



HARDWARE BASICS

build kits · khanin.info

Building instructions

HB-03

The Fractal Machine

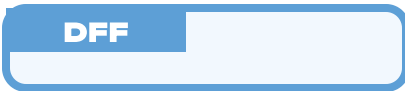
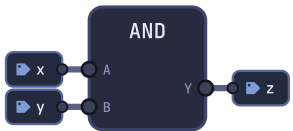
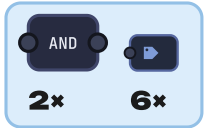
lessons 0-6 · a circuit that draws fractals



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

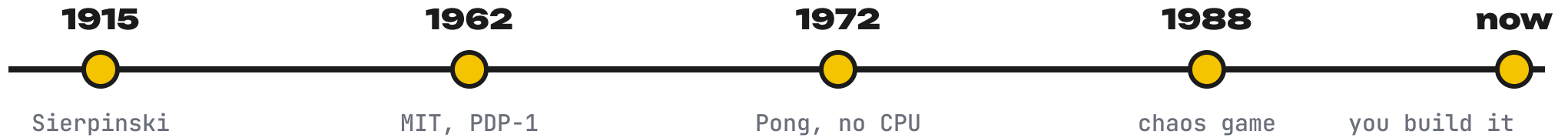
Keys

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



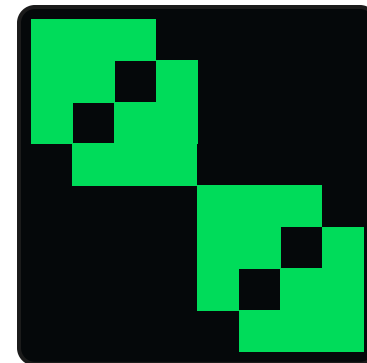
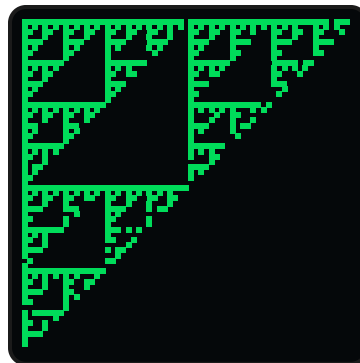
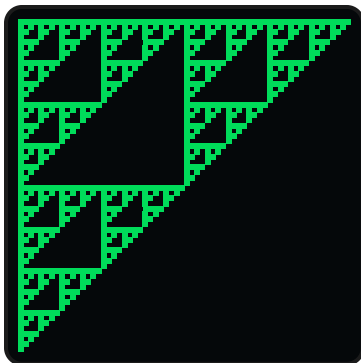
A little history



In 1915 Waclaw Sierpiński described a figure: cut the middle out of a triangle, then out of the three that remain, and so on forever. A part looks like the whole – such figures would be called fractals.

The first arcade machines – Pong, Breakout – had no processor: raster counters ran across the screen, and logic at every dot decided whether it should be lit. Our machine works the same way.

In 1962 at MIT a few lines on the PDP-1 brought the Munching Squares pattern to life: $(x \text{ XOR } y) < t$. And in 1988 Barnsley showed the chaos game: random steps draw a triangle and a fern.



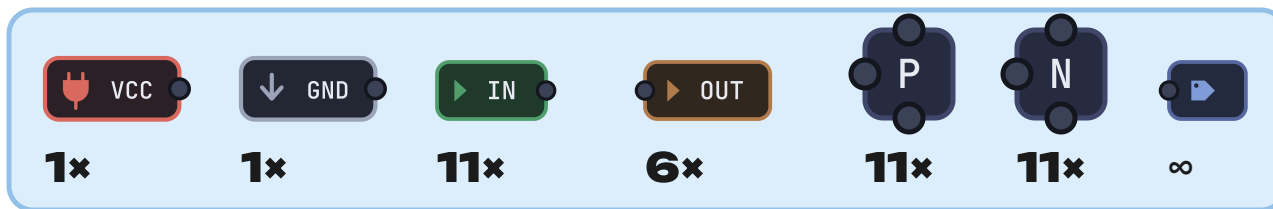
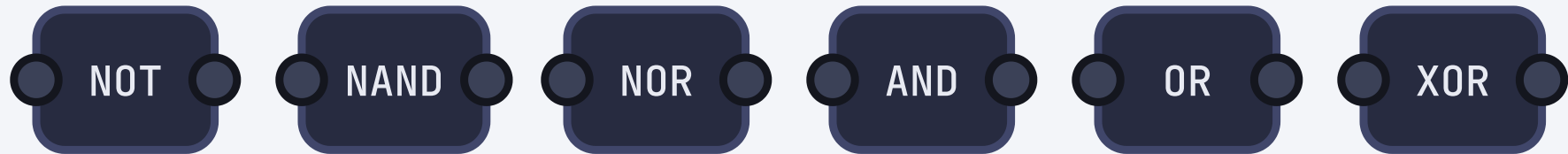
PDP-1 is a trademark of Digital Equipment Corporation; Pong and Breakout are trademarks of their respective owners. This kit is not affiliated with or endorsed by them.



Gates (optional)

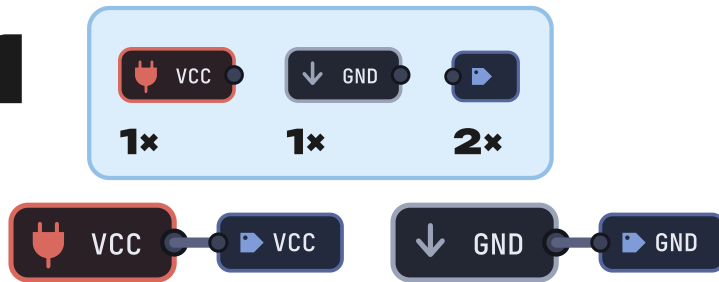
kh HB-03

NOT, NAND, NOR, AND, OR, XOR from transistors



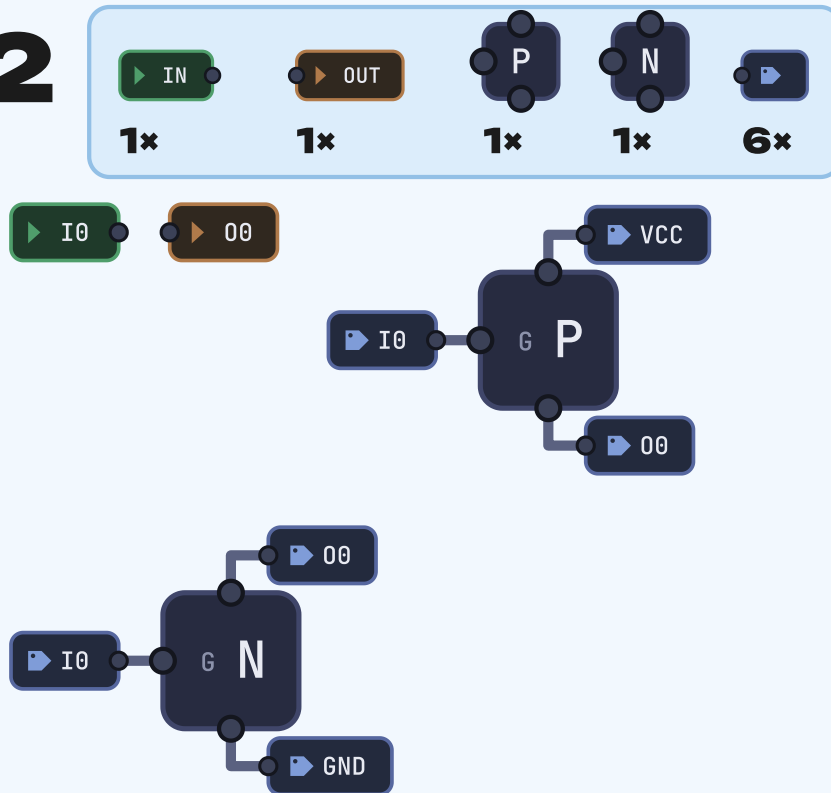
CANVAS

1



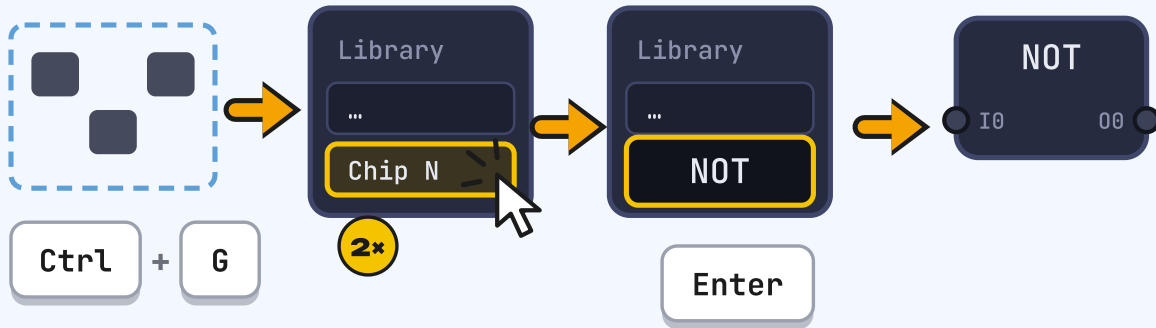
NOT

2



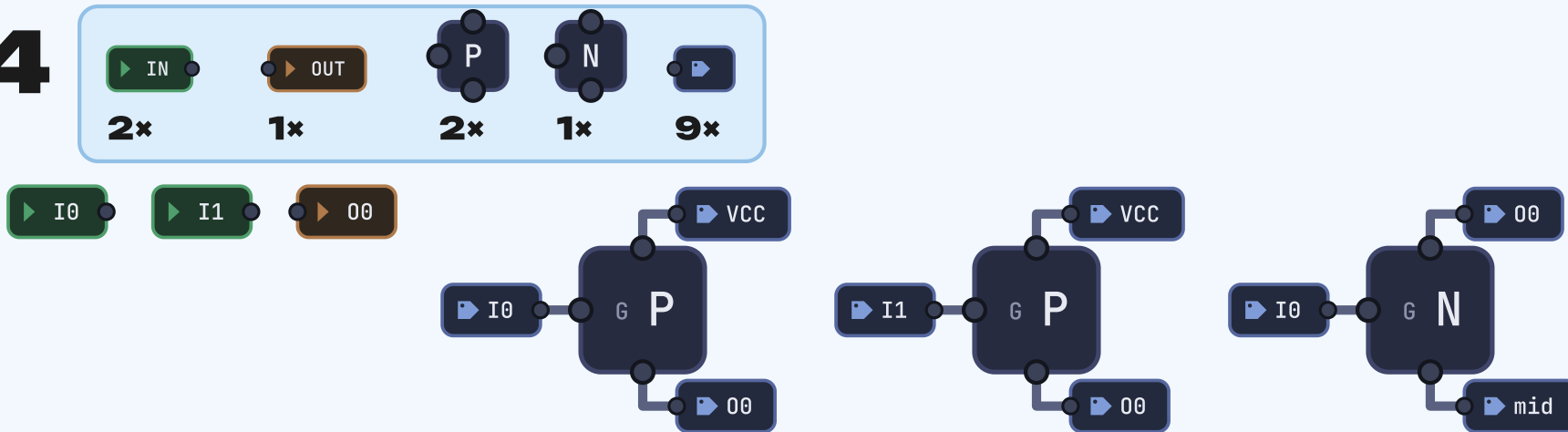
NOT ...

3



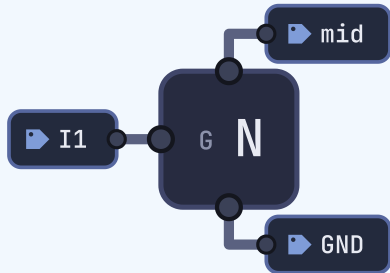
NAND

4

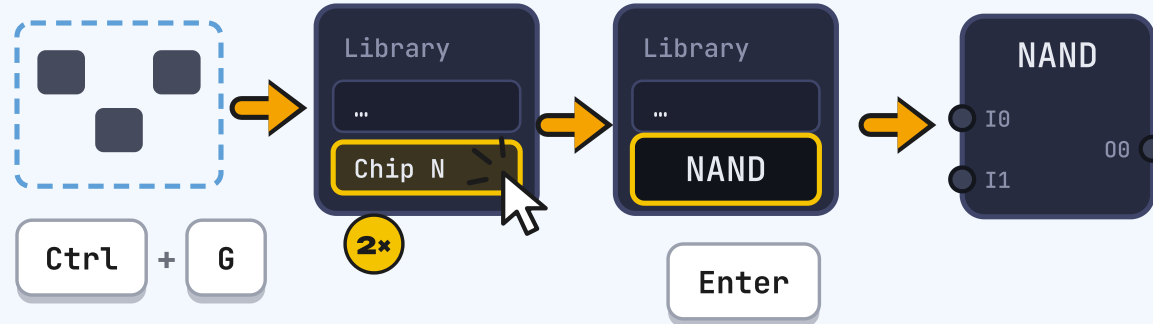


NAND ...

