

Logic Circuit Design Lab (ICE2005)

Final Project

Instructor: Il Yong Chun, EEE, AI, ECE, etc.

(Revised by Il Yong Chun, 25-03-01)

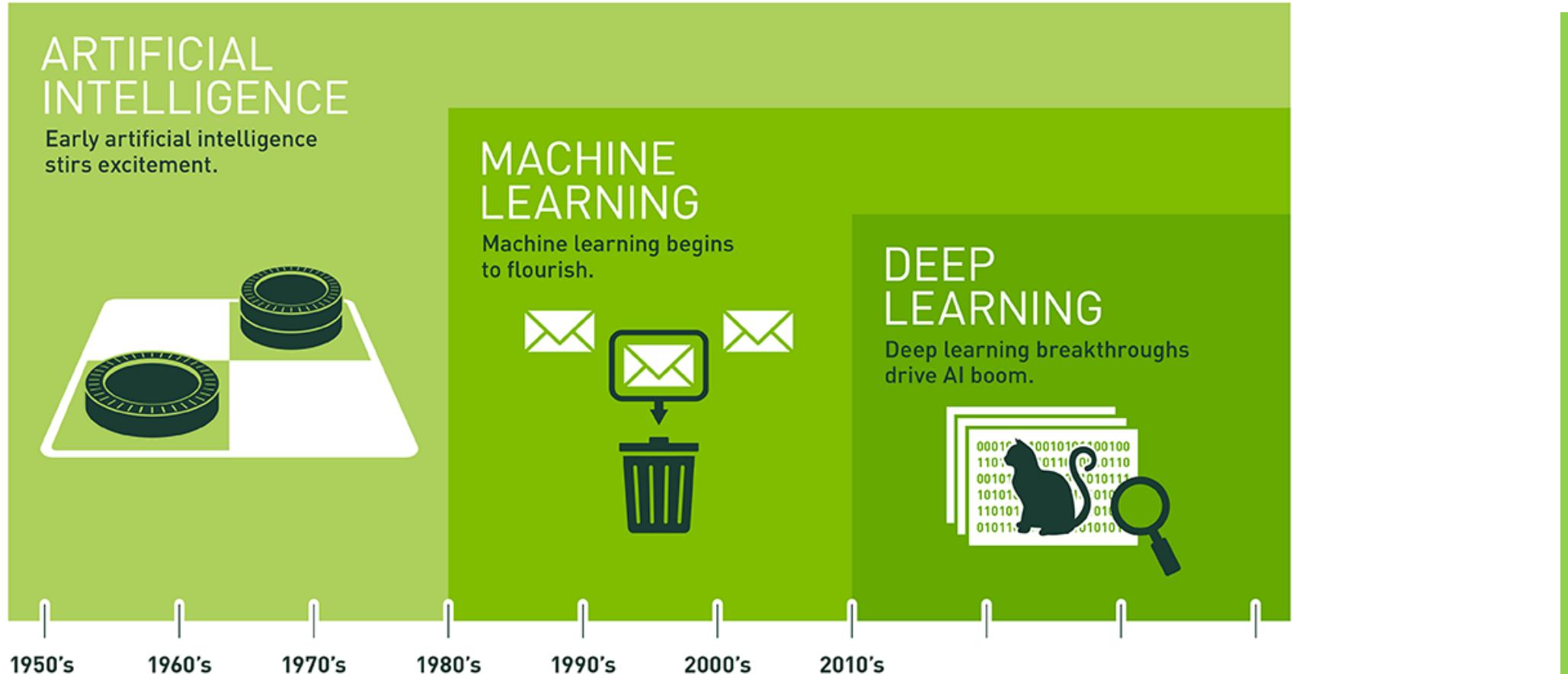
Agenda



- Computations in deep neural networks
- Project assignment



Computations in Deep Neural Networks



Since an early flush of optimism in the 1950s, smaller subsets of artificial intelligence – first machine learning, then deep learning, a subset of machine learning – have created ever larger disruptions.

*Figure from NVIDIA
(<https://developer.nvidia.com/deep-learning>)

Deep Neural Networks (DNNs)

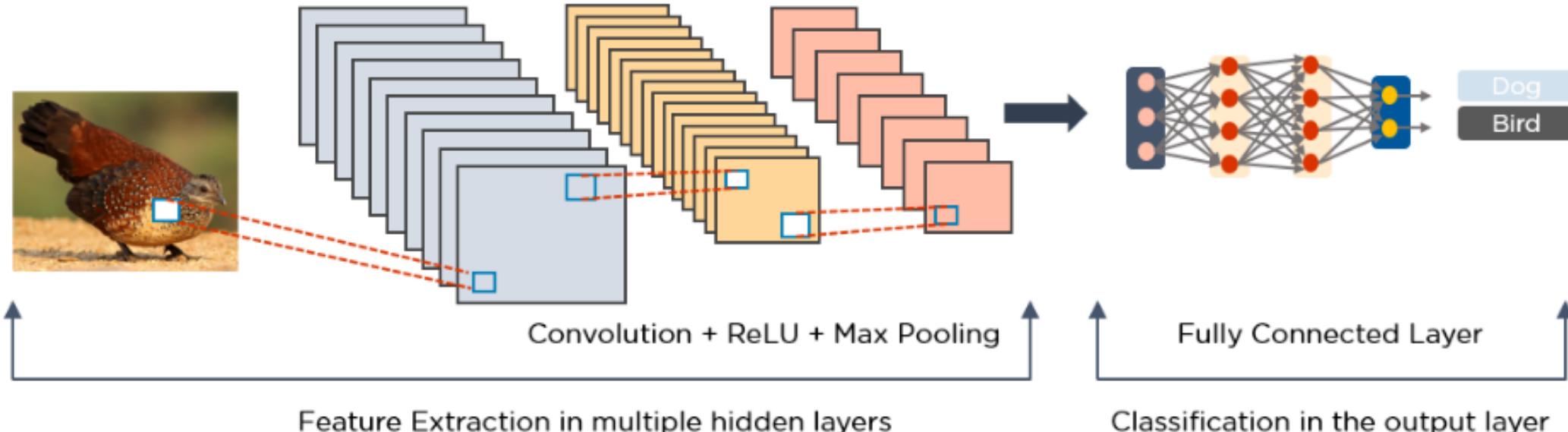


- Fully-connected networks (FCN)
- Convolutional neural network (CNN)
- Recurrent Neural Network
- Generative Adversarial Network
- Iterative Neural Network
- and more....

