EECS150 - Digital Design

Lecture 15 - Video

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MIPS150 Video Subsystem

- Gives software ability to display information on screen.
- Equivalent to standard graphics cards:
  - Processor can directly write the display bit map
  - 2D Graphics acceleration
“Framebuffer” HW/SW Interface

- A range of memory addresses correspond to the display.
- CPU writes (using sw instruction) pixel values to change display.
- No synchronization required. Independent process reads pixels from memory and sends them to the display interface at the required rate.

CPU address map

Ex: 1024 pixels/line X 768 lines

Frame buffer

Display Origin:
Increasing X values to the right. Increasing Y values down.
Framebuffer Implementation

• Framebuffer like a simple dual-ported memory. Two independent processes access framebuffer:
  
  **CPU** writes pixel locations. Could be in random order, e.g. drawing an object, or sequentially, e.g. clearing the screen.
  
  **Video Interface** continuously reads pixel locations in scan-line order and sends to physical display.

• How big is this memory and how do we implement it? For us:

  \[1024 \times 768 \text{ pixels/frame} \times 24 \text{ bits/pixel}\]
Memory Mapped Framebuffer

MIPS address map

0xFFFFFFFF
0x8023FFFFD
0x80000000
0

Frame buffer

1024 pixels/line X 768 lines

Display Origin:
Increasing X values to the right. Increasing Y values down.

(0,0)
(1023, 767)

1024 * 768 = 786,432 pixels

We choose 24 bits/pixel
{ Red[7:0] ; Green[7:0] ; Blue[7:0] }

786,432 * 3 = 2,359,296 Bytes

• Total memory bandwidth needed to support frame buffer?
Frame Buffer Implementation

• Which XUP memory resource to use?

• Memory Capacity Summary:
  • LUT RAM
  • Block RAM
  • External SRAM
  • External DRAM

• DRAM bandwidth:
Framebuffer Details

768 lines, 1024 pixels/line = 786,432 pixel locations

MIPS address map

0xFFFFFFFF

0x80240000

0x80000000

Frame buffer

4K

4K

4K

1024 x 768 locations

XUP DRAM memory capacity: 256 MBytes (in external DRAM).

With Byte addressed memory, best to use 4 Bytes/pixel

Starting each line on a multiple of 4K leads to independent X and Y address: \{Y[9:0] ; X[11:2]\} Y == row number, X == pixel in row
Frame Buffer Physical Interface

Processor Side: provides a memory mapped programming interface to video display.

You do!

DRAM “Hub”: arbitrates among multiple DRAM users.

You do!

Video Interface Block: accepts pixel values from FB, streams pixels values and control signals to physical device.

We do!
Physical Video Interface

DVI connector: accommodates analog and digital formats

DVI Transmitter Chip, Chrontel 7301C.

Implements standard signaling voltage levels for video monitors. Digital to analog conversion for analog display formats.
Framebuffer Details 2009

• One pixel value per memory location.

MIPS address map

0xFFFFFFFF
0x803FFFFFC
0x80000000
0

Frame buffer

768 lines, 1K pixels/line = 786,432 memory locations

Virtex-5 LX110T memory capacity: 5,328 Kbits (in block RAMs).

(5,328 X 1024 bits) / 786432 = 6.9 bits/pixel max!

We choose 4 bits/pixel

• Note, that with only 4 bits/pixel, we could assign more than one pixel per memory location. Ruled out by us, as it complicated software.
Color Map

4 bits per pixel, allows software to assign each screen location, one of 16 different colors.

However, physical display interface uses 8 bits / pixel-color. Therefore entire pallet is $2^{24}$ colors.

Color Map converts 4 bit pixel values to 24 bit colors.

Color map is memory mapped to CPU address space, so software can set the color table. Addresses: $0x8040_0000$  $0x8040_003C$, one 24-bit entry per memory address.
Memory Mapped Framebuffer 2010

- A range of memory addresses correspond to the display.
- CPU writes (using sw instruction) pixel values to change display.
- No handshaking required. Independent process reads pixels from memory and sends them to the display interface at the required rate.

**MIPS address map**

0xFFFFF

0x801D4BFC

0x80000000

Frame buffer

800 pixels/line X 600 lines

Display Origin:
Increasing X values to the right. Increasing Y values down.

8Mbits / 480000 = 17.5 bits/pixel max!

We choose 16 bits/pixel
{ Red[4:0] ; Green[5:0] ; Blue[4:0] }
Framebuﬀer Details 2010

MIPS address map

600 lines, 800 pixels/line = 480,000 memory locations

XUP SRAM memory capacity:
~8 Mbits (in external SRAMs).