5

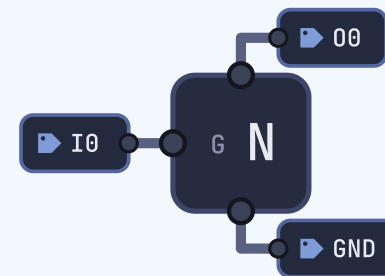
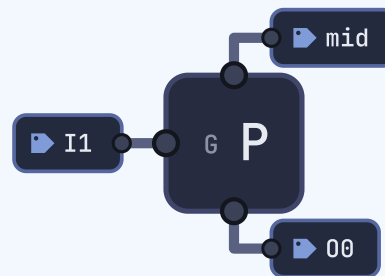
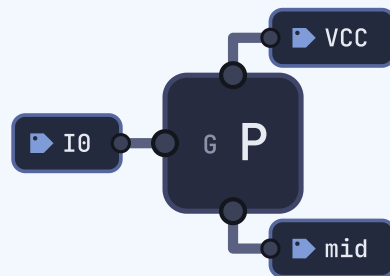


6



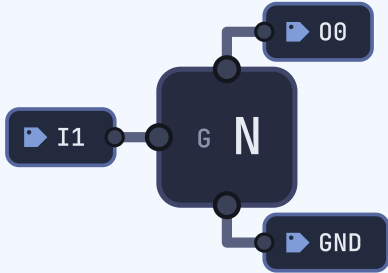
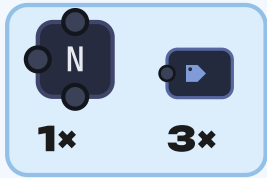
NOR

7

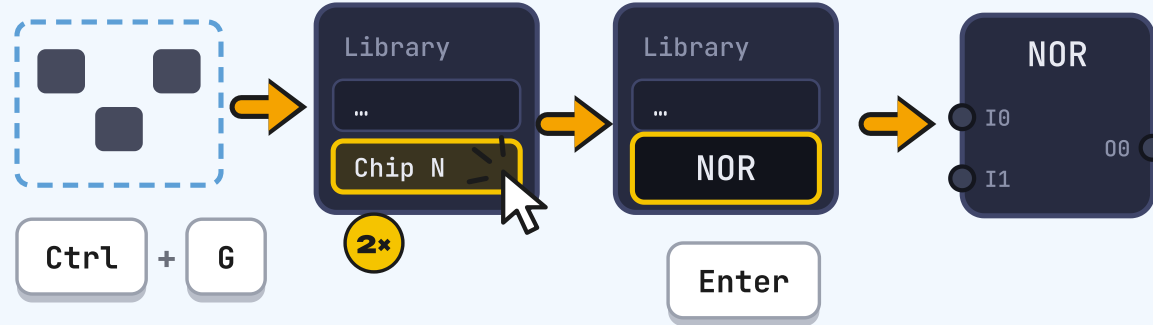


NOR ...

8

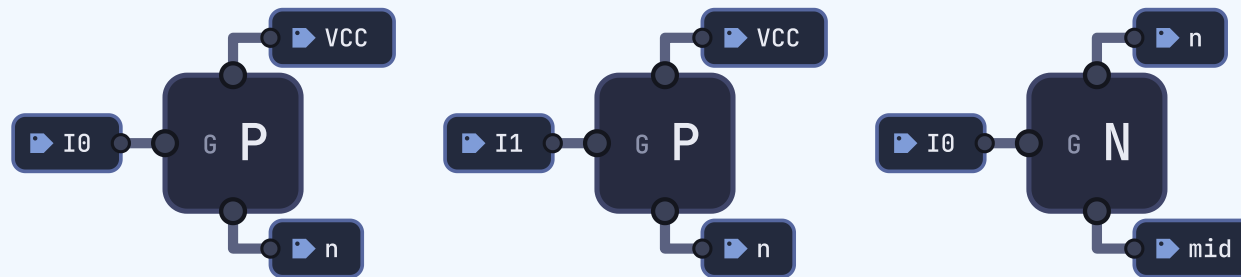


9



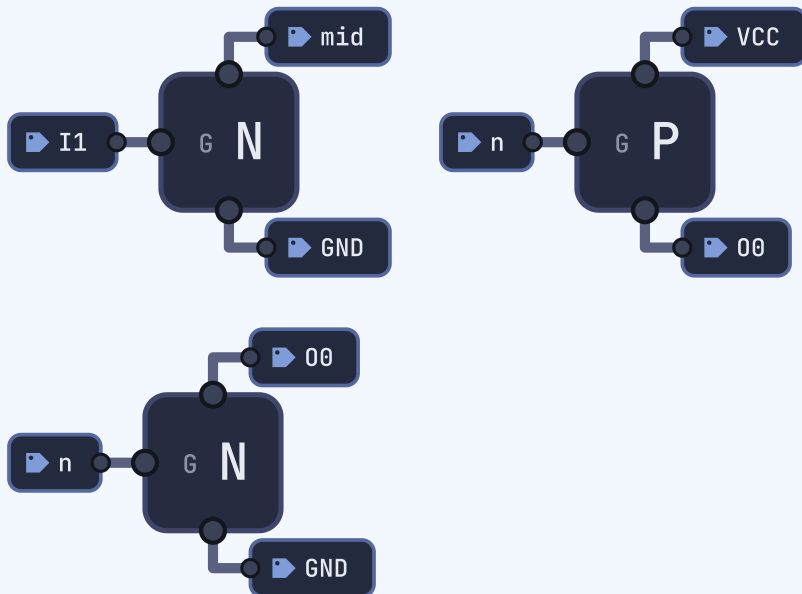
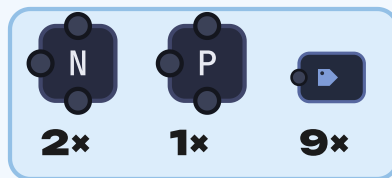
AND

10

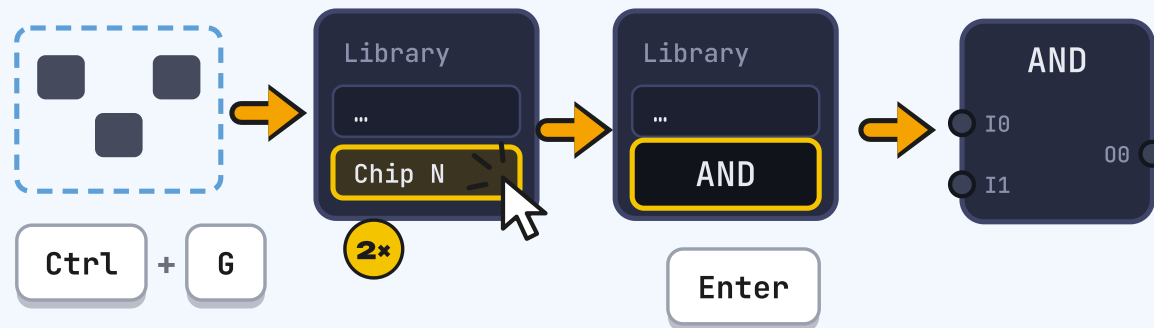


AND ...