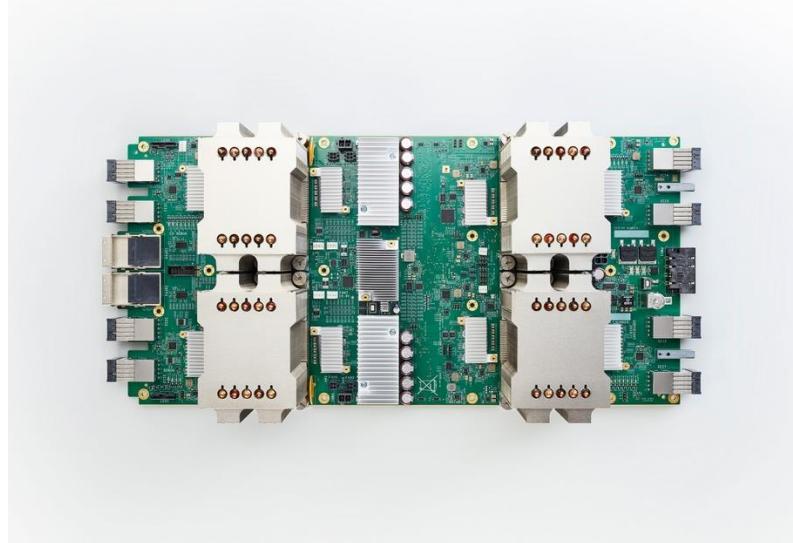


DNN Example for Image Classification

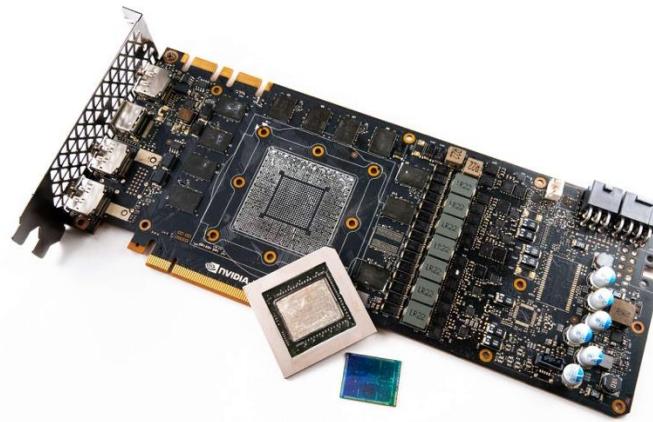
- CNN+FCN



DNN Accelerators



Google TPU



GPUs (including Tensor cores)

What do they accelerate?

Major Computations in DNNs

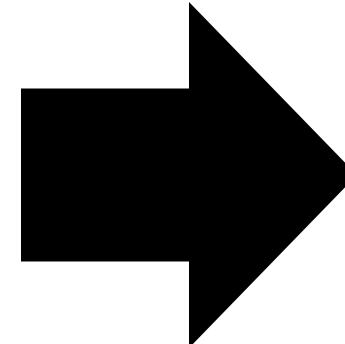
- 2D convolution: Aggregating sums of partial matrix multiplications

A ₁₁	A ₁₂	A ₁₃	A ₁₄
A ₂₁	A ₂₂	A ₂₃	A ₂₄
A ₃₁	A ₃₂	A ₃₃	A ₃₄
A ₄₁	A ₄₂	A ₄₃	A ₄₄

Input

B ₁₁	B ₁₂	B ₁₃
B ₂₁	B ₂₂	B ₂₃
B ₃₁	B ₃₂	B ₃₃

Filter



C ₁₁	C ₁₂
C ₂₁	C ₂₂

Output

Rotated filter by 180 degree!

$$\begin{aligned}
 C_{11} = & A_{11} * B_{33} + A_{12} * B_{32} + A_{13} * B_{31} + \\
 & A_{21} * B_{23} + A_{22} * B_{22} + A_{23} * B_{21} + \\
 & A_{31} * B_{13} + A_{32} * B_{12} + A_{33} * B_{11}
 \end{aligned}$$

B ₃₃	B ₃₂	B ₃₁
B ₂₃	B ₂₂	B ₂₁
B ₁₃	B ₁₂	B ₁₁

Striding

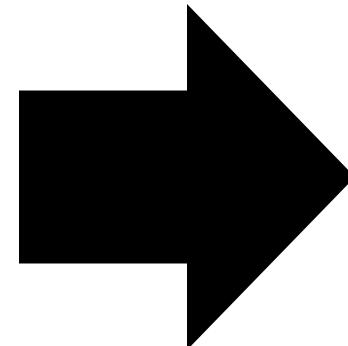


A ₁₁	A ₁₂	A ₁₃	A ₁₄
A ₂₁	A ₂₂	A ₂₃	A ₂₄
A ₃₁	A ₃₂	A ₃₃	A ₃₄
A ₄₁	A ₄₂	A ₄₃	A ₄₄

Input

B ₁₁	B ₁₂	B ₁₃
B ₂₁	B ₂₂	B ₂₃
B ₃₁	B ₃₂	B ₃₃

Filter



C ₁₁	C ₁₂
C ₂₁	C ₂₂

Output

What would the corresponding equation look like?

Next Step

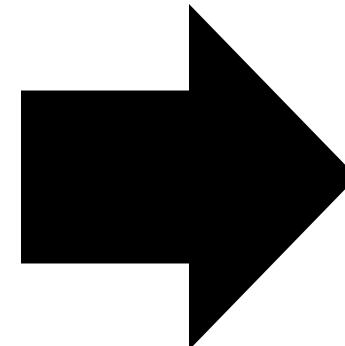


A ₁₁	A ₁₂	A ₁₃	A ₁₄
A ₂₁	A ₂₂	A ₂₃	A ₂₄
A ₃₁	A ₃₂	A ₃₃	A ₃₄
A ₄₁	A ₄₂	A ₄₃	A ₄₄

Input

B ₁₁	B ₁₂	B ₁₃
B ₂₁	B ₂₂	B ₂₃
B ₃₁	B ₃₂	B ₃₃

Filter



C ₁₁	C ₁₂
C ₂₁	C ₂₂

Output

What would the corresponding equation look like?

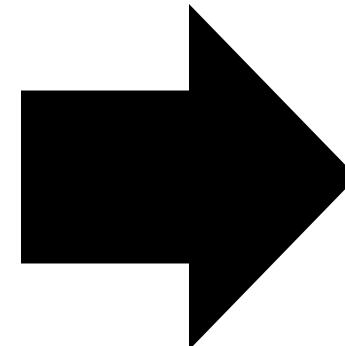
Last Step

A_{11}	A_{12}	A_{13}	A_{14}
A_{21}	A_{22}	A_{23}	A_{24}
A_{31}	A_{32}	A_{33}	A_{34}
A_{41}	A_{42}	A_{43}	A_{44}

Input

B_{11}	B_{12}	B_{13}
B_{21}	B_{22}	B_{23}
B_{31}	B_{32}	B_{33}

Filter



C_{11}	C_{12}
C_{21}	C_{22}

Output

What would the corresponding equation look like?



