FPGA Raycating

Team Lightspeed

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Outline

Project Overview

Design

Hardware

Software & Hardware Interface

Contributions & Lessons Learned

Questions & Demo

Project Overview

Why?

Perfect to demonstrate advantages of hardware vs general solution

90’s games are the best!

Goal 1 - Perfect 60hz timing

Goal 2 - Better performance 1 column resolution

Goal 3 - Memory efficient design

Goal 4 - Texturing in hardware

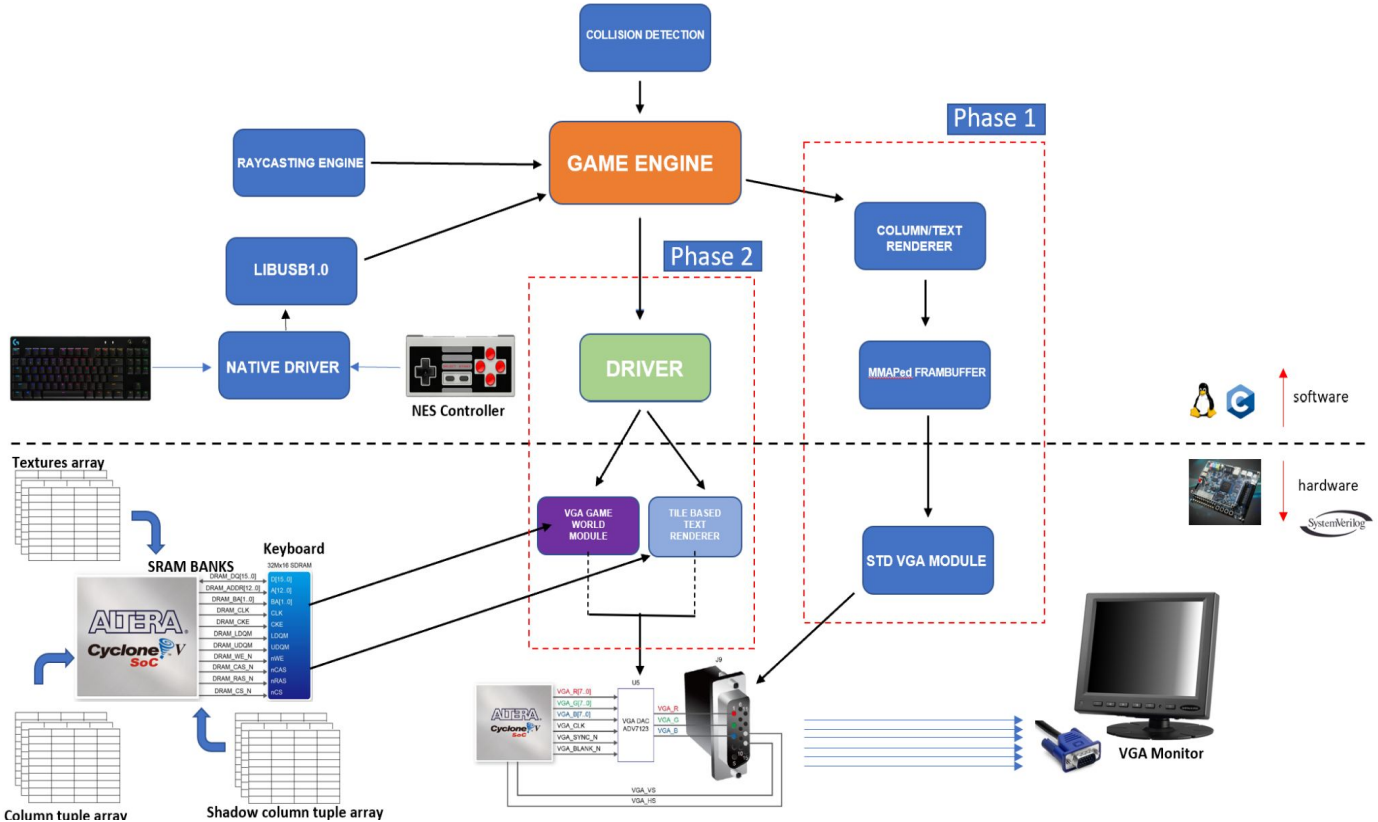
Initial Steps

- Port Java code from tutorial
- Framebuffer and usb code from lab 2 / 3
- Texturing in software
- Collision detection + movement