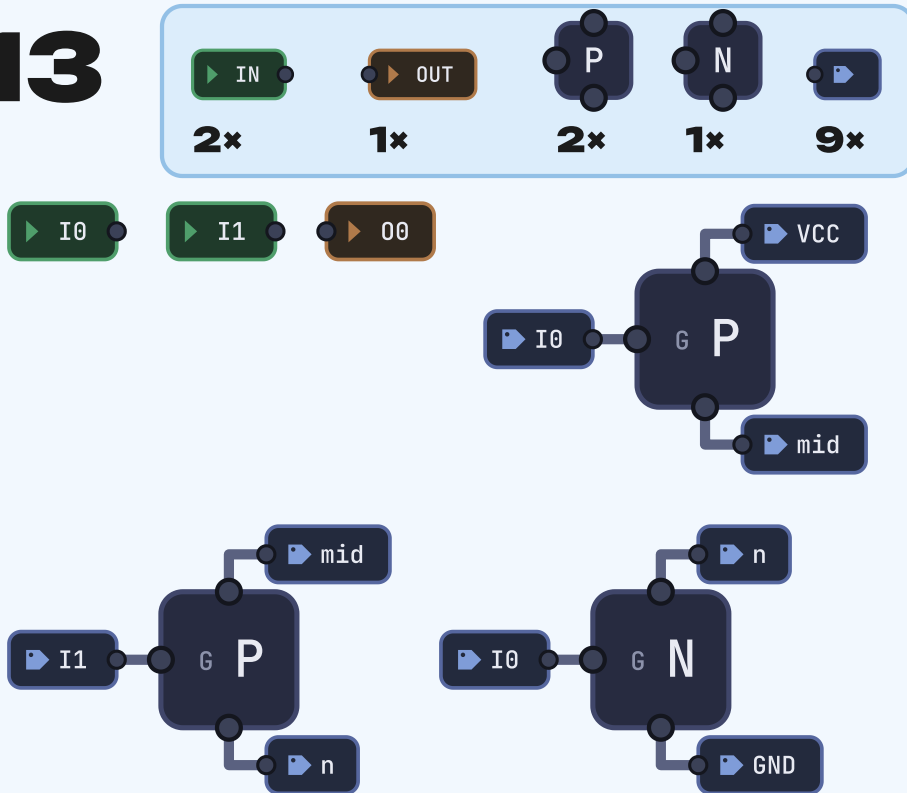
11



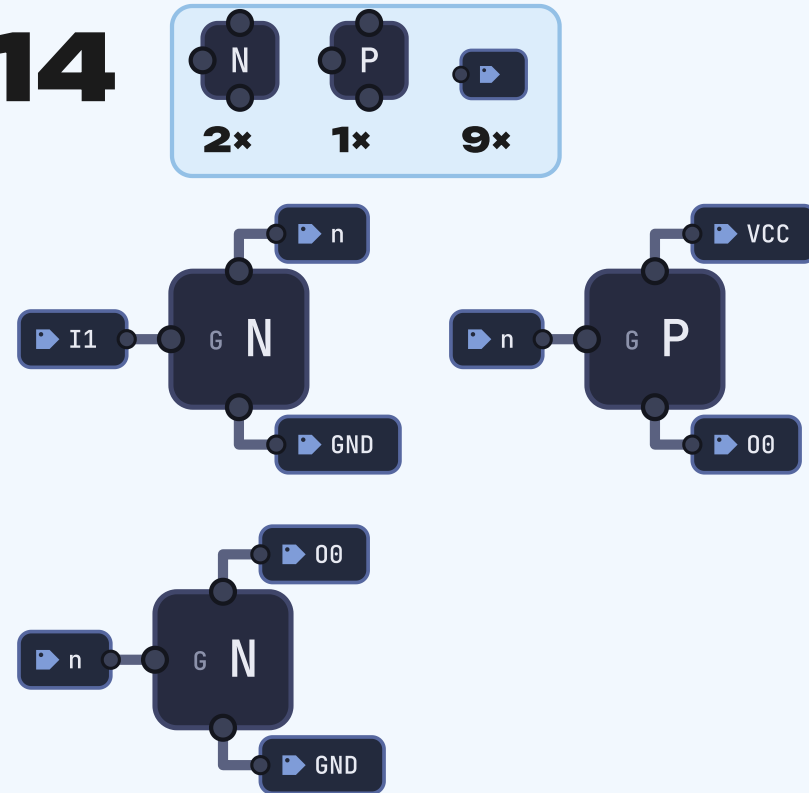
12



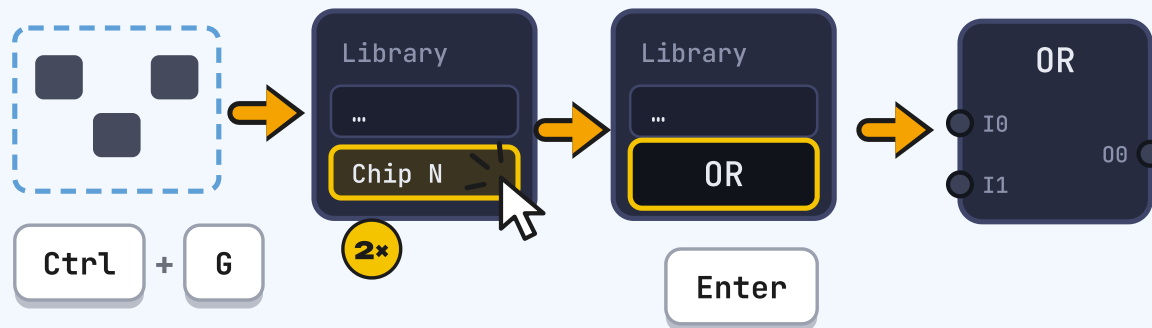
13



14

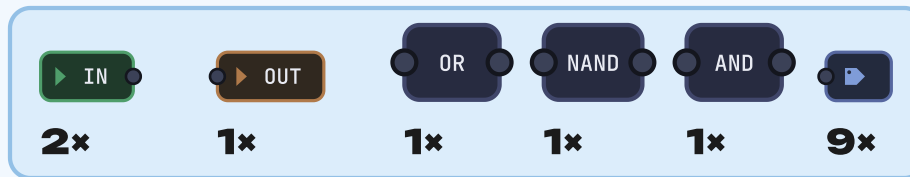


15

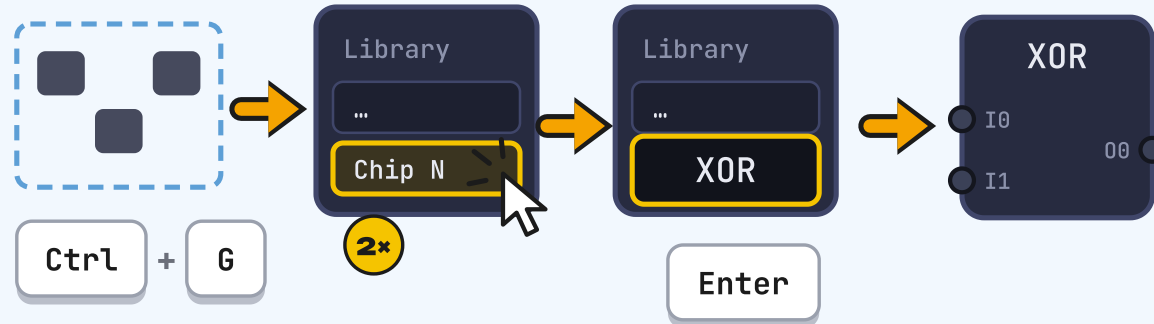


XOR

16



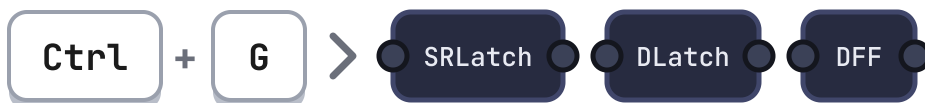
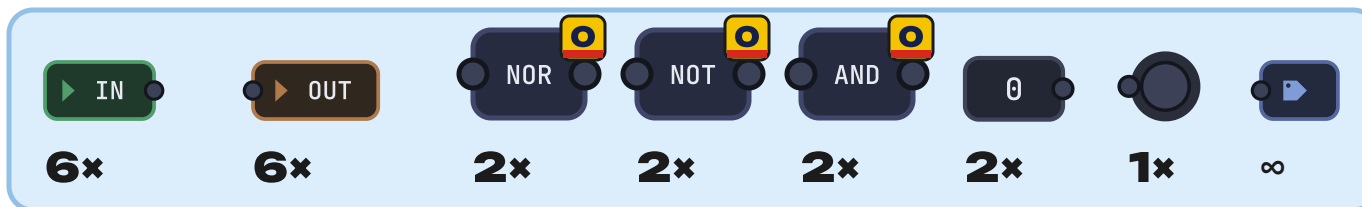
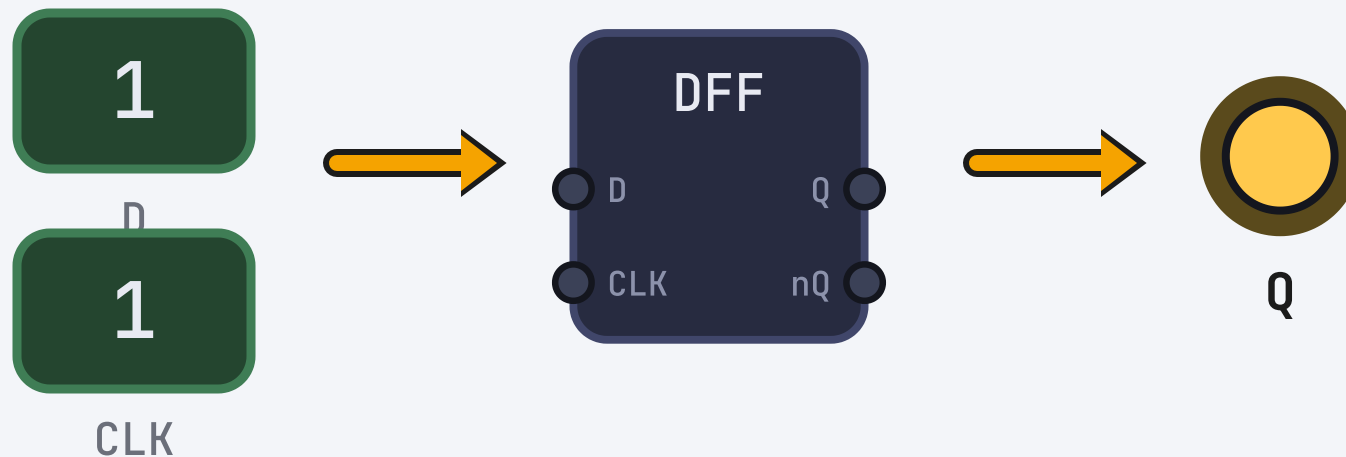
17





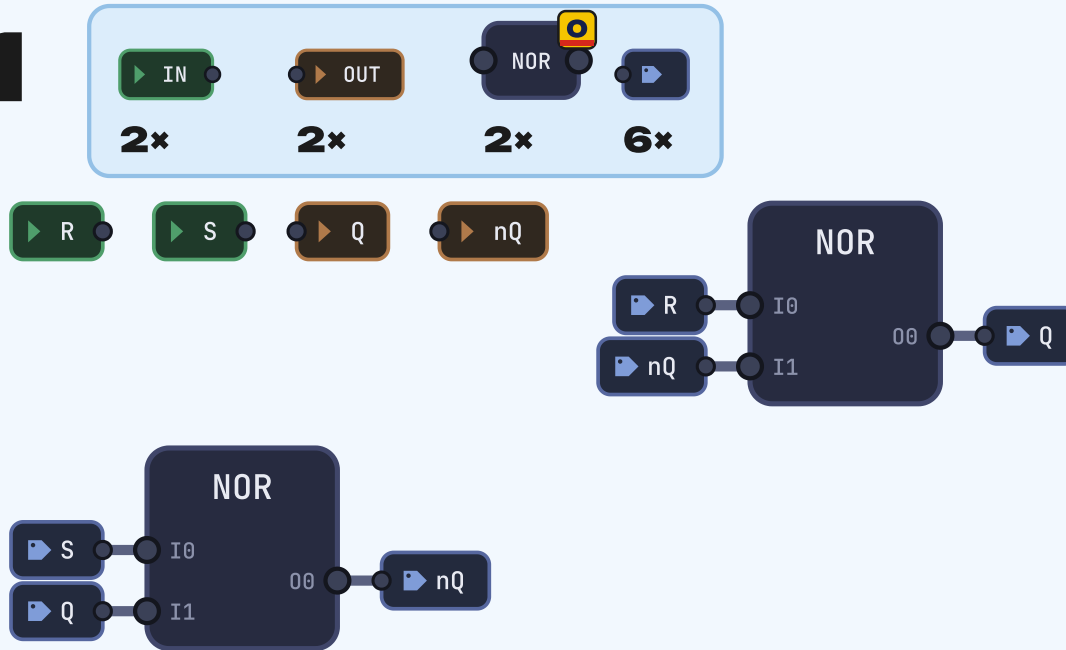
Memory

latch → D flip-flop: writing on the clock edge

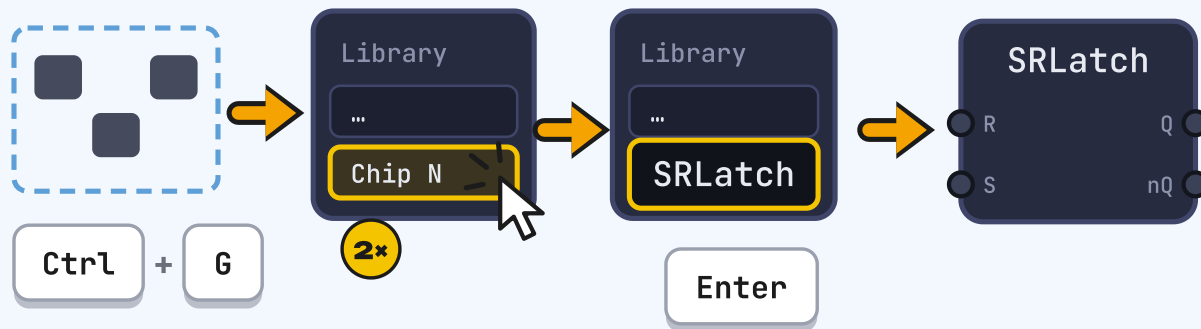


SRLatch

1

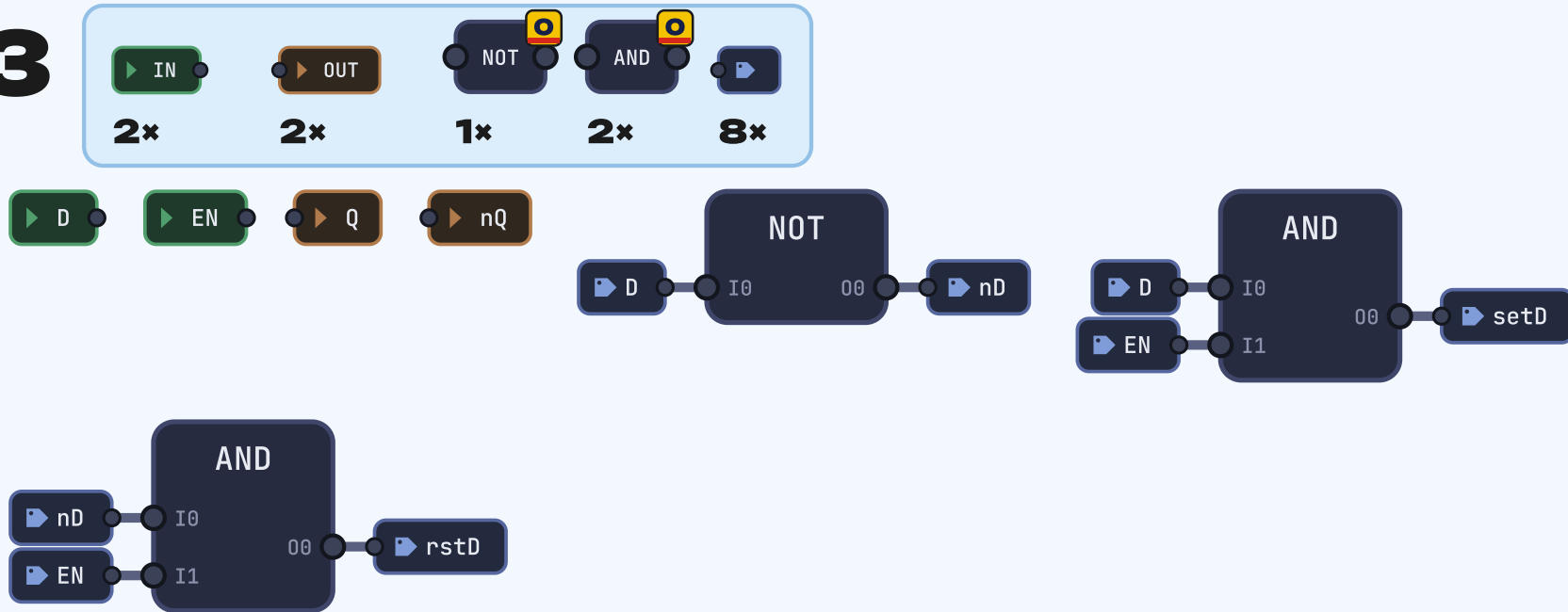


2

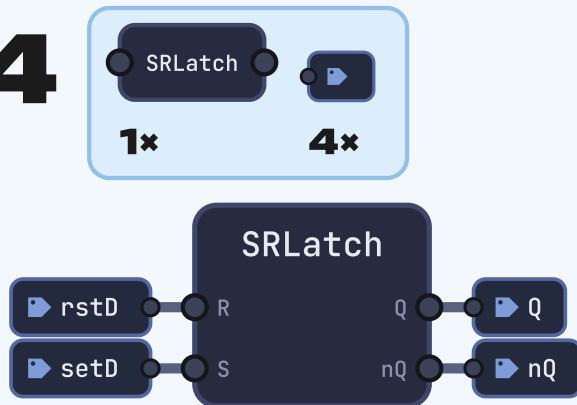


DLatch

3

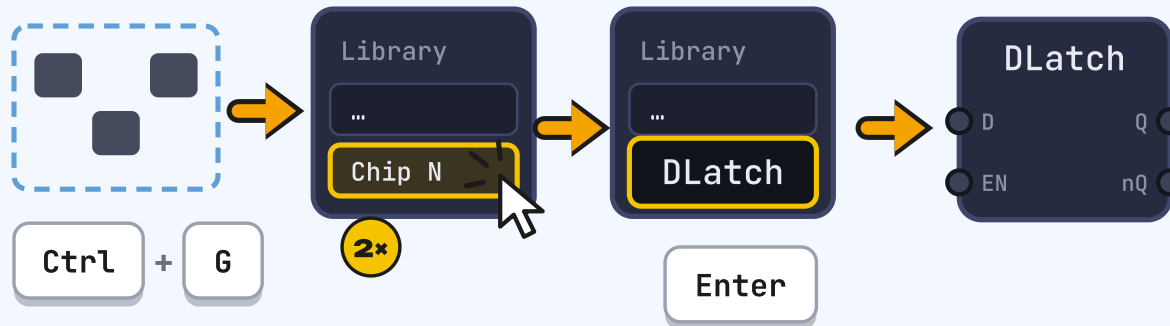


4



DLatch ...

