



POCKET LCD GAMES

build kits · khanin.info

Building instructions

GW-03

Transistor Memory

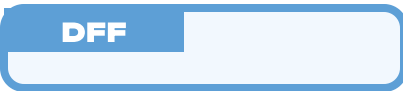
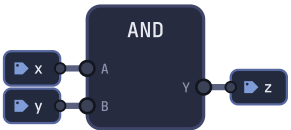
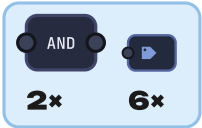
lessons 1-5 · from a latch to our own memory in the processor



simulator: cs.khanin.info

How to read these instructions

3



step number – follow strictly in order

parts for this step: how many to place

a part with labels on its pins

labels with the same name are connected

chip ports: input [and output]

blue frame – building a chip

grey tab – the main canvas

yellow ring – what has changed

remove a part together with its labels

double-click a label – new name

chip built in the lesson with this number

check: this is how it should work

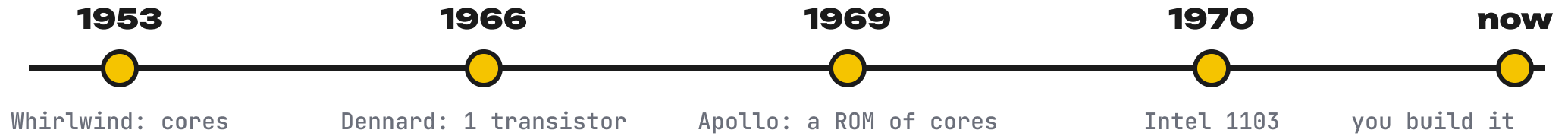
Keys

V	VCC (1)
G	GND (0)
N	transistor
I	switch
O	lamp
L	label
K	clock
U	button
[	port in
]	port out

Ctrl+G – into a chip
on a Mac Ctrl = Cmd



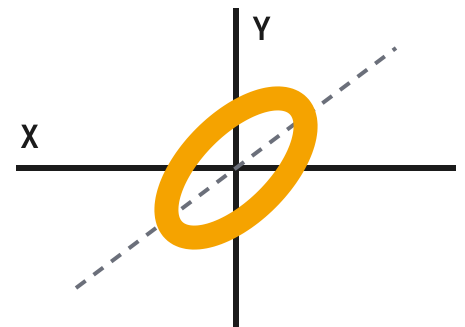
A little history



The first computers remembered on ferrite rings the size of a poppy seed: a ring magnetised clockwise or counter-clockwise is a bit. X and Y wires pass through every ring; only the ring where two half-currents meet flips. The planes were woven by hand.

The Apollo Guidance Computer's ROM was woven from rings too: a wire through a ring is 1, around it is 0. The program was not written but woven in at the factory.

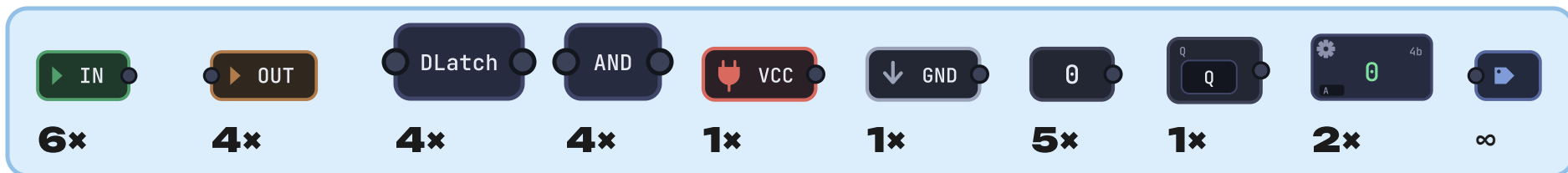
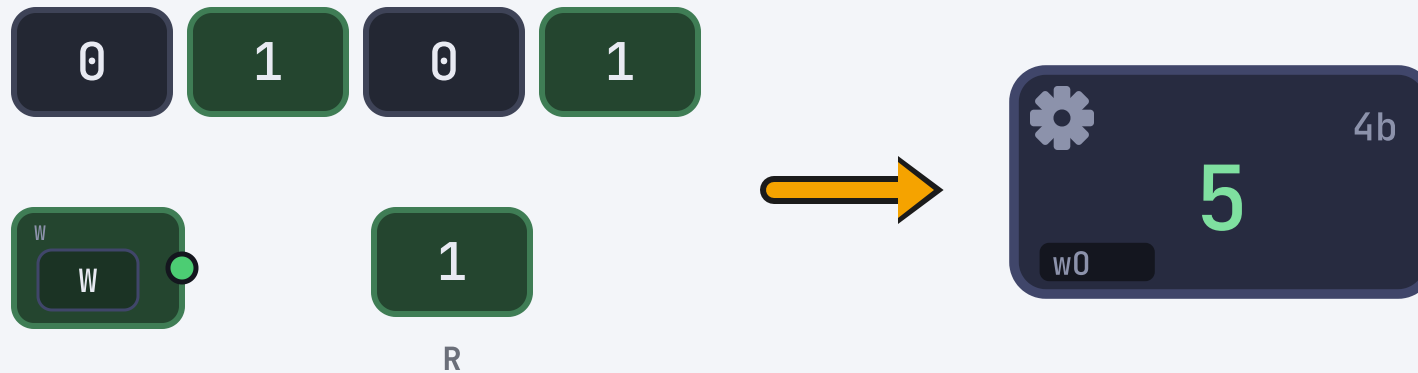
In 1970 the Intel 1103 – 1,024 bits on a chip – replaced the rings. A real cell is 6 transistors, or even one with a capacitor. Ours is a latch of gates, 22 transistors: in a simulator with ideal switches that is more reliable. 1,024 such cells make 41,840 transistors.





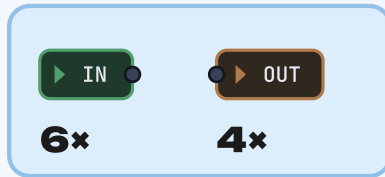
Cell and row

a latch + an output "tap" → a 4-bit word

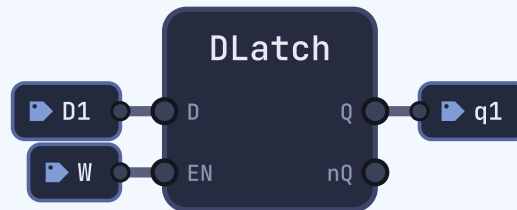
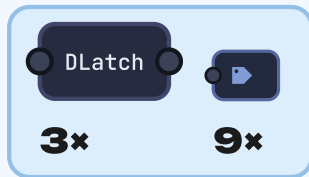


WORD4

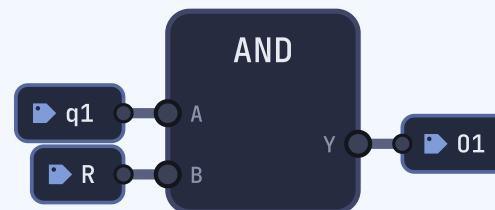
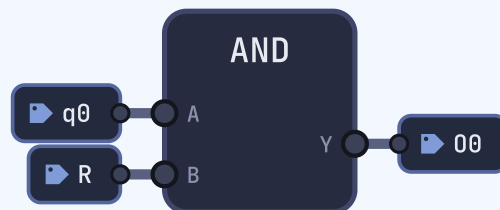
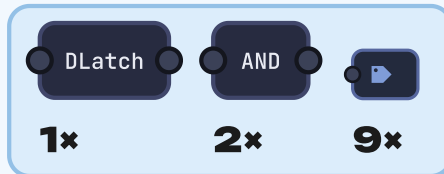
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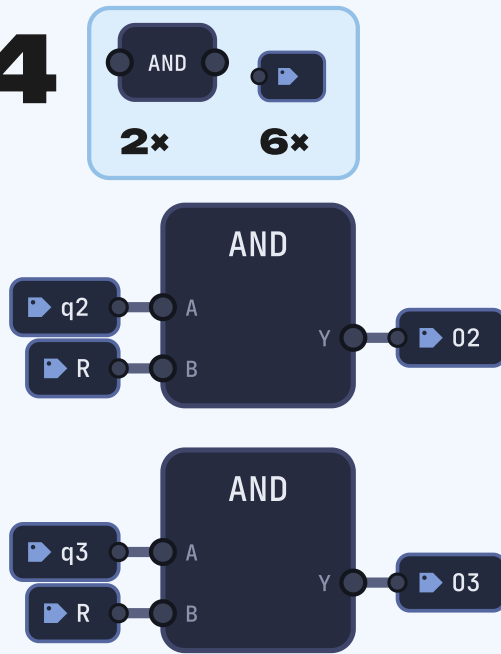


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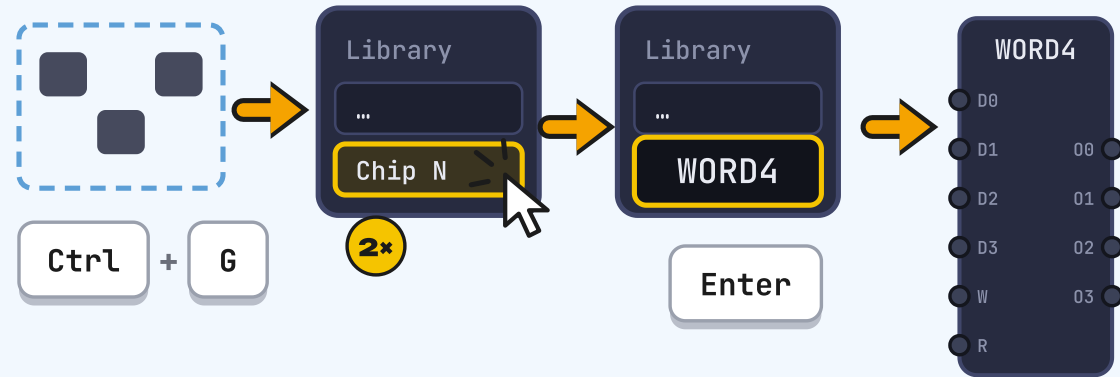


WORD4 ...

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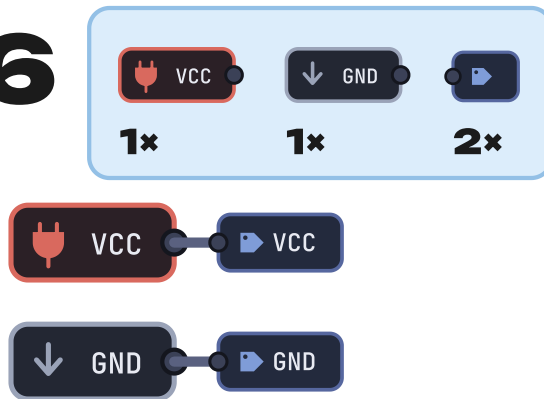


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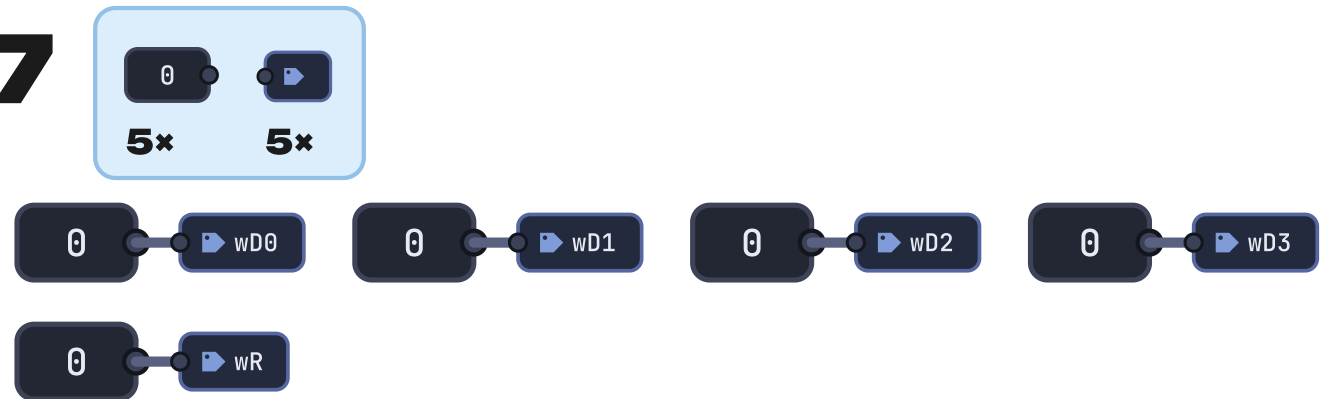


CANVAS

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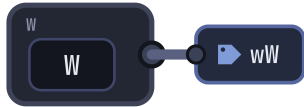
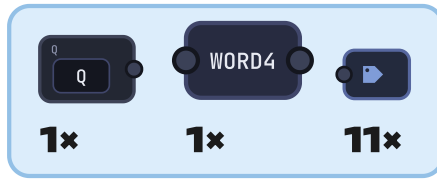


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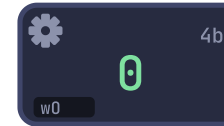
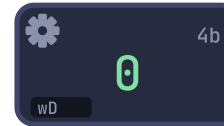


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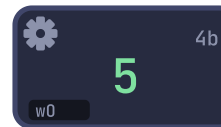
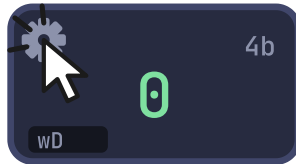
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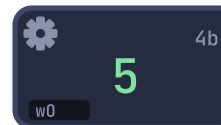
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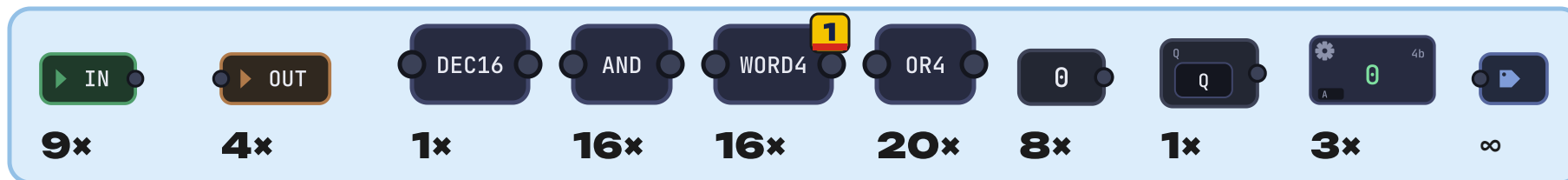
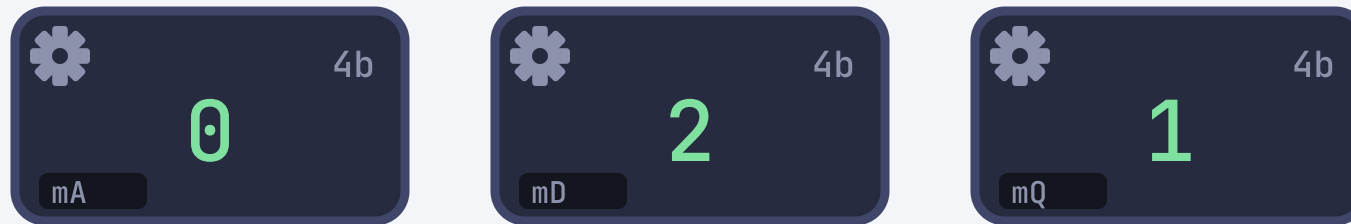
W -





16x4 memory

a decoder picks a row, an OR gathers the output



RAM16x4

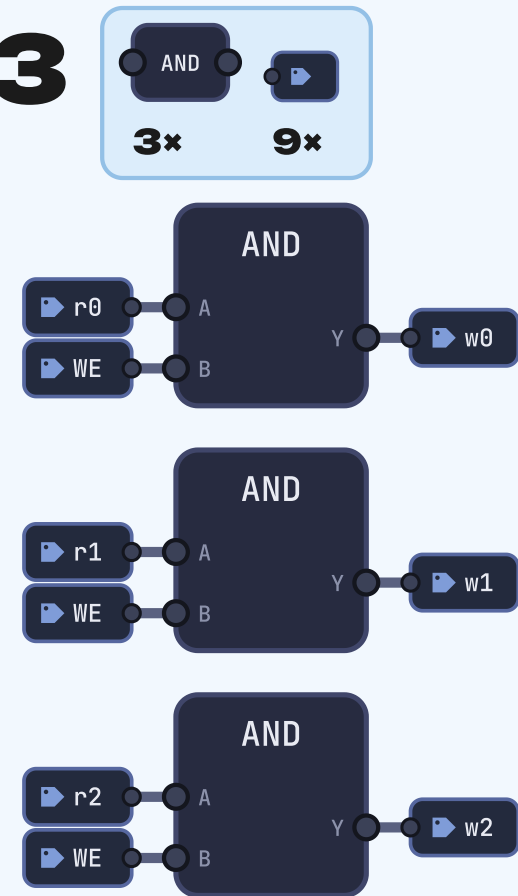
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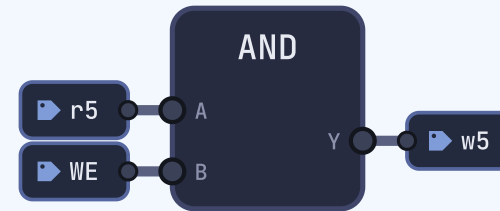
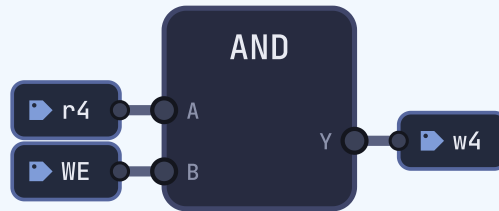
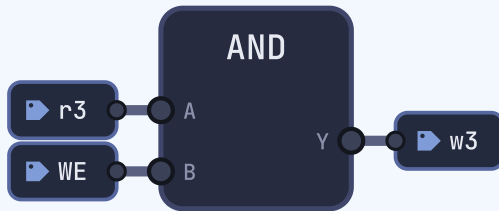


