GameBoy Advance

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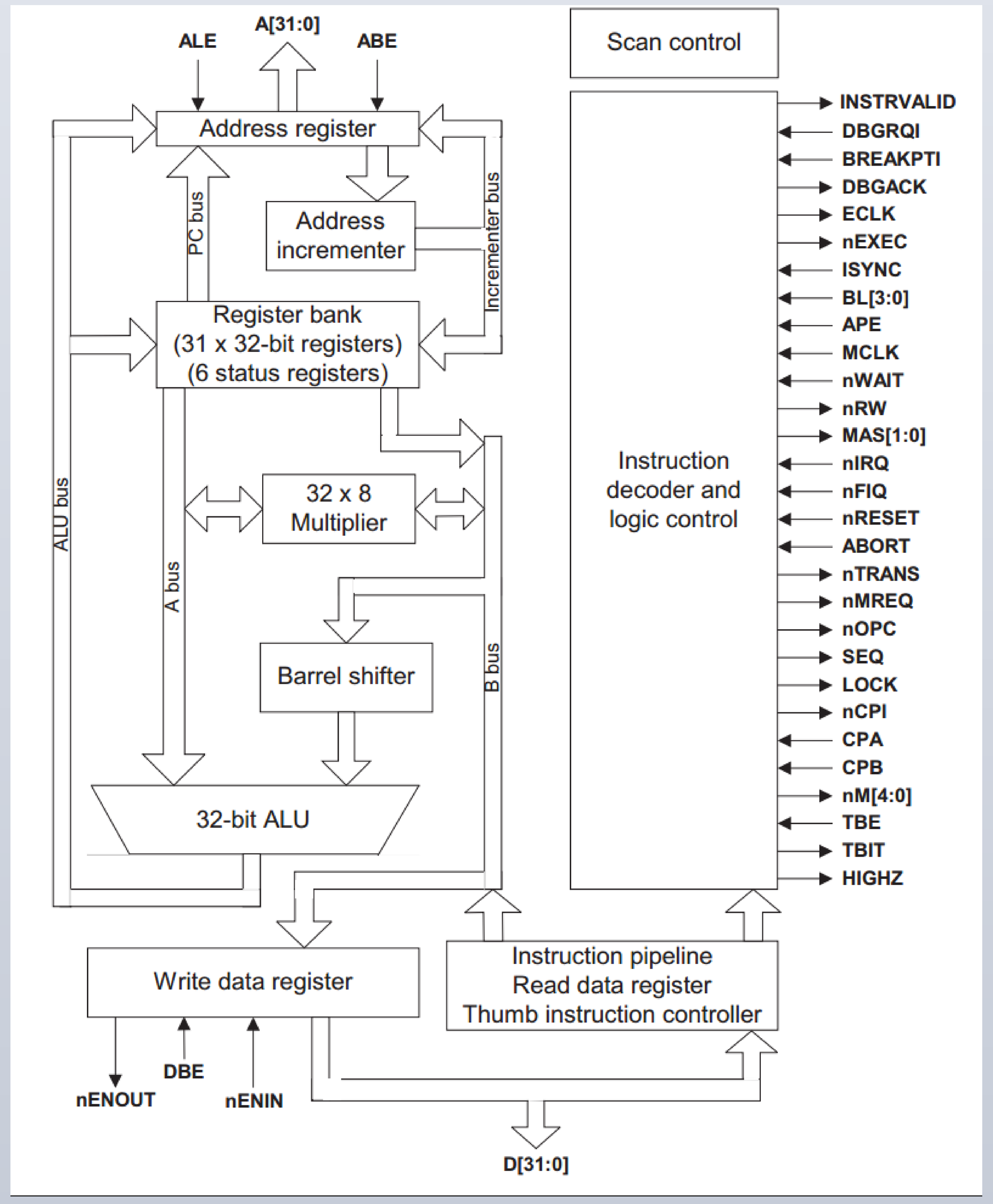
Team N64

Processor and Memory System

The Game Boy Advance uses an ARM7TDMI processor as the main CPU. The ARM7TDMI is a three-stage pipelined RISC processor that implements the ARMv4T ISA. Instructions are generally one-cycle-execute, but the CPU will stall the pipeline for longer instructions. Two instruction modes, ARM mode for 32-bit instructions and THUMB mode for 16-bit instructions, can be switched between with the BX instruction. The CPU also has 5 execution modes.

The GBA has 7 memory regions with varying bus widths and memory access times. We use BRAM for Internal RAM, VRAM, Palette RAM, OAM, GamePak ROM, and System ROM and distributed RAM for MMIO registers.