5



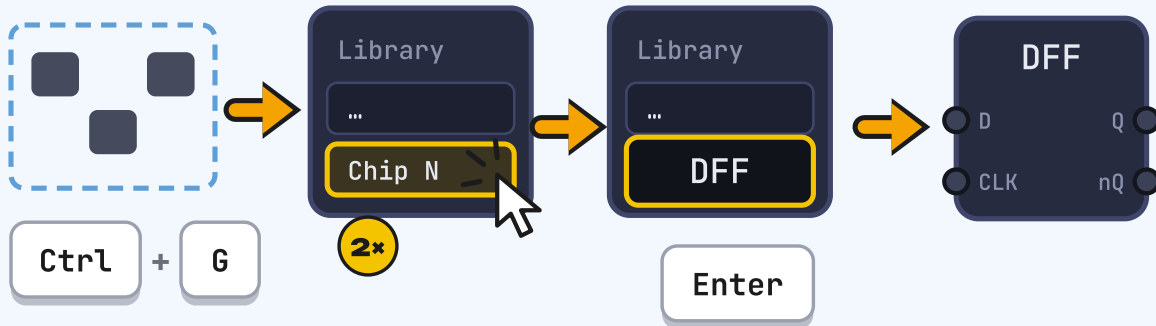
DFF

6



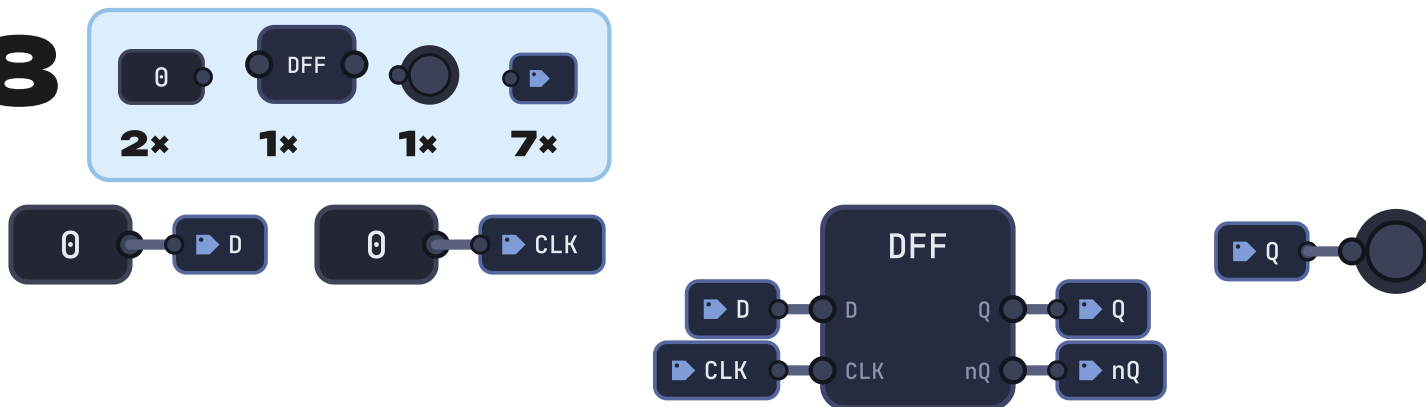
DFF ...

7



CANVAS

8



CLK 0 → 1: Q = D

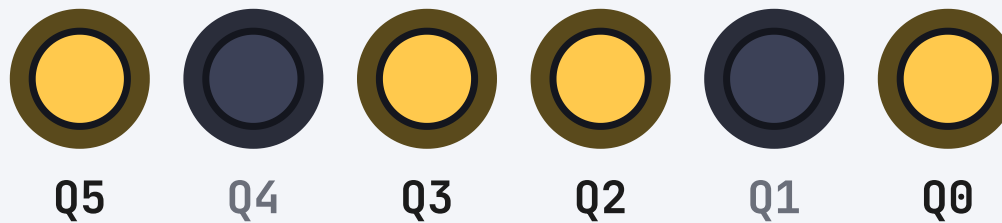


D = 0, CLK = 1: Q



Counter

six flip-flops count 0...63

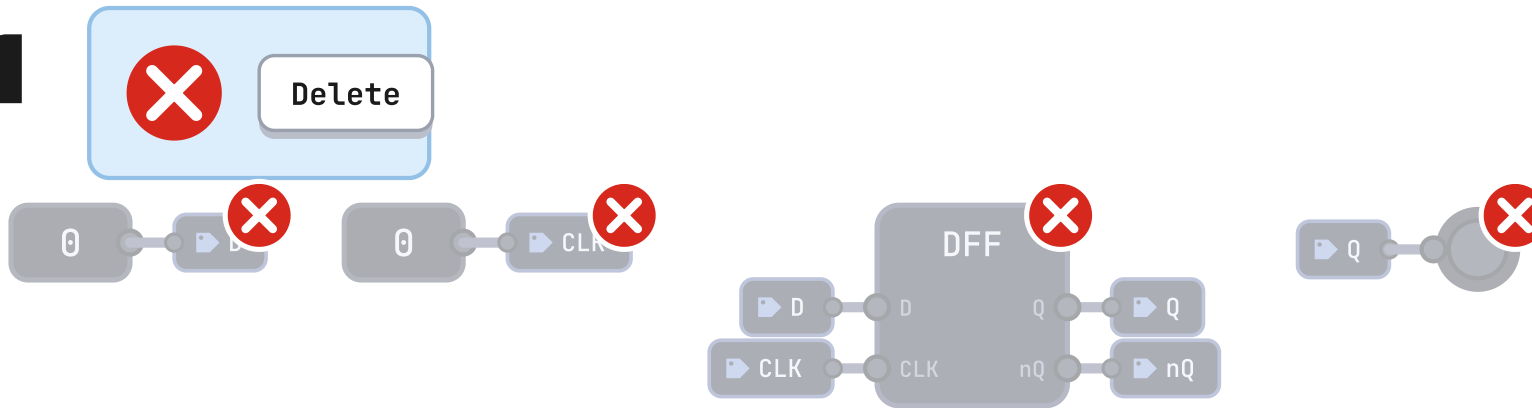


101101 = 45



CANVAS

1

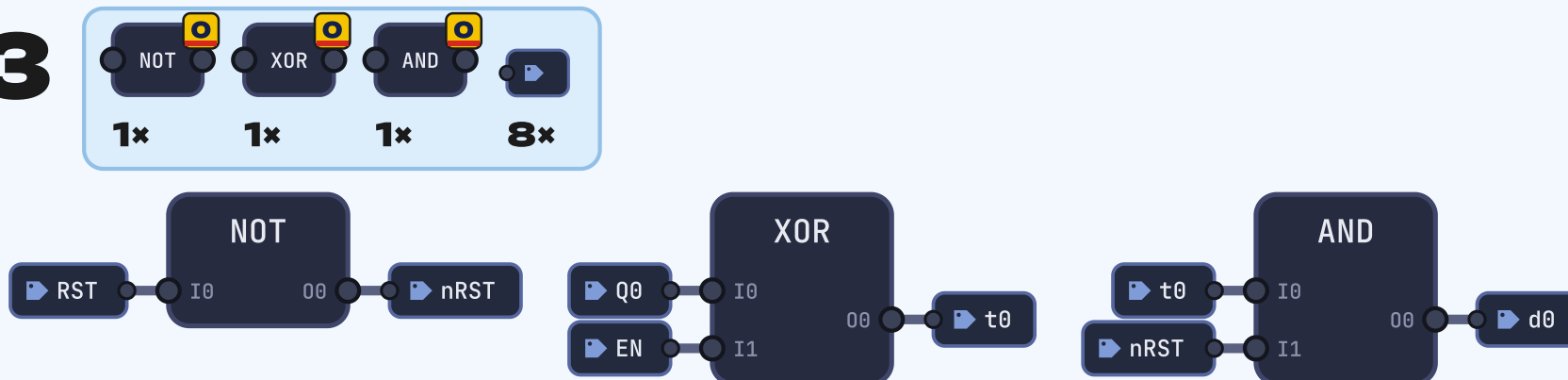


CNT6

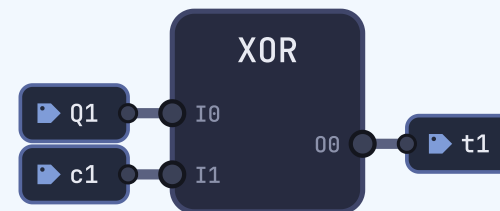
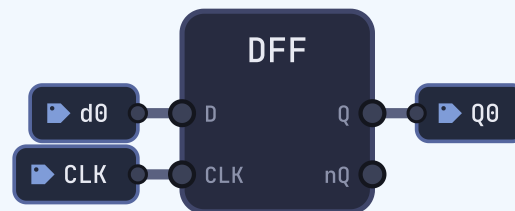
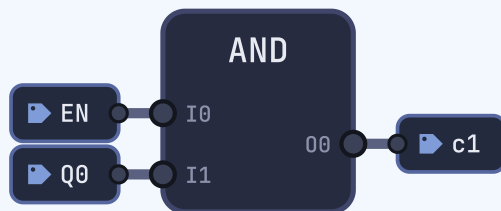
2



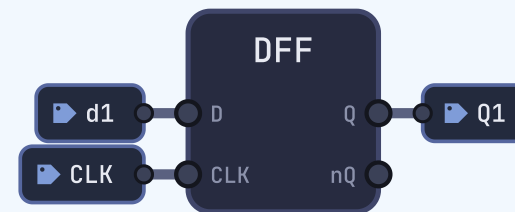
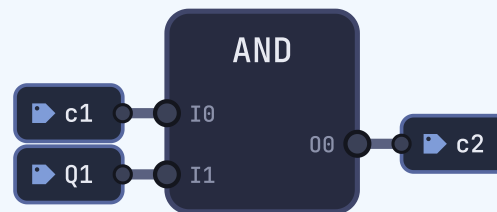
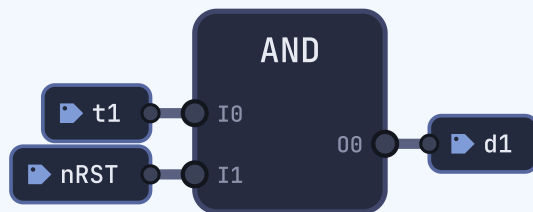
3



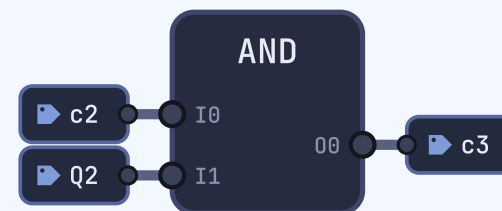
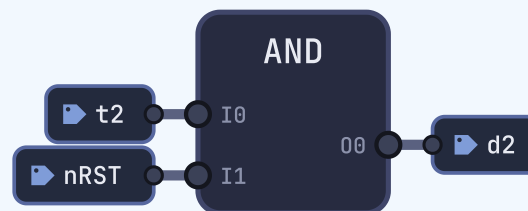
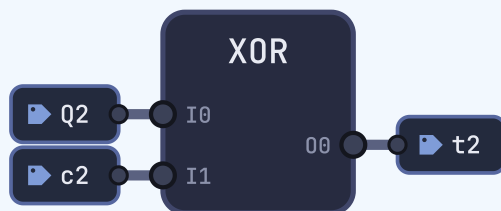
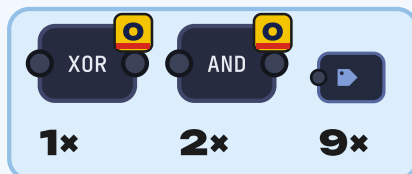
4



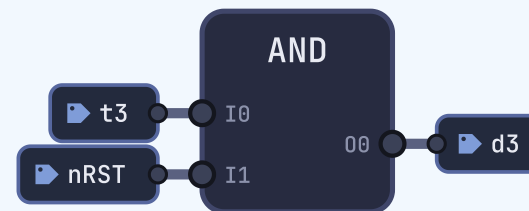
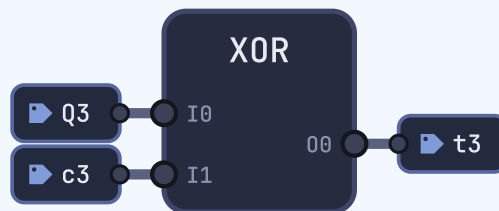
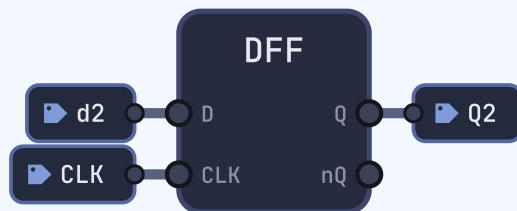
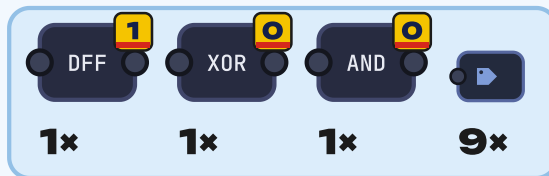
5



