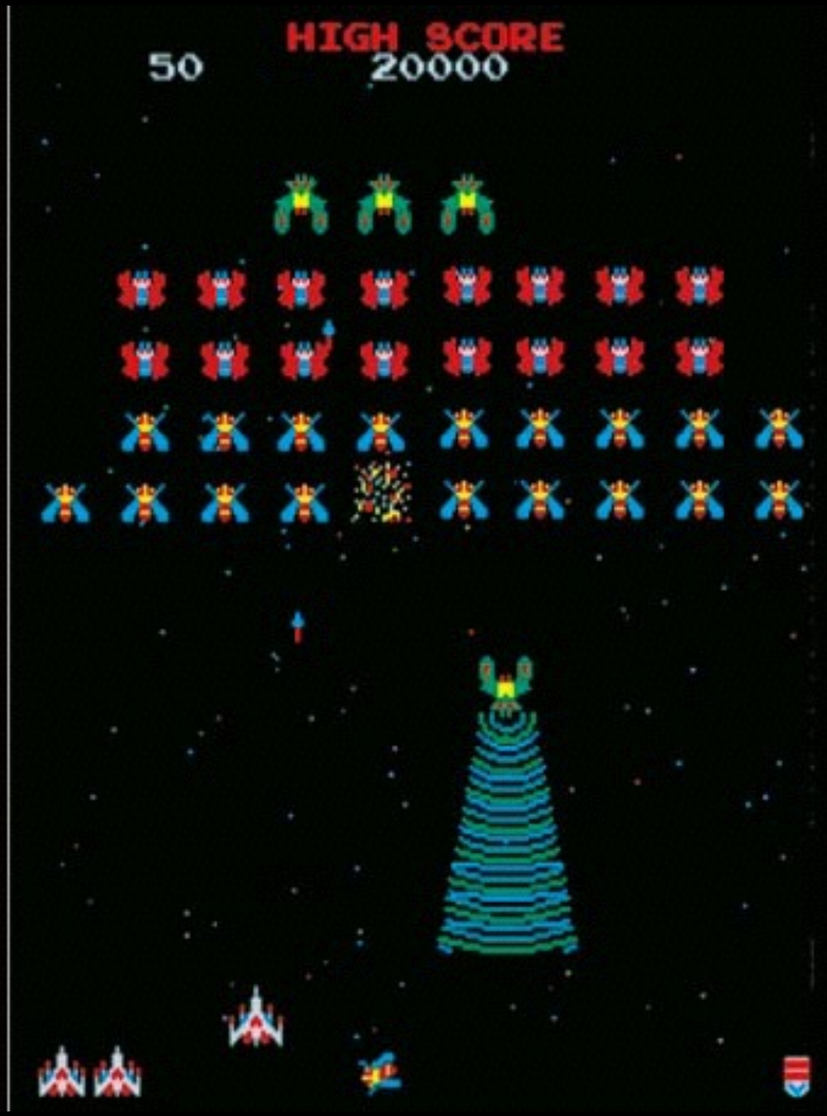
60 times a second

Hardware rendering

Galaga
DOUBLE
DONKEY KONG
Nintendo
Ms. PAC-MAN
MIDWAY
Bally
Home Theater of Arcades
PLEASE DO NOT START GAMES
25¢

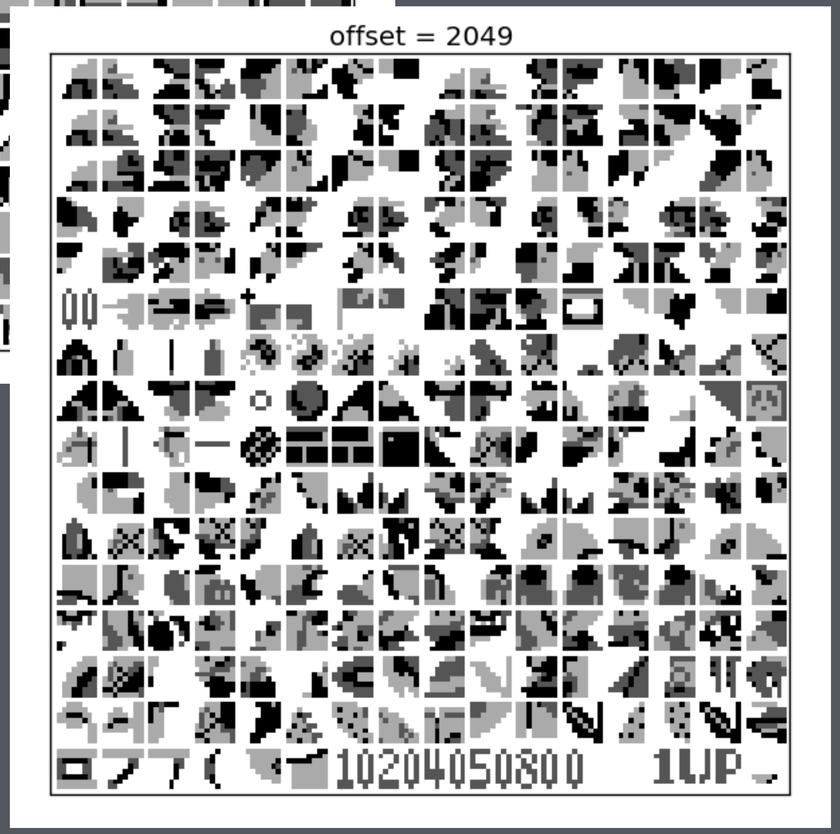

HIGH SCORE
1050
1050


1UP
340
HIGH SCORE
340

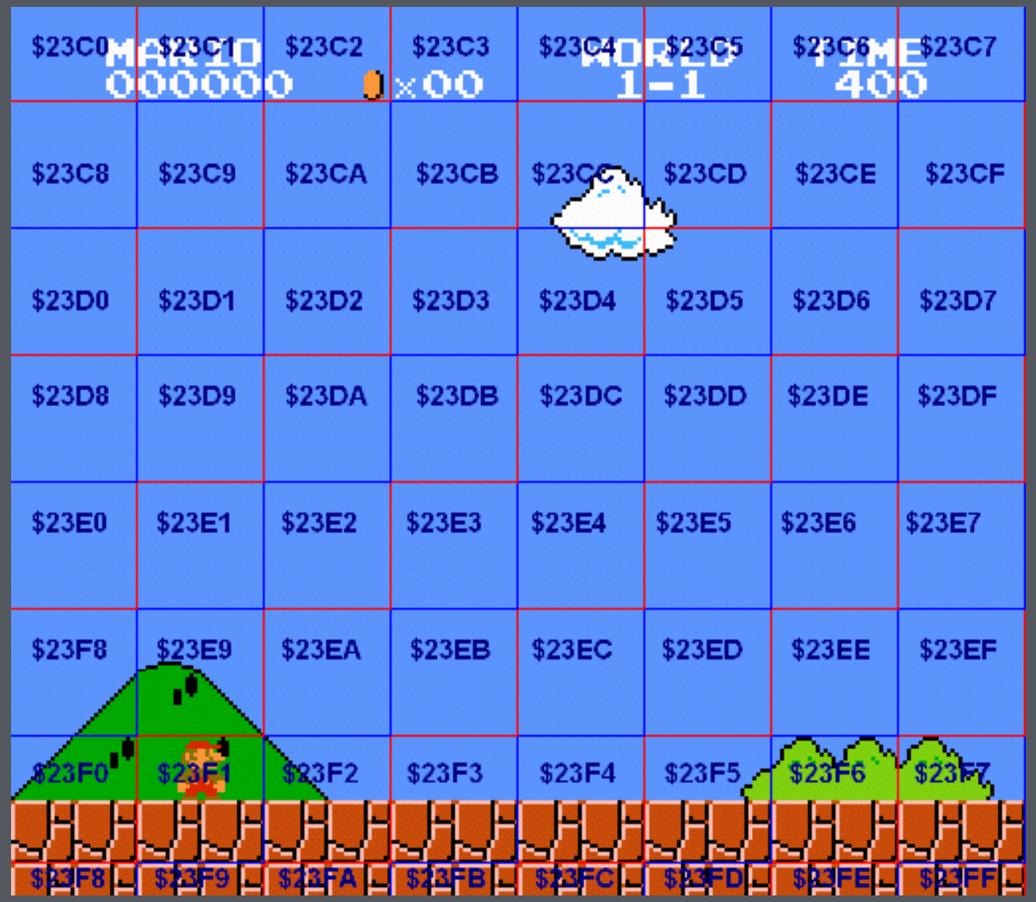

HIGH SCORE
50
20000

Nintendo
ENTERTAINMENT SYSTEM
POWER
RESET
SELECT START
Nintendo
B
A

MARIO
000000
×00
WORLD
1-1
TIME
SUPER
MARIO BROS.
©1985 NINTENDO
1 PLAYER GAME
2 PLAYER GAME
TOP- 000000



00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D	1E	1F
20	21	22	23	24	25	26	27	28	29	2A	2B	2C	2D	2E	2F
30	31	32	33	34	35	36	37	38	39	3A	3B	3C	3D	3E	3F



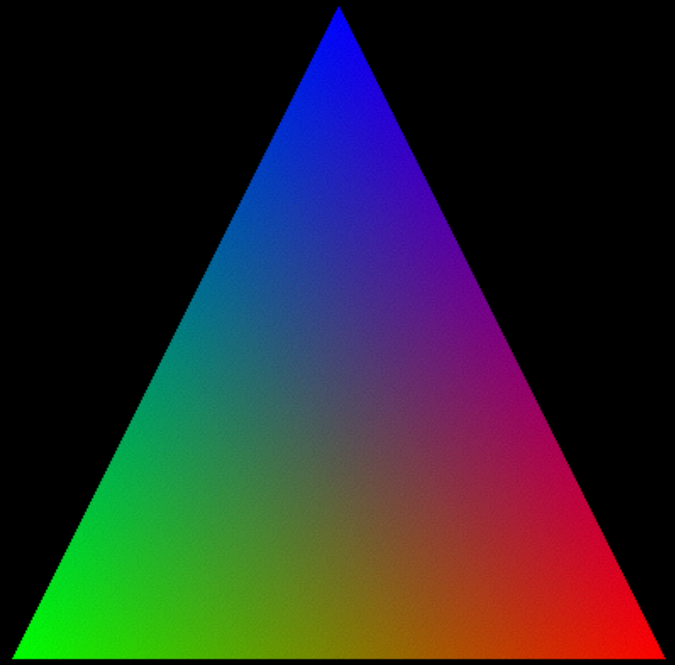
USA
RACE LEADER
RACE LEAD
50
2ND/2
1/4
50
1ST/2

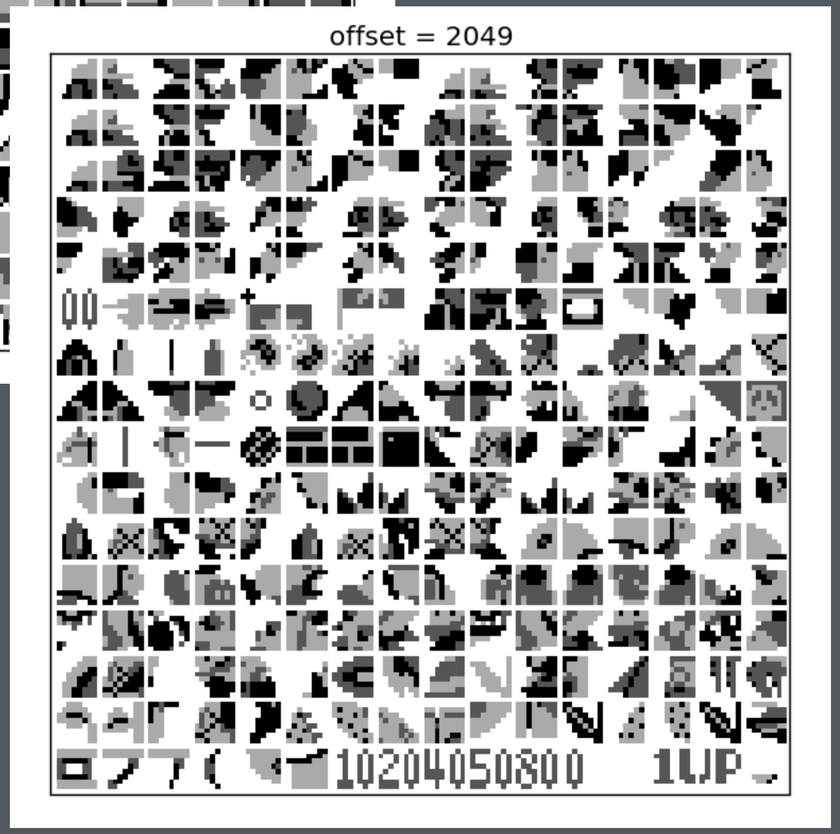
12MB
3D
BLASTER
Hardware XTRA AWARD
PC-Games 05/98
Hardware XTRA AWARD
PC-Action 05/98
PC Games Referenz
PC-Player 06/98
Voodoo 2
FASZINIERENDE SPIELE
4
FASZINIERENDE SPIELE
incoming
actua soccer 2
ULTIMATE RACE PRO
3Dfx
Get the Magic of Speed!
Basiert auf dem neuen Voodoo2 Graphics™-Chipsatz von 3Dfx Interactive™
Ausgestattet mit 12 MB Hochleistungsspeicher für stärkste Leistung
Bis zu 50 Milliarden Operationen und 3 Millionen Triangles pro Sekunde
Bis zu dreimal schnellere 3D-Verarbeitung als beim ursprünglichen Voodoo Graphics™-Chipsatz!
Arbeitet mit Ihrer vorhandenen Grafikkarte zusammen und bietet Ihnen das schnellste 3D-Spiel aller Zeiten
Enthält 4 topaktuelle Spiele
CREATIVE
WWW.SOUNDBLASTER.COM

freakygaming.com

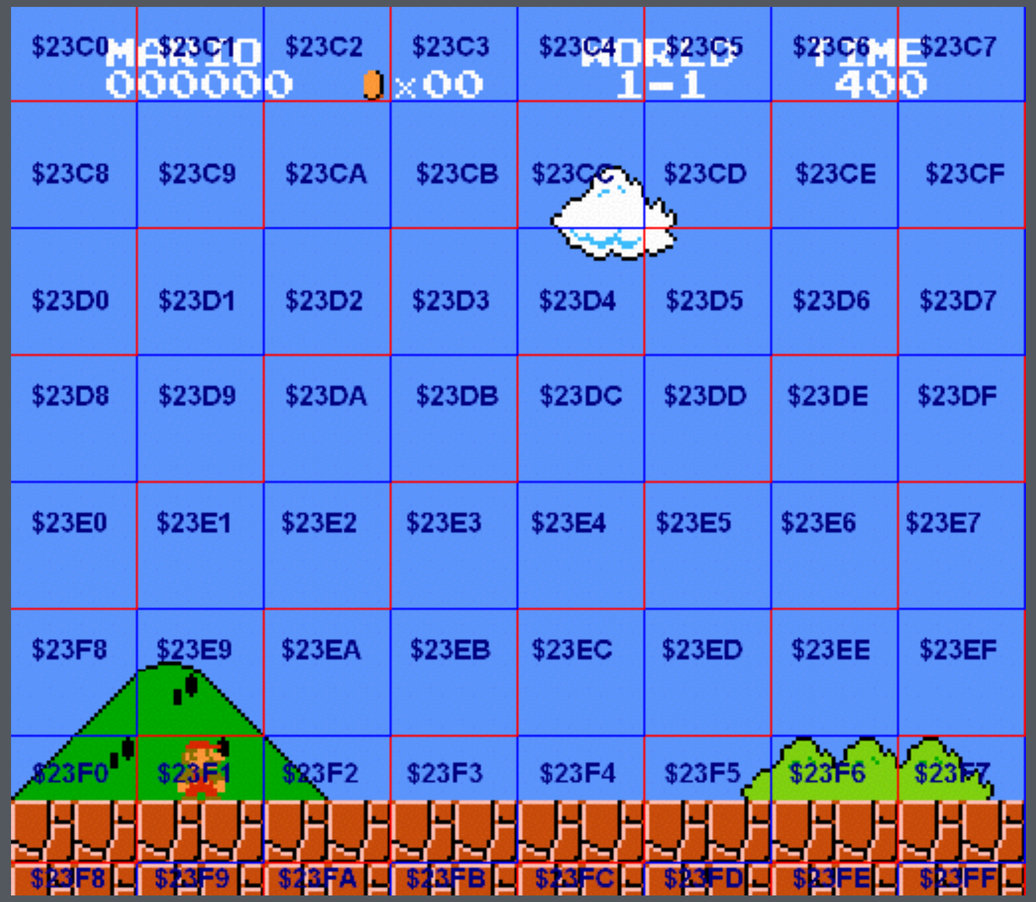
11
108
20
0
0

PARK
ONE W



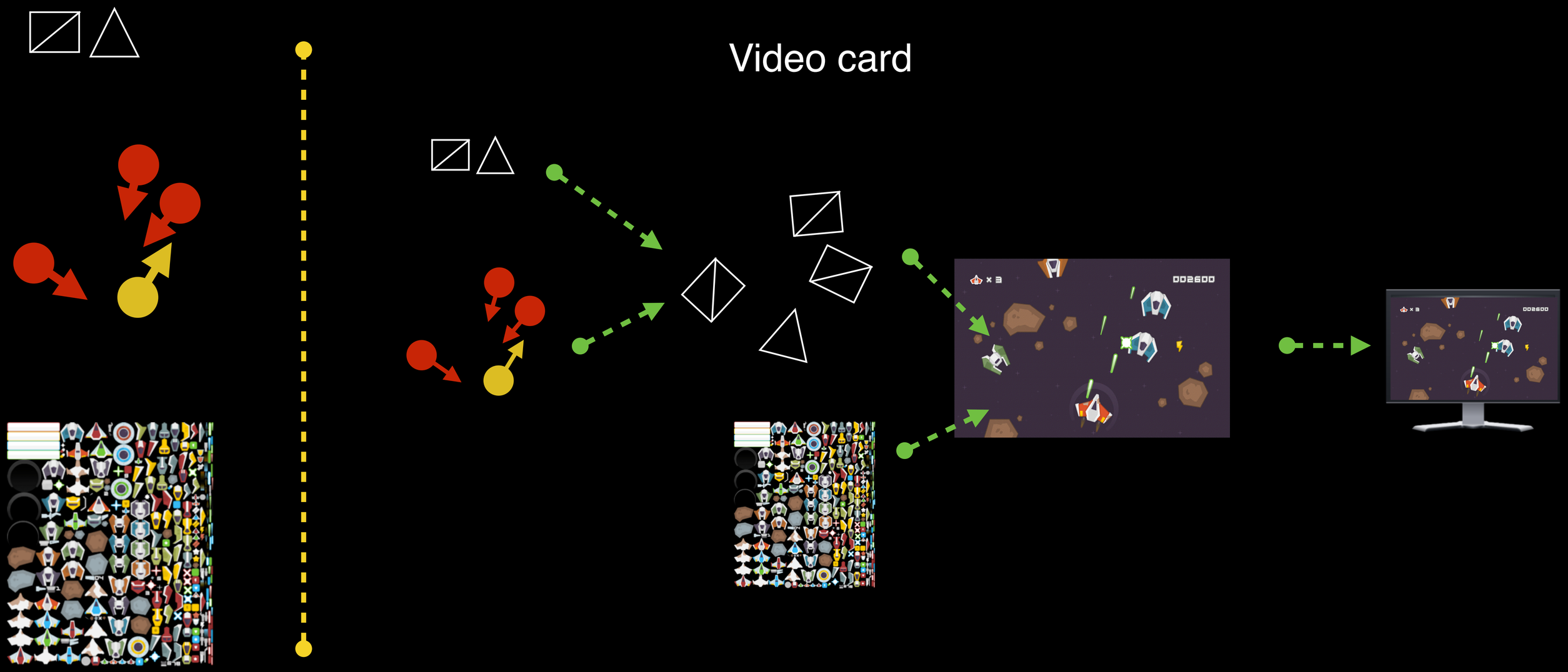


00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D	1E	1F
20	21	22	23	24	25	26	27	28	29	2A	2B	2C	2D	2E	2F
30	31	32	33	34	35	36	37	38	39	3A	3B	3C	3D	3E	3F



Hardware Rendering

Hardware Rendering



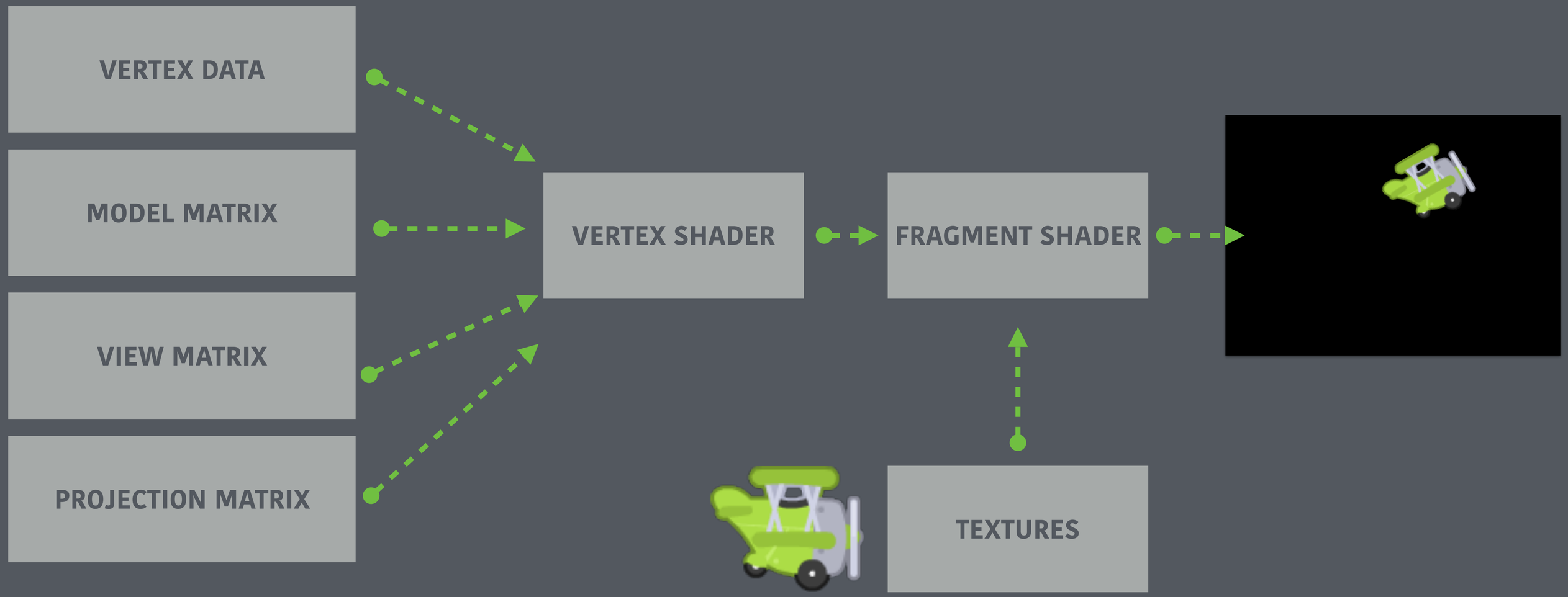
The **GPU** pipeline

What?

