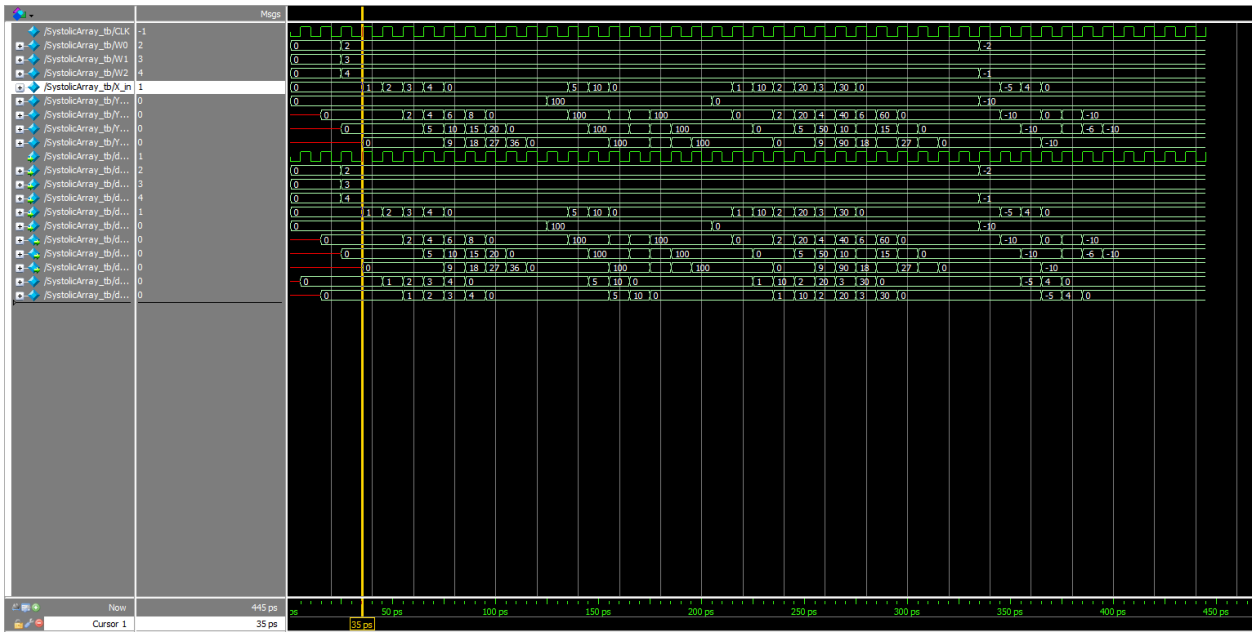
GitHub

Clock Control Discussion: Consider and explain how the X and Y flip-flops should be controlled by the clock. Briefly describe any important considerations to ensure the slice operates correctly (e.g., proper edge sensitivity, timing of value transfers, or avoiding race conditions).

Both flip flops are synchronously controlled by the same clock signal, triggering on the rising edge, ensuring data is being captured simultaneously. This is important as it prevents timing mismatches in the circuit which would lead to corrupted calculations. During each clock cycle the arithmetic is performed on current register values before new values are transferred into the register at the clock edge. This helps to prevent a race condition where data could be transferred before a calculation is done leading to incorrect and nondeterministic behavior.

ModelSim Output:



Here is the modelSim waveform output, weights are initialized at about 25ps and stay constant throughout the duration of the circuit executing until they are changed for test case 4 at the end. There are 3 test scenarios being ran, the first begins at 35ps when Xin is at 1, test #2 starts at 125ps and test 3 begins at 205ps. X and Y data can be seen moving through the system during the same clock cycle. Test 4 is not outlined in the lab assignment but used to verify that signed value arithmetic works correctly, beginning by the weights and Y input being initialized at 335ps. This data can also be read from the Transcript log below, matching the behavior of the python script

Terminal:

```
# Systolic Array Testbench
# INPUT_WIDTH=8, ACCUM_WIDTH=32
# [35] INIT | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=0 Y2=x
```

