



**2001: A Space Odyssey** (Stanley Kubrick-1968)



## Computer Architecture I: Digital Design - Course Room

Unlocked (available)

Create Session



Office Hour (Hossein)

Recurring: 4/14/22, 11:30 AM – 4/21/22, 12:30 PM



Office Hour (Hossein)

4/14/22, 11:30 AM – 4/14/22, 12:30 PM (not yet started)



Office Hour (Hossein)

4/19/22, 11:30 AM – 4/19/22, 12:30 PM (not yet started)



Submiss, —



Office Hour (Hossein)

4/21/22, 11:30 AM – 4/21/22, 12:30 PM (not yet started)



Lab Section 52 (Zahra)

Recurring: 4/14/22, 11:30 AM – 4/14/22, 12:50 PM



Lab Section 52 (Zahra)

4/14/22, 11:30 AM – 4/14/22, 12:50 PM (not yet started)



Lab Section 54 (Roonak)

Recurring: 4/14/22, 1:00 PM – 4/14/22, 2:20 PM



Lab Section 54 (Roonak)

4/14/22, 1:00 PM – 4/14/22, 2:20 PM (not yet started)



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# Survey Review

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3-1-2022 14:53:16	1	1	1	2	1	1	1	2	nothing much			
I am just asking that if there any chances to redo the exam for late submission.												
3-1-2022 14:54:08	0	1	1	1	3	0	0	1	lecture but i cannot understand what is trying to be said sometimes. I have lectures from other prof's Comp 2850 that are way more clearer and easier to understand. No matter how many times I watch it still cannot figure out how to draw circuits or perform signed 2 addition			
3-1-2022 14:54:30	0	1	2	2	1	0	0	2	it's little hard to understand			
3-1-2022 14:55:01	1	1	3	3	0	0	1	0	midterm was impossible to finish, too little time and too difficult			
3-1-2022 14:55:10	1	1	1	1	1	1	1	0	it will be great if there is extra 15 minutes or so for the submission of exam Writing exam then scanning, creating pdf file and finally submission takes time. So yeah it will be great if we have extra time for submission.			
3-1-2022 14:55:10	2	1	0	3	0	1	0	0	GK's do not answer to emails			
3-1-2022 14:55:17	1	1	2	1	2	0	0	1	midterm was very long and complicated and can be explained better in a more digestible way.			
3-1-2022 14:55:47	1	1	1	1	1	1	1	0	Midterm had a little time for uploading and download content. Appreciate the midtermsview though. I hope we can have a final review session too.			
3-1-2022 14:55:59	0	0	3	3	3	0	0	1	Neither systems difficult			
3-1-2022 15:00:09	2	1	2	1	3	1	1	0	Perhaps I may have just missed a lecture, but I was very confused on what was being asked from me for the last 2 midtermquestions. I know we covered those concepts yet I had trouble understanding what the questions wanted from me, they felt like a blend of different things. Besides that, I love the course, a			
3-1-2022 15:00:27	1	1	2	2	1	1	1	0	Doubts are not being cleared. Lab instructor is failing to figure out stuff on my own which is not done because I am having doubts and confusion which is why I am going to them for help. The professor did reply to the mail once for the doubt but then asked something else so again no reply. Even 1 day before the exam, I still didn't receive any reply.			
3-1-2022 15:01:22	0	0	3	3	3	0	0	0	The midterm did not provide enough time for a fair evaluation. Many people I've talked to were not able to answer number 8 due to lack of time. 1.5 hours was not enough for an evaluation of that magnitude.			
3-1-2022 15:01:22	0	0	3	3	3	0	0	1	midterm was graded. Too much work in too little time. I think it would be fair to either curve it or to take some questions off during the marking			
3-1-2022 15:05:36	1	1	1	1	1	1	1	0	Since TAs don't have 1 hour, it's hard to get help with more specific concerns for the labs			
3-1-2022 15:08:09	0	0	2	1	2	0	0	0	TAs have been awful			
3-1-2022 15:12:02	0	0	0	0	0	0	0	0	TAs shouldn't take off half the mark for one simple mistake.			
3-1-2022 15:12:17	1	1	1	3	1	1	1	1	I needed to go to different and future lectures that were not covered to find the answers for the lab assignment. That was difficult because I spent at least 1 hour just to find out that the answer I was looking for was not even in the lecture that the assignment is about (aka lec 3/4 assignment answer is in lecture 4)			
3-1-2022 15:14:11	0	0	3	3	3	0	0	0	There should not be both lab and lecture assignments, and if there has to be they should not be the size they are. It is a never-ending flow of work for this course. Also, I studied extremely hard for the midterm was not able to finish the question with 25 marks due to lack of time. I feel like this was a common problem for everyone. I feel like the marking was unfair. There are so many slides, each slide has a lot of text and there are hundreds of slides, create something that follows the circumstances with simpler examples. As of right now it is difficult to follow, and assign questions from the text book or something with solutions and it would be easier for students.			
3-1-2022 15:18:21	1	0	1	1	1	0	0	0	the midterms was too difficult for most people's midterms. I hate this midterm			
3-1-2022 15:19:51	0	0	3	3	3	0	0	0	leaves give more time for the final. midterms was awful			
3-1-2022 15:22:54	0	0	3	3	3	0	0	0	midterms simply horrendous. Way too little time.			
3-1-2022 15:23:48	1	1	1	1	1	1	1	0	I am satisfied with the marking, but the difficulty of labs and labs, but all of those are regulated by the marking, which is one of the course's goals have ever been. Labs and labs take significantly longer than they should because I am worried about the unfair marking, and I still have to spend more time to so			
3-1-2022 15:23:48	0	0	3	3	3	0	0	0	I am given more time to prepare for the exam. This review given had nothing to do with the actual topics on the midterm. Also, I feel like enough time was given for the exam as many of my peers I have spoken to were not able to finish.			
3-1-2022 15:35:46	2	1	1	3	3	1	0	0	There should not be both lab and lecture assignments, and if there has to be they should not be the size they are. It is a never-ending flow of work for this course. Also, I studied extremely hard for the midterm was not able to finish the question with 25 marks due to lack of time. I feel like this was a common			
3-1-2022 15:38:38	0	0	3	3	3	0	0	0	problem for everyone. I feel like the marking was pretty ridiculous. Losing so many marks for simple tiny errors should not be the way a course is graded. There is too much course work as well. I feel myself doing more work in this class than all the other ones combined. The midterm was not what I was expecting based on the review			
3-1-2022 15:39:49	0	0	3	2	3	0	0	0	number 8 on midterm very difficult, no time to solve			
3-1-2022 15:42:30	2	1	3	3	3	0	0	0	There should not be both lab and lecture assignments, and if there has to be they should not be the size they are. It is a never-ending flow of work for this course. Also, I studied extremely hard for the midterm was not able to finish the question with 25 marks due to lack of time. I feel like this was a common			
3-1-2022 15:42:30	0	2	2	3	3	0	0	0	problem for everyone. I feel like the marking was pretty ridiculous. Losing so many marks for simple tiny errors should not be the way a course is graded. There is too much course work as well. I feel myself doing more work in this class than all the other ones combined. The midterm was not what I was expecting based on the review			
3-1-2022 15:43:57	0	0	2	2	2	0	0	0	course is very difficult, and content not explained well. midterms was too difficult and very less little time. Plus, the slides are useless to study from and the pdfs provided to study from previous exams did not help at all.			
3-1-2022 15:50:59	1	0	1	2	1	3	1	0	I personally found the midtermsingle a bit detached from our coursework. I've done many lecture assignments, quizzes, and lots of questions from practice midterms, yet I still found myself struggling since a few questions were focused on things we only covered once briefly in class. This might be a person			
3-1-2022 15:52:22	2	1	1	1	1	1	1	0	2	There was not enough time during the midtermsingle complete every question, and through social channels I have gathered that my fellow students felt the same way.		
3-1-2022 16:01:01	1	0	1	1	2	1	1	0	3	I think the course needs to be more straight to the point.		
3-1-2022 16:07:47	2	1	1	1	1	1	1	0	2	Slides are hard to follow sometimes.		
3-1-2022 16:20:48	1	0	2	2	2	1	0	0	0	3	Felt like a lot of time was spent on labs and lec assignments would be nice.	
3-1-2022 16:30:03	2	1	1	2	1	0	1	0	0	2	midtermsingle contained questions which were only briefly touched on in class so I didn't know how to do them and the final question (creating a dijkstra's algorithm) needed a lot more time than what was available.	
3-1-2022 16:39:38	0	0	3	3	3	0	0	0	0	midtermsingle awful, too high a difficulty in too little time. I hope it either gets curved or gets cut because everyone I've talked to did not have enough time to finish.		
3-1-2022 16:48:01	2	1	1	1	2	1	1	1	0	3	Please more time for the exam	
Overall in a course there is a certain amount of time allocated to what is going on and I end up missing or time shortage to complete a review on my own. I feel like the topics are very enough but one doesn't need to review, so I usually understand it pretty well without my teacher thinking, I think, at least. I think that Hossain teaches the topics in a very convoluted manner, where it can be taught in a much more simple way of thought. If I had to put it into an analogy, it kind of feels like a robot reading out dictionary definitions to every single fine detail, and I have to think through what the robot just said a few times to simplify it in my head. This is my only complaint regarding teaching, my attitude is fine, which I can't say about all teachers, and the complaint may not even be valid because I have no point of reference to compare how this course can be taught.												
Regarding the midtermsingle may be my own fault, which is fine, but I feel like I didn't have enough time to answer the questions? I don't think I wasted any time stopping to think about a question, and I understood what I was supposed to do, but I still didn't have enough time to answer the final question (designing a circuit from scratch) I may just be slow, but I can't help but feel that it's not really my fault that I didn't get to answer every question? I think that I prepared fine enough, I watched the recording of the office hours that was done during the reading week, but it felt like I didn't have enough time to even get a chance to answer the last question? As a result, I don't even have a gauge of whether or not I'm able to answer those kinds of questions, because I didn't even get to try. It's not a big deal I guess, and I don't really know what the standard is for exams anyways, but I can't help but think that feeling like I prepared well enough for an exam still didn't have the time to attempt every question is not how a test of knowledge is meant to go.												
3-1-2022 16:51:56	1	1	1	1	1	1	1	1	These entries may be a bit noisy so feel free to dismiss them and I hope it's not too harsh because I don't think Hossain has a 0 attitude at the end of the day.			
3-1-2022 16:58:28	0	0	2	1	2	0	1	0	2	Loving the midtermsingle can tell Dr. Hossain cares about students, however Lectures are incredibly unclear and confusing, the Lecture notes might as well be useless because they are impossible to follow even after already completing 3/4 of the course in a previous semester and being knowledgeable on		
3-1-2022 17:05:31	0	0	3	3	3	0	0	0	0	Coding should not be a part of this class. It is never taught, and previous classes hasn't had to do it. Increase the lecture assignment size maybe instead, as those are the only topics discussed in class. The midtermsingle was no where near enough time. I've talked to multiple people and none of them were a		
3-1-2022 17:17:50	0	0	1	1	1	1	1	0	2	Time constraint on midtermsingle biggest issue		
3-1-2022 17:17:50	0	1	1	1	1	1	1	0	2	I feel there wasn't enough time for the midtermsingle to submit. I think we should get 5 hours to write, and the midtermsingle should be due 5-10 minutes after so we have that time to submit it. Otherwise all is well!		
3-1-2022 17:55:41	0	0	2	2	2	1	0	0	2	add more descriptive text to the slides to make reviewing with them easier		
3-1-2022 17:57:30	2	1	0	1	1	1	1	0	3	add more descriptive text to the slides to make reviewing with them easier		
3-1-2022 18:07:51	0	0	3	3	3	0	0	0	0	Not enough time on the midtermsingle		
3-1-2022 18:14:13	1	1	1	1	1	1	1	0	1	Exams were a bit difficult, but more time or 1 question less would of been better		
3-1-2022 18:19:01	2	1	1	1	1	1	1	0	2	Sometimes it's hard to understand the slides, but overall I've had a good time in the class.		
3-1-2022 18:56:13	0	1	1	2	1	2	0	0	2	midtermsingle was a bit difficult, but overall I've had a good time in the class.		
3-1-2022 19:04:43	1	1	1	1	1	1	1	0	2	In my opinion, I believe the teacher should include more information in the slides. If a student wants to go back to look at the slides, they would have to rewatch the entire lecture to entire a point that could've been written in a sentence.		
3-1-2022 20:22:33	0	1	2	3	1	1	0	0	0	no more 10amclasses :)		
3-1-2022 20:23:34	1	1	1	2	2	1	1	0	0	I appreciate how the class is organized. I like how we have a schedule to follow what lectures will be coming up and how the deadlines are always on the same days. I would appreciate if slides could be more informative however (ie. More notes) so that we have some explanations next to the images presented		
Overall the course work is fair. Some of the labs are challenging specifically lab 5. Lecture questions are fair but there are some a bit challenging like I have no idea where it is coming from. I try to supplement with the text book but its not that good. I do think the classes have taken a dip when we switched to flexify but that's more a tech issue I think. Midtermsingle seemed fair as well. Overall I am satisfied with course												
3-1-2022 20:41:29	1	1	2	1	3	0	1	0	2	more time for labs		
3-1-2022 20:50:37	1	1	2	2	2	1	0	0	2	feel slides are really long, which makes studying a pain with 100+ slides per topic. So maybe lowering the number of slides per lesson may be helpful.		
3-1-2022 21:02:12	1	1	2	0	0	1	1	0	2	Hard midtermsingle guess.		
3-1-2022 21:06:57	0	1	3	3	3	1	1	0	2	One of my main critiques is that the slides are very messy, it's very difficult to follow along. I understand alot of information is meant to supplement from reading the lectures but it does feel like they are a bit too barebone. Also, the 90 minute time limit for the midtermsingle was very unreasonable, especially considering the amount of material we covered in the course.		
3-1-2022 21:06:57	0	1	3	3	3	1	1	0	0	3	More bullet points on slides.	
3-1-2022 21:23:27	1	0	1	1	1	1	1	0	2	I don't really see the point of taking this class when I could be learning python instead. I like Hossain though, he's very kind and clear with his explanations! Ques nice and slow, which I appreciate. The labs and labs are all fine and I think the midtermsingle fairly well. Overall, good experience.		
3-1-2022 22:12:33	1	1	2	1	2	1	1	0	2	While doingating Eclipse, I ran into a bug that crashed my computer twice. Notchines was also hard to work with, I'm not a programming student and I live 30 mins away from campus. I also been wary of the pandemic so I did not feel comfortable going into in person labs. I much prefer using online comp		
3-1-2022 22:23:06	0	0	3	3	3	0	0	0	0	1	I really hope the final is easier than the midtermsingle. At least give it more time. Many people not able to finish the midtermsingle due to the fact we run out of time. It is not fair in my opinion.	
3-1-2022 23:58:21	1	0	1	1	1	1	1	0	0	2	ok	
3-1-2022 23:58:49	1	1	3	3	3	1	1	0	1	3	The teaching of professor is really good. A very good communicator. I just wish there were more examples. I would love if we could have a PDF each week with a couple of examples that are solved and explained step by step. This is only due to online classes. Chemistry, I assume I would've understood	
3-1-2022 20:01:58	1	1	2	1	2	0	0	0	0	3	The grading is a bit harsh	
3-1-2022 14:05:36	1	1	2	1	3	1	0	0	0	2	no more 10 amclasses!	
3-1-2022 20:32:04	0	0	3	3	3	0	0	0	0	3	I did the practice questions for the midtermsingle understood most of it, so I had a false sense of security for the midtermsingle didn't do very well. Also not having the solutions to the review questions made it possible to know if you are actually doing well. Lecture slides are confusing and its annoying! Time consuming to have to watch the videos again just to quickly review something.	
Also, I didn't feel like there was enough time for the midtermsingle, there were questions which were basically left blank because I felt like the last question especially was out of the scope of what we learned. I felt blindsided by the midtermsingle because it was nothing like the review questions. Also, having 3 assignments all due at 4 amwas 0. Just overall way too much work for one week, and the labs are way too much work.												
I feel like the content of the lecture assignments are more important to this course so idk why they are so much smaller. We are wasting too much time coding and not actually learning the material of the course.												
3-2-2022 20:36:06	0	1	2	1	2	1	1	2	2	Ronak is an excellent GA		
3-3-2022 09:42:14	1	1	1	1	2	1	1	1	3	If you could provide the solutions to the labs after the due date as well so if we make a mistake we don't lose marks consistently.		
3-3-2022 10:11:12	1	1	1	2	1	2	1	1	2	Very lengthy exam.		
3-3-2022 10:15:28	1	0	2	1	2	0	1	0	2	The lab assignments are not so good cause we're not taught any coding language in this course. Its loading us with 2 assignments weekly which might not be fair in the short run. Also, the time limit for exams is too less. Barely reached question 6 with 2 minutes left (including submission of pdf too)		
3-3-2022 10:22:31	1	1	3	1	3	1	1	0	2	1	2	It took way more time for the midtermsingle, I didn't have time to finish it. I think we should have both the lab and lecture assignments, the labs can be very lengthy and a lot of work. Also, it would be great if you could add more points to your sides, they can sometimes be hard to understand.
I also really like the in-class "polls" because they show how well the class have understood the materials, and the existence of multiple "right answers" shows the different approach we can take to solve a problem. As the class progresses to more complex circuits, visualization of the question options may help better explain why some are "wrong" or "not applicable" to the question.												
3-3-2022 11:31:47	2	1	2	2	1	1	1	1	2	if my assumption is correct, the format and expected answer of most of the questions in the midtermsingle except maybe question 1, were touched upon in class. However, I think the difference in the style of question between the practice midtermsingle and the actual midtermsingle especially on question 5 and 6, and perhaps on question 8) may have three people off in terms of how much they need to prepare and how much they should sit down. This, in combination with the time people need to scan and upload answers, may have been the reason why many people felt overwhelmed by the midtermsingle.		
3-3-2022 13:25:45	1	1	2	1	2	1	0	0	2	Not enough time for midtermsingle.		
3-3-2022 14:50:31	0	0	3	3	3	0	0	0	2	The midtermsingle was very difficult with not enough time given the questions' difficulty and they were hard to understand especially the last question which was worth a lot. The marking was very unfair and given the difficulty of the test compared with the lecture assignment. The labs take a lot of time to finish and g		
3-3-2022 15:39:32	2	1	2	2	2	0	0	1	2	2	While I love the idea of trying to be as traditional as possible with the teaching, I find that the lecture slides don't contain much noteworthy information. Even following through with lectures they tend to not have as much visually to see. Personally I find that I can retain information better from point form diagrams, and diagrams are much easier to remember.	
3-3-2022 15:45:41	1	1	2	1	0	1	1	0	2	2	While I love the idea of trying to be as traditional as possible with the teaching, I find that the lecture slides don't contain much noteworthy information. Even following through with lectures they tend to not have as much visually to see. Personally I find that I can retain information better from point form diagrams, and diagrams are much easier to remember.	
3-3-2022 15:45:46	1	1	1	0	1	1	0	0	2	3	I zone out a lot which is why I like text to refer to. I learn better personally with text and it would be nice to learn from more texty lesson.	
3-3-2022 21:25:23	1	1	1	1	1	0	0	2	2	One question on the midtermsingle failed about 30seconds in sec 2A and never brought up again, but it was worth more points than the truth tables that have been shown to be far more important for the course. There wasn't even enough time to finish the midtermsingle how are we expected to do 2 truth tables, do a		
3-3-2022 13:47:06	1	1	1	2	1	1	0	0	2	2	While willing on the slides would help a lot.	
3-3-2022 13:47:07	1	1	2	1	2	1	1	0	2	3	Not enough time for the midtermsingle.	

## Lectures

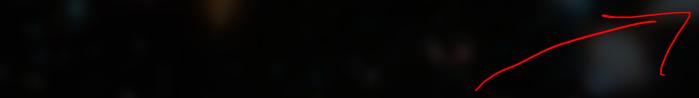
- Slides
  - More written notes *text*
  - More organization
  - More example



Are robots becoming more human or humans  
becoming more robotic?



## Googler vs. Googler



Googler: A Person Who Builds Google

Googler: A Person Who Works for Google

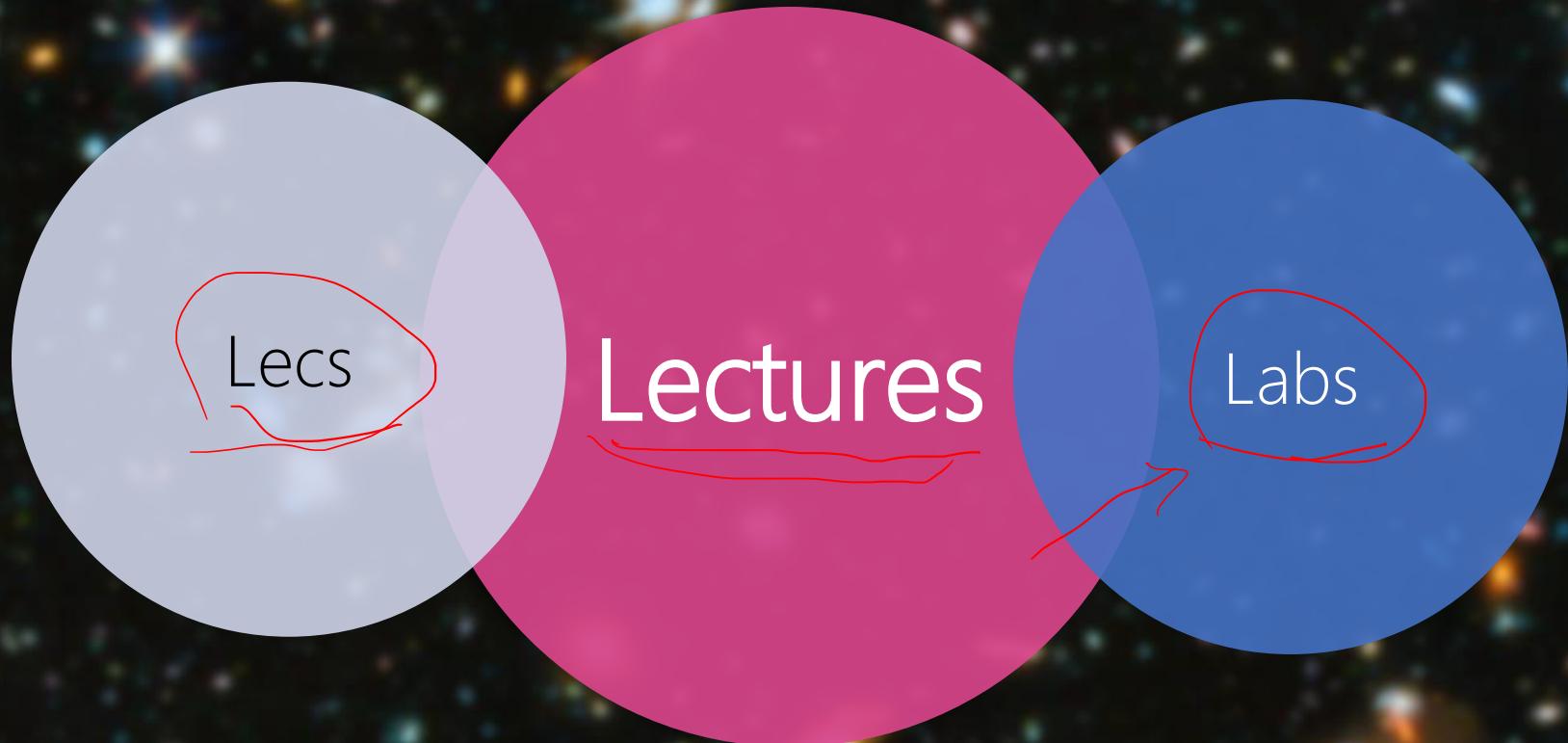
Googler: A Person Who Uses Google



Lecture  
Presentation  
Dialog

vs.  
vs.  
vs.

Text  
Book  
Monolog



## Lectures

- Slides
  - More written notes → Yes but won't replace lectures!
  - More organization → Yes, will work on it
  - More example → No, please attend lab sections!

lec

## Assignments

- Labs
- Those scared of coding, start coding!





**2001: A Space Odyssey** (Stanley Kubrick-1968)

Number Systems |

| Computer Systems

Number Systems |  $(12)_{10} \rightarrow (1100)_2$

| Computer Systems

Number Systems |  $(12)_{10} \rightarrow (1100)_2$   
| Logic Gates | 

| Computer Systems

Number Systems |  $(12)_{10} \rightarrow (1100)_2$

| Logic Gates | 

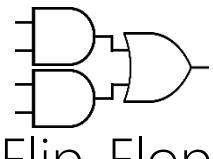


| Computer Systems

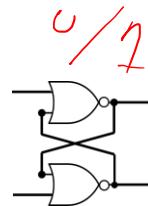
Number Systems |  $(12)_{10} \rightarrow (1100)_2$

| Logic Gates | 

| Combinational Logic |



| Flip-Flops |

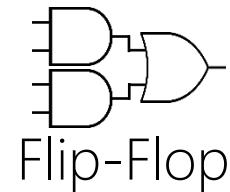


| Computer Systems

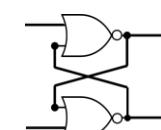
Number Systems |  $(12)_{10} \rightarrow (1100)_2$

| Logic Gates | 

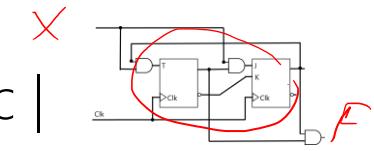
| Combinational Logic |



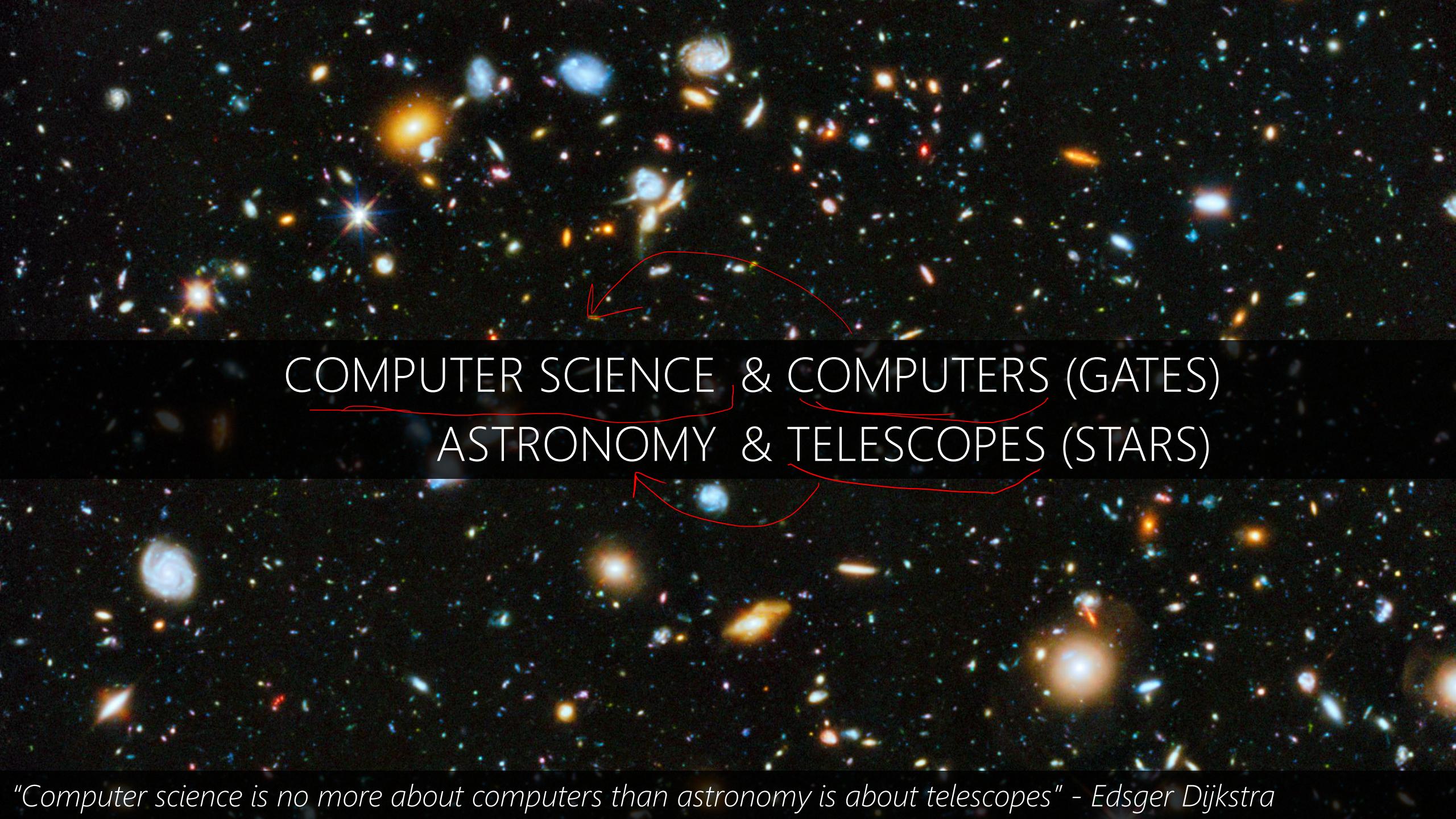
| Flip-Flops |



| Sequential Logic |

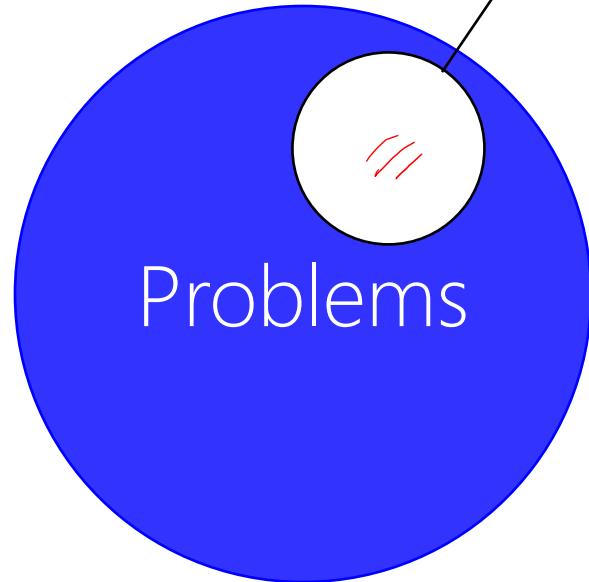


| Computer Systems

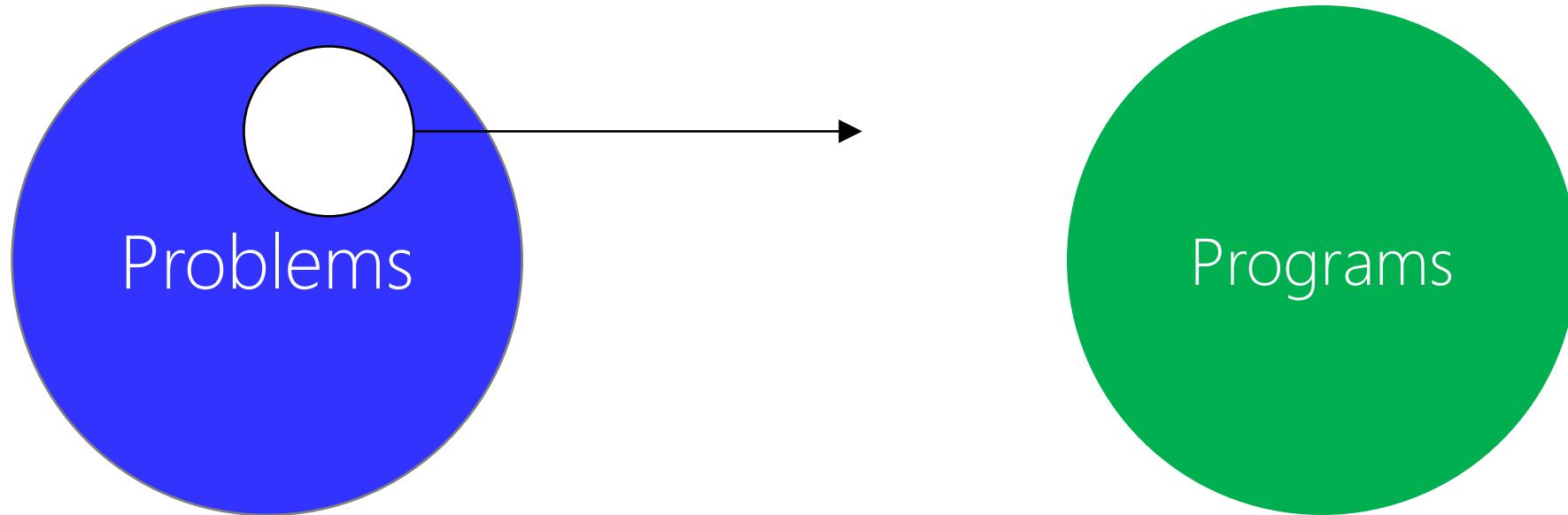


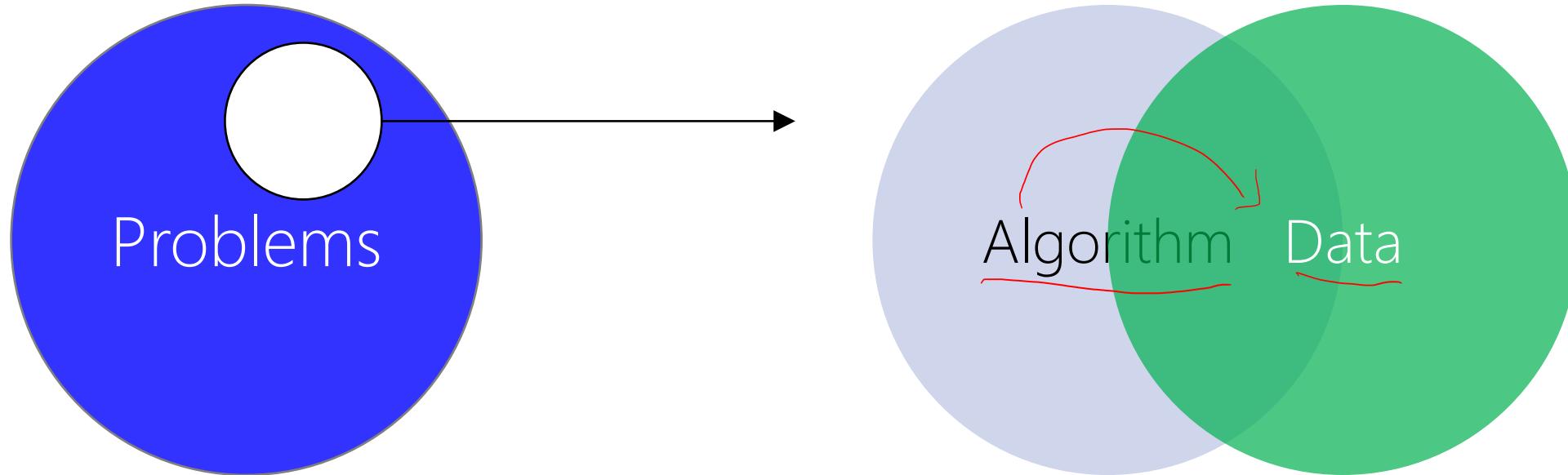
COMPUTER SCIENCE & COMPUTERS (GATES)  
ASTRONOMY & TELESCOPES (STARS)