Term Project

Your Project

- A set of logic that computes a 2x2 output using
 - A single processing element (PE)
 - A 3x3 systolic array
 - A 2x2 systolic array

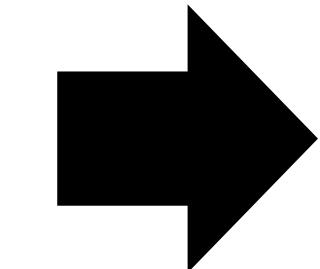
- **Do the following.**
 - **Simulation study**
 - **Verifying your design by displaying results.**

A ₁₁	A ₁₂	A ₁₃	A ₁₄
A ₂₁	A ₂₂	A ₂₃	A ₂₄
A ₃₁	A ₃₂	A ₃₃	A ₃₄
A ₄₁	A ₄₂	A ₄₃	A ₄₄

Input

B ₁₁	B ₁₂	B ₁₃
B ₂₁	B ₂₂	B ₂₃
B ₃₁	B ₃₂	B ₃₃

Filter



2D convolution

C ₁₁	C ₁₂
C ₂₁	C ₂₂

Output



New Tool and FPGA

- Xilinx Vivado

- Refer to
 - TermProject_FPGA_Guide_v1.1.pdf
 - FPGA-Starter-Kit-III-User-Manual-V1.3.pdf

- FPGA Board

- FSK III board from Libertron
- Xilinx Artix-7 Series XC7A75T FPGA Device
- More details in "TermProject_FPGA_Guide_v1.1.pdf"

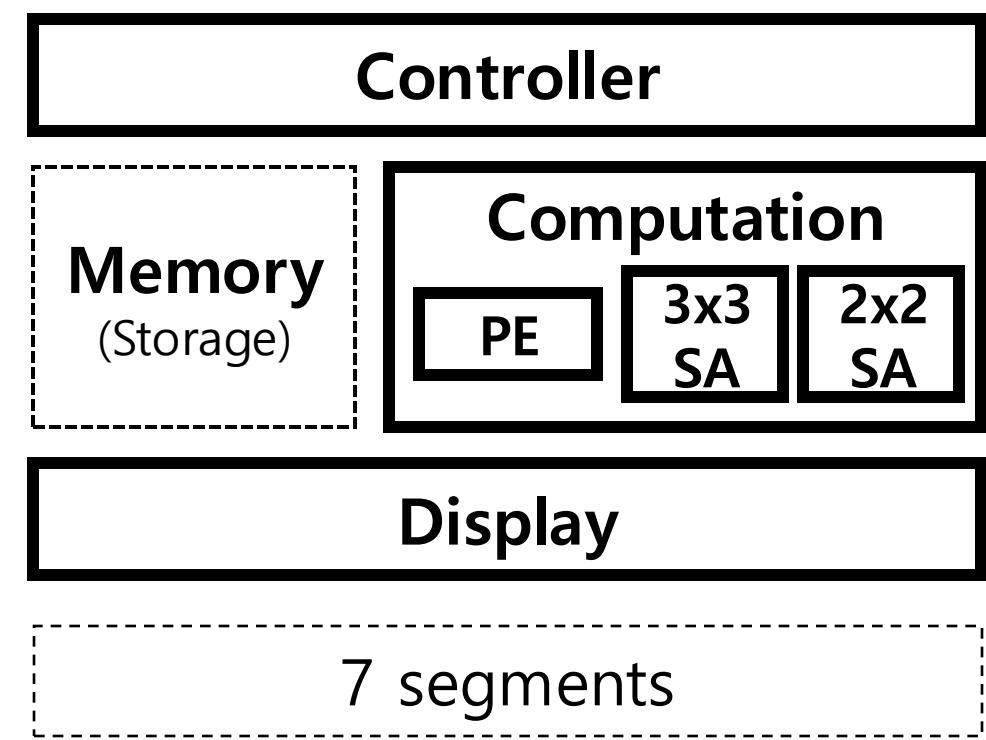
Design Overview (1/2)

● Controller

- Initializes and controls memory, computation module, and display module.
- Takes controls of all the modules.
- For each module, if you need a micro-control inside it, you can implement that control flow in the corresponding module.

● Memory keeps and outputs the numbers of

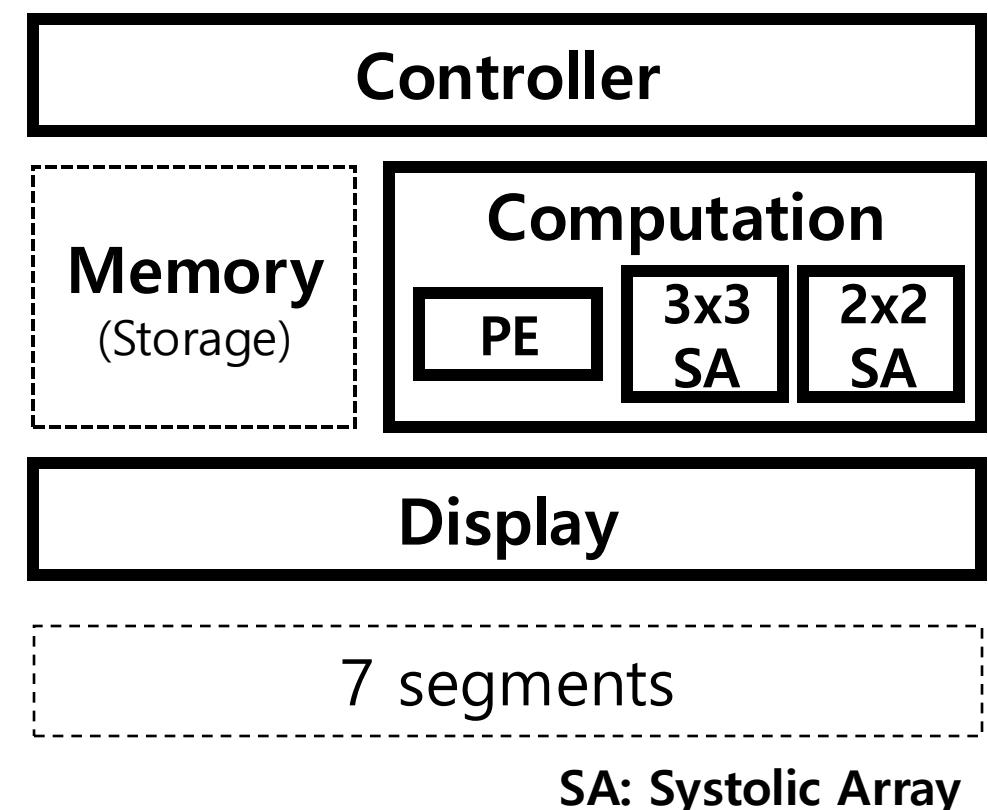
- An input matrix (16 numbers)
- A filter (9 numbers)



