NEA: Font Rasterizer

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Chapter 1

Analysis

Text is a key aspect of how we interact with machines. Virtually everything that is done on a computer requires some form of reading on a screen. The program that converts the binary text data to pixels on a screen is a 'font engine' or 'font rasterizer'. These take some text or a single character and output a texture which will get copied into the screen buffer. There is another component of font rendering, which arranges individual characters output by a font rasterizer into words or paragraphs, called a layout engine.

Creating a full font engine is a very large task - the TrueType format (the industry standard for font files) is a very large specification, and can be further enhanced by vendor-specific extensions. For example, some fonts contain small programs inside them that adjust the actual glyphs to better fit the pixel grid of the screen. These are implemented in a custom virtual machine that is very complex and time consuming to create. However, when rendering characters at a large scale, the impact of these features is far less, yet still comes at a substancial performance cost.

My project has two parts: the parser and the renderer itself. The parser will take a TrueType font file and output the bezier curves of the selected character, by reading the binary file. This is non-trivial, because the TrueType format is relatively complex, and contains a lot of optional features (which this project will largely ignore, unless I have time left over). I will investigate parser-combinator systems and either use that or create my own custom parser architecture.

TrueType fonts are composed of straight line segments and bezier curves. These are primitives that are relatively easy to draw to the screen quickly, and are what the rendering portion of my project will involve. I will initially render at a high resolution, to avoid the need for anti-aliasing and reduce the possibility of artifacts (pixels out of place, etc) in the process. I will potentially implement some form of anti-aliasing at some point, depending on how well the rest of the project goes.

1.1 Project Scope

The TrueType format is very complex, and creating a full implementation is outside the scope of a NEA. For simplicity, I will focus on the most important part of the format: individual character glyphs. This avoids the need for parsing kerning data, ligatures, and other optional features that would be present in a full implementation. In addition, I will not implement the grid-fitting aspect of the specification, as this would require creating a virtual machine to run the instructions contained in the font.

add to this later as i find more stuff i can't do

1.2 Existing Solutions

1.2.1 SDL_ttf

SDL_ttf is a ready to use library for rendering fonts to a texture using the SDL graphics library. Internally, it uses the freetype library, which is discussed below.

Advantages:

- Simple to integrate into applications.
- Uses the freetype backend, which supports a wide range of font features.
- Can be compiled for any platform, due to the fact that it's written using crossplatform libraries and C++.

Disadvantages:

- Slower than using freetype alone, because it adds SDL bindings on top of it.
- Can only render on the CPU, failing to take advantage of any GPU that may be present.
- Since it uses SDL for rendering, it can be quite hard to use with a non SDL project.
- Due to it's simple API, it fails to expose many advanced features of freetype, that might be useful to a client.

1.2.2 freetype

Freetype is a free, open source font engine that is used in many large software projects, such as GNU/Linux, iOS and Postscript. It supports the vast majority of font features and formats, including little-used ones such as .FON files and X11 PCF fonts. However, due to this, it is very large, and rather slow.

Advantages:

- Can handle virtually any font format you may need.

- A full implementation of the TrueType specification, meaning it supports all of the features of the specification, as well as a number of vendor specific extensions.
- Will run on a wide variety of systems, including the 16-bit Atari and Amiga computers.
- Supports a wide range of character encodings, including the full unicode range of encodings, such as UTF-8 and UTF-16.

Disadvantages:

- Slow, due to it's support of the full specification.
- Has a large memory footprint, meaning there is less space available for other programs.
- Has a relatively complex API, that can be harder to integrate into applications already using a different font engine.
- It does not handle complex layouts, which may be useful for some users.

1.2.3 Quartz

Quartz is the font renderer used on MacOS and iOS devices, for almost all software. It uses subpixel positioning, which means each glyph doesn't have to be aligned with the pixel grid, instead being allowed to be anywhere between pixels, using subpixel rendering and anti-aliasing to properly handle this case.