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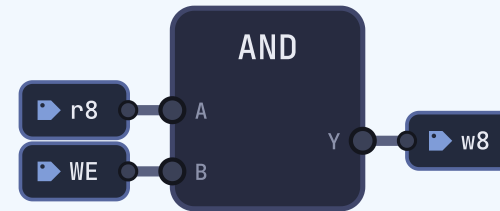
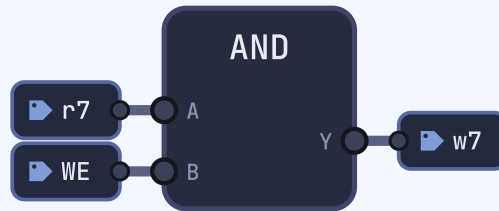
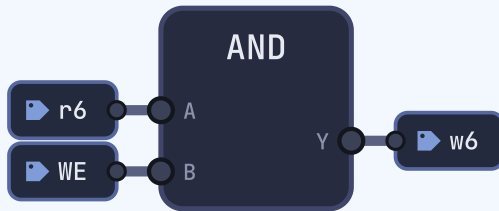
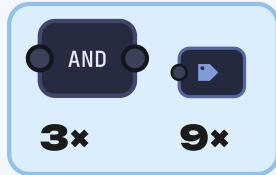


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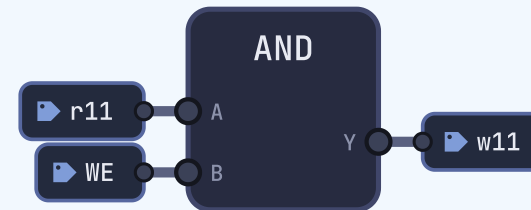
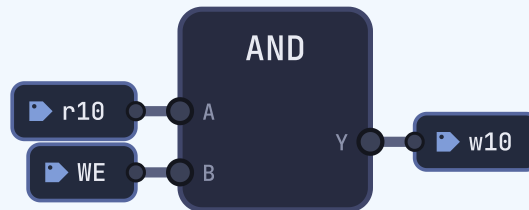
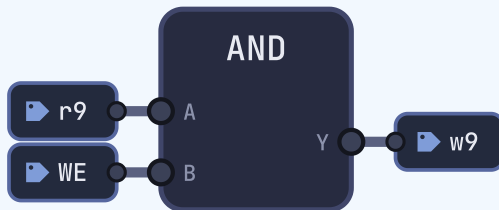
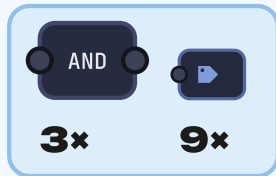
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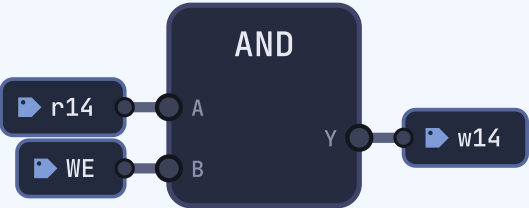
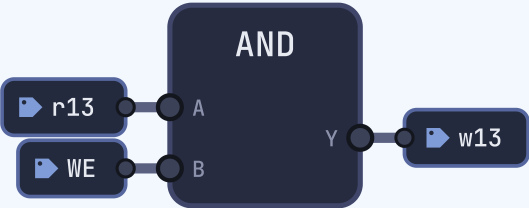
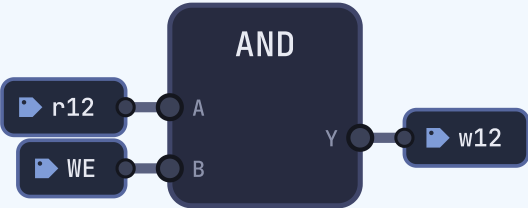


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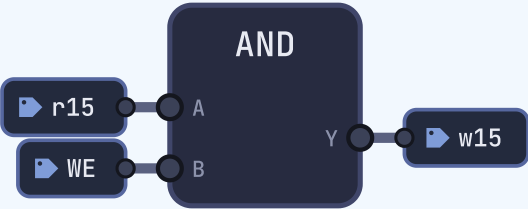
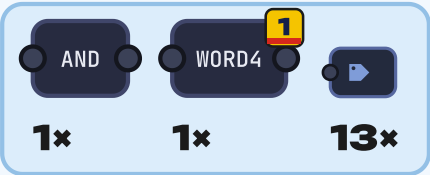


RAM16x4 ...

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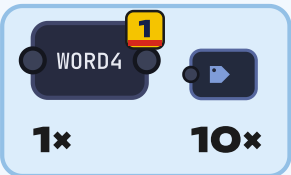


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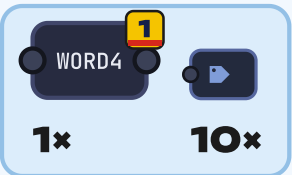


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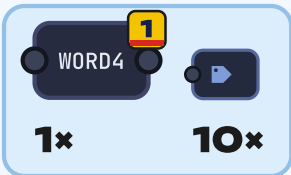
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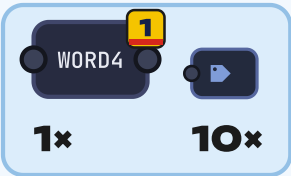
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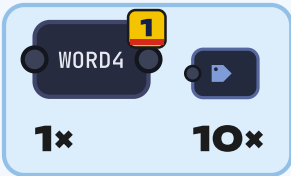
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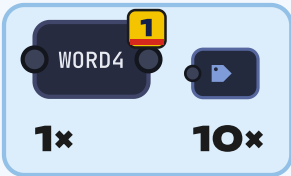
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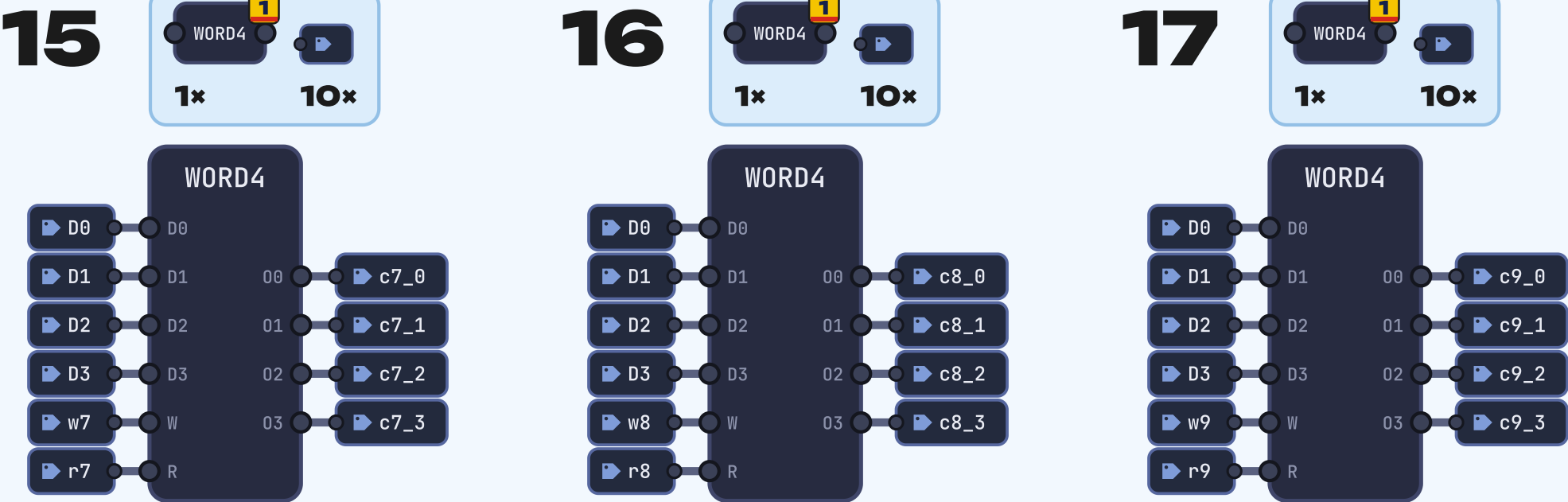


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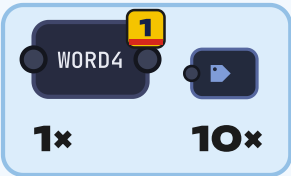


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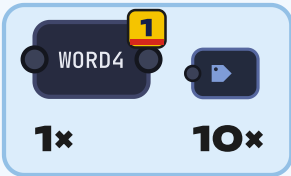




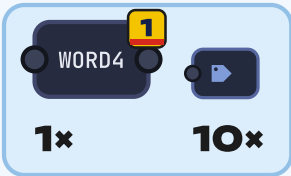
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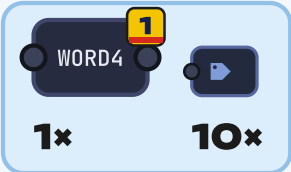
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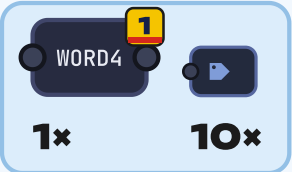
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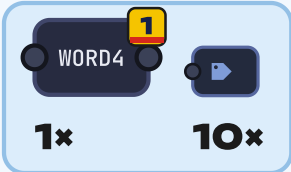
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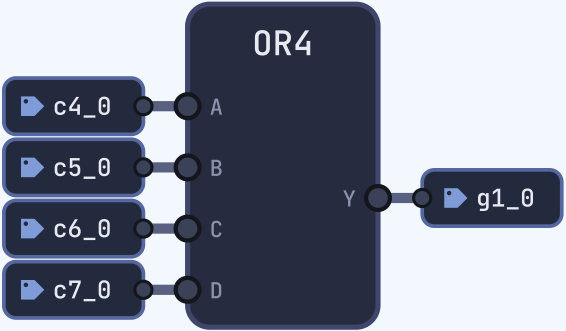
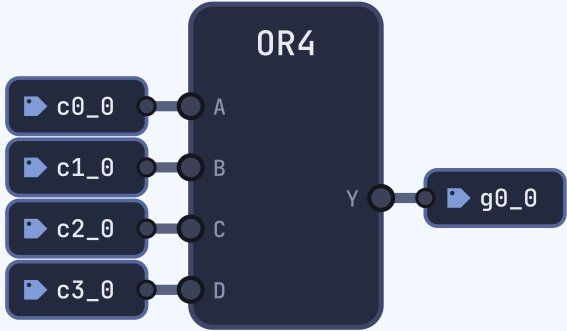
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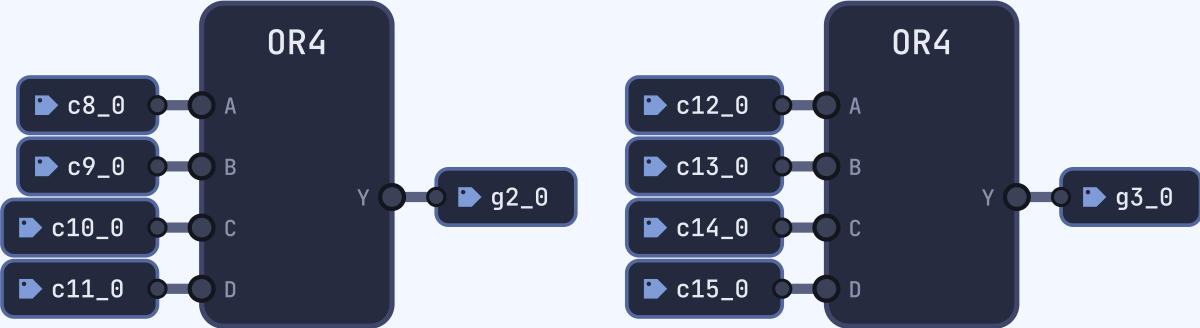
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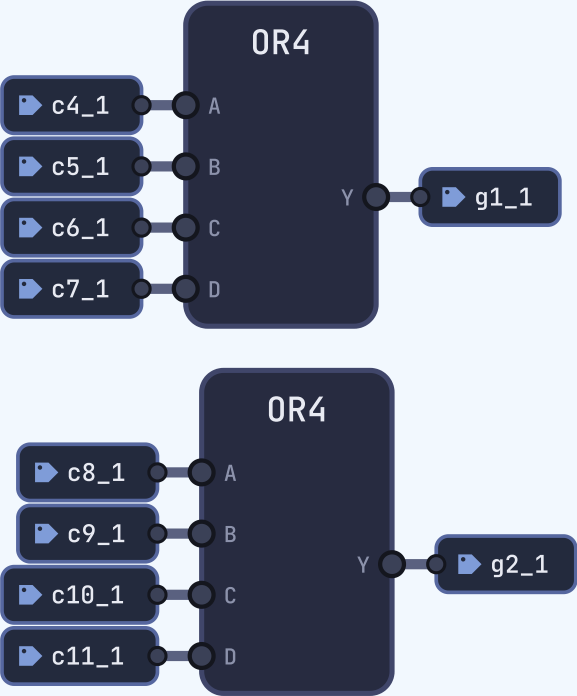
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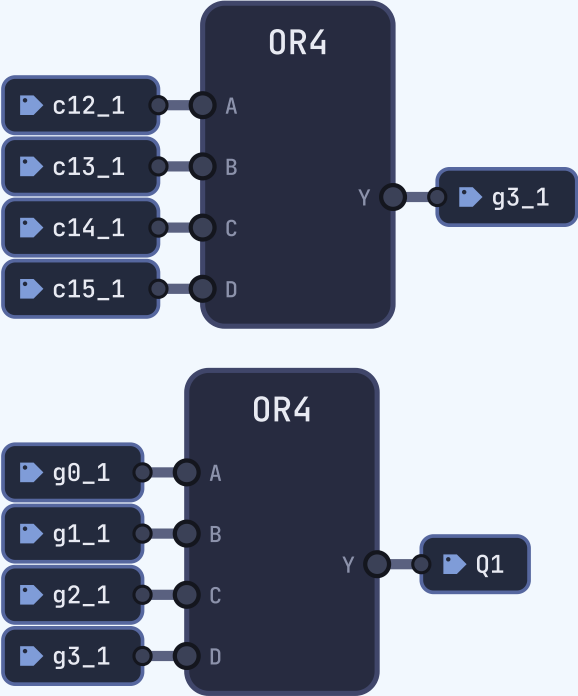
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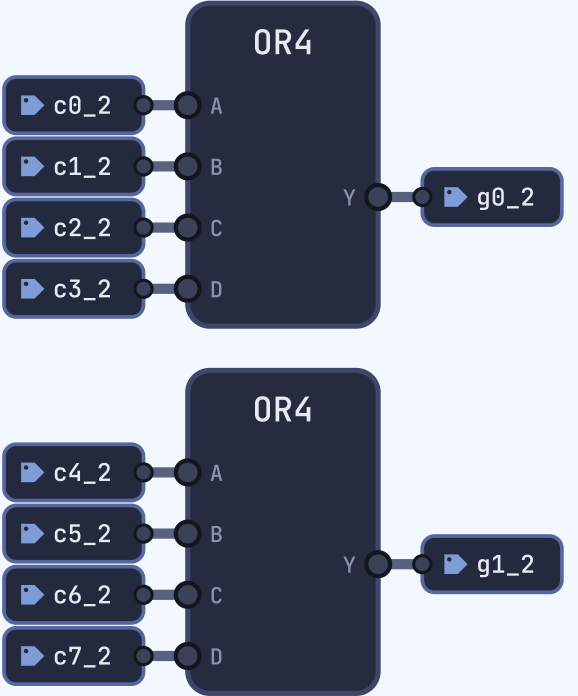
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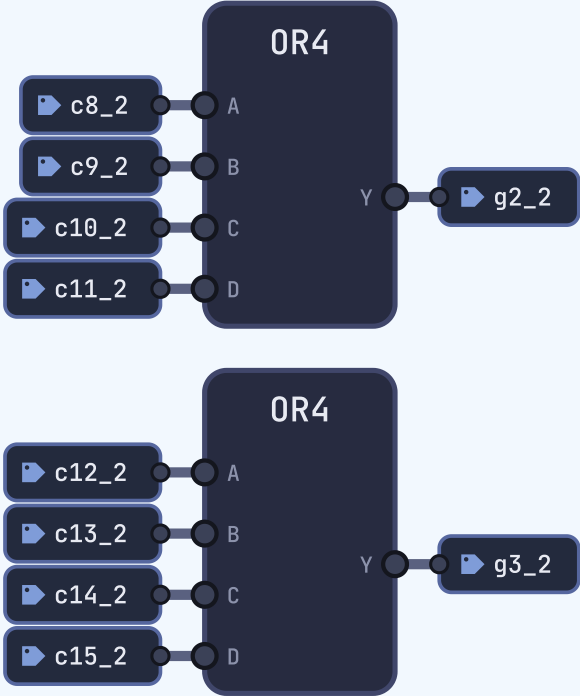
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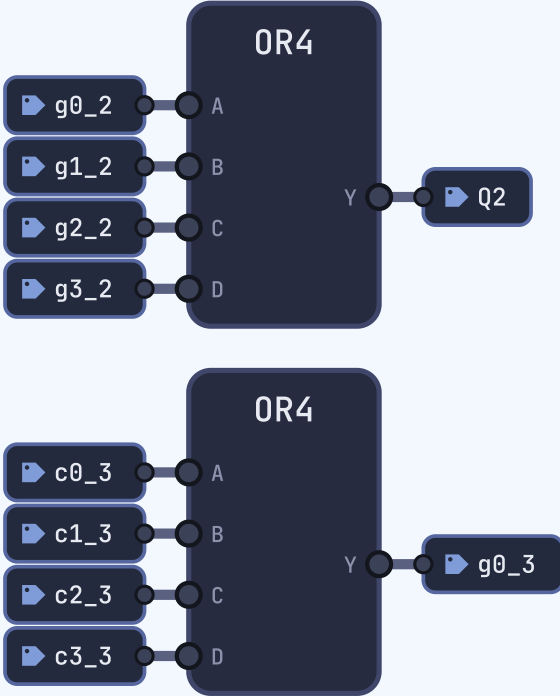
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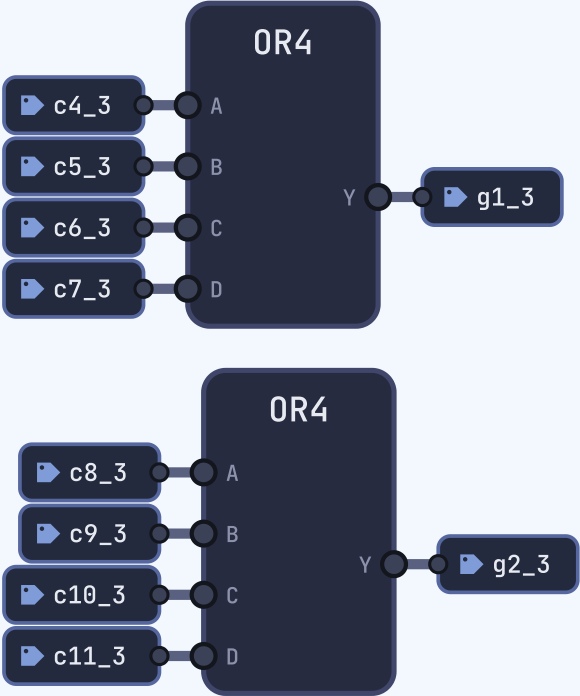
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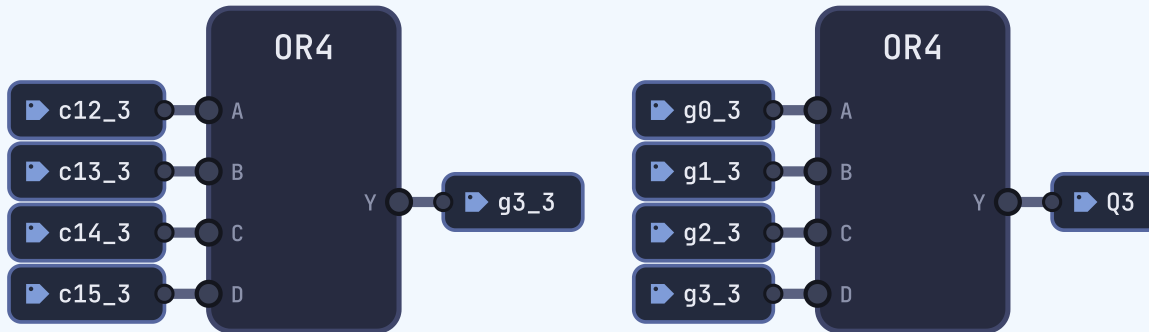