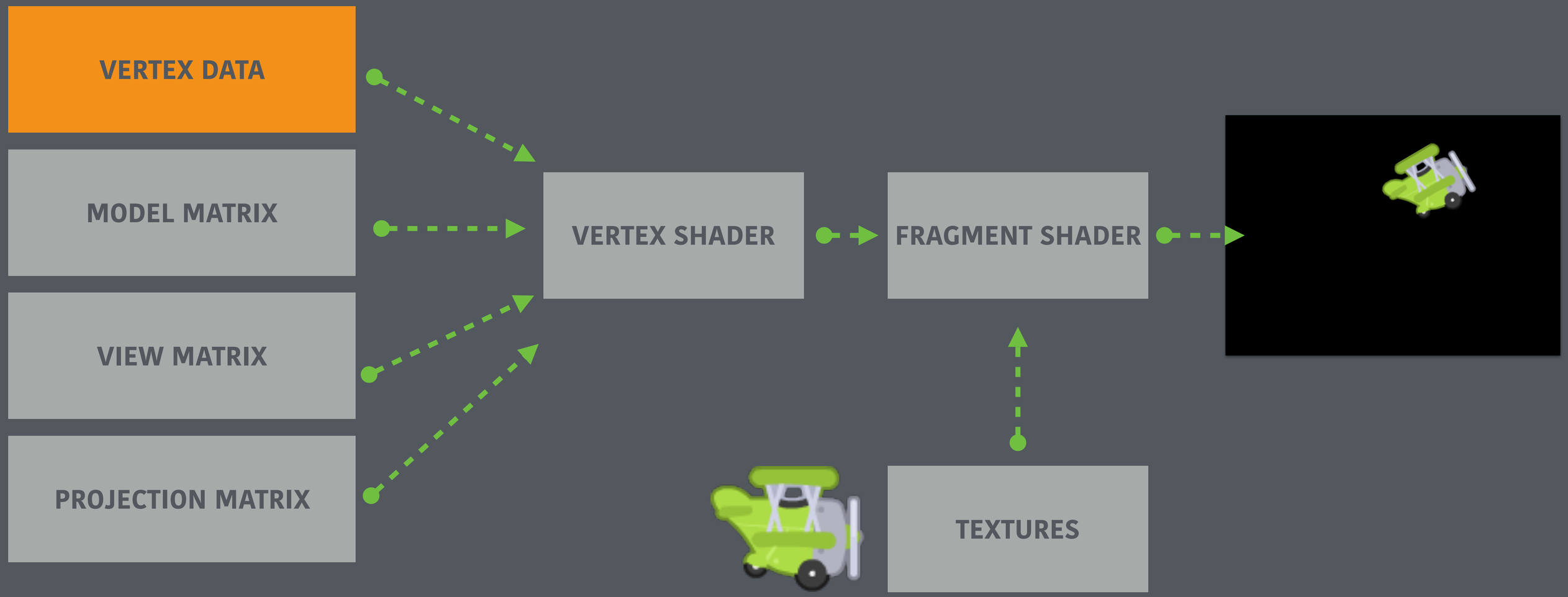
Where?

How?

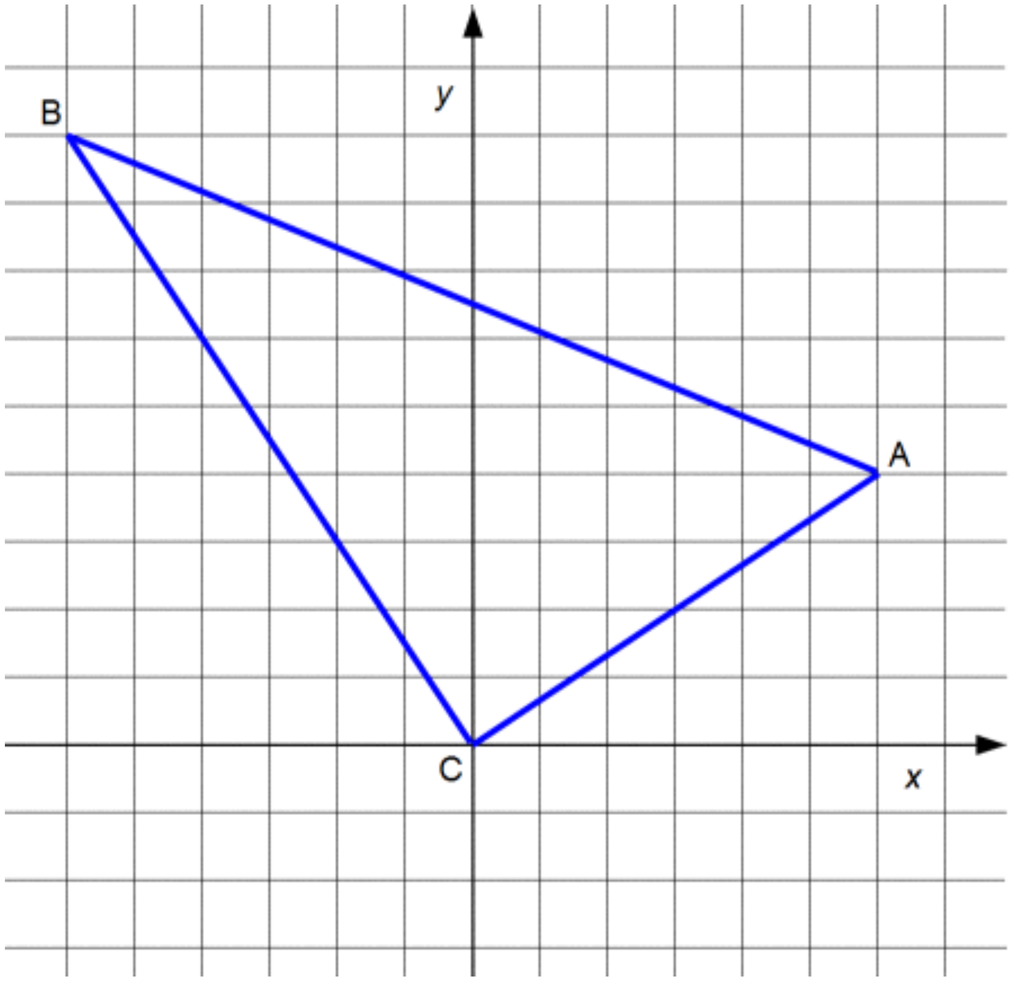
The **GPU** pipeline



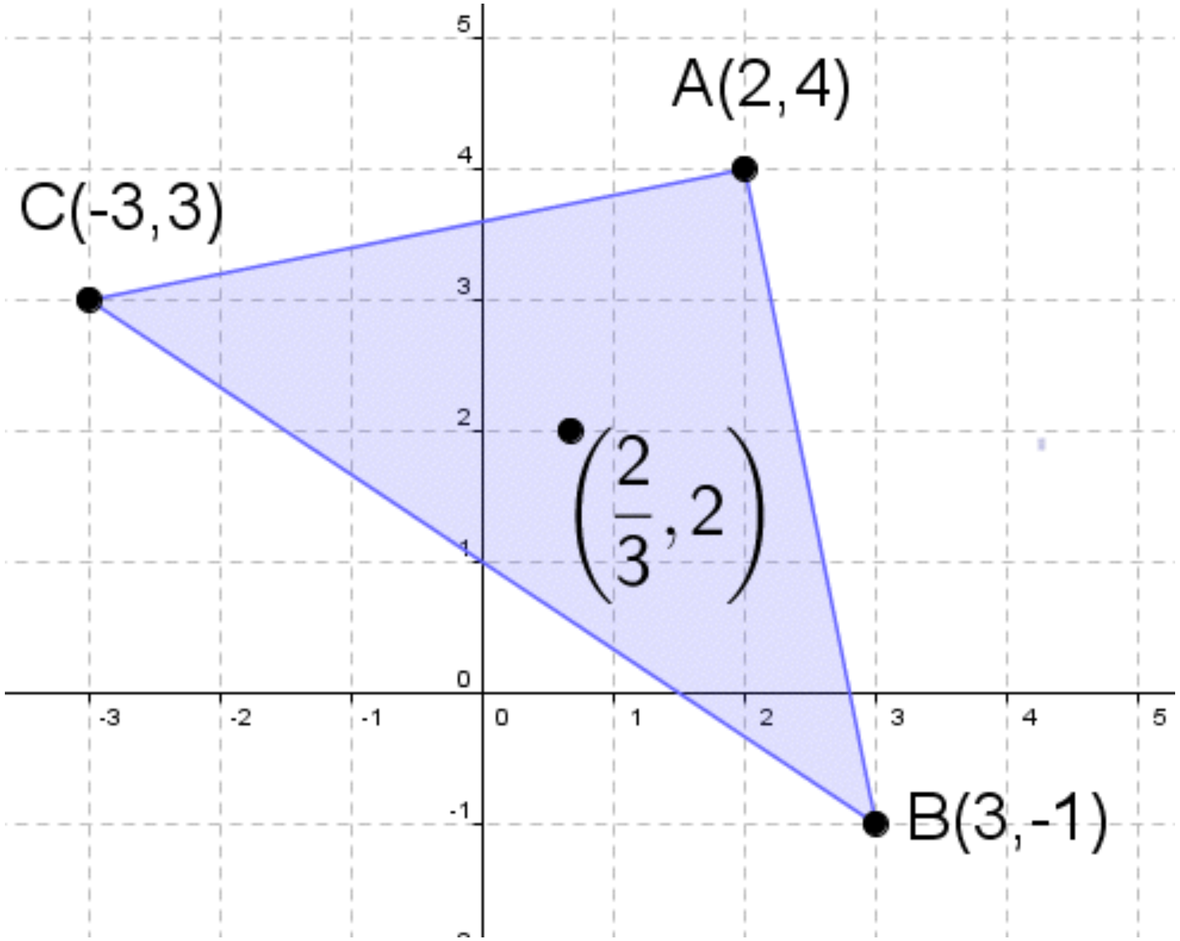
The **GPU** pipeline

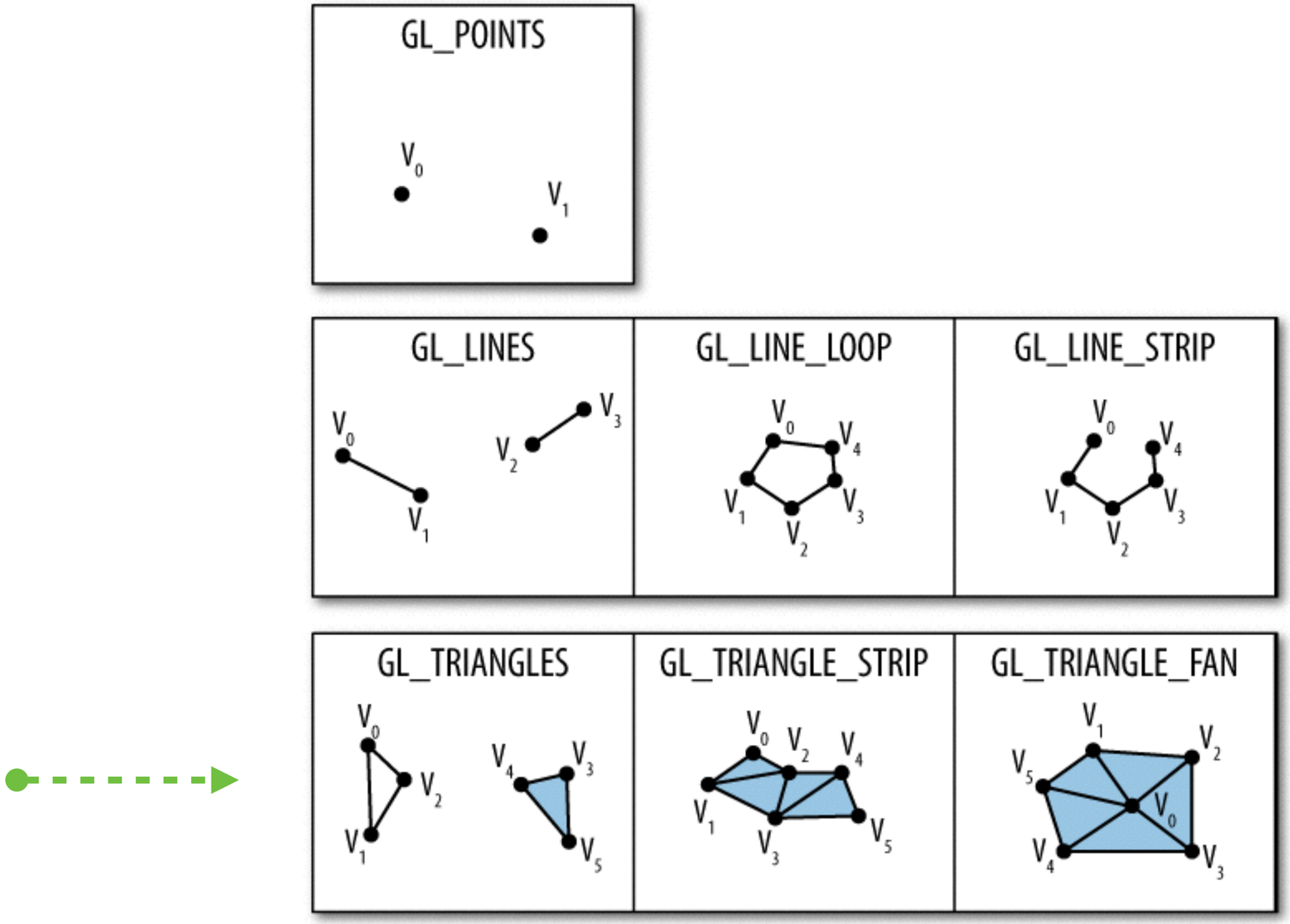


Vertex data

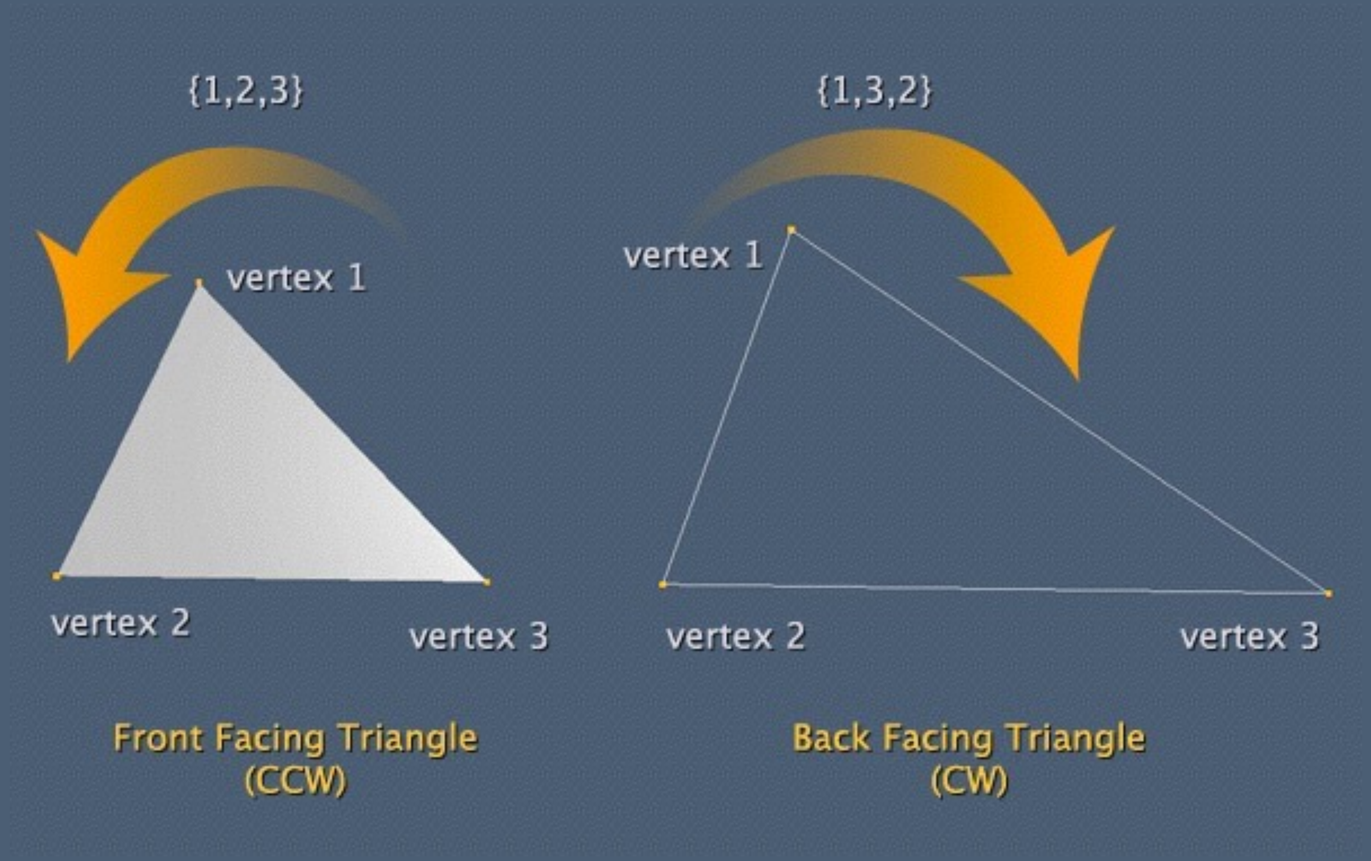

y
B
A
C
x

A **polygon** is defined by
points in space called **vertices**

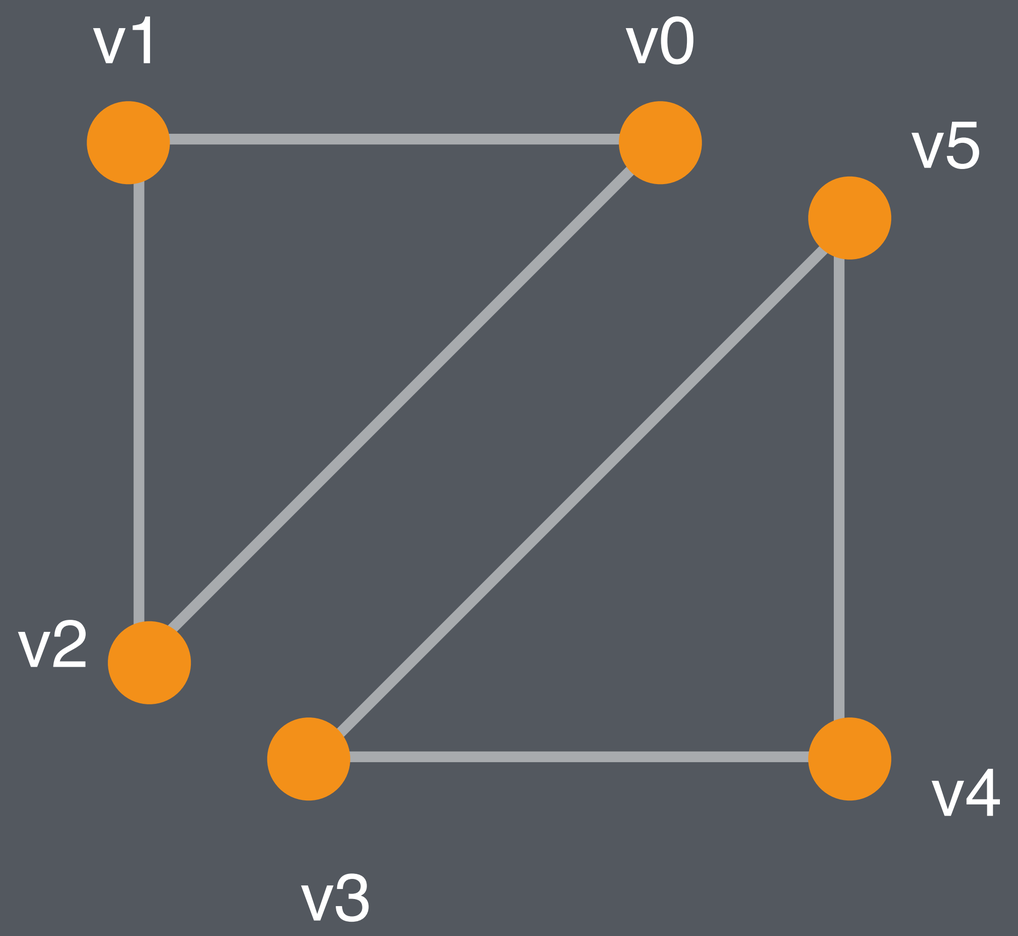

A(2,4)
C(-3,3)
$\left(\frac{2}{3},2\right)$
B(3,-1)
5
4
3
2
1
0
-1
-3
-2
-1
0
1
2
3
4
5