The GBA has an interrupt controller that muxes interrupts from DMA, Timers, VBLANK, HBLANK, and Key Presses. Interrupts are handled synchronous to the instruction stream. The game boy advance has four DMA channels, where lower number DMAs take priority over higher numbered DMAs. All DMAs take priority over the CPU and assert PAUSE on the CPU to preempt it. Like with interrupts, preemption occurs synchronous to the instruction stream.

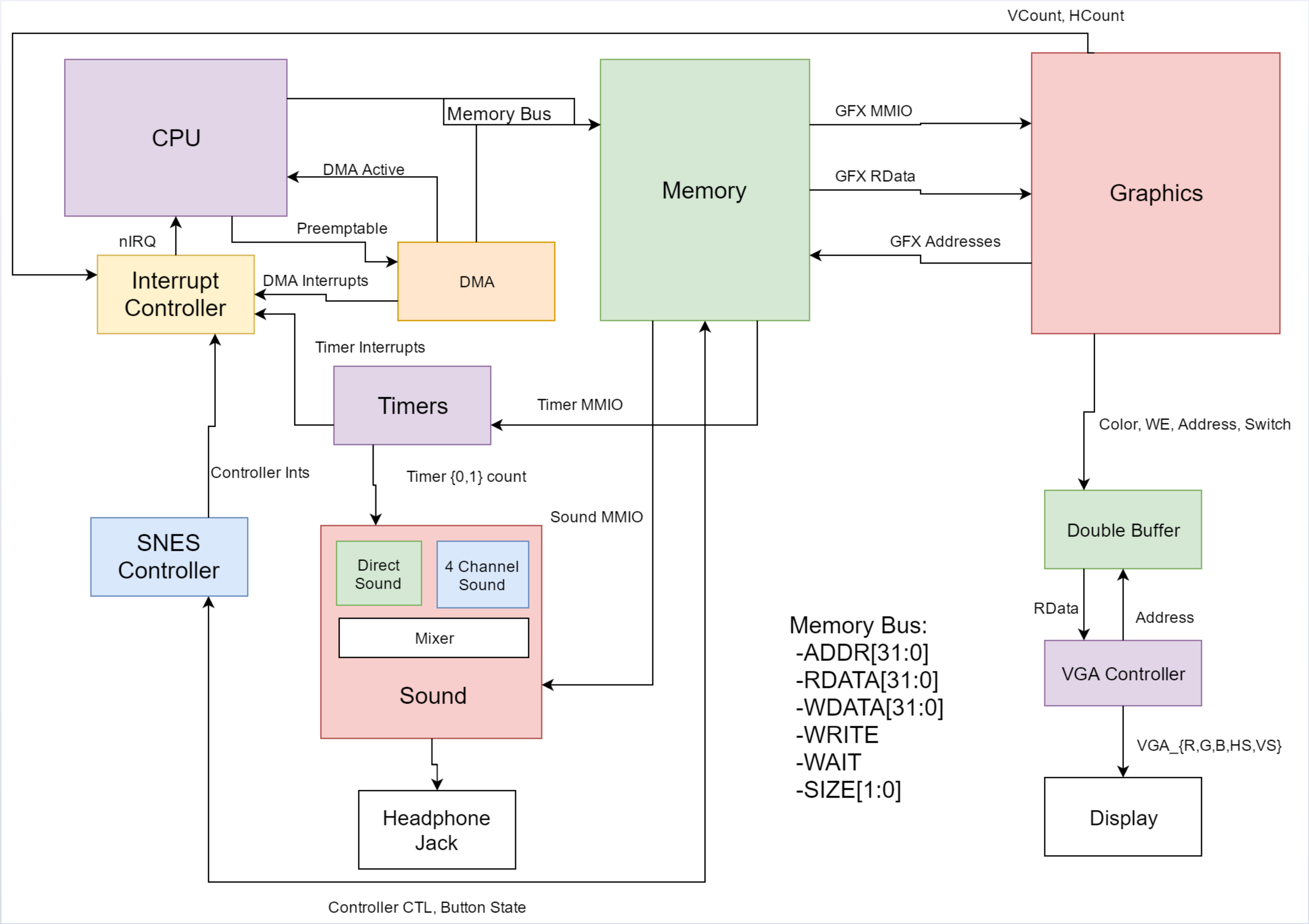


Direct Sound

Direct sound was a new feature added to the GameBoy Advance to add more sound control, over simply mixing together 4 channels of sound. Games could now put streams of 8 bit sound data into memory, and schedule it to play without anymore CPU interaction. The two direct sound channels can be configured to use any combination of the two timers, and two DMA channels. The given timer is set to choose the number of cycles between samples. On every timer overflow the audio data is passed from a FIFO to the mixer. When the FIFO has only 4 words left, a request will be made to the DMA channel to transfer four more words of data to the FIFO. The FIFO has a maximum depth of 8 32 bit words and is written to directly when the DMA channel writes to the Sound FIFO Input MMIO register. The mixer varies the volume, and ratio of direct sound to 4-channel sound, then outputs to the sound circuit.

