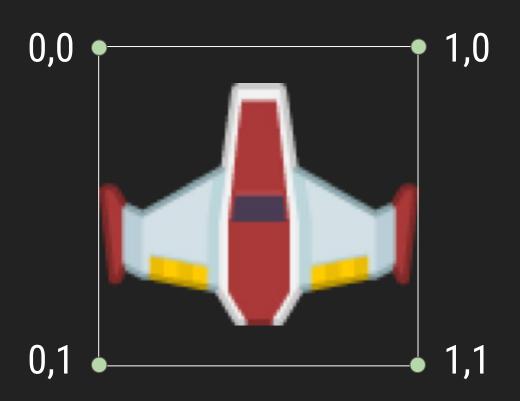
# Textures Texture Atlas Sprite Sheets **Fonts**

# Textures (Review)

#### **Texture Coordinates**

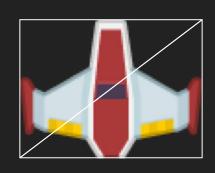


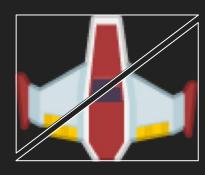
Texture coordinates are referred to as UV coordinates (X, Y and Z were already taken):)

Notice the range from 0.0 to 1.0 and not by pixels.