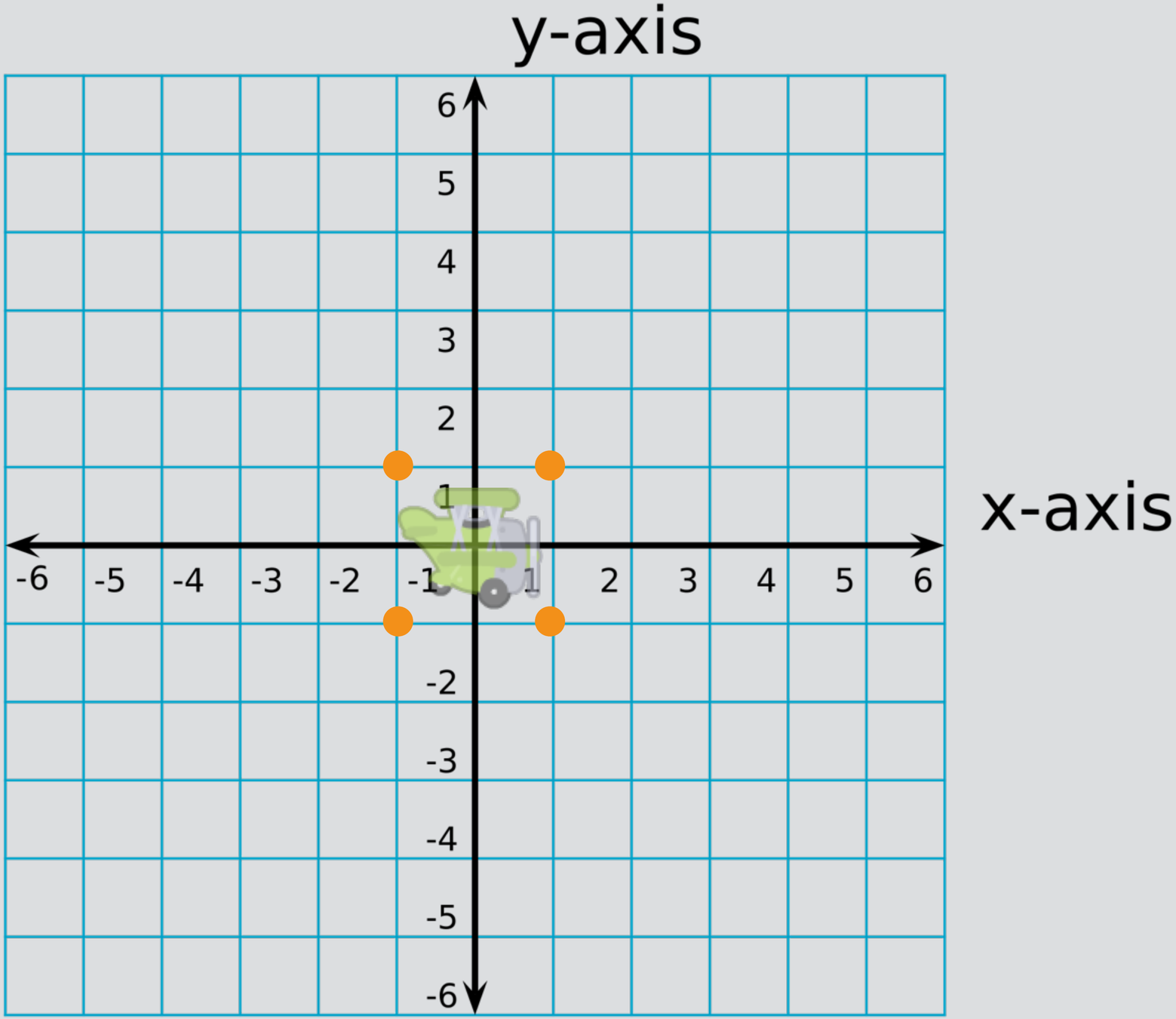

GL_POINTS
V0
V1
GL_LINES
V0
V1
V2
V3
GL_LINE_LOOP
V0
V1
V2
V3
V4
GL_LINE_STRIP
V0
V1
V2
V3
V4
GL_TRIANGLES
V0
V1
V2
V3
V4
V5
GL_TRIANGLE_STRIP
V0
V1
V2
V3
V4
V5
GL_TRIANGLE_FAN
V0
V1
V2
V3
V4
V5

Polygons are **one-sided** and the side is defined by the **order of the vertices**

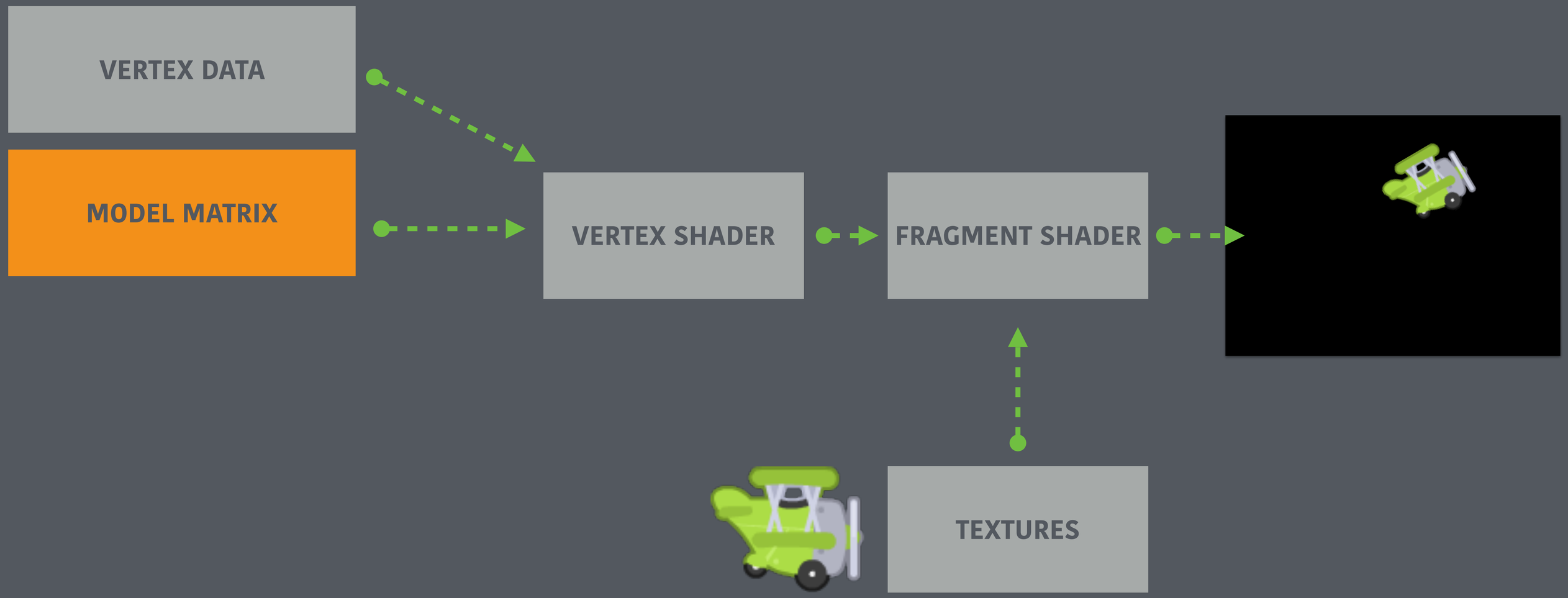


Counter-clockwise order!


v1
v0
v5
v2
v4
v3


y-axis
x-axis
6
5
4
3
2
1
-2
-3
-4
-5
-6
-6
-5
-4
-3
-2
-1
1
2
3
4
5
6

The **GPU** pipeline



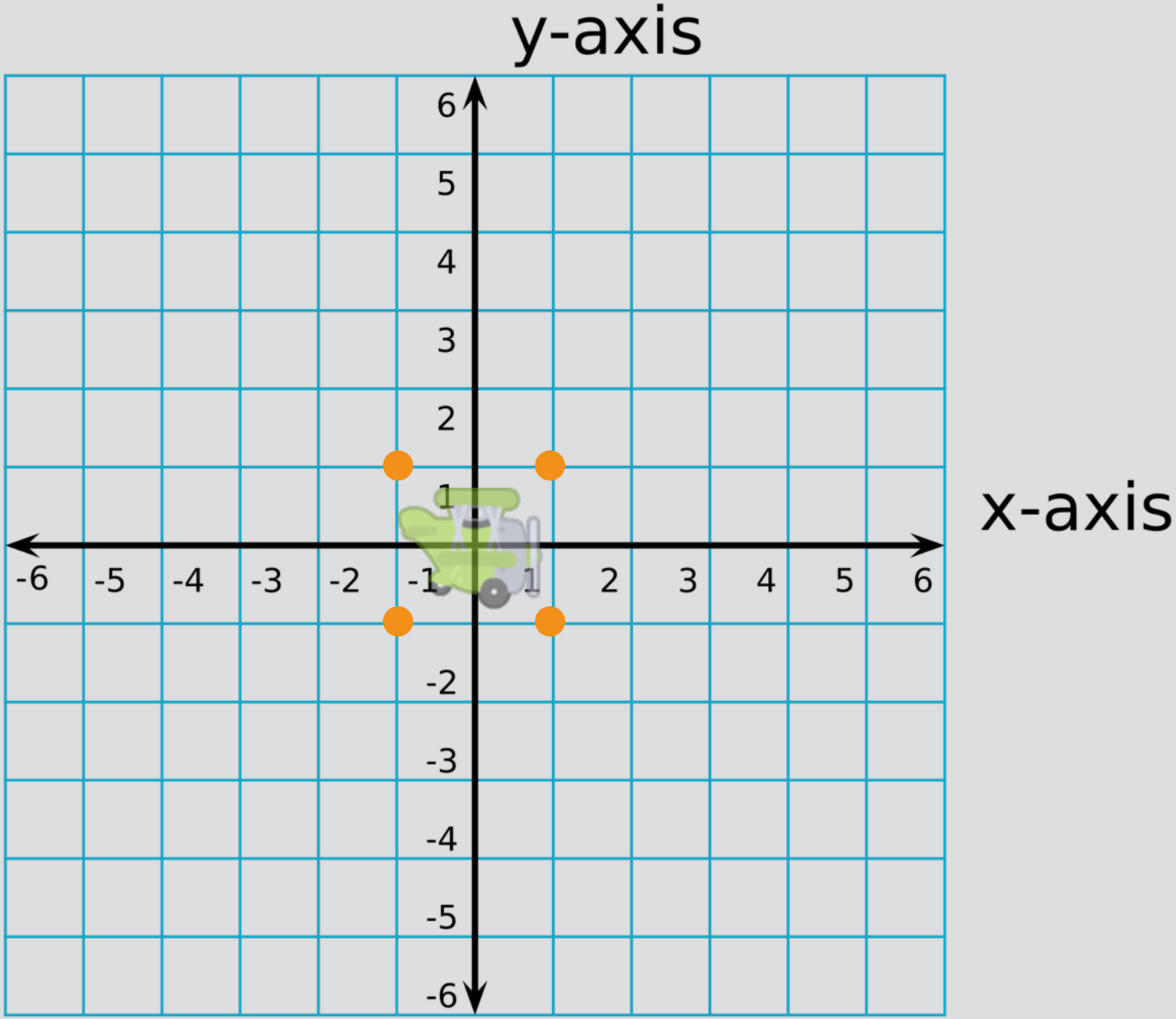
The **model** matrix

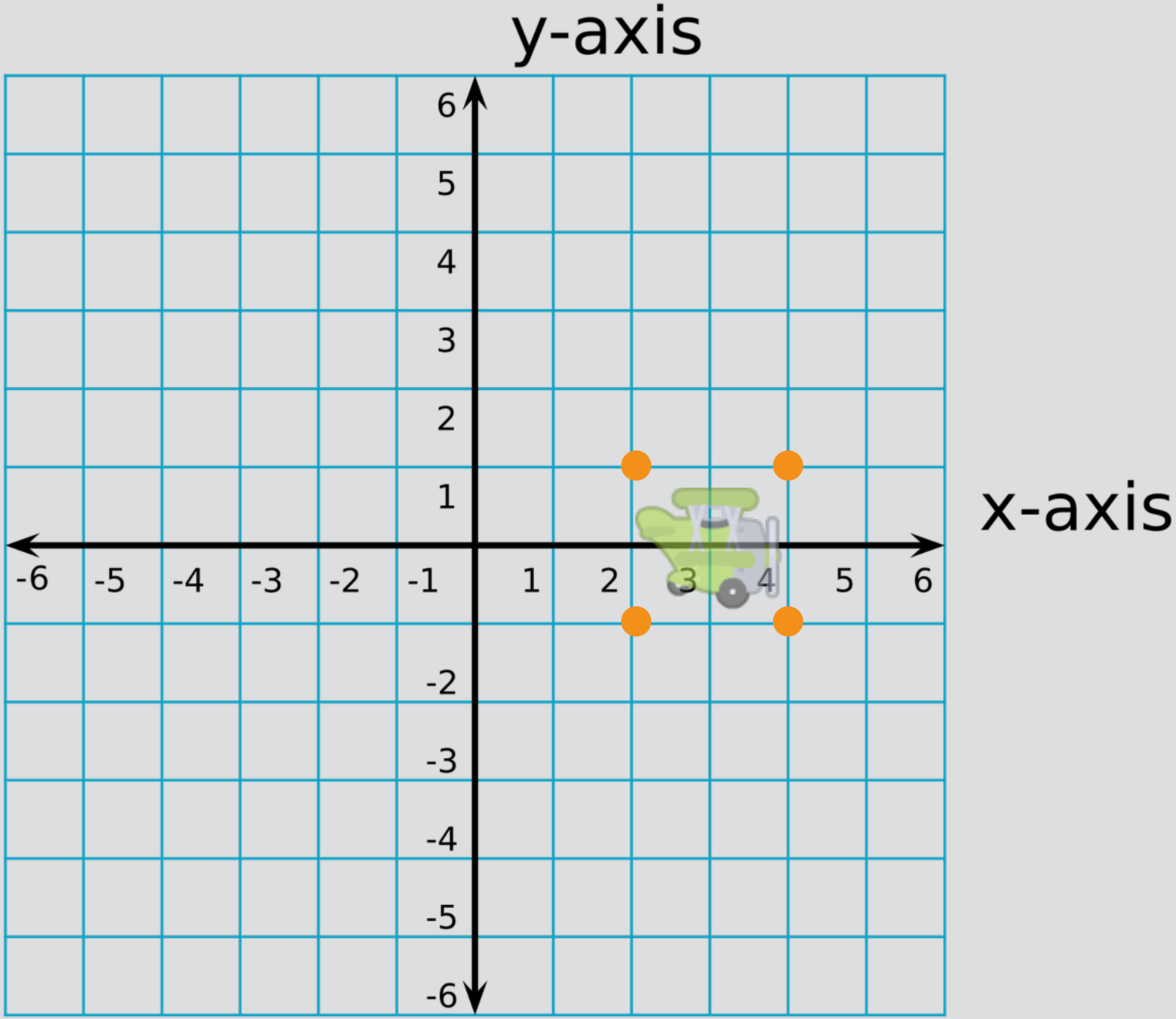
What is a **matrix**?

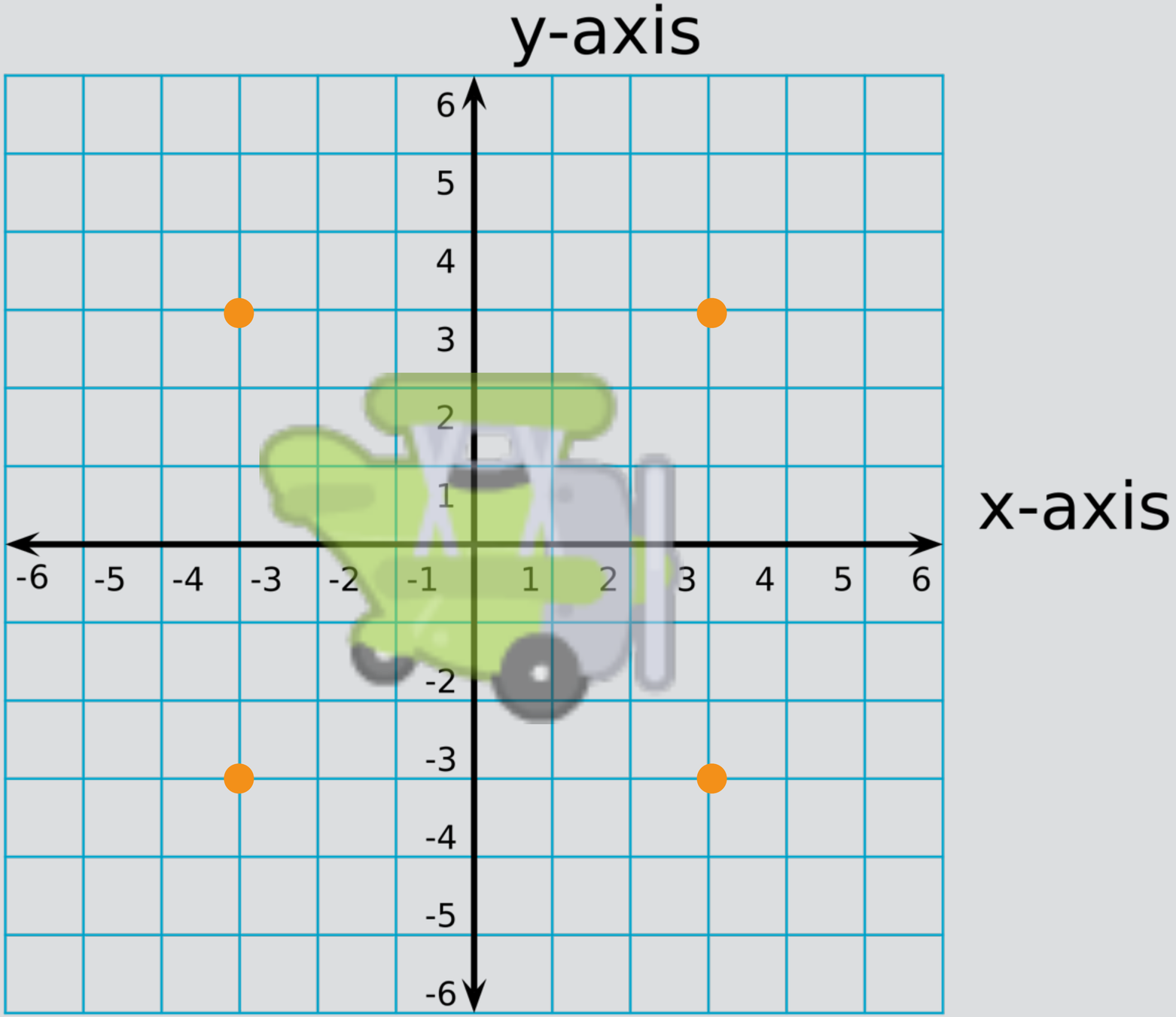
$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} ax + by + cz \\ dx + ey + fz \\ gx + hy + iz \end{bmatrix}$$

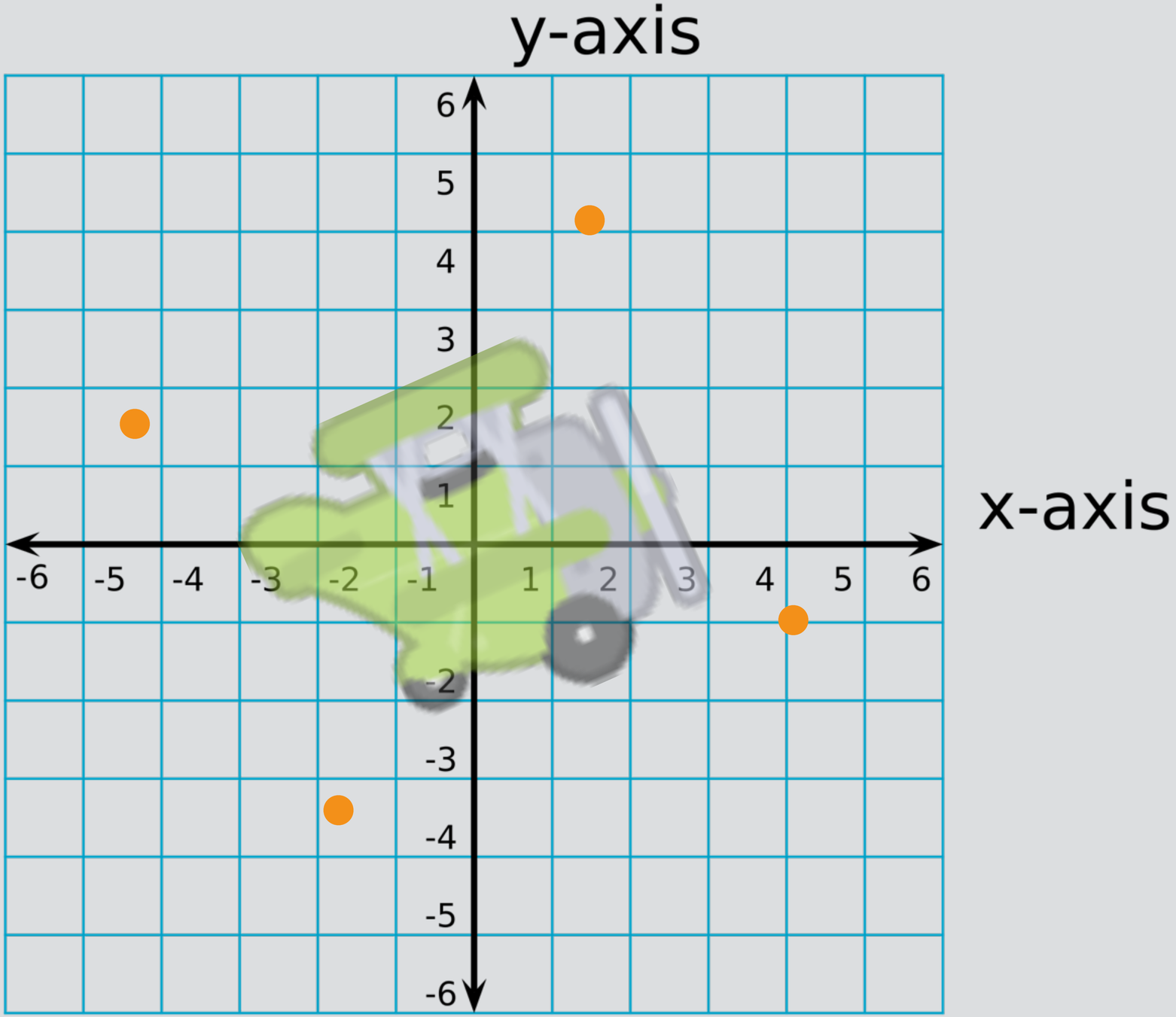
Transformation matrix

Represents a linear transformation in space (**move**, **rotate**, **scale**).


