Lab 8: Convolution Circuit Design

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Lab 8: Convolution Circuit Design

- In this lab, you will design a convolution circuit and use it to count the number of edge pixels in an image
  - Your circuit has an SRAM block that store a 8-bit grayscale image with a resolution of 160×90 pixels
  - When the user hit the WEST button, your circuit will use a 5-tap convolution kernel to estimate the total number of edge pixels in the image
  - When the circuit finishes its computation, it will print the number of edge pixels on the 1602 LCD
- You will demo your design to the TA during the lab hours on 12/6

What is Convolution

- Mathematically, a convolution operation is an operation between a data function $f(x)$ and a kernel function $g(x)$:

$$f(x) \otimes g(x) = \int_{-\infty}^{\infty} f(s)g(x-s)ds$$

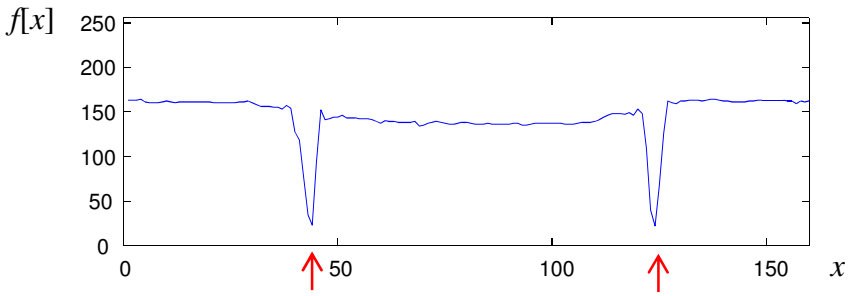
- The kernel function $g(x)$ is designed to extract some features from the data function $f(x)$
  - For example, for an averaging kernel $g(x) = 1/2a$, $-a < x < a$, $f(x) \otimes g(x)$ is a smoothed version of $f(x)$

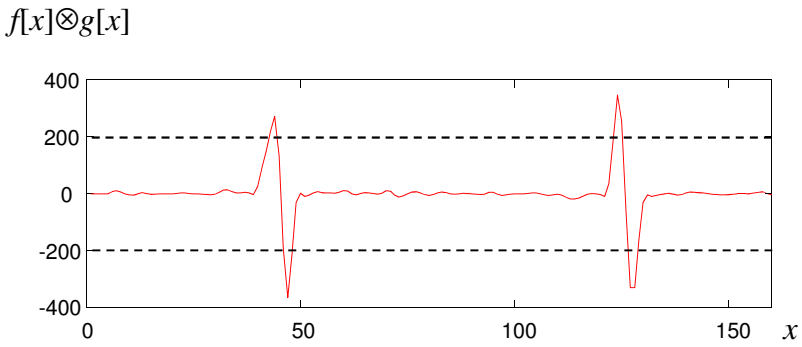
- A digital version of convolution is:

$$f[i] \otimes g[i] = \sum_{k=-N/2}^{N/2} f[i+k]g[\tfrac{N}{2}-k]$$

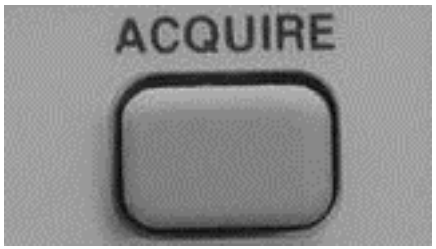
Convolution for Edge Detection (1/2)

- The "edge" of a data array are a data points where "discontinuity" happens
  - 1-D example:





  - 2-D example:



a grayscale image $f[x][y]$

the image of $f[x][y] \otimes g[x]$

Convolution for Edge Detection (2/2)

- The edge detection kernel function $g[x]$ is basically a function that computes the differences of neighboring pixels of $f[x]$ at each position of x.
- For example, previous edge points are computed by the kernel function $g[0{:}4] = \{ -1, -2, 0, 2, 1 \}$.
  - This is called a 5-tap kernel function because the length is five.
  - Apply convolution using $g[0{:}4]$ along each scan line of the image function $f[x][y]$ will give you the edge positions
  - If $| f[x][y] \otimes g[x] |$ is greater than a threshold, say 200, the pixel at (x, y) is counted as an edge point

The C Model of Convolution

- A short C-model that computes the edge point using the 1-D vertical edge kernel function $g[0{:}4]$ is as follows:

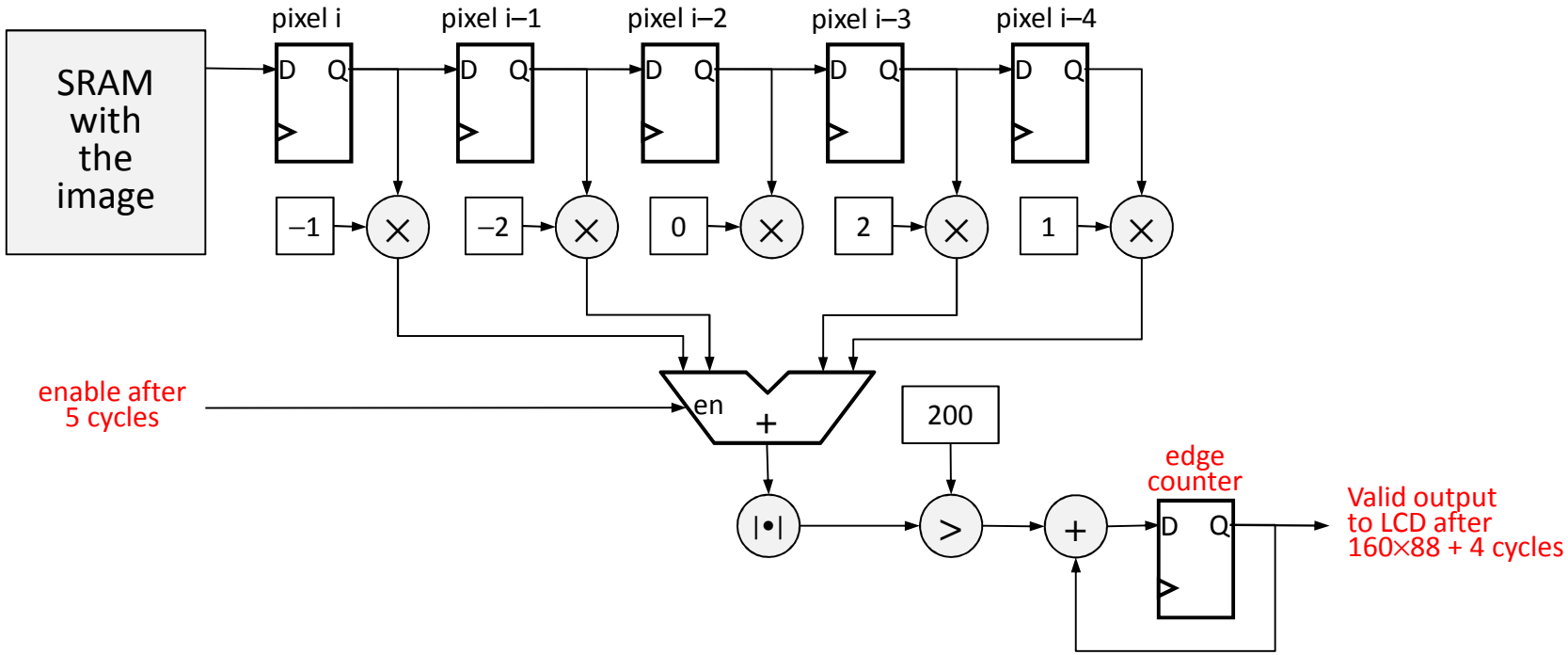
```
unsigned char f[160*90] = { … };
int g[5] = {-1, -2, 0, 2, 1 };
int x, y, k, sum, counter;

counter = 0;
for (y = 1; y < 89; y++)
{
    for (x = 0; x < 160; x++)
    {
        sum = 0;
        for (k = 0; k < 5; k++)
        {
            sum += f[(y*160+x)+(k-2)]*g[4-k];
        }
        if (abs(sum) > 200) counter++;
    }
}
printf("The number of edge pixels = %04x.\n", counter);
```

We skip the first and the last image scanlines to avoid reading outside the f[] array!

Convolution Circuit Design

- You can use a chain of shift registers to read data from the SRAM, begin at address 160 and ends at 160*89–1
  - Each register should be a signed register of at least 11 bits since the result of each convolution is in the range –765 ~ 765.



The Sample Code of Lab 8 (1/2)

- The sample code of lab 8 shows you how to create a SRAM block in FPGA with some data pre-stored in it
  - The image data we use for lab 8 is an 8-bit grayscale image, with resolution 160×90 pixels → need a 16K×8 SRAM
  - Initialization of a SRAM can be done as follows:

```
// This is a code segment from the sram module.

// Declareation of the memory cells
reg [DATA_WIDTH-1 : 0] RAM [RAM_SIZE - 1:0];

// ------------------------------------
// SRAM cell initialization
// ------------------------------------
initial begin
    $readmemh("image.dat", RAM);
end
```

```
95
98
9a
99
95
9a
9c
9b
...
```

This is “image.dat”

$readmemh() is only synthesizable for FPGAs

The Sample Code of Lab 8 (2/2)

- After configuring the sample circuit into the FPGA, you will see the following 1602 LCD screen:

```
Press WEST to
show pixel value
```

- Each time you press the WEST button, the display shows the content of the next pixel data, starting from sram cell 0000:

```
Pixel at [0000]
has the value 95
```

What You have to Do in Lab8

- In Lab 8, after you configured the FPGA, the 1602 LCD should show the following screen:

```
Press WEST to do
edge detection..
```

If the user presses the WEST button, the convolution circuit should be activated. When the circuit is done, the total number of the edge pixels should be displayed on the LCD:

```
The edge pixel
  number is 02E8
```