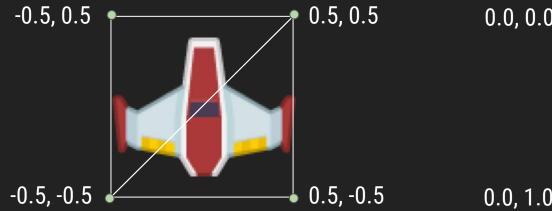
#### 2D Sprite Made of 2 Triangles





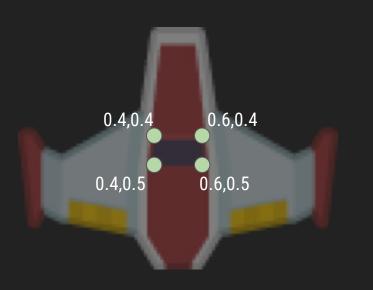


#### Need to match vertices to UV coordinates

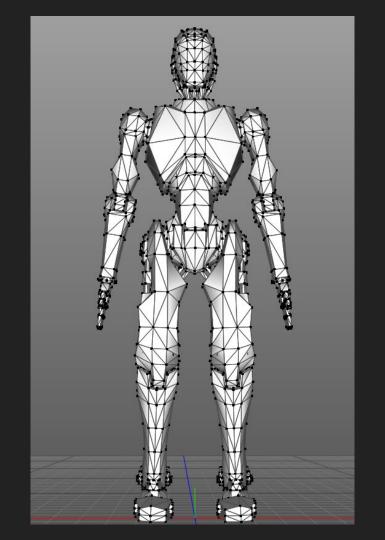


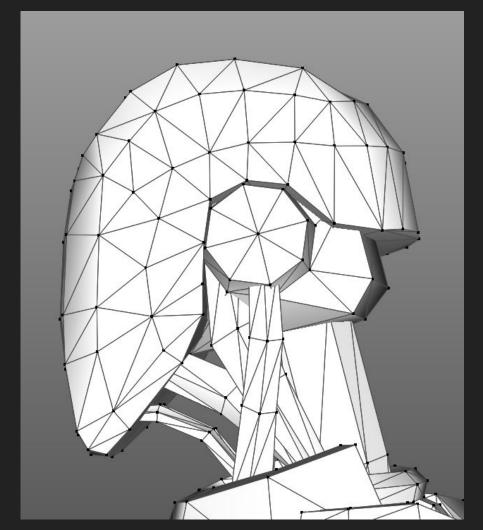


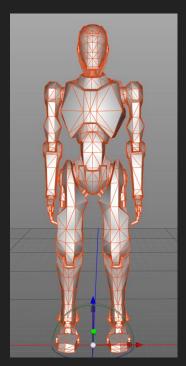
#### Portion of Texture



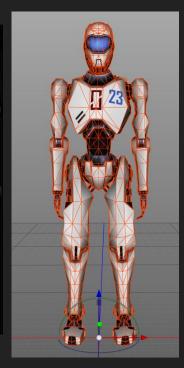


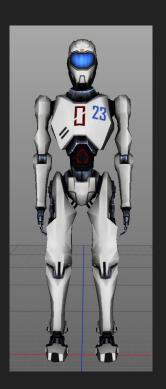






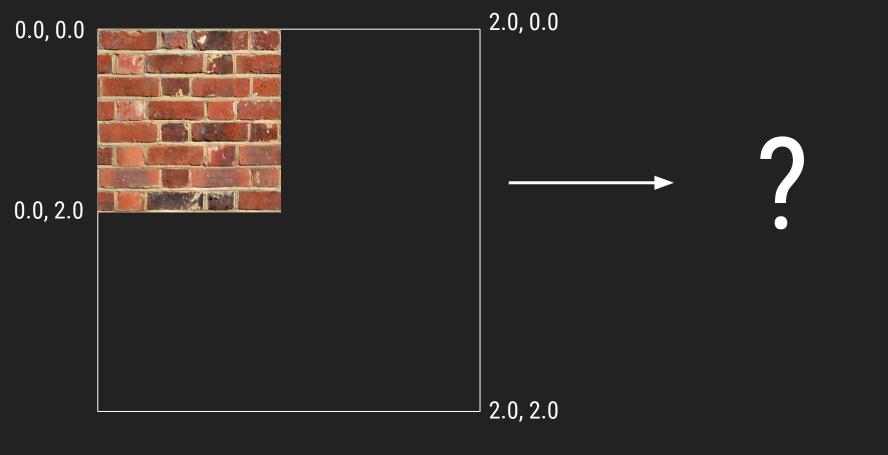






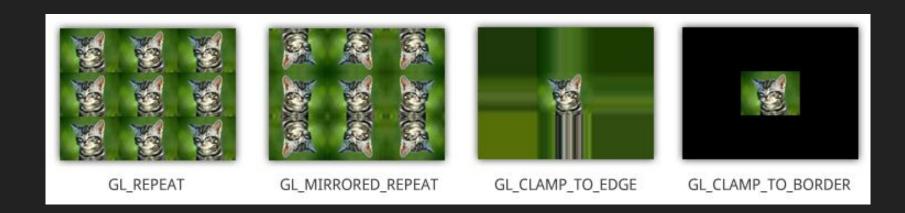
#### Texture Wrap Mode





**float** vertices[] = { -0.5, -0.5, 0.5, -0.5, 0.5, 0.5, -0.5, 0

#### Texture Wrap Mode



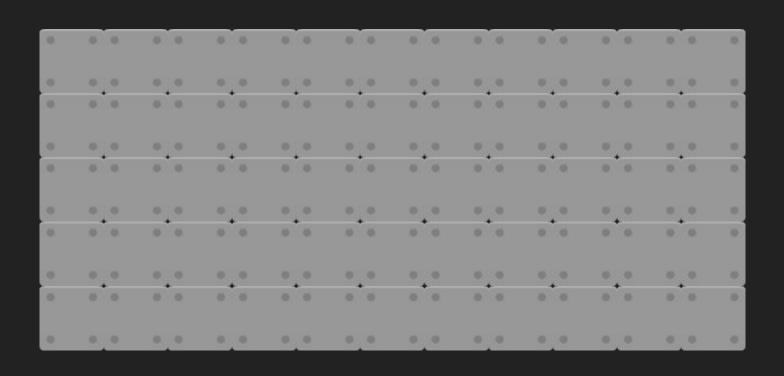
From <a href="https://open.gl/textures">https://open.gl/textures</a>

#### Texture Wrap Mode

You can add these 2 lines.

```
GLuint LoadTexture(const char* filePath) {
    int w, h, n;
    unsigned char* image = stbi_load(filePath, &w, &h, &n, STBI_rgb_alpha);
    if (image == NULL) {
        std::cout << "Unable to load image. Make sure the path is correct\n";
        assert(false):
    GLuint textureID;
    glGenTextures(1, &textureID);
    glBindTexture(GL_TEXTURE_2D, textureID);
    glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, w, h, 0, GL_RGBA, GL_UNSIGNED_BYTE, image);
    glTexParameteri(GL TEXTURE 2D, GL TEXTURE WRAP S, GL REPEAT);
    glTexParameteri(GL TEXTURE 2D, GL TEXTURE WRAP T, GL REPEAT);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
    glTexParameteri(GL TEXTURE 2D, GL TEXTURE MAG FILTER, GL NEAREST);
    stbi image free(image);
    return textureID;
```

