NCTU-EE IC LAB – Fall 2023

Lab02 Exercise

Design: Calculation on the coordinates

Data Preparation

1. Extract test data from TA's directory:
   % tar -xvf ~iclabTA01/Lab02.tar
2. The extracted Lab02/ directory contains:
   a. Practice
   b. Exercise

Design Description

Please design a circuit that supports three modes on a coordinate:

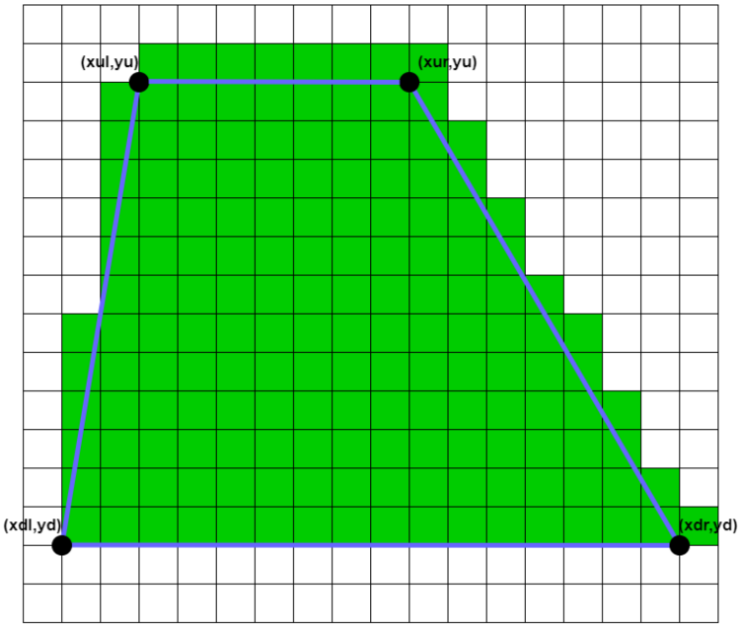
(1) Trapezoid rendering.

(2) Circle and line relationships.

(3) Area computing.

Trapezoid rendering (Mode 0)

When the "**in_valid**" is at high level, pattern will send out the four sets of coordinates for the trapezoid **in the order of (xul, yu), (xur, yu), (xdl, yd), (xdr, yd)**. After a period of circuit operations, the "**out_valid**" will be set to a high level, and the pattern will begin verifying the valid output coordinates **(xo, yo)** at every negative edge of the clock until "**out_valid**" is lowered. **All valid output coordinates requirements are as follows:**



In this design, you are required to **output the coordinates covered by the trapezoid.**

The output coordinate regulations:

(1) If the bottom left coordinate or bottom right coordinate of a square is covered by the trapezoid, please output the coordinates of the bottom left corner of that square.

(2) If the trapezoid exactly covers the bottom left coordinate of the square, please output the coordinates of the bottom left corner of that square.