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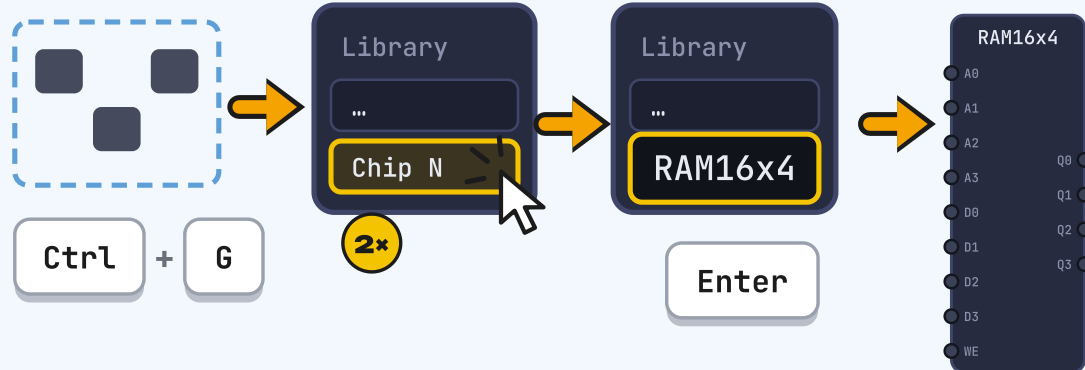


RAM16x4 ...

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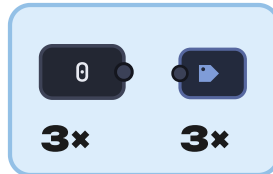
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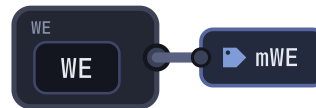
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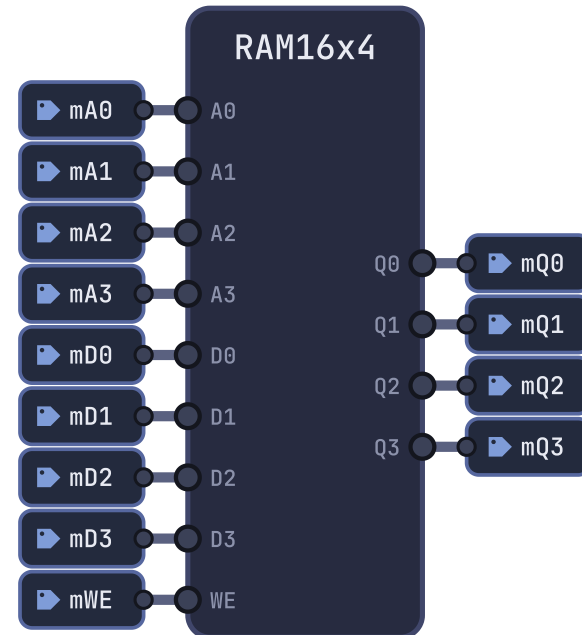
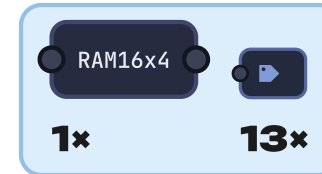
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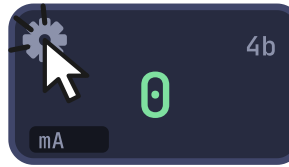


CANVAS ...

39



40



4b

8b

HEX

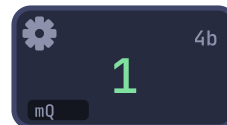
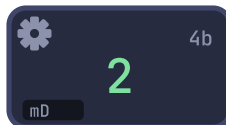
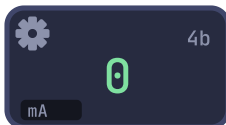
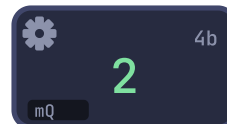
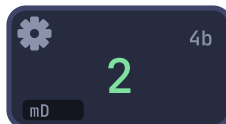
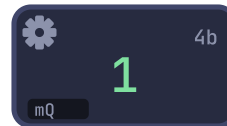
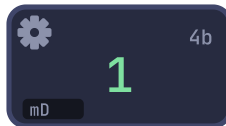
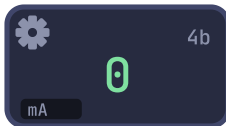
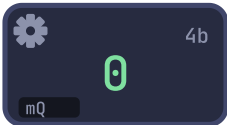
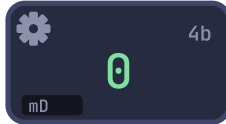
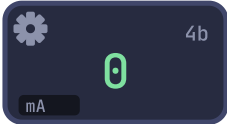
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mA

mD

mQ

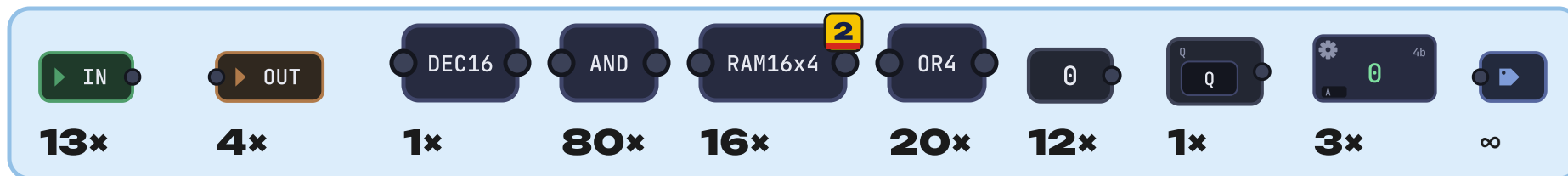
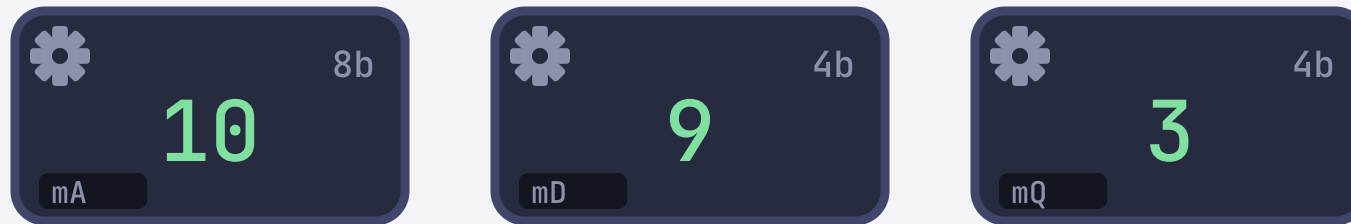
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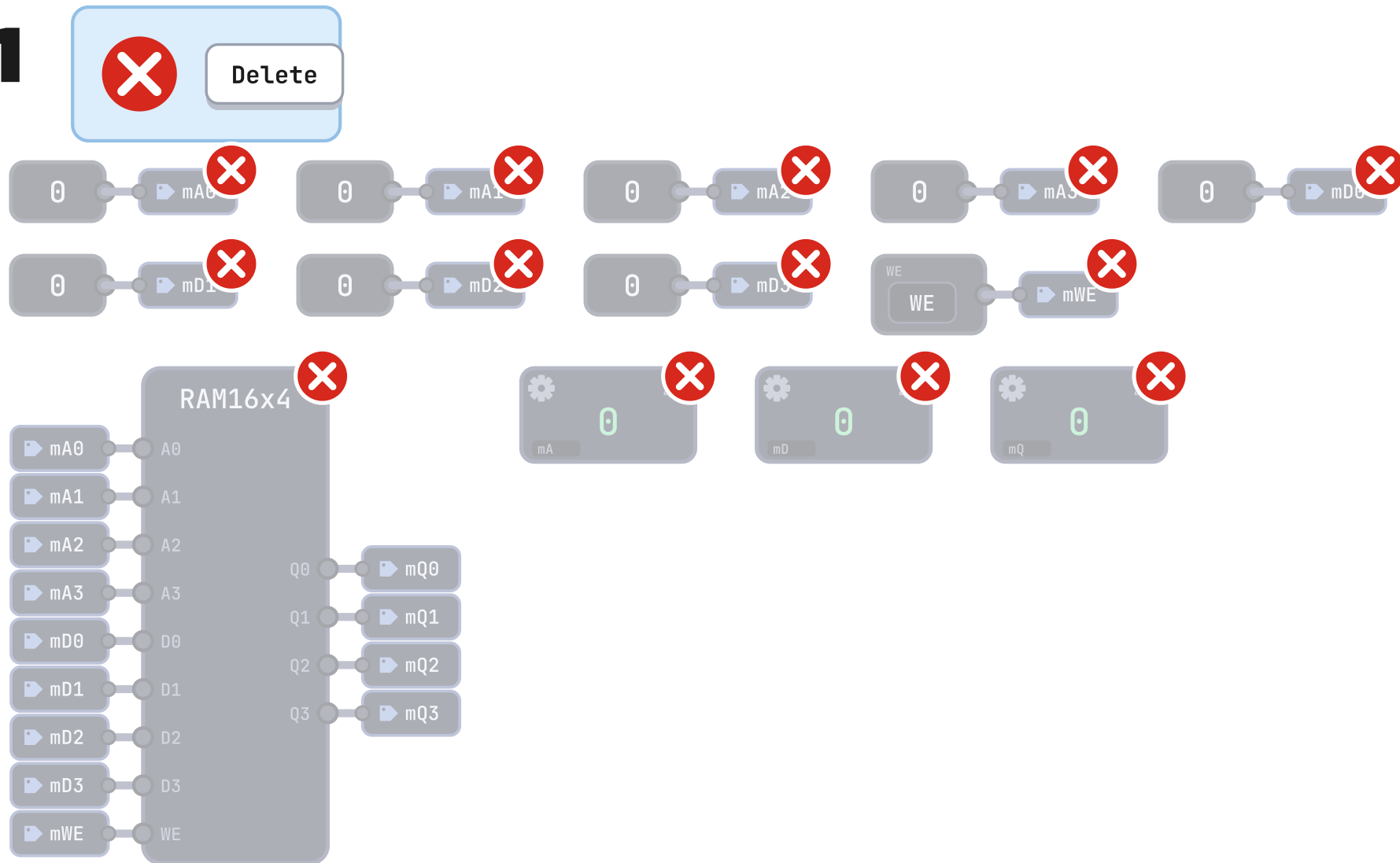