#### Repeating Tiles



#### Texture Atlases

(Multiple Sprites in a Single Texture)

## Sprite Sheet



#### Tileset



#### Tileset



#### 3D Game Example





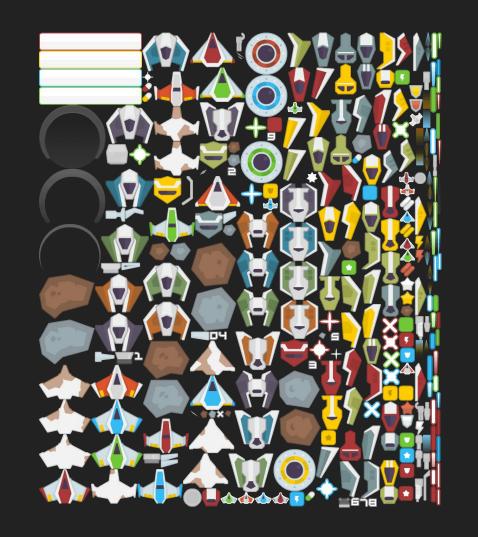
#### Fonts!

```
! " # $ % & ' ( ) * + , - . /
0 1 2 3 4 5 6 7 8 9 : ; < = > ?
@ A B C D E F G H I J K L M N O
PQRSTUVWXYZ[\]^_
`abcdefghijklmno
pqrstuvwxyz { | } ~ [
€ [] , f , ... † ‡ ^ ‰ Š < Œ [] Ž []
° ± 2 3 ′ μ 9 · 1 Ω » 1/4 1/2 3/4 ¿
À Á Â Ā Ä A Æ Ç È É Ê Ë Ì Í Î Ï
ĐNÒÓÔŌÖרÙÚÛÜÝÞß
à á â ā a a ce ç è é ê ë
đ n ò ó ô ō ö ÷ ø ù ú û ü ý þ ÿ
```

# We are going to work with evenly spaced texture atlases.

# Not Evenly Spaced

(you can not make a uniform grid on this)



## **Evenly Spaced**

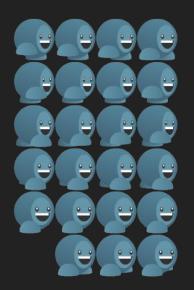


#### **Evenly Spaced**



#### **Evenly Spaced**





```
! " # $ % & ' () * + , - . /
0 1 2 3 4 5 6 7 8 9 : ; < = > ?
@ A B C D E F G H I J K L M N O
P Q R S T U V W X Y Z [ \ ] ^ _
` a b c d e f g h i j k l m n o
p q r s t u v w x y z { | } ~
```

#### Drawing a Single Sprite

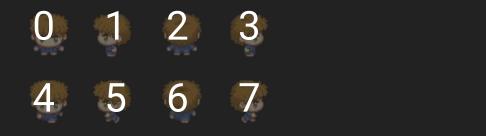
(From a Texture Atlas)



george\_0.png

We need the UV coordinates of the individual sprite.