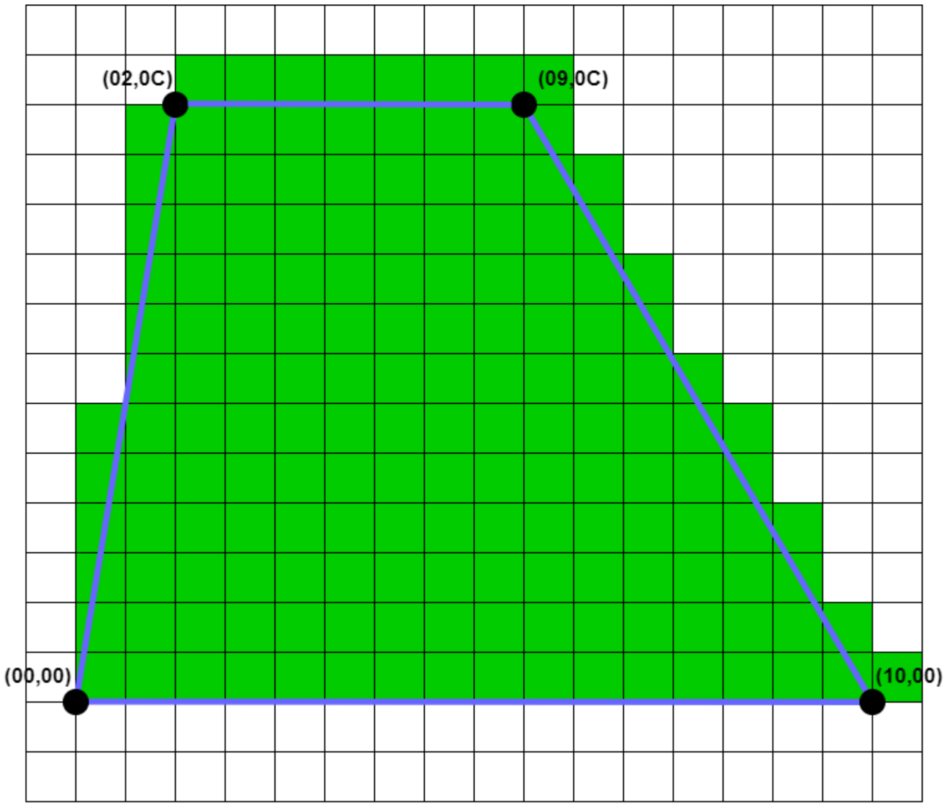
(3) The output order is from left to right, from bottom to up.

Here is an example**:**

Assume you receive four sets of coordinates in order from the pattern as follows:

(xul, yu) = (02,0C), (xur, yu) = (09,0C), (xdl, yd) = (00,00), (xdr, yd) = (10,00).

The valid output is**: (00,00) (01,00) … (10,00), (00,01) (01,01) … (0F,01), (00,02) (01,02) … (0E,02) (00,03) (01,03) … (0E,03), (00,04) (01,04) … (0D,04), (00,05) (01,05) … (0D,05), (01,06) (02,06) … (0C,06), (01,07) (02,07) … (0B,07), (01,08) (02,08) … (0B,08), (01,09) (02,09) … (0A,09), (01,0A) (02,0A) … (0A,0A), (01,0B) (02,0B) … (09,0B), (02,0C) (03,0C) … (09,0C).**



Circle and line relationships (Mode 1)

The relationships between circles and lines can be categorized into three types:

(1) Tangent, (2) Intersecting, (3) non-intersecting

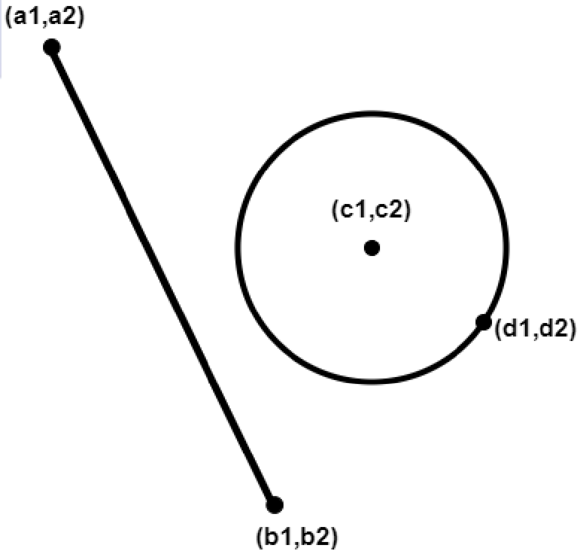
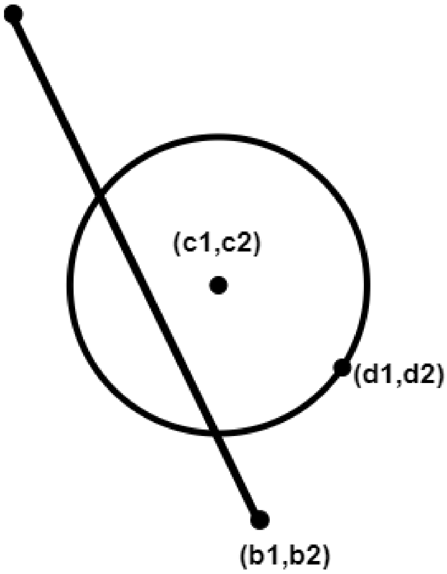
When in_valid is at high level, pattern will send out the four sets of coordinates in the **following order**:

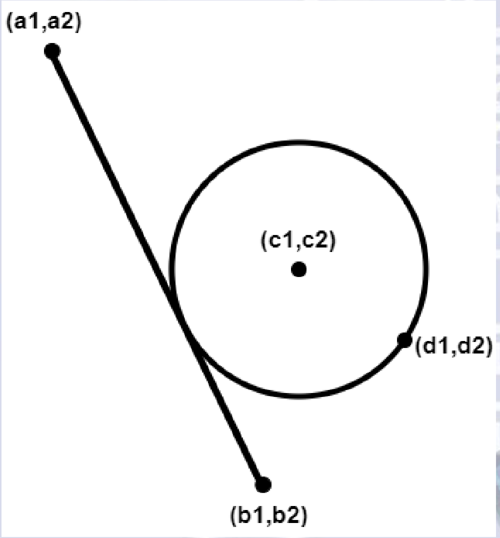
First, you will obtain the two points **(a1, a2)** and **(b1, b2)** on the line.

Next will be the center of the circle **(c1, c2)**, and finally, a point on the circle **(d1, d2)**.

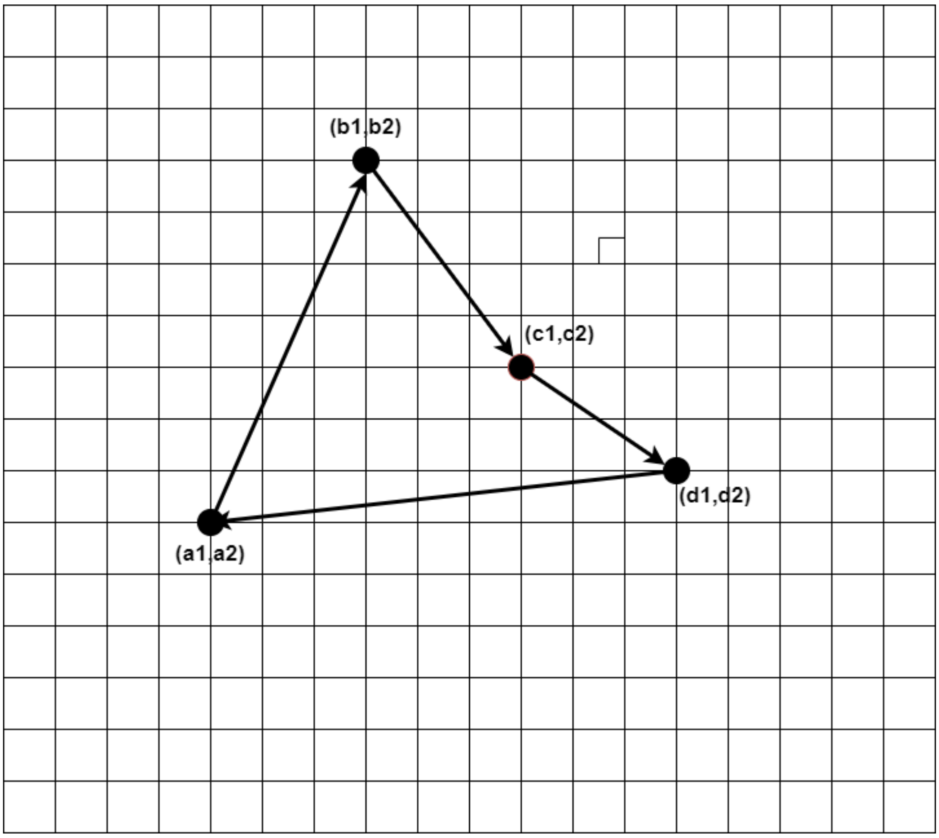
Please find out the relationships between circle and line:

■ To shorten the synthesis time for everyone, the input coordinates here will be limited to 6 bits.