*"Computer science is no more about computers than astronomy is about telescopes"* - Edsger Dijkstra



Computable  
Theory of Automata  
Theory of Computation  
Theory of Computer Science





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# Design a Computer System

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# John von Neumann

(/vən ˈnœmən/)

1903 – 1957

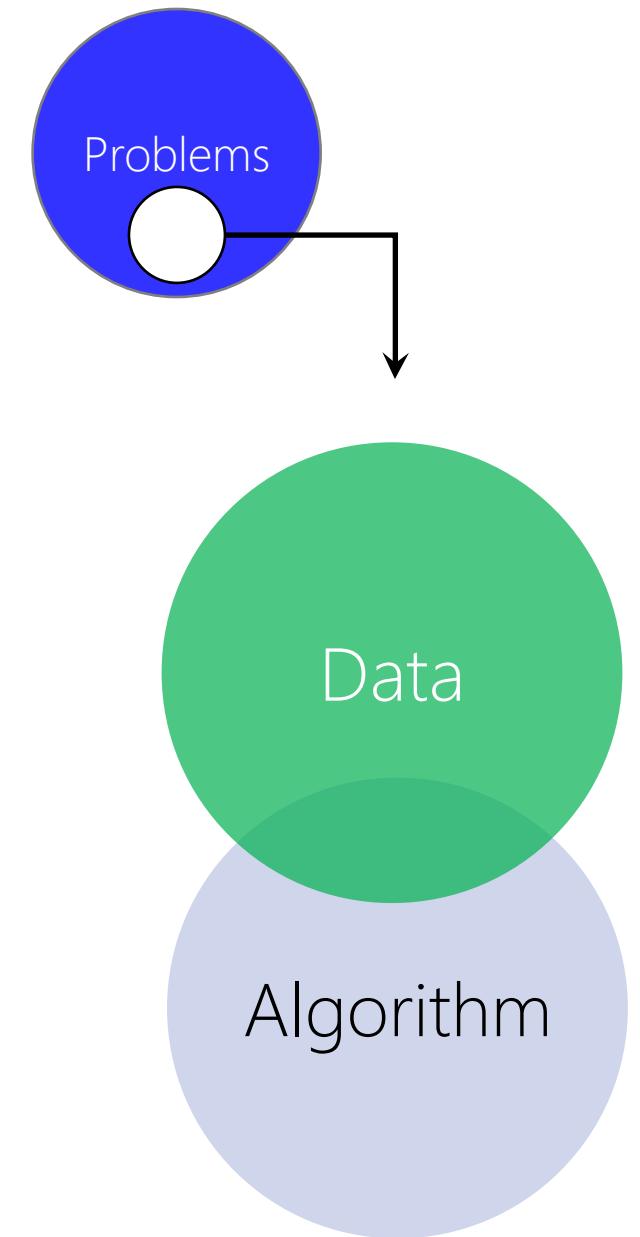
Mathematician, Physicist, Computer Scientist, Engineer

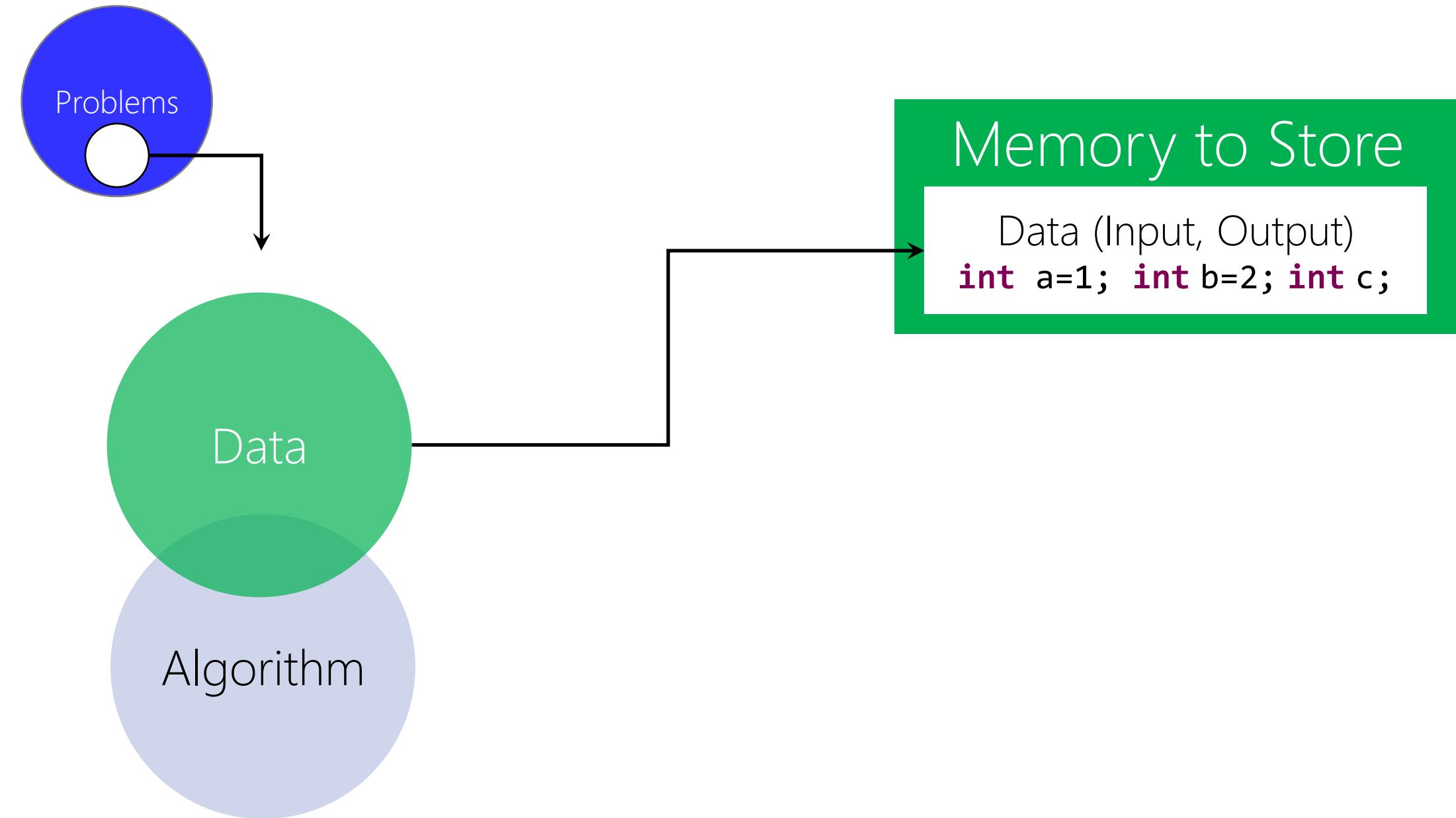
## Polymath

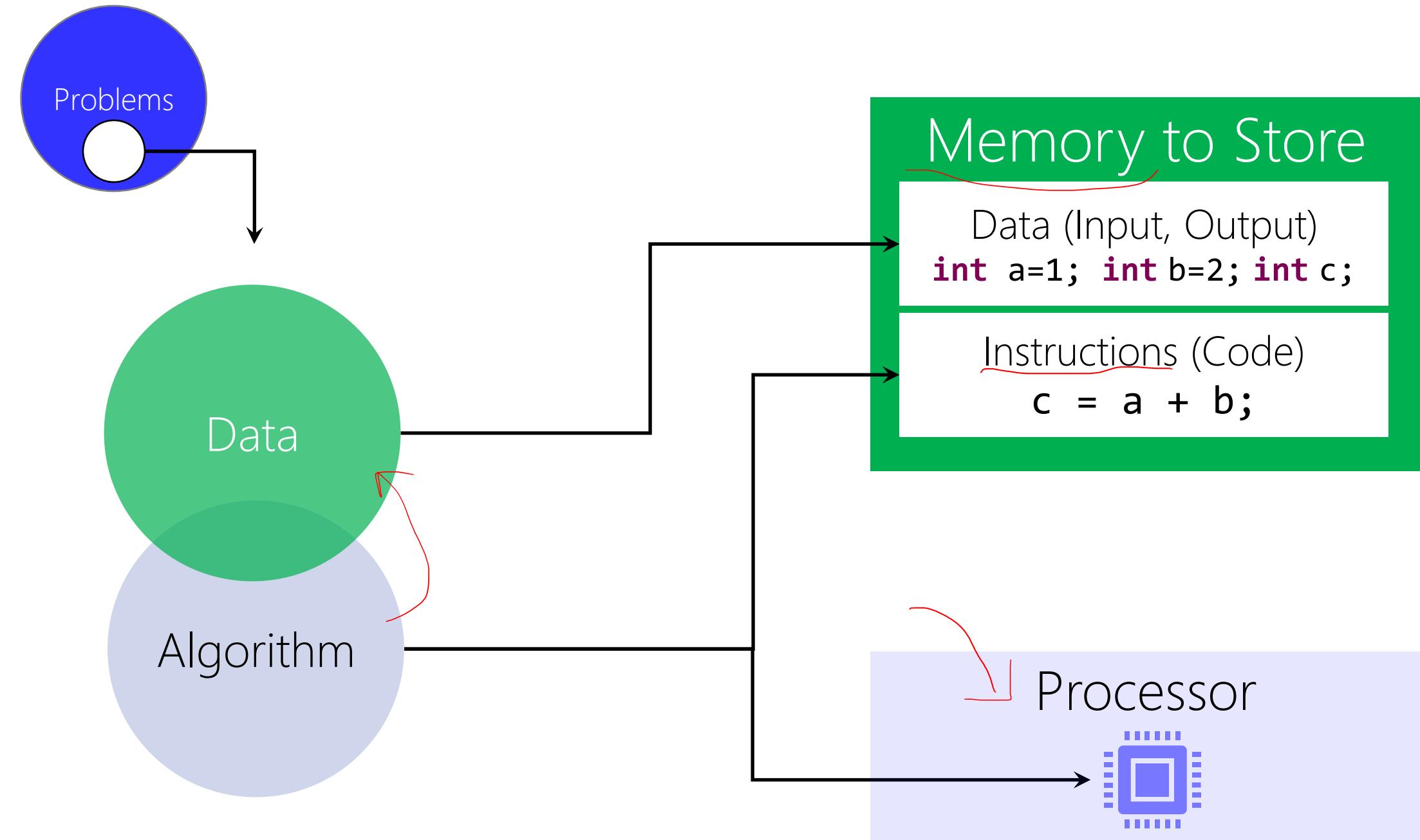
He integrated pure and applied sciences. He made major contributions to many fields, including:

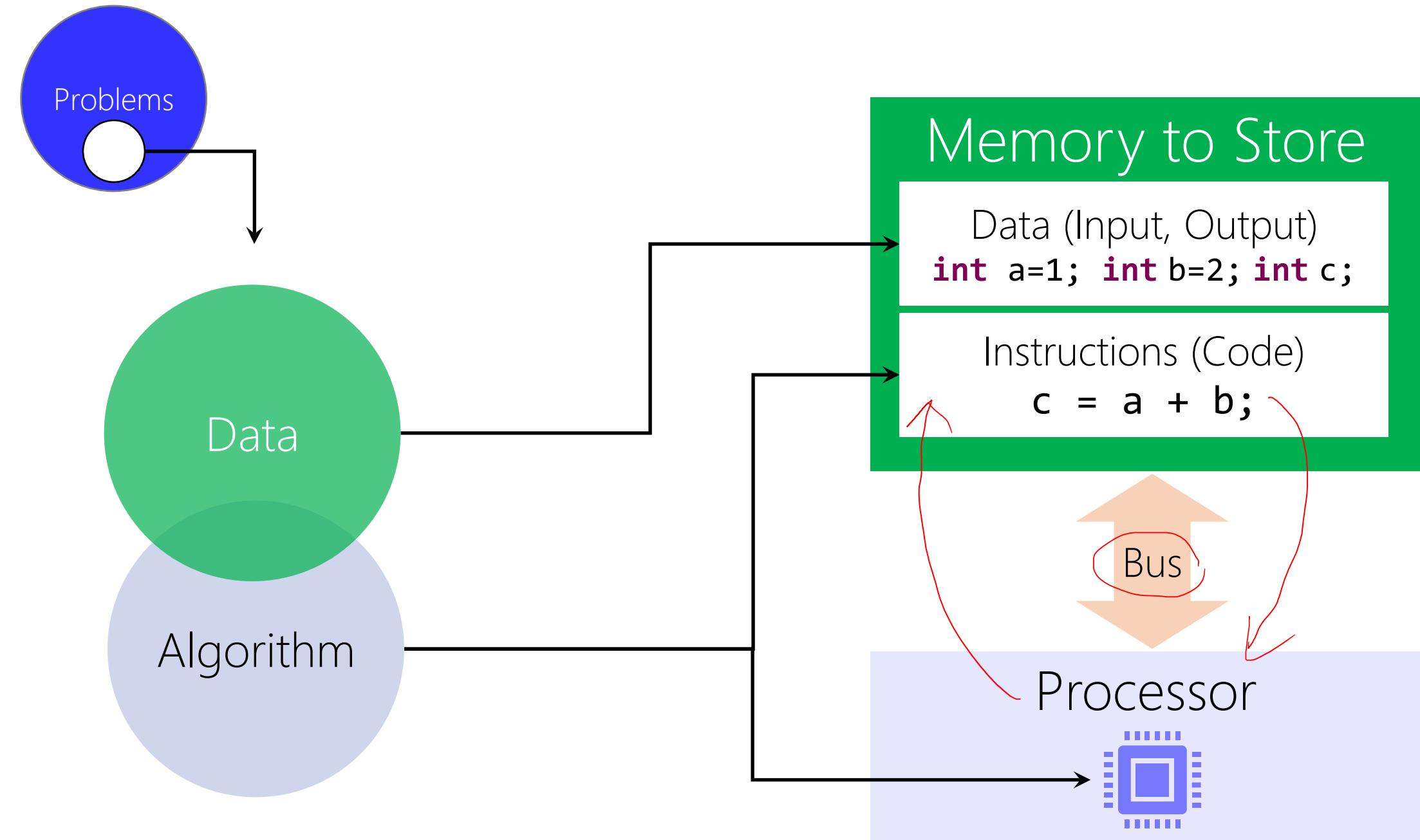
- Mathematics
- Physics
- Economics (game theory)
- Computing
- Statistics

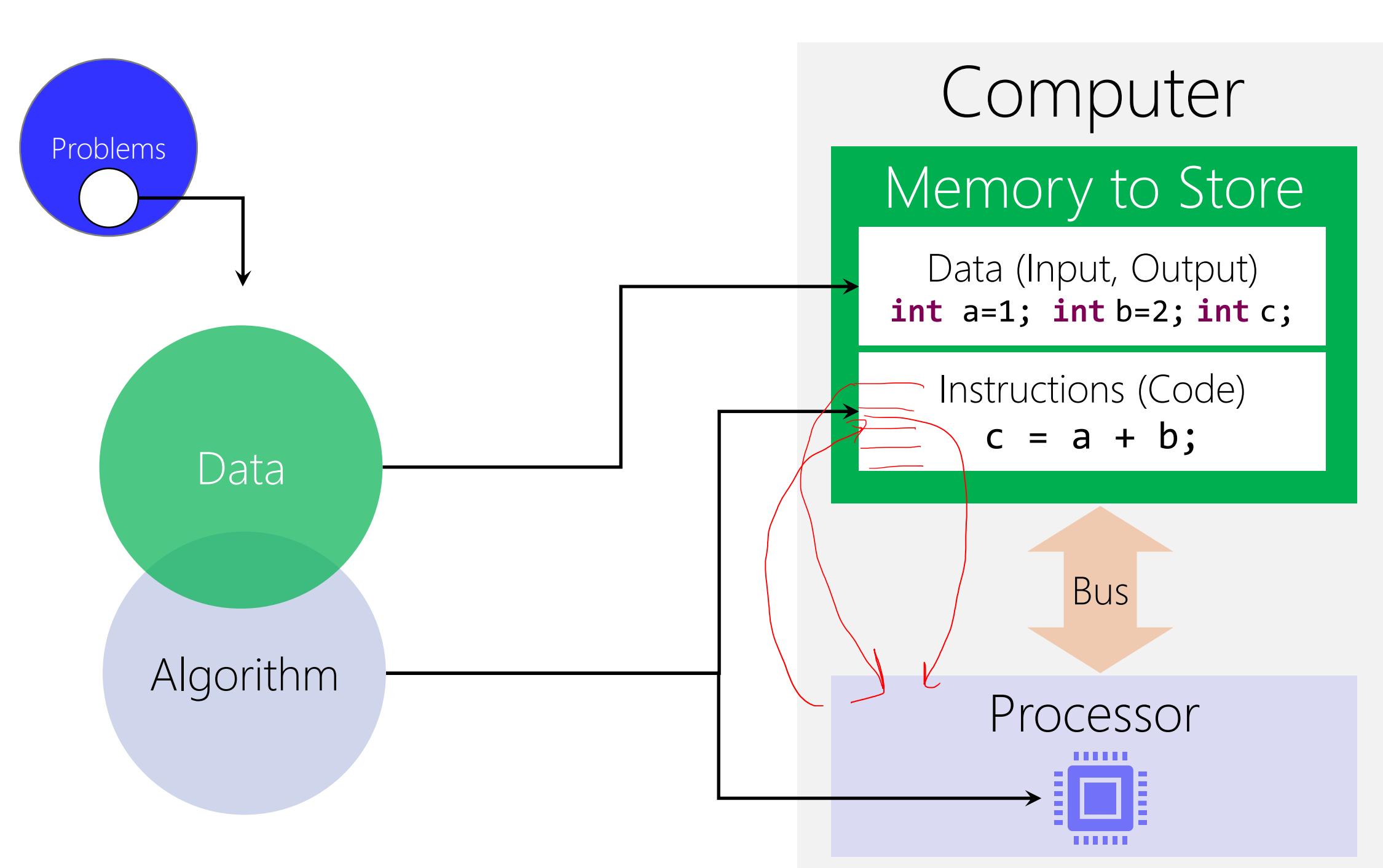












---

# von Neumann Architecture

---

## Principles

- Data and instructions are both stored in the main memory
- The content of the memory is addressable by location (regardless of what is stored in that location)
- Instructions are executed sequentially unless the order is explicitly modified

# Computer System

Computer

Memory to Store

Data (Input, Output)

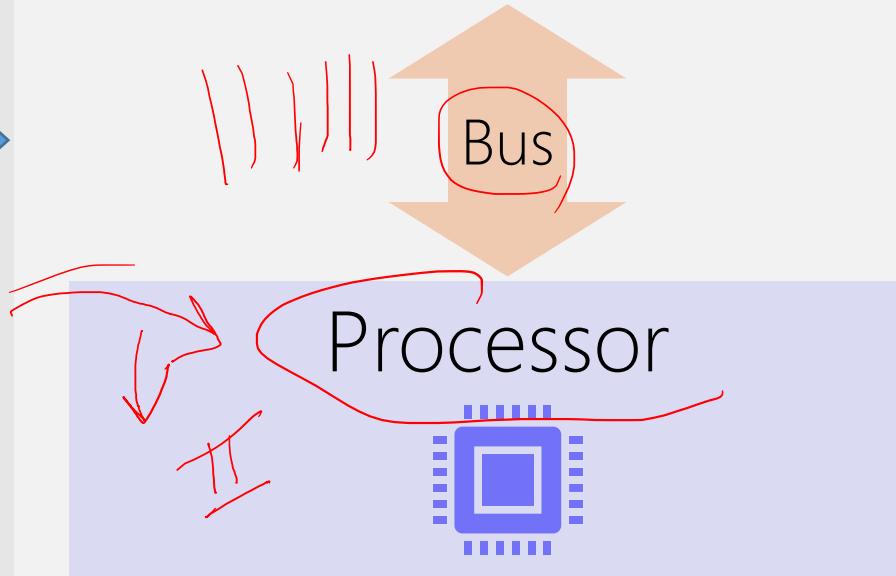
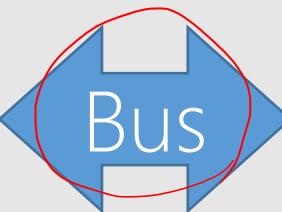
```
int a=1; int b=2; int c;
```

Instructions (Code)

```
c = a + b;
```

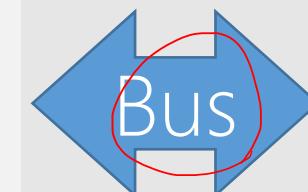
Input/Output  
Devices

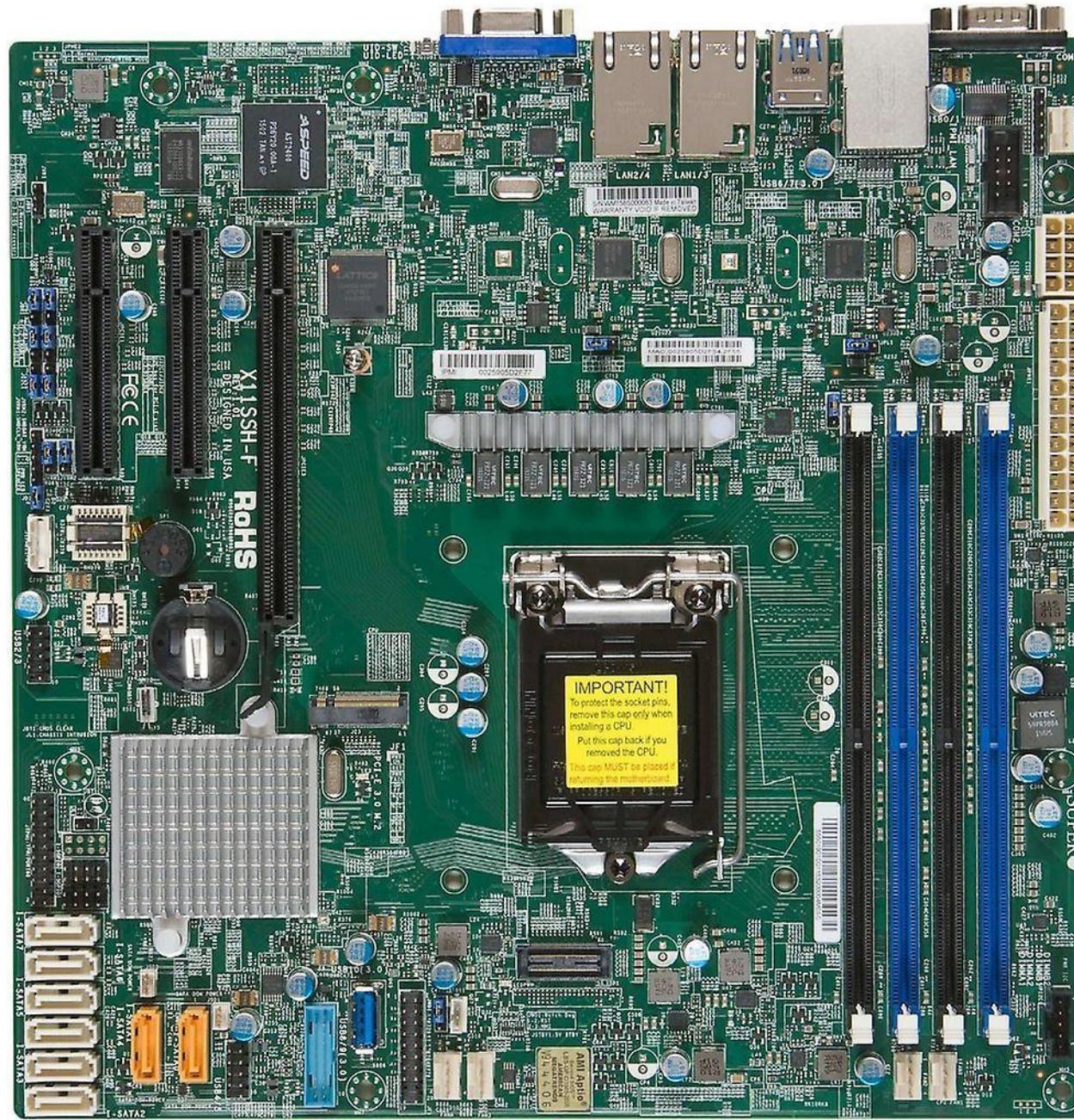
```
scanf("%d", &a);  
scanf("%d", &b);  
printf("%d", c);
```

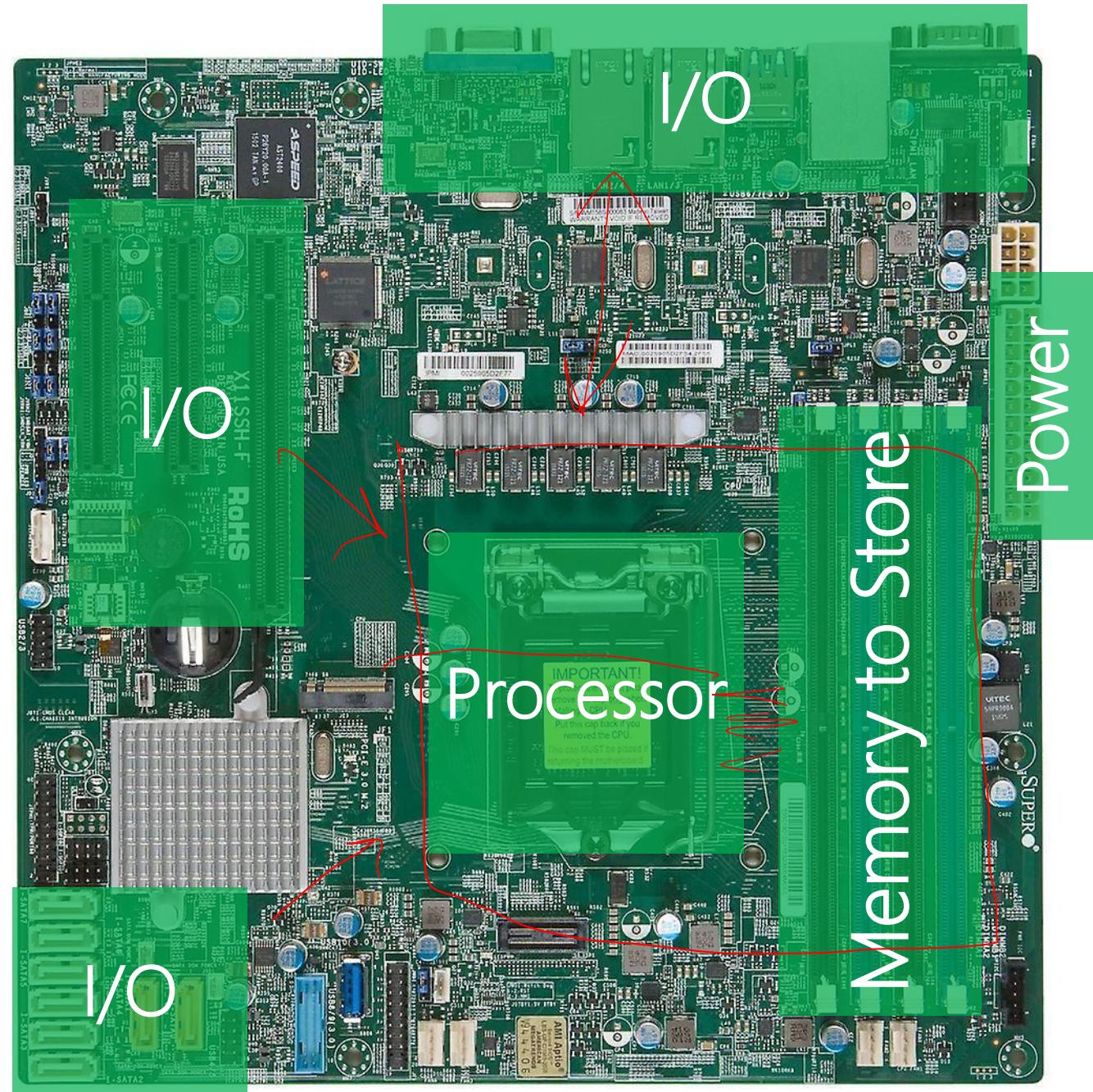


Permanent  
Storage

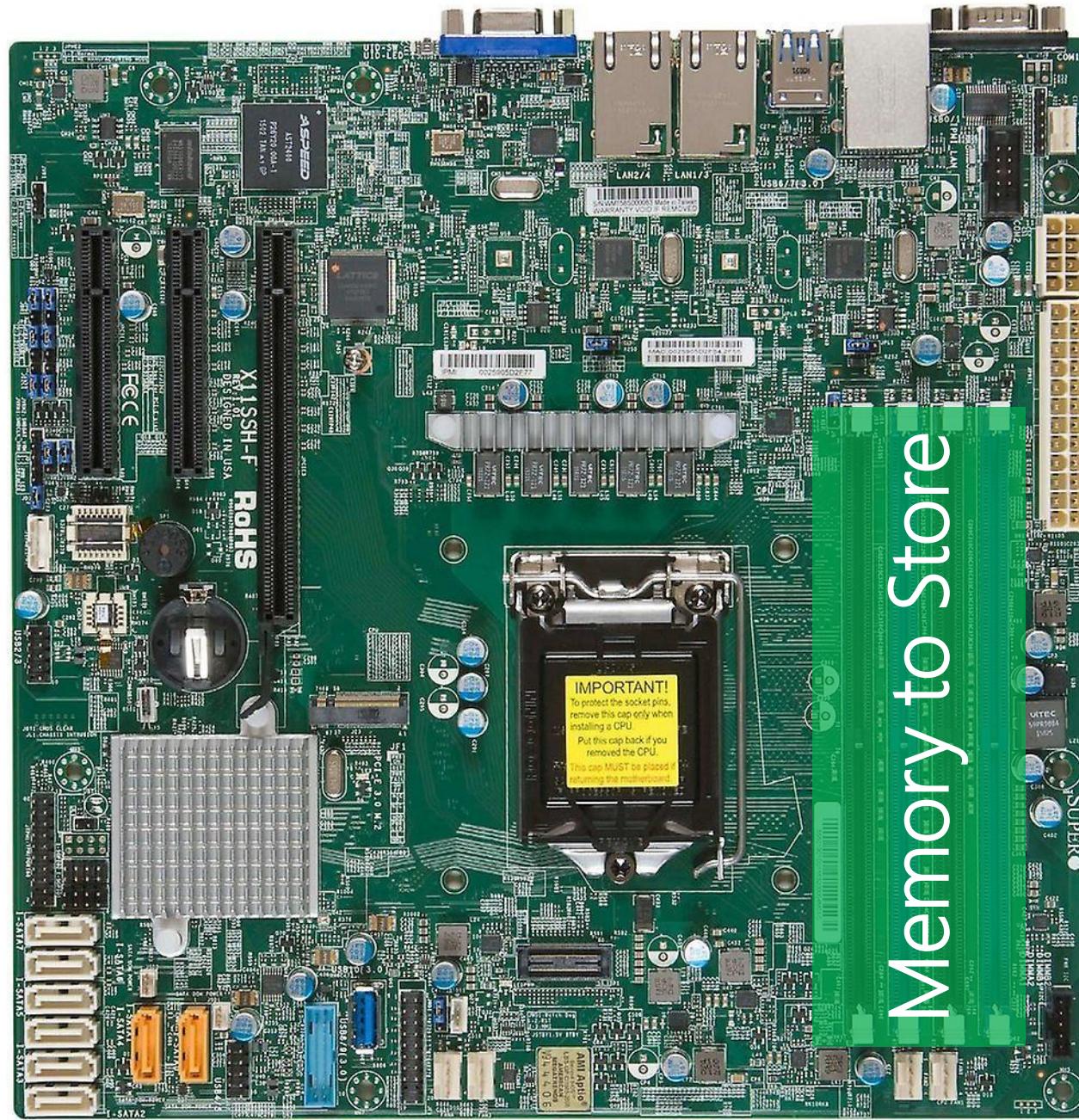
```
fprintf()  
fscanf()  
fread()  
fwrite()  
fseek()
```







Memory to Store



---

Design Memory  
To Store Data + Code

---

---

# Design Memory

Data → Numbers

*(Con) Disc*



---

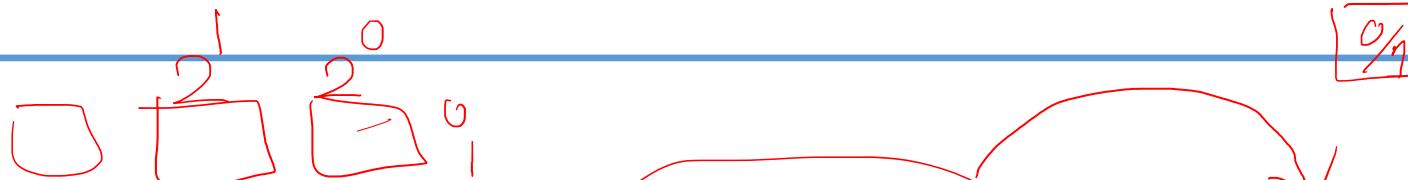
# Design Memory

Each Number  $\in [\min, \max]$   $\rightarrow$  Binary System

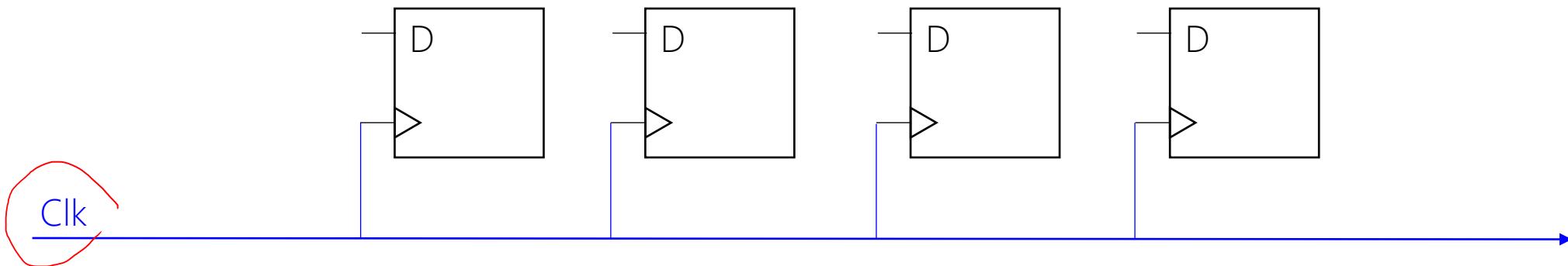
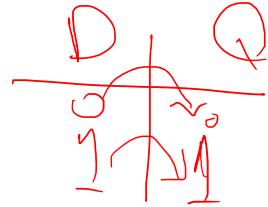
---