y-axis
x-axis
6
5
4
3
2
1
-2
-3
-4
-5
-6
-6
-5
-4
-3
-2
-1
1
2
3
4
5
6


y-axis
x-axis
6
5
4
3
2
1
-2
-3
-4
-5
-6
-6
-5
-4
-3
-2
-1
1
2
3
4
5
6


y-axis
x-axis
6
5
4
3
2
1
-2
-3
-4
-5
-6
-6
-5
-4
-3
-2
-1
1
2
3
4
5
6


y-axis
x-axis
6
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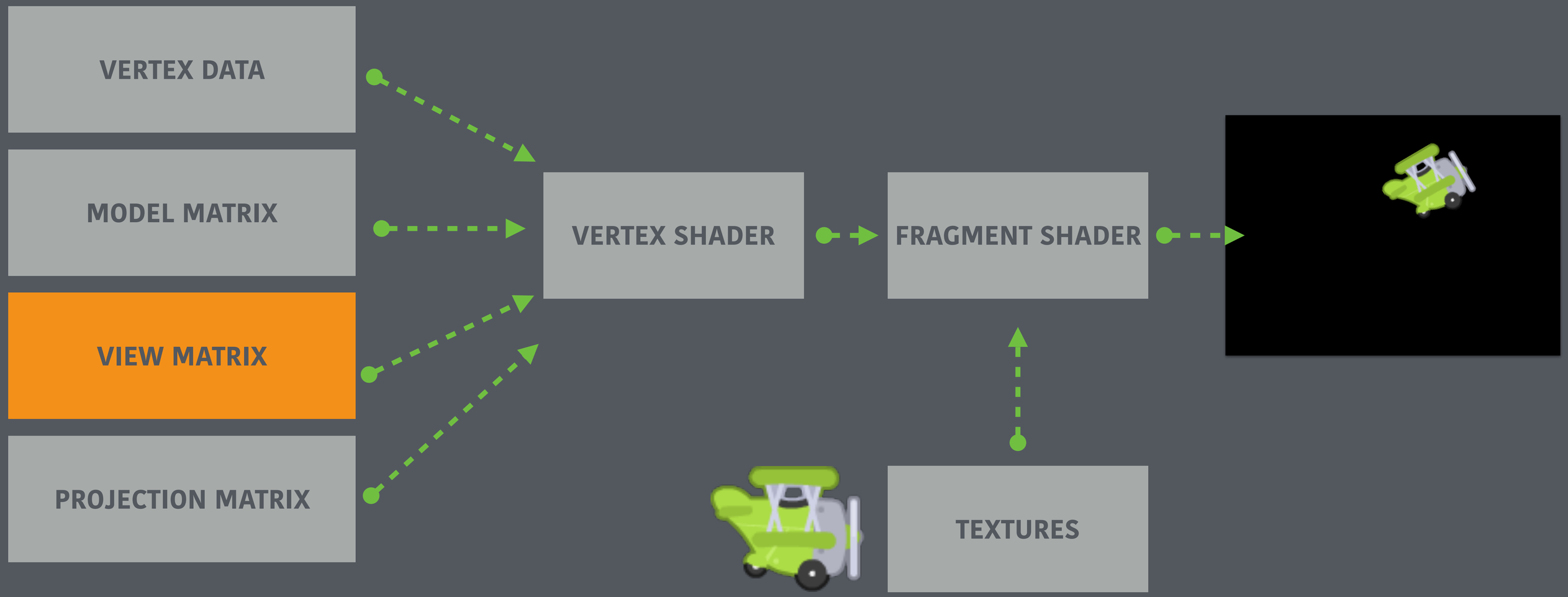
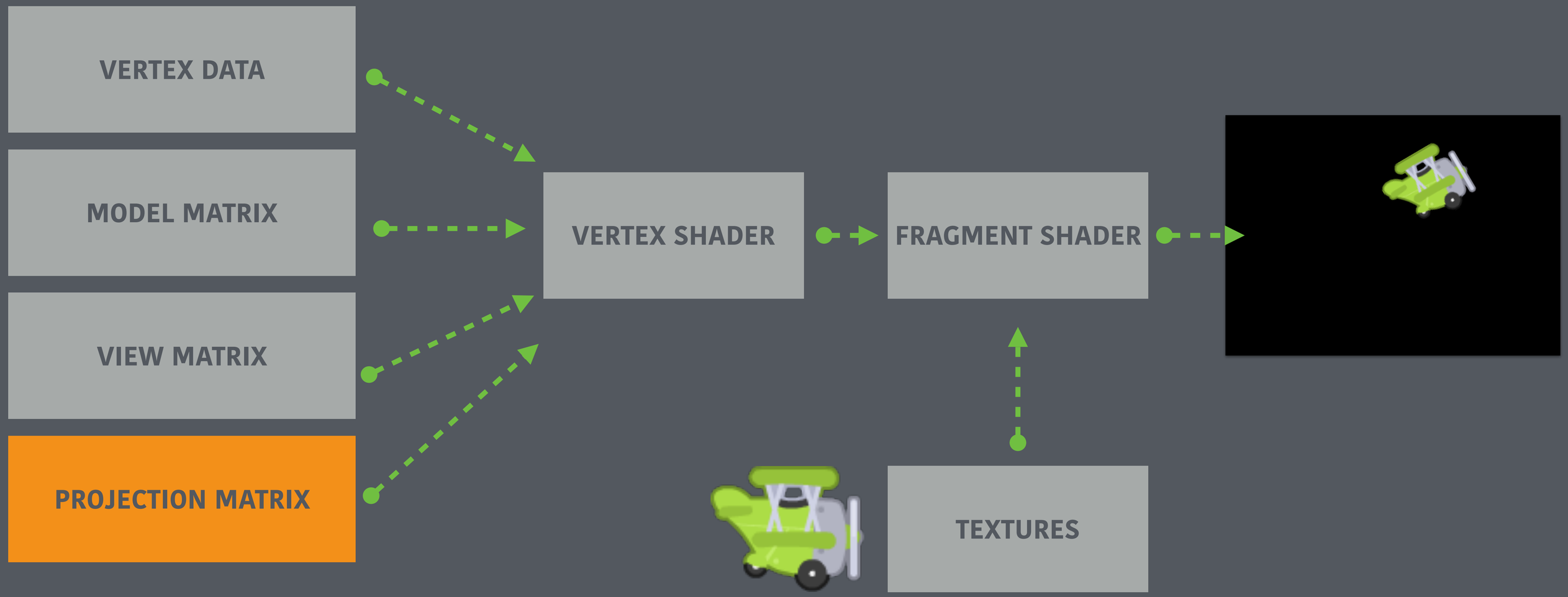
The **model** matrix is a **TRANSFORMATION MATRIX**
that defines the **transform** of each object you draw

The **GPU** pipeline



View matrix

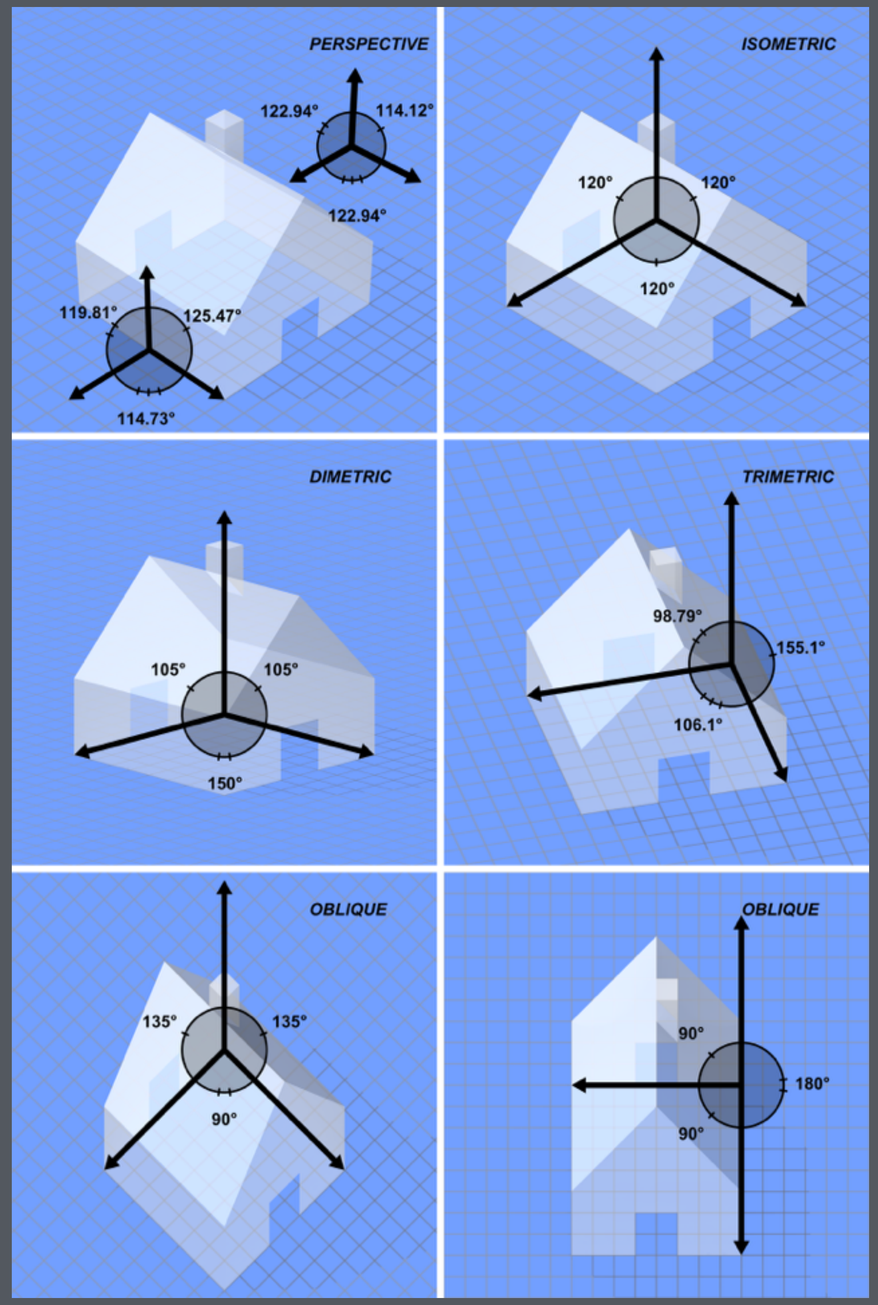
The **GPU** pipeline



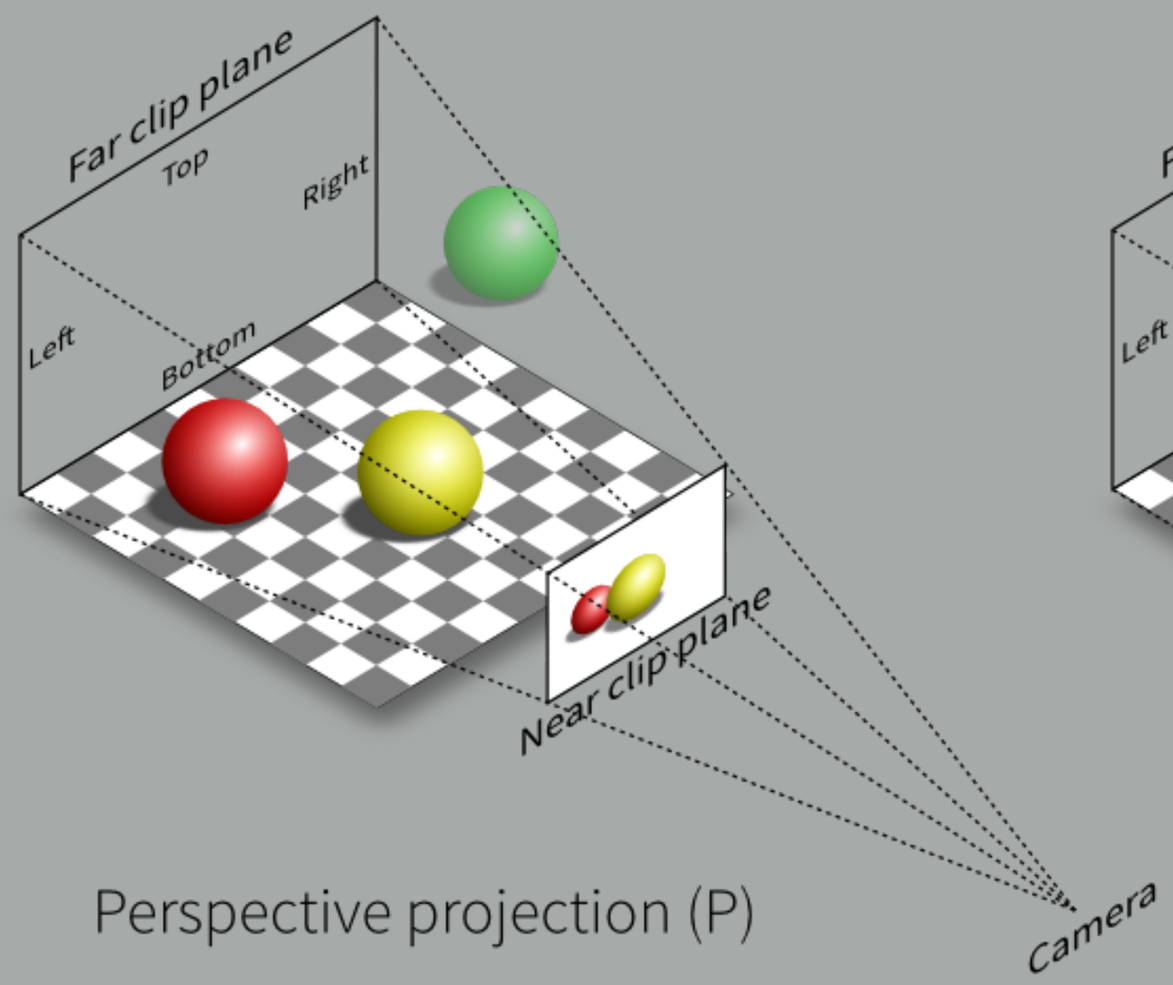
Projection matrix

What is **projection**?

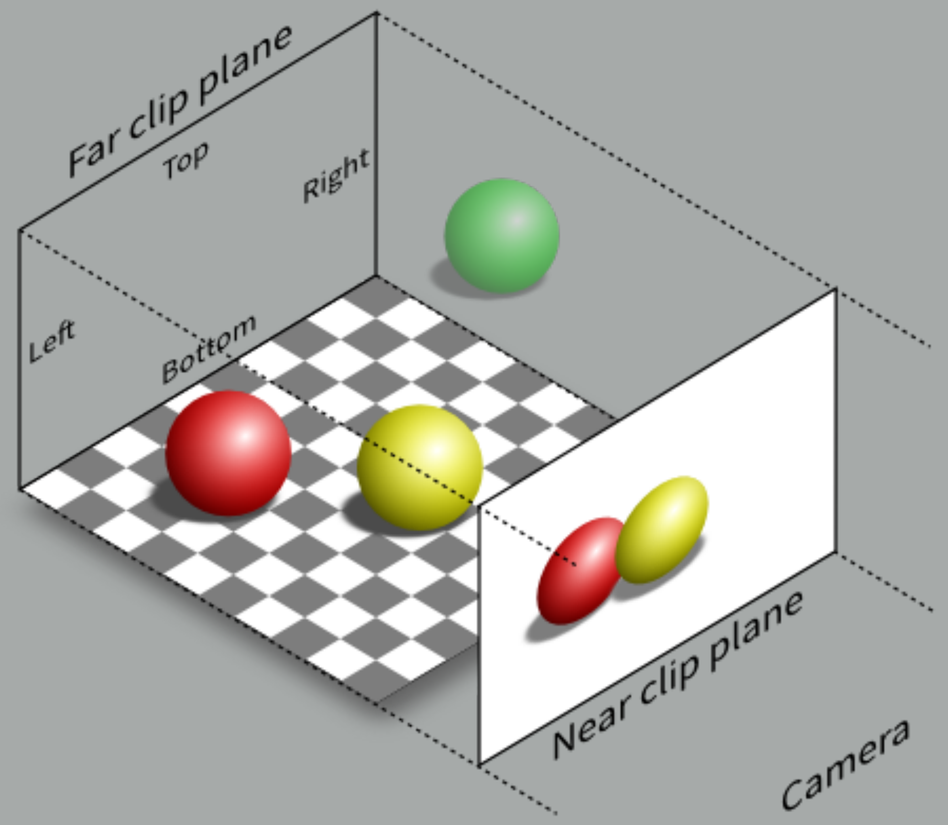
A means of representing a **three-dimensional** object in **two-dimensions**.



Perspective vs. **Orthographic** projection

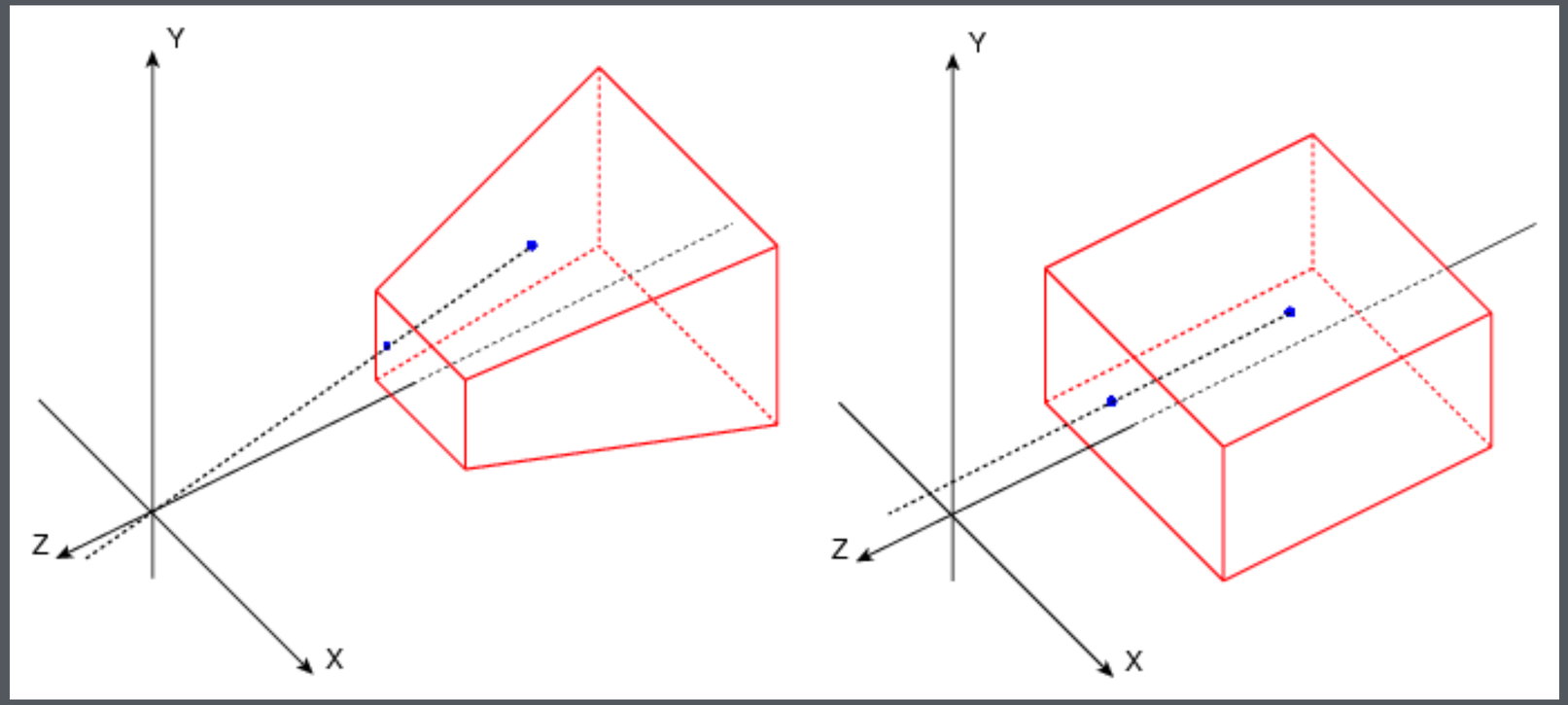


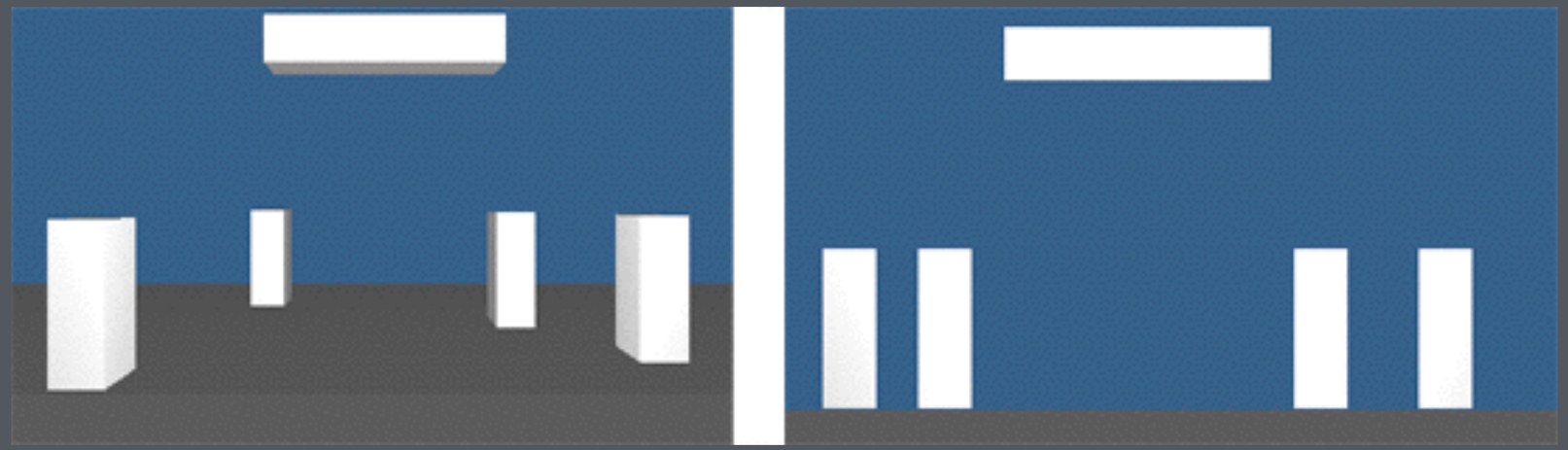
Perspective projection (P)



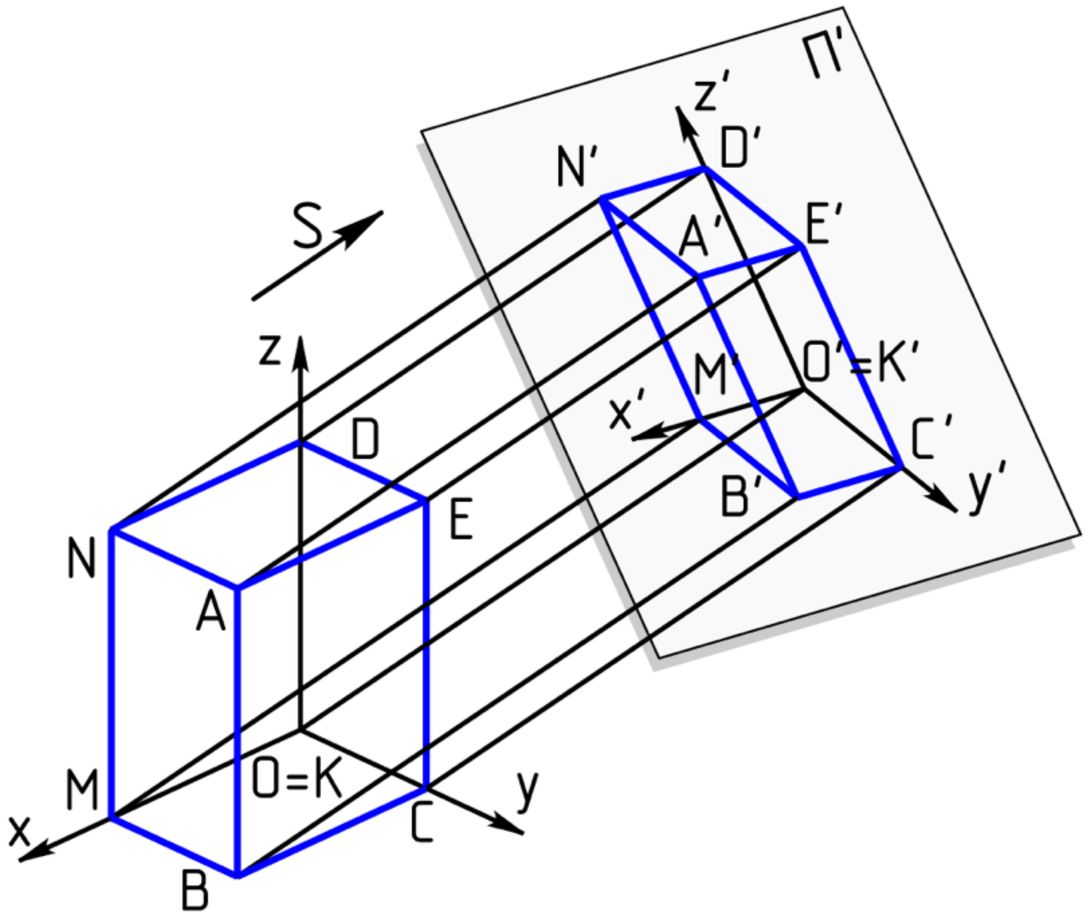
Orthographic projection (O)

