Lab 9: Correlation Filter Design

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Lab 9: Correlation Filter Circuit

- In this lab, you will design a correlation filter circuit and use it to detect the presence of a waveform
  - Your circuit has an SRAM that stores a 1-D waveform $f[\cdot]$ of 1024 data samples and a 1-D pattern $g[\cdot]$ of 64 data samples; each sample in $f[\cdot]$ and $g[\cdot]$ is an 8-bit signed number
  - When the user hit BTN0, your circuit will compute the cross-correlation function $C_{fg}[\cdot]$ between $f[\cdot]$ and $g[\cdot]$, and display the maximal value of $C_{fg}[\cdot]$ and its position on the 1602 LCD

- The deadline of the lab is on 12/19

What is a Correlation Filter

- Mathematically, a correlation filter is the sliding inner product between two signals $f(x)$ and $g(x)$:

$$C_{fg}(x) = f(x) * g(x) = \int_{-\infty}^{\infty} f(s+x)g(s)ds$$

  - If $f(x)$ and $g(x)$ are the same signal, it is called auto-correlation
  - If $f(x)$ and $g(x)$ are different signals, it is called cross-correlation

- Correlation filters can be used to find the period of a (noisy) periodic signal or the alignment of two aperiodic zero mean signals

Digital Version of Correlation Filters

- A digital version of the correlation filter is:

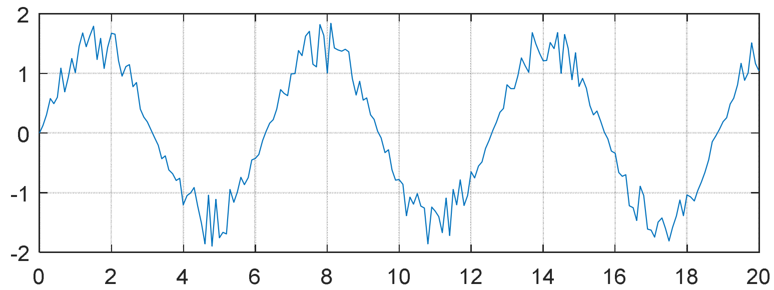
$$c_{fg}[x] = f[x] * g[x] = \sum_{k=0}^{N-1} f[k+x]g[k]$$

- In this lab, $f[0:1023]$ and $g[0:63]$ are 8-bit signed arrays stored in an SRAM block, and the correlation function $c_{fg}[0:959]$ has 960 elements

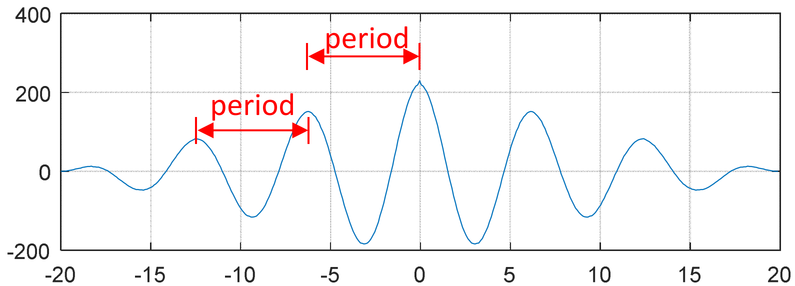
Auto-Correlation Example

- The distances between the peaks of the auto-correlation function of a noisy periodic signals can be used to estimate the period of the signal:

a signal $f(x)$

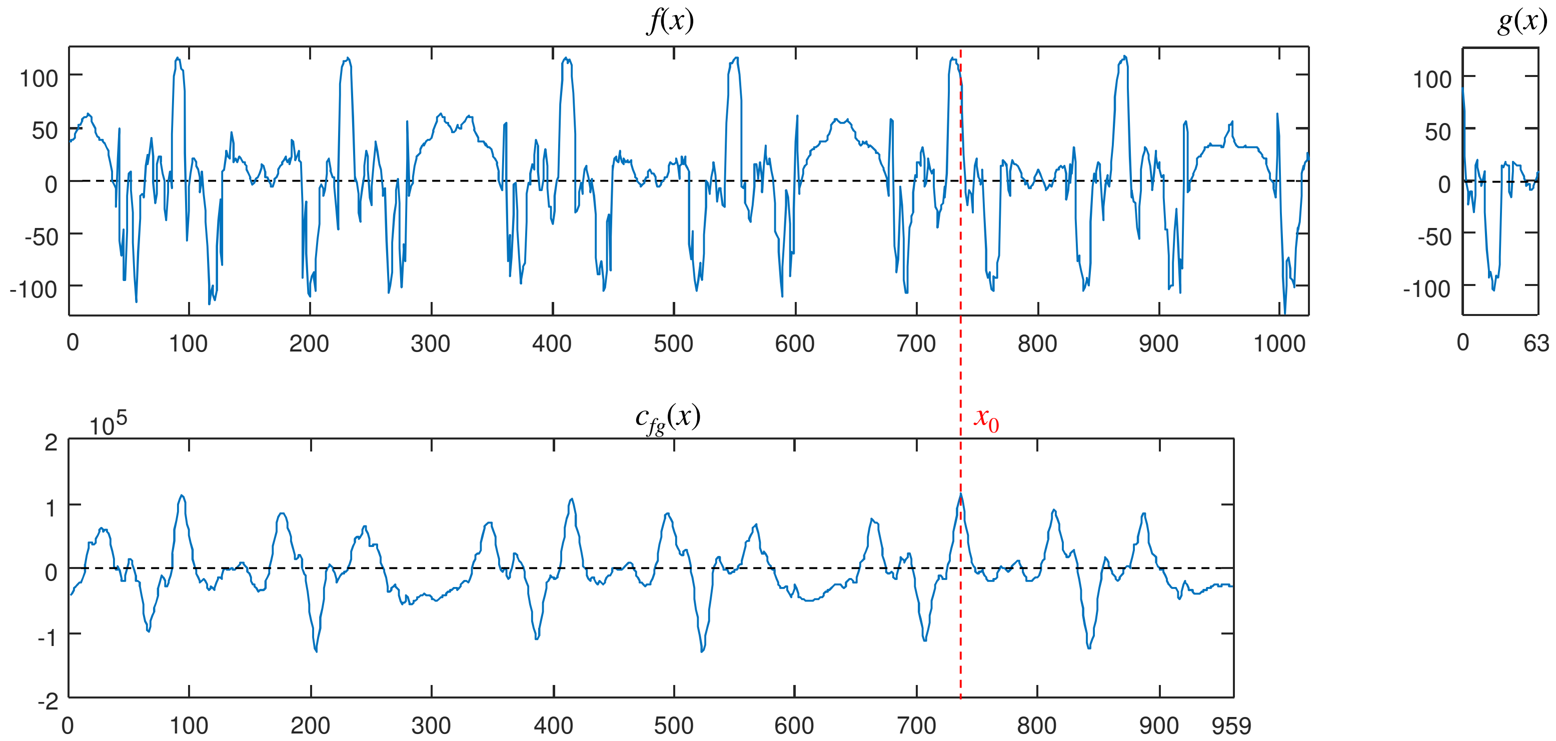


autocorrelation $C_{ff}(y)$



Cross-Correlation Example

- The maximal location x_0 of the cross-correlation function between $g(x)$ and $f(x)$ means that a signal most similar to $g(x)$ is located at x_0 of $f(x)$†:



† Note that $f(x)$ and $g(x)$ have near zero means and $g(x)$ should not be too short.