# Design Memory

Each Number  $\in [0, 2^n)$   $\rightarrow$  n Flip-Flops

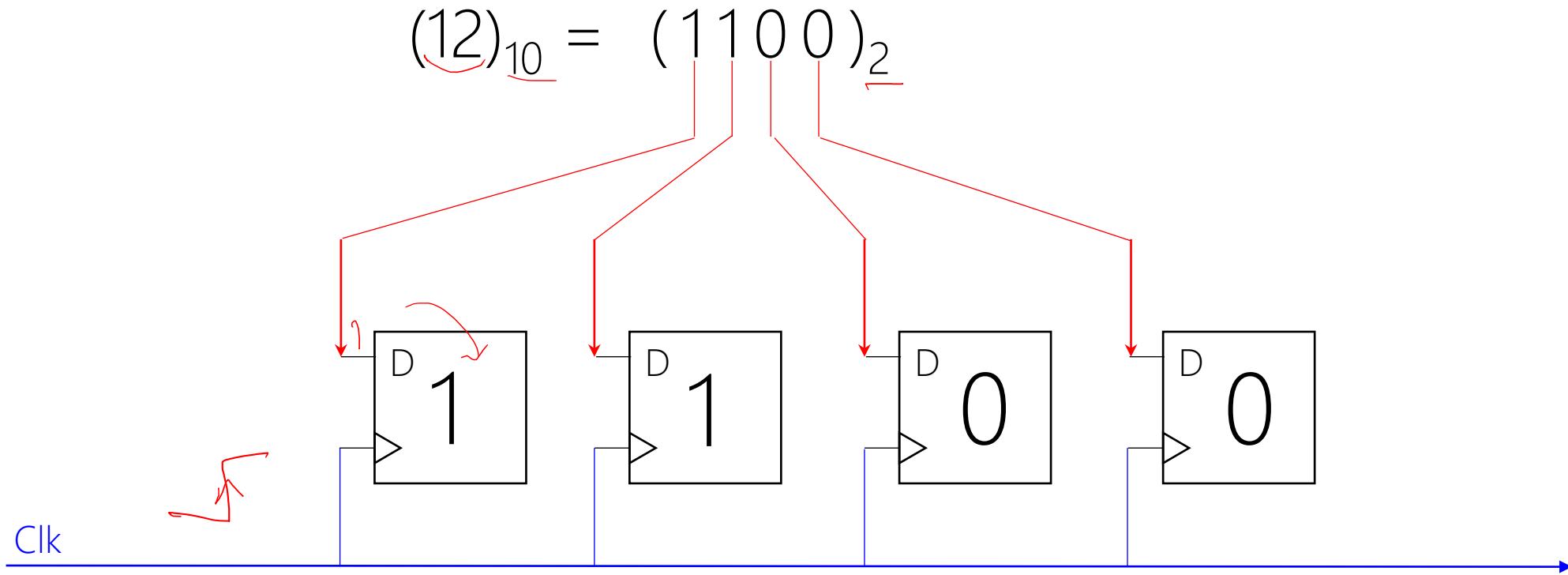


Number System's Position  $\leftrightarrow$  Flip-Flops

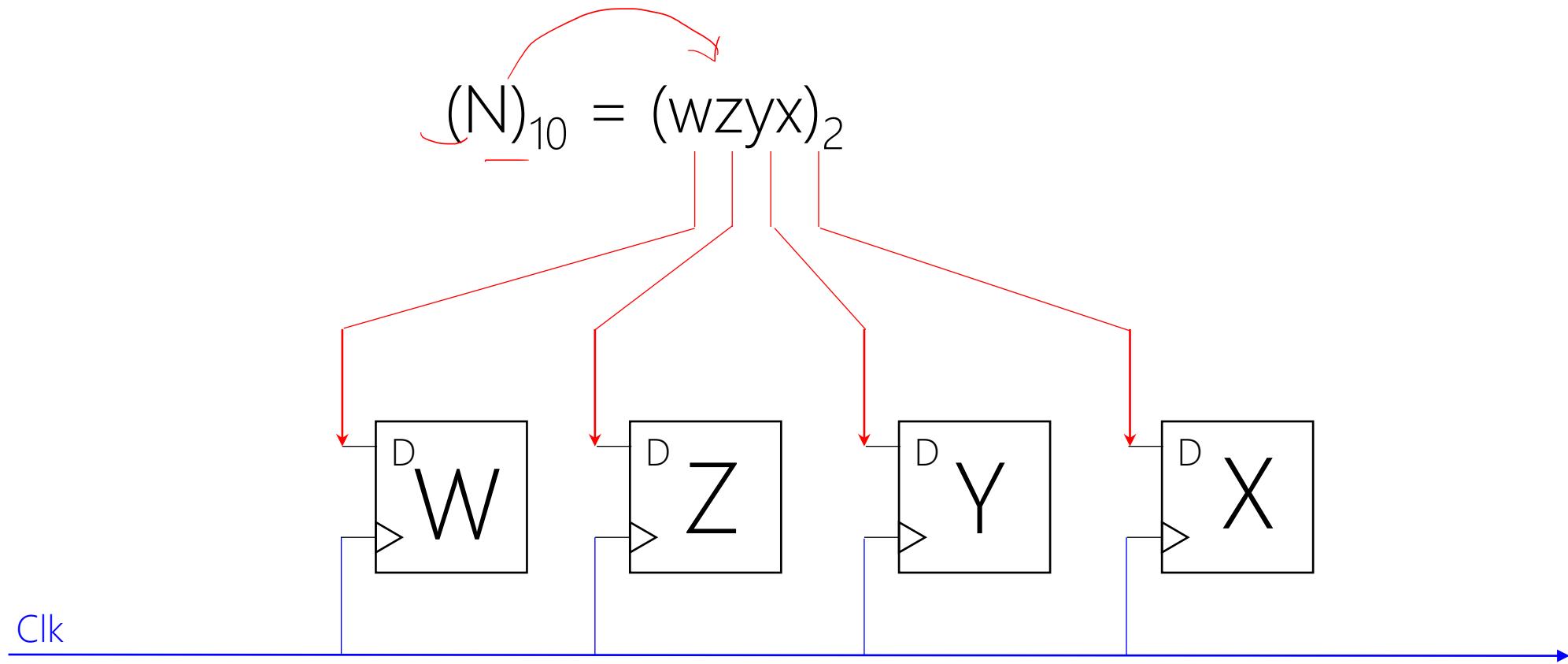


$n=4 \rightarrow$  Each Number  $\in [0, (2^4=16) \rightarrow 4$  Flip-Flops

$$(12)_{10} = (1100)_2$$

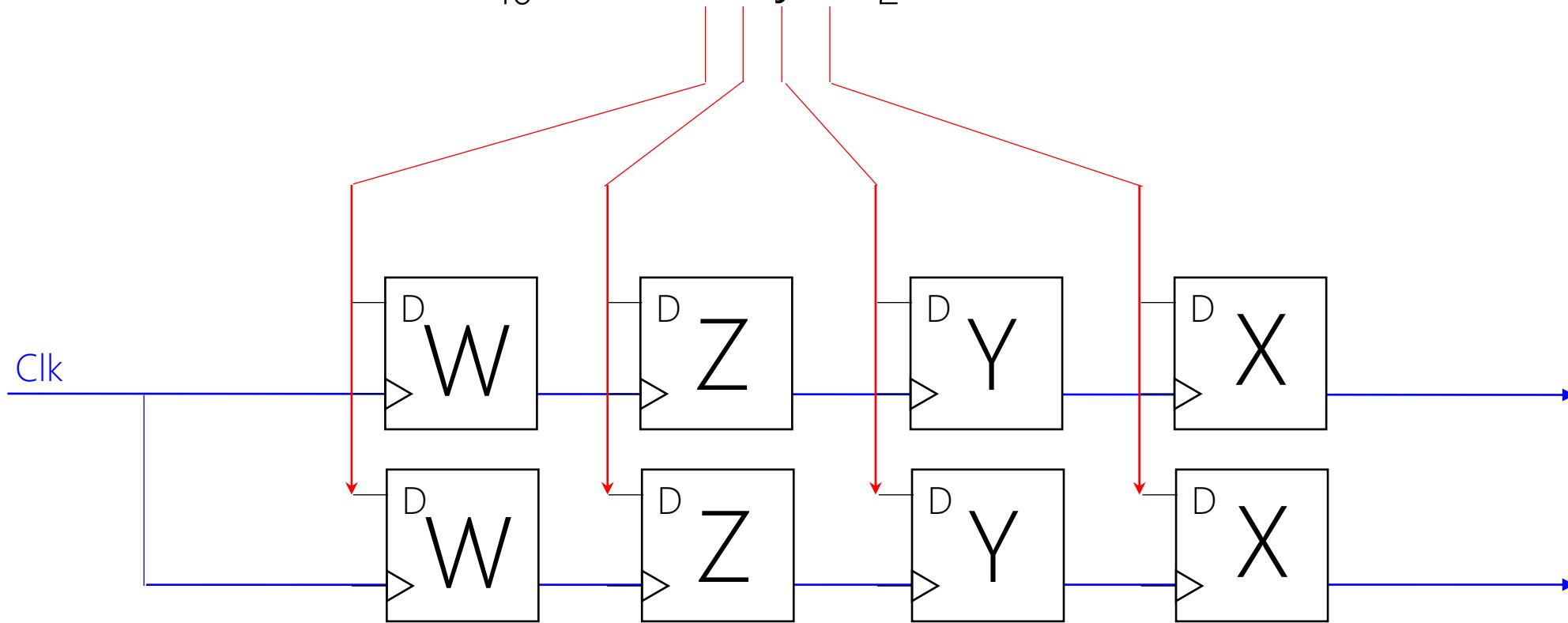


$n=4 \rightarrow$  Each Number  $\in [0, 2^4=16)$   $\rightarrow$  4 Flip-Flops



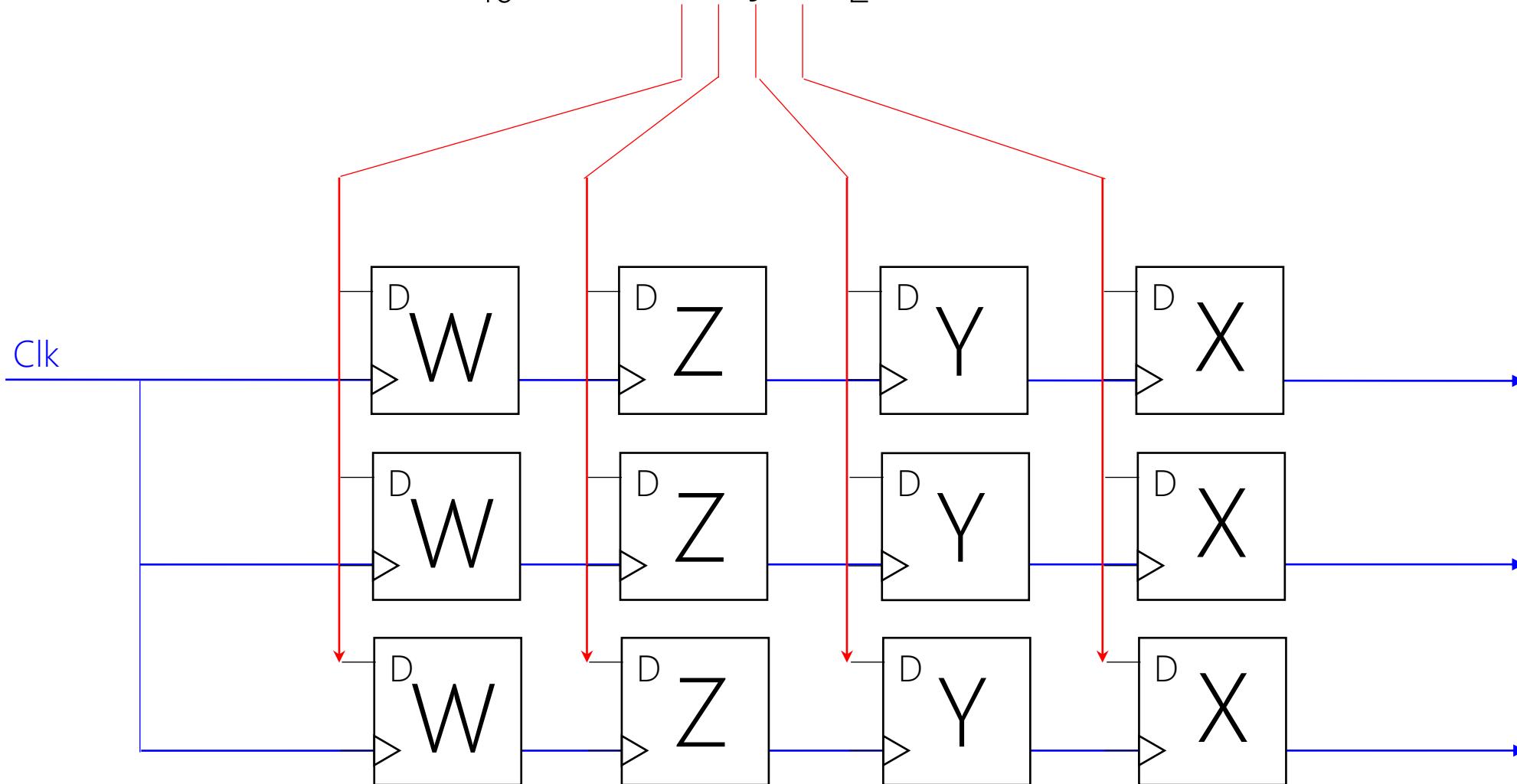
①  $\times \text{Number} \rightarrow 1 \times \underline{n} \text{ FFs} \rightarrow 1 \times \underline{n\text{-bit Register}}$   
 Register  $\rightarrow$  an vector of flip-flops

$$(N)_{10} = (w z y x)_2$$

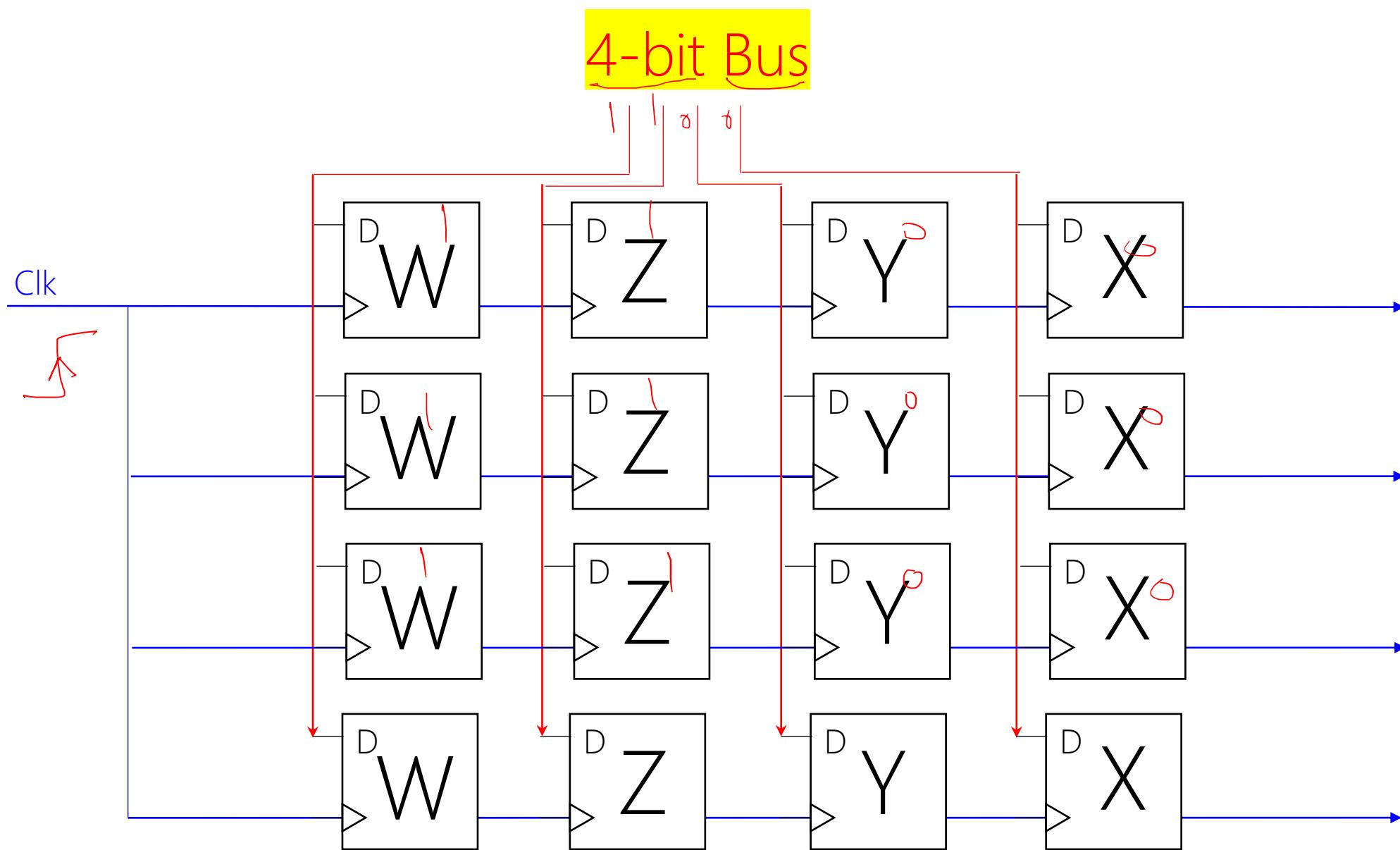


$2 \times \text{Numbers} \rightarrow 2 \times n \text{ FFs} \rightarrow 2 \times n\text{-bit Registers}$

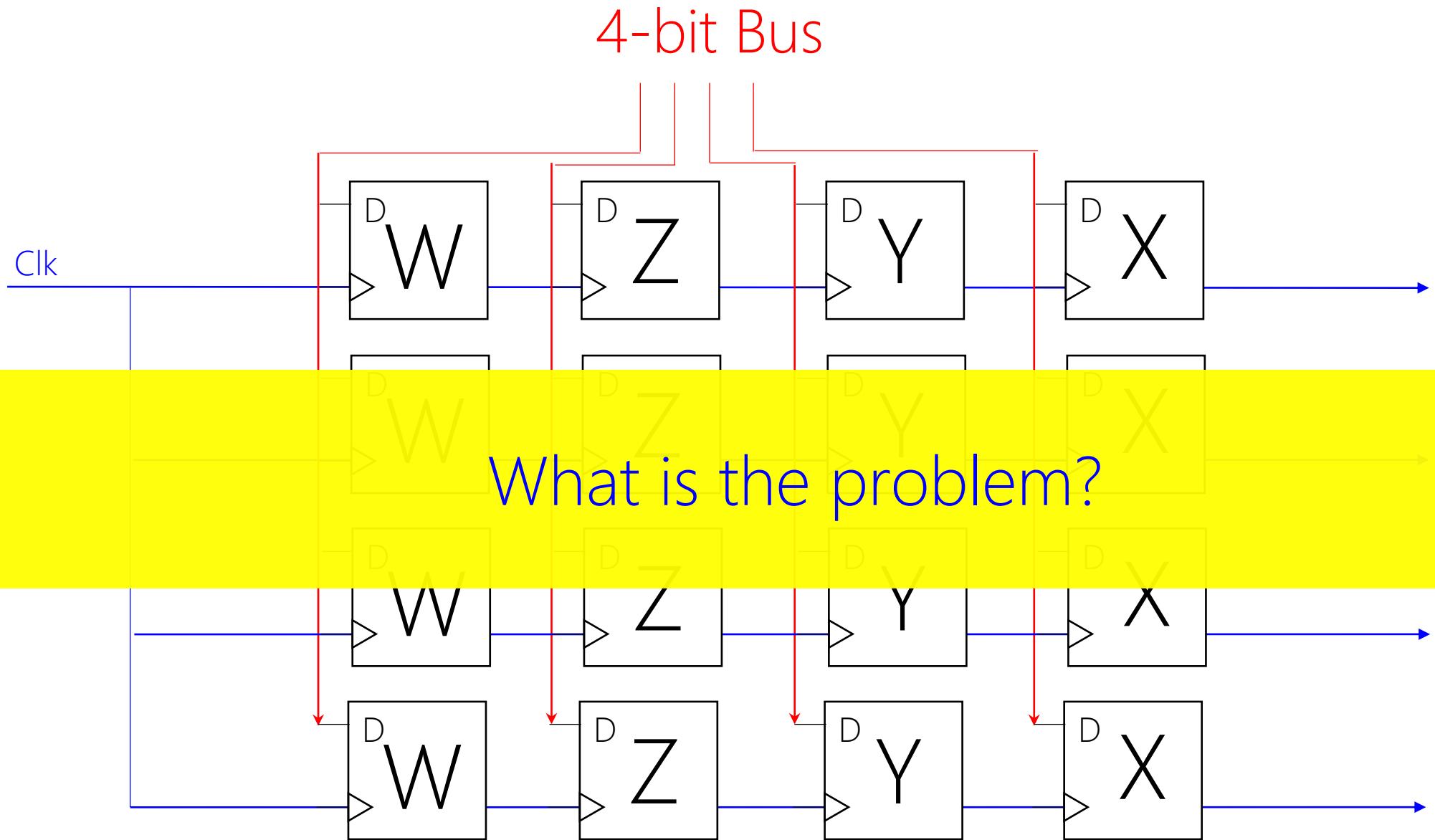
$$(N)_{10} = (w z y x)_2$$



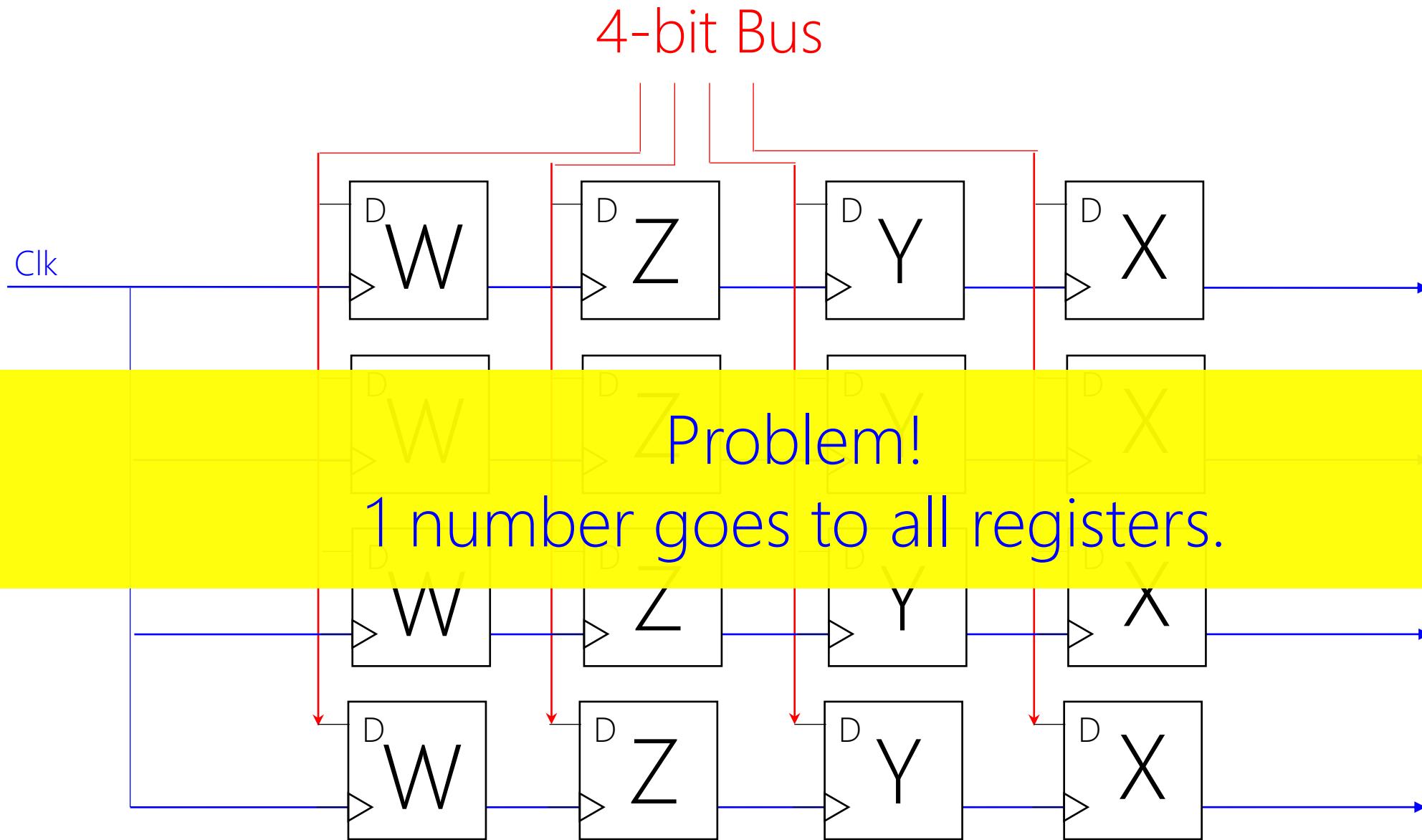
$3 \times \text{Numbers} \rightarrow 3 \times n \text{ FFs} \rightarrow 3 \times n\text{-bit Registers}$



4 × Numbers →  $4 \times n$  FFs →  $4 \times n$ -bit Registers



$4 \times \text{Numbers} \rightarrow 4 \times n \text{ FFs} \rightarrow 4 \times n\text{-bit Registers}$



$4 \times \text{Numbers} \rightarrow 4 \times n \text{ FFs} \rightarrow 4 \times n\text{-bit Registers}$

---

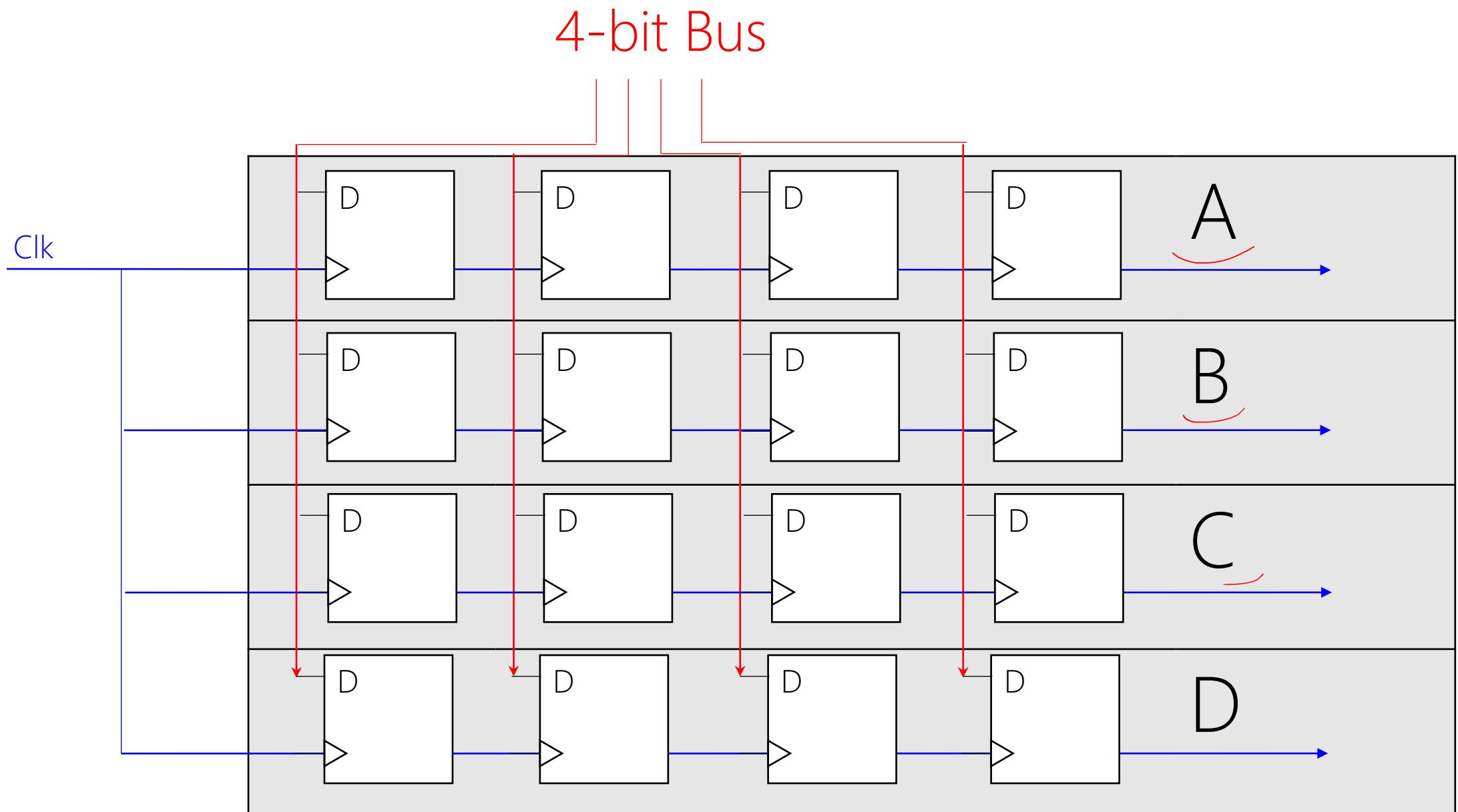
# Which Register?

---

---

Select Register by Name?

---



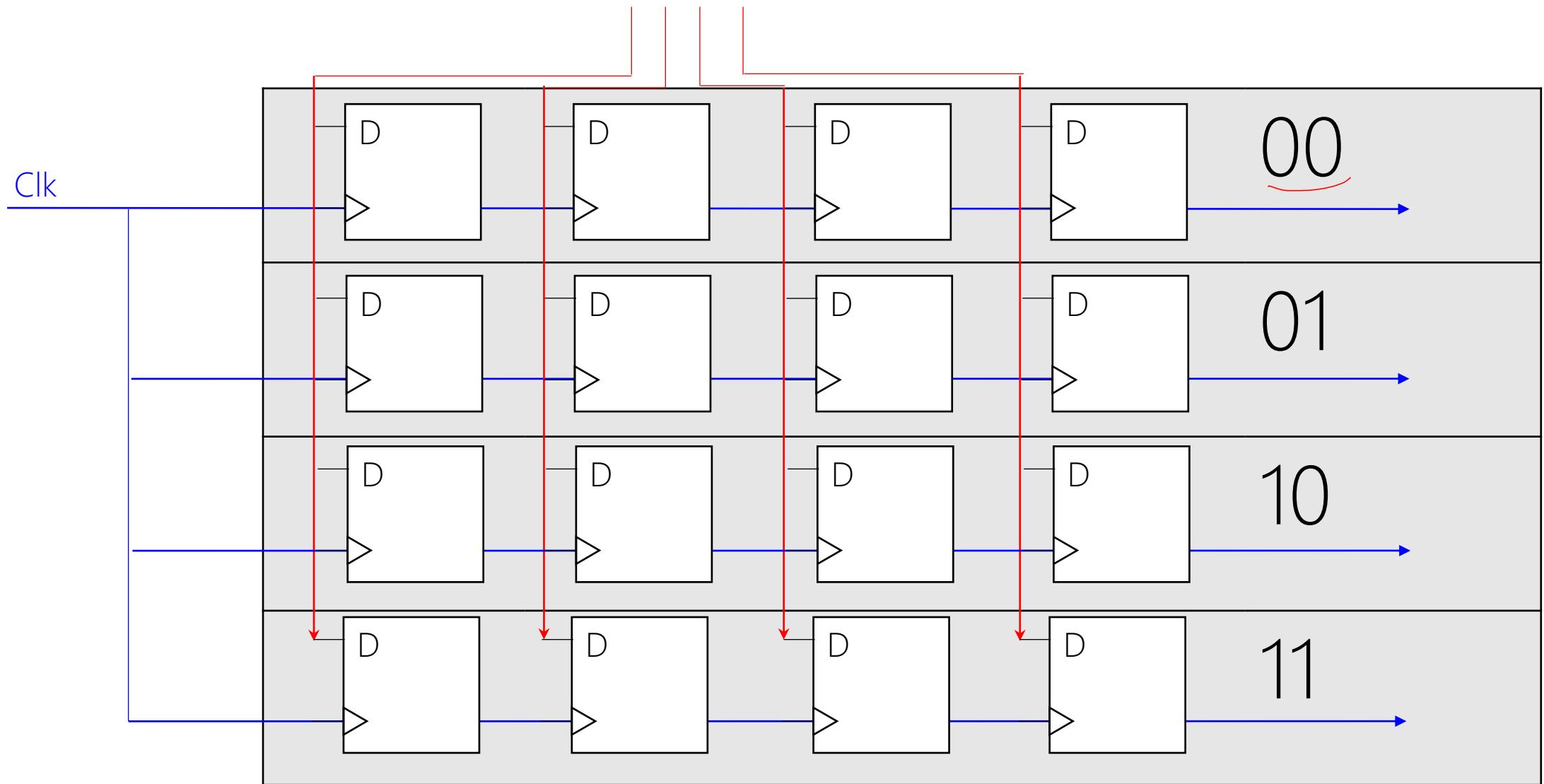
$4 \times \text{Numbers} \rightarrow 4 \times n \text{ FFs} \rightarrow 4 \times n\text{-bit Registers}$

---

Select Register by Address?