[45] X=1 | W=[2,3,4] X_in=1 Yprev=0 | Y0=0 Y1=0 Y2=0
[55] X=2 | W=[2,3,4] X_in=2 Yprev=0 | Y0=0 Y1=0 Y2=0
[65] X=3 | W=[2,3,4] X_in=3 Yprev=0 | Y0=2 Y1=0 Y2=0
[75] X=4 | W=[2,3,4] X_in=4 Yprev=0 | Y0=4 Y1=5 Y2=0
[85] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=6 Y1=10 Y2=9
[95] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=8 Y1=15 Y2=18
[105] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=20 Y2=27
[115] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=0 Y2=36
[125] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=0 Y2=0
[135] INIT | W=[2,3,4] X_in=0 Yprev=100 | Y0=0 Y1=0 Y2=0
[145] X=5 | W=[2,3,4] X_in=5 Yprev=100 | Y0=100 Y1=0 Y2=0
[155] X=10 | W=[2,3,4] X_in=10 Yprev=100 | Y0=100 Y1=100 Y2=0
[165] PROP | W=[2,3,4] X_in=0 Yprev=100 | Y0=110 Y1=100 Y2=100
[175] PROP | W=[2,3,4] X_in=0 Yprev=100 | Y0=120 Y1=125 Y2=100
[185] PROP | W=[2,3,4] X_in=0 Yprev=100 | Y0=100 Y1=150 Y2=145
[195] PROP | W=[2,3,4] X_in=0 Yprev=100 | Y0=100 Y1=100 Y2=190
[205] PROP | W=[2,3,4] X_in=0 Yprev=100 | Y0=100 Y1=100 Y2=100
[215] INIT | W=[2,3,4] X_in=0 Yprev=0 | Y0=100 Y1=100 Y2=100
[225] S1:1 | W=[2,3,4] X_in=1 Yprev=0 | Y0=0 Y1=100 Y2=100
[235] S2:10 | W=[2,3,4] X_in=10 Yprev=0 | Y0=0 Y1=0 Y2=100
[245] S1:2 | W=[2,3,4] X_in=2 Yprev=0 | Y0=2 Y1=0 Y2=0
[255] S2:20 | W=[2,3,4] X_in=20 Yprev=0 | Y0=20 Y1=5 Y2=0
[265] S1:3 | W=[2,3,4] X_in=3 Yprev=0 | Y0=4 Y1=50 Y2=9
[275] S2:30 | W=[2,3,4] X_in=30 Yprev=0 | Y0=40 Y1=10 Y2=90
[285] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=6 Y1=100 Y2=18
[295] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=60 Y1=15 Y2=180
[305] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=150 Y2=27
[315] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=0 Y2=270
[325] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=0 Y2=0
[335] PROP | W=[2,3,4] X_in=0 Yprev=0 | Y0=0 Y1=0 Y2=0
[345] INIT | W=[-2,3,-1] X_in=0 Yprev=-10 | Y0=0 Y1=0 Y2=0
[355] X=-5 | W=[-2,3,-1] X_in=-5 Yprev=-10 | Y0=-10 Y1=0 Y2=0
[365] X=4 | W=[-2,3,-1] X_in=4 Yprev=-10 | Y0=-10 Y1=-10 Y2=0
[375] PROP | W=[-2,3,-1] X_in=0 Yprev=-10 | Y0=0 Y1=-10 Y2=-10
[385] PROP | W=[-2,3,-1] X_in=0 Yprev=-10 | Y0=-18 Y1=-15 Y2=-10
[395] PROP | W=[-2,3,-1] X_in=0 Yprev=-10 | Y0=-10 Y1=-6 Y2=-10
[405] PROP | W=[-2,3,-1] X_in=0 Yprev=-10 | Y0=-10 Y1=-10 Y2=-10
[415] PROP | W=[-2,3,-1] X_in=0 Yprev=-10 | Y0=-10 Y1=-10 Y2=-10
All test cases completed