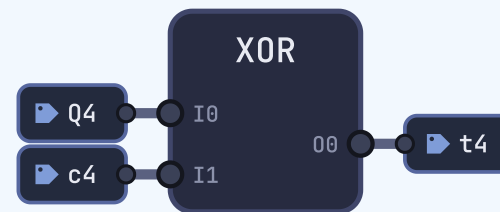
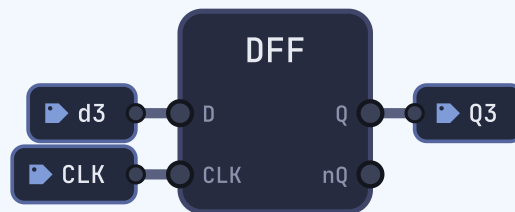
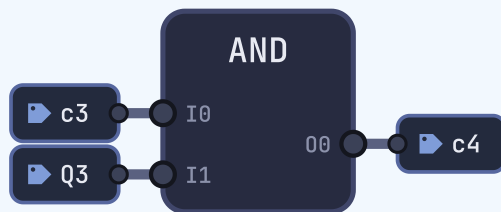
6



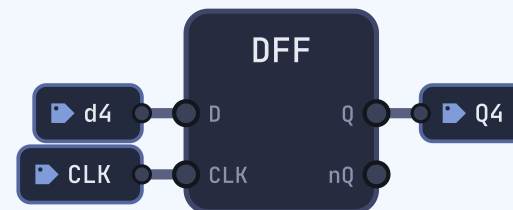
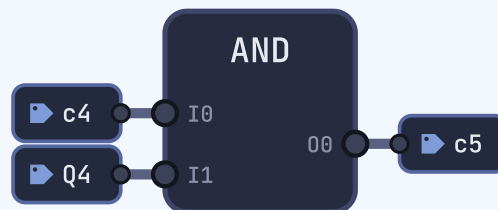
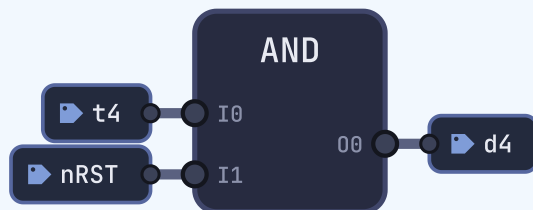
7



8

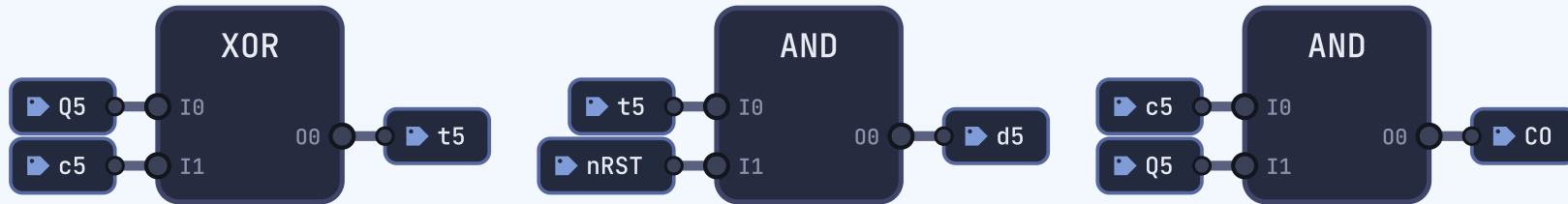


9

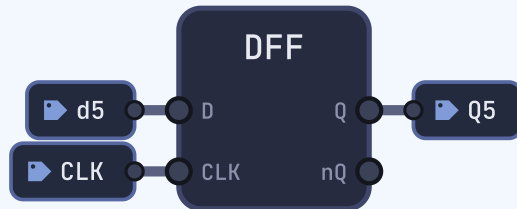


CNT6 ...

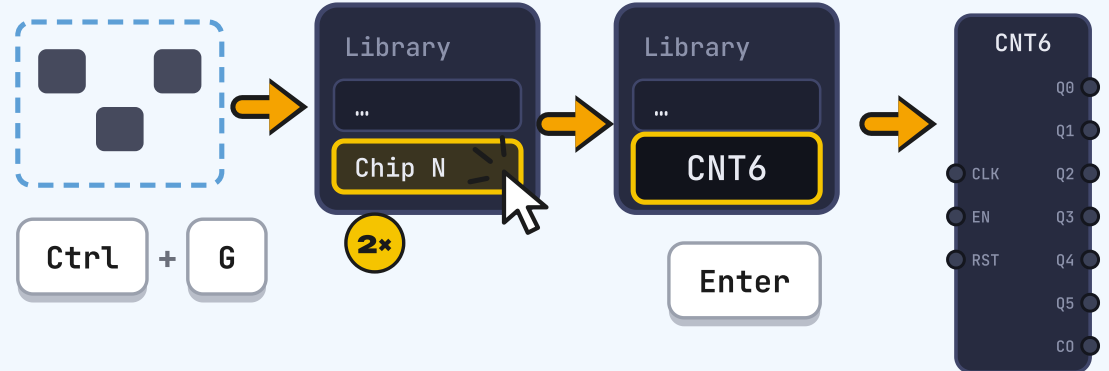
10



11



12

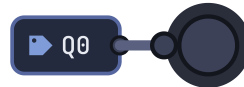
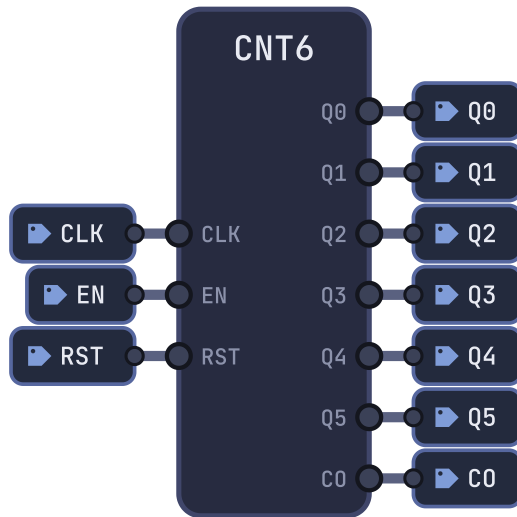
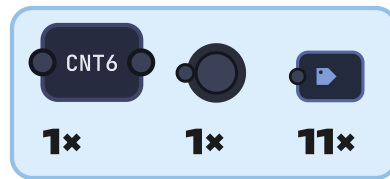


CANVAS

13



14



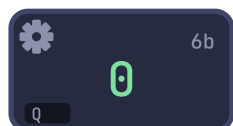
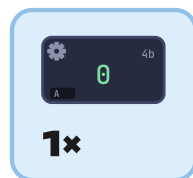
15



16



17



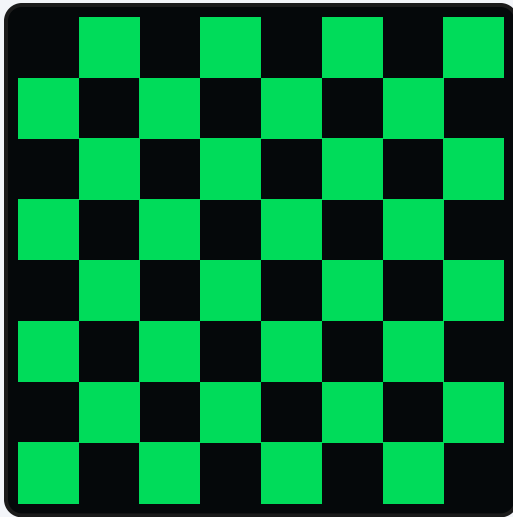
RST: 0

63: C0



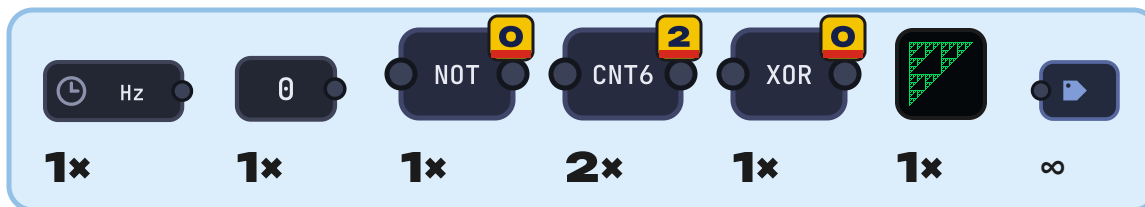
Raster scan

counters X and Y draw the 64×64 screen

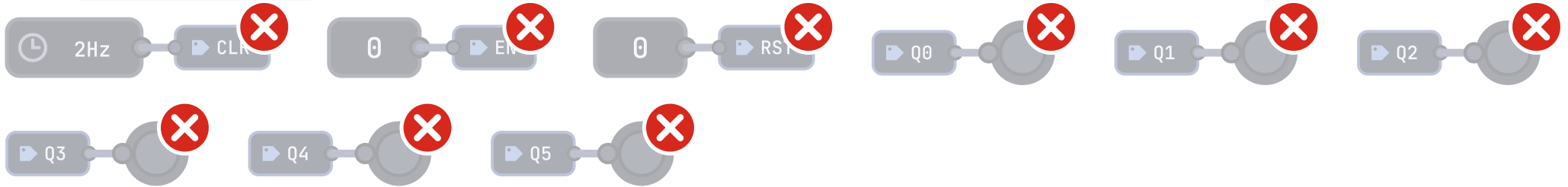


x 0 ... 63

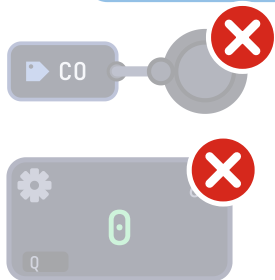
y 0 ... 63



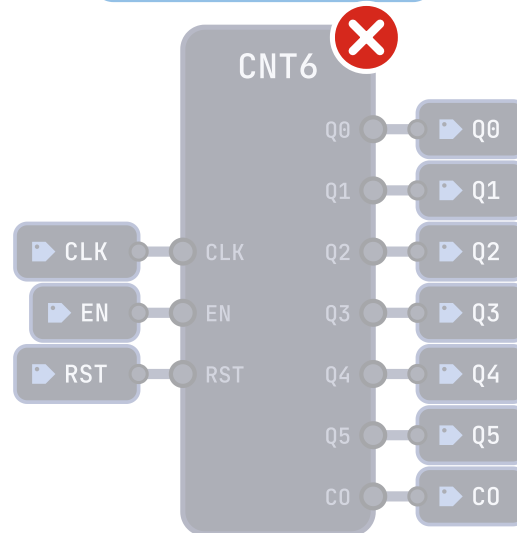
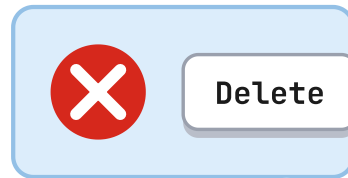
1



2



3

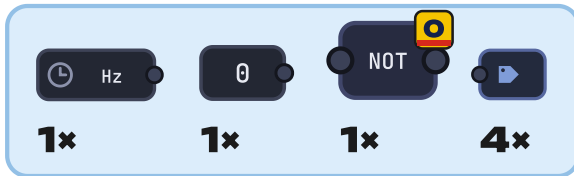


CANVAS ...

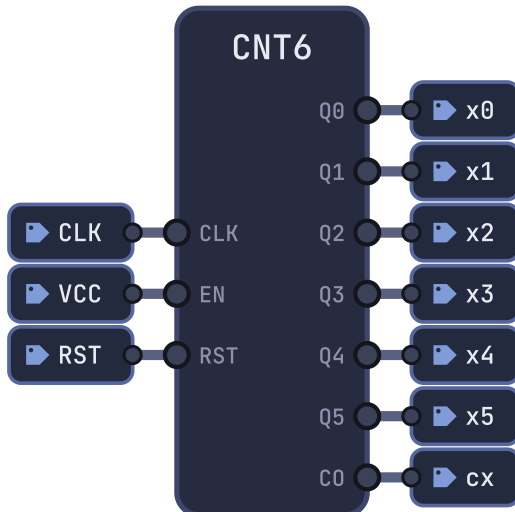
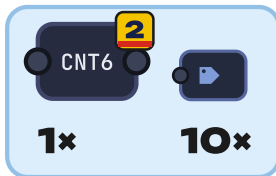
4

Dot display → ⦿: Layout Dots, 64 × 64, Port width 1 dot

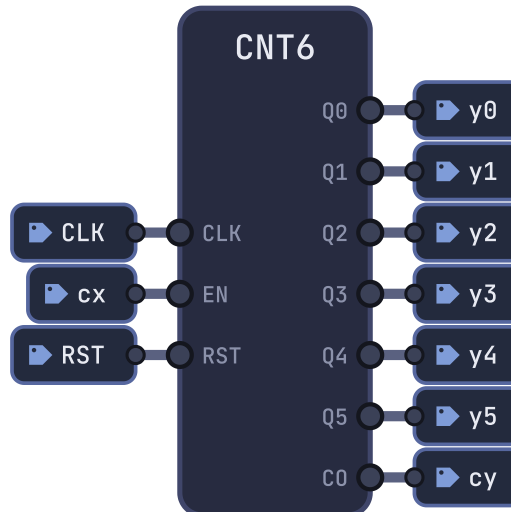
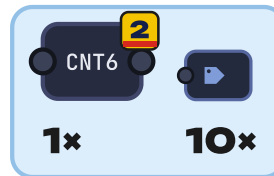
5