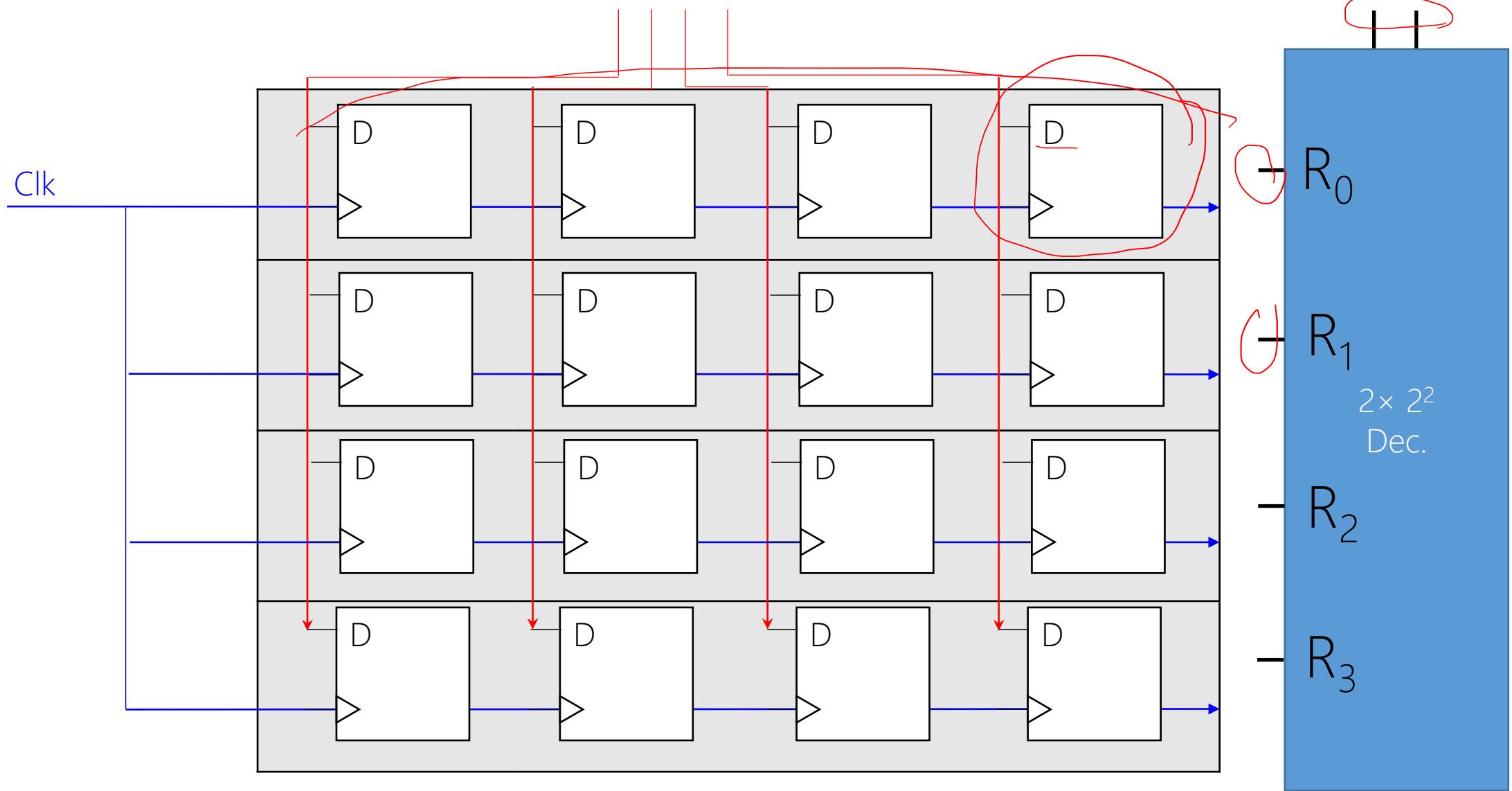
---

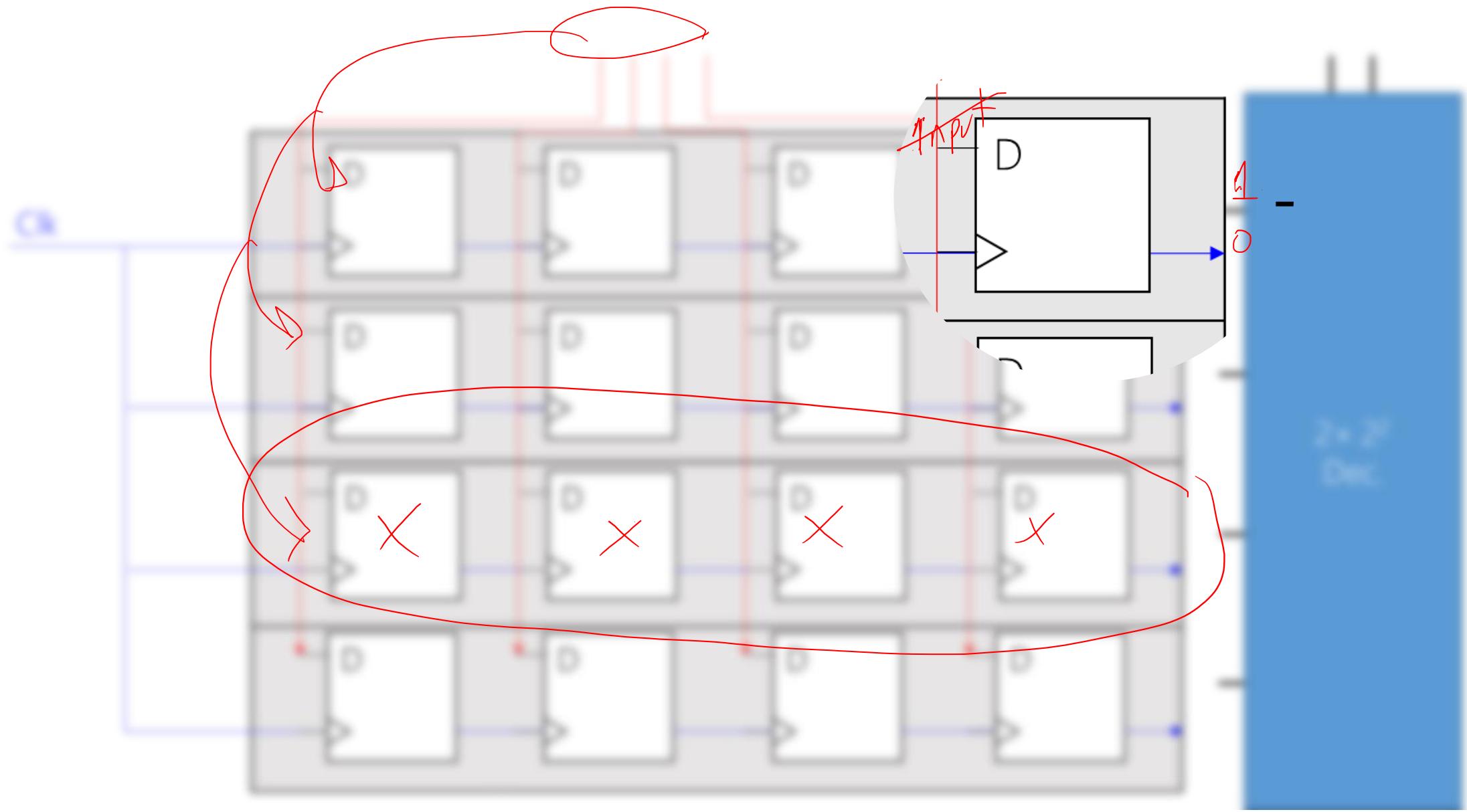
# 4-bit Bus

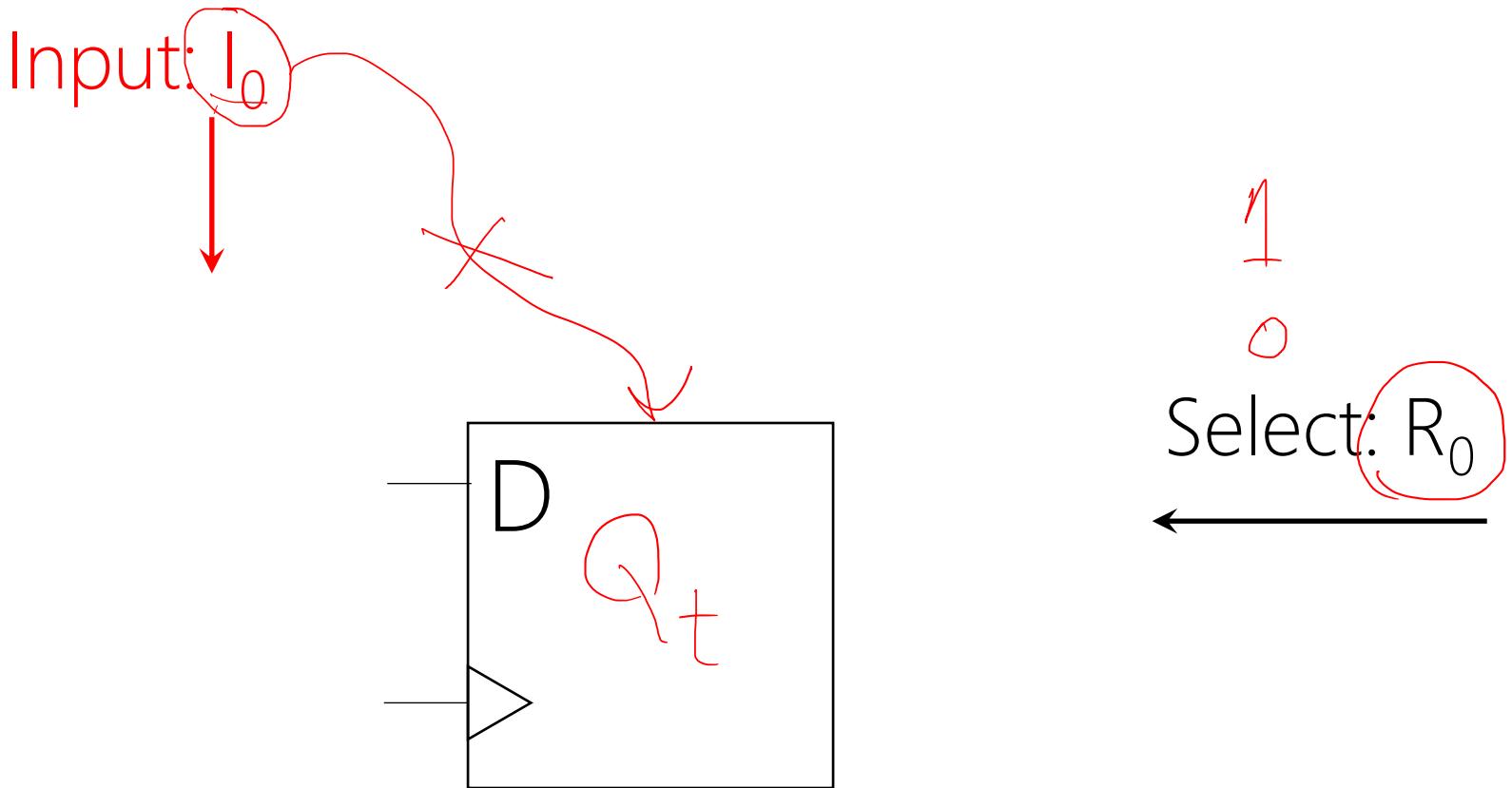


# 4-bit Data Bus

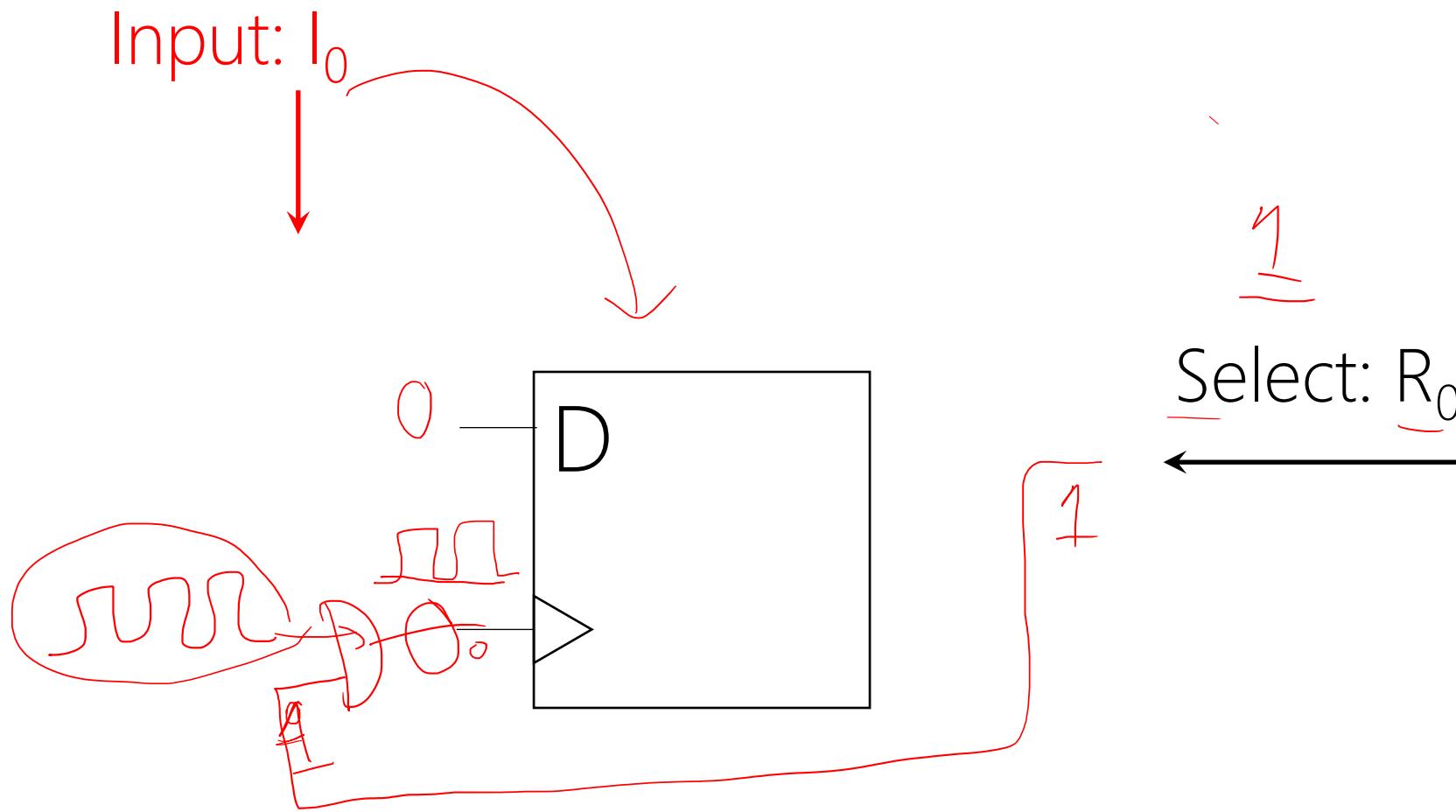
# 2-bit Address Bus



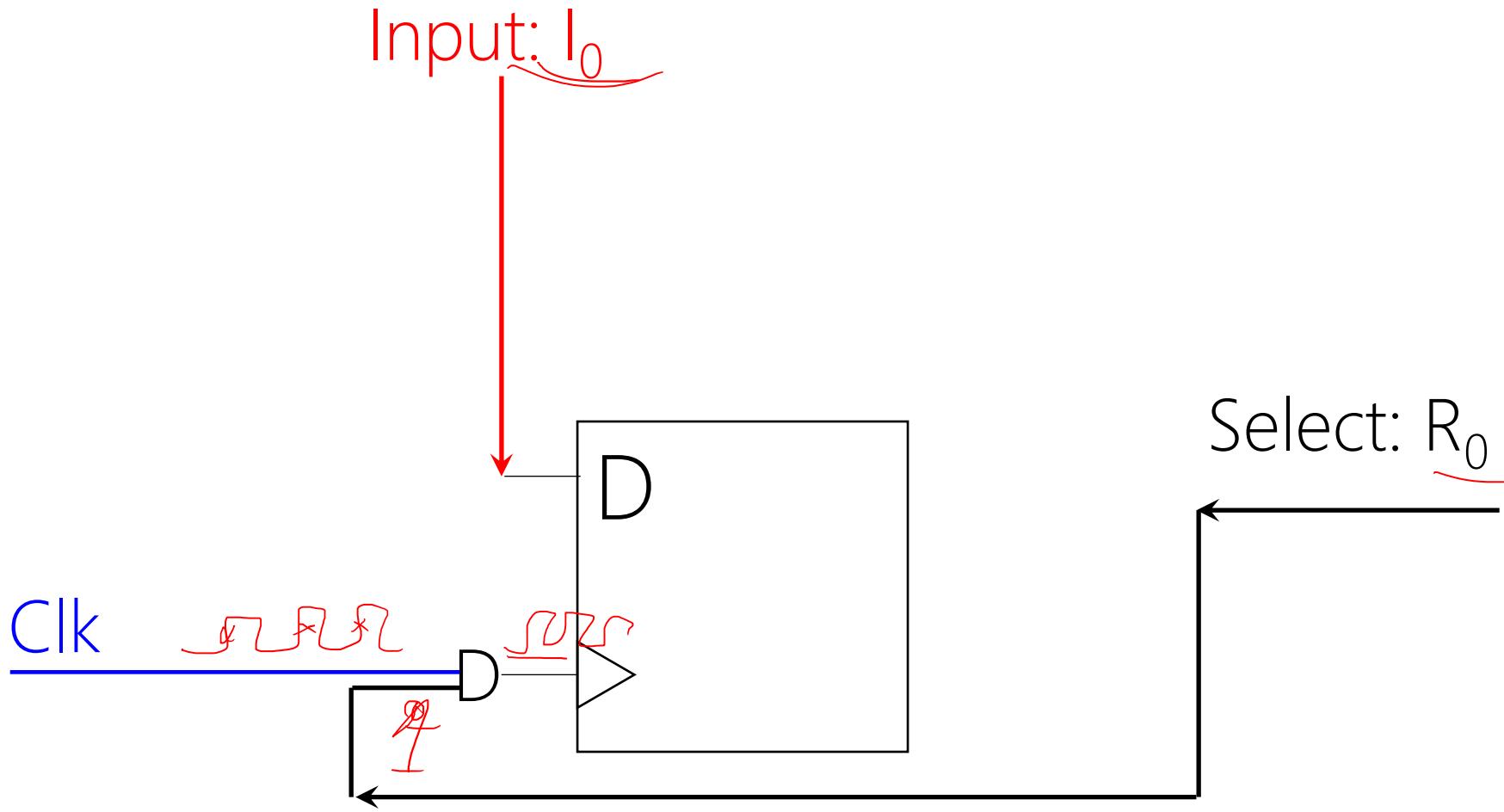


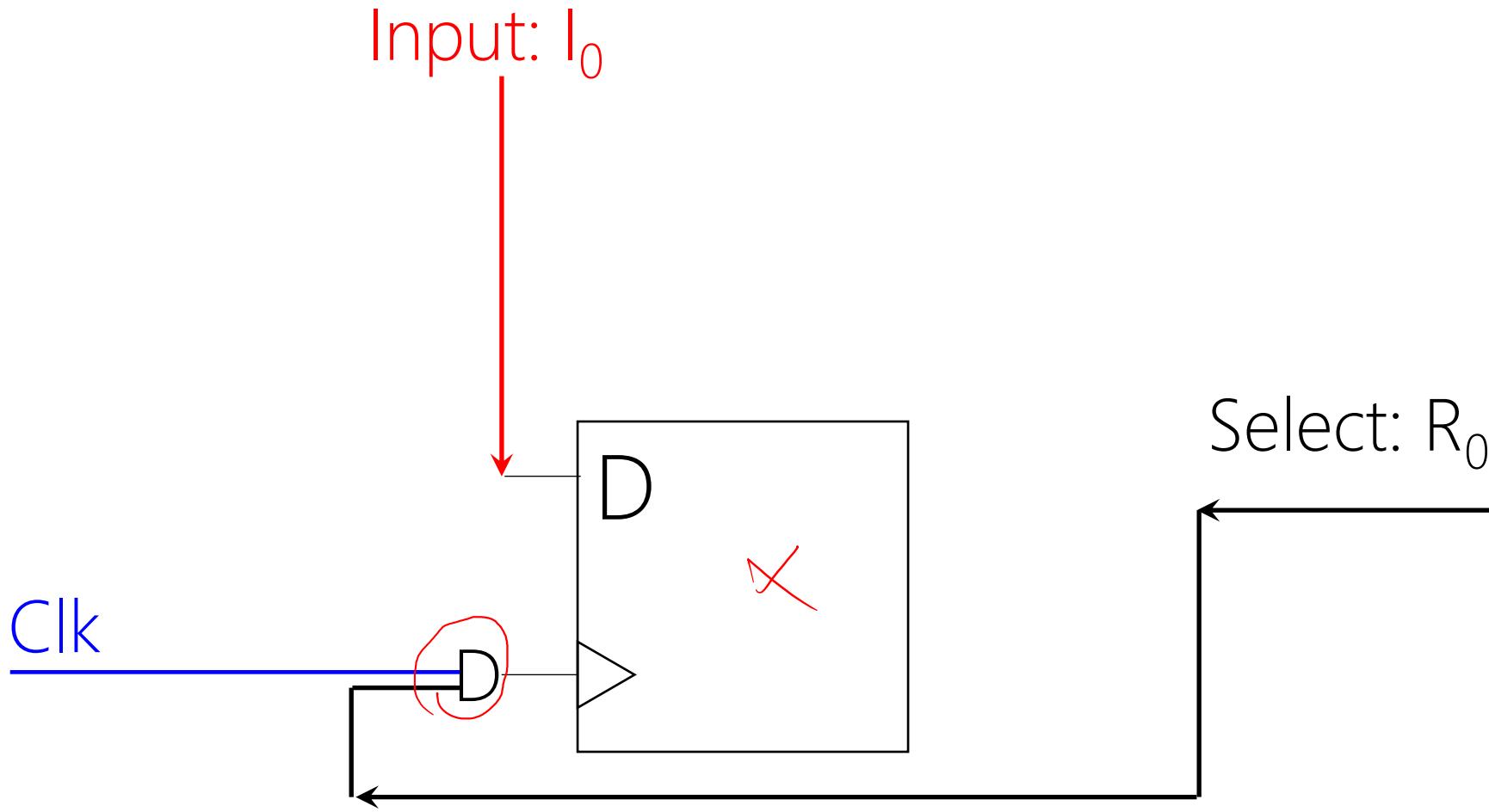


if  $R_0$  (selected) then Write (Load) ( $I_0$ )  $\rightarrow$  D-FF)  
else Store

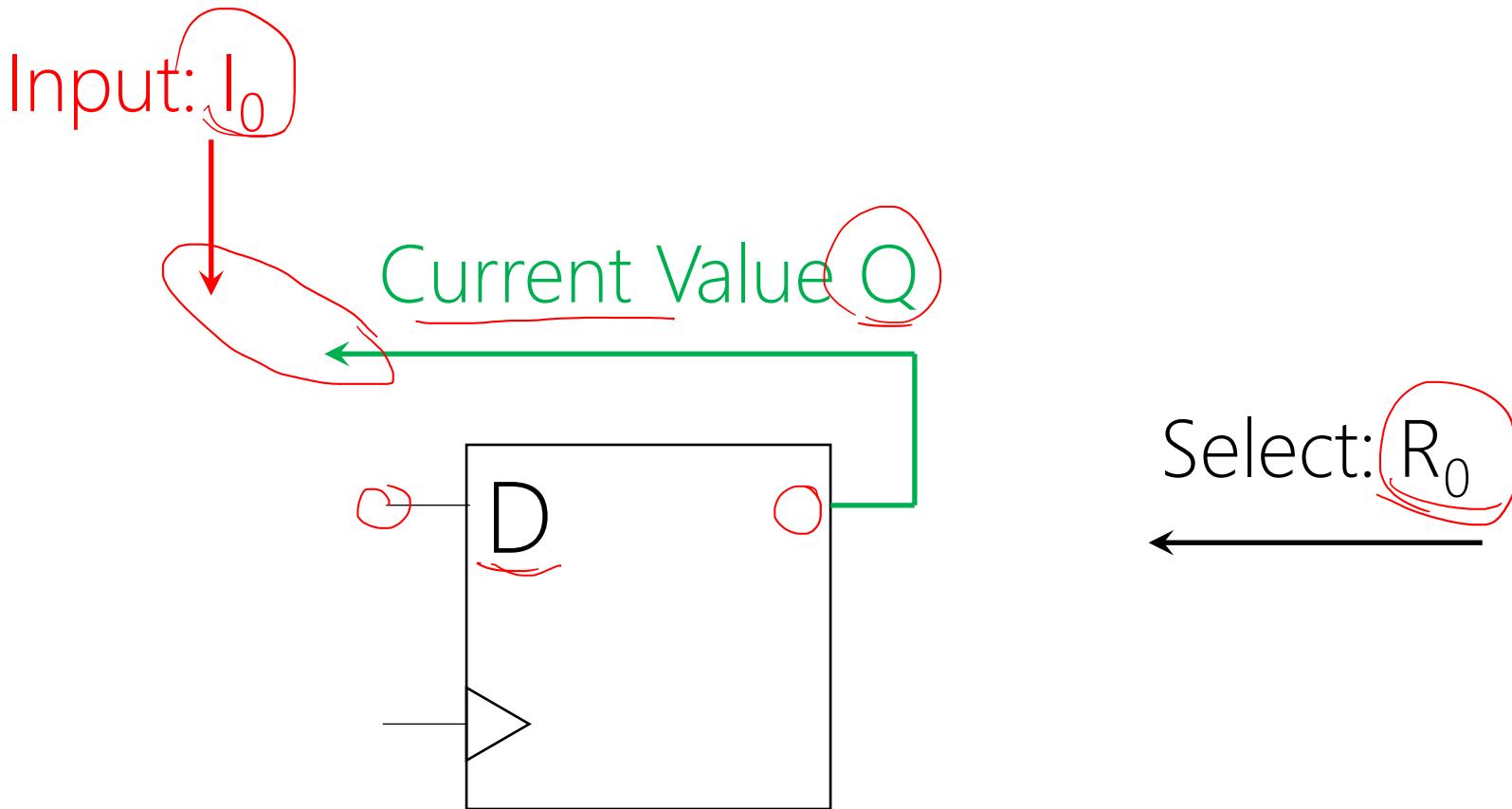


if  $R_0$  (selected) then Write (Load) ( $I_0 \rightarrow \text{D-FF}$ )  
else Store but D-FF does not have store action!

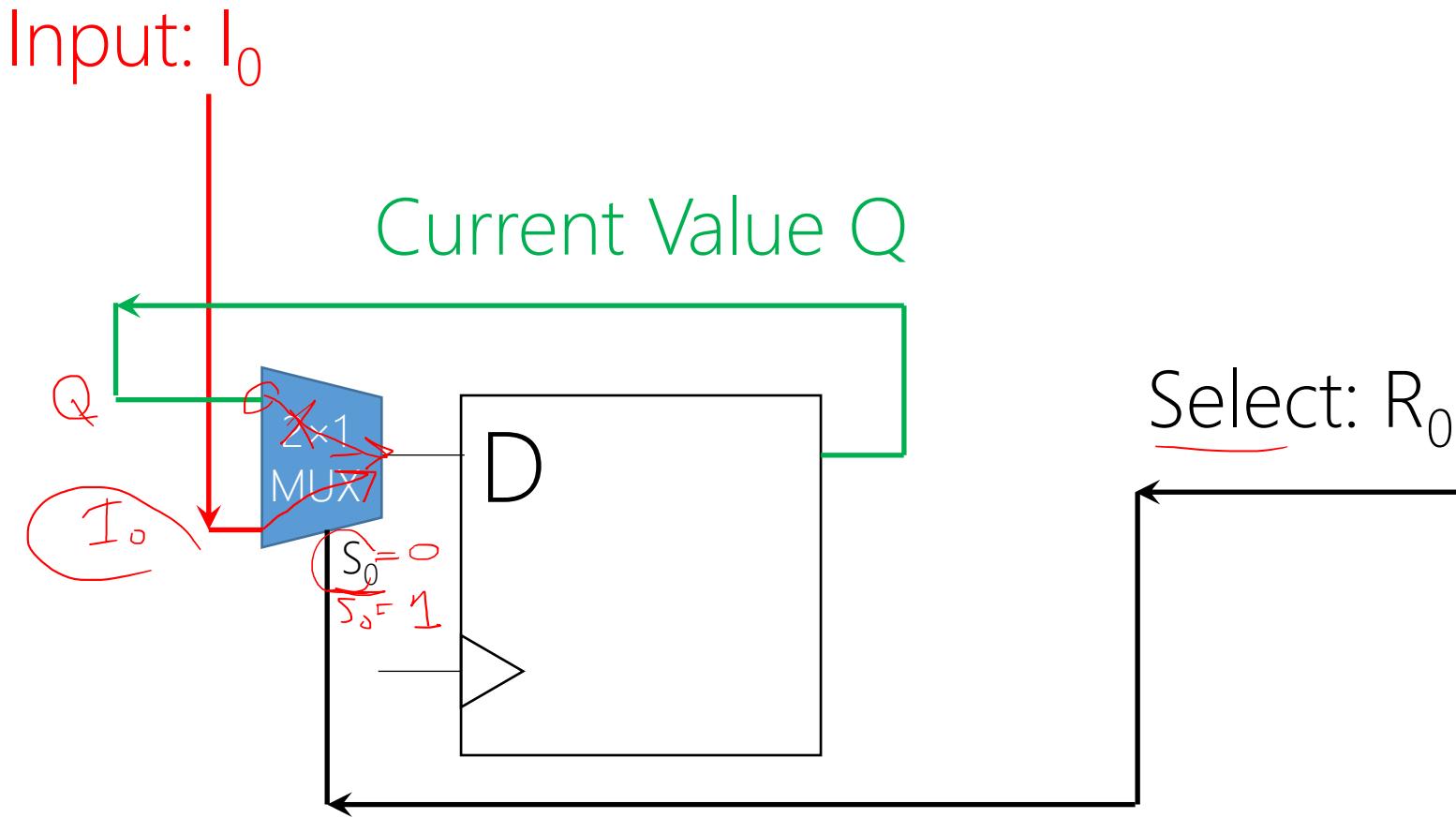




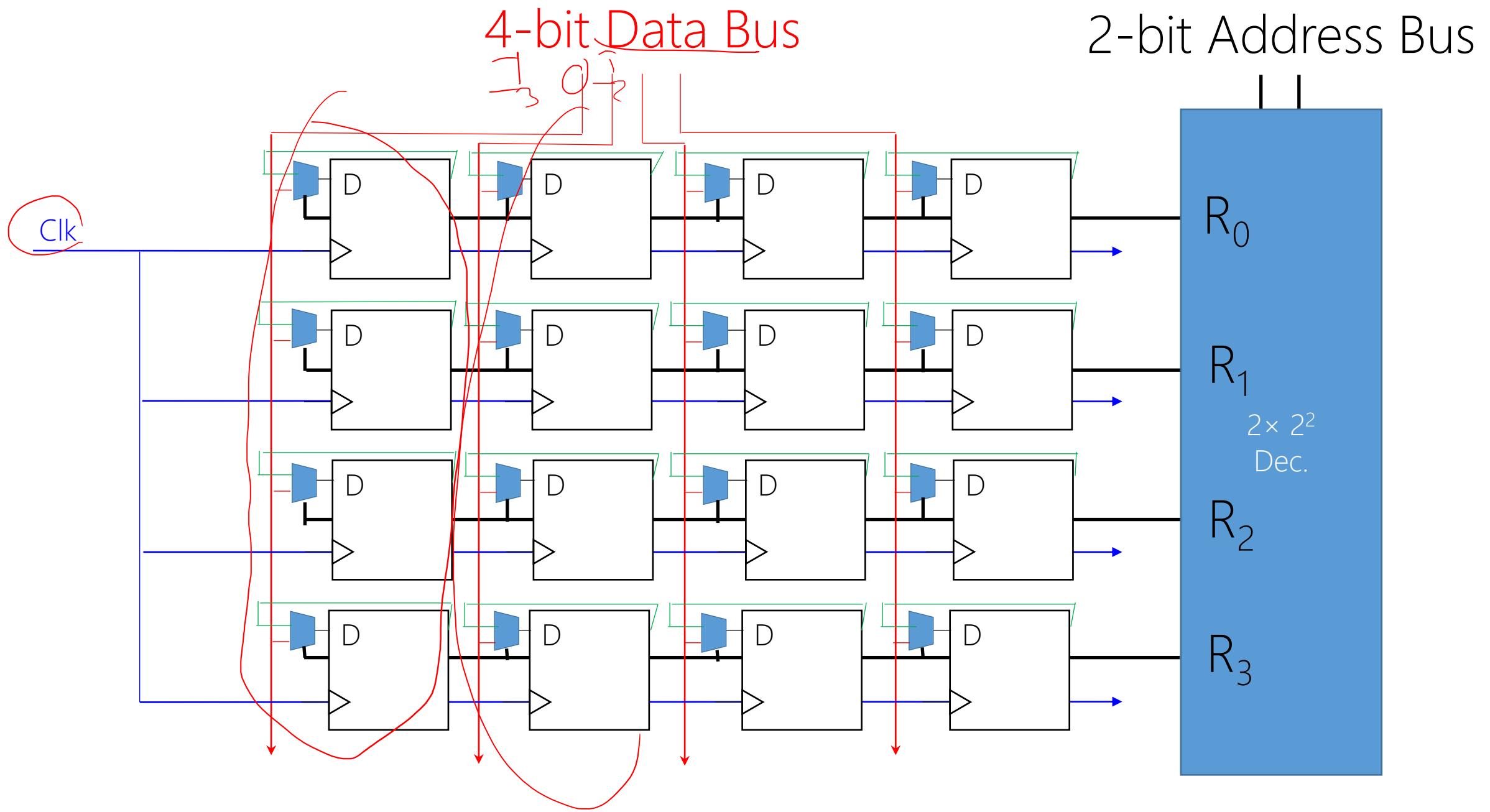
Never ever touch clock! Why?

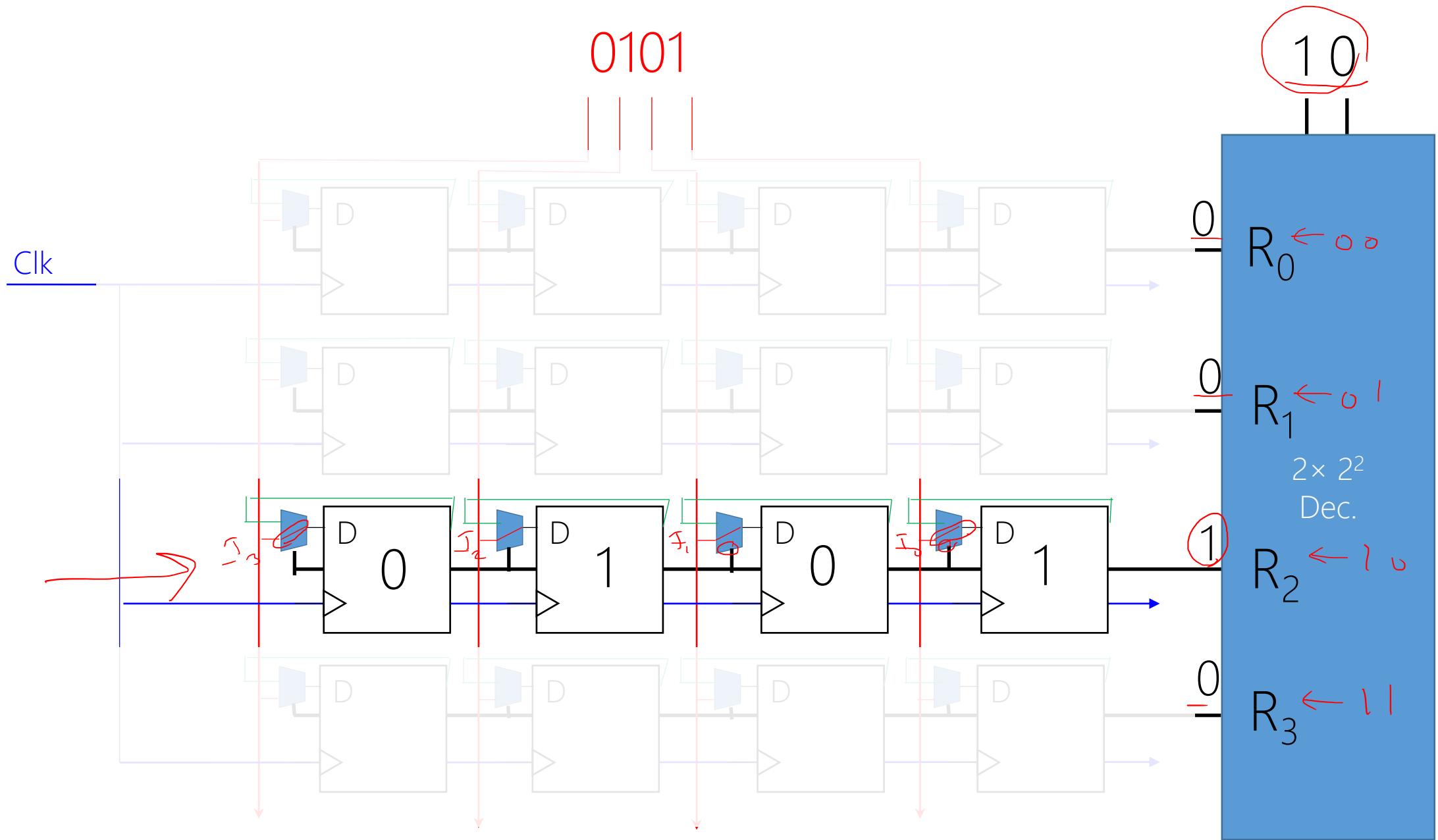


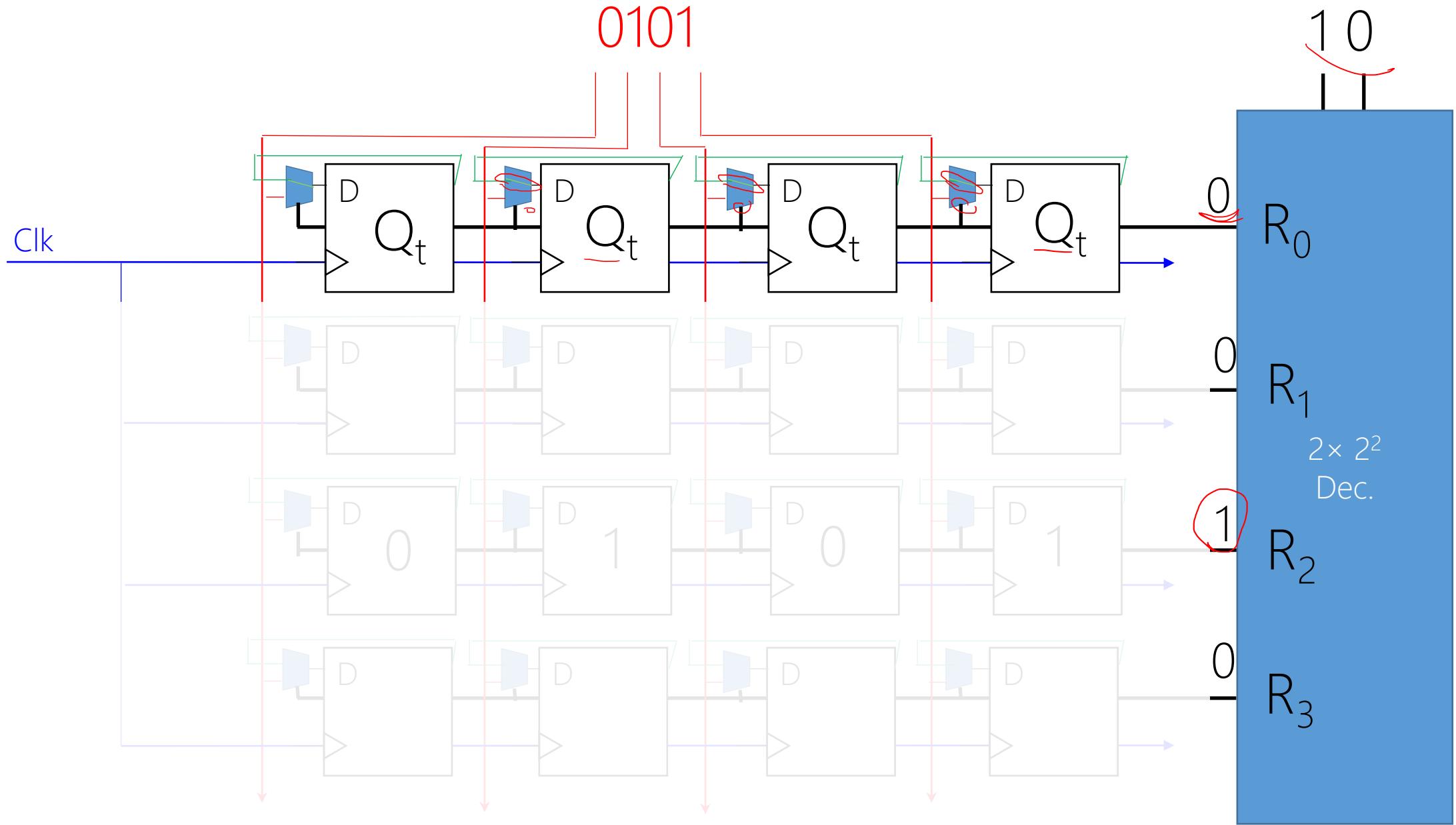
if  $R_0$  (selected) then Write(Load) ( $I_0 \rightarrow D\text{-FF}$ )  
else Store



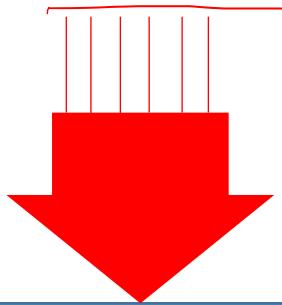
if  $R_0$  (selected) then Write(Load) ( $I_0 \rightarrow D\text{-FF}$ )  
 else Store





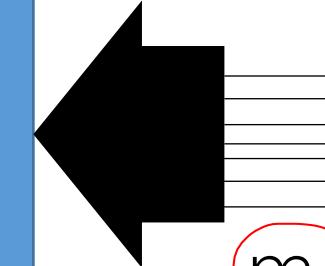


n-bit Data Bus



? × ?