The demonstration of direct sound working demonstrates full system integration. All of the handshaking for the memory controller between the CPU and the DMA has to be fully correct, as well as handshaking between DMA, timers, and sound, as well as the signals crossing clock domains between the main GBA clock and the sound output system.

System Architecture



Graphics

The Gameboy Advance Graphics system consists of four major stages: Backgrounds, Objects, Priority evaluation, and special effects.

The system can display up to four background layers simultaneously. There are three types of backgrounds: text, rotation, and bitmapped. For text backgrounds and objects, the screens are composed of 8x8 pixel block called tiles. Tiles are 8x8 pixel blocks in VRAM where each pixel is represented by an index into a color palette. Rotation backgrounds are also composed of tiles, but the background can be scaled and rotated by amounts set in MMIO registers. Bitmapped backgrounds allow the colors of each individual pixel to be specified directly in VRAM.

Objects can be scaled and rotated like backgrounds, where parameters for rotation/scaling are specified in object attribute memory. Objects can be square or vertical/horizontal rectangles from 8x8 to 64x64 pixels. There are three modes of objects: normal objects, semi-transparent objects, which can be used in the special effects circuit, and obj-window objects, which mark the pixels in the object as part of the object window.

Objects and Backgrounds have a specified priority from 0 to 3. Objects take priority over backgrounds with the same priority.

The GBA has two types of special effects – alpha blending and fade. Alpha blending computes a weighted average of the colors of the two layers involved in the blend; fade does the same, but the second color is always black or white. There are also two windows that can be specified in MMIO registers, where graphics layers can be selectively turned on or off inside the window.

The BIOS

The GameBoy Advance BIOS is about 75 million cycles of instructions. The BIOS was made to show off features of the GBA that were added or upgraded from the GameBoy Color. Namely, all sound produced is done with DMA sound, graphics are a blend of backgrounds and objects (mostly objects), the objects in the graphics heavily rely on rotation and scaling, and the graphics special effects (alpha-blending, Fade-in/Fade-out), as well as windowing. Since real game cartridges are out of the question for our project, the BIOS is the best test we have of a real GameBoy Advance system in action. It is, however, a fantastically aggressive test of system functionality.

Results

This project was a massive undertaking and required full time work from day 1. Unfortunately, we were not able to have our GameBoy Advance play any commercial games, because we did not have enough BRAM on our FPGA. Commercial games have size with magnitude of megabytes; originally we had planned to create a DRAM controller, but with the huge undertaking of the processor, we ran out of time. A DRAM controller was a challenge to create, because it requires using the ARM core on the Zedboard, Vivado's SDK, and HLS to create a master/slave interface with AXI, to communicate between the ARM core and the FPGA hardware.

One of the biggest challenges we had to overcome was to debug, and add to the ARM 7 processor we found. This required a tremendous amount of work, including learning VHDL, learning the ARM architecture, writing a thumb code decoder, and correctly integrating it with the buggy ARM 7 processor. The processor was such a huge undertaking it took until after Thanksgiving (of daily full time work) to get fully operational. This led to a huge crunch time of only one week to integrate the entire rest of the system.

The graphics pipeline in this project was also a huge undertaking. Besides the regular background, objects, scrolling, and rotation in the previous gaming consoles, this graphics pipeline supports rotation scaling, and special effects. Rotation scaling adds complexity in the way the objects are being addressed. The graphics pipeline has so many options it supports thousands of different combinations, making it impossible to fully test before integration.

The sound system in the GBA is a combination of 4 channel sound, and direct sound. 4 channel was feasible to test from the beginning because it was a combination of a 4 tone generators. But the direct sound could not be tested until the CPU was finished, and the timers and DMA were first integrated and tested with the CPU.

At first we was somewhat disappointed that we were not able to add DRAM and create a working system that plays any game, but after realizing how huge of an undertaking this project was in compared to the GameBoy Color, we are proud of what we were able to pull off in only one semester. For future groups that work on this project if they use this ARM processor, the project will still be challenging because of the complex graphics and sound systems, but it will be much more doable.

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