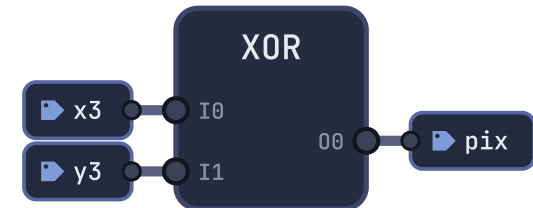
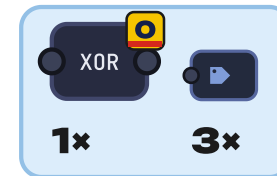
6



7



8



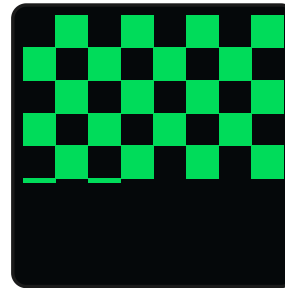
9



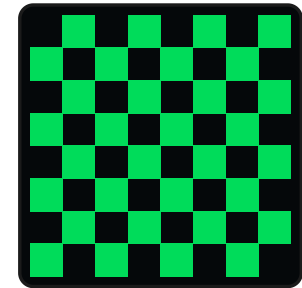
1×



16×



60Hz → 4kHz

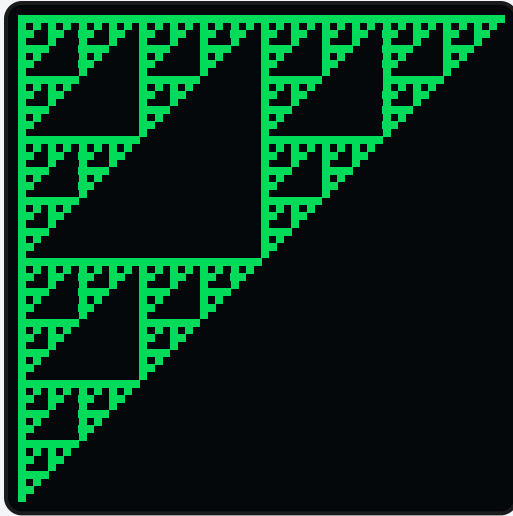


4

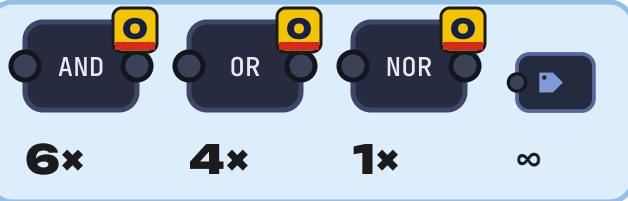
The Sierpinski triangle

$(x \text{ AND } y) = 0$ – a fractal from ten gates

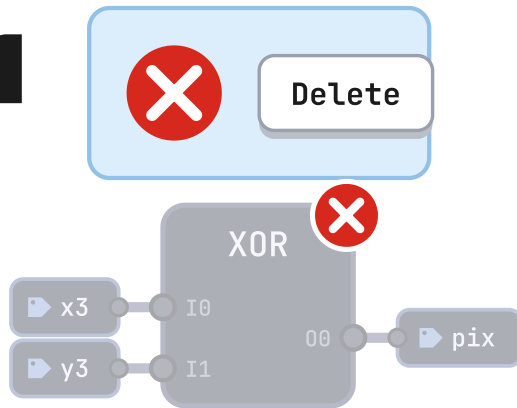
kh HB-03



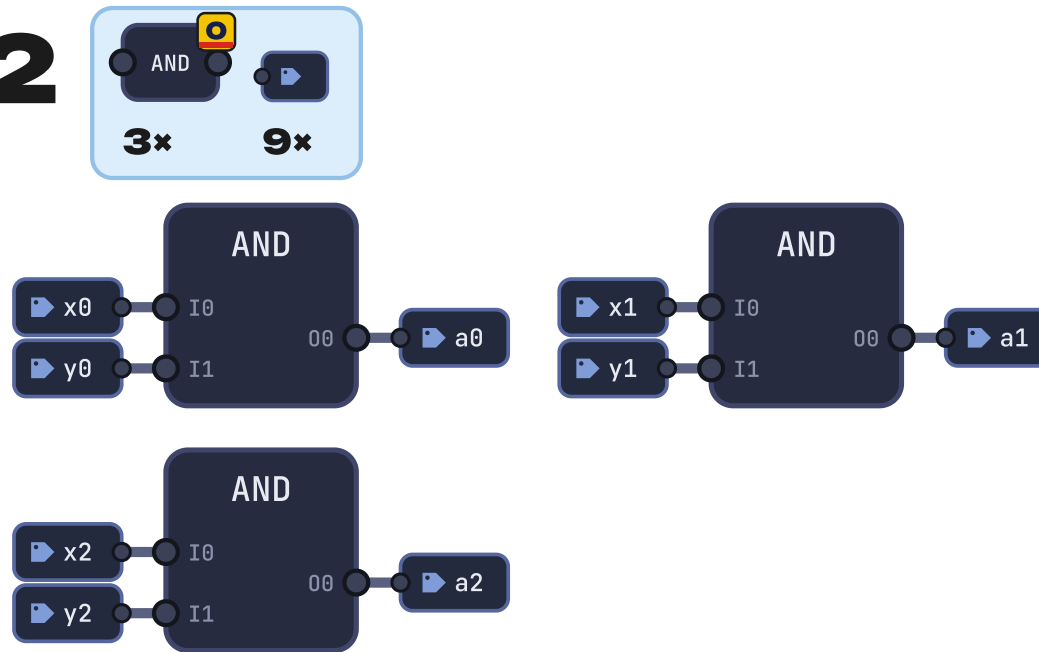
$$(x \text{ AND } y) = 0$$



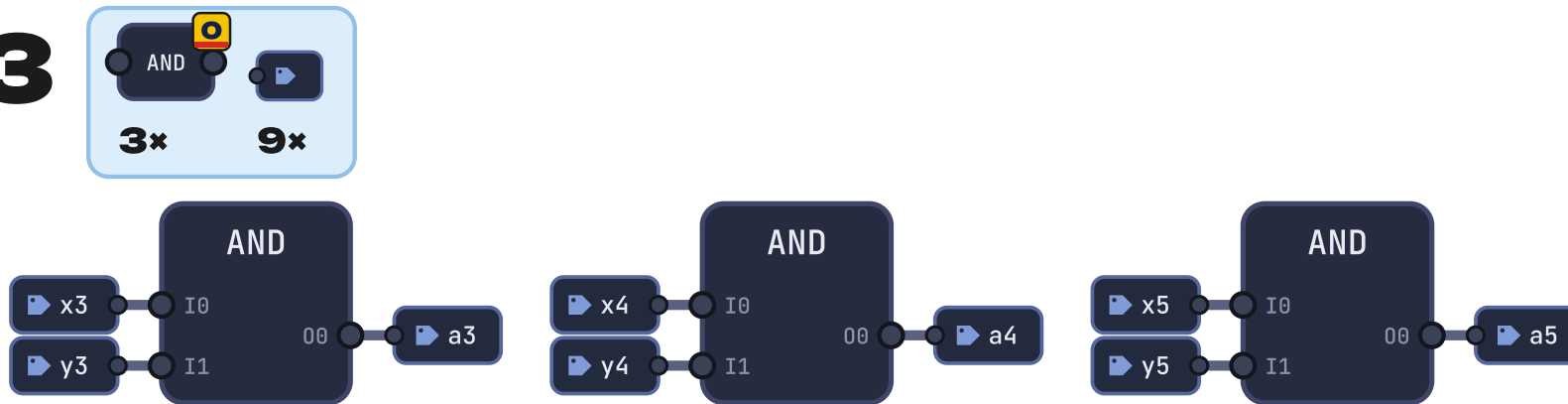
1



2

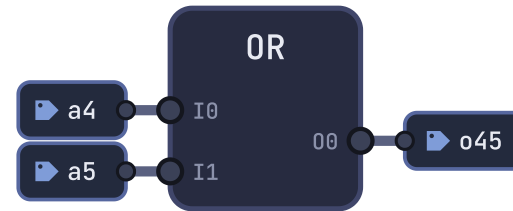
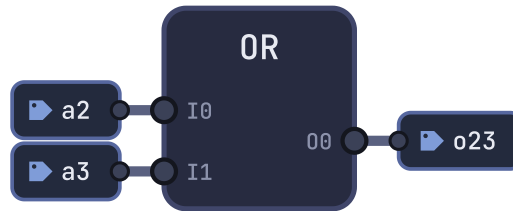
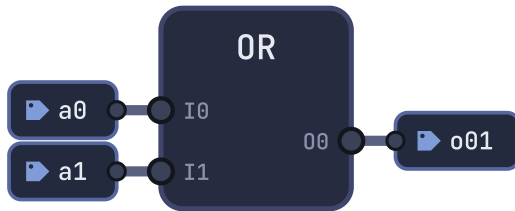


3

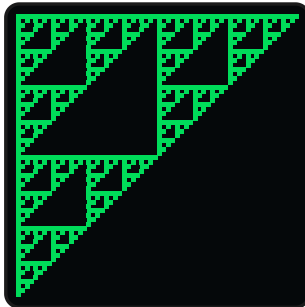
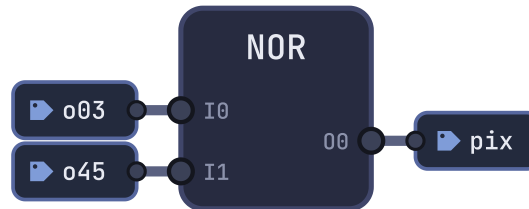
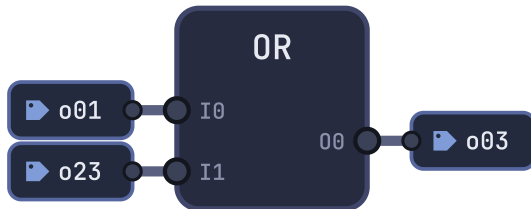


CANVAS ...

4



5

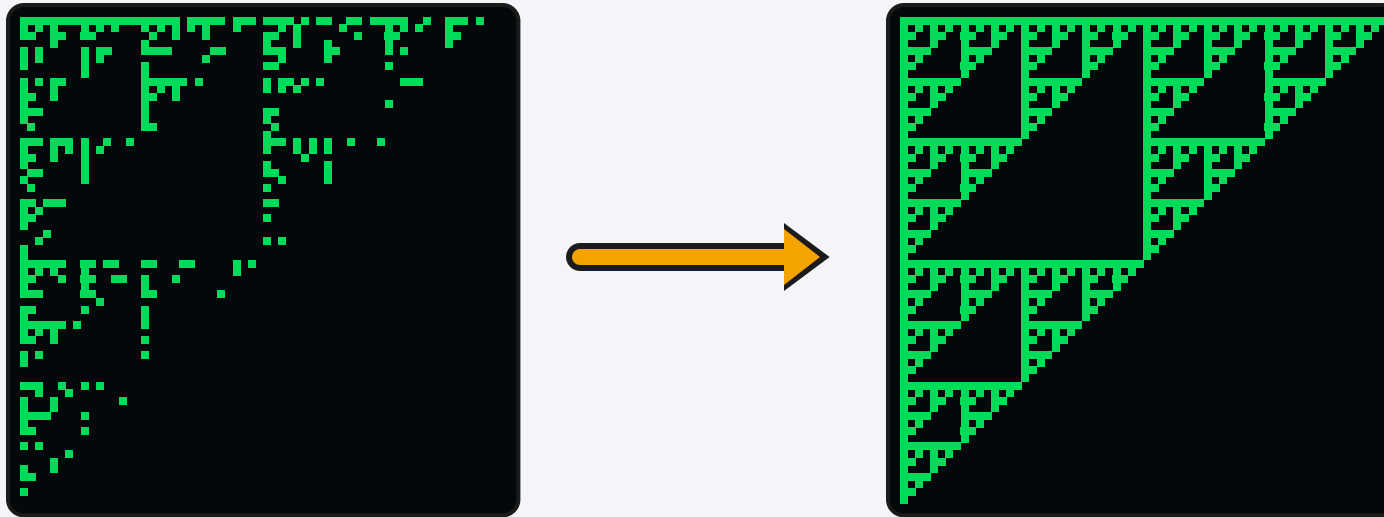


729



The chaos game

the same triangle from random dots



▶ IN

▶ OUT

NOT

XOR

AND

OR

DFF

▶

5×

8×

4×

3×

20×

3×

18×

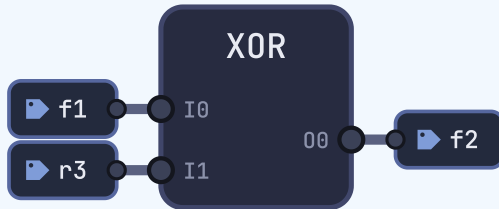
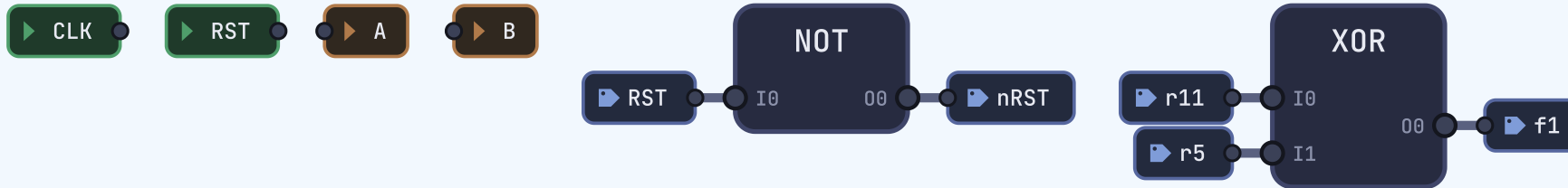
1×