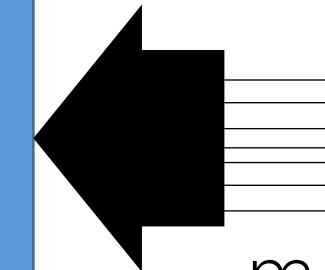
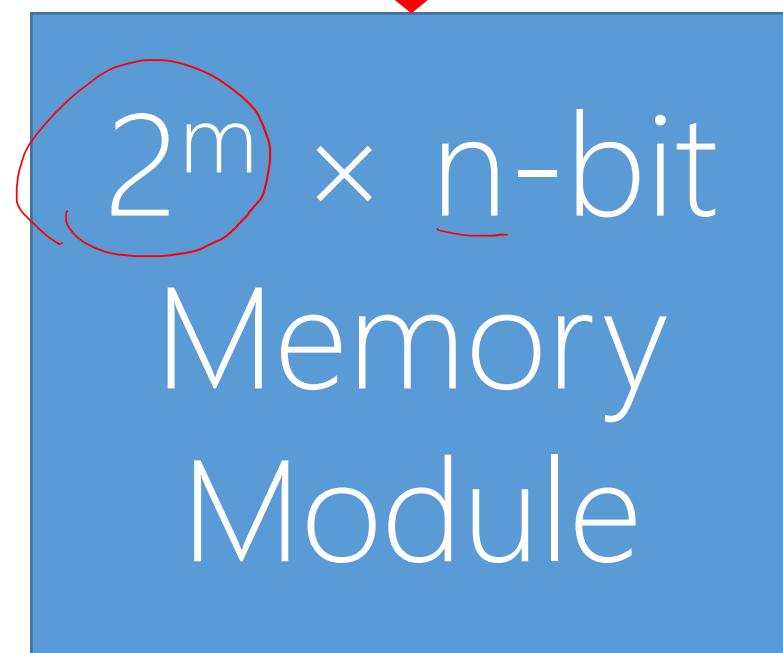
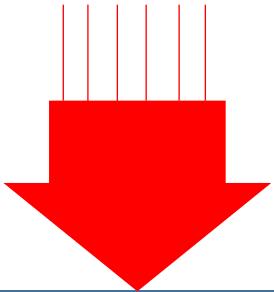
Memory  
Module



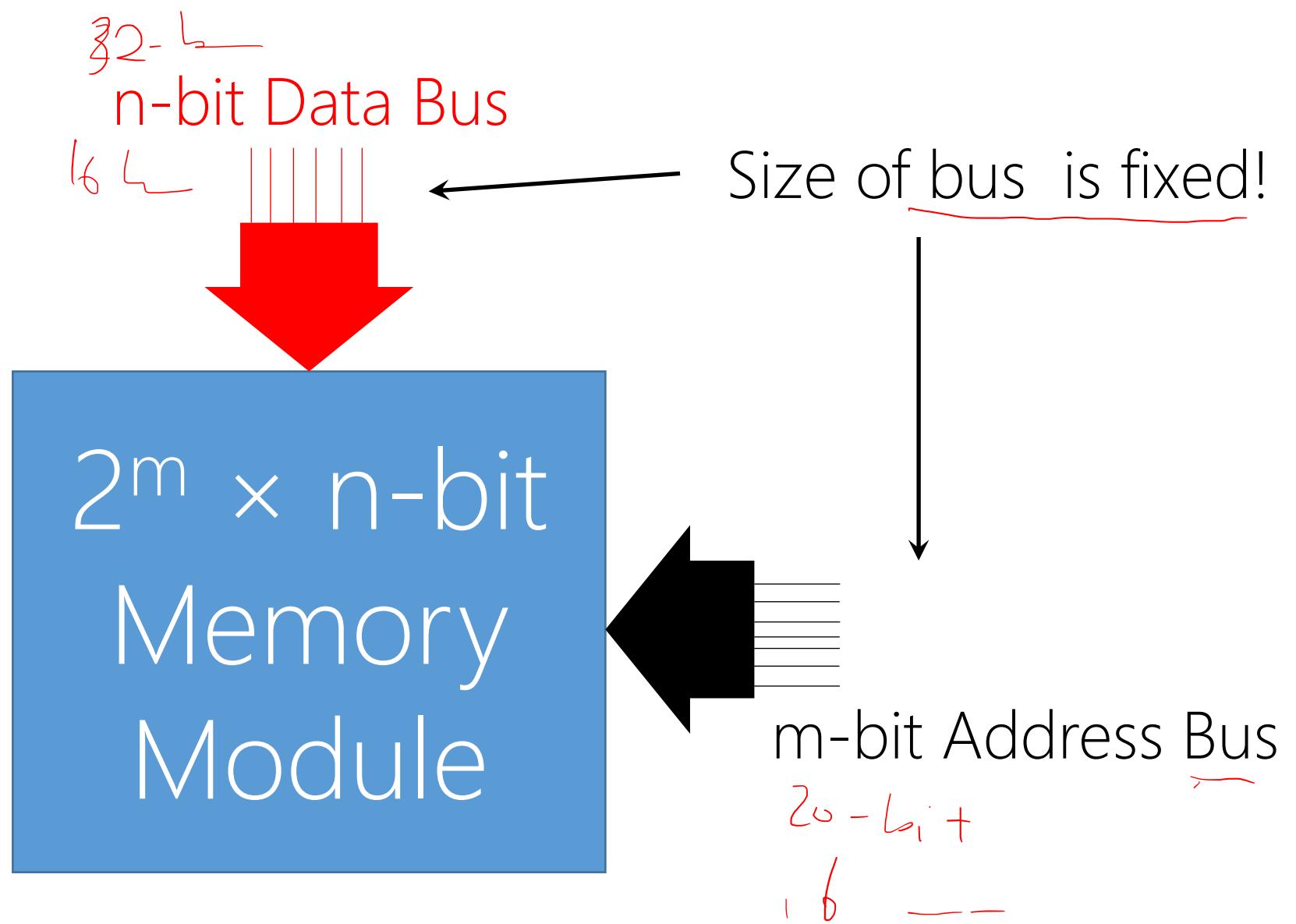
m-bit Address Bus

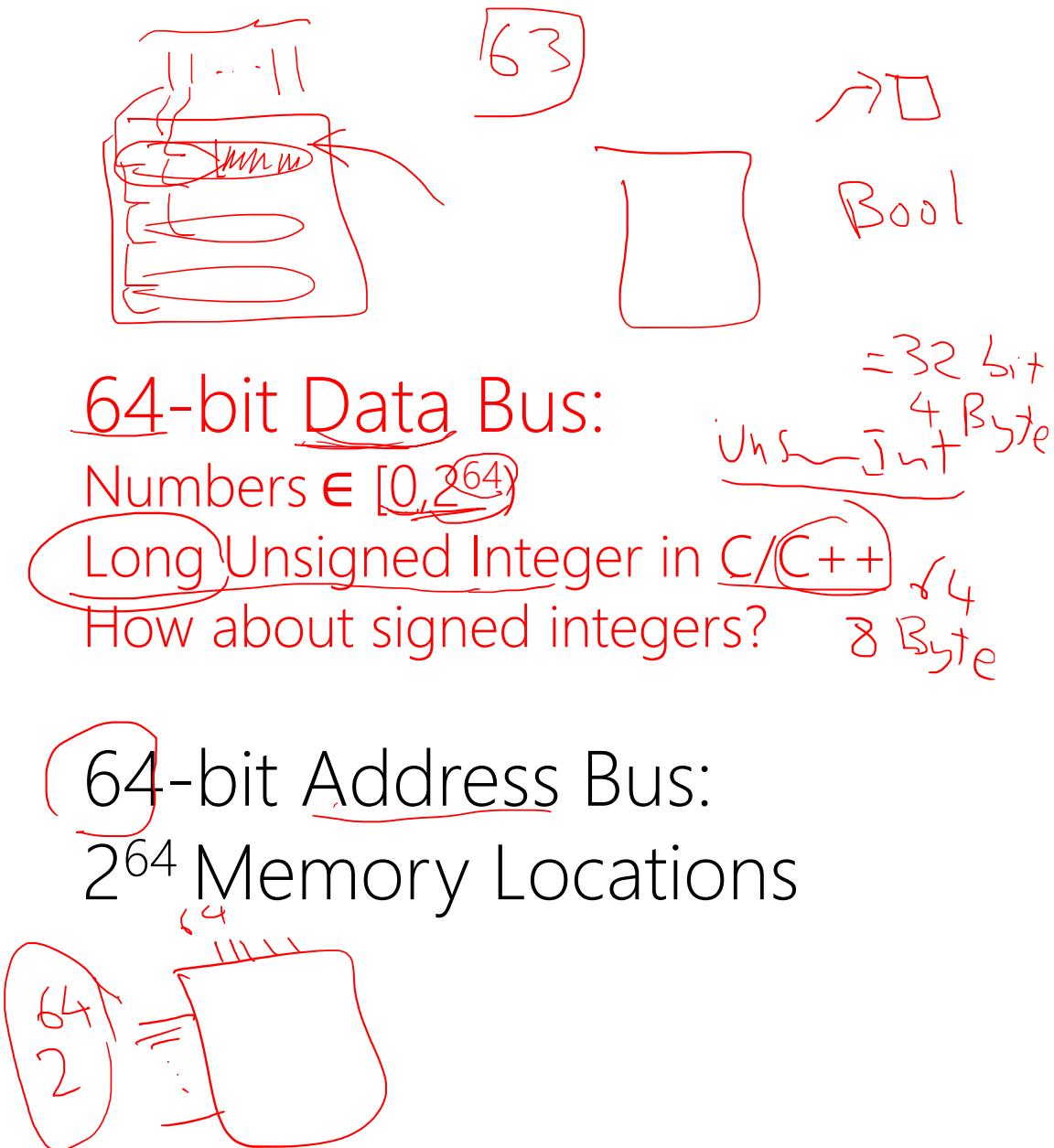
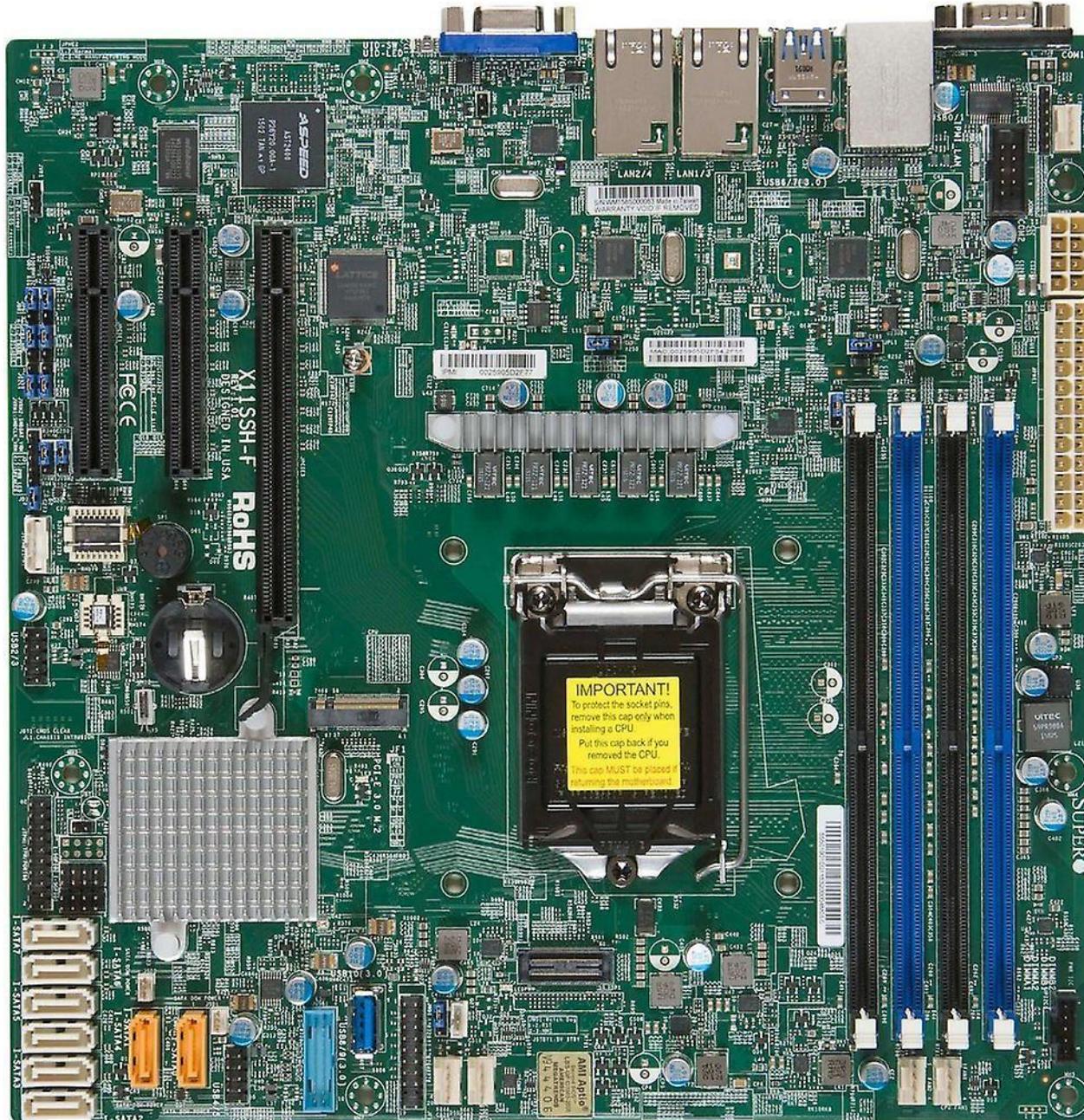
$m \times 2^m$

n-bit Data Bus

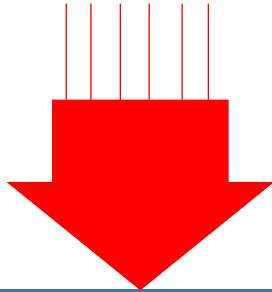


m-bit Address Bus

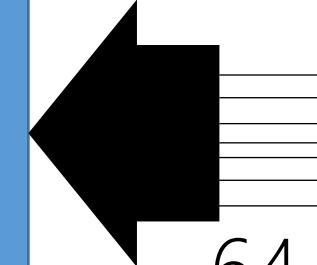
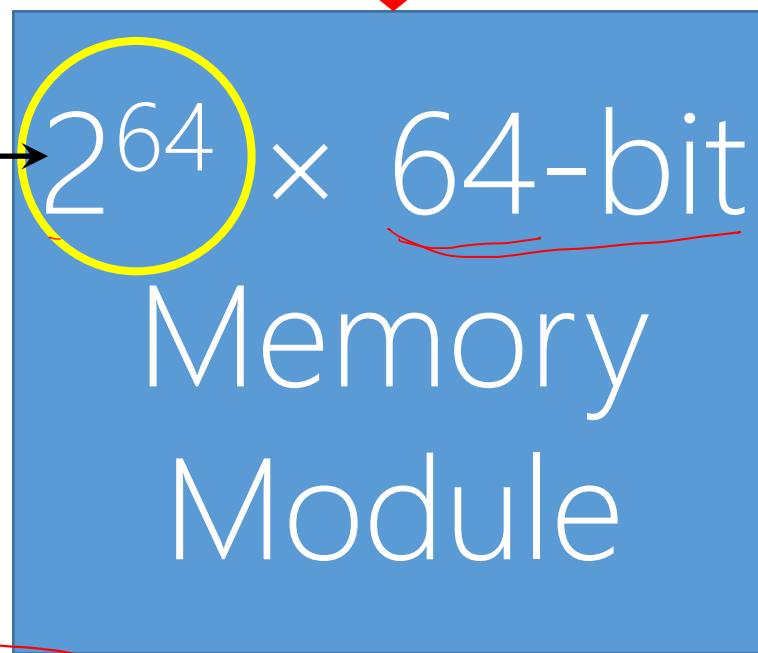




64-bit Data Bus



Buying  $2^{64}$ !  
You must be rich.  
You don't need it



64-bit Address Bus

$$2^{64} = 2^{10} \times 2^{10} \times 2^{10} \times 2^{10} \times 2^{10} \times 2^{10} \times 2^4 = 16 \text{ Exa Memory Locations}$$

Kilo → Mega → Giga → Peta → Exa

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  $64\}$   
 $2\}$



**Crucial RAM 16GB DDR4 2400 MHz CL17 Desktop Memory**  
CT16G4DFD824A  
Visit the Crucial Store  9,324 ratings | 46 answered questions  
Price: **CDN\$ 81.01** & FREE Shipping  
Get a \$5 promotional credit on purchase of \$25 or more in Amazon.ca Gift Cards. Restrictions Apply

$16 \text{ G} = 16 \times 2^{10} (\text{M}) = 16 \times 2^{10} \times 2^{10} (\text{K}) = \boxed{16 \times 2^{10} \times 2^{10} \times 2^{10}} \text{ Memory Locations}$

3 VIDEOS

16GB Dual Rank 2400 MT/s 2666 MT/s 3200 MT/s

$2^3 \times 2^4 \times 64 \text{ bit}$

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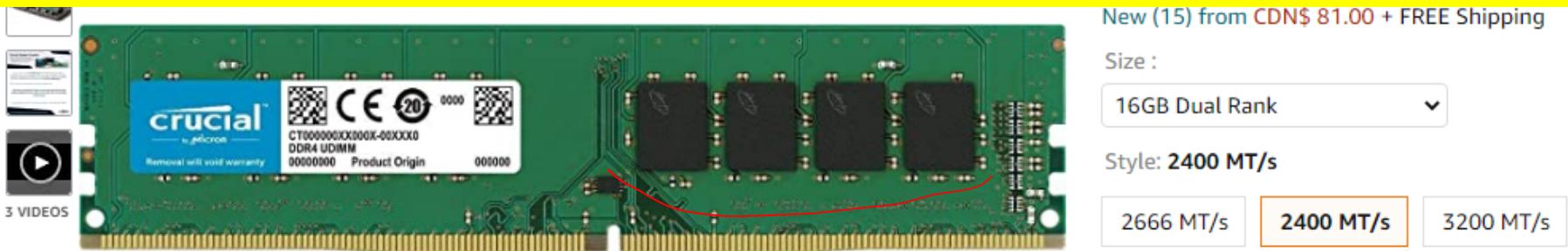
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 9.324 ratings | 46 answered questions

16 G =  $16 \times 2^{10}$  (M) =  $16 \times 2^{10} \times 2^{10}$  (K) =  $16 \times 2^{10} \times 2^{10} \times 2^{10}$  Memory Locations  
→ How many FFs?



Electronics > Computers & Accessories > Computer Components > Memory



Crucial RAM 16GB DDR4 2400 MHz CL17 Desktop Memory

$16 \text{ G} = 16 \times 2^{10} (\text{M}) = 16 \times 2^{10} \times 2^{10} (\text{K}) = 16 \times 2^{10} \times 2^{10} \times 2^{10} \text{ Memory Locations}$

# Rows

How many FFs?

$(2^4=16) \times 2^{10} \times 2^{10} \times 2^{10} \times (2^6=64\text{-bit Data Bus}) = 2^{40}$

2<sup>40</sup>



3 VIDEOS

New (15) from CDN\$ 81.00 + FREE Shipping

Size :

16GB Dual Rank

Style: 2400 MT/s

2666 MT/s

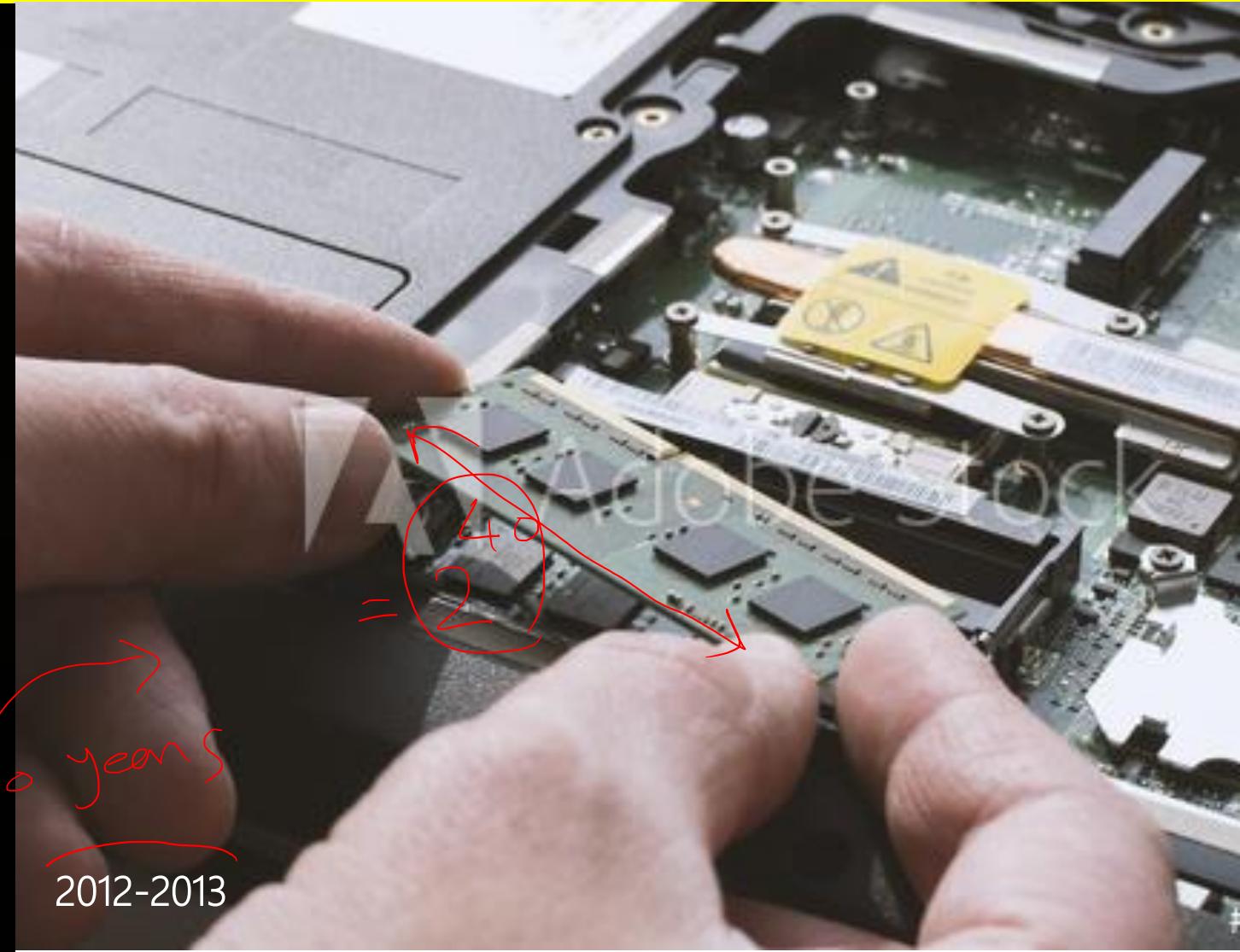
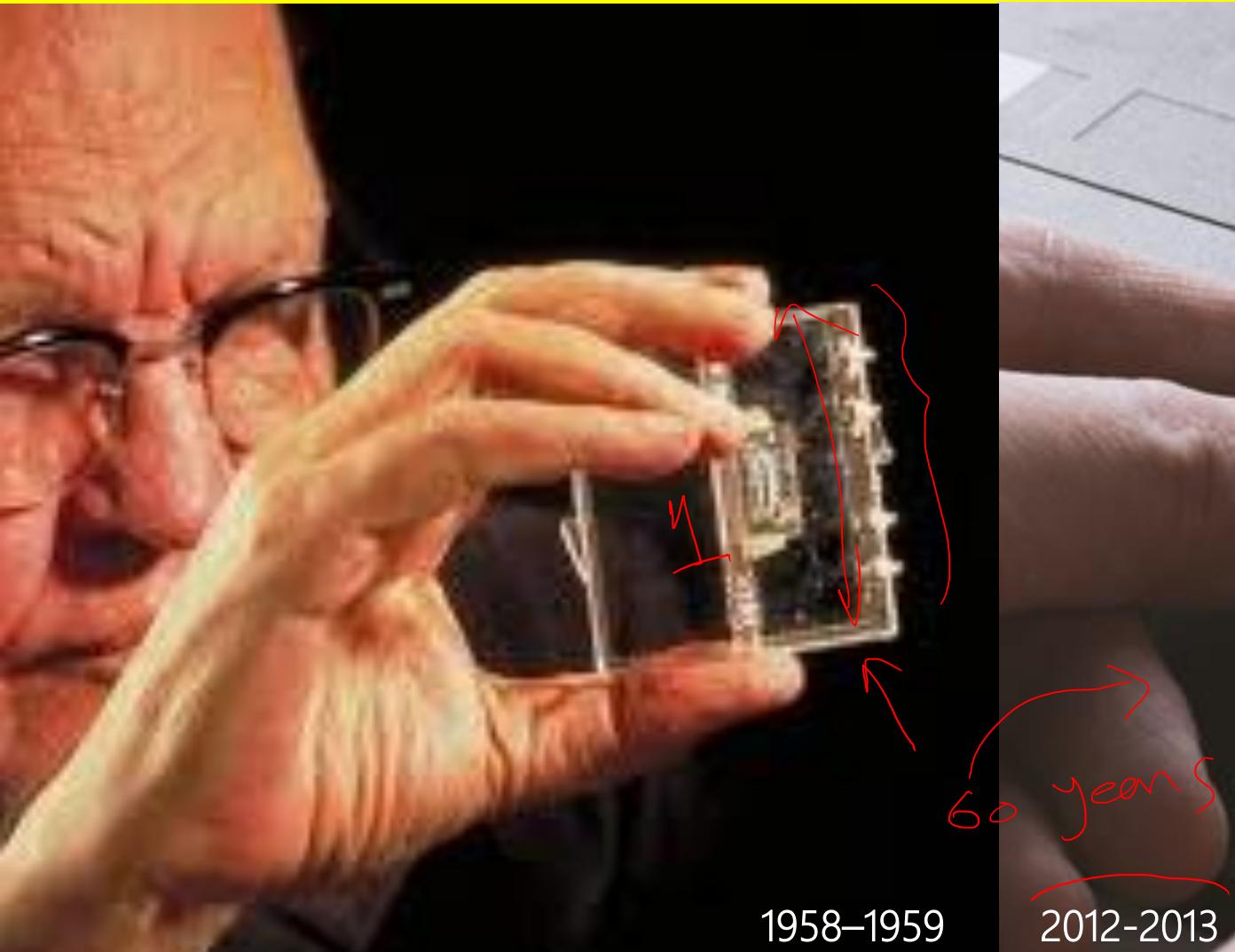
2400 MT/s

3200 MT/s

$16\text{ G} = 16 \times 2^{10} (\text{M}) = 16 \times 2^{10} \times 2^{10} (\text{K}) = 16 \times 2^{10} \times 2^{10} \times 2^{10}$  Memory Locations

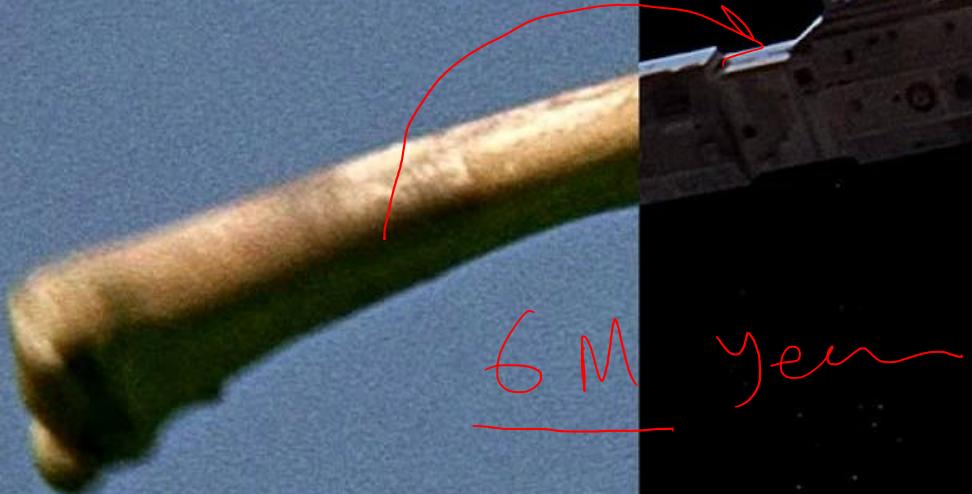
How many FFs?

$(2^4=16) \times 2^{10} \times 2^{10} \times 2^{10} \times (2^6=64\text{-bit Data Bus}) = 2^{40}$

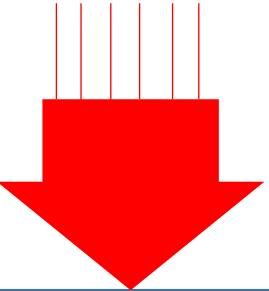


# 2022: A Digital Odyssey

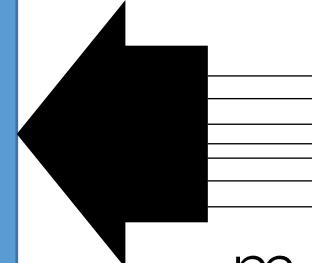
The Ultimate Trip.