The C Model of Correlation

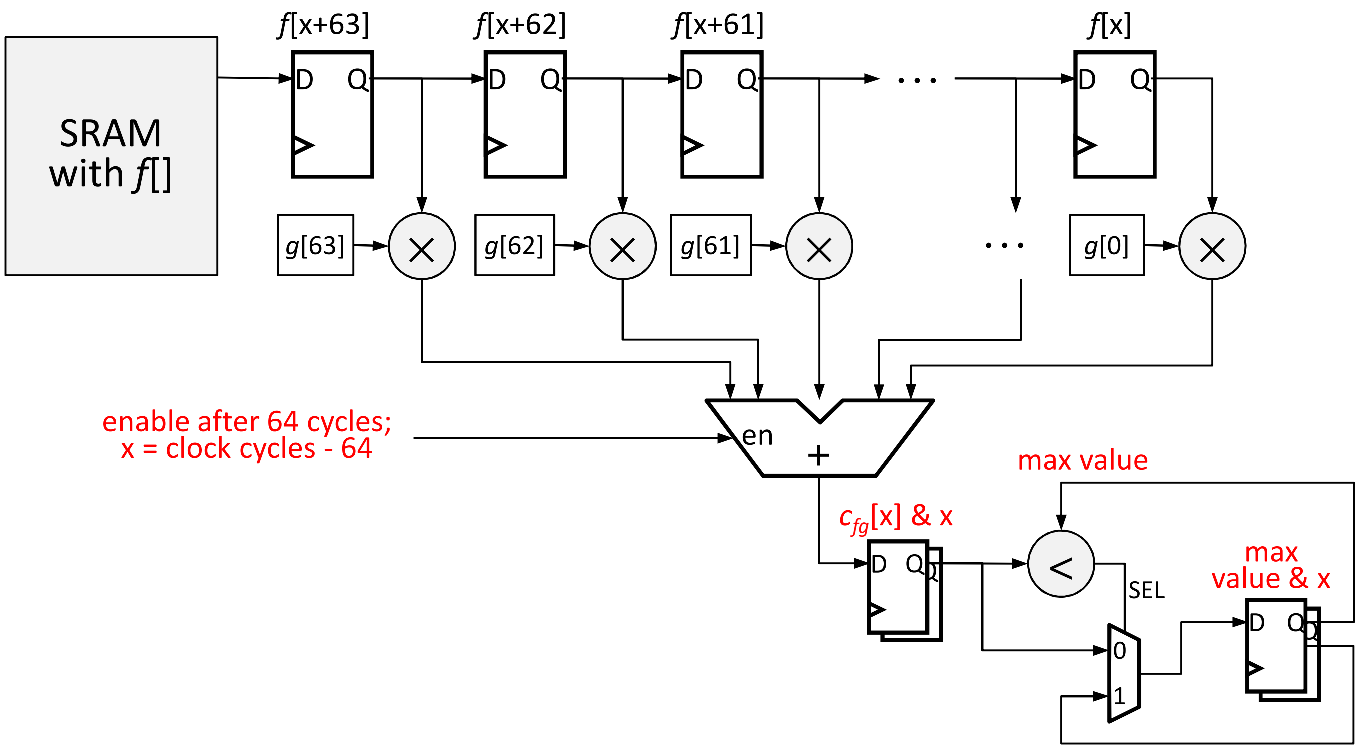
- A short C-model that computes the correlation function between f[] and g[] and record the maximal c_{fg}[] and its location is as follows:

```
char f[1024] = { … };
char g[64] = { … };
int  c[960];
int x, y, k, sum, max, max_pos;

max = max_pos = 0;
for (x = 0; x < 1024 - 64; x++)
{
    sum = 0;
    for (k = 0; k < 64; k++)
    {
        sum += f[k+x] * g[k];
    }
    c[x] = sum;
    if (sum > max) max = sum, max_pos = x;
}
```

Correlation Circuit Design

- You can use a chain of shift registers to read data from the SRAM, begin at address 0 and ends at 1023
  - The output $c_{fg}[]$ should be a signed register of at least 22 bits.



The Sample Code of Lab 9 (1/3)