∞

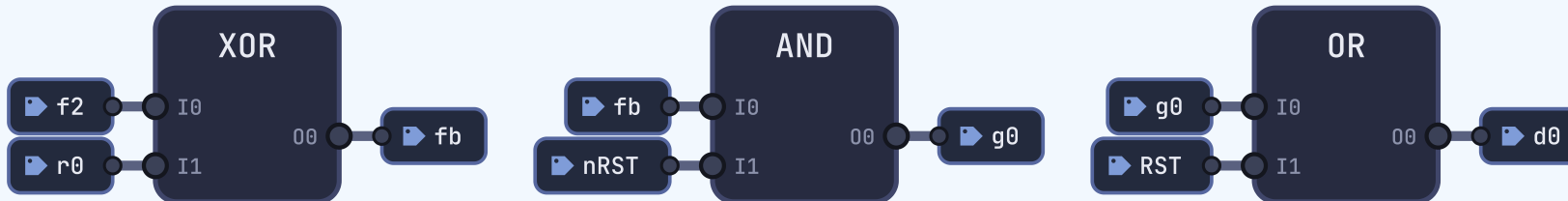
Ctrl + G > LFSR12 SHIFT6

LFSR12

1

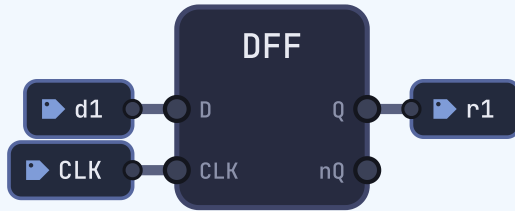
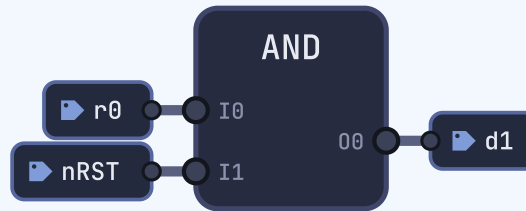
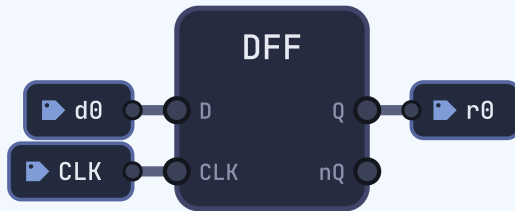
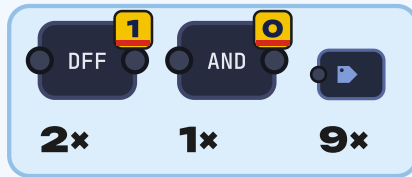


2

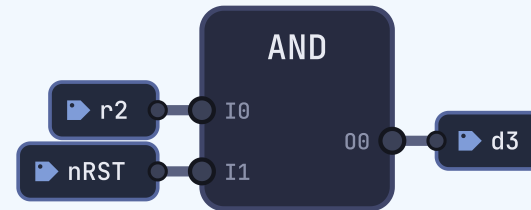
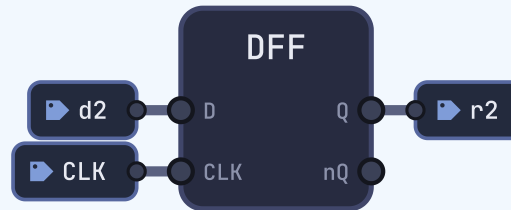
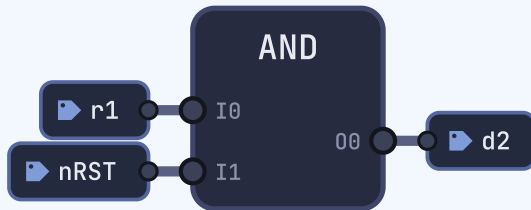


LFSR12 ...

3

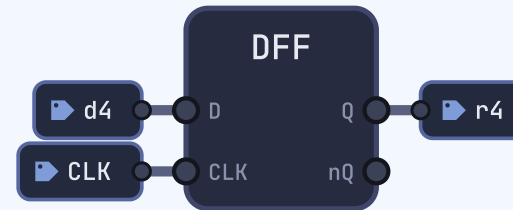
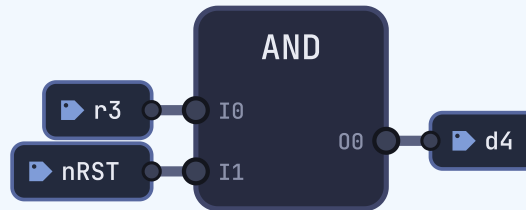
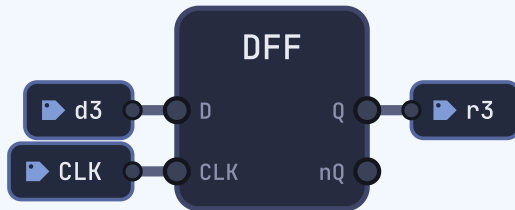
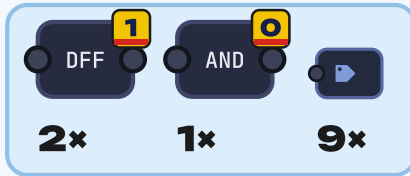


4

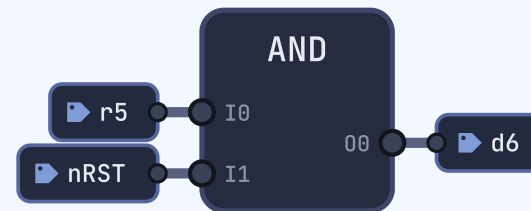
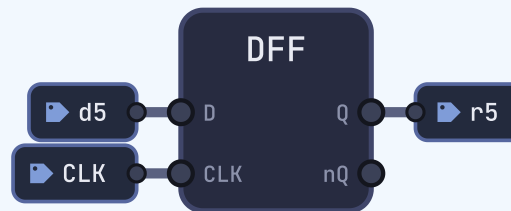
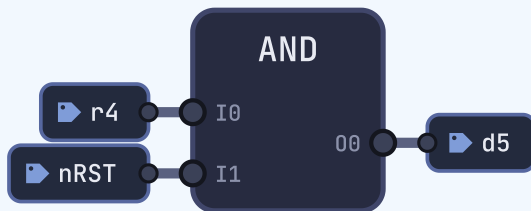


LFSR12 ...

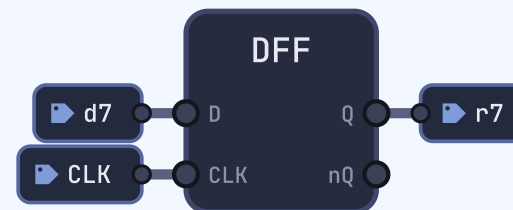
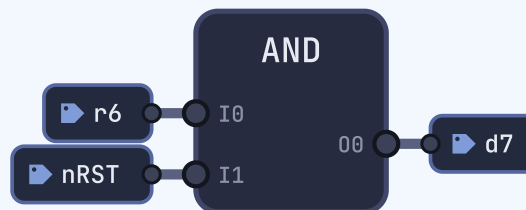
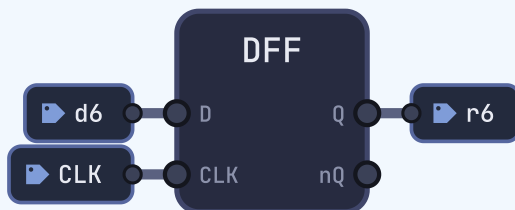
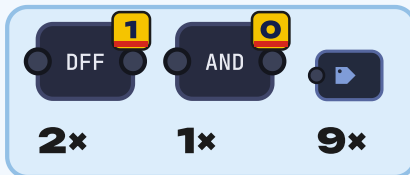
5



6

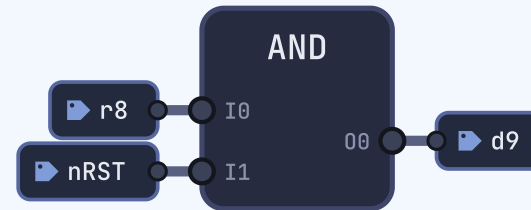
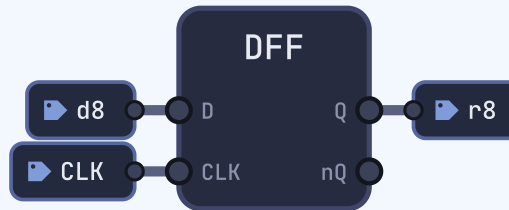
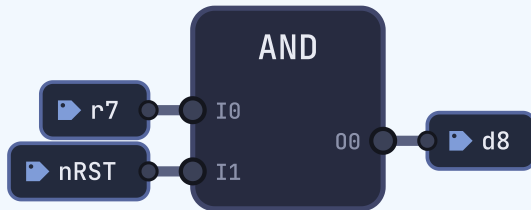


7

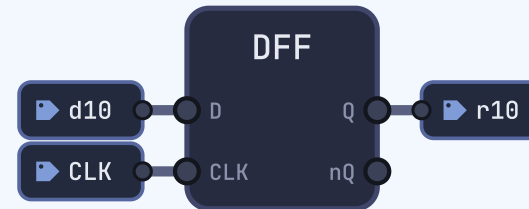
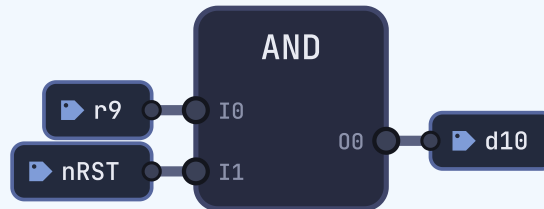
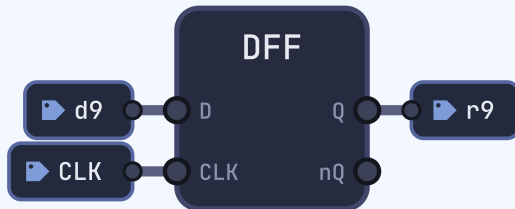
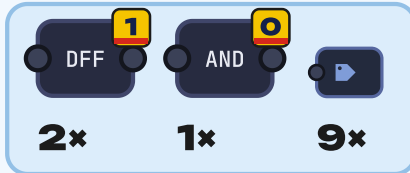


LFSR12 ...

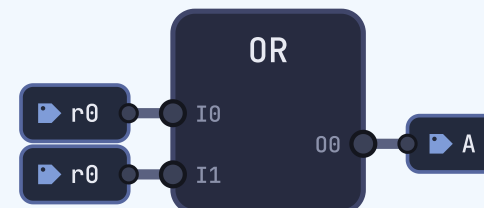
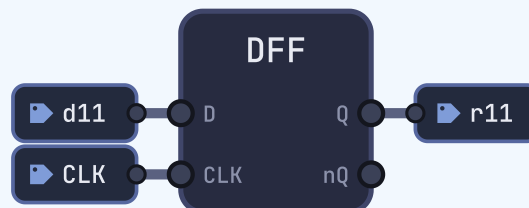
8



9

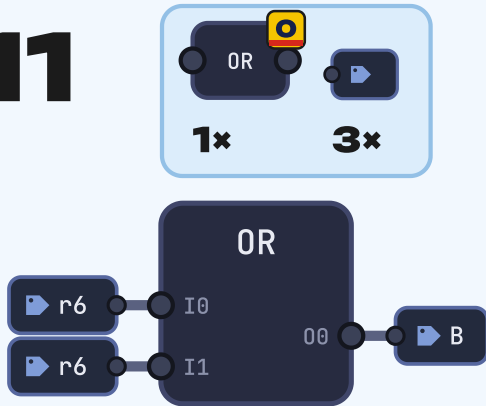


10

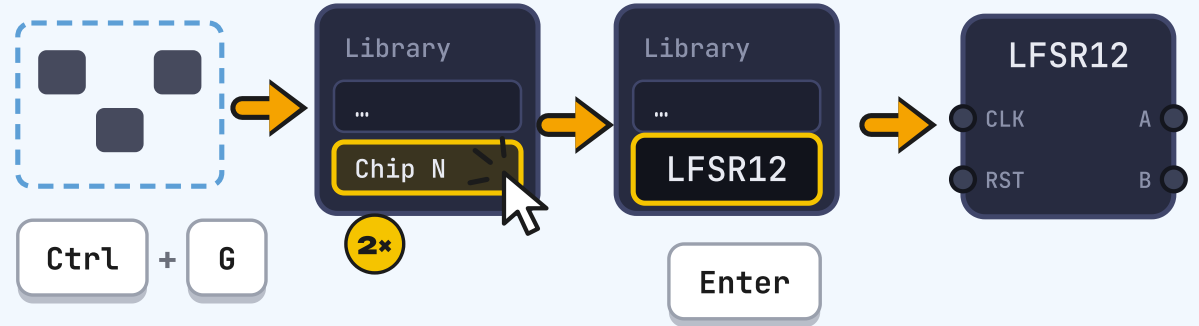


LFSR12 ...