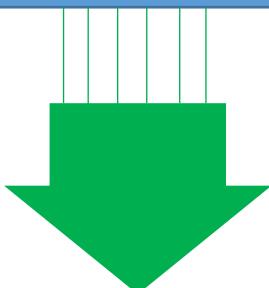
n-bit Data Bus (Write)



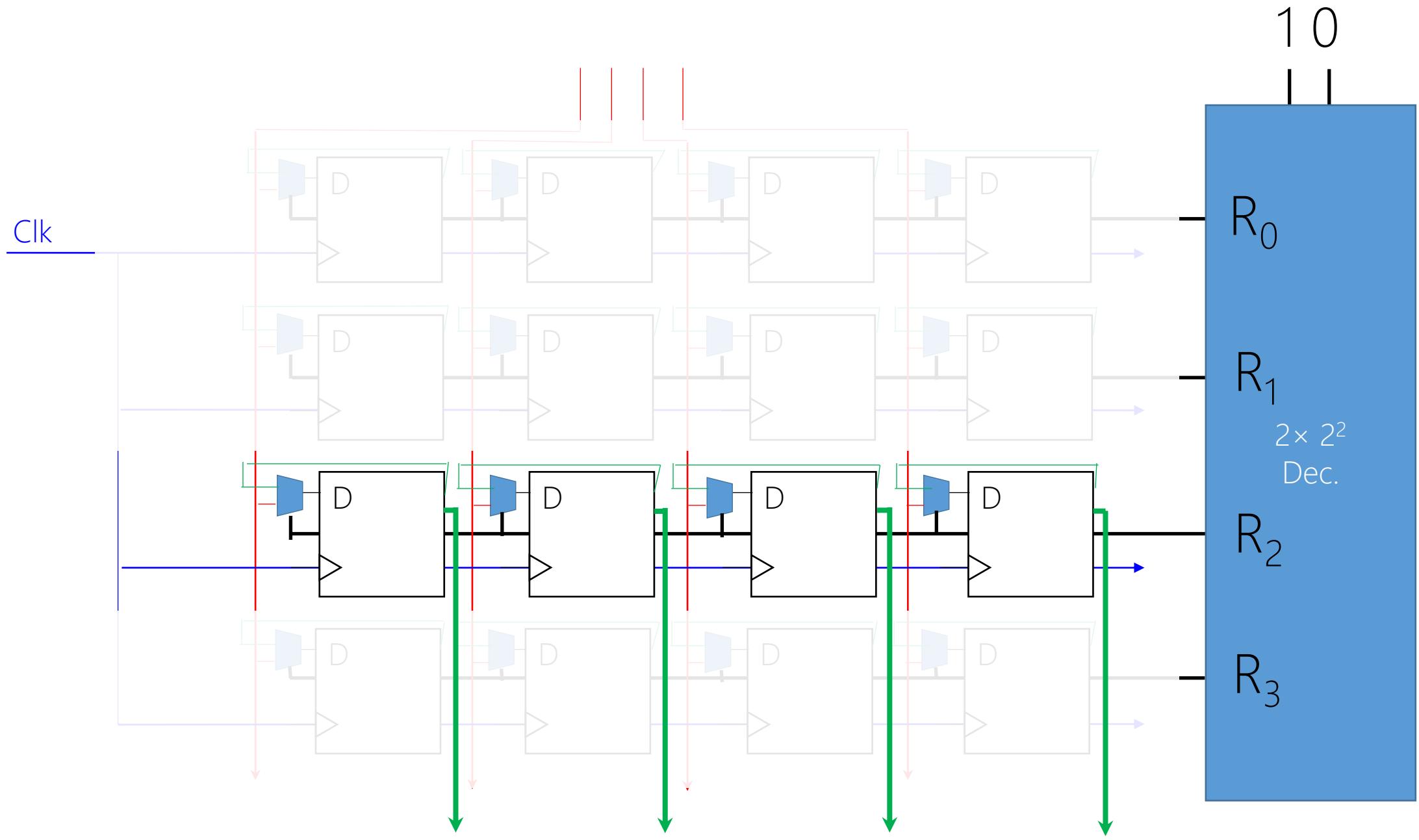
$2^m \times n$ -bit  
Memory  
Module

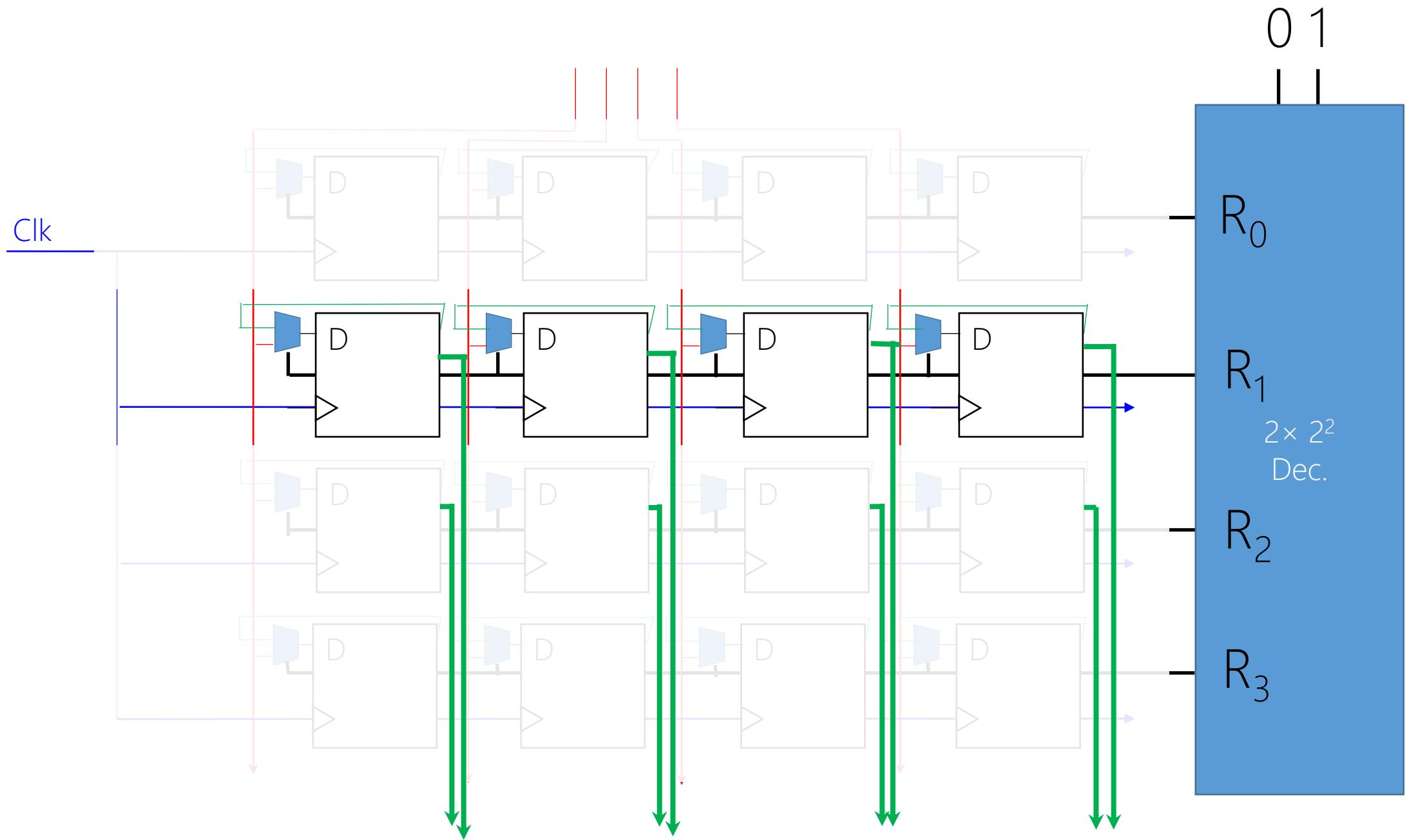


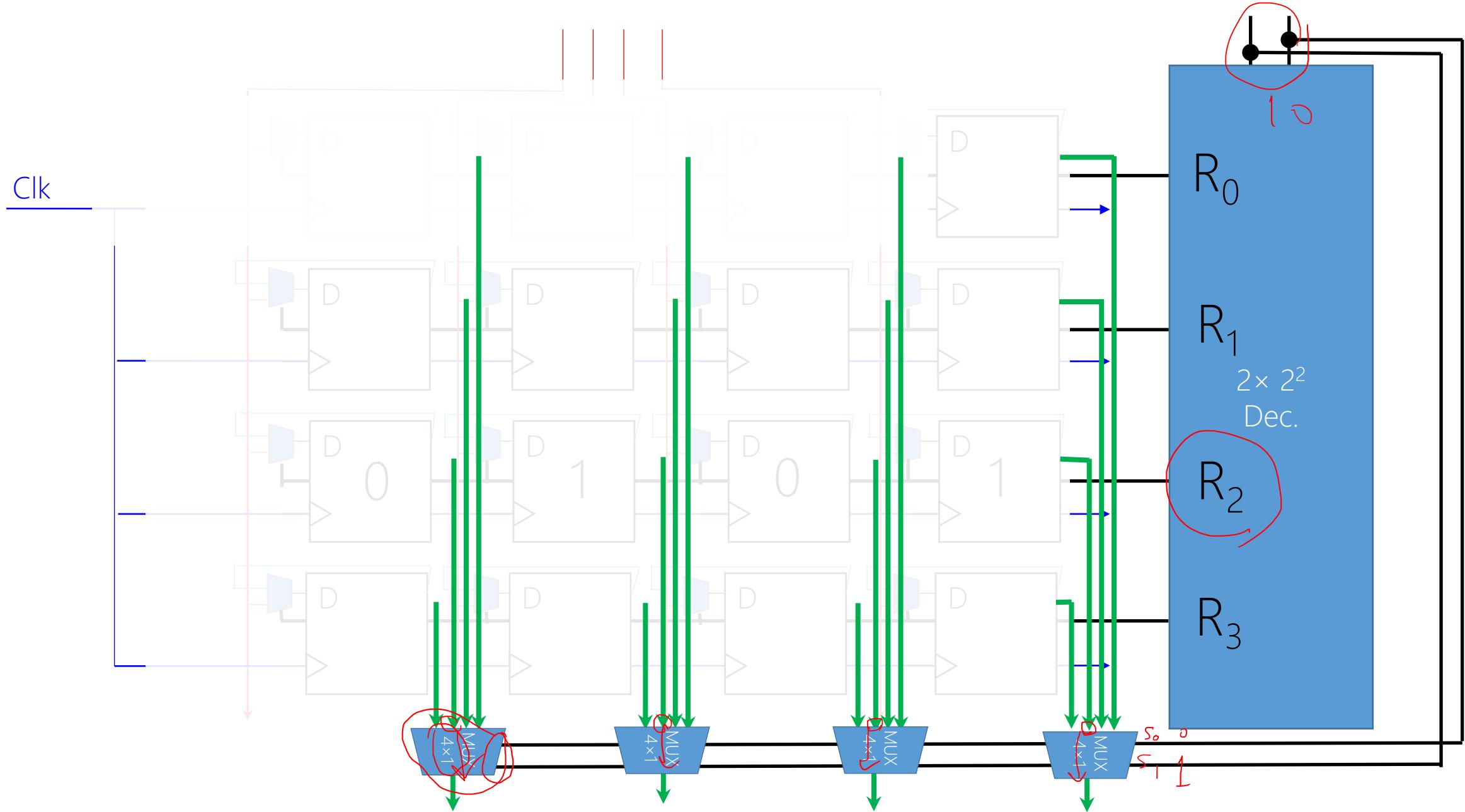
m-bit Address Bus

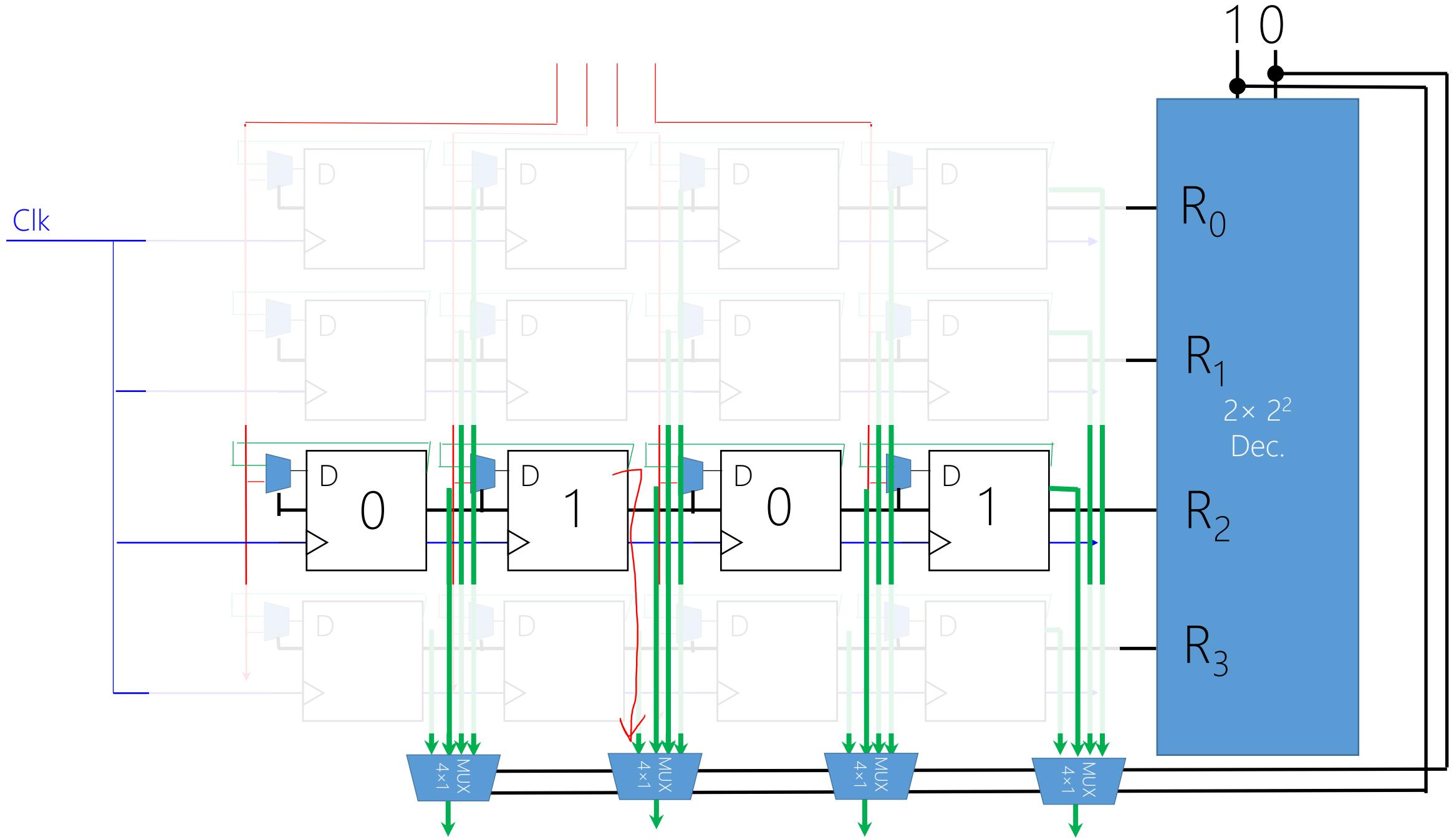


n-bit Data Bus (Read)



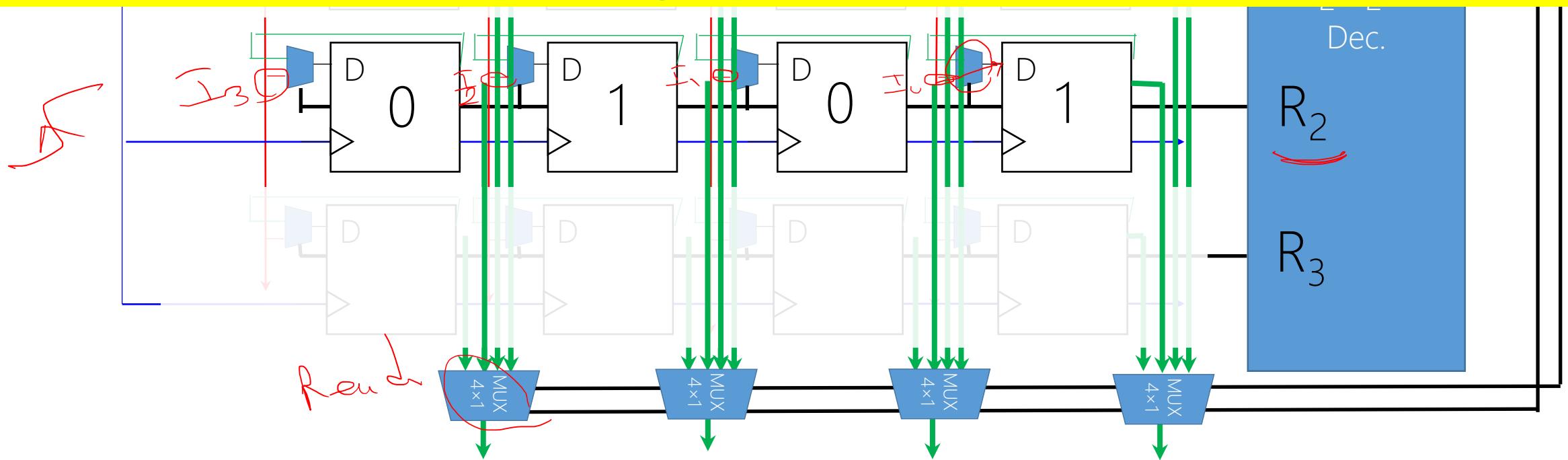








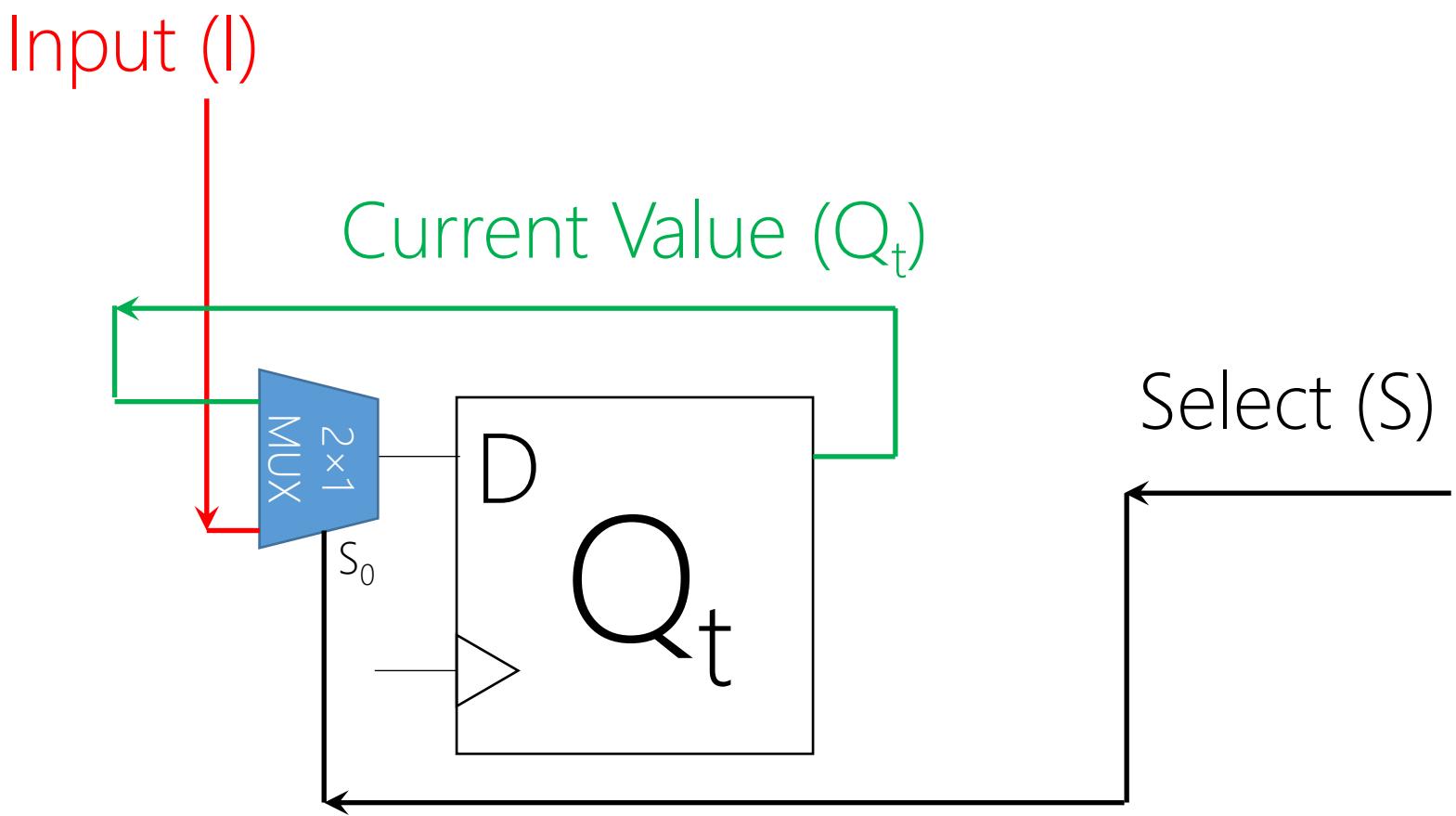
At the positive edge, both write and read!

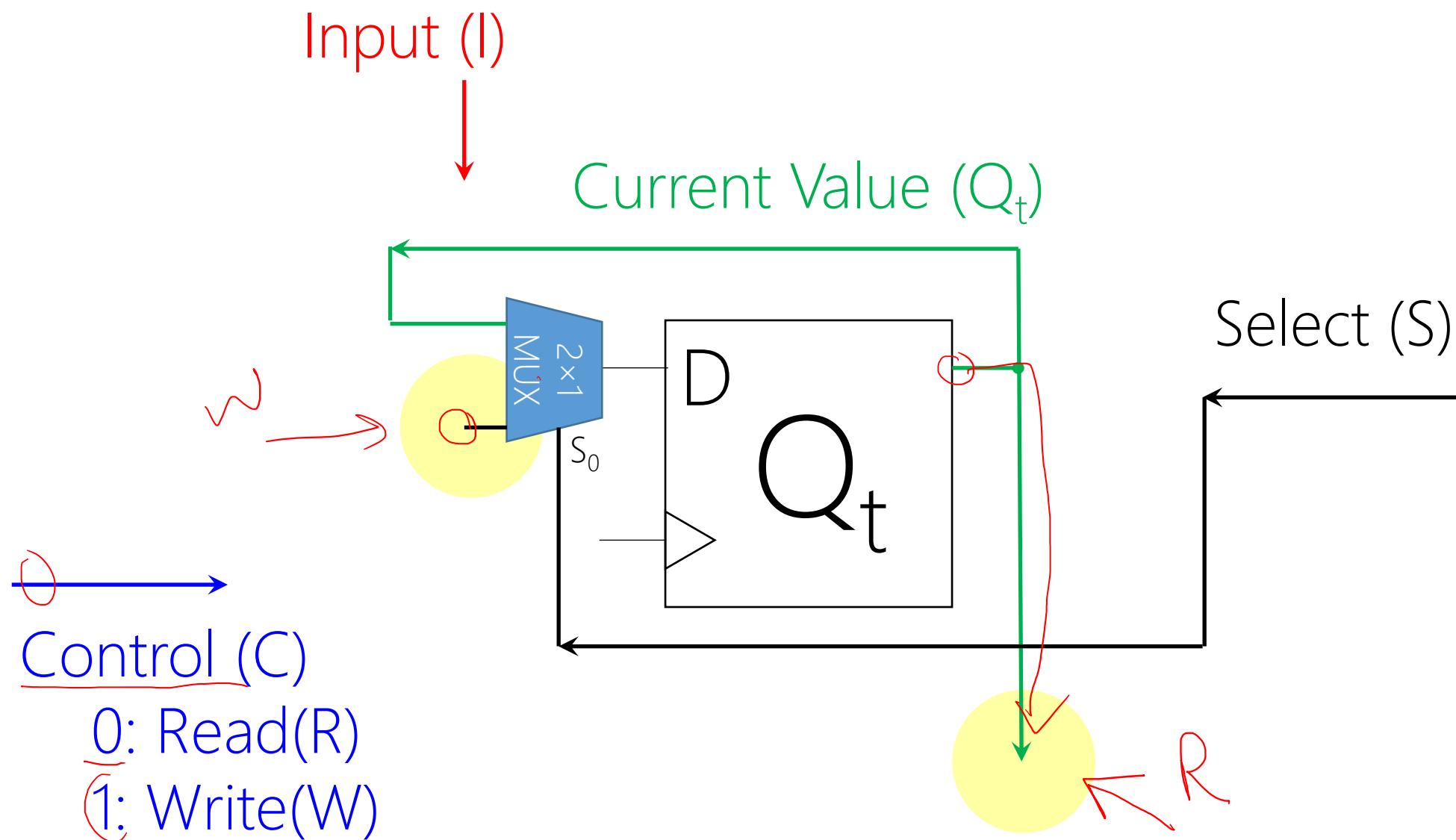


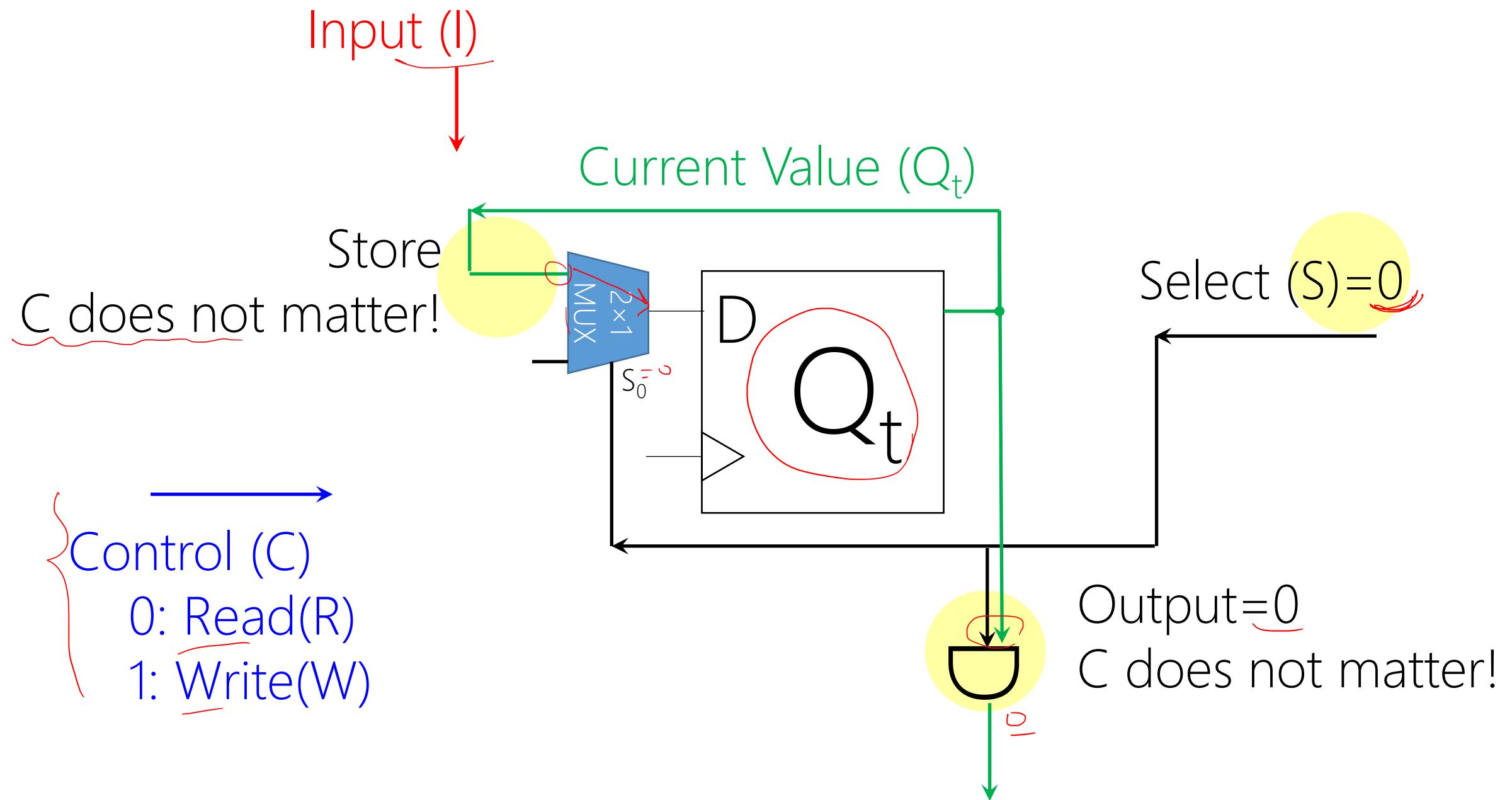
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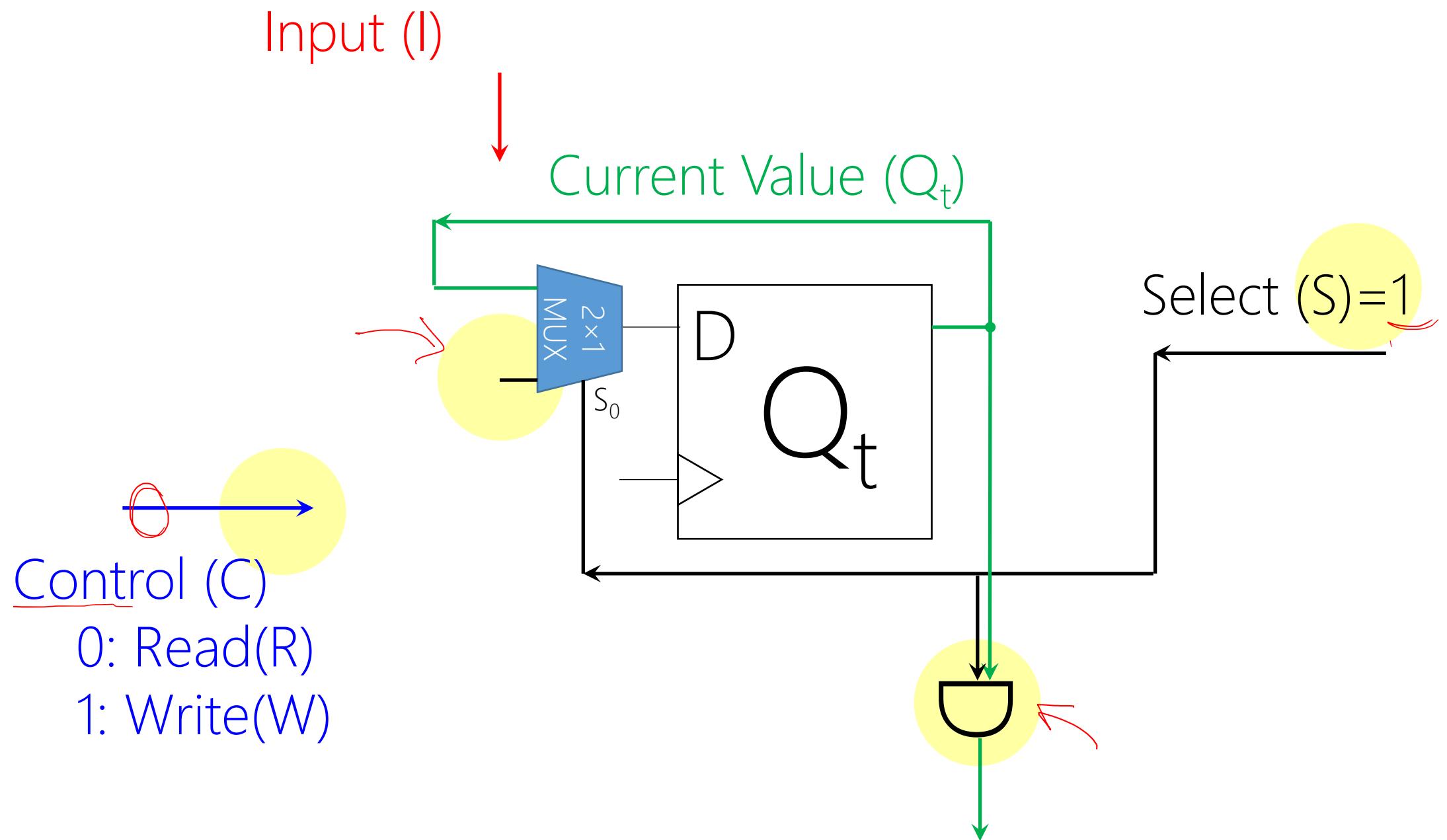
# Alternative Design

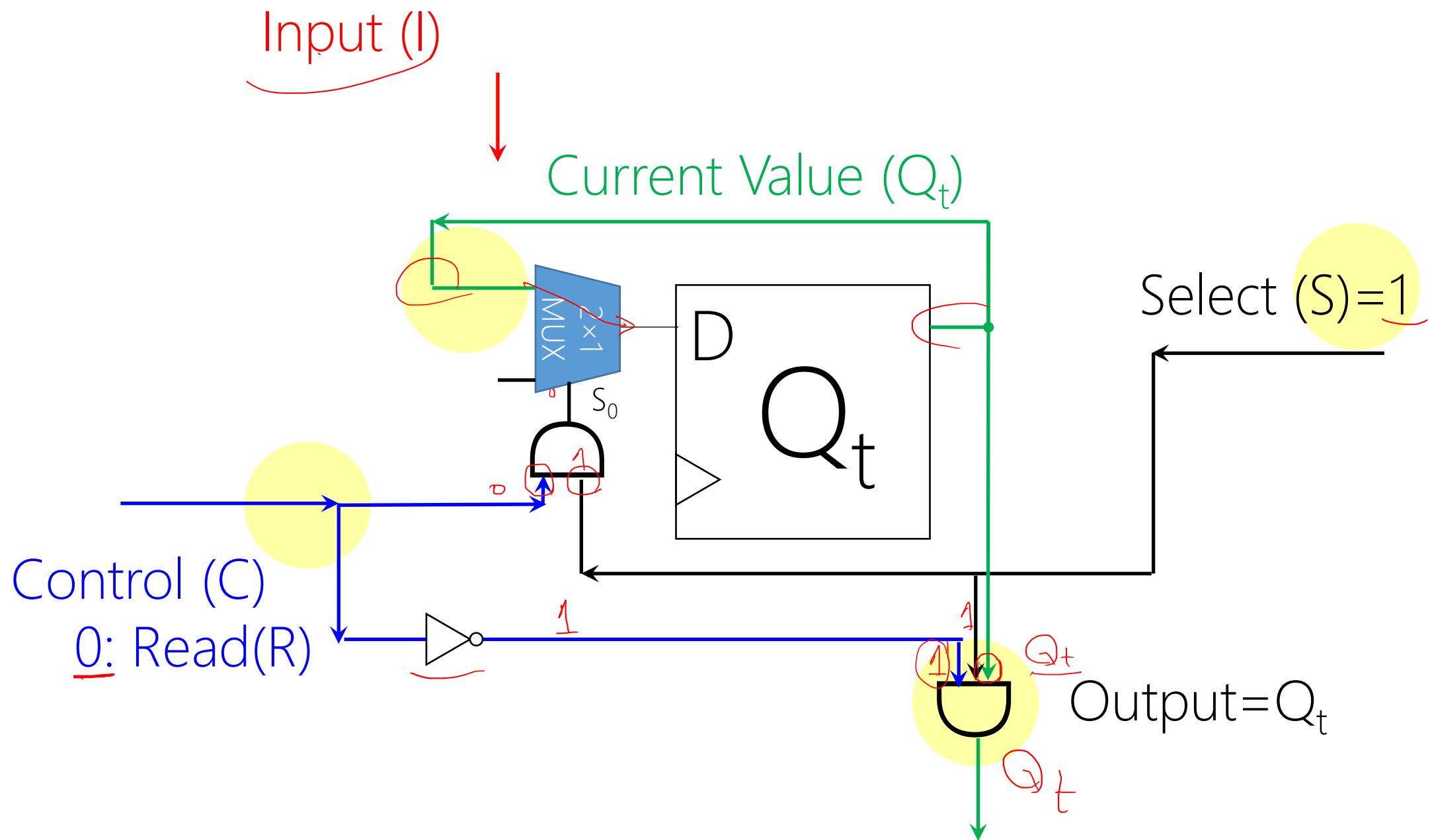
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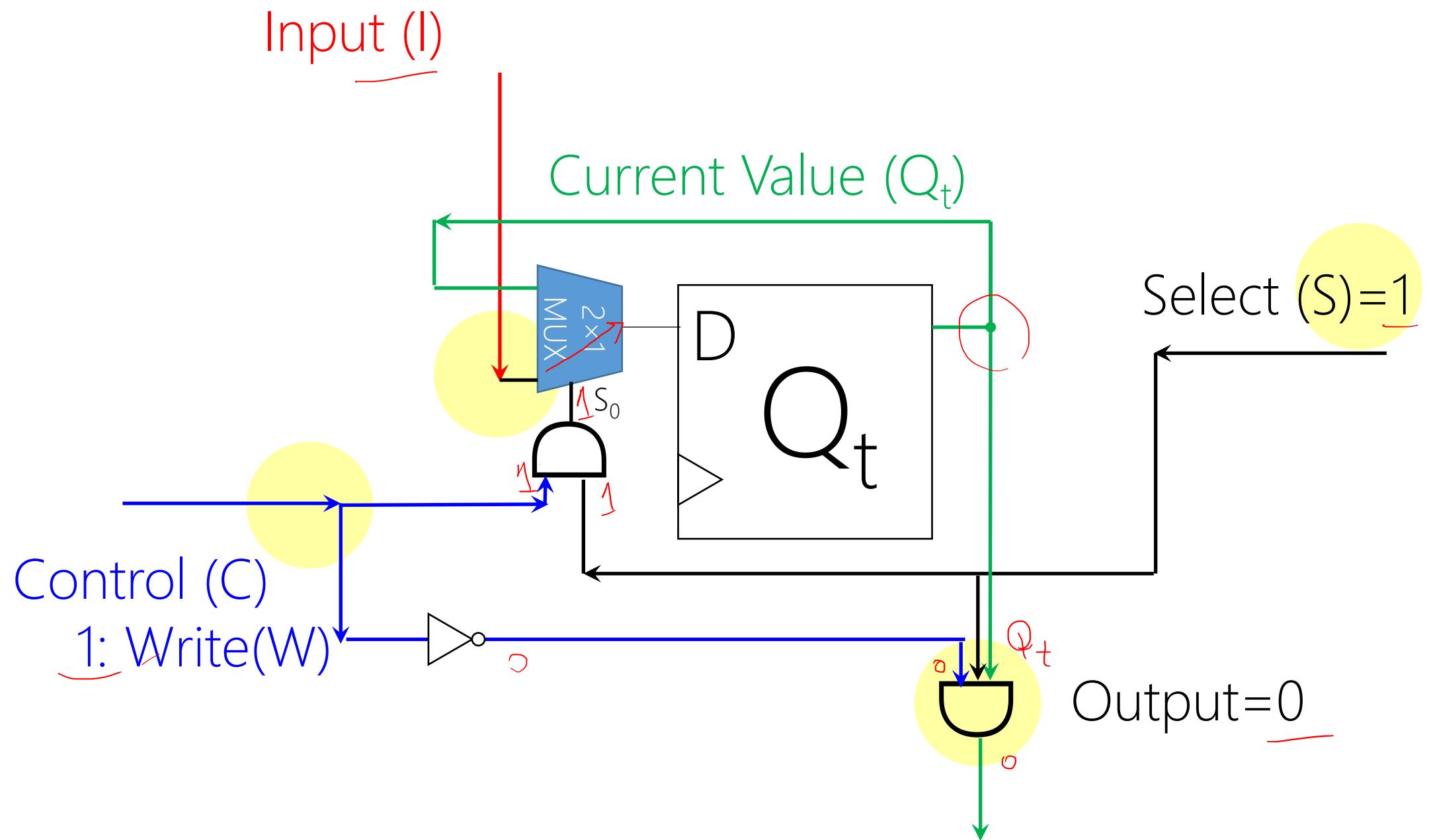