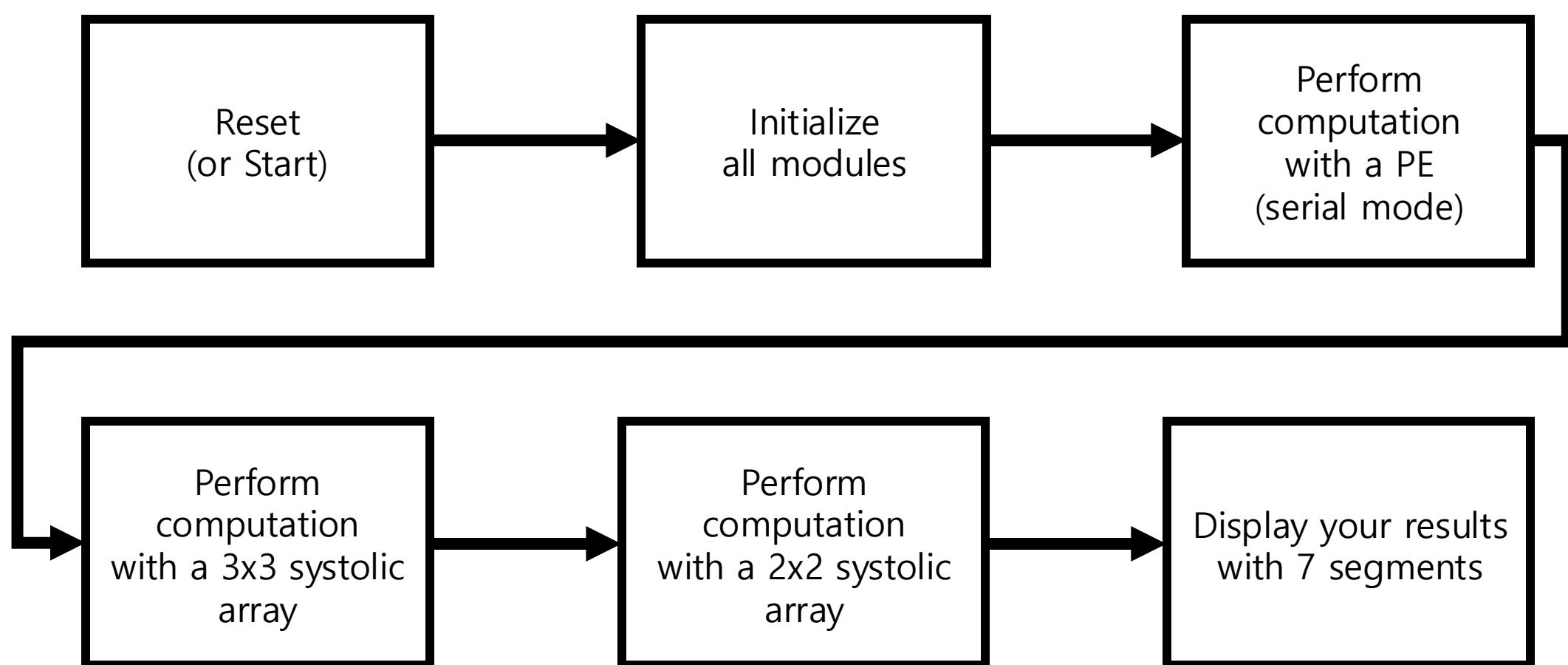
SA: Systolic Array

Design Overview (2/2)

- **Computation module** performs computations in two modes.
 - **Serial mode**: Compute with a single PE.
 - **Parallel mode 1**: Compute with 3x3 systolic array.
 - **Parallel mode 2**: Compute with 2x2 systolic array.
- **Display module** shows computation results.



Execution Flow



Simulation Study (1/3)

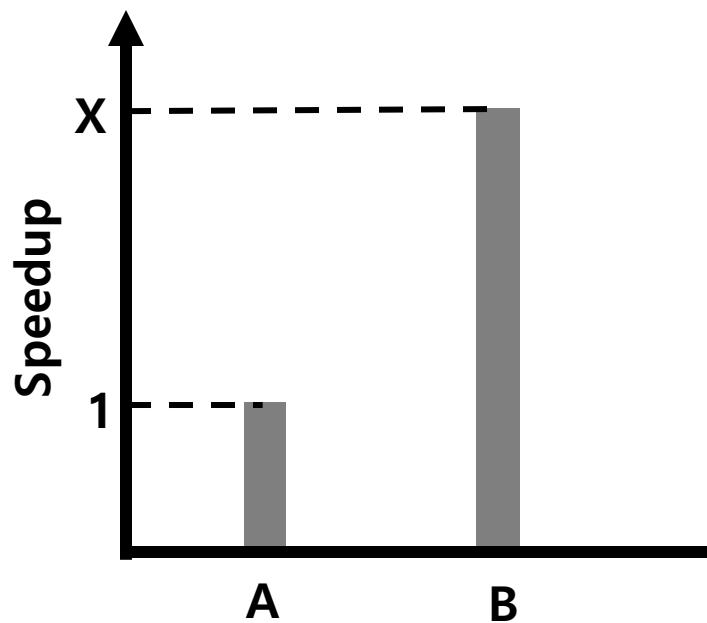
- **Set a test plan for each module (7 testbench files)**

- Controller
- Memory
- PE
- Two systolic arrays
- Display module
- Top module

Simulation Study (2/3)

- **Do performance comparisons**

- A single PE vs a systolic array



$$X = \text{Speedup}_{BA} = \frac{\text{Execution Time}_A}{\text{Execution Time}_B}$$



Simulation Study (3/3)

- Report the following
 - Speedup of 3x3 systolic array over a single PE
 - Speedup of 2x2 systolic array over a single PE

Demonstration using FPGA

- **Show all the computation results with 7 segments.**
 - 4 values in 2x2 output matrix
 - Computed by a 3x3 systolic array
 - Computed by a 2x2 systolic array
 - More details in Requirement 5
- Don't need to display the results with a single PE.





Requirement 0: General

- Follow the design overview.
- Follow the execution flow.
- Satisfy all the following requirements.
- Refer to the following implementation styles.
- Everything except the execution flow and the guidelines are free to choose/design/implement.

Remind that you may follow the honor code.