256x4 memory

the same circuit one level up: 16 blocks

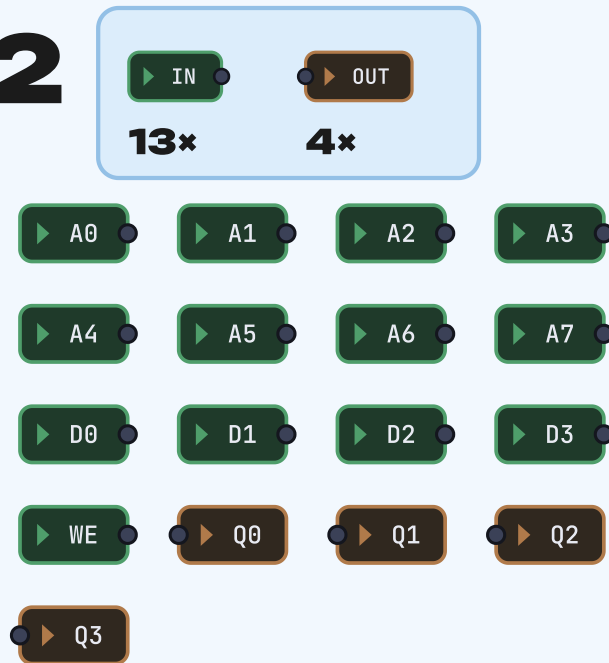


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RAM256x4

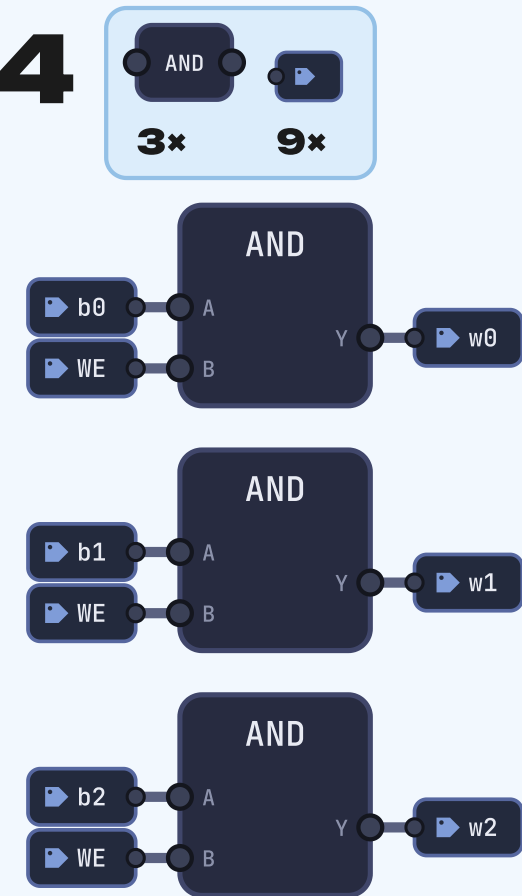
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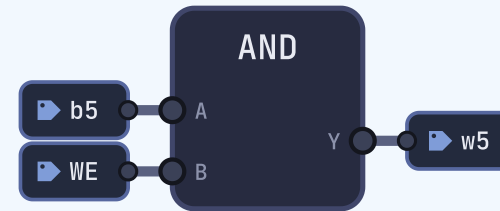
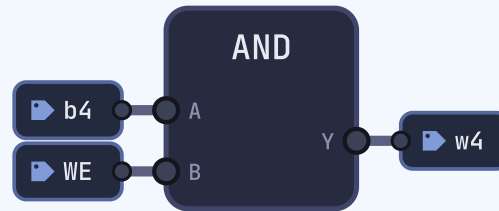
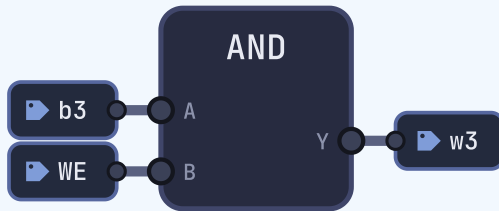


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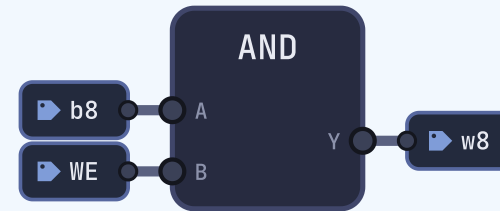
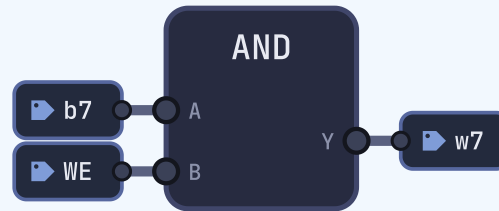
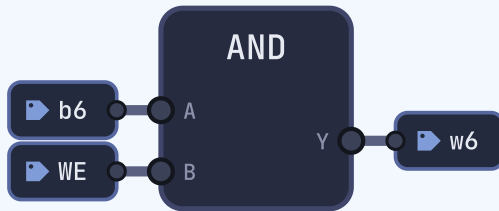
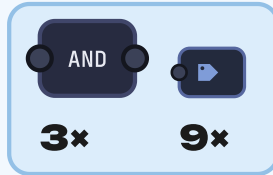


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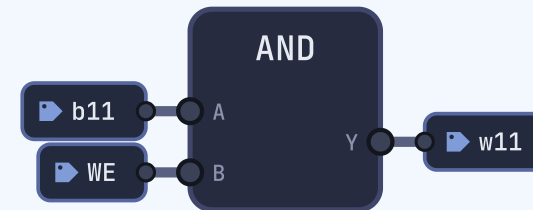
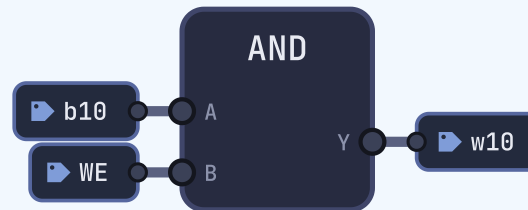
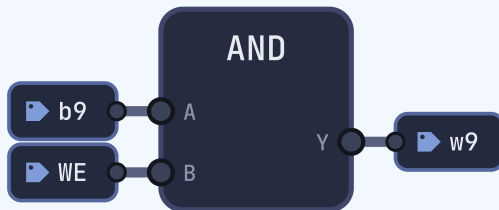
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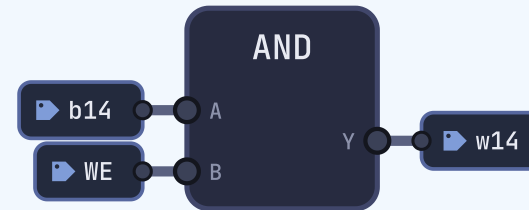
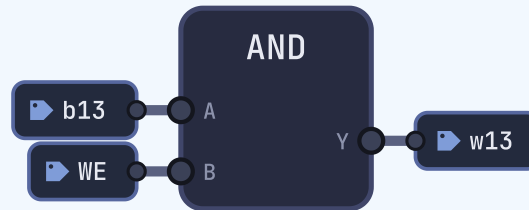
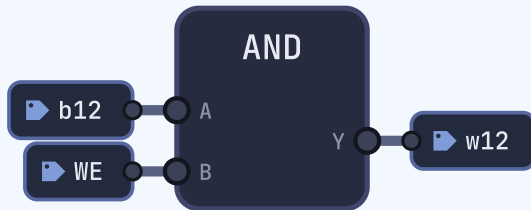


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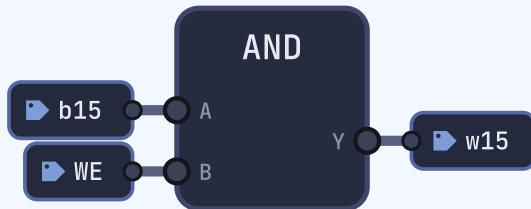
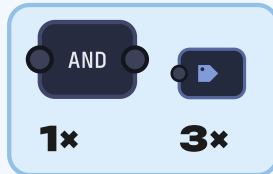


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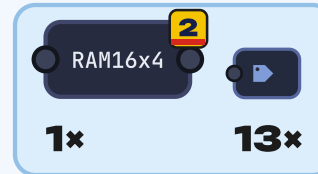
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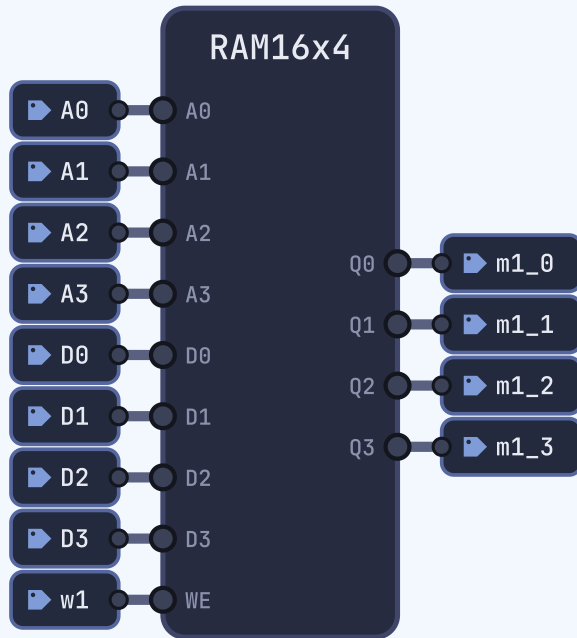
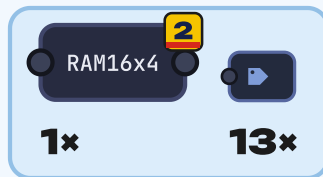


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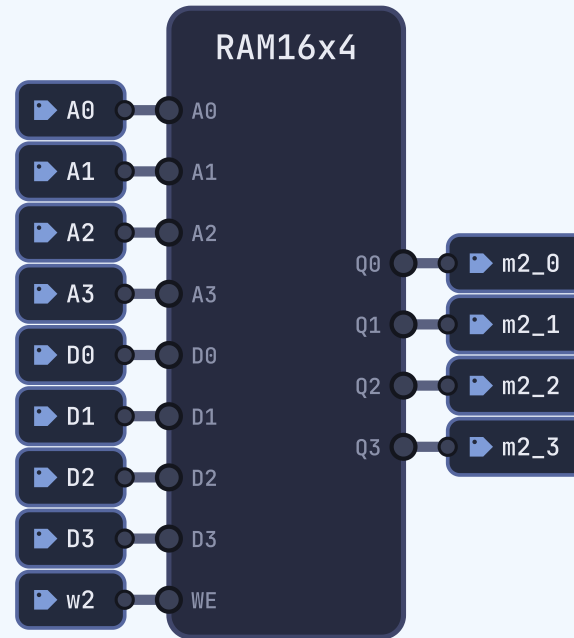
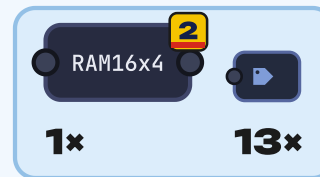


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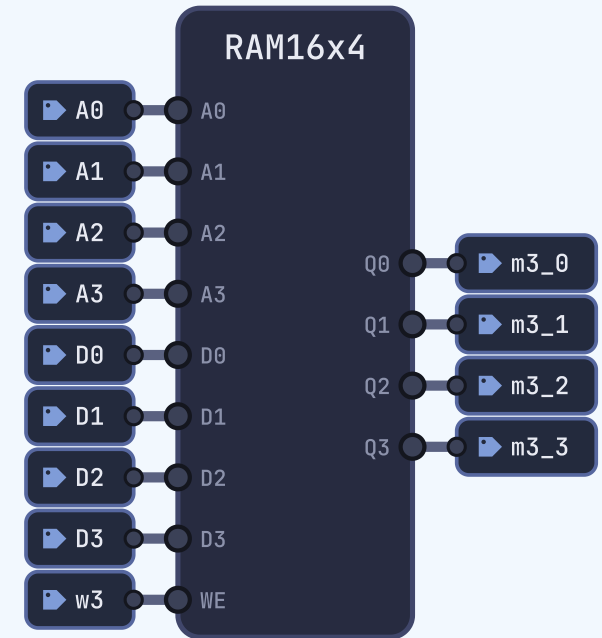
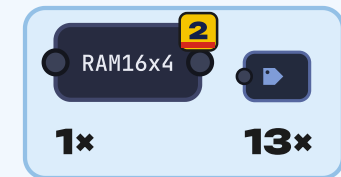
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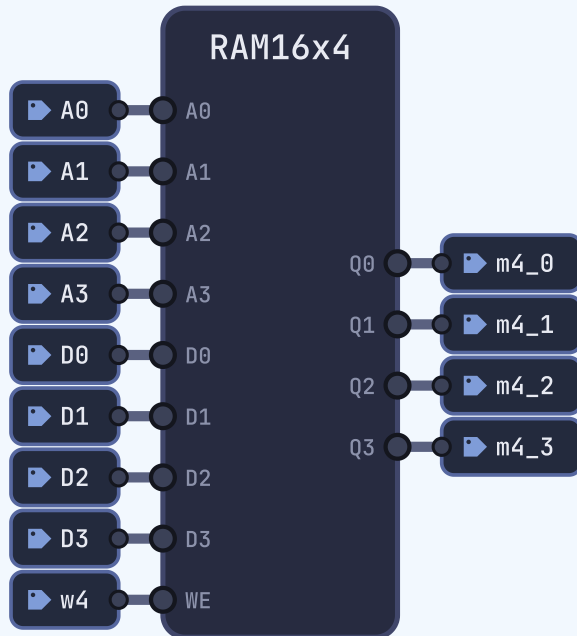
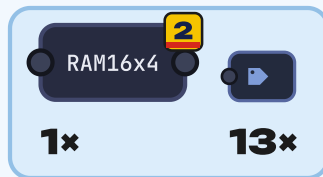


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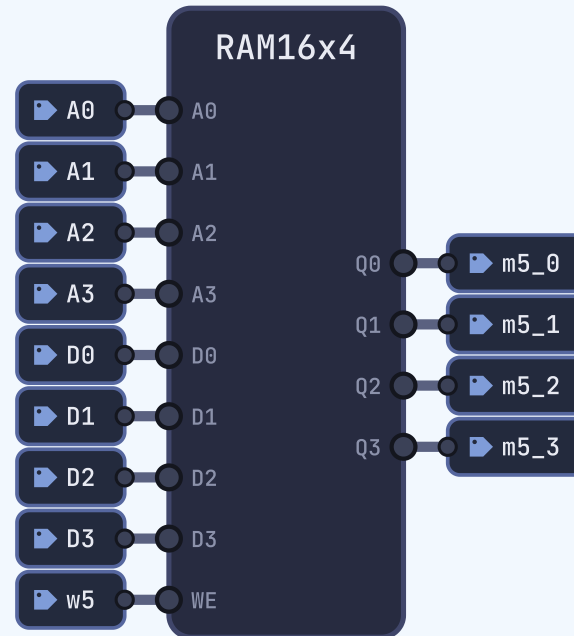
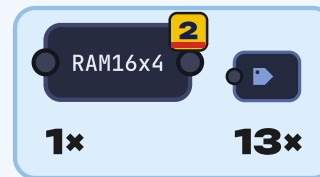


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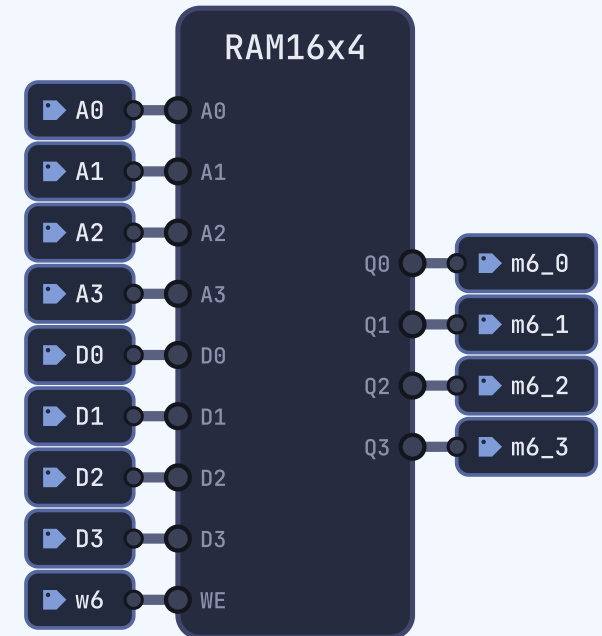
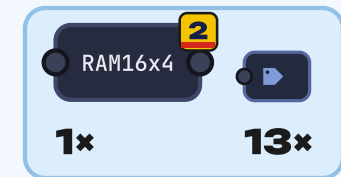
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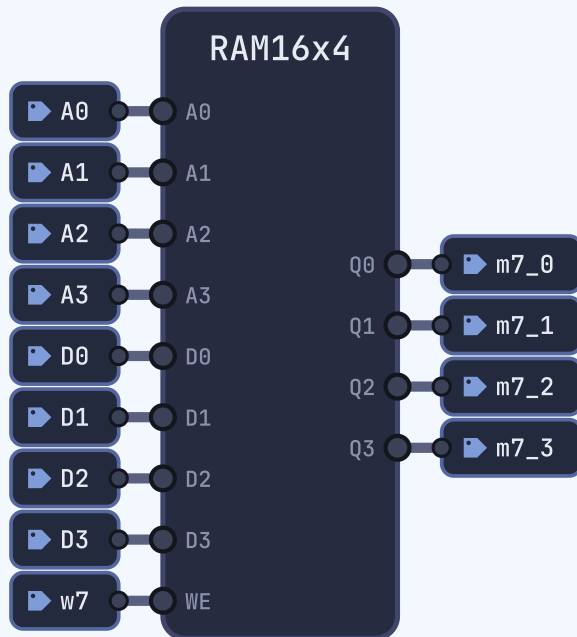
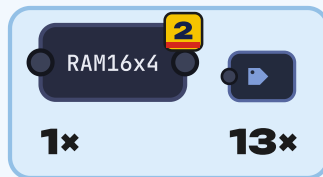


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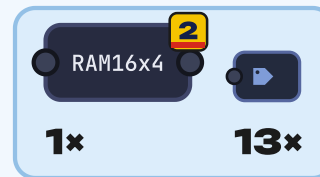