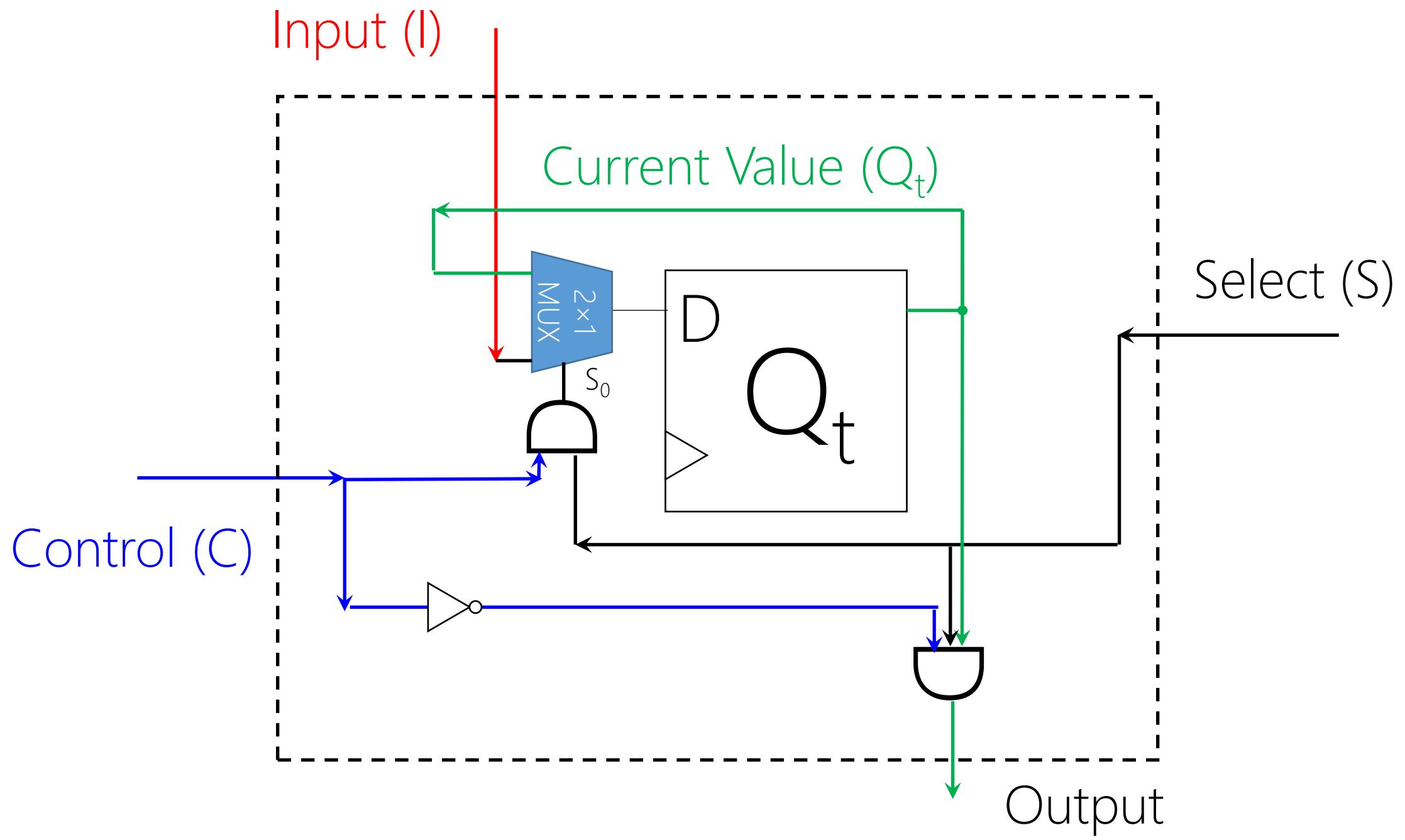


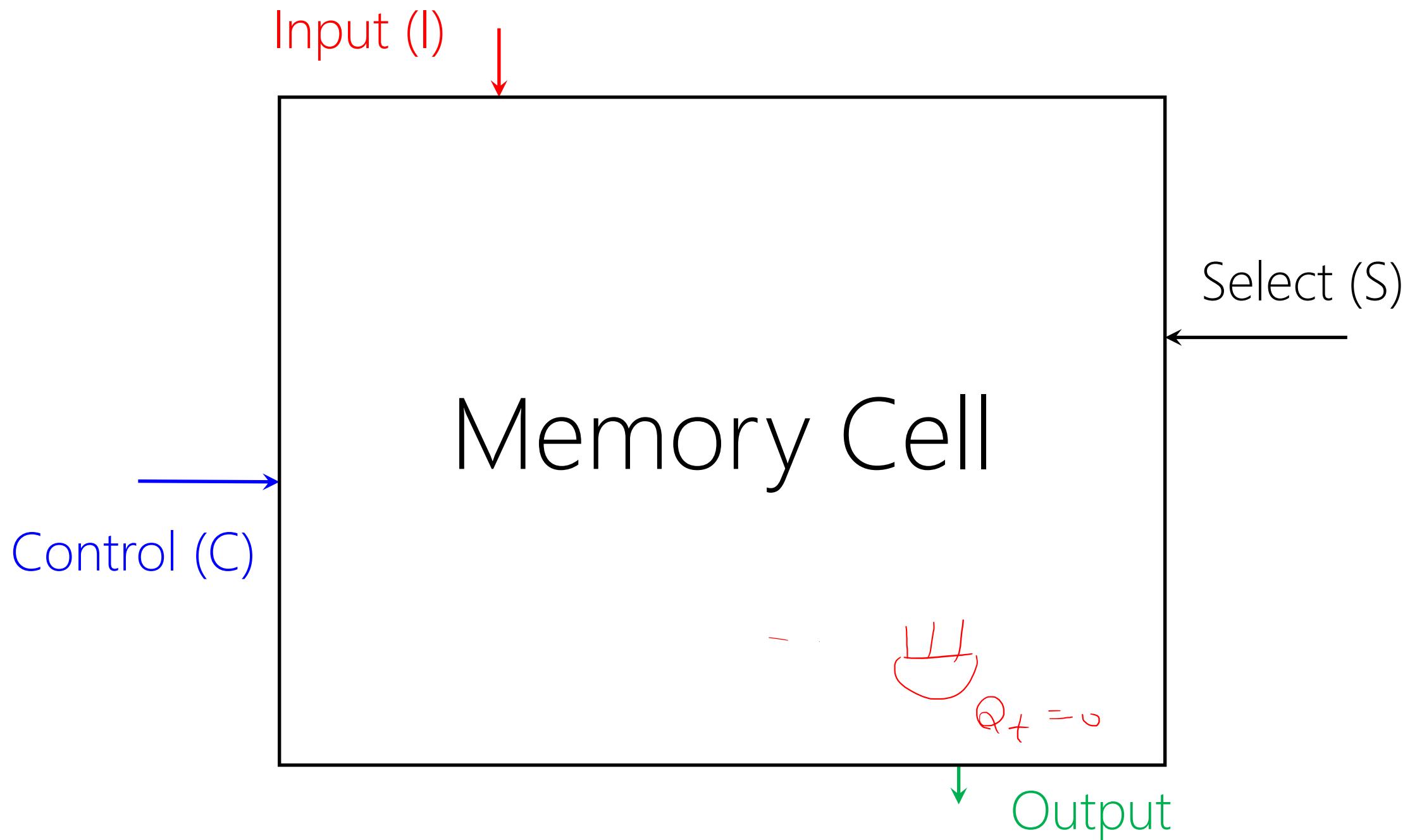












Clk is not shown but exists!

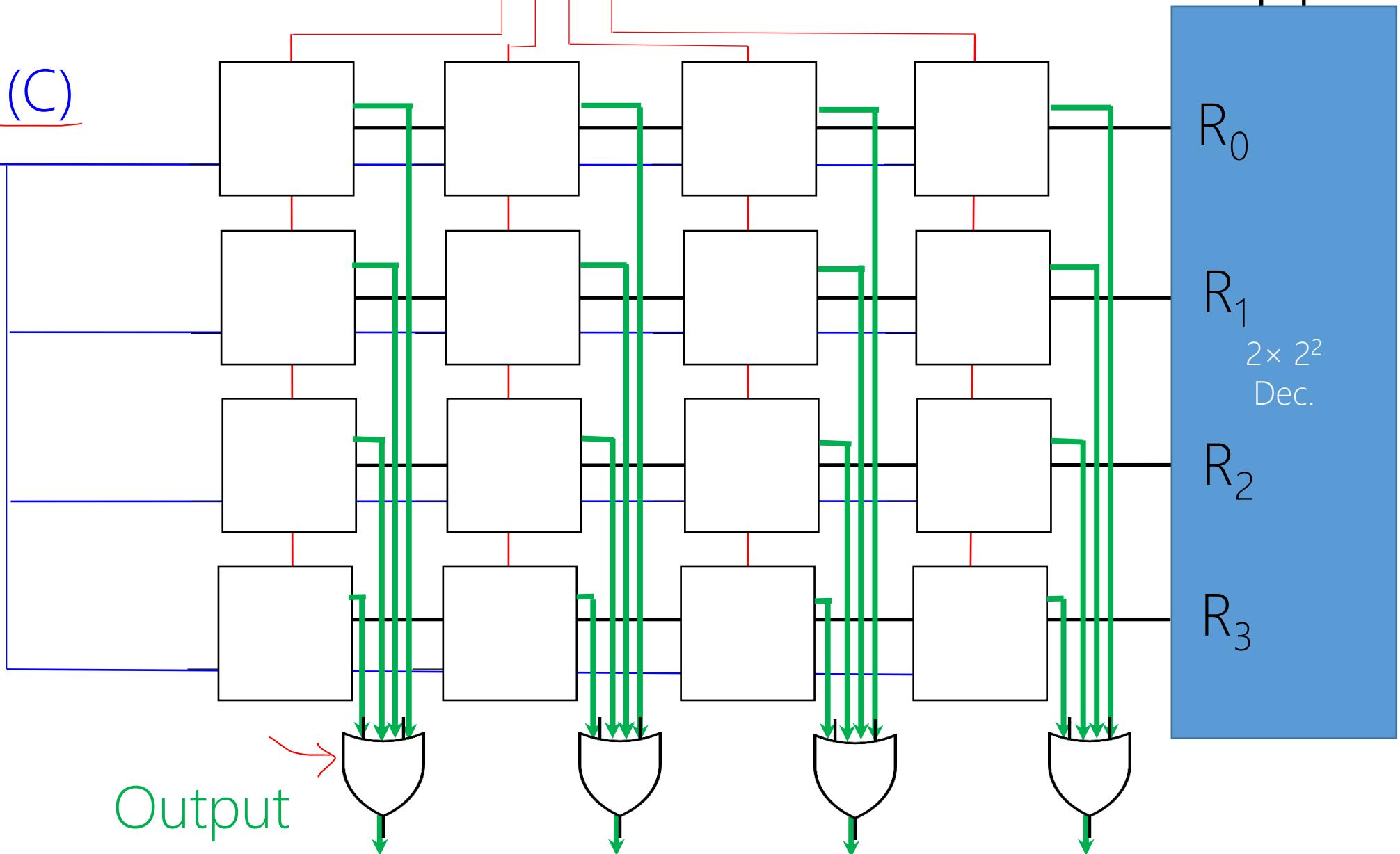
Control (C)

(R/W)

R'/W

Input (I)

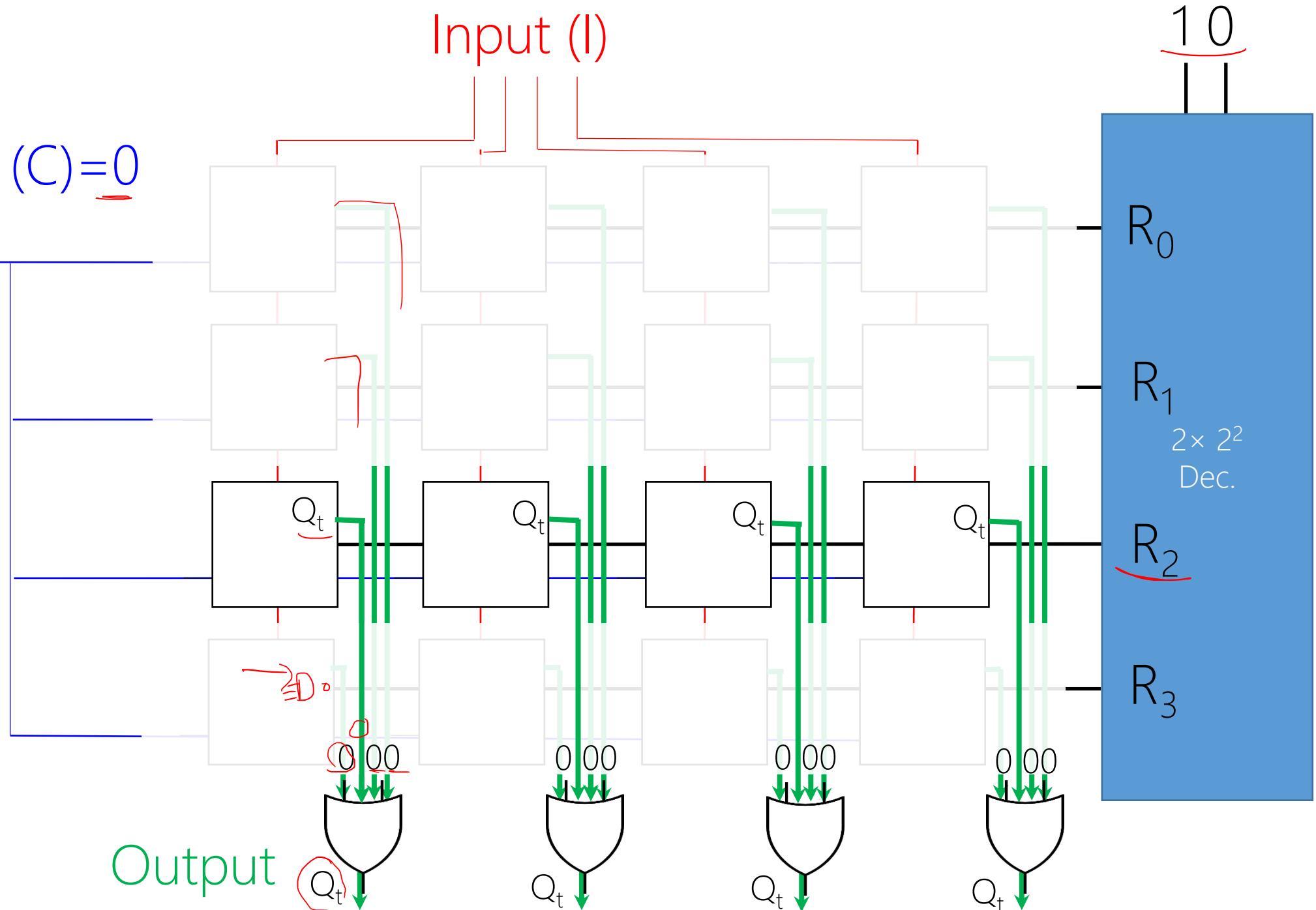
Select (S)



Clk is not shown but exists!

Control ( $C=0$ )  
(Read)

Input (I)

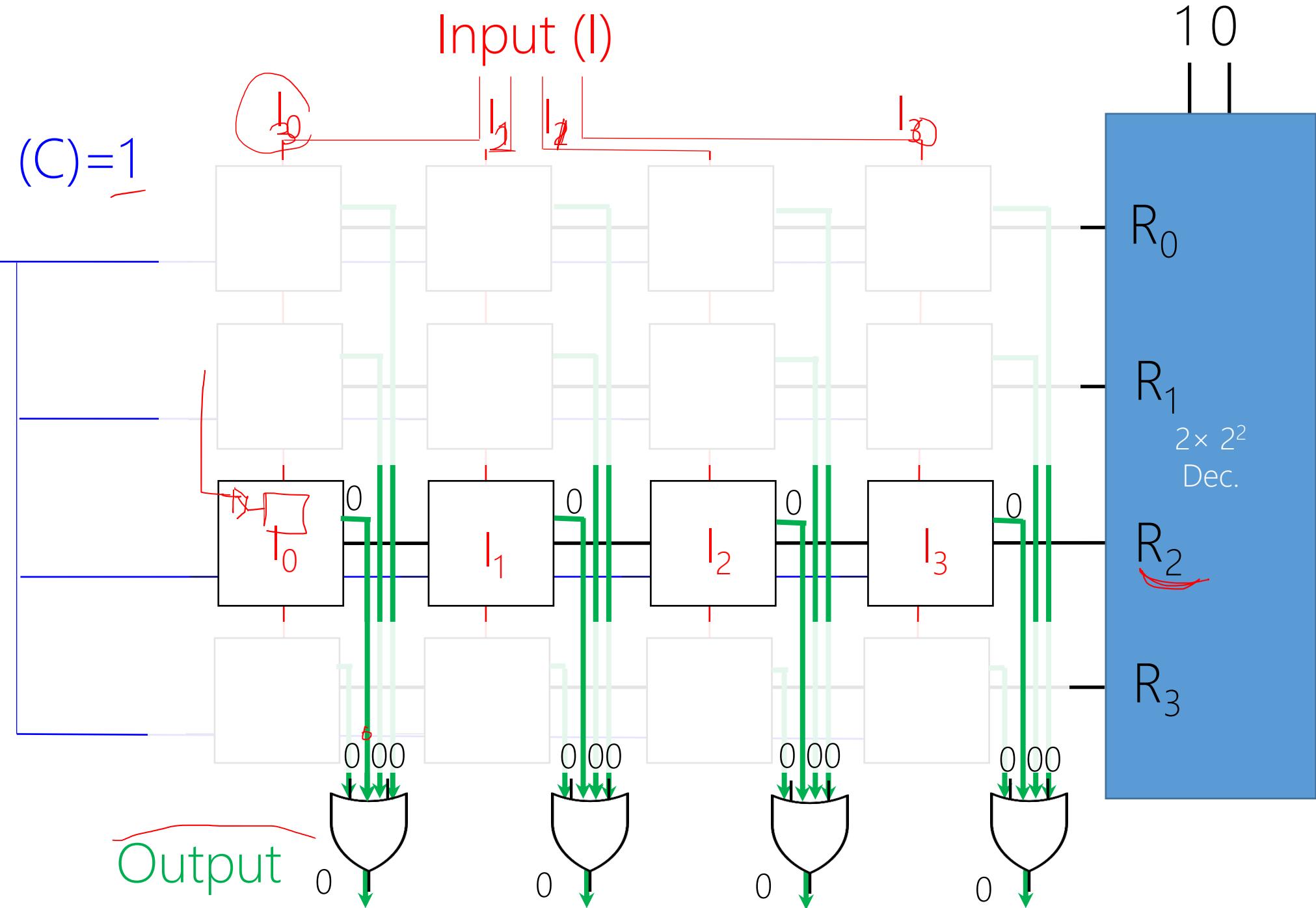


Clk is not shown but exists!

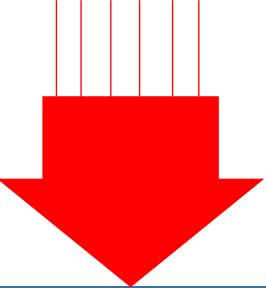
Control (C)=1  
(Write)

Input (I)

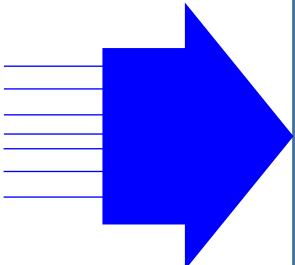
10



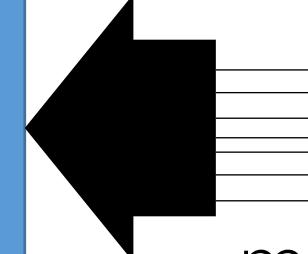
n-bit Data Bus (Write)



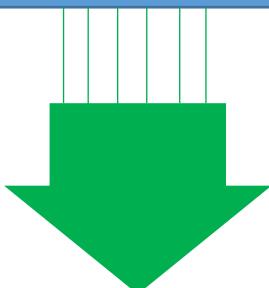
$2^m \times n$ -bit  
Memory  
Module



(k-bit Control Bus)



m-bit Address Bus



n-bit Data Bus (Read)

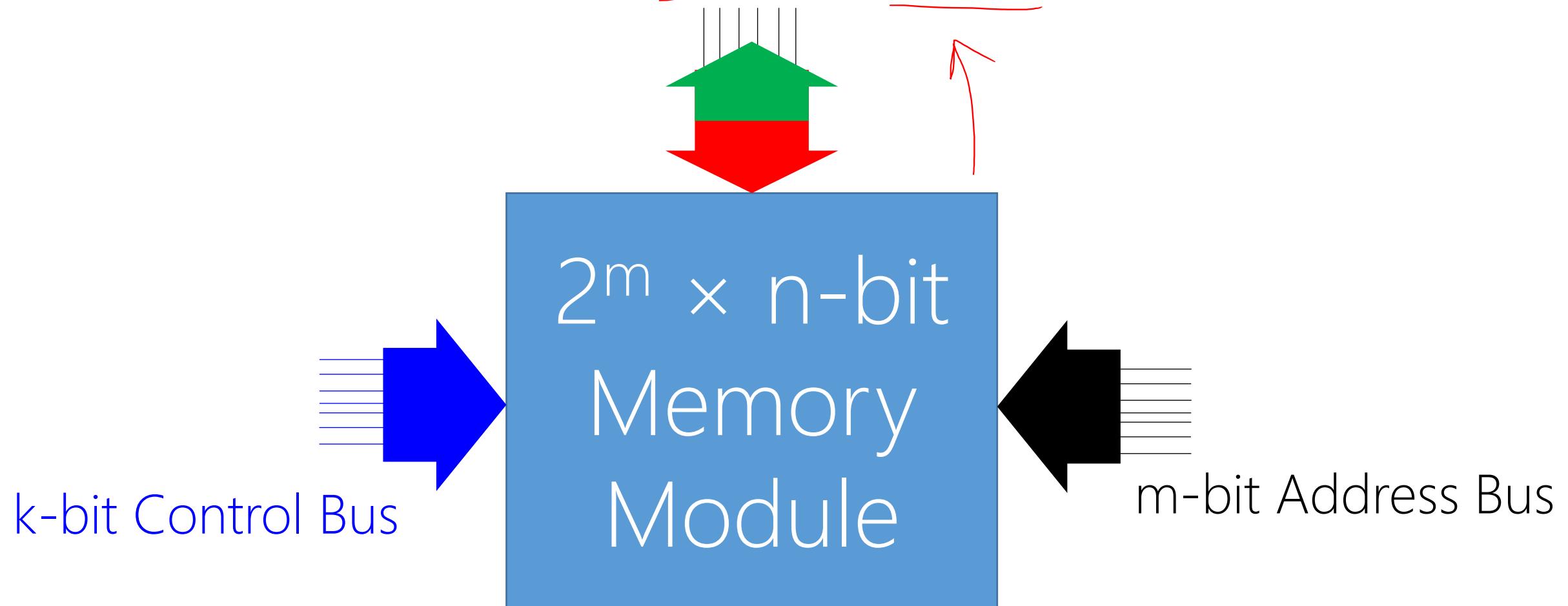
---

# Input and Output

## Same Data Bus vs. Another Data Bus

---

n-bit Data Bus (Write/ Read)



---

# Access

## Random vs. Sequential

---

---

# Access

## Random vs. Sequential

---

Random: regardless of location, always fixed  $\Delta t$ .

Sequential: closer location sooner, farther location longer!

---

# Access

## Random vs. Sequential

How long does it take to select a memory location (register)?

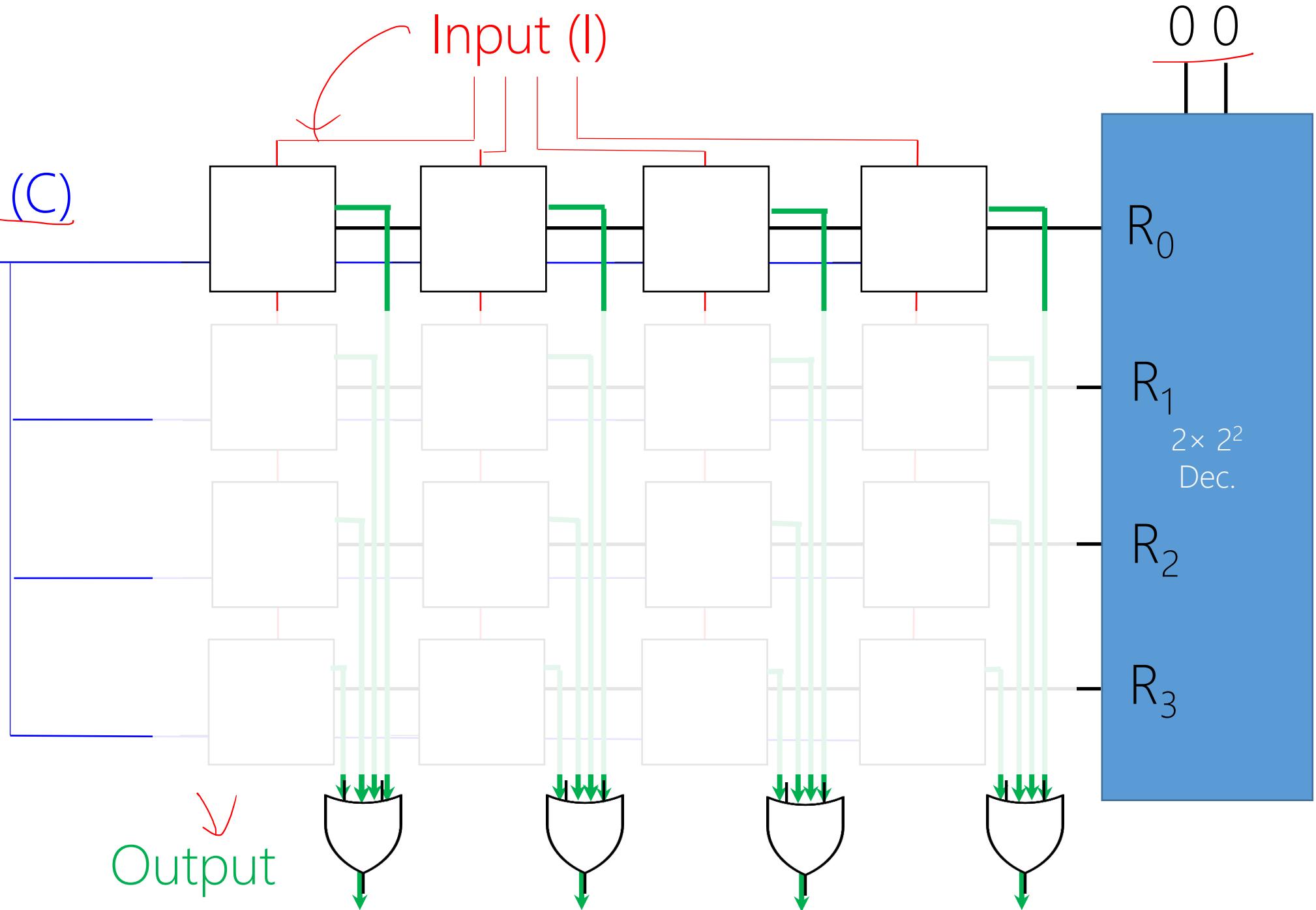
E.g., if address bus loads 00,

- how long is the wait to read this memory location?
- how long is the wait to write this memory location?

Clk is not shown but exists!

Control (C)  
(R/W')

Input (I)



---

# Access

## Random vs. Sequential

---

How long does it take to select a memory location (register)?

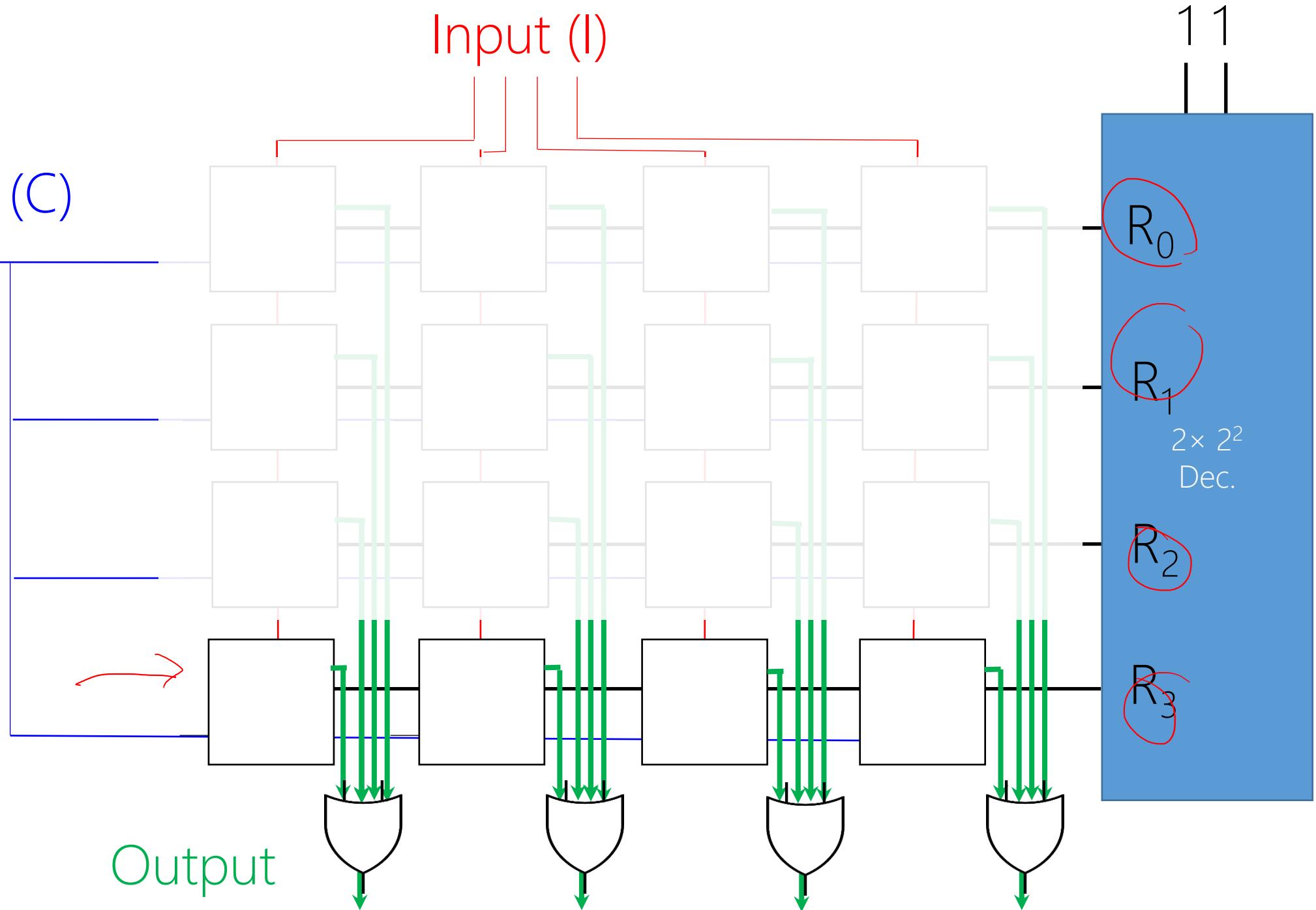
E.g., if address bus loads **11**,

- how long is the wait to read this memory location?
- how long is the wait to write this memory location?

Clk is not shown but exists!