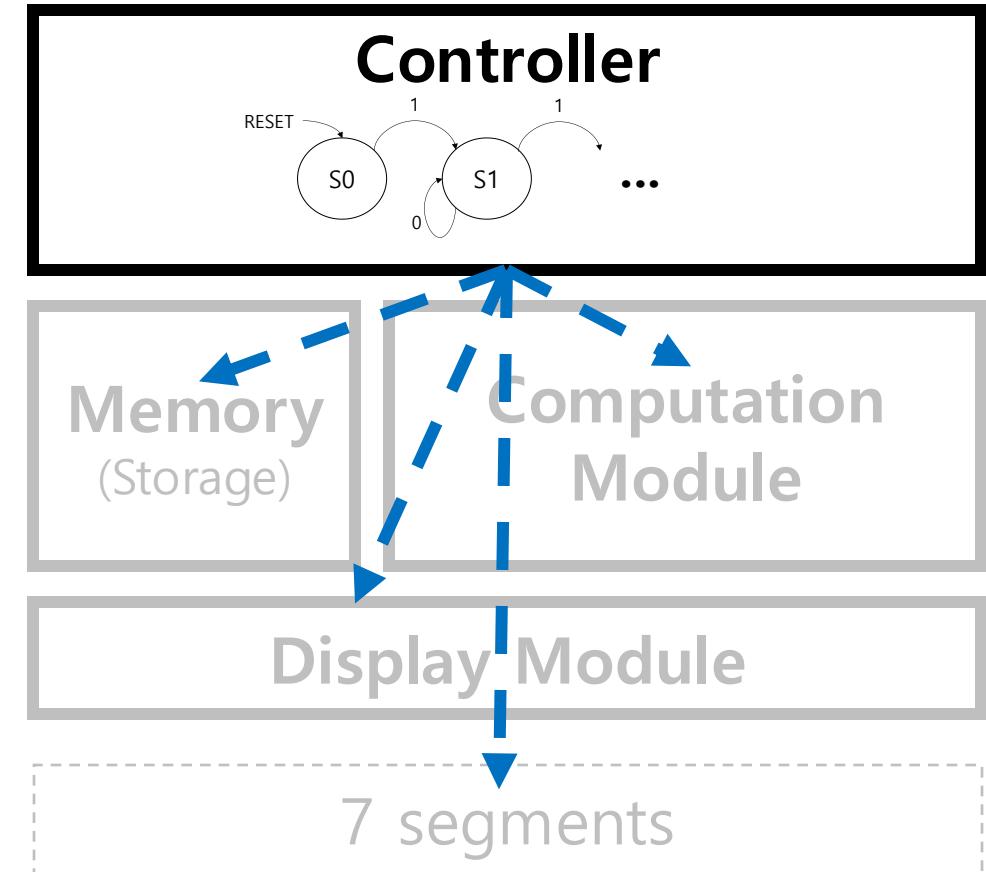


Requirement 0: General (2/2)

- All the numbers in the input matrix, the filter, and the output (output matrix) are 8-bit unsigned integers.
- If a calculation result incurs overflow, simply use the lower 8 bits only.

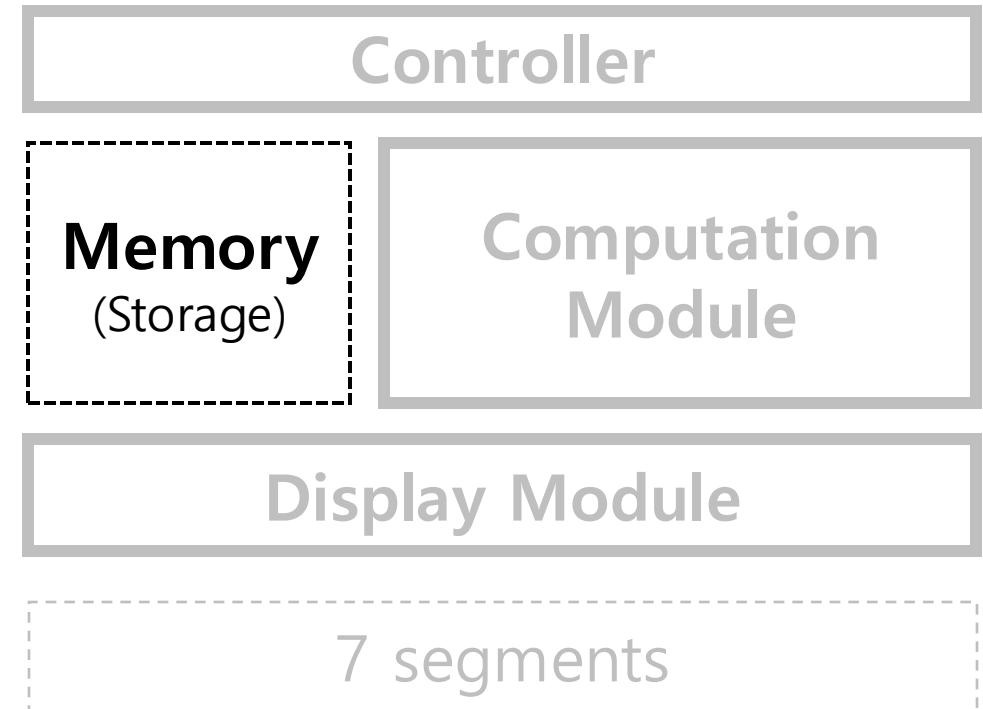
Requirement 1: Controller

- Design your controller with state machine(s).
Week 10
- Design a complete flow for initializing and taking controls of all the modules.
(Memory, computation modules, and display modules)
- Moore machine or Mealy machine?
→ Use what you prefer.
- Reset or Start: Design it as you want
 - You may use any buttons.
 - You may set an automatic reset or start.