- The sample code of lab 9 shows you how to create a SRAM block in FPGA with some data pre-stored in it
  - The signal data we use for f[] and g[] are pre-stored in SRAM $\rightarrow$ need a 2KB 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("signals.mem", RAM);
end
```

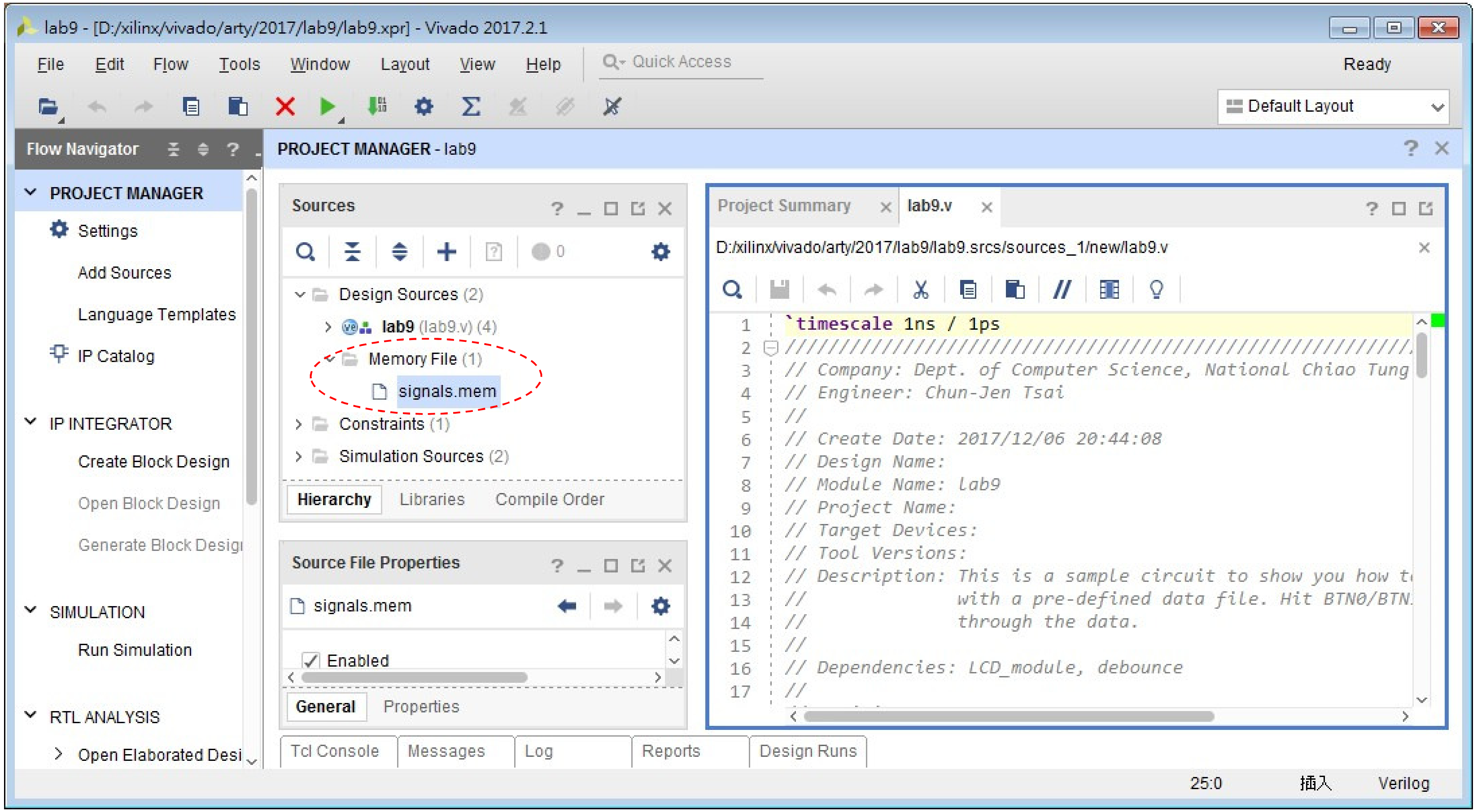
This is "signals.mem"

```
24
24
27
26
29
2c
2f
32
...
```

$readmemh() is only synthesizable for FPGAs

The Sample Code of Lab 9 (2/3)

- The memory data file, signals.mem, is added into the Vivado project space as a design source file:



The Sample Code of Lab 9 (3/3)

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

```
Sample at [000h]
is equal to +24h
```

- You can use BTN0 and BTN1 to browse through all the data of f[] and g[] in SRAM
  - The array f[] is stored in SRAM address 0 ~ 1023, while the array g[] is stored in 1024 ~ 1087

What You have to Do in Lab9

- In Lab 9, after you configured the FPGA, the 1602 LCD should show the following screen:

```
Press BTN0 to do
x-correlation...
```

If the user presses BTN0, the correlation circuit should be activated. When the circuit is done, the maximal value of the correlation and its location should be displayed on the LCD:

```
Max value 01C44D
Max location 2E0
```