Control (C)  
(R/W')

Input (I)

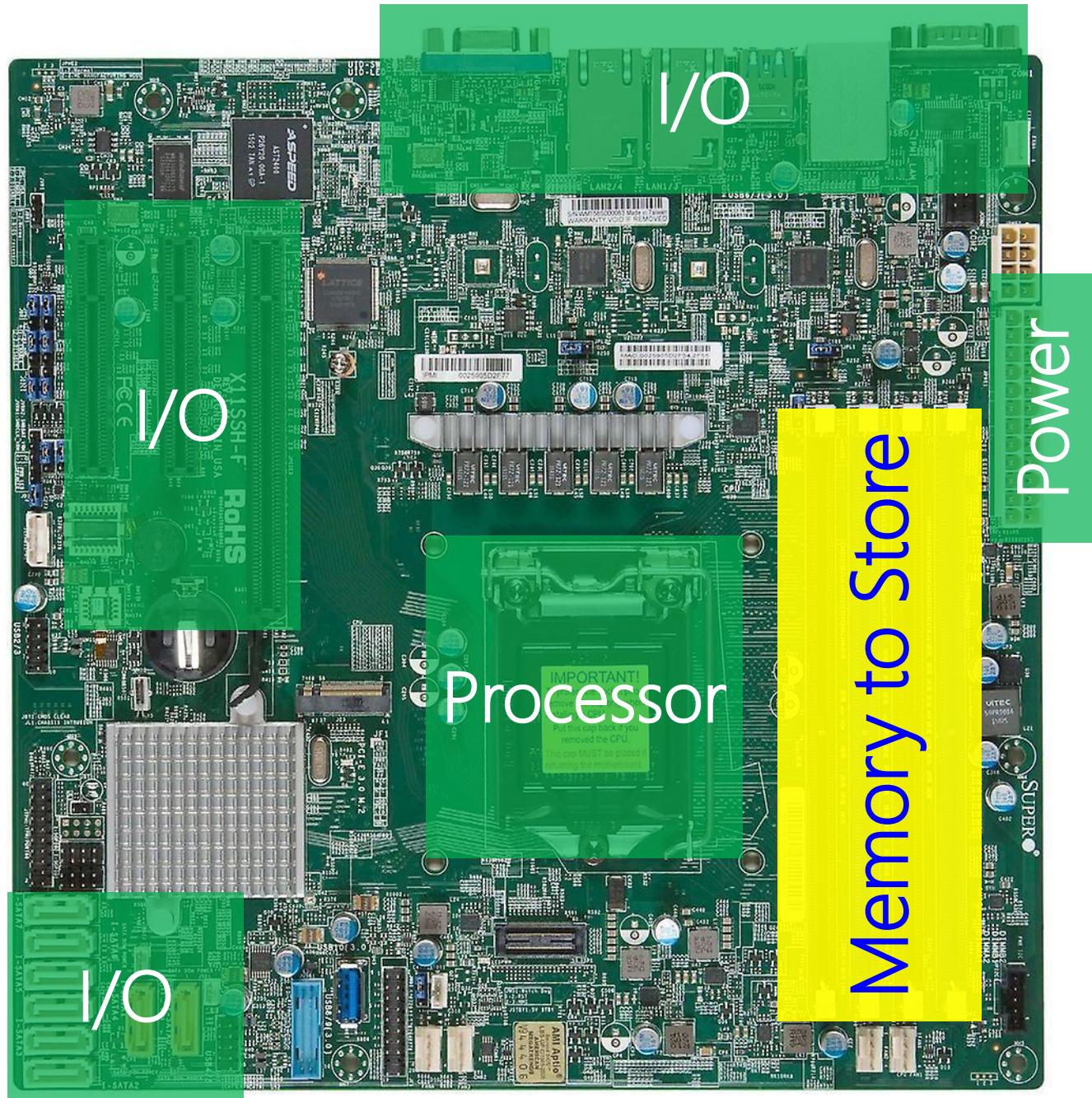


---

# Random Access Memory (RAM)

---

Regardless of memory location, always fixed  $\Delta t$ .



---

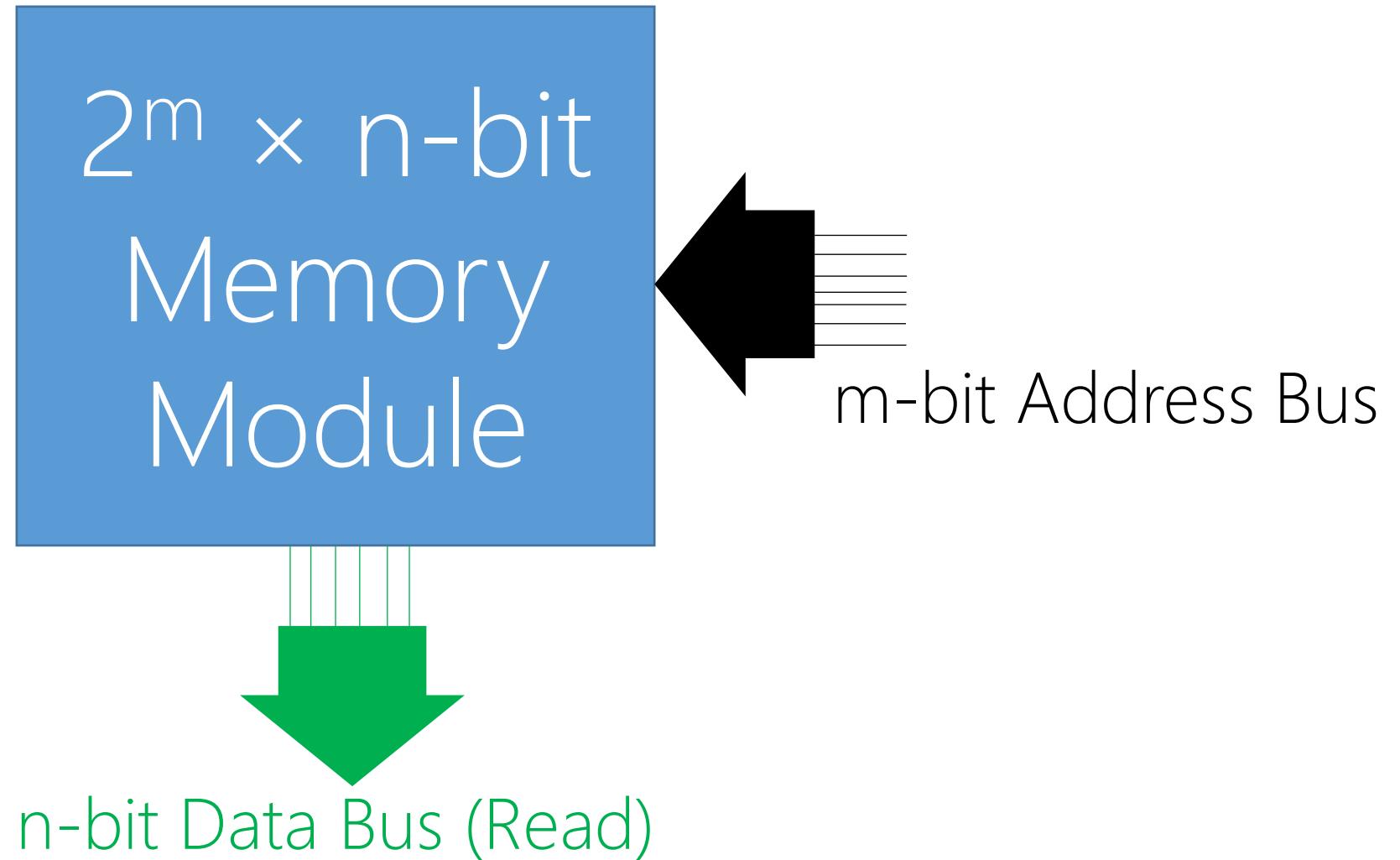
# Random Access Read-only Memory (ROM)

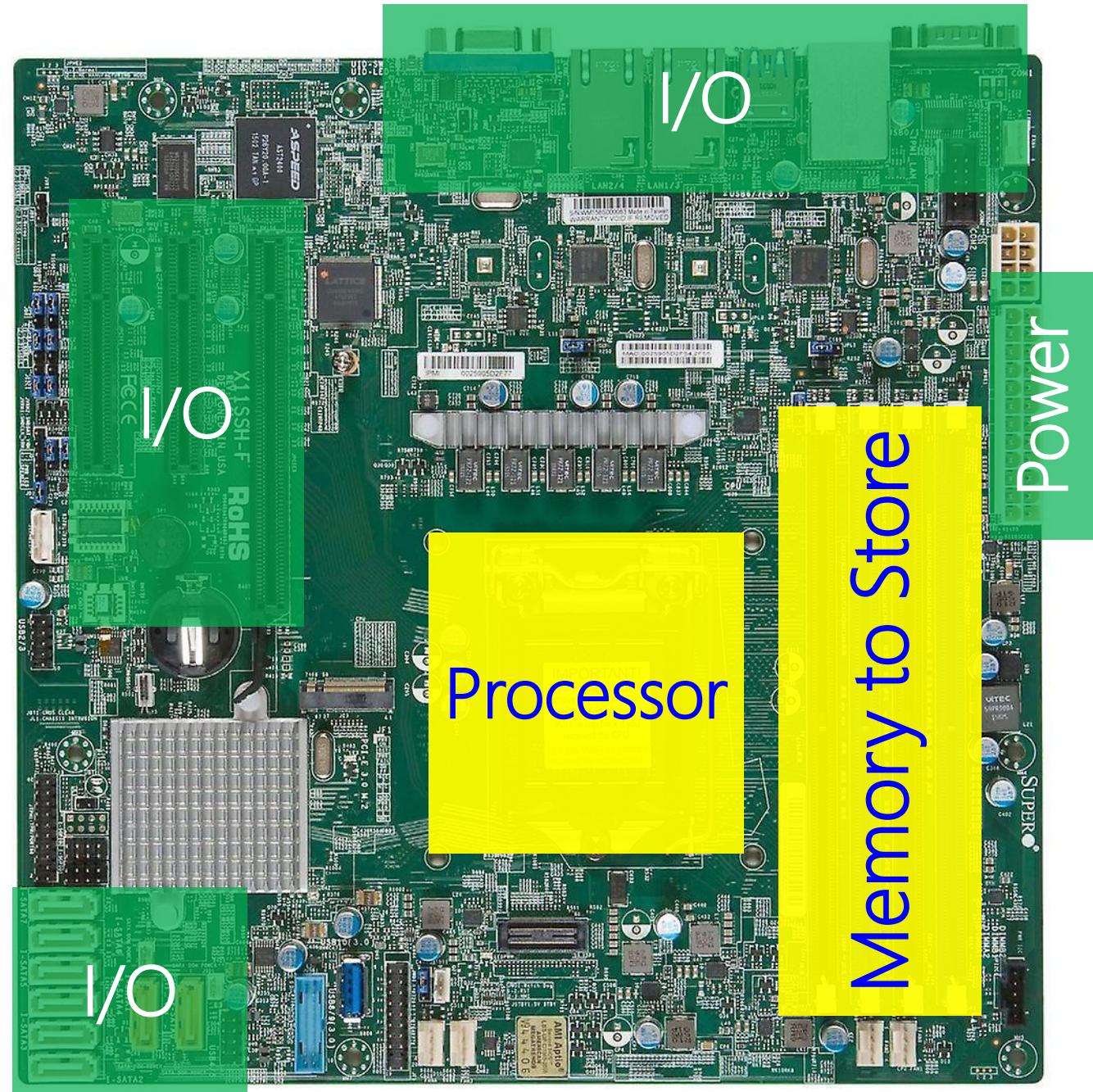
---

They don't have control bus for writing!

To store static data.

Still can write (update) but via physical procedures.





---

# Design Processor

## Do Calculation

---

---

# Design Processor

Calculation on Data → Calculation on Numbers

---

---

# Design Processor

## Number → Binary

---

# Computer

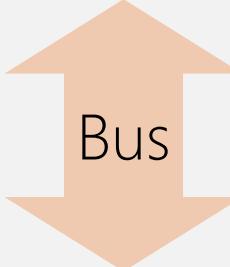
## Memory to Store

Data (Input, Output)

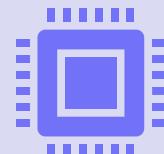
```
int a=1; int b=2; int c;
```

Instructions (Code)

```
c = a + b;
```



Processor



1. We instruct the processor what to do!
2. Write instructions (programs)
3. Processor does our instructions

---

# Design Processor

## Instruction Set

---

1. Cannot instruct a processor to do whatever we want!
2. Any processors have limitations.
  1. Some can only do addition,
  2. Some can do both addition and subtraction, but no division



# Intel® 64 and IA-32 Architectures Software Developer's Manual

Volume 2 (2A, 2B, 2C & 2D):  
Instruction Set Reference, A-Z

<https://www.intel.com/content/dam/www/public/us/en/documents/manuals/64-ia-32-architectures-software-developer-instruction-set-reference-manual-325383.pdf>

**NOTE:** The Intel 64 and IA-32 Architectures Software Developer's Manual consists of three volumes: *Basic Architecture*, Order Number 253665; *Instruction Set Reference A-Z*, Order Number 325383; *System Programming Guide*, Order Number 325384. Refer to all three volumes when evaluating your design needs.

---

# Design Processor

## Assembly Language

---

Writing programs using the Instruction Set of a particular processor

- RISC (/rɪsk/): Reduced Instruction Set Computer
- CISC (/'sɪsk/): Complex Instruction Set Computer

---

# Design Processor

## RISC

---

Small but highly optimized set of instructions  
e.g., integer calculation

[https://en.wikipedia.org/wiki/Reduced\\_instruction\\_set\\_computer](https://en.wikipedia.org/wiki/Reduced_instruction_set_computer)

---

# Design Processor

## CISC

---

Large and NOT highly optimized set of instructions  
e.g., integer and floating-point calculations

[https://en.wikipedia.org/wiki/Complex\\_instruction\\_set\\_computer](https://en.wikipedia.org/wiki/Complex_instruction_set_computer)

---

# Current Processors

x86, x64

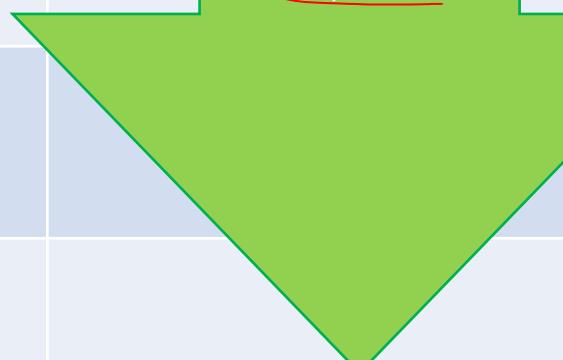
---

By Intel and AMD  
instruction set size: ~981

[How Many x86-64 Instructions Are There Anyway?](#)

Human Natural Language	Type	Example
High Level Programming Language	Imperative (What)	SQL <code>SELECT * FROM Students</code>
Middle Level Programming Language	Declarative (What + How)	C, C++, Java, Python <code>int a = 1;</code> <code>a = a + 1;</code>
Low Level Programming Language (Assembly Language)		Assembly x86, Assembly Z80 <code>MOV 1, AX</code> <code>INC AX</code>
Binary Digits (Machine Language)		<u>00010011</u> 00001011

Human Natural Language			Example
High Level Programming Language	Imperative		SQL <code>SELECT * FROM Students</code>
Middle Level Programming Language	Declarative Object-Oriented	Compilers Interpreters	C, C++, Java, Python <code>int a = 1;</code> <code>a = a + 1;</code>
Low Level Programming Language (Assembly Language)			Assembly x86, Assembly Z80 <code>MOV 1, AX</code> <code>INC AX</code>
Binary Digits (Machine Language)			<u>00010011</u> <u>00001011</u>



---

# C/C++

## Hossein's Computer

---

eclipse-workspace - COMP2650\_W13\_hfani/src/COMP2650\_W13\_hfani.c - Eclipse IDE

File Edit Source Refactor Navigate Search Project Run Window Help

Debug Project Explorer

COMP2650\_W13\_hfani.c main() at COMP2650\_W13\_hfani.c:2 0x10040108d

```
1 int main(void) {  
2     int a=1;  
3     int b=2;  
4     int c;  
5     c = a + b;  
6  
7     return 0;  
8 }
```

Thread #1 [COMP2650\_W13\_hfani] 0 (Suspended : Container)  
Thread #2 0 (Suspended : Container)  
Thread #3 0 (Suspended : Container)  
Thread #4 [sig] 0 (Suspended : Container)  
gdb (8.3.1)

Variables Breakpoints Expressions Modules Disassembly

Enter location here

00000010040107e: nop  
00000010040107f: nop  
000000100401080: push %rbp  
000000100401081: mov %rsp,%rbp  
000000100401084: sub \$0x30,%rsp  
000000100401088: callq 0x1004010d0 <\_\_main>  
00000010040108d: movl \$0x1,-0x4(%rbp)  
000000100401094: movl \$0x2,-0x8(%rbp)  
00000010040109b: mov -0x4(%rbp),%edx  
00000010040109e: mov -0x8(%rbp),%eax  
0000001004010a1: add %edx,%eax  
0000001004010a3: mov %eax,-0xc(%rbp)  
0000001004010a6: mov \$0x0,%eax  
0000001004010ab: add \$0x30,%rsp  
0000001004010af: pop %rbp  
0000001004010b0: retq  
0000001004010b1: nop  
0000001004010b2: nop  
0000001004010b2: nop

Console Registers Problems Executables Debugger Console Memory

COMP2650\_W13\_hfani.exe [C/C++ Application]

Writable Smart Insert 3 : 1 [10]

Diagram annotations:

- A red arrow points from the variable declaration "int a=1;" in the C code to the assembly instruction "movl \$0x1,-0x4(%rbp)".
- A red arrow points from the variable declaration "int b=2;" in the C code to the assembly instruction "movl \$0x2,-0x8(%rbp)".
- A red circle highlights the value "0" in the assembly instruction "movl \$0x1,-0x4(%rbp)".
- A red circle highlights the value "4" in the assembly instruction "movl \$0x2,-0x8(%rbp)".

eclipse-workspace - COMP2650\_W13\_hfani/src/COMP2650\_W13\_hfani.c - Eclipse IDE

File Edit Source Refactor Navigate Search Project Run Window Help

Debug Project Explorer

COMP2650\_W13\_hfani.c main() at COMP2650\_W13\_hfani.c:2 0x10040108d

```
1 int main(void) {  
2     int a=1;  
3     int b=2;  
4     int c;  
5     c = a + b;  
6  
7     return 0;  
8 }
```

Thread #1 [COMP2650\_W13\_hfani] 0 (Suspended : Container)  
Thread #2 0 (Suspended : Container)  
Thread #3 0 (Suspended : Container)  
Thread #4 [sig] 0 (Suspended : Container)  
gdb (8.3.1)

Variables Breakpoints Expressions Modules Disassembly

Enter location here

00000010040107e: nop  
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000000100401080: push %rbp  
000000100401081: mov %rsp,%rbp  
000000100401084: sub \$0x30,%rsp  
000000100401088: callq 0x1004010d0 <\_\_main>  
00000010040108d: movl \$0x1,-0x4(%rbp)  
000000100401094: movl \$0x2,-0x8(%rbp)  
00000010040109b: mov -0x4(%rbp),%edx  
00000010040109e: mov -0x8(%rbp),%eax  
0000001004010a1: add %edx,%eax  
0000001004010a3: mov %eax,-0xc(%rbp)  
0000001004010a6: mov \$0x0,%eax  
0000001004010ab: add \$0x30,%rsp  
0000001004010af: pop %rbp  
0000001004010b0: retq  
0000001004010b1: nop  
0000001004010b2: nop  
0000001004010b2: nop

Console Registers Problems Executables Debugger Console Memory

COMP2650\_W13\_hfani.exe [C/C++ Application]

Writable Smart Insert 3 : 1 [10]

The screenshot shows the Eclipse IDE interface with the C code 'main()' in the center-left panel and its assembly translation in the center-right panel. Red arrows highlight specific instructions: one from the 'return 0;' line to the assembly 'movl' instruction, and another from the 'c = a + b;' line to the assembly 'add' instruction.

eclipse-workspace - COMP2650\_W13\_hfani/src/COMP2650\_W13\_hfani.c - Eclipse IDE

File Edit Source Refactor Navigate Search Project Run Window Help

Debug Project Explorer

COMP2650\_W13\_hfani.c main() at COMP2650\_W13\_hfani.c:2 0x10040108d

Variables Breakpoints Expressions Modules Disassembly

Enter location here

00000010040107e: nop  
00000010040107f: nop  
000000100401080: main:  
000000100401081: push %rbp  
000000100401082: mov %rsp,%rbp  
000000100401084: sub \$0x30,%rsp  
000000100401088: callq 0x1004010d0 <\_\_main>  
00000010040108d: movl \$0x1,-0x4(%rbp)  
000000100401094: movl \$0x2,-0x8(%rbp)  
00000010040109b: mov -0x4(%rbp),%edx  
00000010040109e: mov -0x8(%rbp),%eax  
0000001004010a1: add %edx,%eax  
0000001004010a3: mov %eax,-0xc(%rbp)  
0000001004010a6: mov \$0x0,%eax  
0000001004010ab: add \$0x30,%rsp  
0000001004010af: pop %rbp  
0000001004010b0: retq  
0000001004010b1: nop  
0000001004010b2: nop  
0000001004010b3: nop

Memory Addresses

Console Registers Problems Executables Debugger Console Memory

COMP2650\_W13\_hfani.exe [C/C++ Application]

To see the actual binary machine language (OP Code) for each instruction, open your executable file that the compiler makes. E.g., \*.exe in Windows systems.

COMP2650\_W13\_hfarni.exe

```
hfani@alpha:~$ hexdump main.o
00000000 457f 464c 0102 0001 0000 0000 0000 0000
00000010 0001 003e 0001 0000 0000 0000 0000 0000
00000020 0000 0000 0000 0000 0208 0000 0000 0000
00000030 0000 0000 0040 0000 0000 0040 000b 000a
00000040 4855 e589 45c7 01fc 0000 9000 c35d 4700
00000050 4343 203a 4428 6265 6169 206e 3031 322e
00000060 312e 362d 2029 3031 322e 312e 3220 3230
00000070 3031 3131 0030 0000 0014 0000 0000 0000
00000080 7a01 0052 7801 0110 0c1b 0807 0190 0000
00000090 001c 0000 001c 0000 0000 0000 000e 0000
000000a0 4100 100e 0286 0d43 4906 070c 0008 0000
000000b0 0000 0000 0000 0000 0000 0000 0000 0000
000000c0 0000 0000 0000 0000 0001 0000 0004 ffff1
000000d0 0000 0000 0000 0000 0000 0000 0000 0000
000000e0 0000 0000 0003 0001 0000 0000 0000 0000
000000f0 0000 0000 0000 0000 0000 0000 0003 0002
00000100 0000 0000 0000 0000 0000 0000 0000 0000
00000110 0000 0000 0003 0003 0000 0000 0000 0000
00000120 0000 0000 0000 0000 0000 0000 0003 0005
00000130 0000 0000 0000 0000 0000 0000 0000 0000
```

---

# Program vs. Process

---

- Program: **dead** body of the instructions stored in **permanent place** (flash drive, ssd, hard disk, paper!)
- Process: **live** body of the instructions stored in **memory**, *ready to be fetched by the Processor and be executed!*

---

# Program vs. Process

---

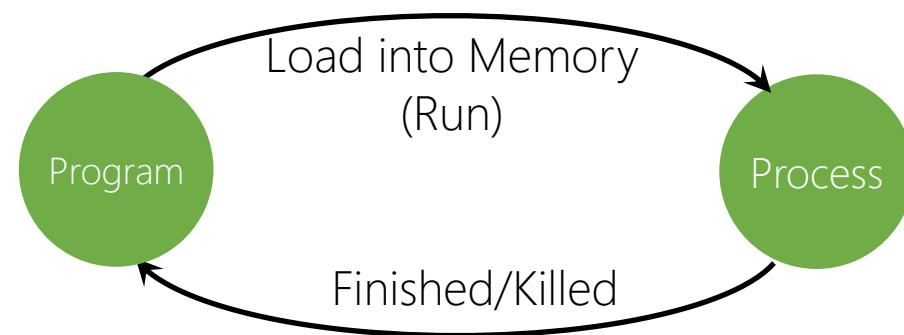
C, C++, Java, Python

```
int a = 1;  
a = a + 1;
```

Assembly x86, Assembly Z80

```
MOV 1, AX  
INC AX
```

```
00010011  
00001011
```



```
00010011  
00001011
```

```
00010011  
00001011
```

```
00010011  
00001011
```

# Compilers vs. Interpreters

## Instruction Encoders

Compilers

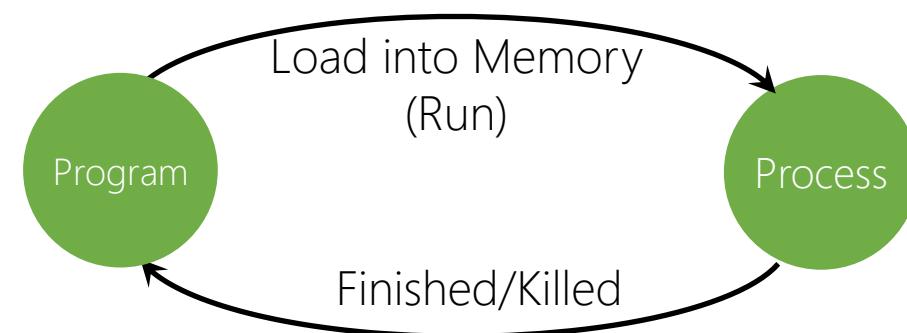
C, C++, Java, Python

```
int a = 1;  
a = a + 1;
```

Assembly x86, Assembly Z80

```
MOV 1, AX  
INC AX
```

```
00010011  
00001011
```



Interpreters

```
int a = 1; → 00010011  
a = a + 1; → 00001011
```

Instruction	Operation Code (OP Code)
$c = a + b$	000 XXXX YYYYY ZZZZZ
$c = a - b$	001 XXXX YYYYY ZZZZZ
$c = a / b$	010 XXXX YYYYY ZZZZZ
$c = a * b$	011 XXXX YYYYY ZZZZZ
$c = \{number\}$	100 XXXX XXX XXXX
...	...

Instruction Encoders  
very simplified version!

---

# Design Processor

---

Processor can only see binary-coded instructions

Processor only understand machine language

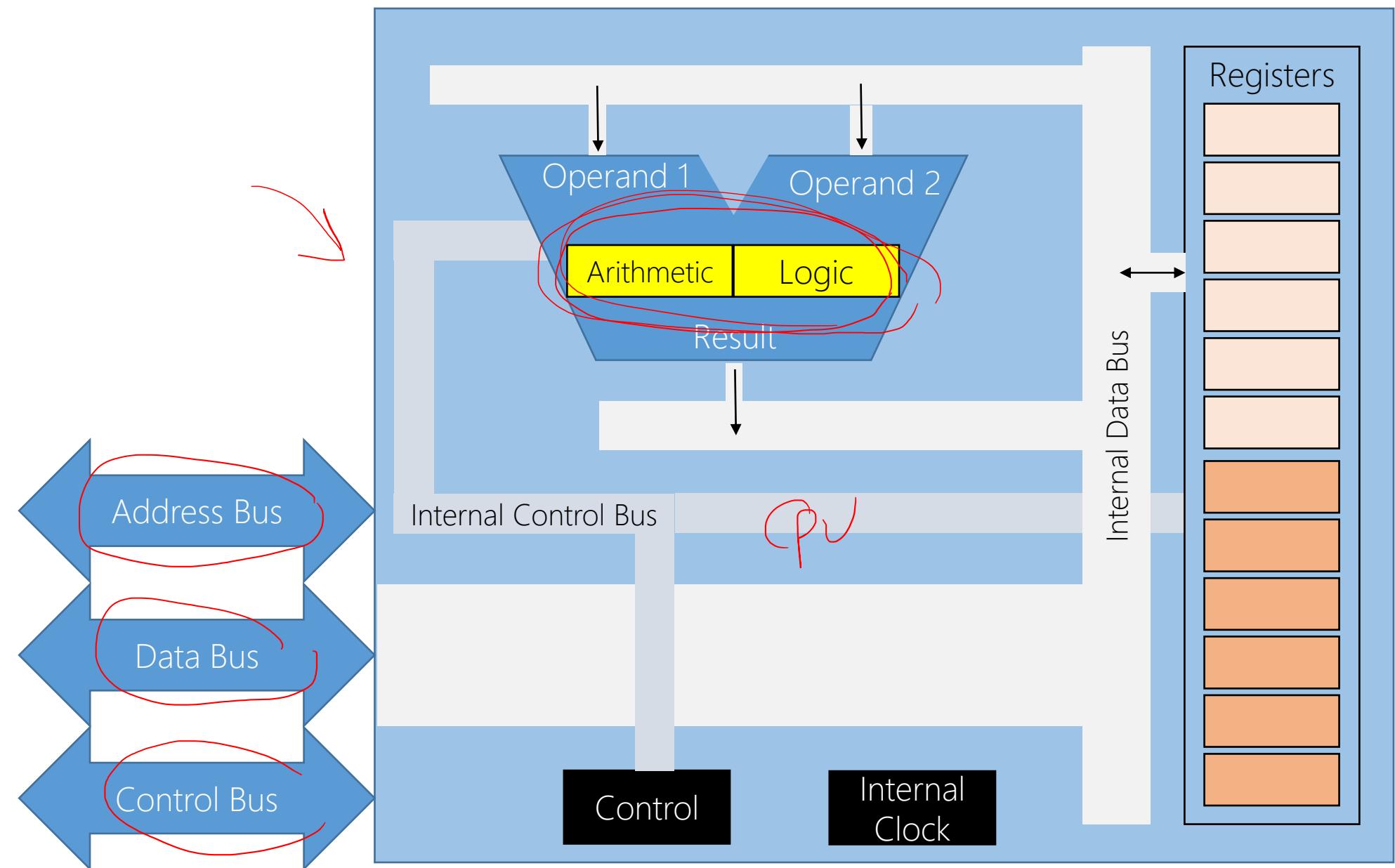
Instruction Set → Instruction Decoder

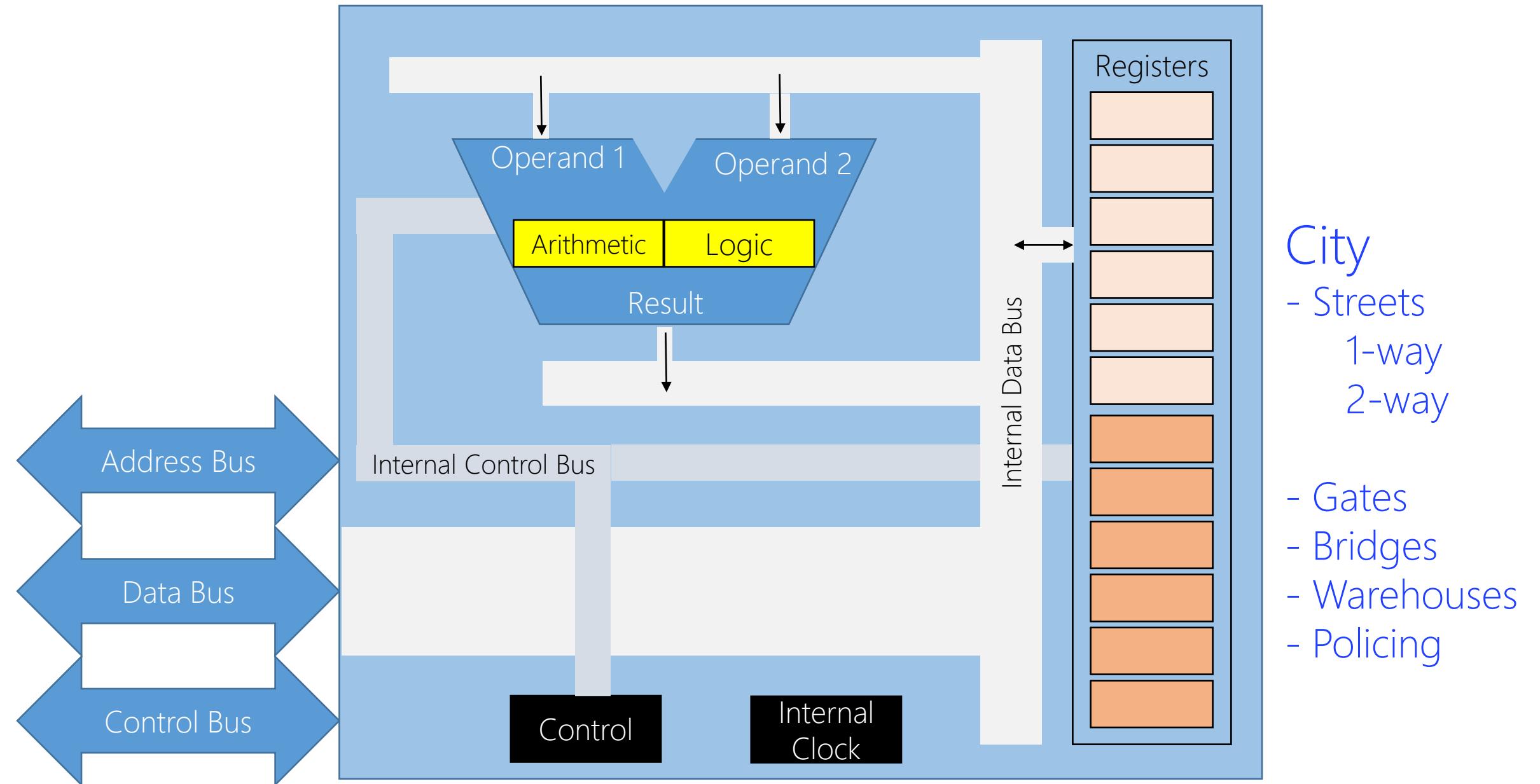
Operation Code (OP Code)	What to do?
000 XXXX YYYY ZZZZ	<ul style="list-style-type: none"> <li>1) Fetch the first operand from memory at XXXX address</li> <li>2) Store the first operand inside somewhere (AX)</li> <li>3) Fetch the second operand from memory at YYYY address</li> <li>4) Store the first operand inside somewhere else (BX)</li> <li>5) Use the n-bit Adder to add AX and BX</li> <li>6) Store the result inside somewhere else (CX)</li> <li>7) Push CX to memory at ZZZZ address</li> </ul>
001 XXXX YYYY ZZZZ	
010 XXXX YYYY ZZZZ	
011 XXXX YYYY ZZZZ	
100 XXXX XXX XXXX	
...	

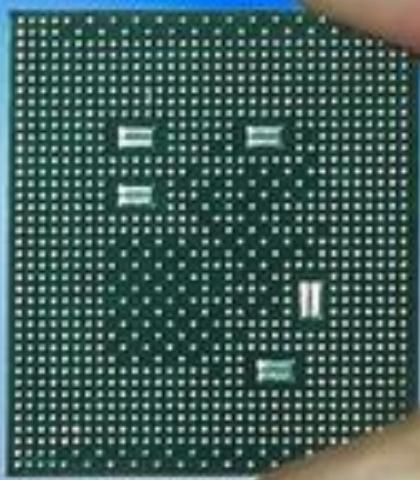
Instruction Decoder  
very simplified version!

Operation Code (OP Code)	What to do?
000 XXXX YYYY ZZZZ	<ol style="list-style-type: none"> <li>1) Fetch the first operand from memory at XXXX address</li> <li>2) Store the first operand inside somewhere (AX)</li> <li>3) Fetch the second operand from memory at YYYY address</li> <li>4) Store the second operand inside somewhere else (BX)</li> <li>5) Use the n-bit Adder to add AX and BX</li> <li>6) Store the result inside somewhere else (CX)</li> <li>7) Push CX to memory at ZZZZ address</li> </ol>
001 XXXX YYYY ZZZZ	
010 XXXX YYYY ZZZZ	
011 XXXX YYYY ZZZZ	
100 XXXX XXX XXXX	
...	

Instruction Decoder  
very simplified version!







# Microprocessor

Central Processing Unit (CPU)

Intel (Xeon), AMD (Ryzen)

Graphic Processing Unit (GPU)

nVidia (GeForce) for Video Card (Gaming)

AI Acceleration (Neural Nets)

Tensor Processing Unit (TPU)

Google (TensorFlow AI Lib for Neural Nets)

---

COMP-2660  
Computer Architecture II  
Microprocessor Programming

---

$\begin{smallmatrix} +5 \\ 0 \\ -5 \end{smallmatrix}$  bit

Quantum  
Computer