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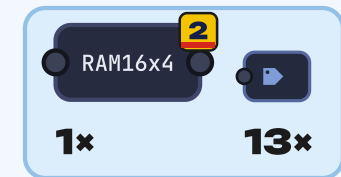
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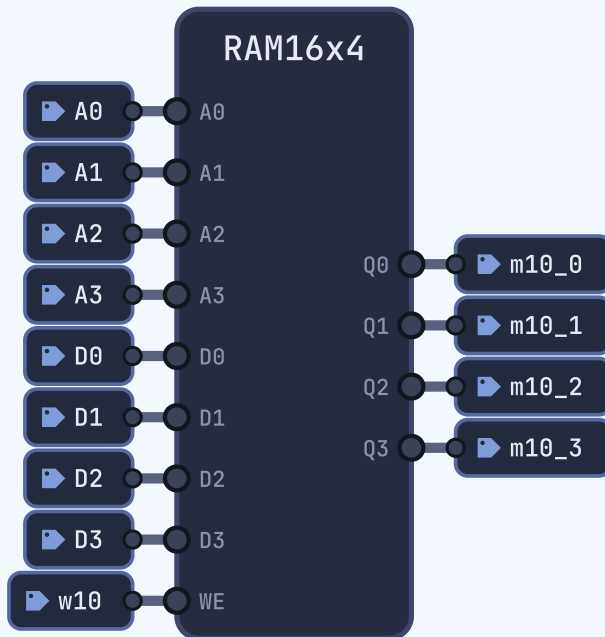
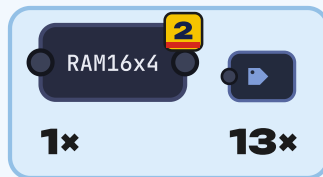


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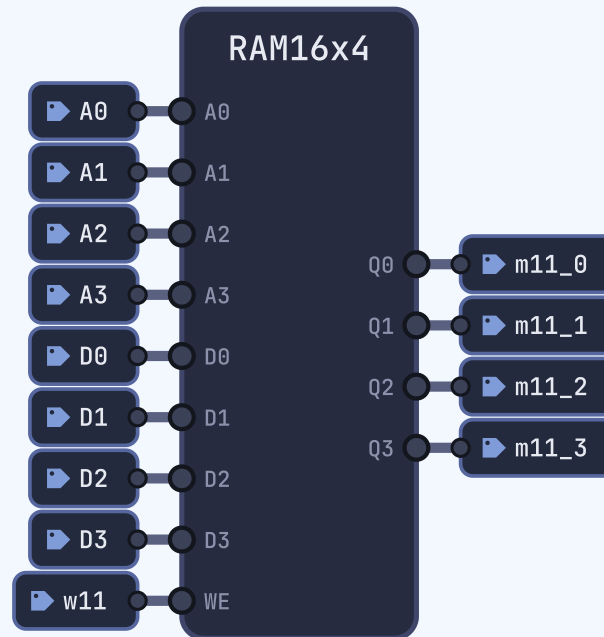
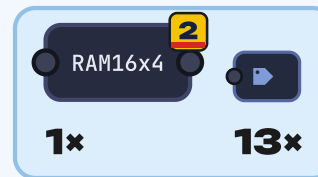


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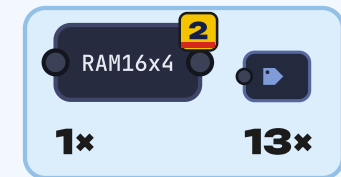
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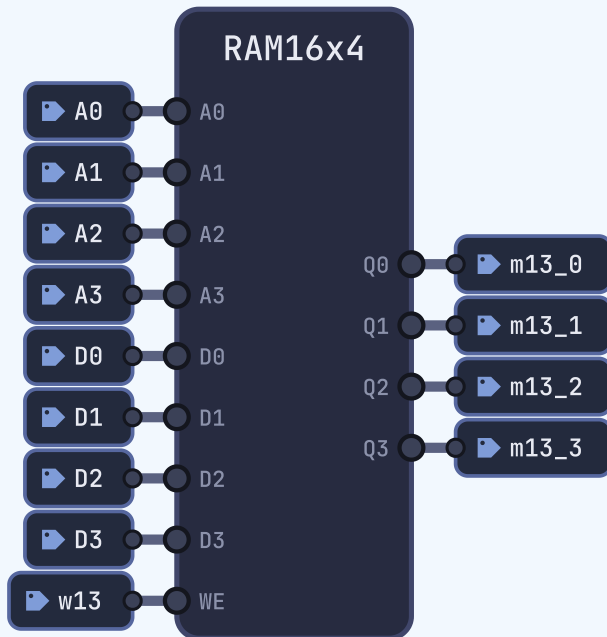
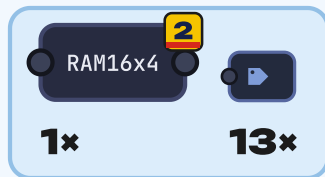


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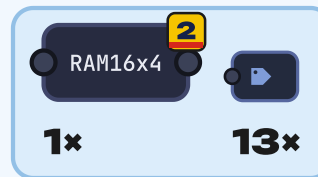