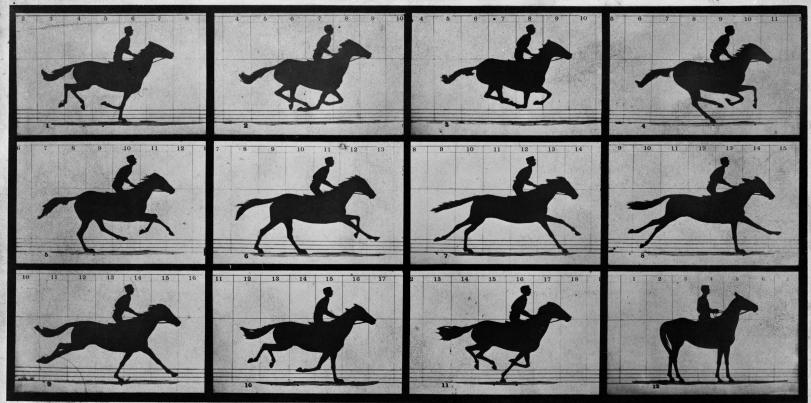
```
u,v • • 7
```

```
float u = (float)(index % cols) / (float)cols;
float v = (float)(index / cols) / (float)rows;
float width = 1.0f / (float)cols;
float height = 1.0f / (float)rows;
float texCoords[] = { u, v + height, u + width, v + height, u + width, v,
                  u, v + height, u + width, v, u, v };
-0.5, -0.5, 0.5, 0.5, -0.5, 0.5 };
```

```
float u = (float)(index % cols) / (float)cols;
   float v = (float)(index / cols) / (float)rows;
   float width = 1.0f / (float)cols;
   float height = 1.0f / (float)rows;
   float texCoords[] = { u, v + height, u + width, v + height, u + width, v,
                        u, v + height, u + width, v, u, v ;
   -0.5, -0.5, 0.5, 0.5, -0.5, 0.5;
   glBindTexture(GL TEXTURE 2D, textureID);
   glVertexAttribPointer(program->positionAttribute, 2, GL_FLOAT, false, 0, vertices);
   glEnableVertexAttribArray(program->positionAttribute);
   glVertexAttribPointer(program->texCoordAttribute, 2, GL_FLOAT, false, 0, texCoords);
   glEnableVertexAttribArray(program->texCoordAttribute);
   glDrawArrays(GL_TRIANGLES, 0, 6);
   glDisableVertexAttribArray(program->positionAttribute);
   glDisableVertexAttribArray(program->texCoordAttribute);
void Entity::Render(ShaderProgram *program) {
   glm::mat4 modelMatrix = glm::mat4(1.0f);
   modelMatrix = glm::translate(modelMatrix, position);
   program->SetModelMatrix(modelMatrix);
   DrawSpriteFromTextureAtlas(program, 7);
```

void Entity::DrawSpriteFromTextureAtlas(ShaderProgram \*program, int index)

#### Animation!



Copyright, 1878, by MUYBRIDGE.

MORSE'S Gallery, 417 Montgomery St., San Francisco.

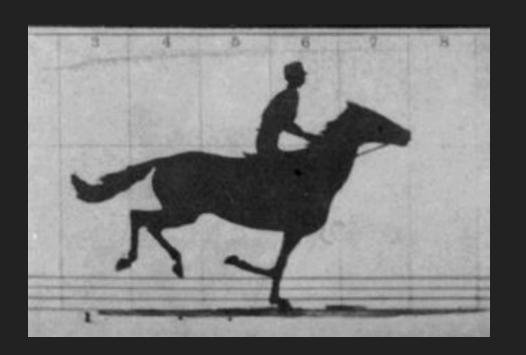
THE HORSE IN MOTION.

Illustrated by MUYBRIDGE.

AUTOMATIC ELECTRO-PHOTOGRAPH.

"SALLIE GARDNER," owned by LELAND STANFORD; running at a 1.40 gait over the Palo Alto track, 19th June, 1878.

The negatives of these photographs were made at intervals of twenty-seven inches of distance, and about the twenty-fifth part of a second of time; they illustrate consecutive positions assumed in each twenty-seven inches of progress during a single stride of the mare. The vertical lines were twenty-seven inches apart; the horizontal lines represent elevations of four inches each. The exposure of each negative as less than the two-thousandth part of a second.





Define indices of animation: (3, 7, 11, 15)

Have a timer.

Go to next frame when timer hits value.

If last frame (go to first) - looping.

```
player.textureID = LoadTexture("george_0.png");
player.cols = 4;
player.rows = 4;
player.animIndices = new int[4] {3, 7, 11, 15};
player.animFrames = 4;
```

```
void Entity::Update(float deltaTime)
    position += movement * speed * deltaTime;
    animTime += deltaTime;
    if (animTime >= 0.25f)
        animTime = 0.0f;
        animIndex++;
        if (animIndex >= animFrames)
            animIndex = 0;
void Entity::Render(ShaderProgram *program) {
    glm::mat4 modelMatrix = glm::mat4(1.0f);
    modelMatrix = glm::translate(modelMatrix, position);
    program->SetModelMatrix(modelMatrix);
```

DrawSpriteFromTextureAtlas(program, animIndices[animIndex]);