Perspective vs. **Orthographic** projection



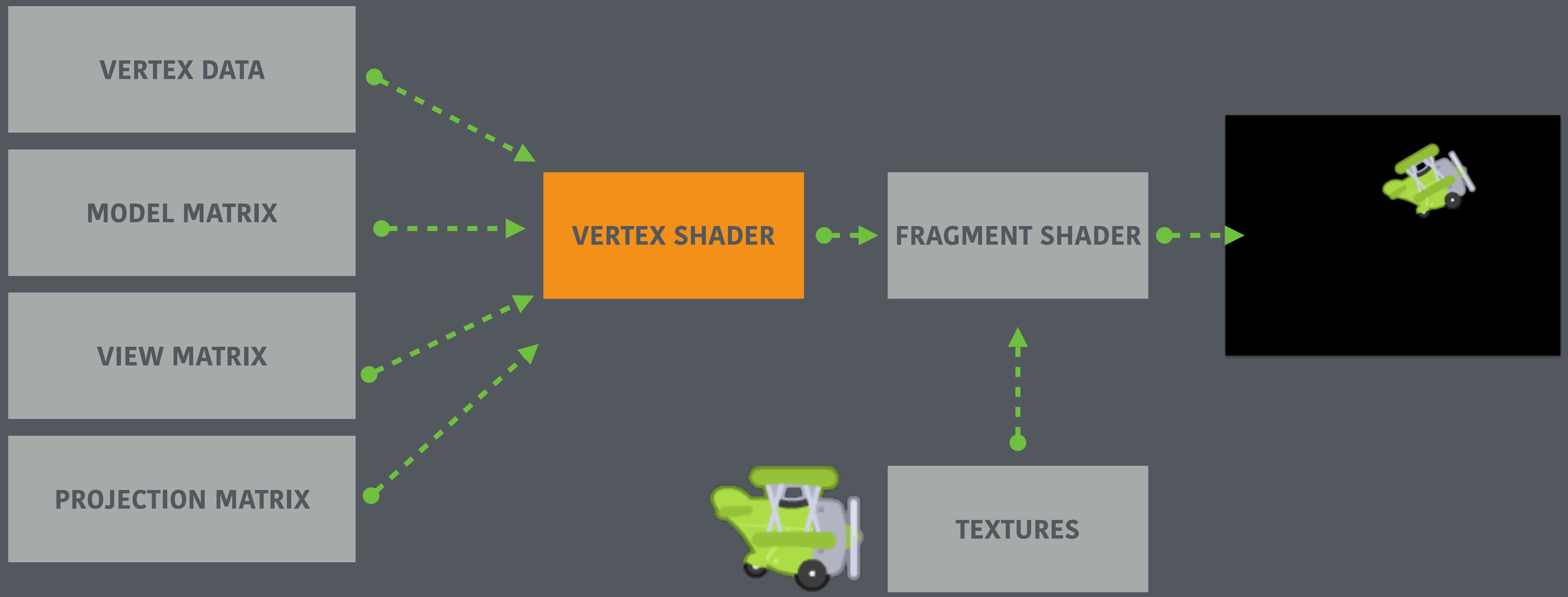


Projection matrix



Vertex position * projection matrix = screen vertex position

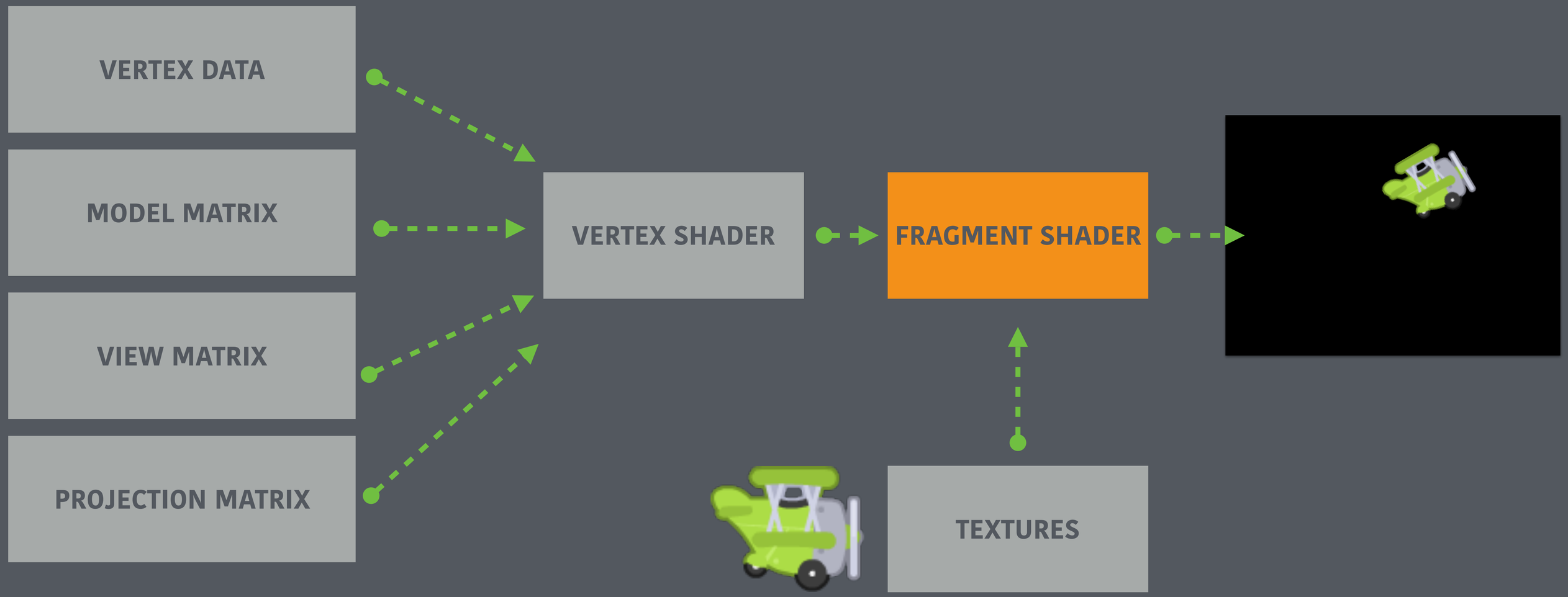
The **GPU** pipeline



The **vertex** shader

A **program** that transforms the **attributes**
(such as position, color or others)
of **every vertex** passed to the **GPU**.

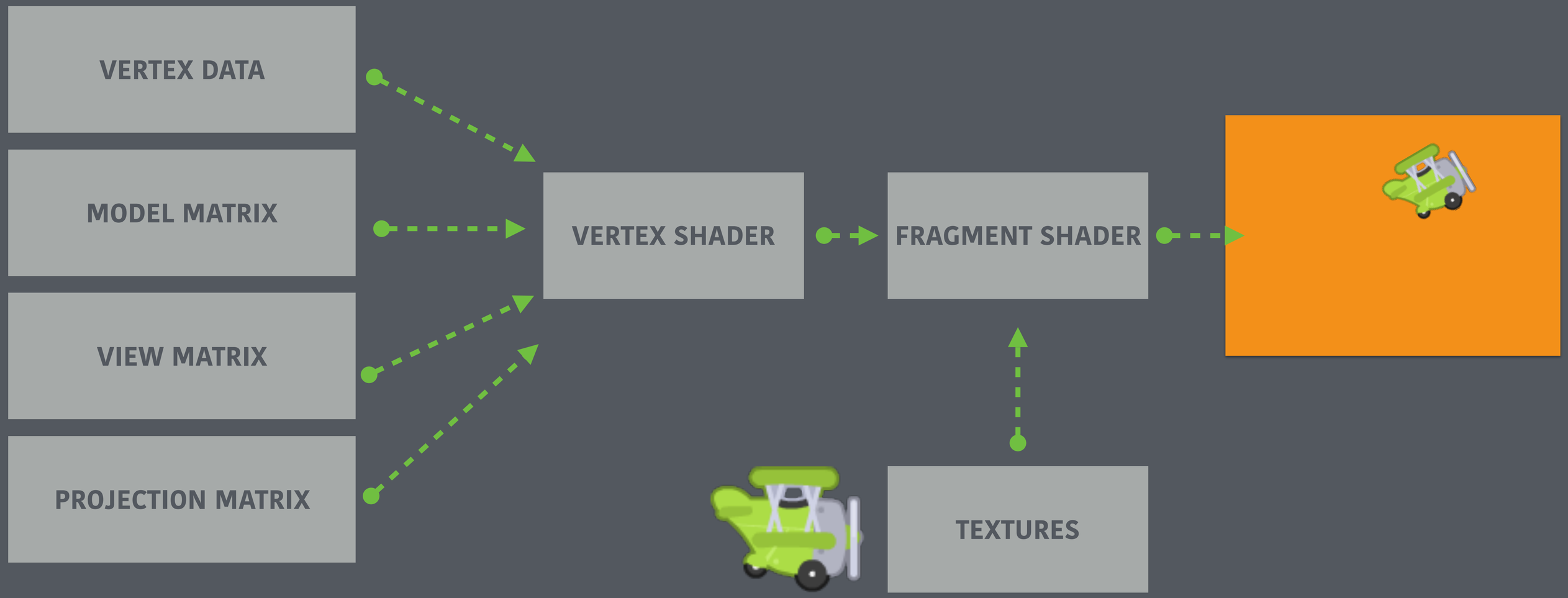
The **GPU** pipeline



The **fragment** shader

A **program** that returns **the color of each pixel** when geometry is rasterized on the **GPU**.

The **GPU** pipeline



OpenGL®

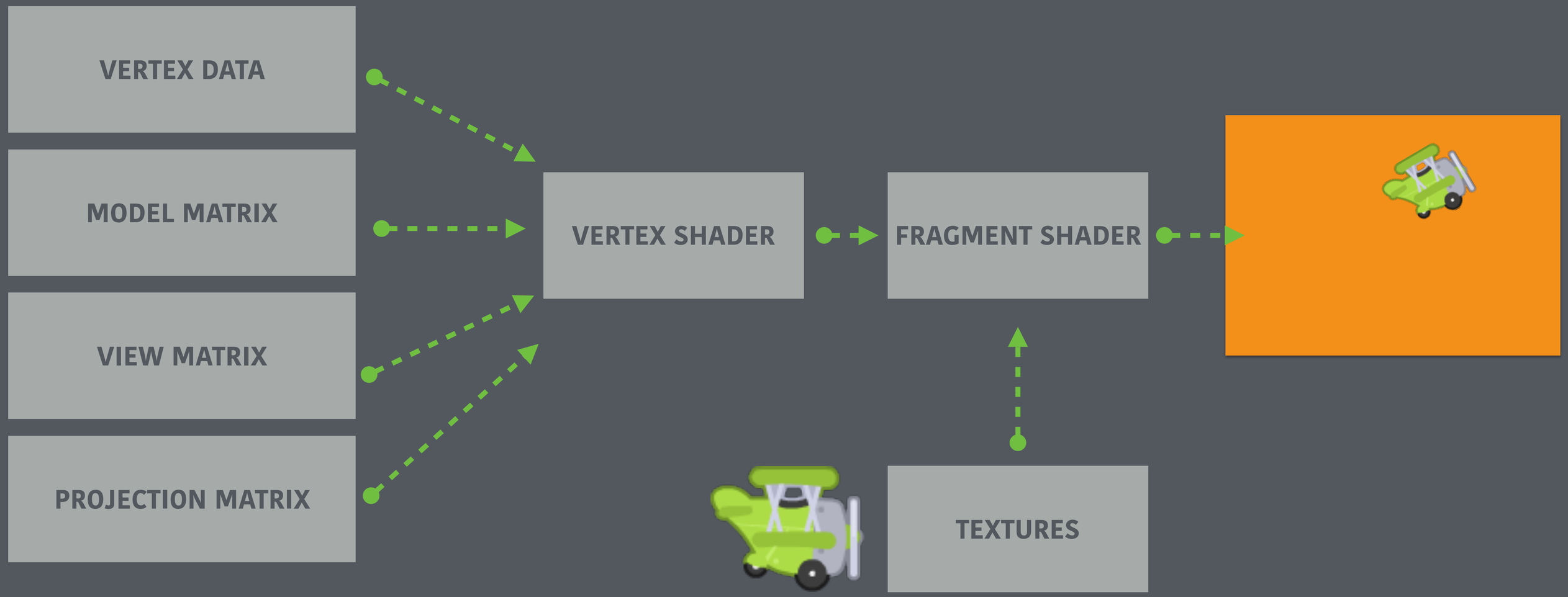
The **setup**

(happens only once!)

```
void glViewport (GLint x, GLint y, GLsizei width, GLsizei height);
```

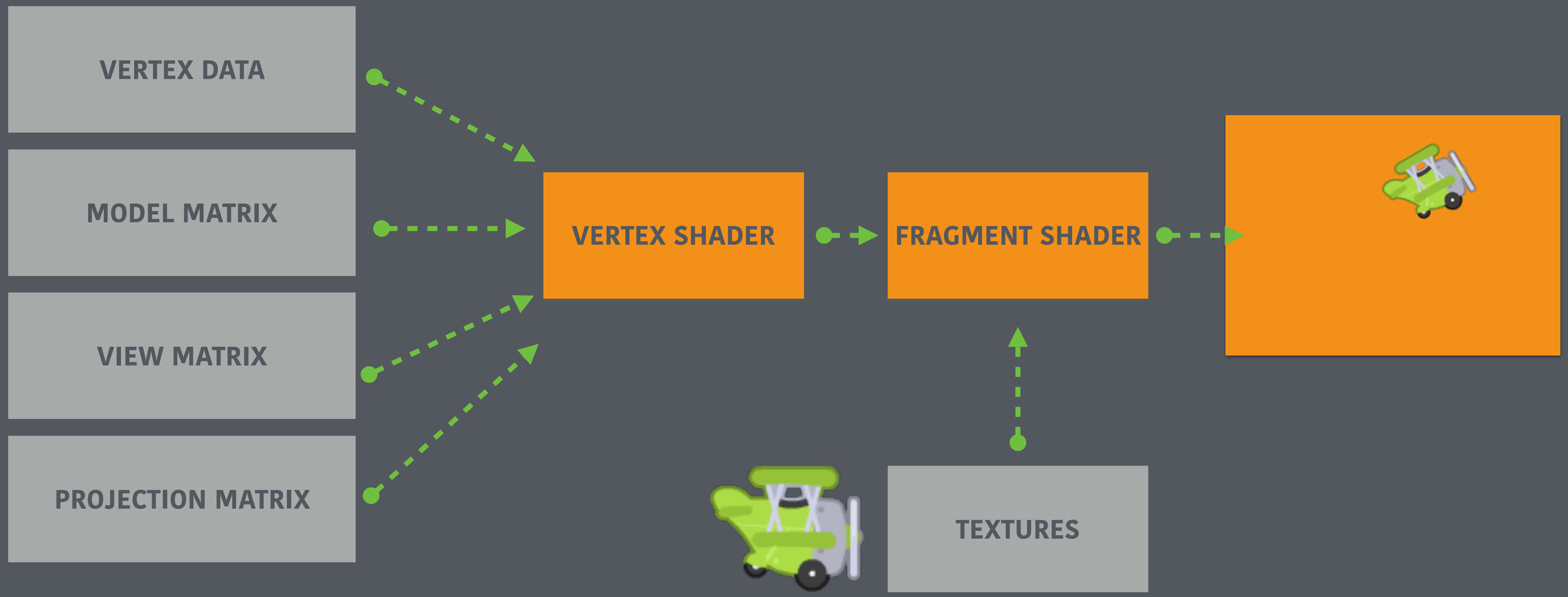
Sets the **pixel size** and **offset** of rendering area.

```
glViewport(0, 0, 640, 360);
```


VERTEX DATA
MODEL MATRIX
VIEW MATRIX
PROJECTION MATRIX
VERTEX SHADER
FRAGMENT SHADER
TEXTURES

The **ShaderProgram** class.

```
#include "ShaderProgram.h"

// …

ShaderProgram program(RESOURCE_FOLDER"vertex.glsl", RESOURCE_FOLDER"fragment.glsl");
```


VERTEX DATA
MODEL MATRIX
VIEW MATRIX
PROJECTION MATRIX
VERTEX SHADER
FRAGMENT SHADER
TEXTURES

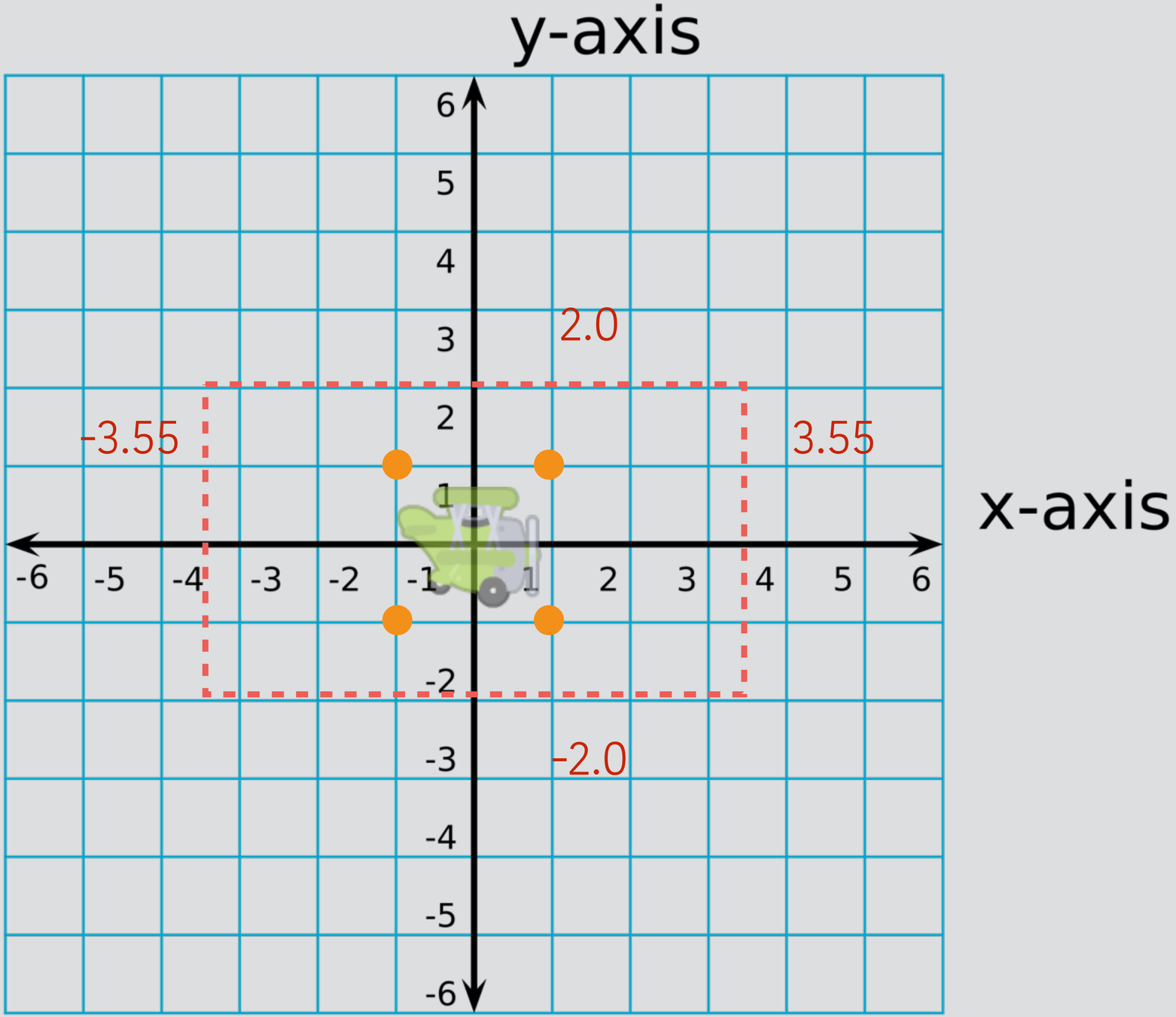
The **Matrix** class.

```
#include "Matrix.h"

// …

Matrix projectionMatrix;
Matrix modelMatrix;
Matrix viewMatrix;
```

```
void Matrix::setOrthoProjection (float left, float right,
float bottom, float top, float near, float far);
```