Whilst this can result in clearer display at high dpi resolutions, (such as Apple's retina displays), at lower dpi monitors or smaller font sizes it can result in harder to read text.

Advantages:

- Provides the closest similarity to printed text when viewed on high DPI displays.
- Is included by default with MacOS and iOS

Disadvantages:

- Will only run on MacOS / iOS devices
- The subpixel grid can make fonts look blurry at low DPI monitors.

1.3 Project Background

1.3.1 Domain Terminology

Font Family: a collection of typefaces, at different weights, or styles such as italics.
Typeface: commonly referred to as a font, a typeface is a style of lettering that can be displayed on the screen or in print.
Font: an instance of a typeface at a specfic size.
Glyph: the shape corresponding to a specific character in a specific font.

1.3.2 Bezier Curves

Individual glyphs of a font are built up using *outlines*, which are themselves built of several segments of line and curve. More specifically, an outline consists of a set of line segments and quadratic bezier curves, which create a closed loop that forms all or part of the glyph. Luckily, both line segments and bezier curves are fairly easy for computers to render, and have been used in computer graphics since it's inception.

A quadratic bezier curve is described by the equation

$$\mathbf{B}(t) = (1-t)^2\mathbf{P}_0 + 2(1-t)t\mathbf{P}_1 + t^2\mathbf{P}_2$$

where $\mathbf{P}_0$, $\mathbf{P}_1$, $\mathbf{P}_2$ are the position vectors of the 3 control points for the curve, as t ranges from 0 to 1. We can draw this in a similar way to how we draw line segments: for a sufficient sample rate over t, we can evaluate $\mathbf{B}(t)$ and, rounding to the nearest pixel, plot that point.

Similarly, we can describe a line segment (which is effectively a linear bezier curve) using the following equation:

$$\mathbf{B}(t) = \mathbf{P}_0 + t(\mathbf{P}_1 - \mathbf{P}_0)$$

where $\mathbf{P}_0$, $\mathbf{P}_1$ are the two control points, the beginning and end of the line segment.

needs pictures

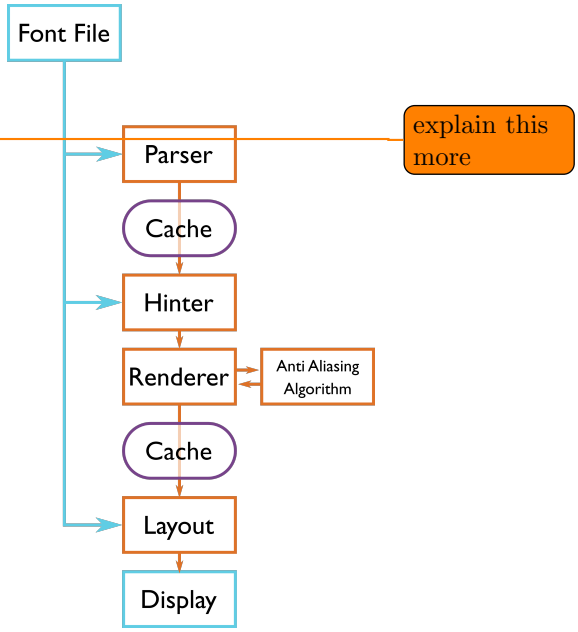
1.3.3 The Font Pipeline

There are several stages involved in getting text to display on the screen. First, the file containing the font is read. Often these are in a standard folder, but all font systems support reading from arbutrary files. The file is parsed (which means broken down into the data that's needed for the specific task) and various tables in the font file are read. The glyph coordinate data will then be parsed and read, usually into a cache.

Next is the hinting step. Because fonts are usually distributed as vectors, yet they are being displayed on a fine pixel grid, naievely rendering them can result in poor font quality. Hinting is an process of distorting the glyph to better fit the pixel grid and size that it will be displayed on. A properly hinted

font contains a small program for each glyph, to be executced in a virtual machine, that distorts the vector data to align with the pixel grid. This is a very complex process that is responsible for most of the time rendering the font.