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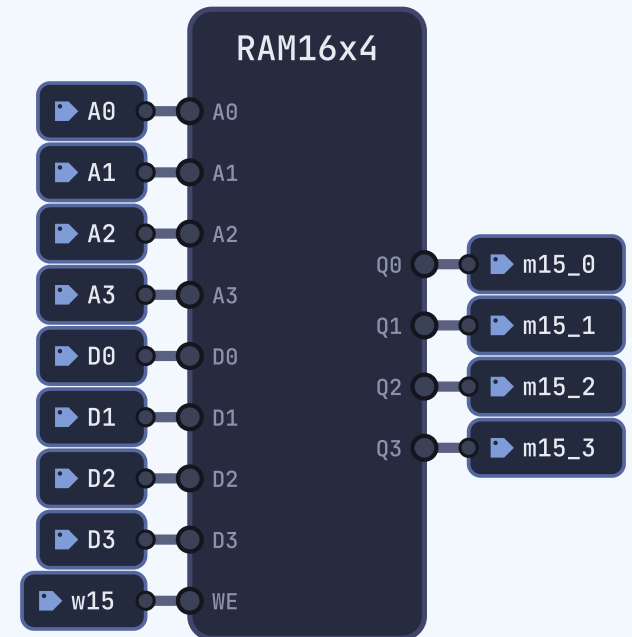
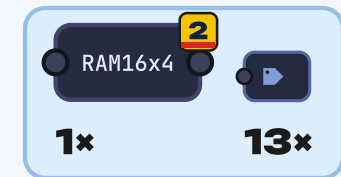
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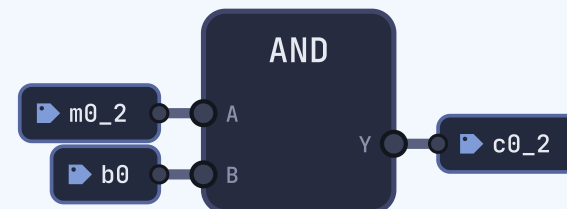
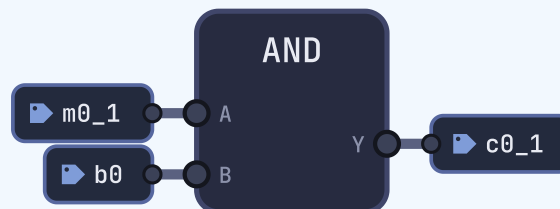
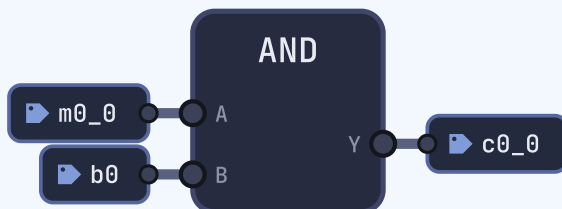
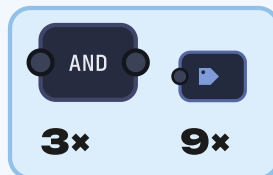
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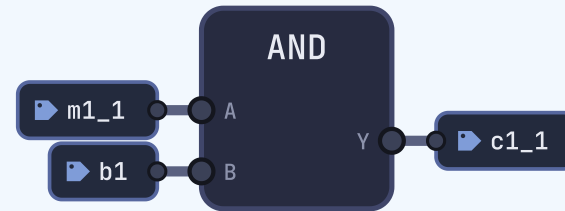
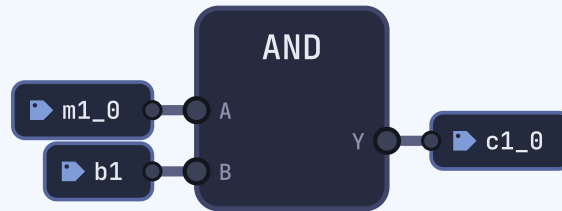
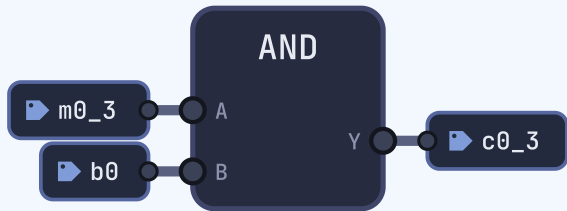
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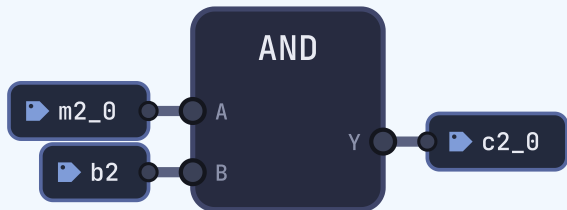
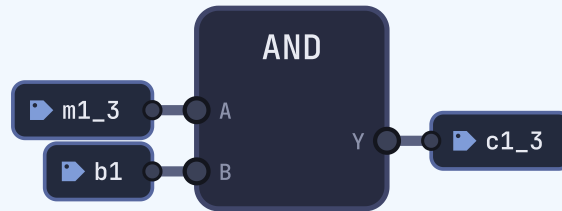
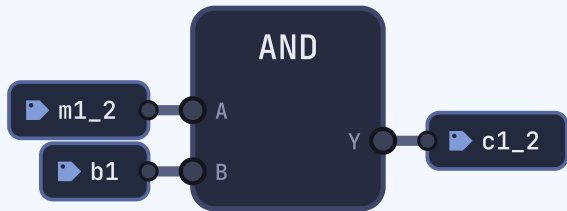
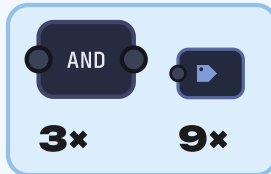
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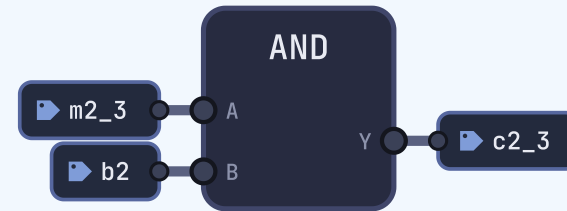
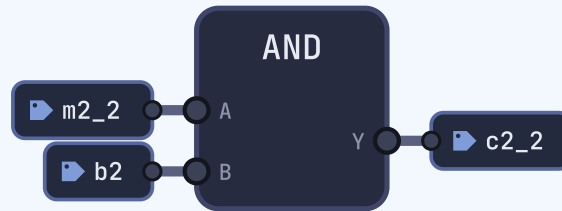
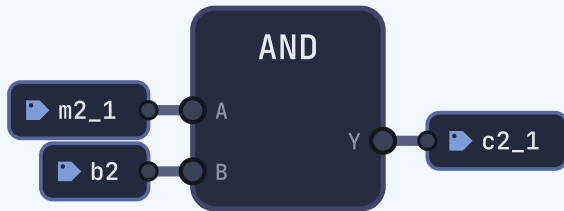
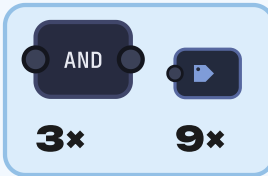
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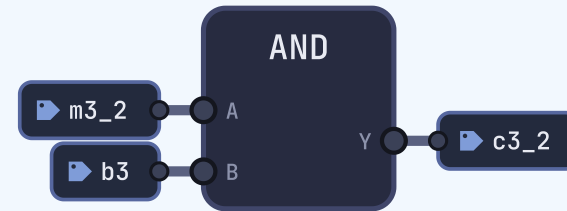
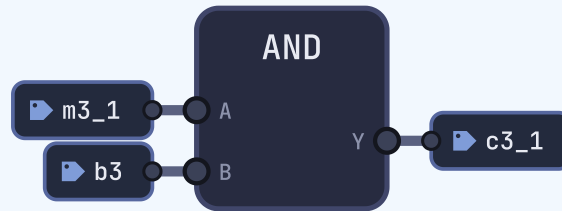
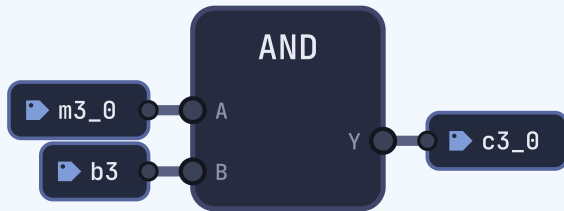
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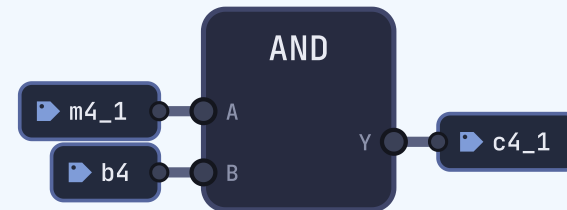
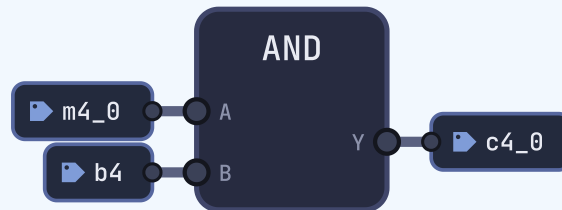
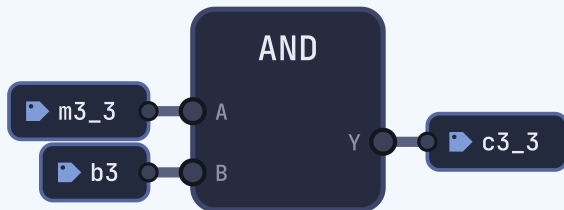
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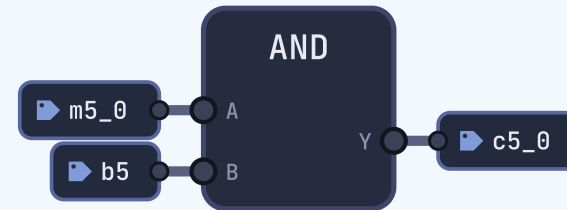
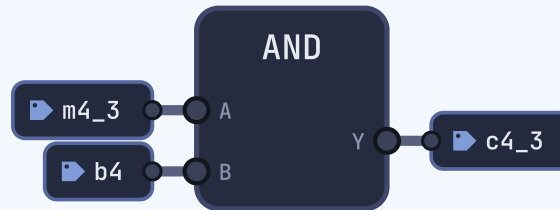
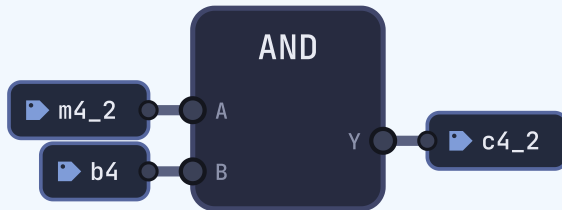
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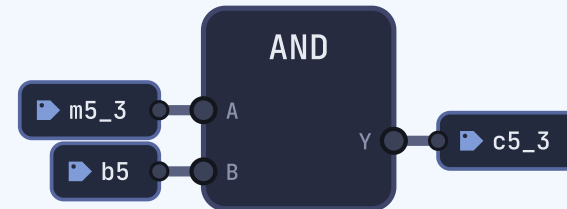
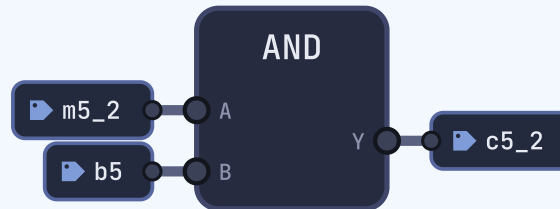
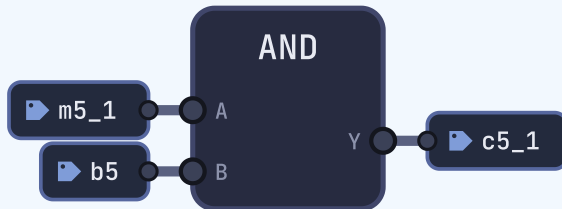
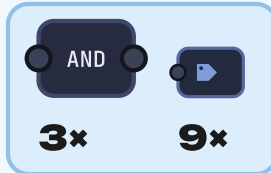
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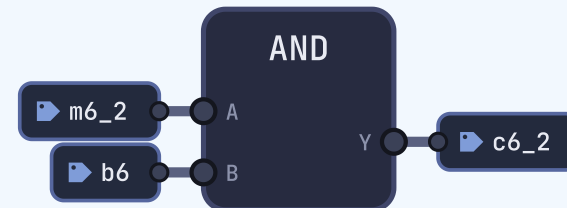
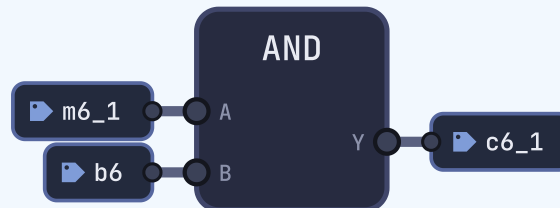
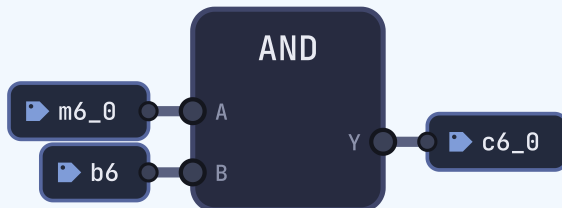
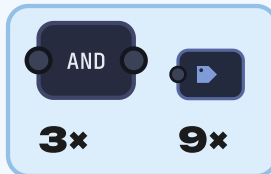
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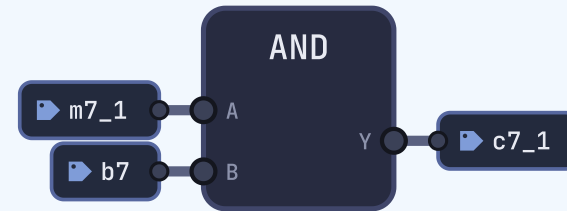
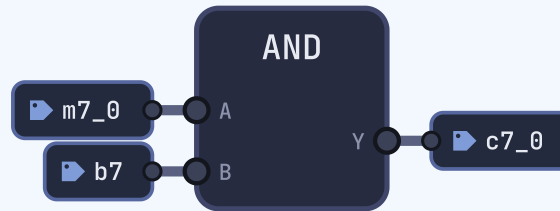
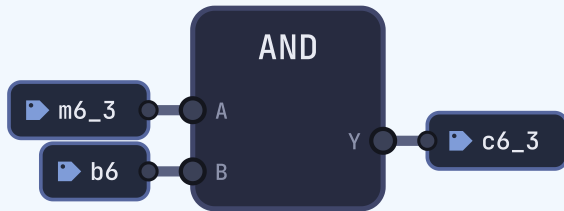
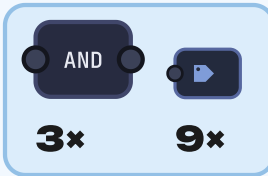
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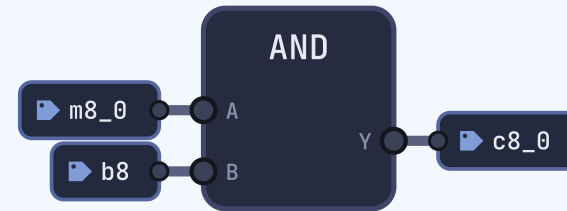
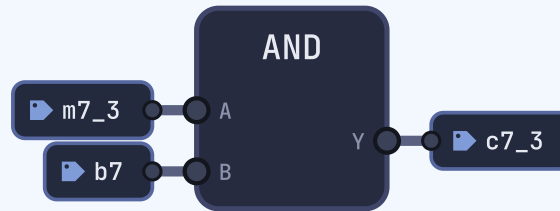
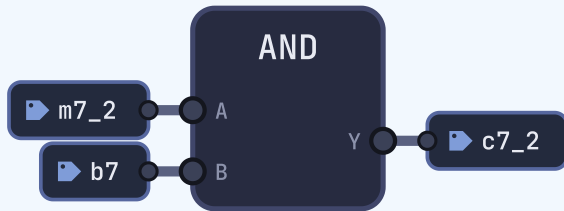
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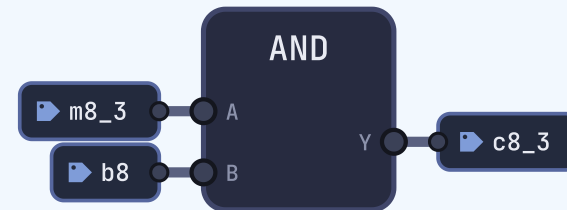
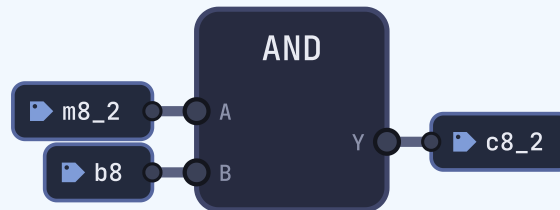
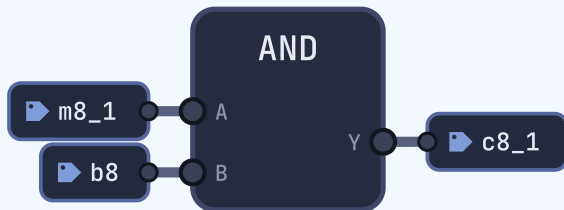
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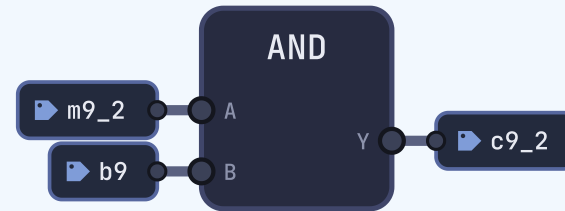
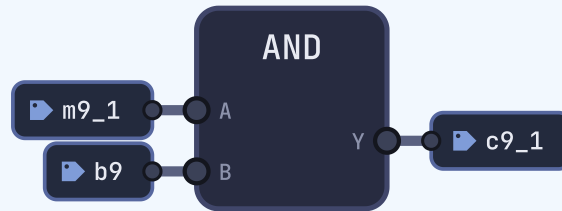
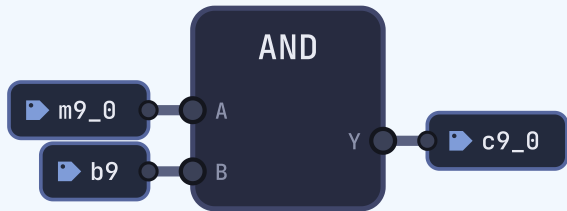
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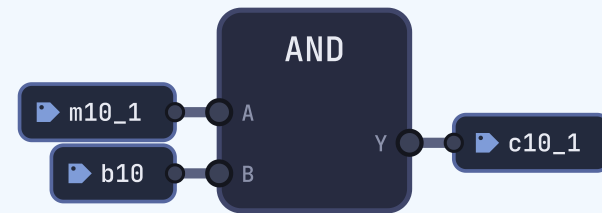
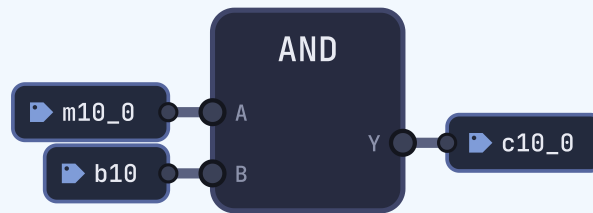
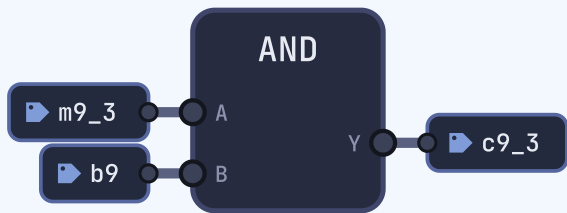
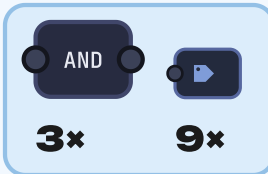
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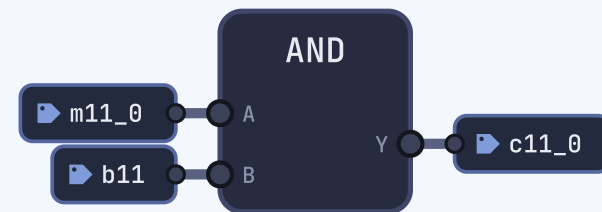
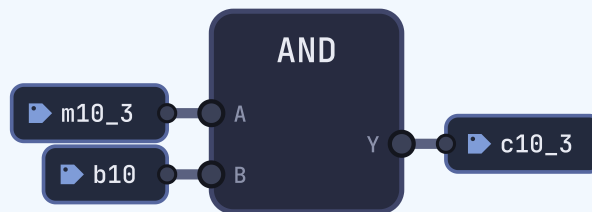
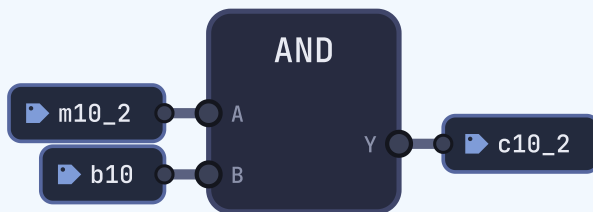
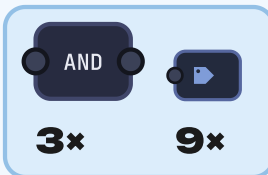
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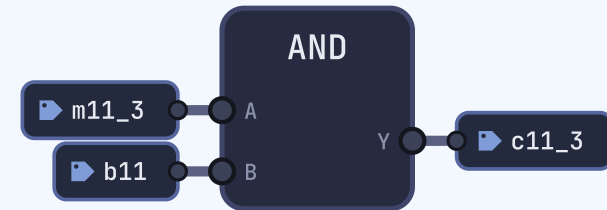
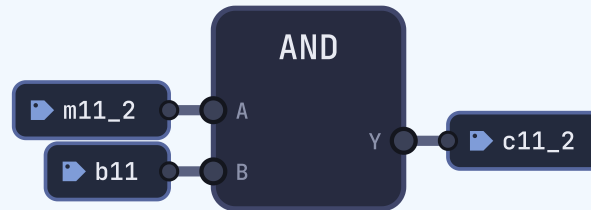
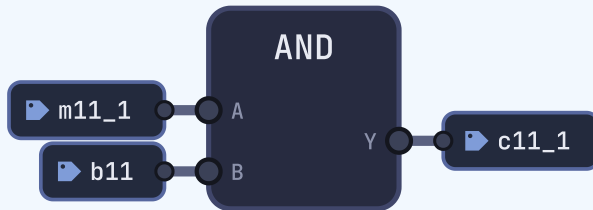
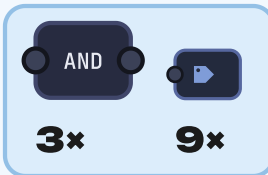
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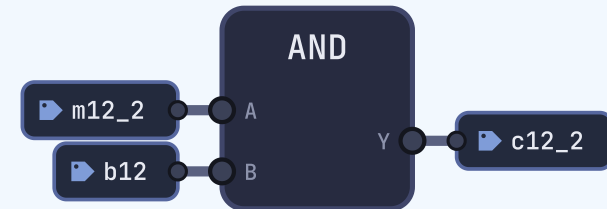
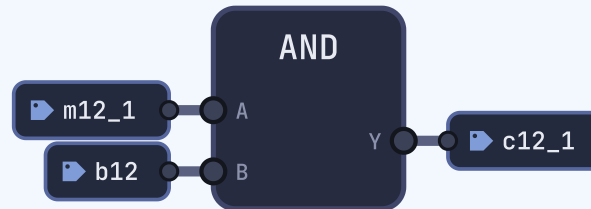
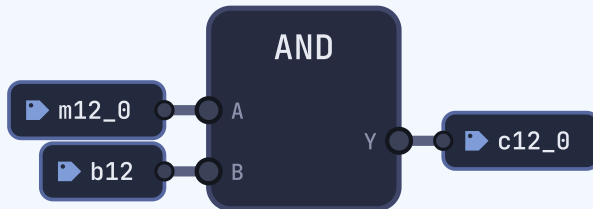
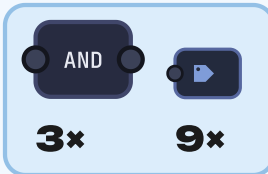
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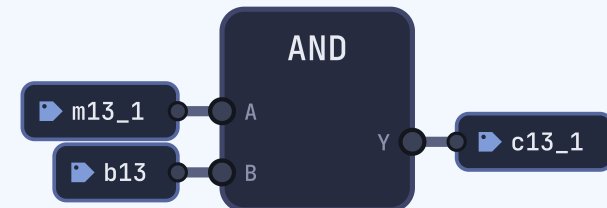
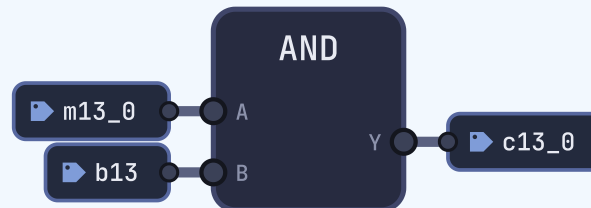
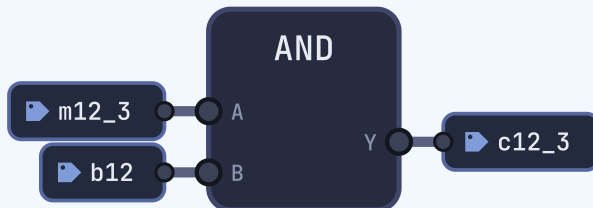
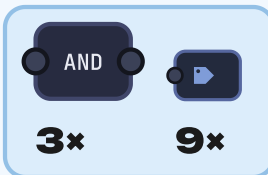
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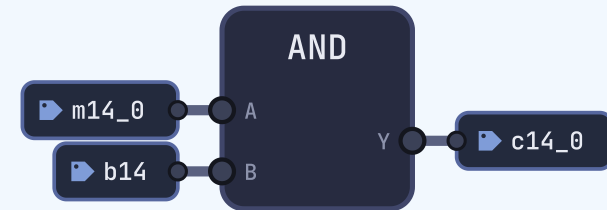
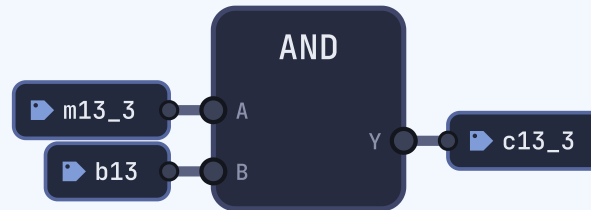
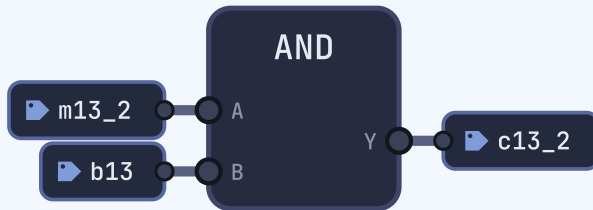
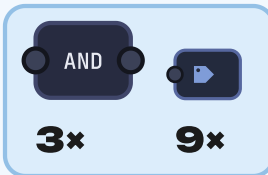
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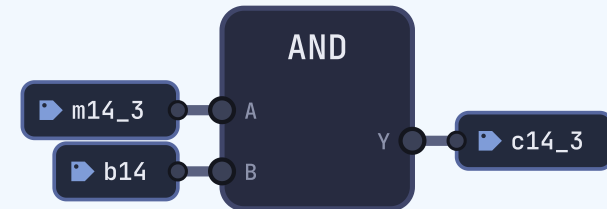
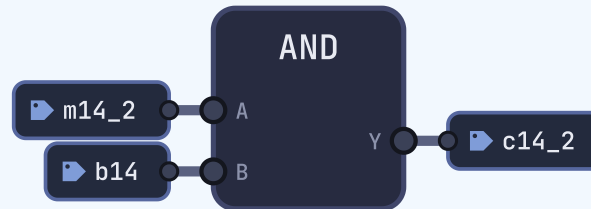
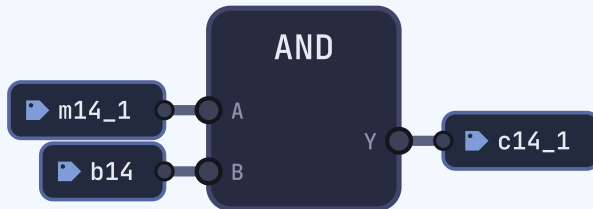
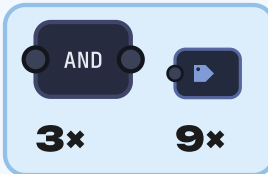
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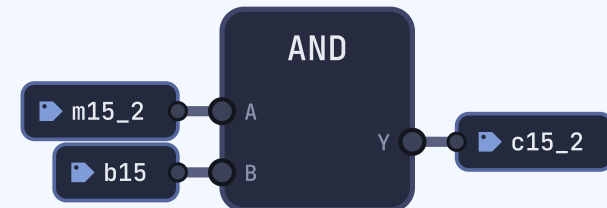
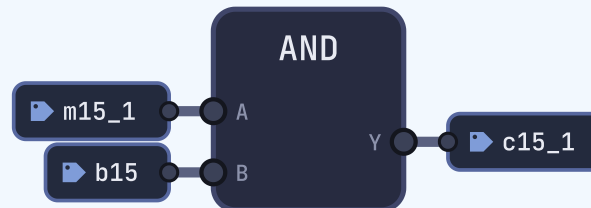
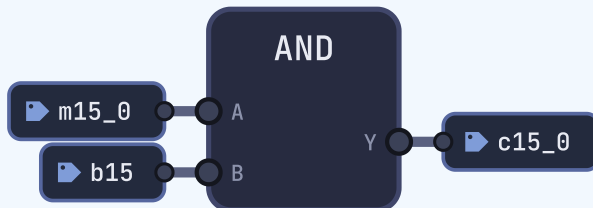
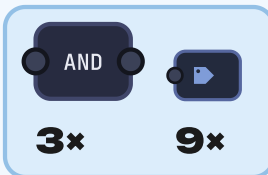
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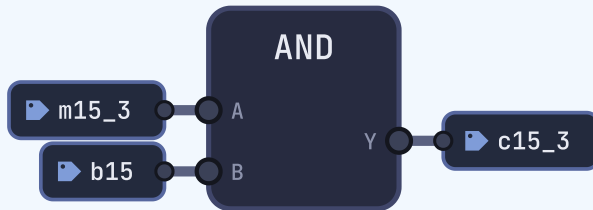
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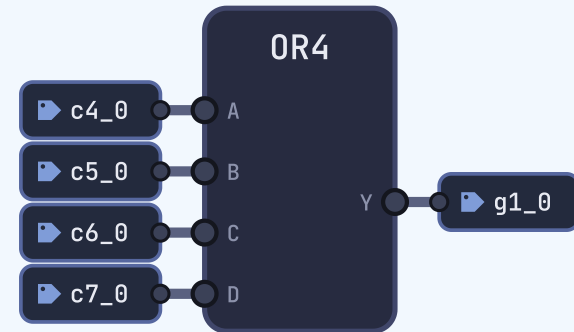
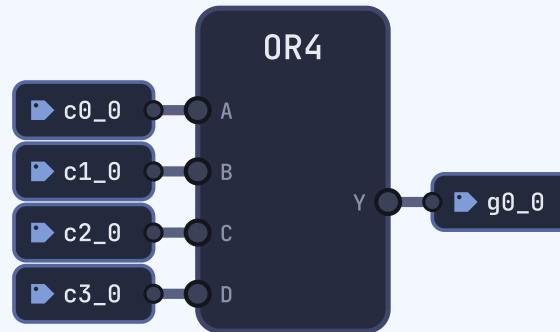
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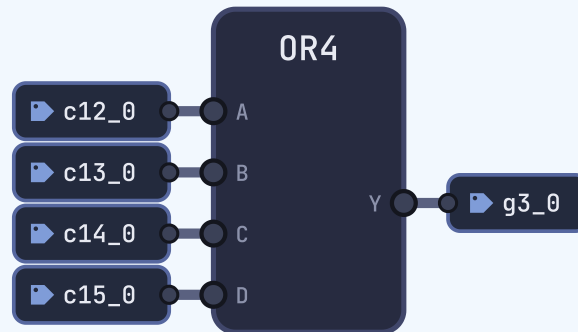
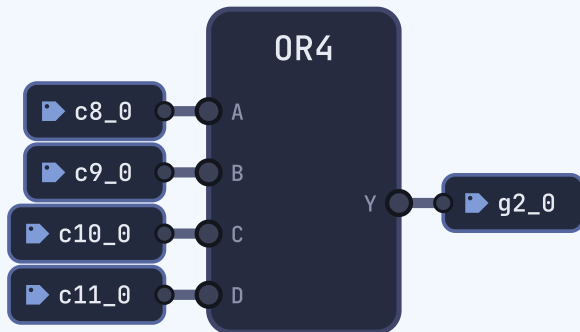
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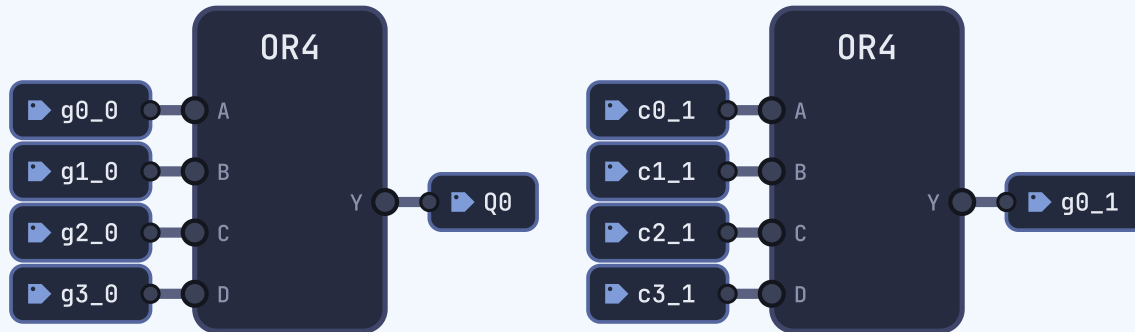
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49