Sets an **orthographic projection** in a **matrix.**

```
Matrix projectionMatrix;
projectionMatrix.setOrthoProjection(-3.55, 3.55, -2.0f, 2.0f, -1.0f, 1.0f);
```


y-axis
x-axis
2.0
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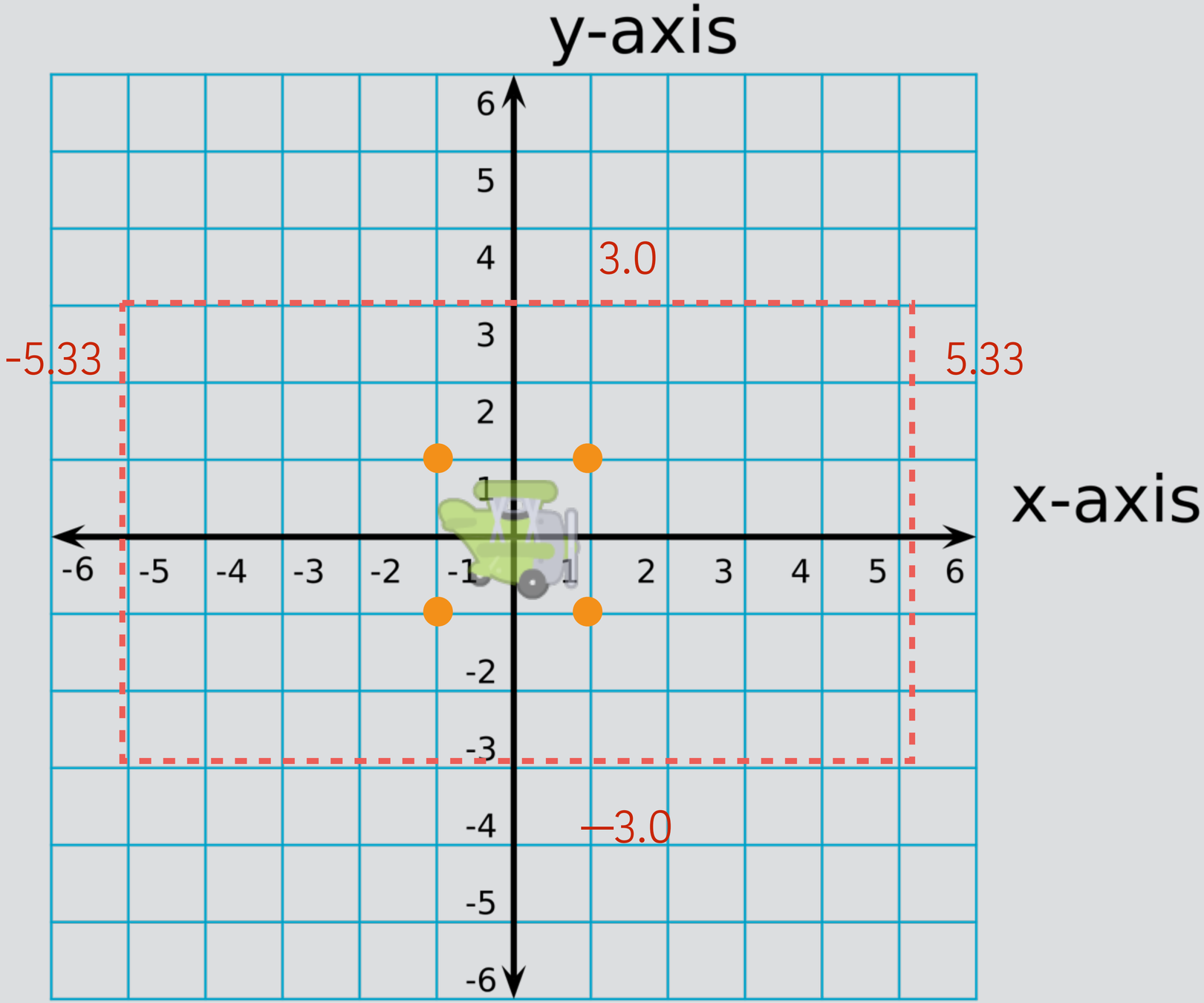
y-axis
x-axis
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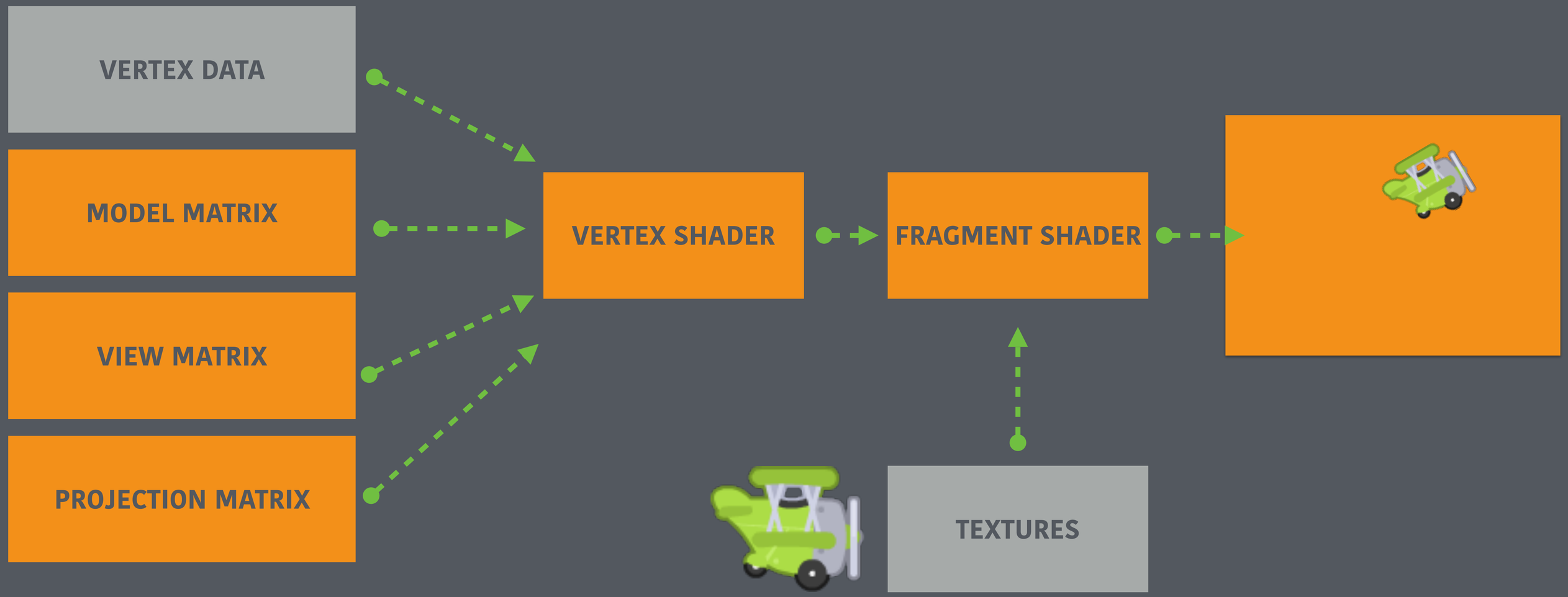

VERTEX DATA
MODEL MATRIX
VIEW MATRIX
PROJECTION MATRIX
VERTEX SHADER
FRAGMENT SHADER
TEXTURES

Drawing **polygons**.

(happens every frame!)

Pass the **matrices** to our **program**.

```
program.setModelMatrix(modelMatrix);
program.setProjectionMatrix(projectionMatrix);
program.setViewMatrix(viewMatrix);
```

```
void glUseProgram (GLint programID);
```

Use the specified **program id**.

```
glUseProgram(program.programID);
```

```
void glVertexAttribPointer (GLint index, GLint size, GLenum type, GLboolean normalized, GLsizei stride, const GLvoid *pointer);
```

Defines an array of **vertex data** (**counter**-clockwise!).

```
float vertices[] = {0.5f, -0.5f, 0.0f, 0.5f, -0.5f, -0.5f};

glVertexAttribPointer(program.positionAttribute, 2, GL_FLOAT, false, 0, vertices);
```

```
void glEnableVertexAttribArray (GLuint index);
```

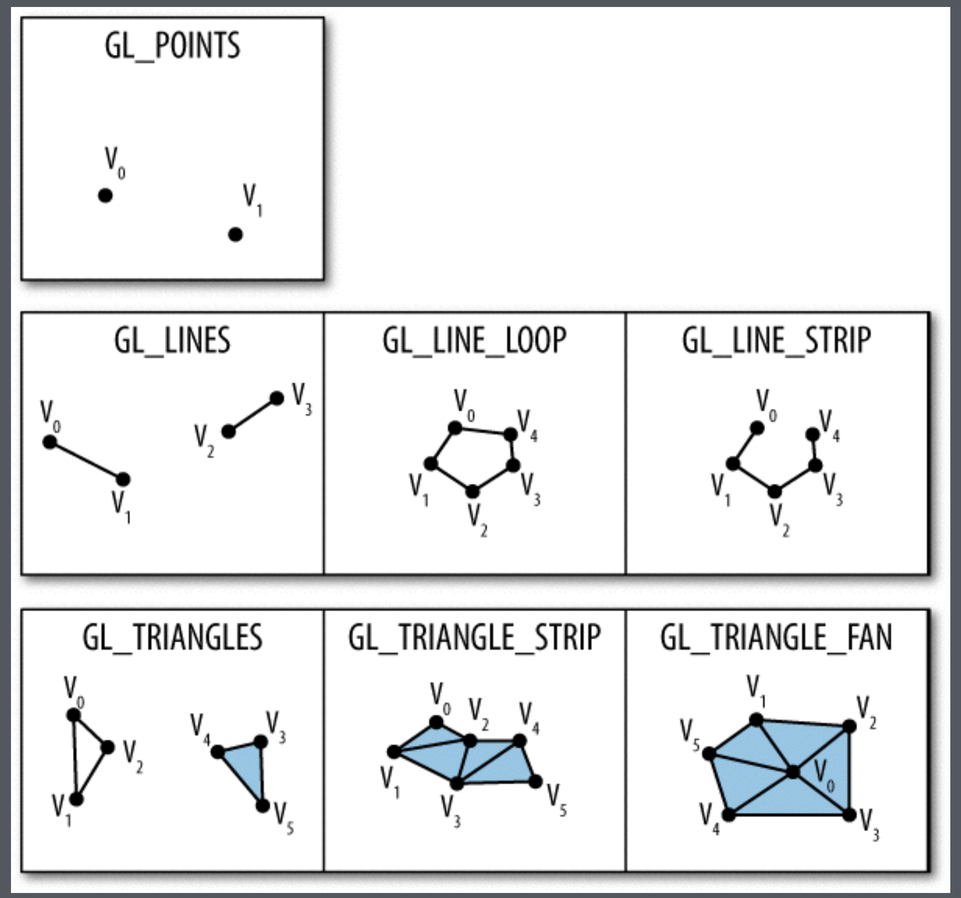
Enables a **vertex attribute array**.

```
glEnableVertexAttribArray(program.positionAttribute);
```

```
glDrawArrays (GLenum mode, GLint first,
GLsizei count);
```

Render previously defined **arrays**.

```
glDrawArrays(GL_TRIANGLES, 0, 3);
```

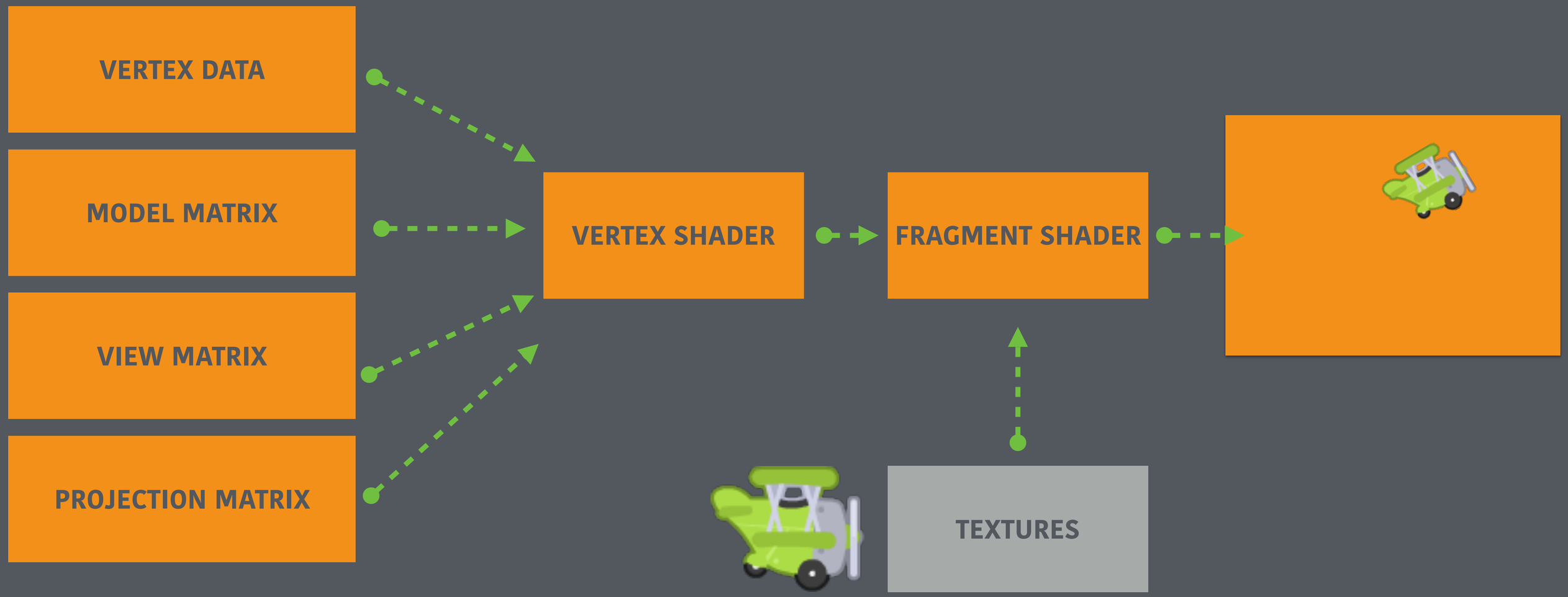


```
void glDisableVertexAttribArray (GLuint index);
```

Disables a **vertex attribute array**.

```
glDisableVertexAttribArray(program.positionAttribute);
```

Putting it all together.


VERTEX DATA
MODEL MATRIX
VIEW MATRIX
PROJECTION MATRIX
VERTEX SHADER
FRAGMENT SHADER
TEXTURES

Setup (before the loop)

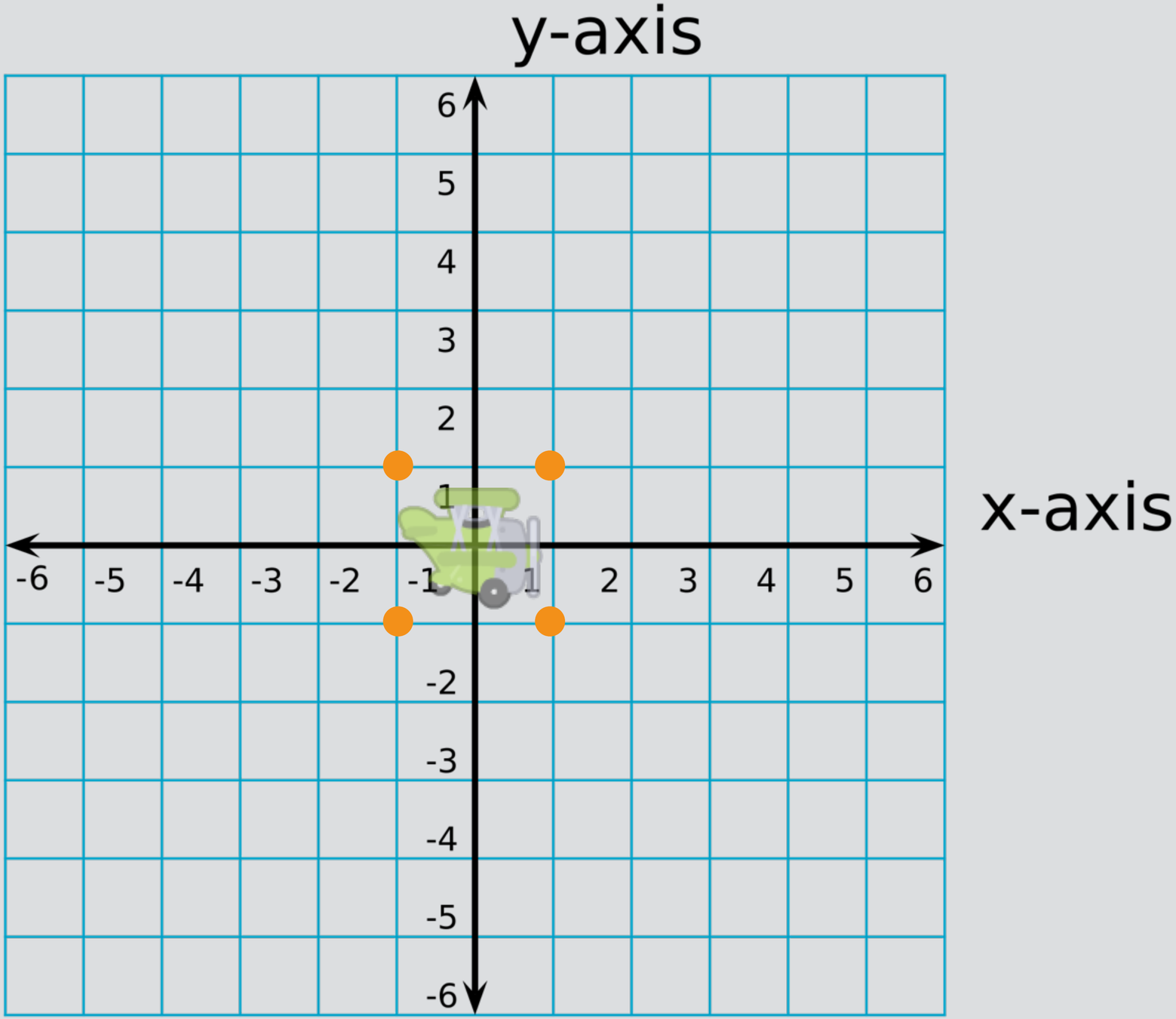
```
glViewport(0, 0, 640, 360);

ShaderProgram program(RESOURCE_FOLDER"vertex.glsl", RESOURCE_FOLDER”fragment.glsl");

Matrix projectionMatrix;
Matrix modelMatrix;
Matrix viewMatrix;

projectionMatrix.setOrthoProjection(-3.55, 3.55, -2.0f, 2.0f, -1.0f, 1.0f);

glUseProgram(program.programID);
```

Drawing (in your game loop)

```
glClear(GL_COLOR_BUFFER_BIT);

program.setModelMatrix(modelMatrix);
program.setProjectionMatrix(projectionMatrix);
program.setViewMatrix(viewMatrix);

float vertices[] = {0.5f, -0.5f, 0.0f, 0.5f, -0.5f, -0.5f};
glVertexAttribPointer(program.positionAttribute, 2, GL_FLOAT, false, 0, vertices);
glEnableVertexAttribArray(program.positionAttribute);

glDrawArrays(GL_TRIANGLES, 0, 3);

glDisableVertexAttribArray(program.positionAttribute);

SDL_GL_SwapWindow(displayWindow);
```

Transformations

Identity matrix.


y-axis
x-axis
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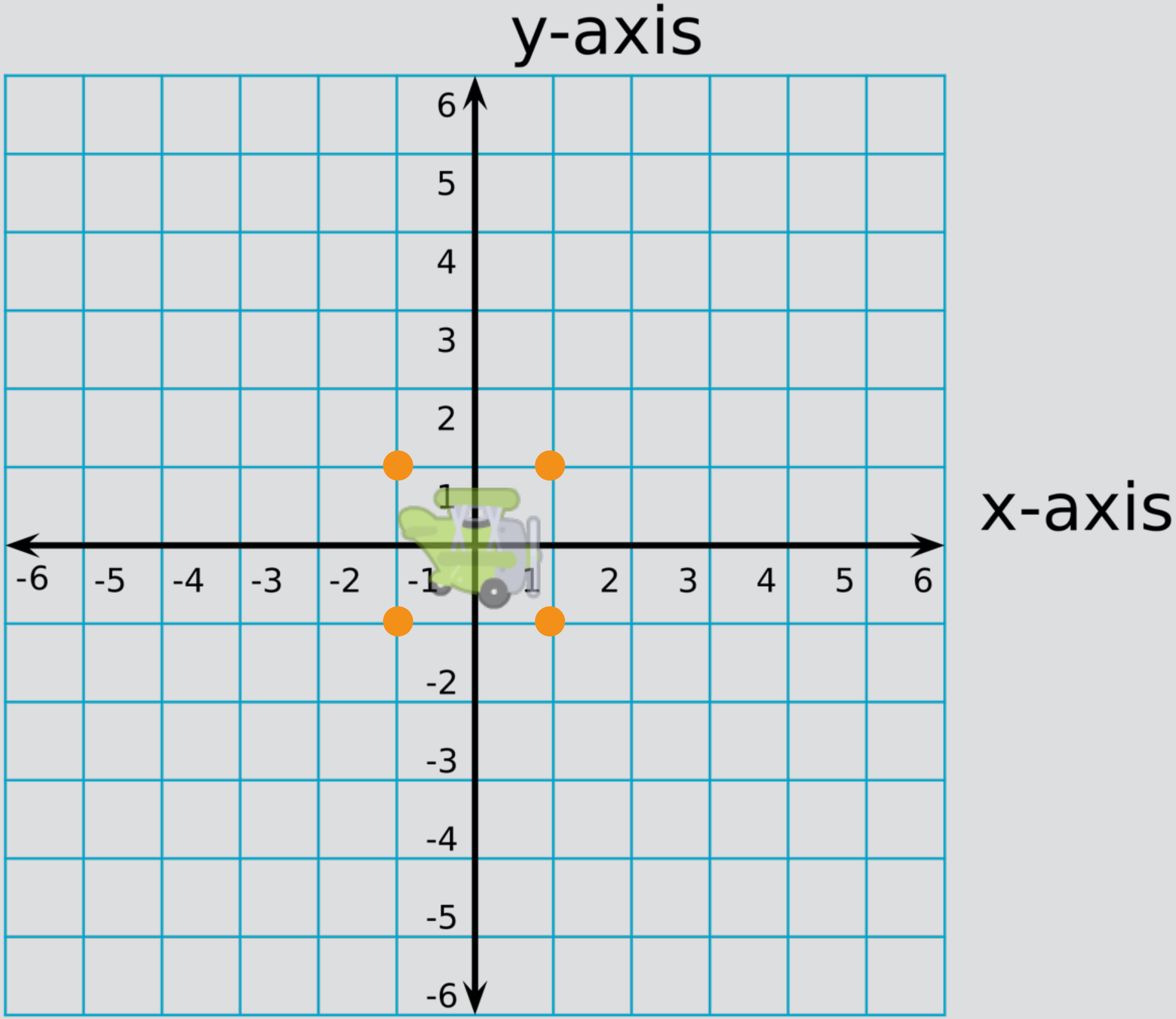
```
void Matrix::identity();
```

Resets a matrix to have no transformations.

```
Matrix modelMatrix;
modelMatrix.identity();
```