The hinted font is then rendered, taking the bezier curves of the font and creating a raster image. This image is then anti-aliased, probably through supersampling , which is a process that turns a black-and-white image to a greyscale one which looks sharper on the screen. Some advanced anti-aliasing techniques take advantage of the RGB format of our displays, to get a larger effective resolution to work with.



Finally, the anti-aliased image is displayed on the screen. The exact process behind where it should be placed is handled by a layout engine, which is responsible for forming individual glyphs into words and pages. A layout engine still needs to reference the original font file, as kerning information which dictates the individual spacing between characters is stored in a table there.

font file $\rightarrow$ *parser* $\rightarrow$ *cache* $\rightarrow$ *hinting* $\rightarrow$ *rendering* $\rightarrow$ *anti−aliasing* $\rightarrow$ *layout*

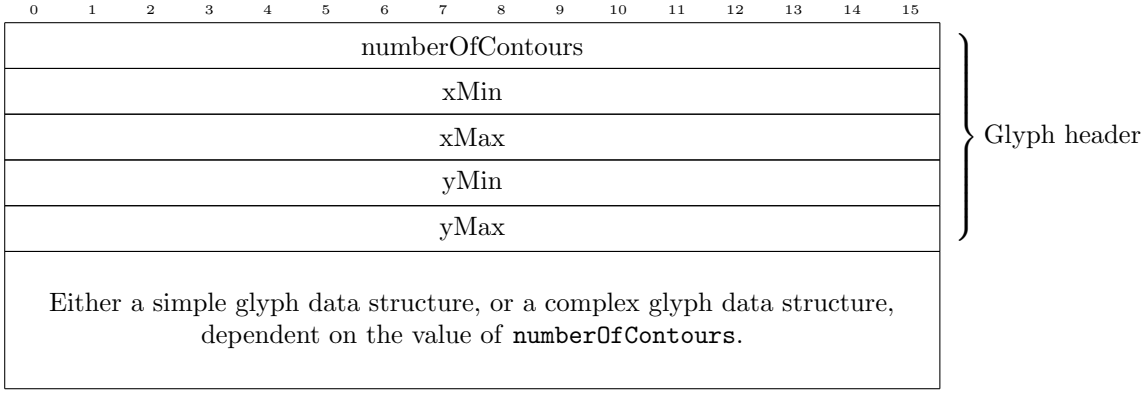
1.3.4 The TrueType Format

A TrueType font file is a binary file that contains all the data needed to display a font on the screen. The format, initially codenamed 'Bass', was designed by Apple in the 1980s for Mac System 7, and has continued to evolve and is now used by virtually every consumer operating system and font engine. The full specification is available at `https://developer.apple.com/fonts/TrueType-Reference-Manual/`, which will be summarized here.

A TrueType font is identified by the magic bytes (the first few bytes of many file formats are different to aid in distinguishing them) `0x00010000`. This is followed by a table directory which provides offsets to the various tables used in the file. Each table contains some information about how the font should be rendered, or metadata such as the font licence or author. For example, the `kern` table contains data related to font kerning, which controls the spacing between individual letters.

Of primary relevance to this project is the `glyf` table, which contains the actual glyph data used in the character to be rendered. It is structured as an array of

glyphs, with each glyph as follows:



Simple Glyph Data

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Array of glyph contour endpoints, one word wide, `numberOfContours` long.															
instructionLength															
Instruction 1								Instruction 2							
Instruction 3								···							
···								Instruction n							
Array of flags, length can be determined from the final endpoint index Example: C xSh ySh R xR yR Reserved															
Array of deltaX															
Array of deltaY															

Complex Glyph Data

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flags (see full spec for details)															
Glyph Index															
variable size Argument 1 (flag dependent)															
variable size Argument 2 (flag dependent)															

Note: Most uses of complex glyph tables are out of the scope of this project.

Using this table, and the `whatever the char map table is called`, we can turn a single character into a set of curves and line segments that can be scaled and drawn to the screen.