Problems Identified for Hardware

- Floating Point calc in texturing
- How to store texture data in hardware
- Too many calculations for one cycle

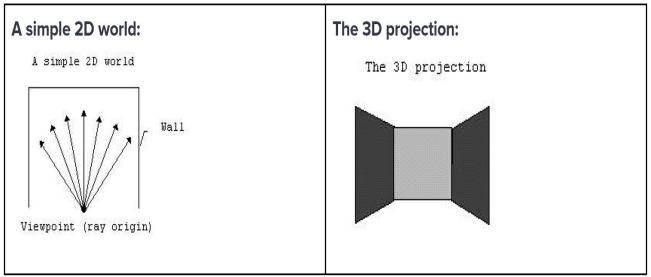
Design

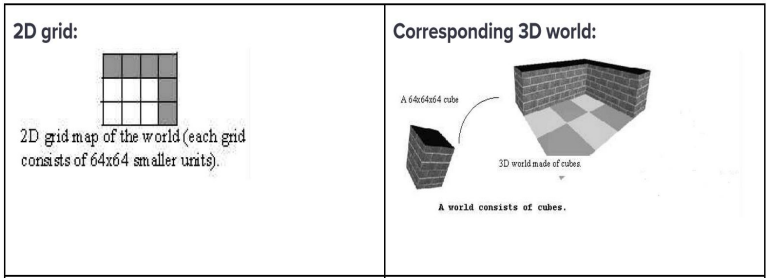

COLLISION DETECTION
RAYCASTING ENGINE
GAME ENGINE
Phase 1
LIBUSB1.0
Phase 2
COLUMN/TEXT RENDERER
NATIVE DRIVER
NES Controller
DRIVER
MMAPed FRAMBUFFER
software
hardware
Textures array
Keyboard
SRAM BANKS
VGA GAME WORLD MODULE
TILE BASED TEXT RENDERER
STD VGA MODULE
Column tuple array
Shadow column tuple array
VGA Monitor

Raycasting Algorithm

- ➔ Subset of the ray tracing algorithm, with geometric constraints, making it much faster
  - ◆ 64x64x64 cubes
  - ◆ Cannot rotate around x or z axis -> walls are always perfectly straight (columns)
- ➔ Based on basic high school trigonometry
- ➔ Rays are traced backwards, from the players eyes; march rays towards walls
- ➔ Raycasting is traced in groups (1 ray per column), whereas ray tracing is per pixel

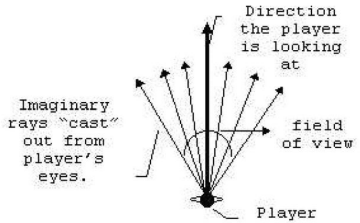
2D grid to a 3D world…



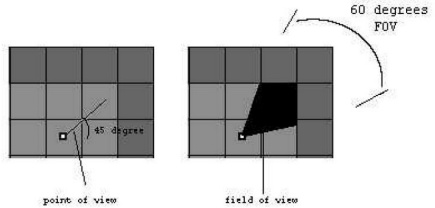


Some definitions...