Translations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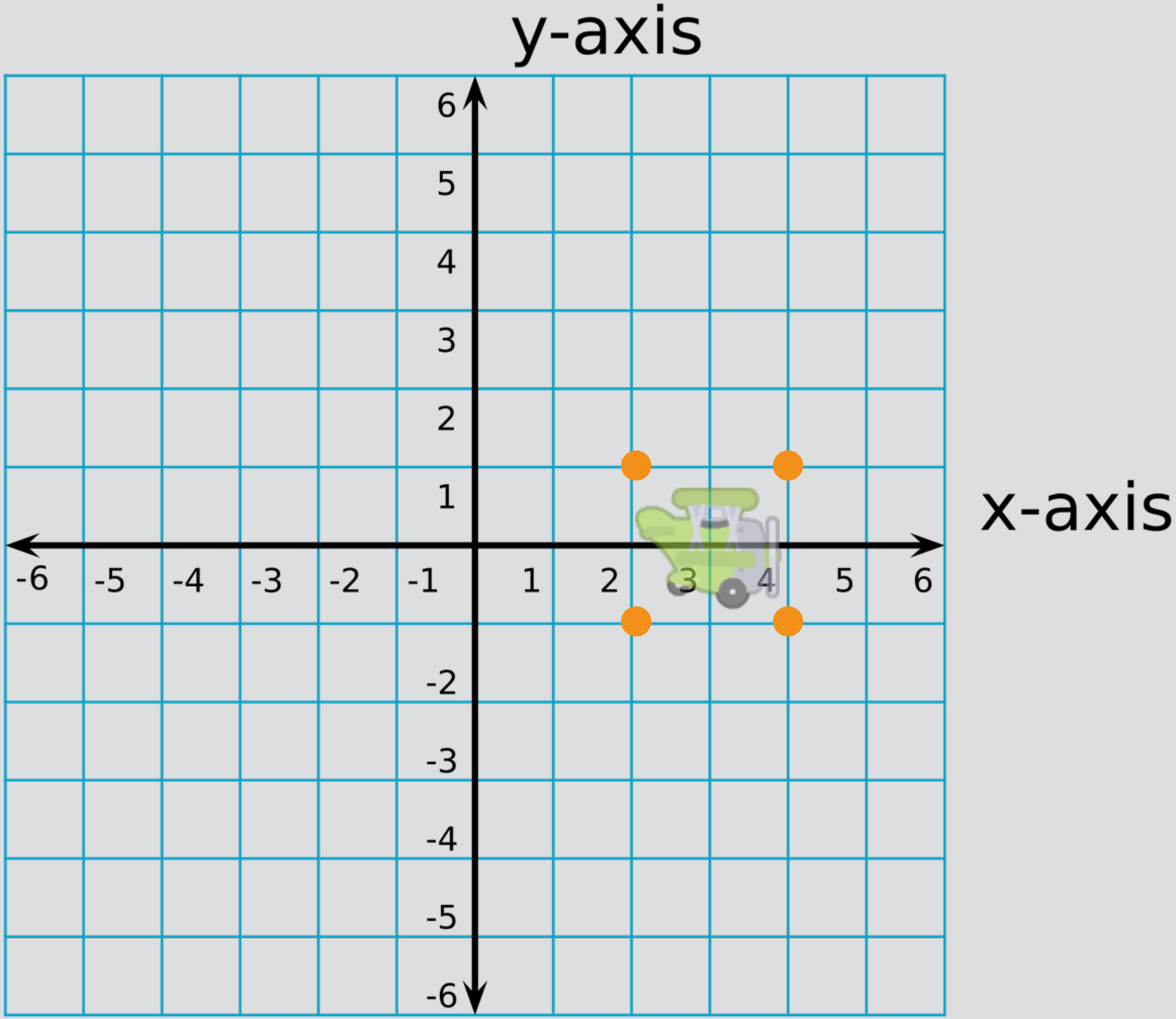
y-axis
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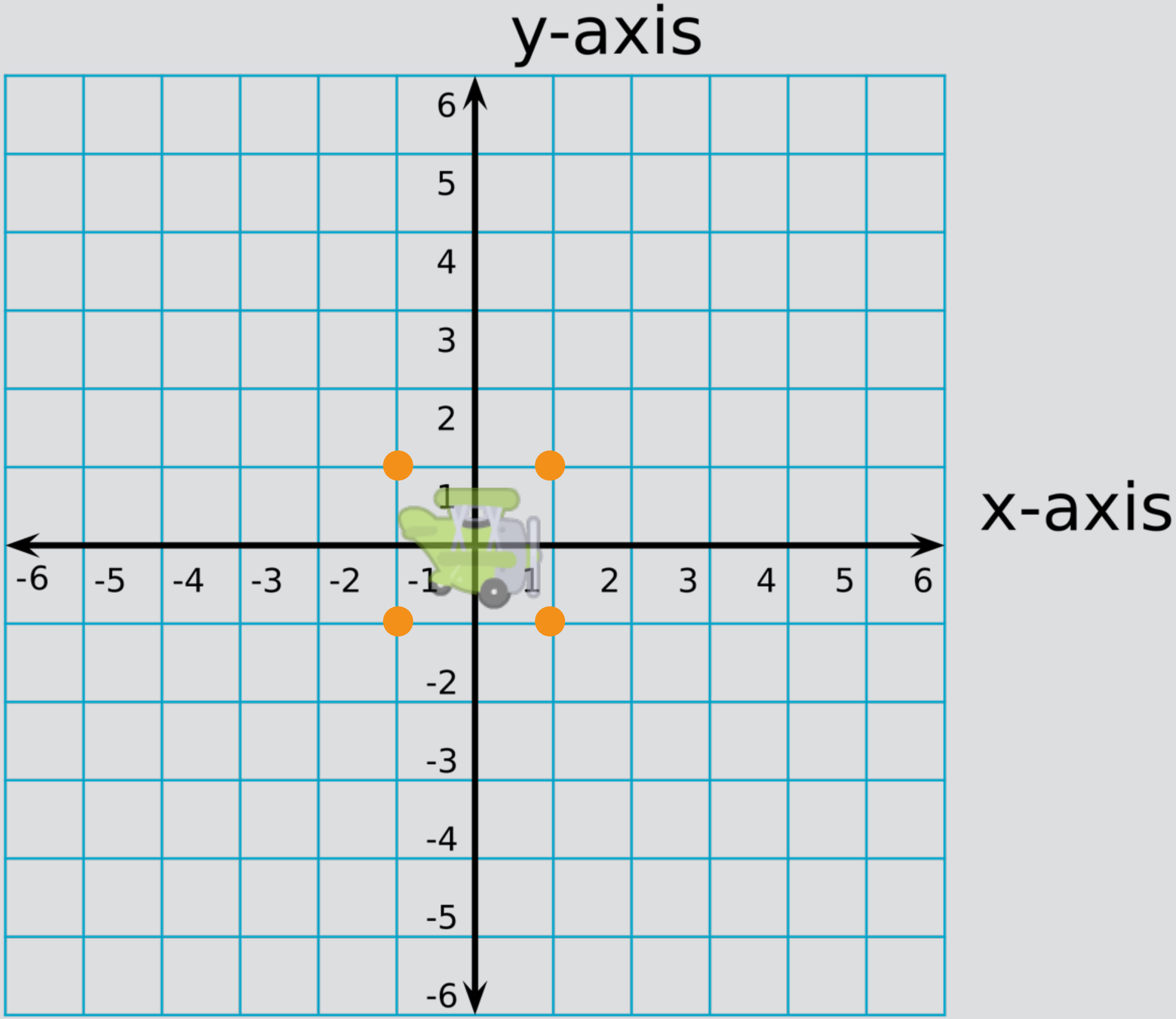
```
void Matrix::Translate (float x, float y, float z);
```

Translates a matrix by specified coordinates.

```
Matrix modelMatrix;
modelMatrix.Translate(1.0, 0.0, 0.0);
```

Scaling


y-axis
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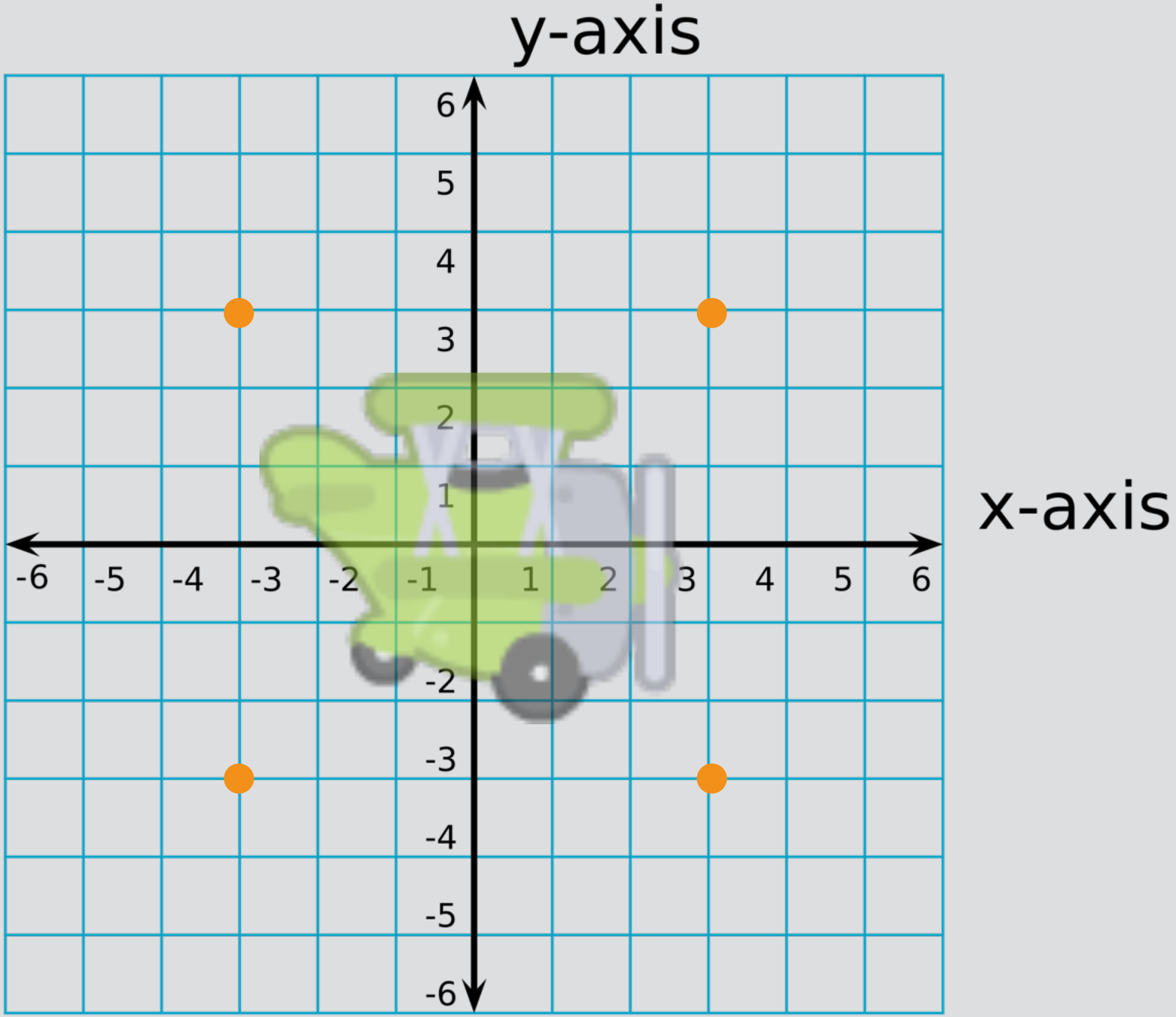
y-axis
x-axis
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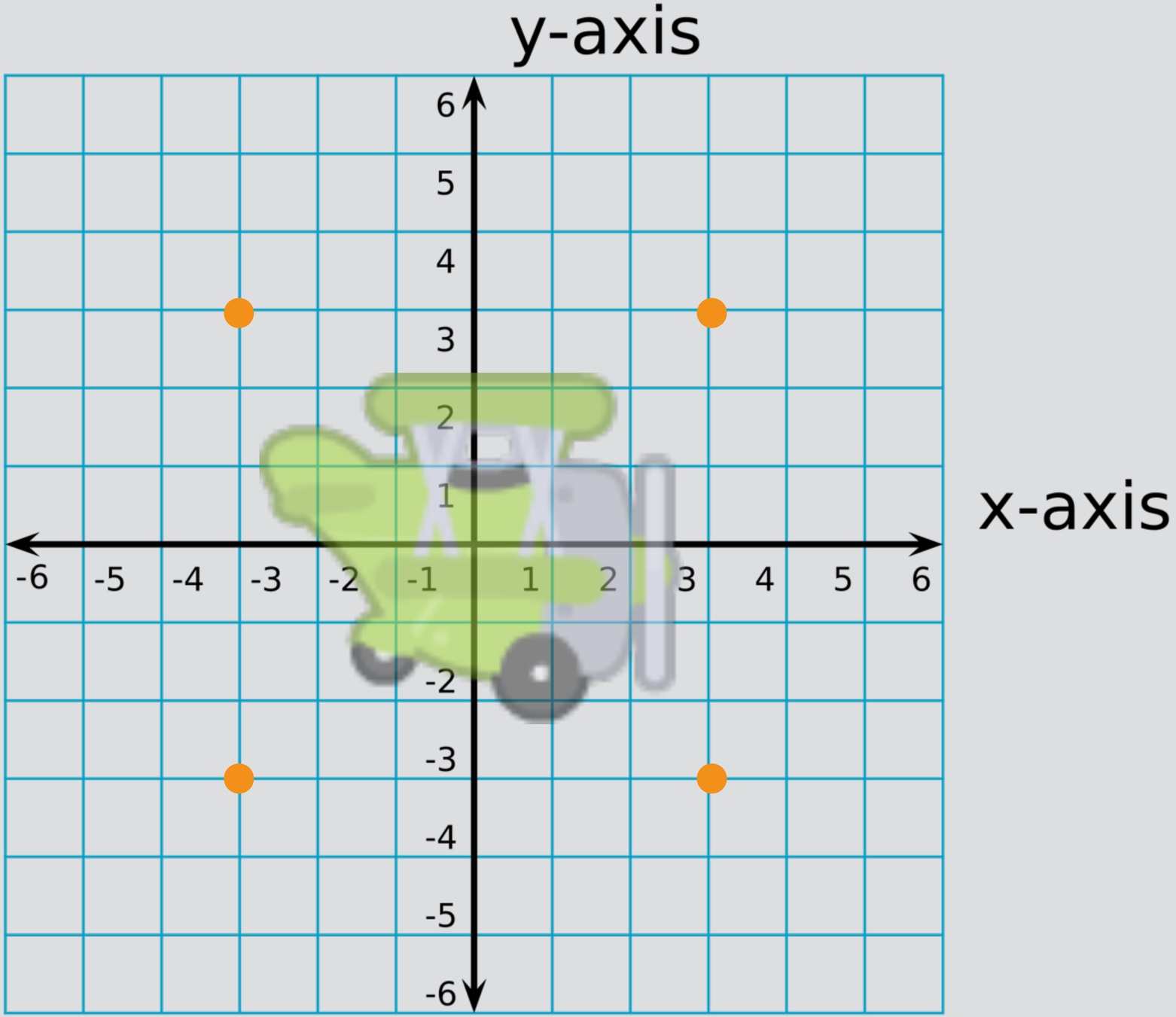
```
void Matrix::Scale (float x, float y, float z);
```

Scales a matrix by specified coordinates.

```
Matrix modelMatrix;
modelMatrix.Scale(2.0, 2.0, 1.0);
```

Rotation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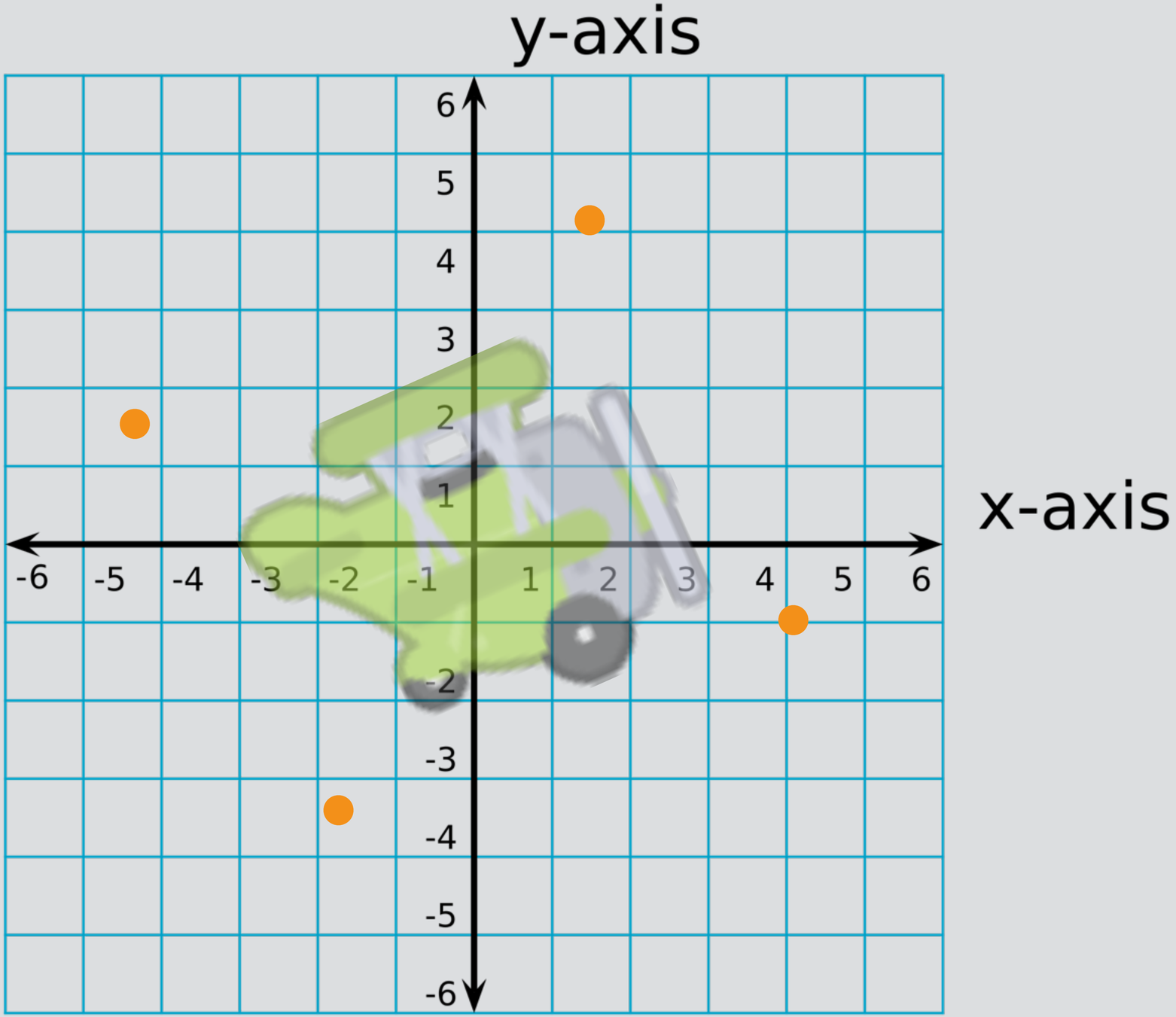
y-axis
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```
void Matrix::Rotate(float radians);
```

Rotates a matrix by specified radians.

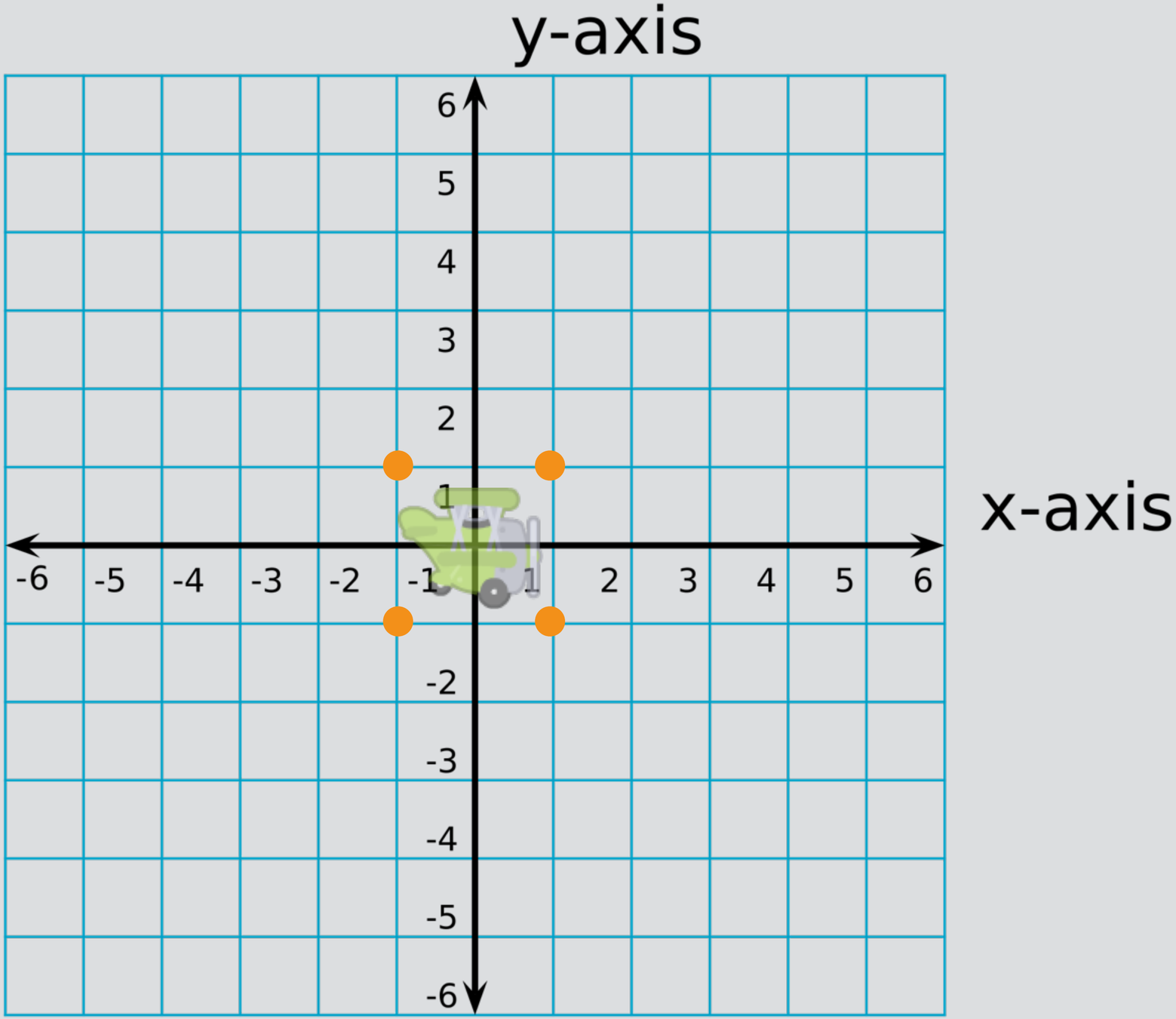
```
Matrix modelMatrix;
modelMatrix.Rotate(45.0 * (3.1415926 / 180.0));
```

To convert from **degrees** to **radians**:

RADIANS = DEGREES * (PI / 180)

Matrix transformations
are **additive!**