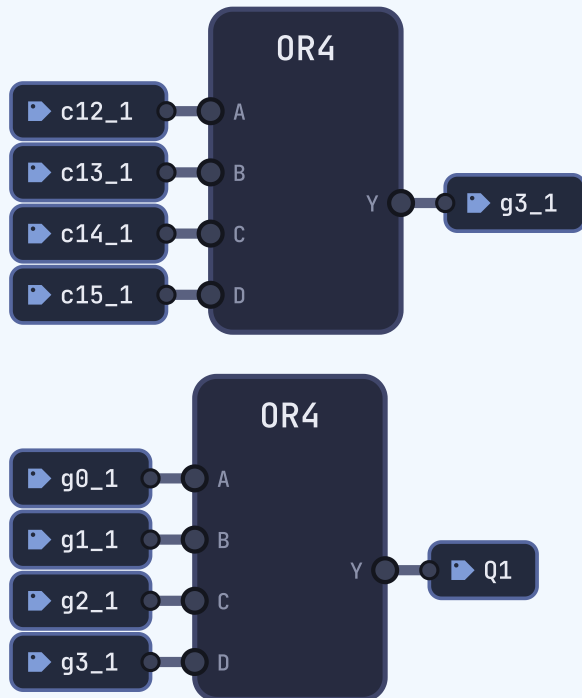
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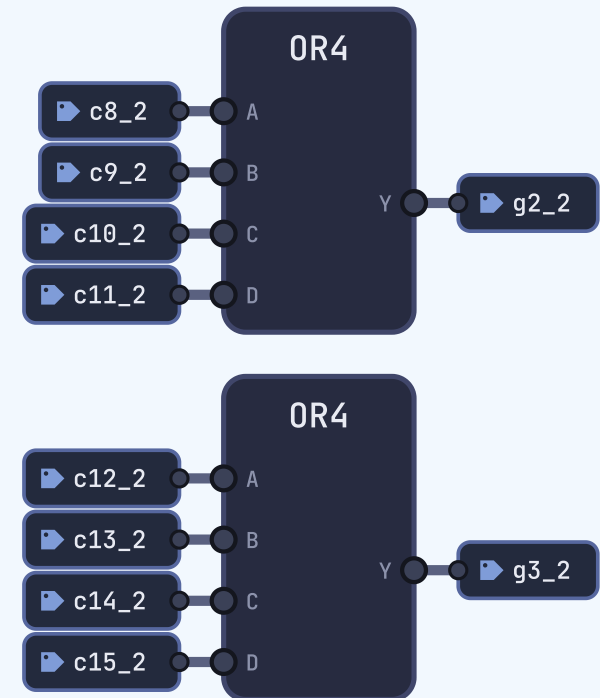
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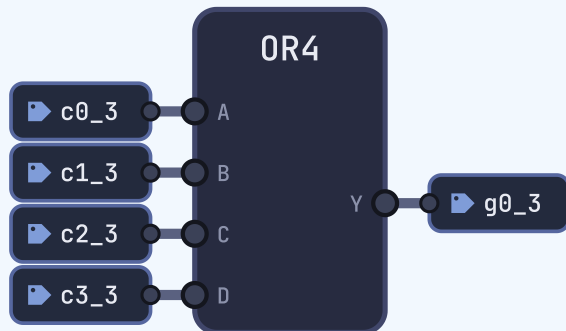
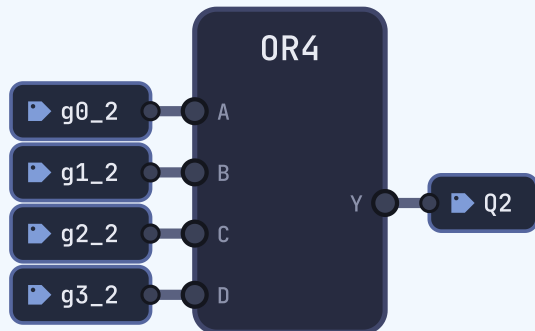
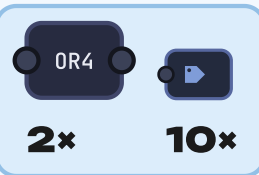
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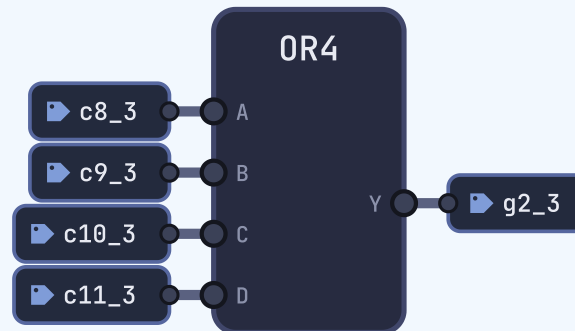
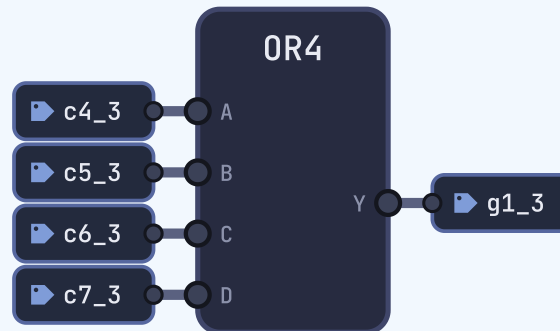
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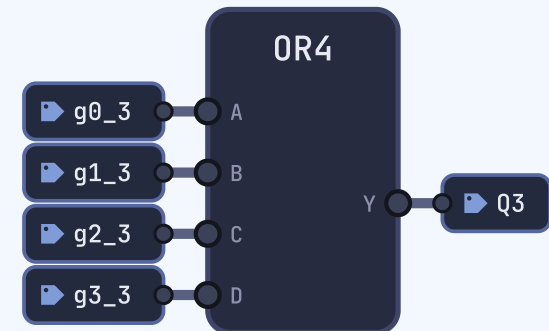
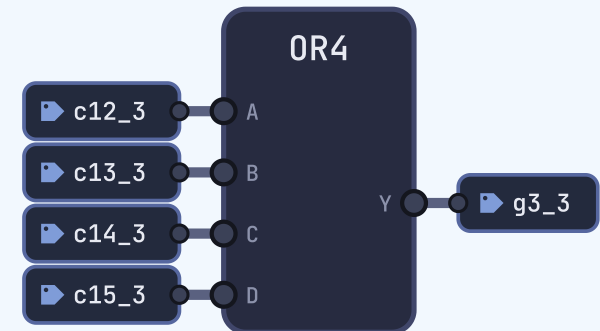
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56

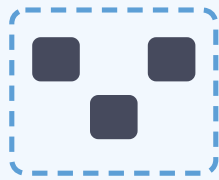


57



RAM256x4 ...

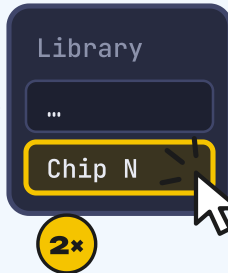
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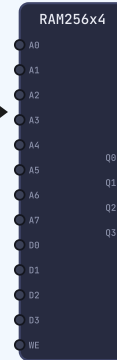
Ctrl

+

G

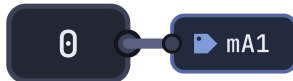


Enter



CANVAS

59



60



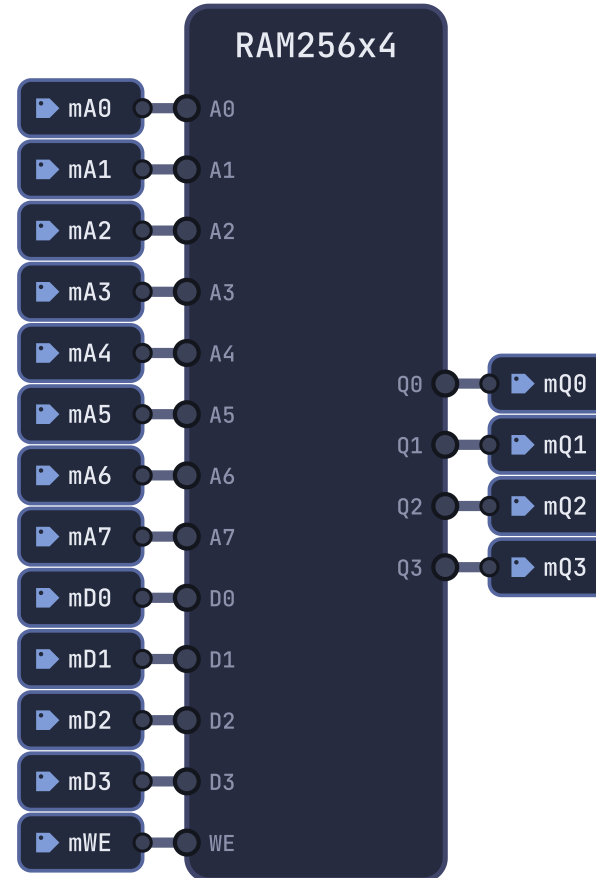
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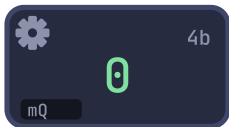
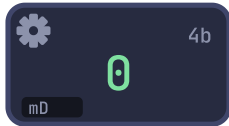
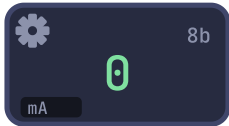
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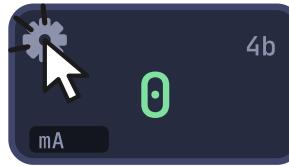
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64

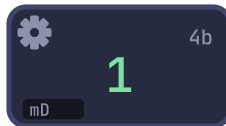
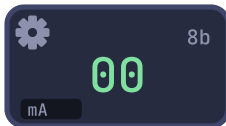


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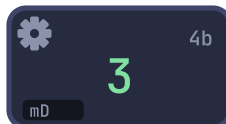
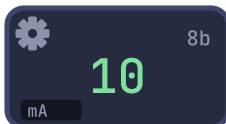
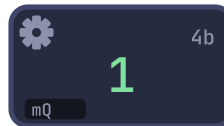


gear > 4b 8b HEX

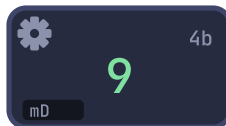
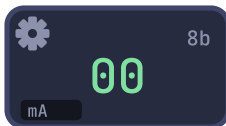
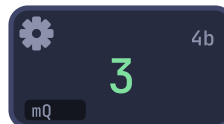
PIN > mA mD mQ Enter