# Monospaced Font Rendering

```
! " # $ % & ' ( ) * + , - . /
0 1 2 3 4 5 6 7 8 9 : ; < = > ?
 ABCDEFGHIJKLMNO
PQRSTUVWXYZ[\]^_
`abcdefghijklmn<mark>o</mark>
pqrstuvwxyz{|}~[
€ [] , f " ... † ‡ ^ ‰ Š < Œ [] Ž []
□ ' ' " " • - - - ™ ; > œ □ ž Ÿ
 | ¢ £ ¤ \ | § " © \ | « \ - \ | 8 -
° ± 2 3 ′ μ 9 · 1 Ω » 1/4 1/2 3/4 ¿
À Á Â Ã Ä Å Æ Ç È É Ê Ë Ì Í Î Ï
ĐNÒÓÔŌÖרÙÚÛÜÝÞß
à á â ā a a ceçè é ê ë ì í î ï
đ n ò ó ô ō ö ÷ ø ù ú û ü ý þ ÿ
```

For each character in a string

- Draw 2 Triangles
- Use UV coordinates for character

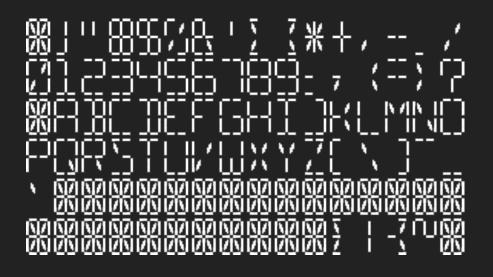


0 0 000 NUL (null) 1 1 001 SOH (start of heading) 3 2 20 040   Space 3 3 21 041 !! 3 2 20 42 "" 4 4 044   B A 97 61 141 a a 4 2 2 002 STX (start of text) 3 3 20 042 "" 6 6 42 102 B B 98 62 142 b b 3 3 030 ETX (end of text) 3 5 20 043 # # 67 43 103 C C 99 63 143 c c 4 4 044 &**EOT (end of transmission) 5 5 005 ENQ (enquiry) 6 6 006 ACK (acknowledge) 7 7 007 BEL (bell) 8 8 010 BS (backspace) 9 9 011 TAB (horizontal tab) 10 A 012 LF (NL line feed, new line) 11 B 013 VT (vertical tab) 12 C 014 FF (NP form feed, new page) 15 F 015 ST (carriage return) 16 F 017 SI (shift in) 16 10 020 DLE (data link escape) 17 17 07 SI (shift in) 18 12 022 DC2 (device control 1) 19 13 023 DC3 (device control 3) 18 12 022 DC2 (device control 4) 29 13 023 DC3 (device control 3) 21 14 C 024 DC4 (device control 4) 21 15 025 NAK (negative acknowledge) 21 16 026 SYN (synchronous idle) 22 16 026 SYN (synchronous idle) 23 17 027 ETB (end of transmission) 35 20 044 4 b 66 44 0 100 B D 99 60 140 ` C 7 43 103 B C 99 63 143 c C 99 61 144 a a 66 44 104 B D 99 63 143 c C 99 62 142 b b 66 44 104 B D 99 63 143 c C 100 65 145   C 99 63 143 c C 100 65 145   C 100 65 145   C 100 65 154   C 100 65 154   C 100 65 154   C 100 65 15																				
2 2 002 STX (start of text)	0	0	000	NUL	(null)	32	20	040		Space	64	40	100	a#64;	0	96	60	140	`	
2 2 002 STX (start of text)	1	1	001	SOH	(start of heading)						65	41	101	A	A	97	61	141	a	a
4 4 004 EOT (end of transmission) 36 24 044 4#36; \$ 68 44 104 4#68; D 10 64 144 4#100; d 5 5 005 ENQ (enquiry) 37 25 045 4#37; \$ 69 45 105 4#50; D 100 64 144 6#100; d 6 6 06 ACK (acknowledge) 38 26 046 4#39; C 70 46 106 4#70; F 102 66 146 4#102; f 7 7 007 BEL (bell) 39 27 047 4#39; C 71 47 107 4#71; G 103 67 147 4#103; g 8 8 010 BS (backspace) 40 28 050 4#40; C 72 48 110 4#73; I 105 69 151 4#103; g 10 40 12 LF (NI line feed, new line) 41 29 051 4#41; C 73 49 111 4#73; I 105 69 151 4#103; i 10 4 012 LF (NI line feed, new page) 42 20 052 4#42; T 44 112 4#74; J 106 6A 152 4#106; j 11 B 013 VT (vertical tab) 42 2A 052 4#42; T 74 4A 112 4#74; J 106 6A 152 4#106; j 11 B 013 VT (vertical tab) 42 2A 052 4#42; T 75 4B 113 4#75; K 107 6B 153 4#107; k 12 D 015 CR (carriage return) 45 2D 055 4#46; T 76 4C 114 4#76; L 108 6C 154 4#108; l 107 6B 153 4#107; k 107 6B 15	2					34	22	042	a#34;	rr	66	42	102	a#66;	В	98	62	142	b	b