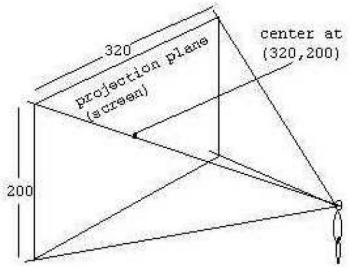
Field of View:



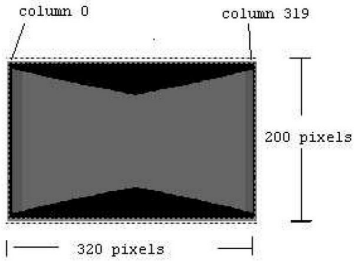
Field and point of view on the grid:



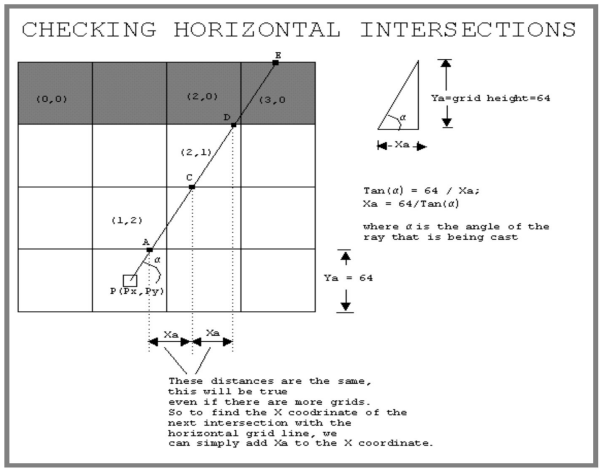
The projection plane:

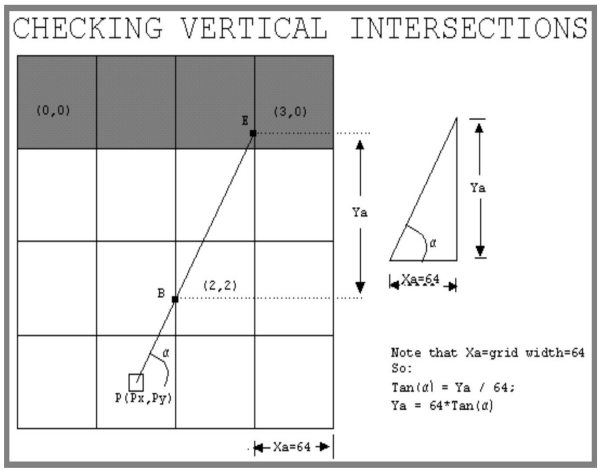


The ray cast on the screen (projection plane)