Requirement 2: Memory

- Implement it by yourself.
- **Memory** keeps and outputs the numbers of
 - An input matrix (16 numbers)
 - A filter (9 numbers)

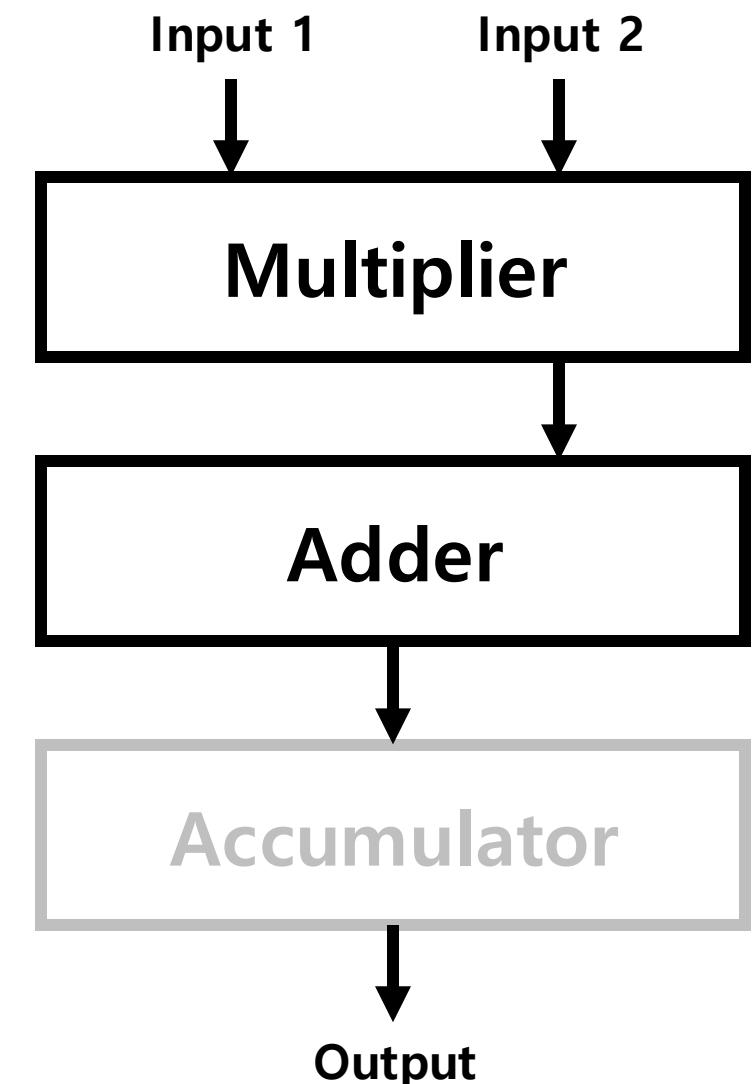


Requirement 3: PE

- Three basic modules
 - Multiplier: You can implement it with adders.
 - Adder
 - Accumulator
 - It keeps an intermediate calculation result.
 - Decide the case that we need it.
 - If you don't need it at all, it's fine not to use it.
 - Any other resources?

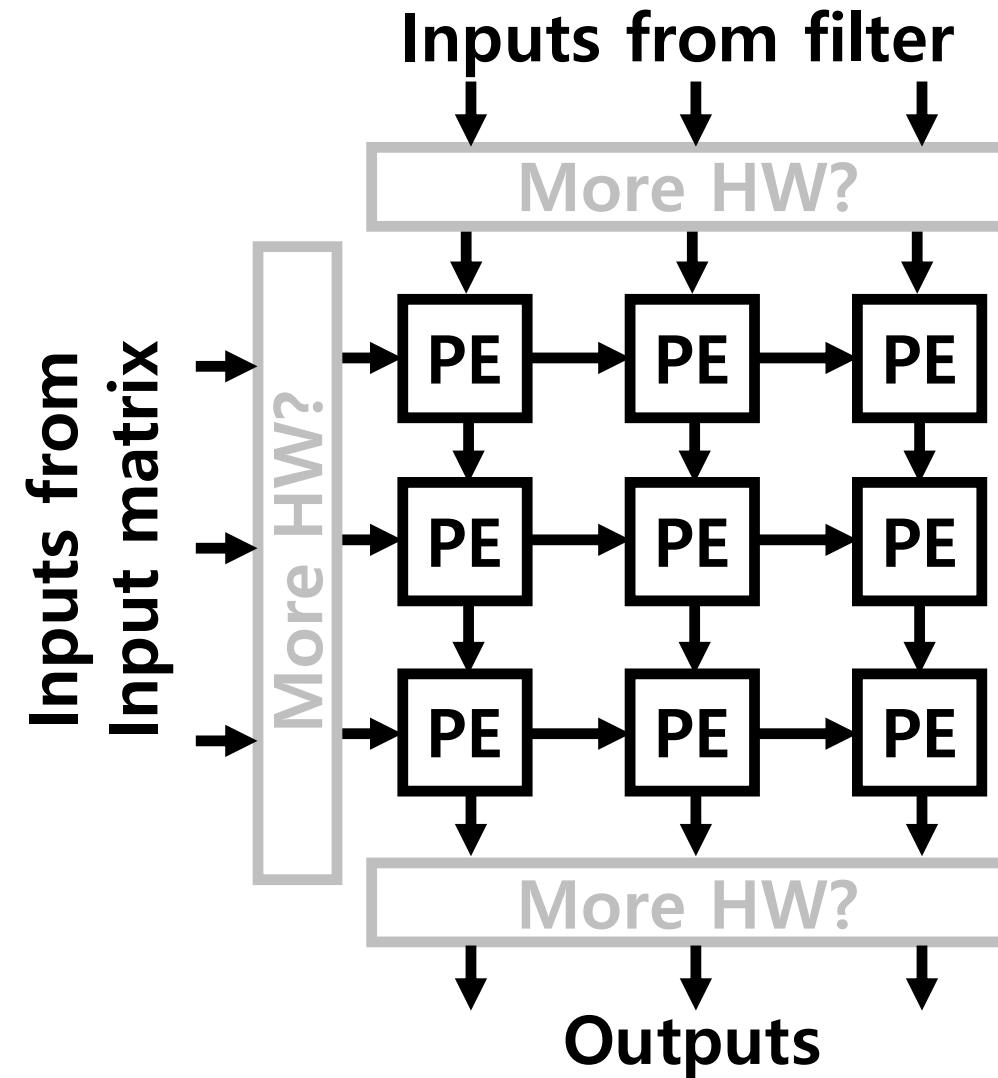
- Implement the modules by reminding
 - Three modeling methodologies ([Week 2](#))
 - Structural modeling ([Week 6](#))
 - Adders with what? ([Week 3](#))
 - Multipliers with what? ([Week 3](#))
 - Registers with what? ([Week 8](#))