5 5 005 ENQ (enquiry) 6 6 006 ACK (acknowledge) 7 7 007 BEL (bell) 39 27 047 4899; ' 7 1 47 107 4871; 6 103 67 147 48103; g 8 8 010 BS (backspace) 9 9 011 TAB (horizontal tab) 10 A 012 LF (NL line feed, new line) 11 B 013 VT (vertical tab) 12 C 014 FF (NP form feed, new page) 13 D 015 CR (carriage return) 14 E 016 SO (shift out) 15 F 017 SI (shift in) 16 10 020 DLE (data link escape) 17 1 1 021 DC1 (device control 1) 18 1 2 022 DC2 (device control 1) 19 1 3 023 DC3 (device control 1) 19 1 3 023 DC3 (device control 4) 19 1 1 3 024 DC4 (device control 4) 21 1 1 5 025 NAK (negative acknowledge) 22 1 6 026 SYN (synchronous idle) 23 1 7 027 ETB (end of trans. block) 25 1 9 031 EM (end of medium) 25 7 30 EX 034 FS (file separator) 26 1 10 036 RS (record separator) 27 1 1 1 036 RS (record separator) 28 1 1F 037 US (unit separator) 29 2 CL (durit separator) 29 2 CL (durit separator) 20 3 2 0 3 2 0 62 (specific separator) 20 40 24 RS 030 CRS (record separator) 20 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	3	3	003	ETX	(end of text)	35	23	043	#	#	67	43	103	a#67;	C	99	63	143	c	C
6 6 006 ACK (acknowledge) 38 26 046 4#38; 4 70 46 106 4#70; F 102 66 146 4#102; f 7 7 007 BEL (bell) 39 27 047 4#39; ' 71 47 107 4#71; G 103 67 147 4#103; g 8 8 010 BS (backspace) 40 28 050 4#40; ( 72 48 110 4#72; H 104 68 150 4#104; h 105 69 151 4#105; i 10 A 012 LF (NL line feed, new line) 41 29 051 4#41; ) 73 49 111 4#73; I 105 69 151 4#105; i 11 B 013 VT (vertical tab) 41 29 051 4#41; ) 75 4B 113 4#75; K 107 68 153 4#105; i 11 B 013 VT (vertical tab) 42 2A 052 4#42; * 74 4A 112 4#74; J 106 6A 152 4#106; j 11 B 013 VT (vertical tab) 42 2D 055 4#42; * 75 4B 113 4#75; K 107 6B 153 4#105; i 107 6B 1	4	4	004	EOT	(end of transmission)	36	24	044	\$	ş	68	44	104	D	D	100	64	144	d	d
7 7 007 BEL (bell)	5					37	25	045	%	*	69	45	105	E	E	101	65	145	e	е
7 7 007 BEL (bell)	6	6	006	ACK	(acknowledge)	7-7-7				100	70	46	106	F	F	102	66	146	f	f
9 9 011 TAB (horizontal tab) 10 A 012 LF (NL line feed, new line) 11 B 013 VT (vertical tab) 12 C 014 FF (NP form feed, new page) 13 D 015 CR (carriage return) 14 E 016 SO (shift out) 15 F 017 SI (shift in) 16 10 020 DLE (data link escape) 17 11 021 DC1 (device control 1) 18 12 022 DC2 (device control 2) 19 13 023 DC3 (device control 3) 20 14 024 DC4 (device control 4) 21 15 025 NAK (negative acknowledge) 22 16 026 SYN (synchronous idle) 23 17 027 ETB (end of trans. block) 23 17 027 ETB (end of medium) 25 18 032 SUB (substitute) 26 18 032 SUB (substitute) 27 18 033 ESC (escape) 28 16 036 RS (record separator) 29 10 11 037 US (unit separator) 30 12 0 034 PC3 (unit separator) 41 29 051 4#41; ) 42 2A 052 4#42; * 44 2C 054 4#42; * 75 4B 113 4#75; K 76 4C 114 4#76; L 77 4D 115 4#77; M 109 6D 155 4#109; m 77 4D 115 4#77; M 109 6D 155 4#109; m 78 4E 116 4#78; N 110 6E 156 4#110; n 79 4F 117 4#79; O 111 6F 157 4#111; O 102 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	7					39	27	047	@#39;	F.	71	47	107	G	G	100	700	100		
10 A 012 LF (NL line feed, new line) 11 B 013 VT (vertical tab) 12 C 014 FF (NP form feed, new page) 13 D 015 CR (carriage return) 14 E 016 SO (shift out) 15 F 017 SI (shift in) 16 10 020 DLE (data link escape) 17 11 021 DC1 (device control 1) 18 12 022 DC2 (device control 2) 19 13 023 DC3 (device control 3) 20 14 024 DC4 (device control 4) 21 15 025 NAK (negative acknowledge) 22 16 026 SYN (synchronous idle) 23 17 027 ETB (end of trans. block) 24 18 030 CAN (cancel) 25 19 031 EM (end of medium) 26 10 036 RS (record separator) 27 18 037 US (unit separator) 28 16 036 RS (record separator) 30 15 CR (carriage return) 42 2A 052 * * 43 2B 053 * * 44 2C 054 , , 75 4B 113 K K 107 