Relation	Description
{xo, yo} = {00,00}	non-intersecting: 
{xo, yo} = {00,01}	Intersecting: 

{xo, yo} = {00,02}	Tangent: 

Area computing (Mode 2)



When in_valid is at high level, pattern will send out the four sets of coordinates in the **following order**:

(a1, a2) => (b1, b2) => (c1, c2) => (d1, d2)

Please find out the area of the quadrilateral:

If the final answer has a decimal point, please round down!

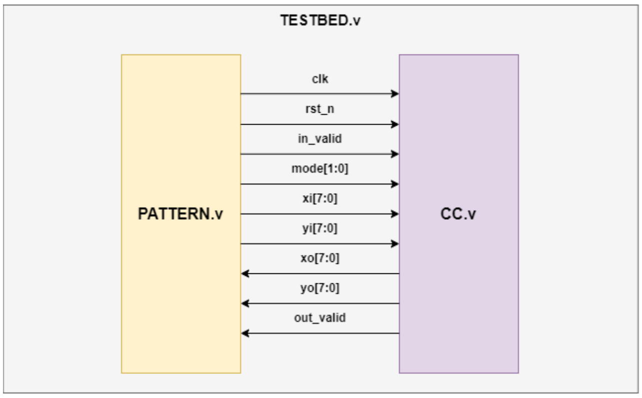
I/O specification

Signals name	Direction	Bit Width	Definition
clk	input	1	Clock.
rst_n	input	1	Asynchronous active-low reset.
mode	input	2	Mode 0: Do trapezoid rendering. Mode 1: Derive the relationships between circle and line. Mode 2: Derive the area.
in_valid	input	1	High when input signals are valid.
xi	input	8	Input of the X coordinate, in two's complement form.
yi	input	8	Input of the Y coordinate, in two's complement form.
out_valid	output	1	High when output is valid.
xo	output	8	Mode 0: Output of the trapezoid X coordinate, in two's complement form. Mode 1: Set to 0. Mode 2: Area [15:8]
yo	output	8	Mode 0: Output of the trapezoid Y coordinate, in two's complement form. Mode 1: Relationships outcome. Mode 2: Area [7:0]

Specifications

1. Top module name：CC (Filename: CC.v)
2. It is an asynchronous reset and active-low architecture. If you use synchronous reset (reset after clock starting) in your design, you may fail to reset signals.
3. The clock period of the design is fixed to 12ns.
4. The next group of inputs will come in 2~5 cycles after your out_valid pull down.
5. The synthesis result of data type cannot include any LATCH.
6. After synthesis, you can check CC.area and CC.timing in the folder "Report".
7. The slack in the timing report should be non-negative and the result should be MET.
8. The gate level simulation cannot include any timing violation.
9. The latency of your design in each pattern should not be larger than 100 cycles. The latency is the clock cycles between the falling edge of the **in_valid** and the rising edge of the **out_valid**.
10. Any words with "error", "latch" or "congratulation" can't be used as variable name.
11. The out_valid cannot overlap in_valid.