Starting each line on a multiple of 1K leads to independent X and Y address:
{Y[9:0] ; X[9:0]}
Y == row number, X == pixel in row

• Note, that we assign only one 16 bit pixel per memory location.
• Two pixel address map to one address in the SRAM (it is 32bits wide).
• Only part of the mapped memory range occupied with physical memory.
More generally, how does software interface to I/O devices?

"ZBT" synchronous SRAM, 9 Mb on 32-bit data bus, with four "parity" bits 256K x 36 bits (located under the removable LCD)

*ZBT (ZBT stands for zero bus turnaround) — the turnaround is the number of clock cycles it takes to change access to the SRAM from write to read and vice versa. The turnaround for ZBT SRAMs or the latency between read and write cycle is zero.
MIPS150 Video Subsystem

- Gives software ability to display information on screen.
- Equivalent to standard graphics cards:
  - Processor can directly write the display bit map
  - 2D Graphics acceleration
“Clearing” the screen - fill the entire screen with same color

Remember Framebuffer base address: 0x8000_0000
Size: 1024 x 768

clear:  # a0 holds 4-bit pixel color
        # t0 holds the pixel pointer
        ori  $t0, $0, 0x8000  # top half of frame address
        sll  $t0, $t0, 16    # form framebuffer beginning address
        # t2 holds the framebuffer max address
        ori  $t2, $0, 768    # 768 rows
        sll  $t2, $t2, 12    # * 1K pixels/row * 4 Bytes/address
        addu $t2, $t2, $t0   # form ending address
        addiu $t2, $t2, -4   # minus one word address
        
        # the write loop
L0:    sw   $a0, 0($t0)            # write the pixel
        bneq $t0, $t2, L0       # loop until done
        addiu $t0, $t0, 4      # bump pointer
        jr    $ra

How long does this take? What do we need to know to answer?
How does this compare to the frame rate?
Optimized Clear Routine

clear:

. Amortizing the loop overhead.

. 

# the write loop

L0:

sw $a0, 0($t0)             # write some pixels
sw $a0, 4($t0)
sw $a0, 8($t0)
sw $a0, 12($t0)
sw $a0, 16($t0)
sw $a0, 20($t0)
sw $a0, 24($t0)
sw $a0, 28($t0)
sw $a0, 32($t0)
sw $a0, 36($t0)
sw $a0, 40($t0)
sw $a0, 44($t0)
sw $a0, 48($t0)
sw $a0, 52($t0)
sw $a0, 56($t0)
sw $a0, 60($t0)
bneq $t0, $t2, L0            # loop until done
addiu $t0, $t0, 64        # bump pointer
jr $ra

What's the performance of this one?
From \((x_0, y_0)\) to \((x_1, y_1)\)

Line equation defines all the points:

\[
y - y_0 = \frac{y_1 - y_0}{x_1 - x_0}(x - x_0)
\]

For each \(x\) value, could compute \(y\), with:
then round to the nearest integer \(y\) value.

Slope can be precomputed, but still requires floating point \(*\) and \(+\) in the loop: slow or expensive!
Bresenham Line Drawing Algorithm

Developed by Jack E. Bresenham in 1962 at IBM. "I was working in the computation lab at IBM's San Jose development lab. A Calcomp plotter had been attached to an IBM 1401 via the 1407 typewriter console. ..."

- Computers of the day, slow at complex arithmetic operations, such as multiply, especially on floating point numbers.
- Bresenham's algorithm works with integers and without multiply or divide.
- Simplicity makes it appropriate for inexpensive hardware implementation.
- With extension, can be used for drawing circles.
**Line Drawing Algorithm**

This version assumes: \( x_0 < x_1, \ y_0 < y_1, \ \text{slope} \leq 45 \text{ degrees} \)

```java
function line(x0, x1, y0, y1)
    int deltax := x1 - x0
    int deltay := y1 - y0
    int error := deltax / 2
    int y := y0
    for x from x0 to x1
        plot(x,y)
        error := error - deltay
        if error < 0 then
            y := y + 1
            error := error + deltax
```

