Game Boy Emulation on FPGA

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Use Case

- Compare software vs hardware emulation performance
- Understand Game Boy architecture to improve knowledge of classical architectures
- Recreate classic consoles on modern hardware
- Areas: Hardware, Software

Aintendo GAMEBOY

Solution

Components overview:
 Altera DE10 Standard
 NES Controllers with USB
 VGA display
 Speaker

Solution - System Block Diagram



Requirements - Performance

- Have games running at the same frame rate as they would on an actual Game Boy
- Achieve cycle accuracy on all non-illegal behavior
- Be able to load and switch between Pokémon Red and Tetris

Requirements - Usability

- Video and audio should be in sync and should match that of the original
- React to its inputs in a timely manner with the same input delay as the original (32 - 48 ms)
- Be able to save game progress to persistent storage (i.e. user, should be able to get back to the point they were in last time they played)

Testing, Verification, and Metrics

- Cycle accurate comparison of Mooneye emulator against Game Boi
 - Trace both Game Boi and Mooneye emulator while playing Pokémon Red and Tetris
- Use video recordings to calculate the input lag
 We may use more sophisticated methods in the future
 There are video tests that we can use to look for graphical glitches

Testing, Verification, and Metrics

- The emulator community has a lot of emulator verification tools, we'll make use of them to lighten the load on us.
- Tests that we have to write:
 - Driver tests
 - Game switching

Blargg's tests: Cpu instruction tests Ο Instruction timing tests 0 Memory timing tests 0 Mooneye GB Acceptance tests: Instruction timing tests Interrupt handling Ó ØAM DMA 0 **PPU timings** Serial Tests \bigcirc Timer Tests Ο Mooneye GB emulator only: All the Memory Bank tests

Tasks and Division of Labor

Tess
 CPU
 Sound
 Memory
 State saving

Adolfo

• CPU

- Graphics PPU & VGA
- Memory

State saving

Pratyusha

o CPU

• Drivers for controllers

- Game loader and switching
- Memory

Schedule

| Game Boi Timeline | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | _ | | | | | | | | | | | | | |
|--|-----------------|------|----------------------|-------------------|---------|--------|-----------|--------|------|-----------|--------|------|-----------|------|---|------|---------|----|-----|------|----|------|----------|-----|--------|--------|---|-------|------------|---------------|------|-----------|---------|-----|--------|---------|-------|-----|--------|--------|----|-------|------|-------|--|
| Total Slack: 2 weeks Blue - All; Red - Tess; Green - Adolfo; Ye | slow - Pratyusl | 18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TASK NAME | | | DURATION WORK DAY | TEAM S) MEMBER | PERCENT | WEEK : | 1 Th E | 5 50 1 | WEEK | 2 Th E | 5 50 B | WEEI | 3 Th E | 5 50 | W | EK 4 | 5 51 | WE | EK5 | 5 51 | WE | EK 6 | 5 50 | V T | VEEK 7 | 5 5 50 | W | EEK 8 | 5 54 | WEER M T W | Th C | DI M | WEEK 10 | E 5 | SI M T | WEEK 11 | c < 5 | W T | EEK 12 | 5 5 50 | WE | EK 13 | 5 51 | WEEK: | a Th E |
| Documentation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Abstract | 1/16 | 1/23 | 7 | All | 100% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Proposal Presentation | 1/27 | 2/2 | 5 | All | 100% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Design Review Presentation | 2/8 | 2/16 | 8 | All | 0% | | | | | | | | | | | | | | | 1000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Design Review Report | 2/8 | 3/2 | 24 | All | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Final Presentation | 4/5 | 4/26 | 21 | All | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| СРО | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Instruction Decoder | 2/5 | 2/9 | 4 | Tess | 0% | | | | | | | | | | | | and the | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Register File + ALU | 2/5 | 2/7 | 2 | Tess | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Memory Controller | 2/5 | 2/14 | 9 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PPU interconnect | 2/20 | 2/25 | 5 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Interrupts | 2/5 | 2/14 | 9 | Pratyusha | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| MCU interconnect | 2/29 | 3/6 | 6 | Pratyusha | 095 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PPU & Graphics | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| VGA Controller | 2/5 | 2/7 | 2 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | hard and the |
| Display RAM Reading | 2/8 | 2/9 | 1 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Tiles, Background and Window Display | 2/8 | 2/14 | 6 | Adolfo | 095 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sprites | 2/11 | 2/17 | 6 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Full Frame display | 2/14 | 2/19 | 5 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CPU interconnect | 2/20 | 2/25 | 5 | Adolfo | 095 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sound (APU) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pulse Generation | 2/5 | 2/8 | 3 | Tess | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Noise output | 2/8 | 2/9 | 1 | Tess | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Waveform Output | 2/8 | 2/15 | 7 | Tess | 095 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Full Stereo Ouput | 2/15 | 2/22 | 7 | Tess | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | hand 1 |
| Game Boi integration | 2/22 | 3/6 | 14 | Tess | 0% | | | | | | | | | | | | | | | | | | and sold | | | | | | | | | | | | | | | | | | | | 1 | | |
| Drivers and MCU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | la su a |
| Controller driver | 2/7 | 2/14 | 7 | Pratyusha | 095 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | hanna i |
| Flash Driver | 2/7 | 2/14 | 7 | Pratyusha | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Memory Mapped RAM | 2/16 | 2/22 | 6 | Pratyusha | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | · · · · · · · · · · · · · · · · · · · |
| Game State Saving | 2/22 | 2/29 | 7 | Pratyusha | 095 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Game Boi MCU interface | 2/29 | 3/6 | 6 | Pratyusha | 0% | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Memory | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Block RAM | 3/6 | 3/8 | 2 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | alares and | | | | | | | | | | | | | | | | ind and the |
| ROM loading | 3/8 | 3/12 | 4 | Adolfo | 0% | | | | | | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | | | | | | | harris and the second s |
| CPU integration | 3/10 | 3/20 | 10 | Tess | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | hanna |
| Game Boi integration | 3/10 | 3/20 | 10 | Adolfo & Tess | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | A set and | | | | | | | | | | | | | (|
| Testing (and debugging) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Blarggs Tests | 3/26 | 3/31 | 5 | All | 095 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mooneye Tests | 3/26 | 4/4 | 8 | All | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Video Tests | 3/26 | 4/4 | 8 | All | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Audio Tests | 3/26 | 4/4 | 8 | All | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | - | | | | | L | | |
| Input Lag Tests | 4/4 | 4/10 | 6 | All | 0% | | | | | | | | I | | | | | | | III | | | 1 | | | | | | | | I | | | | | | | | | | | | f | | |

Stretch Goals

Link cable

- Make a breakout board for the link cable
- Allow FPGA emulator to interact with Game Boy

User profiles

 Allow each game to have multiple user profiles, just like on the Nintendo Switch