Python Output:
Systolic Array Python Simulation
INPUT_WIDTH=8, ACCUM_WIDTH=32

EST CASE 1: Yprev = 0

```
INIT      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=     0 Y2=     0
X=1       | W=[ 2, 3, 4] X_in=  1 Yprev=   0 | Y0=     0 Y1=     0 Y2=     0
X=2       | W=[ 2, 3, 4] X_in=  2 Yprev=   0 | Y0=     0 Y1=     0 Y2=     0
X=3       | W=[ 2, 3, 4] X_in=  3 Yprev=   0 | Y0=     2 Y1=     0 Y2=     0
X=4       | W=[ 2, 3, 4] X_in=  4 Yprev=   0 | Y0=     4 Y1=     5 Y2=     0
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     6 Y1=    10 Y2=     9
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     8 Y1=    15 Y2=    18
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=    20 Y2=    27
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=     0 Y2=    36
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=     0 Y2=     0
```

TEST CASE 2: Non-zero Yprev

```
INIT      | W=[ 2, 3, 4] X_in=  0 Yprev= 100 | Y0=     0 Y1=     0 Y2=     0
X=5       | W=[ 2, 3, 4] X_in=  5 Yprev= 100 | Y0=   100 Y1=     0 Y2=     0
X=10      | W=[ 2, 3, 4] X_in= 10 Yprev= 100 | Y0=   100 Y1=   100 Y2=     0
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev= 100 | Y0=   110 Y1=   100 Y2=   100
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev= 100 | Y0=   120 Y1=   125 Y2=   100
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev= 100 | Y0=   100 Y1=   150 Y2=   145
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev= 100 | Y0=   100 Y1=   100 Y2=   190
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev= 100 | Y0=   100 Y1=   100 Y2=   100
```

TEST CASE 3: Interleaved Streams

```
INIT      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=   100 Y1=   100 Y2=   100
S1:1      | W=[ 2, 3, 4] X_in=  1 Yprev=   0 | Y0=     0 Y1=   100 Y2=   100
S2:10     | W=[ 2, 3, 4] X_in= 10 Yprev=   0 | Y0=     0 Y1=     0 Y2=   100
S1:2      | W=[ 2, 3, 4] X_in=  2 Yprev=   0 | Y0=     2 Y1=     0 Y2=     0
S2:20     | W=[ 2, 3, 4] X_in= 20 Yprev=   0 | Y0=    20 Y1=     5 Y2=     0
S1:3      | W=[ 2, 3, 4] X_in=  3 Yprev=   0 | Y0=     4 Y1=    50 Y2=     9
S2:30     | W=[ 2, 3, 4] X_in= 30 Yprev=   0 | Y0=    40 Y1=    10 Y2=    90
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     6 Y1=   100 Y2=    18
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=    60 Y1=    15 Y2=   180
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=   150 Y2=    27
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=     0 Y2=   270
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=     0 Y2=     0
PROP      | W=[ 2, 3, 4] X_in=  0 Yprev=   0 | Y0=     0 Y1=     0 Y2=     0
```

TEST CASE 4: Negative Arithmetic Validation

```
INIT       | W=[-2, 3,-1] X_in=  0 Yprev= -10 | Y0=     0 Y1=     0 Y2=     0
X=-5       | W=[-2, 3,-1] X_in= -5 Yprev= -10 | Y0=   -10 Y1=     0 Y2=     0
X=4        | W=[-2, 3,-1] X_in=  4 Yprev= -10 | Y0=   -10 Y1=   -10 Y2=     0
PROP       | W=[-2, 3,-1] X_in=  0 Yprev= -10 | Y0=     0 Y1=   -10 Y2=   -10
PROP       | W=[-2, 3,-1] X_in=  0 Yprev= -10 | Y0=   -18 Y1=   -15 Y2=   -10
PROP       | W=[-2, 3,-1] X_in=  0 Yprev= -10 | Y0=   -10 Y1=    -6 Y2=   -10
PROP       | W=[-2, 3,-1] X_in=  0 Yprev= -10 | Y0=   -10 Y1=   -10 Y2=   -10
PROP       | W=[-2, 3,-1] X_in=  0 Yprev= -10 | Y0=   -10 Y1=   -10 Y2=   -10
All test cases completed
```