1.4 Measurable Objectives

1. The program will parse TTF files correctly, extracting character and glyph data from them.
2. The program will display single characters on the screen in a specified font.
3. The program will display these characters in a reasonable amount of time, say, not longer than a second (1000ms)
4. The program will anti-alias these characters for improved readability
5. The program will reject incorrectly formed TTF files in a safe manner

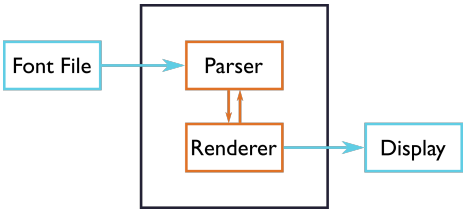
Chapter 2

Design

2.1 High Level Design

The task has 2 clear subdivisions:

1. Parsing the specified font file.
2. Displaying the parsed bezier curves on the screen.



I anticipate task 1 being the hardest, because the TrueType format is very complex and requires sophisticated parsing to extract the data needed. In contrast, rendering bezier curves to the screen is a task is moderately simple, as the bezier curve is used frequently in computer graphics applications.

I will program in C++, using the cmake build system, and use the SDL graphics library to display the GUI and rendered characters on the screen. Other libraries involved will be `sdl_ttf` for rendering the GUI text, and `sdl_gfx` to simplify bezier curve rendering.

perhaps

Whilst it may seem strange to include a different font rasterizer in a project involving font rasterization, this rasterizer will be used only for the GUI, not the actual display of characters itself. This is because, when debugging, the GUI will need to remain in a functional state despite the font rasterizer itself not being functional. Should the rasterizer get to a sufficiently stable state I shall consider removing `sdl_ttf` in favor of my own rasterizer.

2.1.1 The Parser

The parser needs to take the filename of a font, and by examining the associated file, read various data about the font. The following is a loose list of the data needed; other data may be needed to properly parse this, or for other purposes.

1. The `head` table, which contains information about the rest of the file
2. The `cmap` table, which contains the mapping between character and glyph index
3. The `loca` table, which maps glyph indices to offsets from the start of the `glyf` table
4. The individual glyph data, which requires the above data points to find in the file
5. Various font metrics, contained in various tables around the font file

At the very beginning of the file is the table directory, which contains the locations and length of all the font tables. Parsing this allows us to look up the locations of the rest of the data in the file. Next we will examine the `head` table to store important metrics that will be used elsewhere in the file.

At this point, the program will prompt the user for the character that they would like displayed. This character will be looked up in the `cmap` table, to get a glyph index, and then the `loca` table, to convert the index into a glyph offset and length.

Finally, we lookup the glyph in the `glyf` table, and store the entire glyph data structure. This is quite complex to parse, and will have it's own section of the program specifically. Parsing this will result in a list of bezier curves to be rendered, which is then passed to the renderer.

The `Font` class

A key data structure in this project will be the `Font` class. This is a large structure that contains, through composition, all the data needed to display the font.

The `Font` class		
Type	**Name**	**Access**
`std::map<std::string, TableData>`	tables	private
`std::map<char, Glyph>`	glyphs	private
`std::string`	fontName	private
Signature	**Returns**	**Access**
`Font()`	Font	public
`parse(std::string filename)`	void	public
`glyphExists(char glyph)`	bool	public
`getGlyph(char glyph)`	Glyph*	public
Plus many more private methods used for parsing...		

The table directory

This is at the beginning of the file; no offset is needed to find it. The first few bytes are magic numbers and version information that will be checked, to ensure that the file is in fact a TTF file. First, we check the initial 32 bits for the values `0x00010000` or `0x74727565`. These indicate that the file is a TTF font that should be processed using the standard scaler (what Apple calls the rasterizer). If this is not met, we will reject the file. Next, we parse the table of tables, starting at offset `0xC`, which contains a list of tables, alongside pointers to them, their length, and their checksums, to verify the integrity of the file. We will use a Dictionary system to store this data, with the table names as keys, and the values being a `TableData` class that contains the length, checksum, and data of each table.