Note: error starts at \( \text{deltax}/2 \) and gets decremented by \( \text{deltay} \) for each \( x \), \( y \) gets incremented when error goes negative, therefore \( y \) gets incremented at a rate proportional to \( \text{deltax}/\text{deltay} \).
Line Drawing, Examples

deltay = 1 (very low slope). y only gets incremented once (halfway between x0 and x1)

\[
\begin{array}{cccccccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 \\
1 & & & & & & & & & & & & 1 \\
2 & & & & & & & & & & & & 2 \\
3 & & & & & & & & & & & & 3 \\
4 & & & & & & & & & & & & 4 \\
5 & & & & & & & & & & & & 5 \\
6 & & & & & & & & & & & & 6 \\
7 & & & & & & & & & & & & 7 \\
\end{array}
\]

\[
\begin{array}{cccccccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 \\
1 & & & & & & & & & & & & 1 \\
2 & & & & & & & & & & & & 2 \\
3 & & & & & & & & & & & & 3 \\
4 & & & & & & & & & & & & 4 \\
5 & & & & & & & & & & & & 5 \\
6 & & & & & & & & & & & & 6 \\
7 & & & & & & & & & & & & 7 \\
\end{array}
\]

deltay = deltax (45 degrees, max slope). y gets incremented for every x
function line(x0, x1, y0, y1)
    int deltax := x1 - x0
    int deltay := y1 - y0
    int error := deltax / 2
    int y := y0
    for x from x0 to x1
        plot(x,y)
        error := error - deltay
        if error < 0 then
            y := y + 1
            error := error + deltax
    x = 1: plot(1,1)
    error = 5 - 4 = 1
    x = 2: plot(2,1)
    error = 1 - 4 = -3
    y = 1 + 1 = 2
    error = -3 + 10 = 7
    x = 3: plot(3,2)
    error = 7 - 4 = 3
    x = 4: plot(4,2)
    error = 3 - 4 = -1
    y = 2 + 1 = 3
    error = -1 + 10 = 9
    x = 5: plot(5,3)
    error = 9 - 4 = 5
    x = 6: plot(6,3)
    error = 5 - 4 = 1
    x = 7: plot(7,3)
    error = 1 - 4 = -3
    y = 3 + 1 = 4
    error = -3 + 10 = 7
    x = 8: plot(8,4)
    error = 7 - 4 = 3
    x = 9: plot(9,4)
    error = 3 - 4 = -1
    y = 4 + 1 = 5
    error = -1 + 10 = 9
    x = 10: plot(10,5)
    error = 5 - 4 = 1
    x = 11: plot(11,5)
    error = 1 - 4 = -3
    y = 5 + 1 = 6
    error = -3 + 10 = 7
    x = 12: plot(12,6)
    error = 1 - 4 = -3
    y = 6 + 1 = 7
    error = -3 + 10 = 7
#define SWAP(x, y) (x ^= y ^= x ^= y)
#define ABS(x) (((x)<0) ? -(x) : (x))

void line(int x0, int y0, int x1, int y1) {
    char steep = (ABS(y1 - y0) > ABS(x1 - x0)) ? 1 : 0;
    if (steep) {
        SWAP(x0, y0);
        SWAP(x1, y1);
    }
    if (x0 > x1) {
        SWAP(x0, x1);
        SWAP(y0, y1);
    }
    int deltax = x1 - x0;
    int deltay = ABS(y1 - y0);
    int error = deltax / 2;
    int ystep;
    int y = y0
    int x;
    ystep = (y0 < y1) ? 1 : -1;
    for (x = x0; x <= x1; x++) {
        if (steep)
            plot(y, x);
        else
            plot(x, y);
        error = error - deltay;
        if (error < 0) {
            y += ystep;
            error += deltax;
        }
    }
}
### Hardware Implementation Notes

<table>
<thead>
<tr>
<th>Description</th>
<th>Addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read-only control register</td>
<td>0x8040_0064:</td>
</tr>
<tr>
<td></td>
<td>0x8040_0060:</td>
</tr>
<tr>
<td>Write-only trigger registers</td>
<td>0x8040_005c:</td>
</tr>
<tr>
<td></td>
<td>0x8040_0058:</td>
</tr>
<tr>
<td>Write-only non-trigger registers</td>
<td>0x8040_004c:</td>
</tr>
<tr>
<td></td>
<td>0x8040_0048:</td>
</tr>
<tr>
<td></td>
<td>0x8040_0044:</td>
</tr>
<tr>
<td></td>
<td>0x8040_0040:</td>
</tr>
</tbody>
</table>

- CPU initializes line engine by sending pair of points and color value to use. Writes to 0x8040_005* trigger engine.
- Framebuffer has one write port - Shared by CPU and line engine. Priority to CPU - Line engine stalls when CPU writes.