How the rays are traced to cast an image



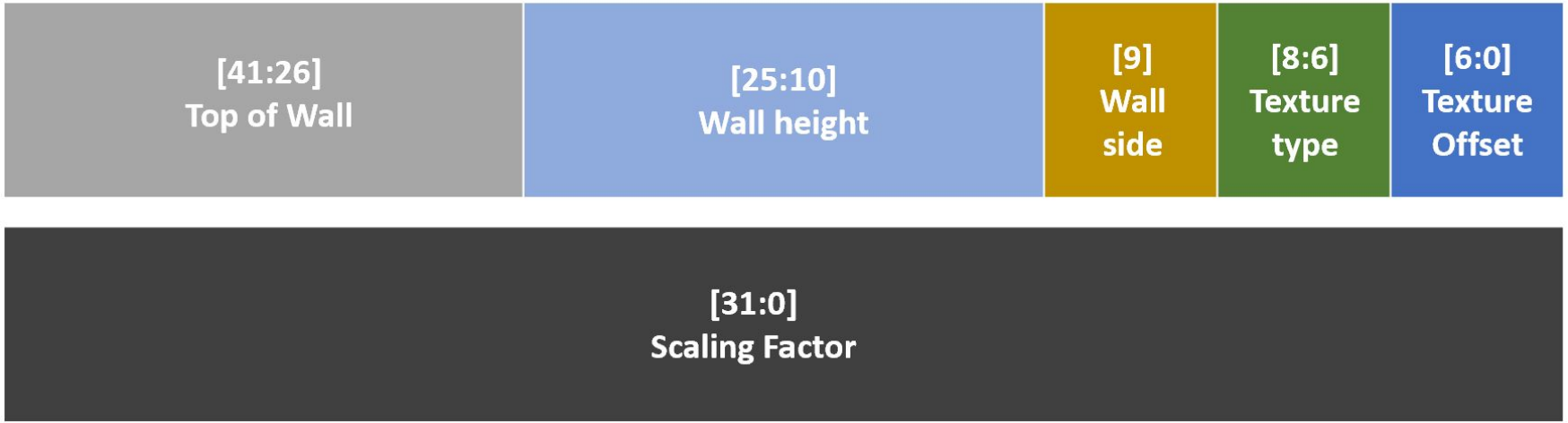


Hardware

- Started with vga_ball as blueprint
- Used Qsys to edit input and output
- Written in verilog
- Column, Texture, and Char modules in addition to supplied VGA module

Column Data Format

COLUMN DATA FORMAT



Pixel Pipeline

- Column decoder and renderer custom vga module
  - Six stage pixel pipeline
  - Texture data storage and retrieval
  - Triple buffering
  - Array storage and retrieval: Double barrel design
- Tile based character renderer
  - Two stage pipeline

Pixel Pipeline for Scene Rendering

Timing Frames with VBLANK and Triple Buffering

- ➔ Triple buffer design with two back buffers and one front buffer allows async data transfer
  - ◆ After each frame, hardware decides which buffer has data that is
    - Newest
    - Complete
- ➔ Query register for VBLANK status for software to time itself to 60hz
  - ◆ Otherwise have to rely on sleep functions (amateur hour)
  - ◆ We use polling but Interrupt is more fussy but less resource intensive

Tile Based Character Module

- ➔ Implemented after scene rendering
  - ◆ Outputs just 1 bit **on** or **off**
  - ◆ Stores all font data as array from lab 2 in registers (**readmemh**)
  - ◆ Can display white text on clear background or vice versa
  - ◆ Array storage and retrieval: Double barrel design
- ➔ Tile based character renderer
  - ◆ Two stage pipeline