6B 153 k k 76 4C 114 L L 76 4C 114 L L 77 4D 115 M M 109 6D 155 m m 77 4D 115 M M 100 6D 155 m m 78 4E 116 N M 110 6E 156 n n 78 4E 116 N M 110 6E 156 n n 78 4E 116 N M 110 6E 156 n n 78 4E 116 N M 110 6E 156 n n 78 4E 116 N M 110 6E 156 m m 111 6F 157 o o 80 50 120 P P 111 70 160 p p 80 50 120 P P 80 50 120 P P 81 113 71 161 q q 81 51 121 Q Q 81 113 71 161 q q 81 51 121 Q Q 81 113 71 161 q q 81 51 121 Q Q 81 113 71 161 q q 81 51 121 Q Q 81 71 71 66 o p 81 71 60 p p 82 52 122 R R 81 71 71 66 o p 81 71 66 p p 82 52 122 R R 81 71 72 162 r r 83 53 123 S S 84 54 124 T T 85 51 125 U U 86 56 126 V V 87 71 72  75 165 w W 87 71 72  75 165 w W 88 58 130 X Y 89 59 131 Y Y 89 59 131 Y Y 80 12 77 17 y Y 81 10 10 10 6E 156 n n 81 110 04 14 04 06 04 04 04 04 04 04 04 04 04 04 04 04 04	8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	6#72;	H	104	68	150	h	h
11 B 013 VT (vertical tab) 12 C 014 FF (NP form feed, new page) 13 D 015 CR (carriage return) 14 E 016 SO (shift out) 15 F 017 SI (shift in) 16 10 020 DLE (data link escape) 17 11 021 DC1 (device control 1) 18 12 022 DC2 (device control 2) 19 13 023 DC3 (device control 3) 20 14 024 DC4 (device control 4) 21 15 025 NAK (negative acknowledge) 22 16 026 SYN (synchronous idle) 23 17 027 ETB (end of trans. block) 23 17 027 ETB (end of medium) 25 18 030 CAN (cancel) 26 18 032 SUB (substitute) 27 18 033 ESC (escape) 28 16 036 RS (record separator) 30 1F 037 US (unit separator) 43 2B 053 + + 75 4B 113 K K 107 6B 153 k k #107 6B 153 k k #107 6B 153 k k #107 6B 153 k k #108 for 4 #108; l #108 for 5 #108; l #108 for 5 #108; l #108 for 6 #108 for 6 #108; l #108 for	9					37.577		2.70.77			73	49	111	6#73;	I	105	69	151	i	i
12 C 014 FF (NP form feed, new page) 13 D 015 CR (carriage return) 14 E 016 SO (shift out) 15 F 017 SI (shift in) 16 10 020 DLE (data link escape) 17 11 021 DC1 (device control 1) 18 12 022 DC2 (device control 2) 19 13 023 DC3 (device control 3) 20 14 024 DC4 (device control 4) 21 15 025 NAK (negative acknowledge) 22 16 026 SYN (synchronous idle) 23 17 027 ETB (end of trans. block) 25 19 031 EM (end of medium) 26 1A 032 SUB (substitute) 27 1B 033 GS (group separator) 30 1E 036 RS (record separator) 31 1F 037 US (unit separator) 44 2C 054 6#44; , 76 4C 114 6#76; L 108 6C 154 6#108; L 77 4D 115 6#77; M 109 6D 155 6#109; m 109 6D 155 6#1109; m 109 6D 155 6#109; m 109 6D 155 6#1109; m 109 6D	10				(NL line feed, new line)						1006	004 T DI				7-90007				
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14 E 016 SO (shift out)	12	C	014	FF	(NP form feed, new page)	28.5	47.50	V7170 E		100						1000000				
15 F 017 ST (shift in) 16 10 020 DLE (data link escape) 17 11 021 DC1 (device control 1) 18 12 022 DC2 (device control 2) 19 13 023 DC3 (device control 3) 20 14 024 DC4 (device control 4) 21 15 025 NAK (negative acknowledge) 22 16 026 SYN (synchronous idle) 23 17 027 ETB (end of trans. block) 24 18 030 CAN (cancel) 25 18 032 SUB (substitute) 26 1A 032 SUB (substitute) 27 1B 033 ESC (escape) 28 1C 034 FS (file separator) 30 1E 036 RS (record separator) 31 1F 037 US (unit separator) 47 2F 057 / / 48 30 060 0 0 48 35 121 Q 0 113 71 161 r 0 113 71 161 	13	D	015	CR	(carriage return)	47.50		45 19305		100						1.000				
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```