Block Diagram



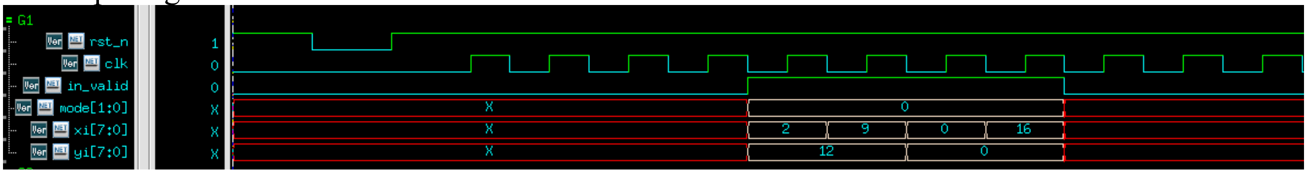
Note

1. **Grading policy:**
   RTL and gate-level simulation correctness: 70%
   Performance (Area * Execution Cycle): 30%
2. **Please submit your design through Lab02/09_SUBMIT/01_SUBMIT**
   - 1st_demo deadline: 2023/10/02(Mon.) 12:00:00
   - 2nd_demo deadline: 2023/10/04(Wed.) 12:00:00
   - If uploaded files violate the naming rule, you will get 5 deduct points.
3. **Template folders and reference commands:**

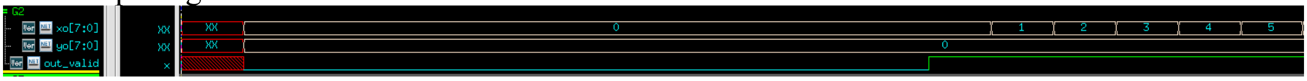
   01_RTL/ (RTL simulation) **./01_run_vcs_rtl**
   02_SYN/ (Synthesis) **./01_run_dc_shell**
   (Check the design if there's latch or not in ***syn.log***)
   (Check the design's timing in /Report/ CC.***timing***)
   03_GATE / (Gate-level simulation) **./01_run_vcs_gate**
   09_SUBMIT/(tar all your design) **./00_tar**
   09_SUBMIT/(submit files) **./01_submit**
   09_SUBMIT/(check files) **./02_check**

Sample Waveform

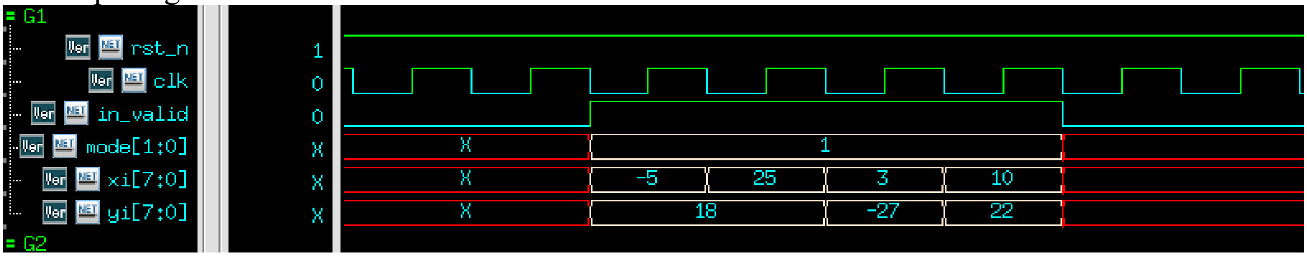
- Trapezoid rendering:
  - Input signal:



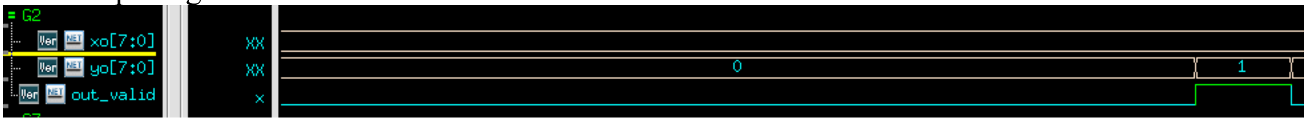
  - Output signal:



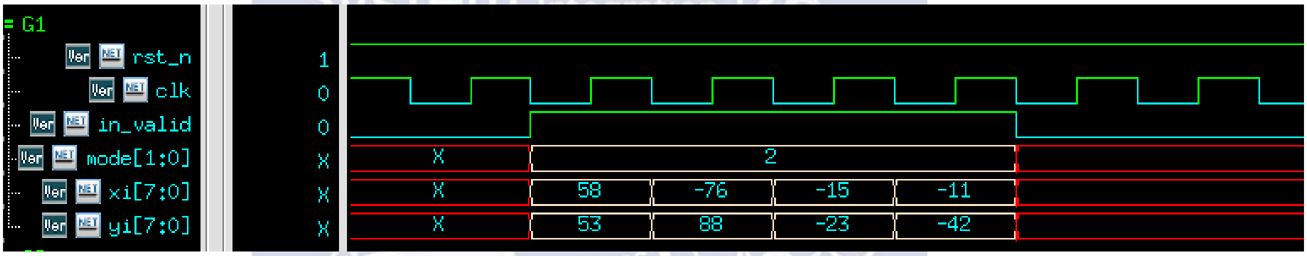
- Circle and line relationships:
  - Input signal:



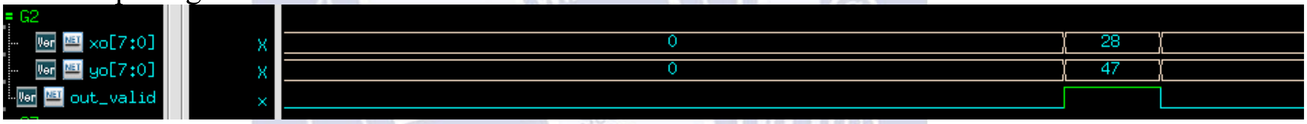
  - Output signal:



- Area computing:
  - Input signal:



- Output signal:

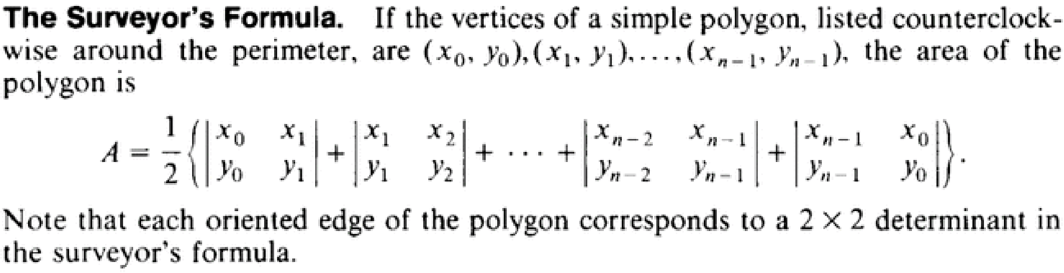


Appendix

1. To find out the distance from a point $\mathbf{P}(\boldsymbol{x_0}, \boldsymbol{y_0})$ to line L: $\boldsymbol{ax} + \boldsymbol{by} + \boldsymbol{c} = 0$, you may need the following equation:

$$\mathrm{d(P,L)} = \frac{|\,\boldsymbol{a}\boldsymbol{x}_0 + \boldsymbol{b}\boldsymbol{y}_0 + \boldsymbol{c}\,|}{\sqrt{\boldsymbol{a}^2 + \boldsymbol{b}^2}}$$

2. You may use the Surveyor's formula to compute area



The Surveyor's Formula. If the vertices of a simple polygon, listed counterclockwise around the perimeter, are $(x_0, y_0), (x_1, y_1), \ldots, (x_{n-1}, y_{n-1})$, the area of the polygon is

$$A = \frac{1}{2}\left\{\begin{vmatrix} x_0 & x_1 \\ y_0 & y_1 \end{vmatrix} + \begin{vmatrix} x_1 & x_2 \\ y_1 & y_2 \end{vmatrix} + \cdots + \begin{vmatrix} x_{n-2} & x_{n-1} \\ y_{n-2} & y_{n-1} \end{vmatrix} + \begin{vmatrix} x_{n-1} & x_0 \\ y_{n-1} & y_0 \end{vmatrix}\right\}.$$

Note that each oriented edge of the polygon corresponds to a 2×2 determinant in the surveyor's formula.