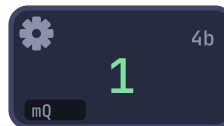
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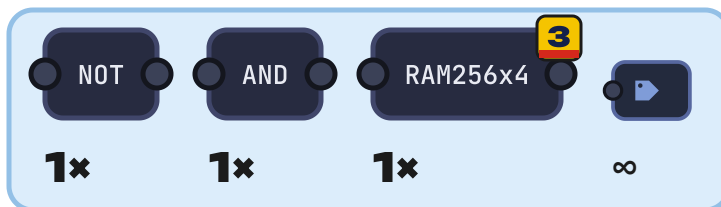
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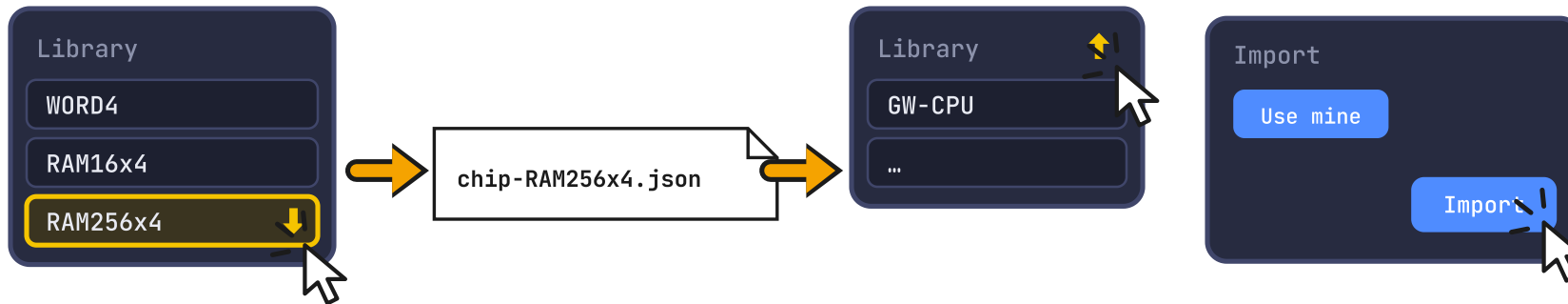
Our memory in the processor

put RAM256x4 into GW-CPU – and catch the bug



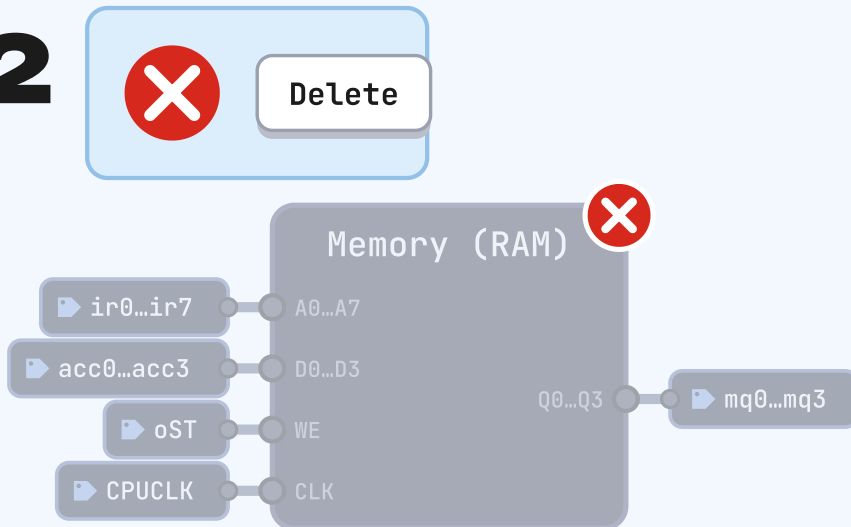
CANVAS

1



GW-CPU

2



3

NOT

1x

AND

1x

RAM256x4

1x

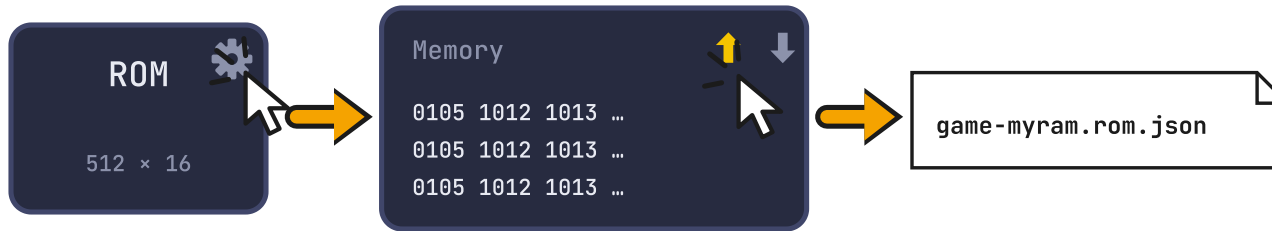
3

22x

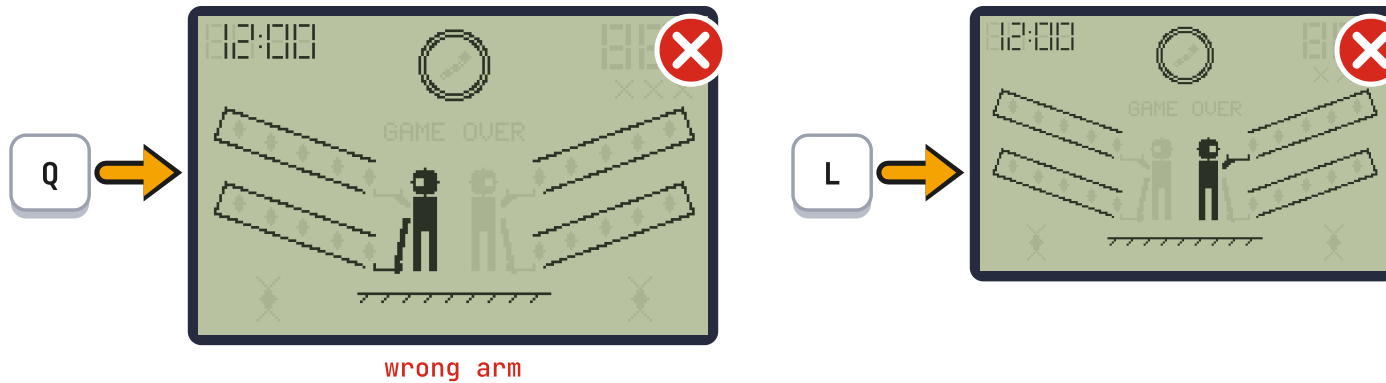


CANVAS

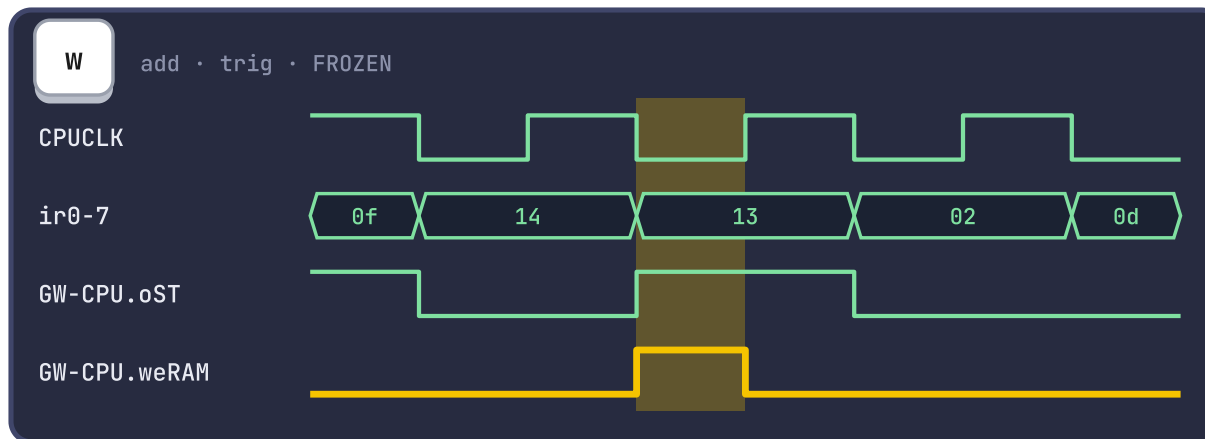
4



Fast



5



the address changed and the window opened in one slice

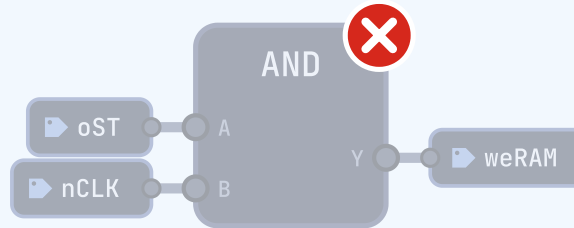
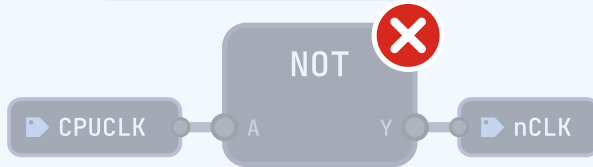


Two-phase clock

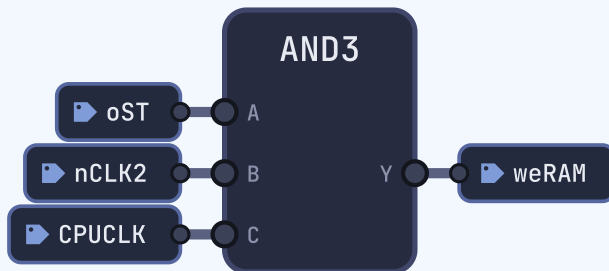
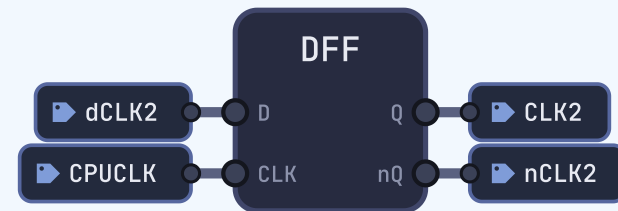
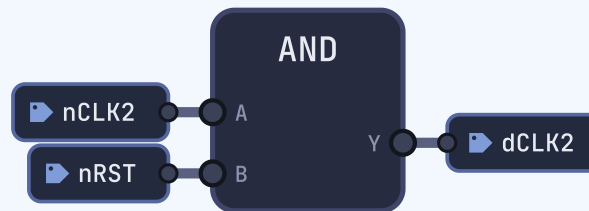
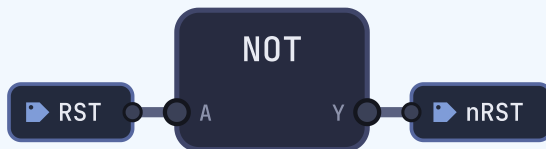
divide by 2 and a write window: the game works



1

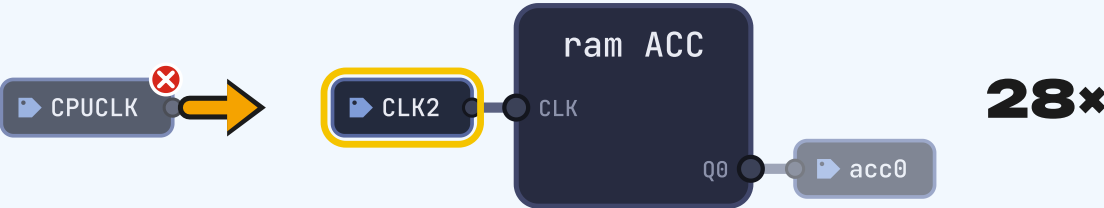


2



3

on all 28 registers, pin CLK: label CPUCLK → CLK2

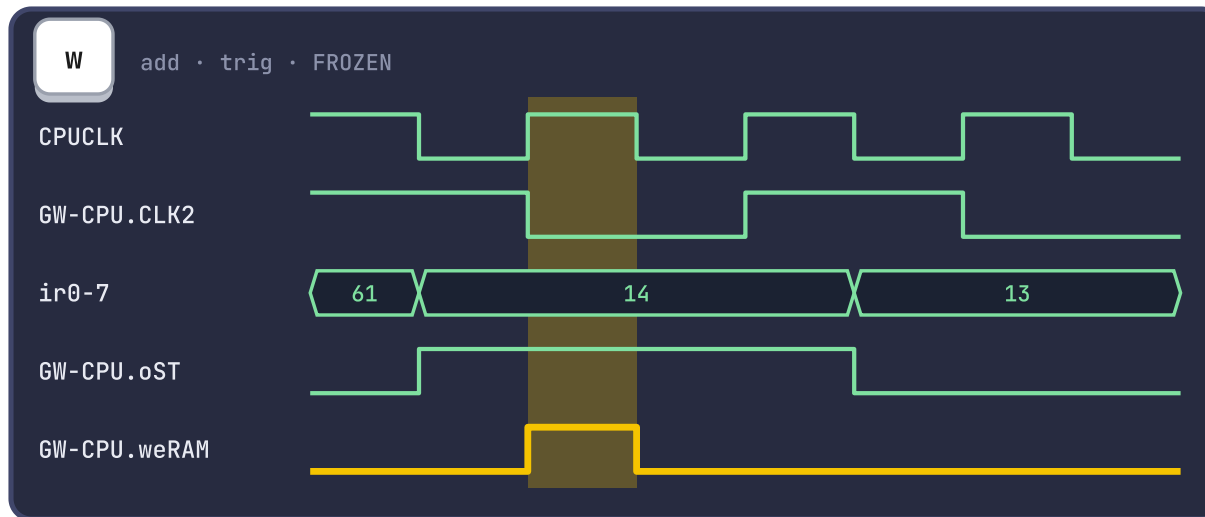


ACC	FZ	FC	PC	PH	PT	P
HT	H	MT	M	STK	STATE	T0
T0HI	T1	T1HI	T2	T2HI	T3	T3HI
ARMS	BODY	MISS	OVER	FALL	COMET	LEVEL

⚠ don't rename this one: cut the wire and place a new label



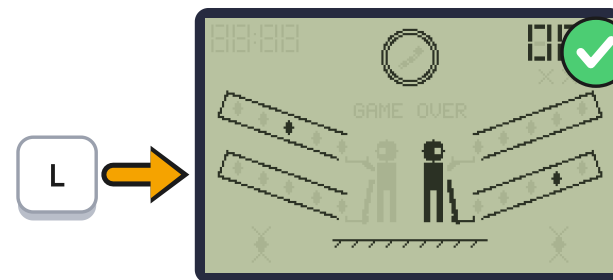
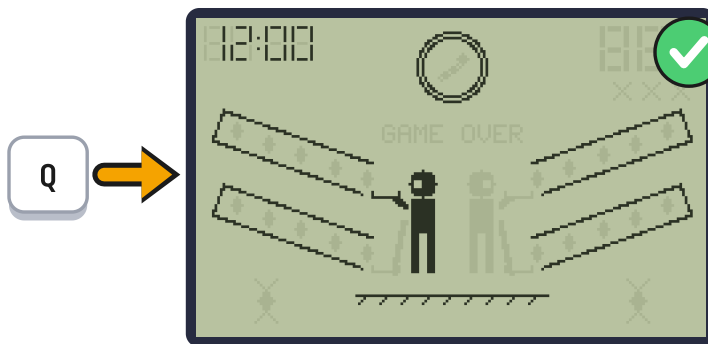
4



the window comes a slice after the address and closes early



Fast



Kit parts

how many times you place each part over all the lessons



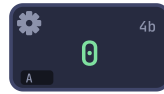
1x



1x



25x



8x



3x



28x



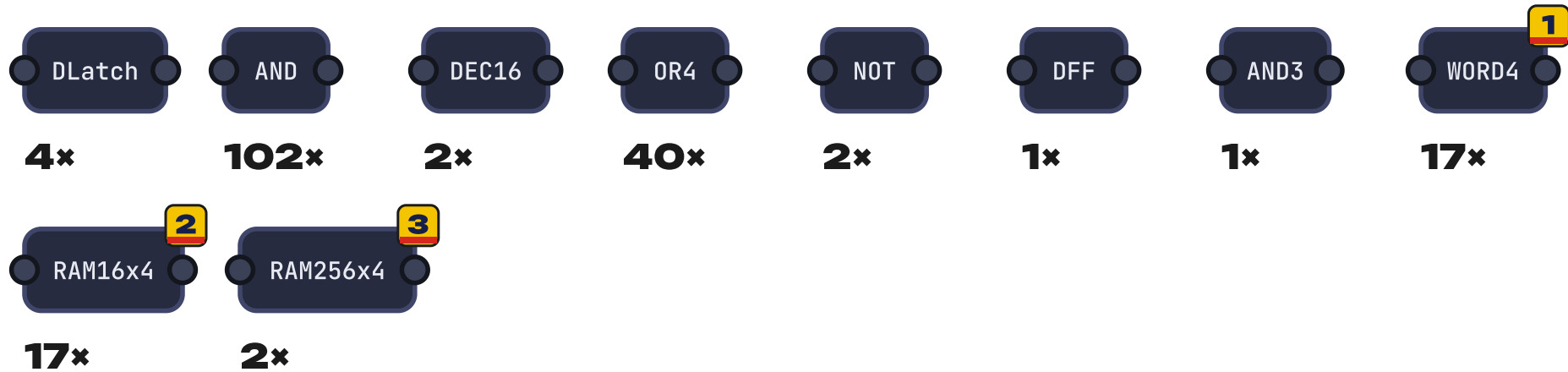
12x



1025x

Kit chips

this kit's chips carry a lesson number; without one – from earlier kits



Done!



the game runs on memory you built yourself: 1,024 bits, 41,840 transistors

Q / A – left pipes, P / L – right pipes, space – new game

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GW-03