Depending on the font texture, you may have to shift the character value.

```
void DrawText(ShaderProgram *program, GLuint fontTextureID, std::string text, float size, float spacing, glm::vec3 position) {
   float width = 1.0f / 16.0f;
    float height = 1.0f / 16.0f;
    std::vector<float> vertices:
    std::vector<float> texCoords;
    for (int i = 0; i < text.size(); i++)
       int index = (int)text[i];
       float u = (float)(index % 16) / 16.0f;
       float v = (float)(index / 16) / 16.0f;
       texCoords.insert(texCoords.end(), { u, v + height, u + width, v + height, u + width, v,
                                                  u, v + height, u + width, v, u, v );
       float offset = (size + spacing) * i;
       vertices.insert(vertices.end(), { offset + (-0.5f * size), (-0.5f * size),
                                            offset + (0.5f * size), (-0.5f * size),
                                            offset + (0.5f * size), (0.5f * size),
                                            offset + (-0.5f * size), (-0.5f * size),
                                            offset + (0.5f * size), (0.5f * size),
                                            offset + (-0.5f * size), (0.5f * size) });
```

# After the vertices and texCoords are setup, we can draw using familiar code.

```
glm::mat4 modelMatrix = glm::mat4(1.0f);
modelMatrix = glm::translate(modelMatrix, position);
program->SetModelMatrix(modelMatrix);
glBindTexture(GL_TEXTURE_2D, fontTextureID);
glVertexAttribPointer(program->positionAttribute, 2, GL_FLOAT, false, 0, vertices.data());
glEnableVertexAttribArray(program->positionAttribute);
glVertexAttribPointer(program->texCoordAttribute, 2, GL_FLOAT, false, 0, texCoords.data());
glEnableVertexAttribArray(program->texCoordAttribute);
glDrawArrays(GL_TRIANGLES, 0, vertices.size() / 2.0f);
glDisableVertexAttribArray(program->positionAttribute);
glDisableVertexAttribArray(program->texCoordAttribute);
```

#### Let's Animate George!

(grab code from the "Animation" example in github)