- **You may want to reuse your source codes implemented in previous labs.**



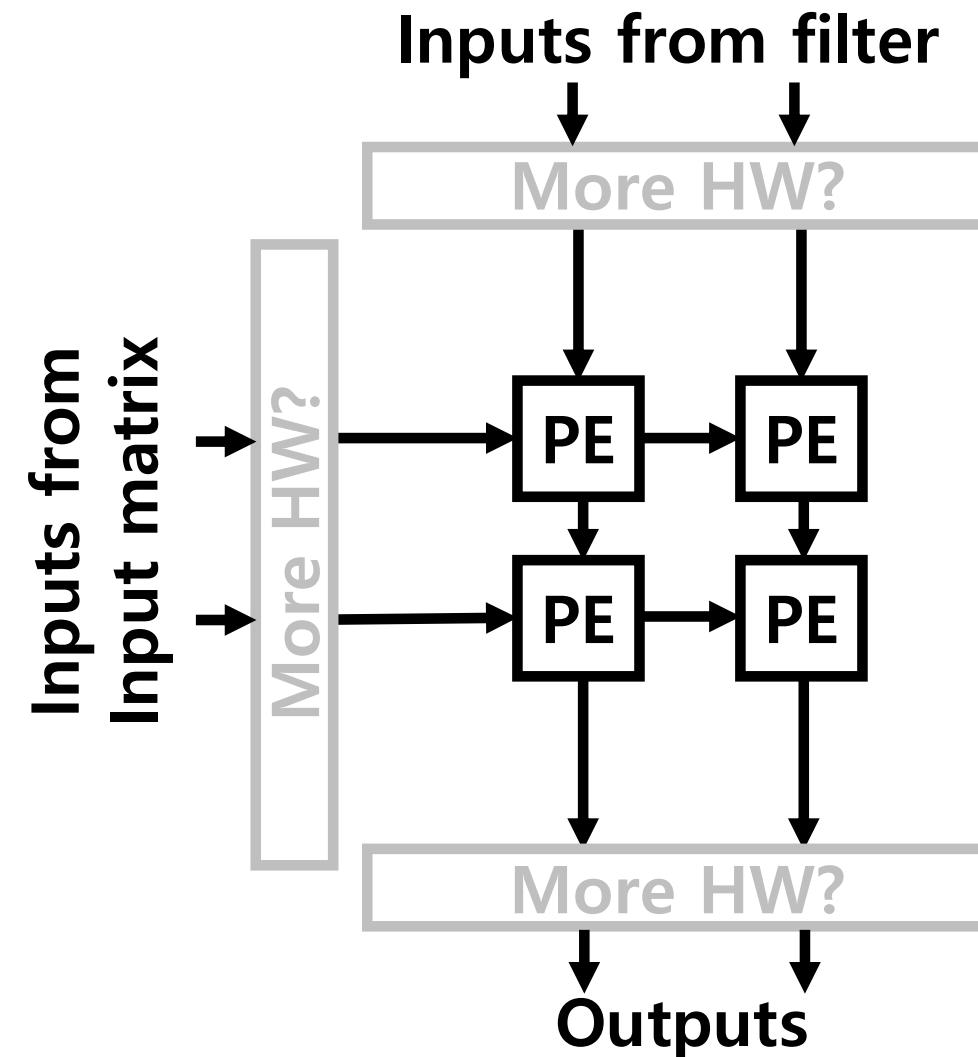
Requirement 4: Systolic Array (1/2)

- Implement a 3x3 systolic array.
- Implement the modules by structural modeling (**Week 6**).
- You may add any resources if needed.
 - Just, be clear about your design.
- Refer to an example.
(Systolic_Array_Example.pdf)



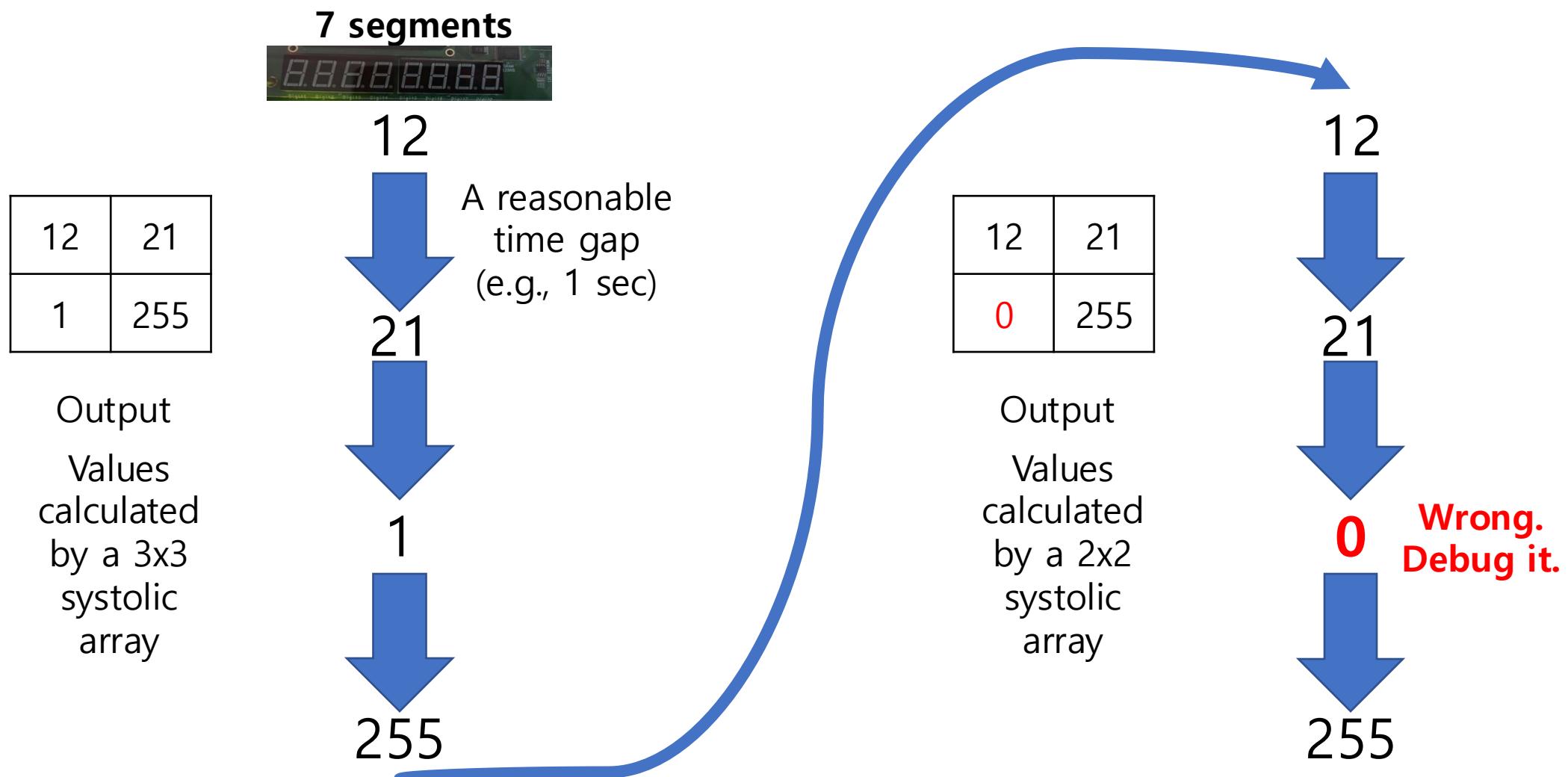
Requirement 4: Systolic Array (2/2)

- Implement a 2x2 systolic array.
- Implement the modules by structural modeling (**Week 6**).
- You may add any resources if needed.
 - Just, be clear about your design.
- Change the dataflow of the input matrix and the filter accordingly.
 - You should implement a different dataflow from the dataflow shown in "Systolic_Array_Example.pdf."