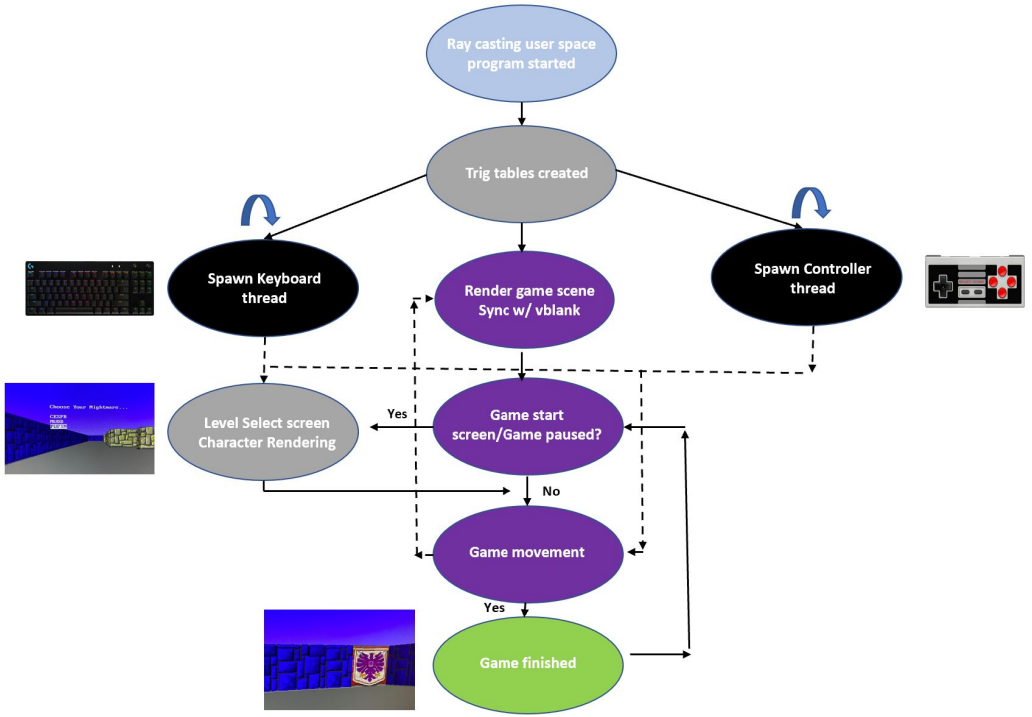
The Software

Salient features

- ➔ Raycasting engine ported from a Java implementation to C
- ➔ Multi-threaded environment allowing real time update of player coordinates on screen using both a controller and a keyboard. Jumping enabled too!
- ➔ Level select, pause menu, and end of game logic
- ➔ Infinite game loop incorporating all of the above features in logical flow
- ➔ Timing with vblank using a ioctl read
- ➔ Custom map struct holding metadata and map layout for each level of game

Game Flow/Logic

- ➔ Libusb1.0 library used to interface with keyboard/controller
- ➔ Pthreads library to run keyboard/controller/main threads



Custom Maze datatype/layout

```
typedef struct {
      int width;
      int height;
      int area;
      char name[20];
      short map[1296]; //make this
largest area of any map
} maze_t;
```

```
{ 24, 24, 576, "MUDD",
                {
                R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,
                R,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,R,
                R,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,O,R,
                R,O,O,O,O,O,O,O,O,O,O,O,W,O,W,W,W,W,W,O,O,O,O,R,
                R,O,O,O,O,W,O,O,O,W,O,W,O,O,O,O,O,O,W,O,O,O,O,R,
                R,O,O,W,O,W,W,O,W,O,W,O,W,O,O,O,O,O,O,W,O,O,O,R,
                R,O,O,W,O,O,W,O,W,O,W,O,W,O,W,W,W,W,W,W,O,O,O,R,
                R,O,O,O,W,O,W,O,W,O,W,O,W,O,W,O,O,O,O,O,O,O,O,R,
                R,O,O,O,W,O,W,O,W,O,W,O,W,O,W,O,W,W,W,W,W,W,W,R,
                R,O,O,O,W,O,W,O,W,O,W,O,W,O,W,O,O,O,O,O,O,O,O,R,
                R,O,O,O,W,O,W,O,W,O,W,O,W,O,W,O,O,O,O,O,O,O,O,R,
                R,O,O,O,W,O,W,O,W,O,W,O,W,O,W,W,W,W,W,W,O,W,W,R,
                R,O,W,O,W,O,W,O,W,O,O,O,W,O,O,O,O,O,O,W,O,O,O,O,R,
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                R,O,O,O,W,O,O,W,O,O,O,O,O,O,O,W,W,O,O,O,O,O,O,R,
                R,O,O,O,W,W,W,W,O,O,O,W,O,O,O,O,O,R,O,O,O,O,O,R,
                R,O,W,O,O,O,O,O,O,O,O,W,O,O,O,W,O,W,O,O,O,O,O,E,
                R,O,W,O,O,O,O,O,O,O,O,W,O,O,O,W,O,W,O,O,O,O,O,R,
                R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R
                }
},
```

Hardware-Software Interface

Things Worthy of Note

- ➔ Column**s** data transfer handled by driver
  - Receives pointer to **columns_t** struct
  - Expanded data width to 16 bits
  - Sends over each column as **5** parts, using bit shifting and logical OR ops
- ➔ Other things it does:
  - Blackout screen, check VBLANK, send char data, reset columns

What Each Member Worked On

& Lessons Learned

Questions?

Let’s get to the demo…