```
Matrix modelMatrix;
modelMatrix.Translate(2.0, 0.0, 0.0);
modelMatrix.Rotate(45.0 * (3.1415926 / 180.0));
```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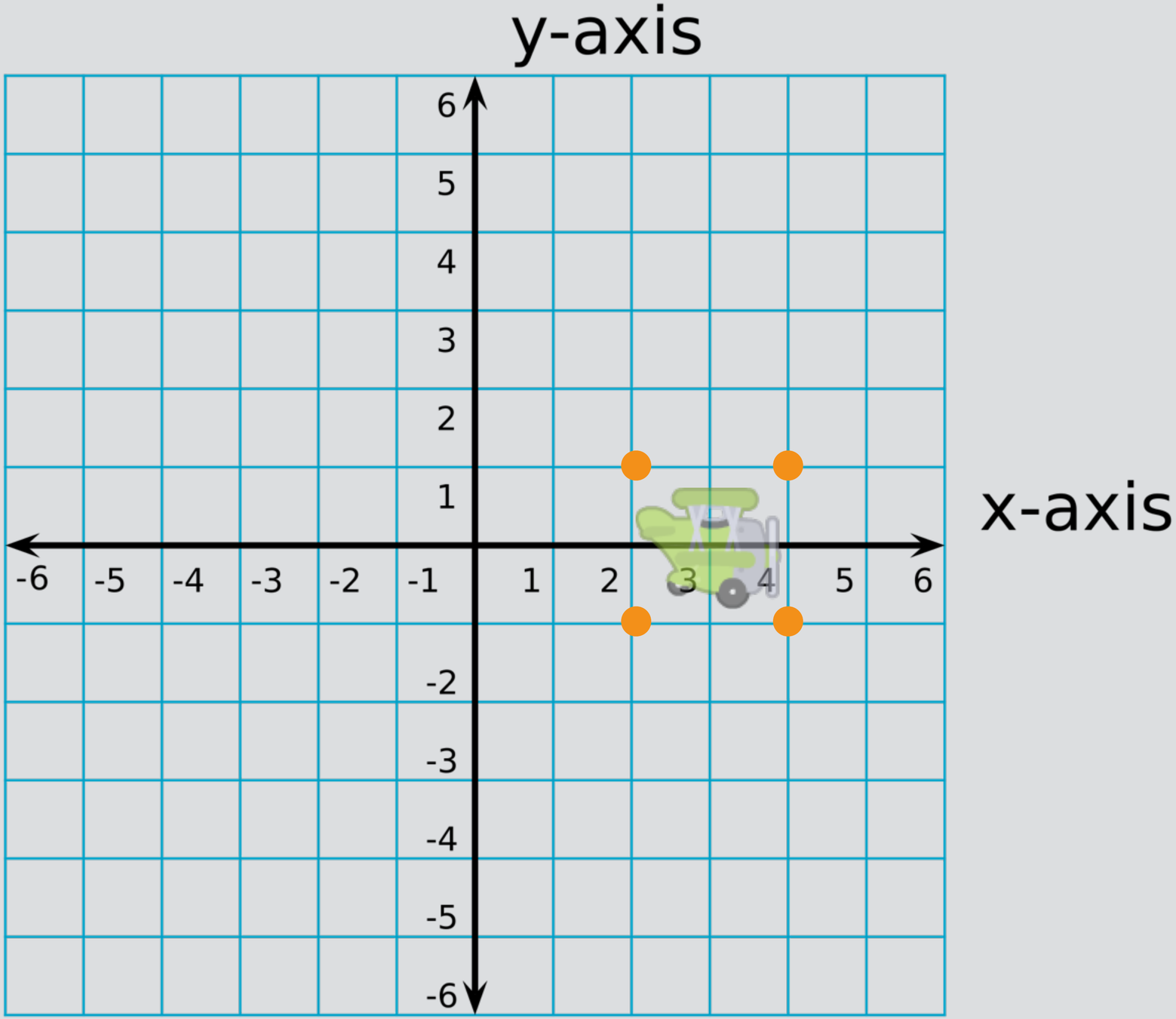
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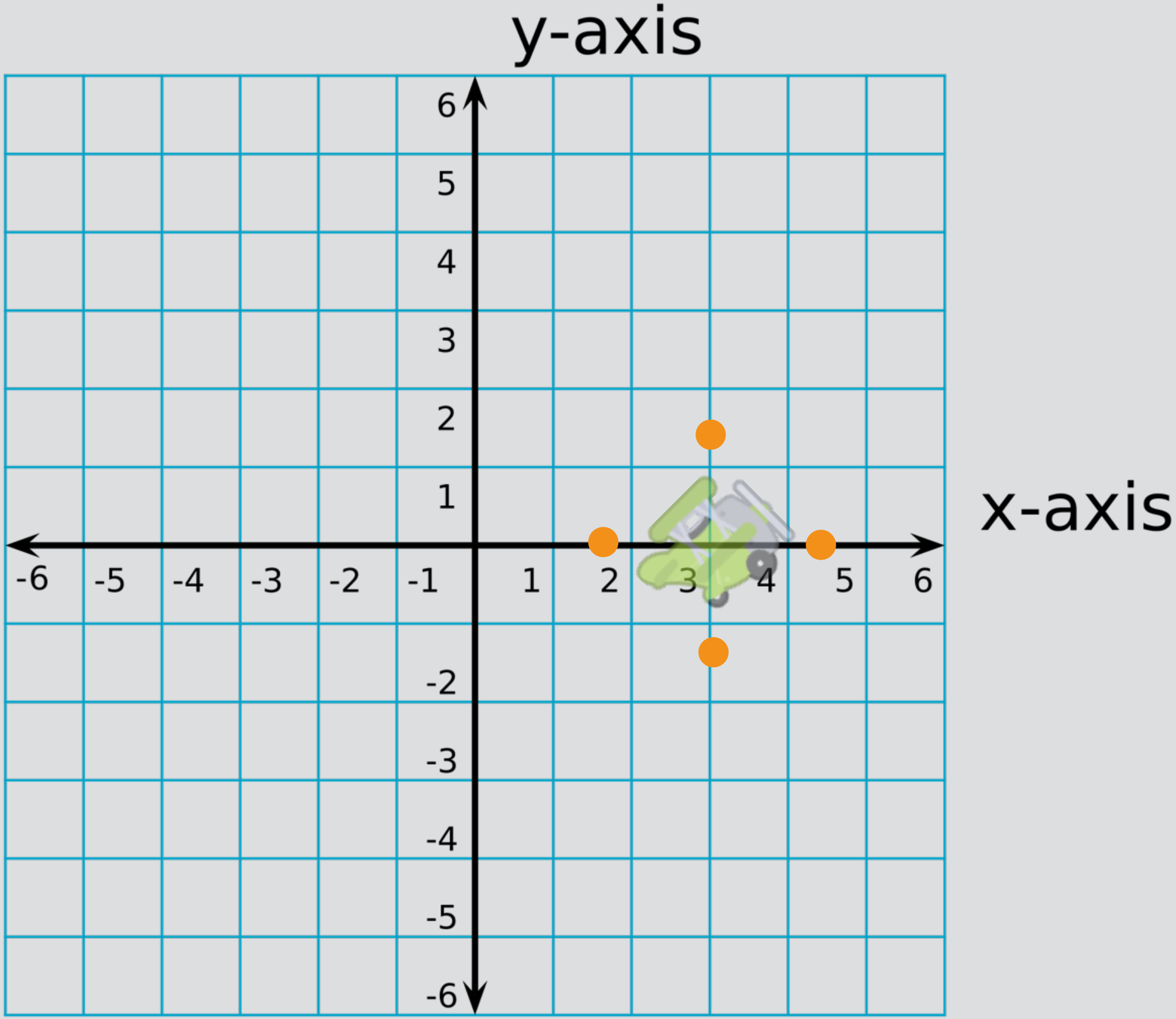
y-axis
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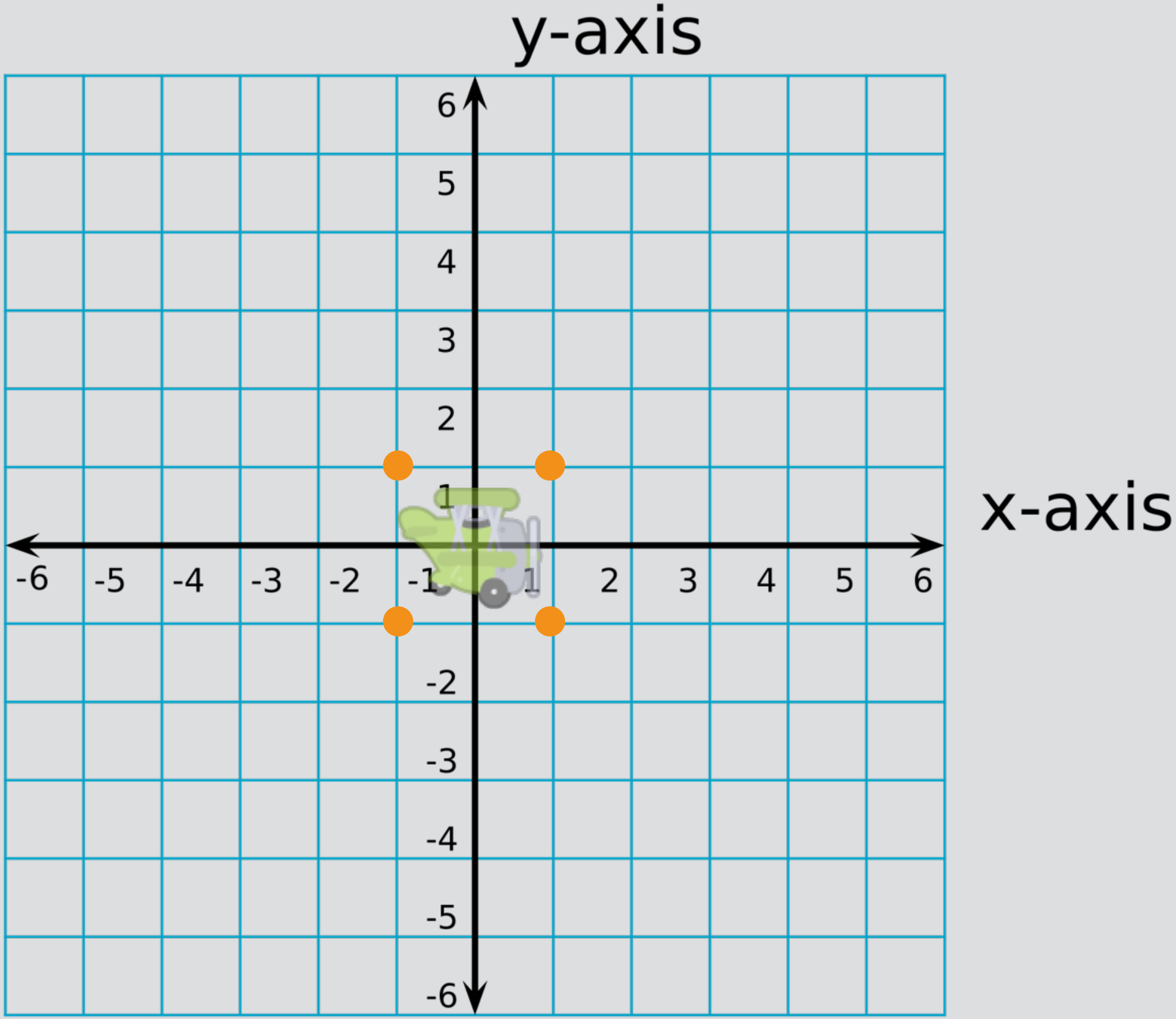
```
Matrix modelMatrix;
modelMatrix.Rotate(45.0 * (3.1415926 / 180.0));
modelMatrix.Translate(2.0, 0.0, 0.0);
```


y-axis
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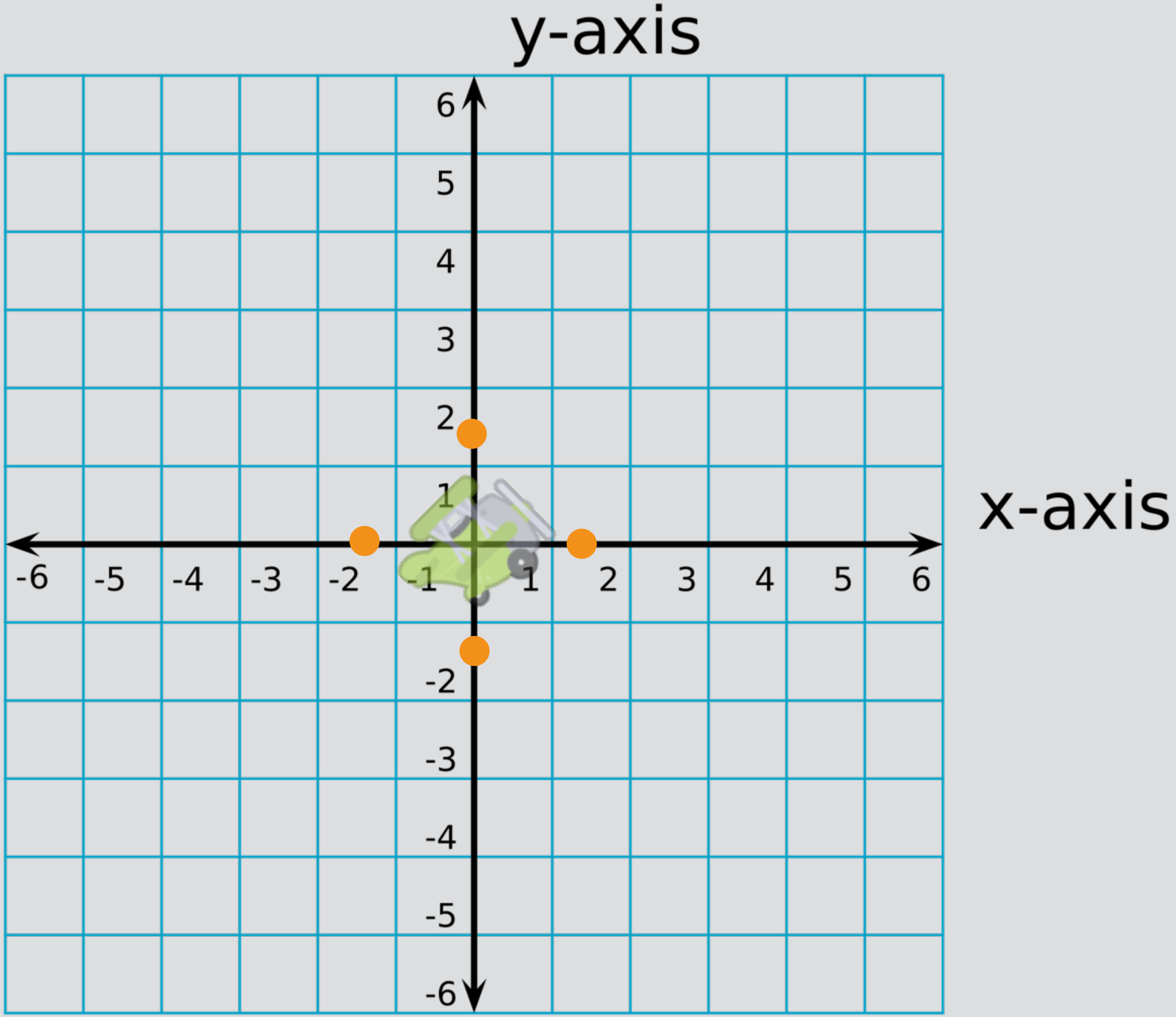
y-axis
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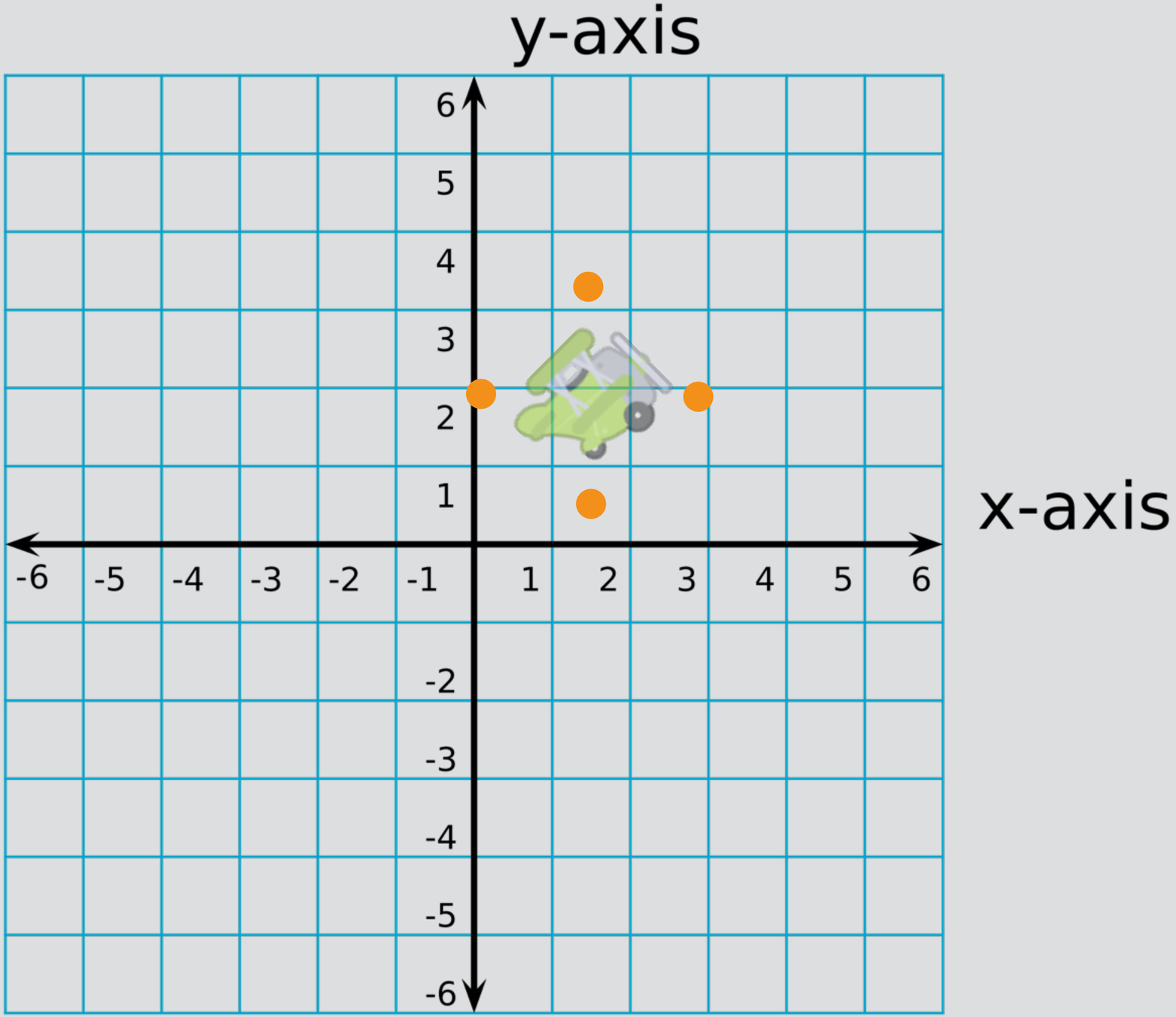
y-axis
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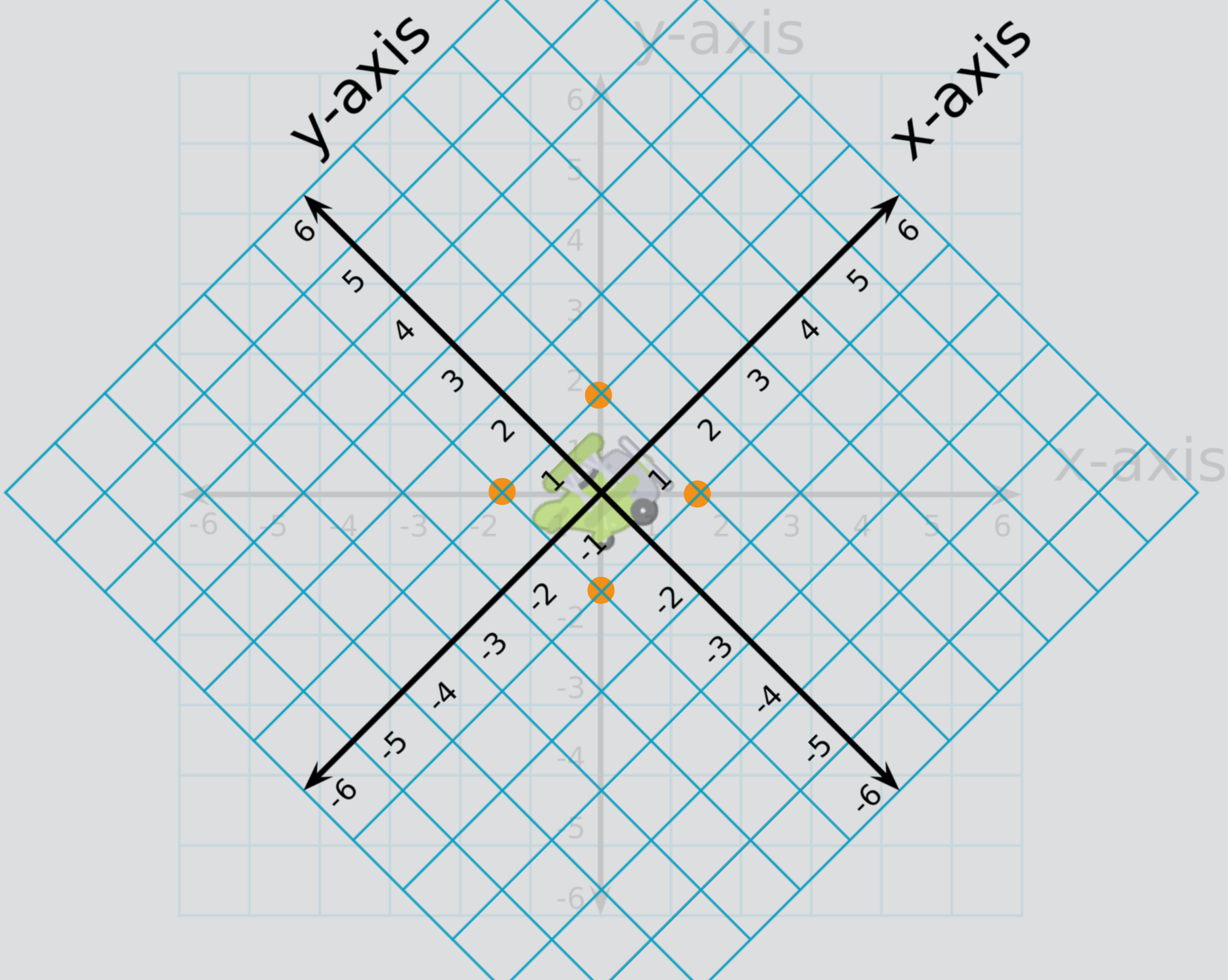
y-axis
x-axis
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