Requirement 5: Display Flow



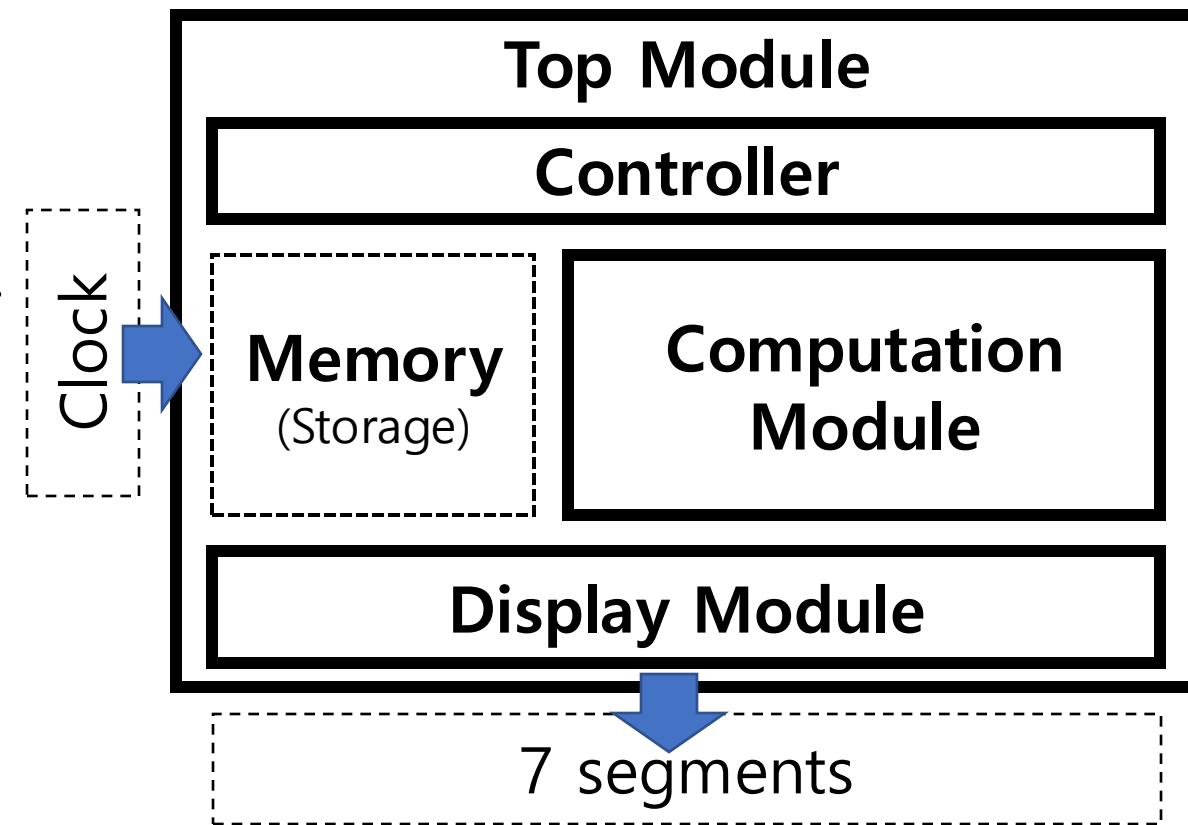
Requirement 6: Demonstration

- Once you are done with implementing Requirements 1—5 with FPGA board, let me or TAs know.
- We will give you a random 4×4 input matrix and a random 3×3 filter.
- Apply them to your source codes and show your calculation results following Requirement 5.
- If everything is ok, your demonstration is successful!
- Results from the final demo will be evaluated.

Requirement 7: Top Module

- You may want to implement a top module.

- Top module
 - Includes all the modules.
 - does not include a test pattern.
 - Triggers initialization and makes your design work.
 - Interfaces with external components of your modules. (e.g., clock, 7 segments)



- Top module just activates all the modules and make them work.



Requirement 8: Testbench

- Create a test bench file for each module.
- Report only the pre-synthesis simulation results, which you have been doing throughout this semester.
 - You may use ModelSim or Vivado.



Requirement 9: Collaboration

- Each member should implement at least one module and one testbench.
- All members review source code each other and make all the codes best.
- Have deep discussions regarding interfaces between the modules.
- Clearly write down what I emphasized above in your final report.

Implementation Styles

- You would need structural modeling (**Week 6**) everywhere.
- Along with the structural modeling methodology, use either
 - Behavioral modeling: Easiest except for what?
 - Gate-level modeling: Hardest except for what?
 - If you use a more difficult methodology, I'll give a higher score.
 - Try to reuse the source code that you implemented during this semester.
- If you employ gate-level modeling, use
 - AND, OR, NOT gates that the instructor provided
 - XNOR gate
- For the controller, just use "behavioral modeling."

Available Questions



Please find out what to do by yourselves.

- Remind that this is a project.
- Questions regarding the following may **not** be answered.
 - Specifications of the modules in this project
 - ex) PE and systolic array structures, memory structure, etc.
 - Abstract questions
 - ex) I can't compile. How can I fix it?

Overall evaluation criterion

- **FPGA demonstration**

- Will be evaluated real-time in each class

- **Report**

- 1 report per group
- Page limit: 25 pages
- What to include
 - Brief description about the project's objective
 - Theoretical design (I believe that you all figure out what is needed.)
 - Simulation results and discussions (waveform, analysis, and answer to question on p.20)
 - FPGA results
 - Contributions from each team member.

- **Source code files**



Share Your Questions

- Ask questions via
 - Q&A board in i-Campus (responses may be delayed)
 - Offline Q&A sessions

- **Questions asked via any private channels, including**
 - e-mails
 - i-Campus messages
 - phone calls**will *not* be answered.**



Your Source Codes

- Upload to i-Campus
 - Copy all the files into the project folder.
 - Submit the zip file with your report to i-Campus.



Deadline

- Refer to i-Campus.
- I STRONGLY recommend avoiding late submission.
- Each delay in submission of a second after the deadline will result in penalty in the attendance score.
- Each delay in submission of a day and more after the deadline will result in....
 - 0 score for the corresponding report.
 - **Regarded as an absence.**