11

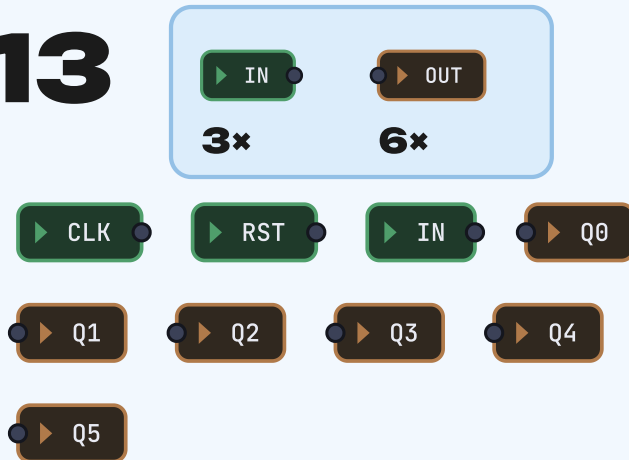


12

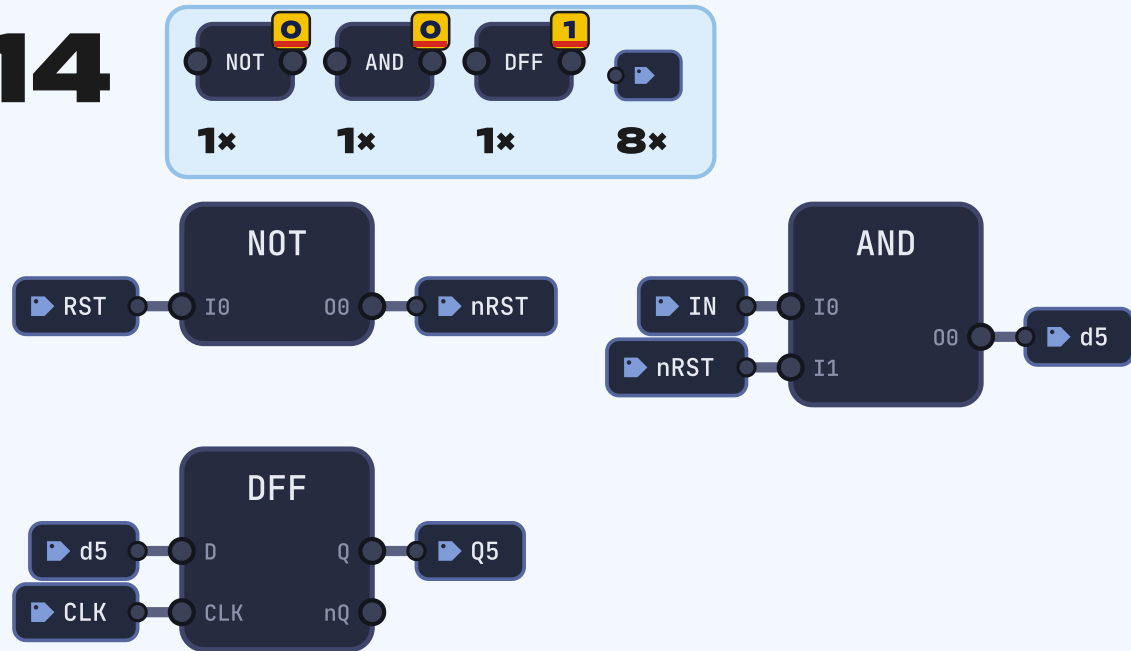


SHIFT6

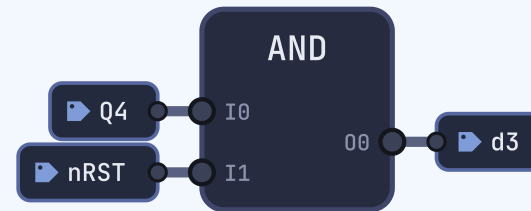
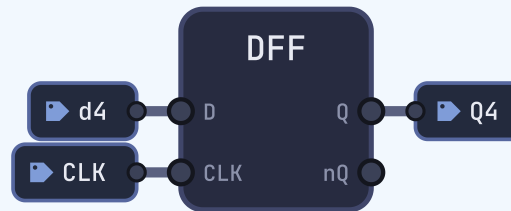
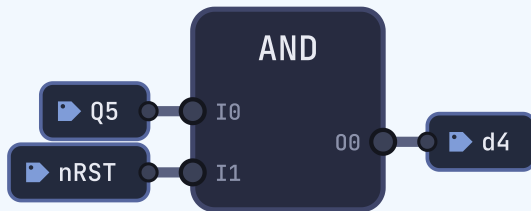
13



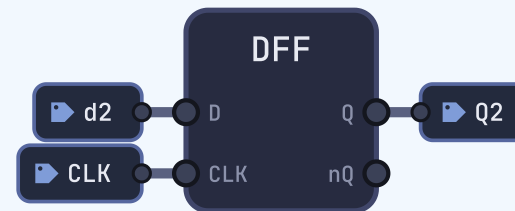
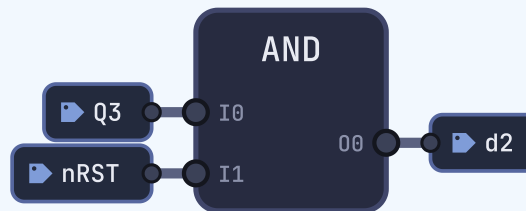
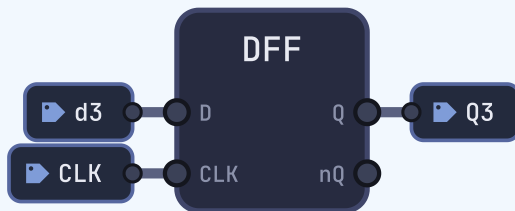
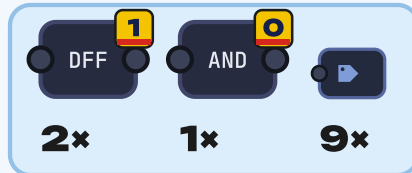
14



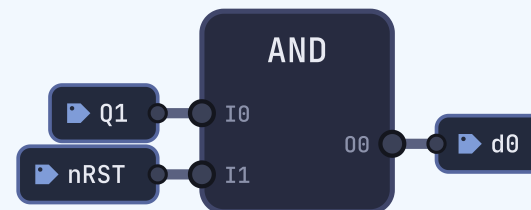
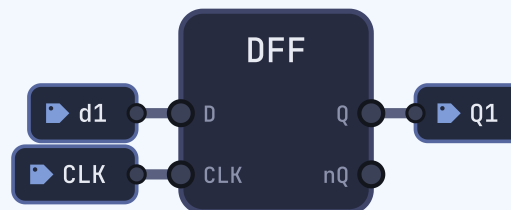
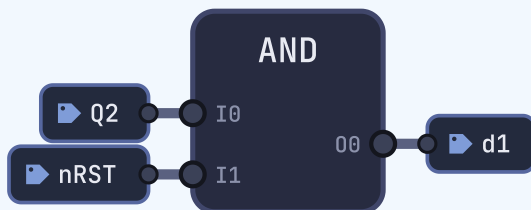
15



16

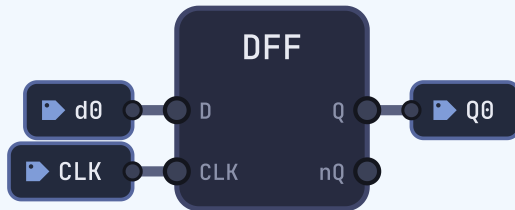


17

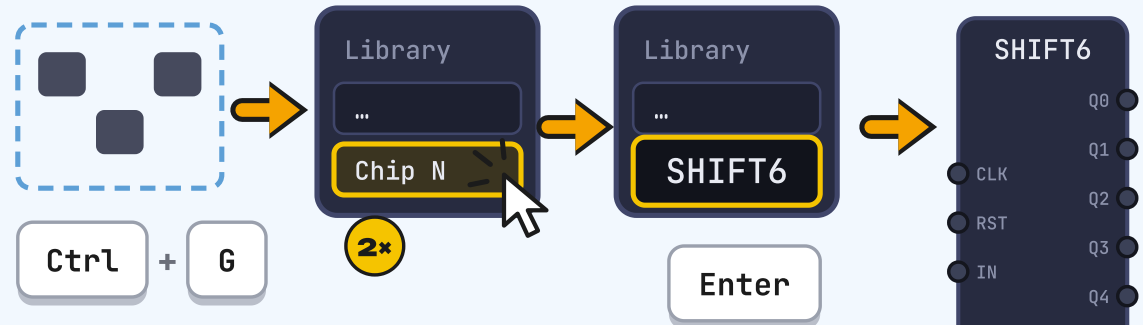


SHIFT6 ...

18



19

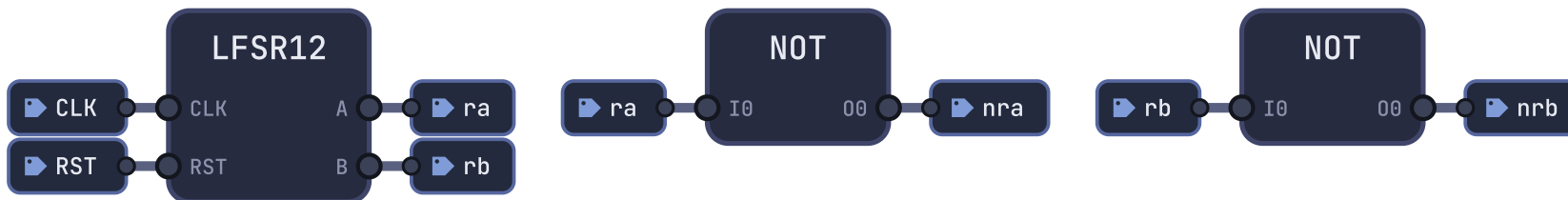
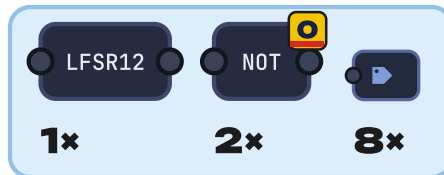


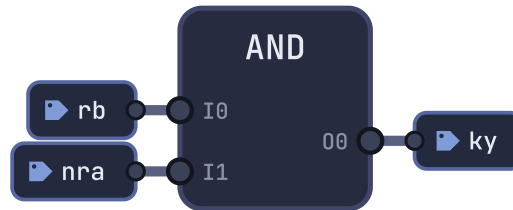
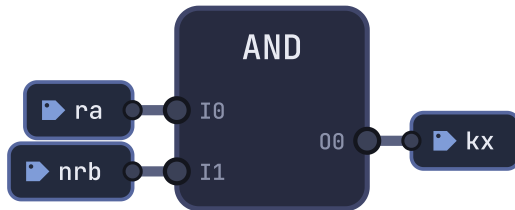
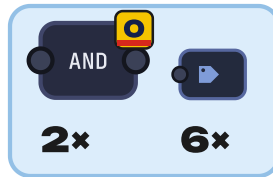
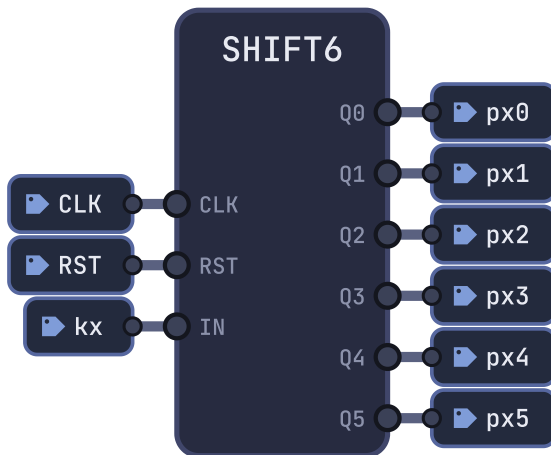
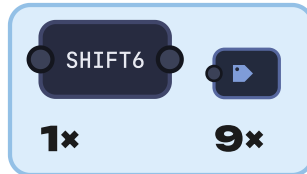
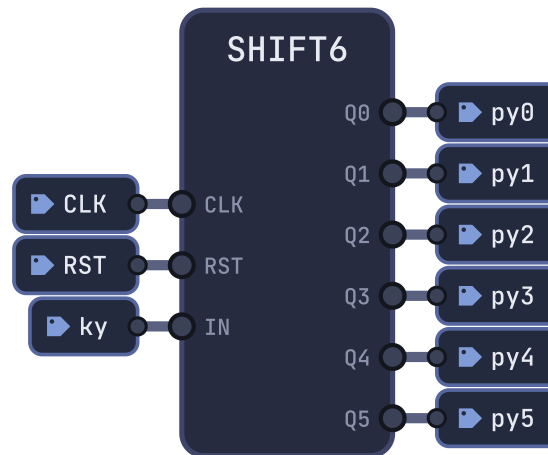
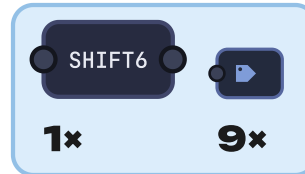
CANVAS

20

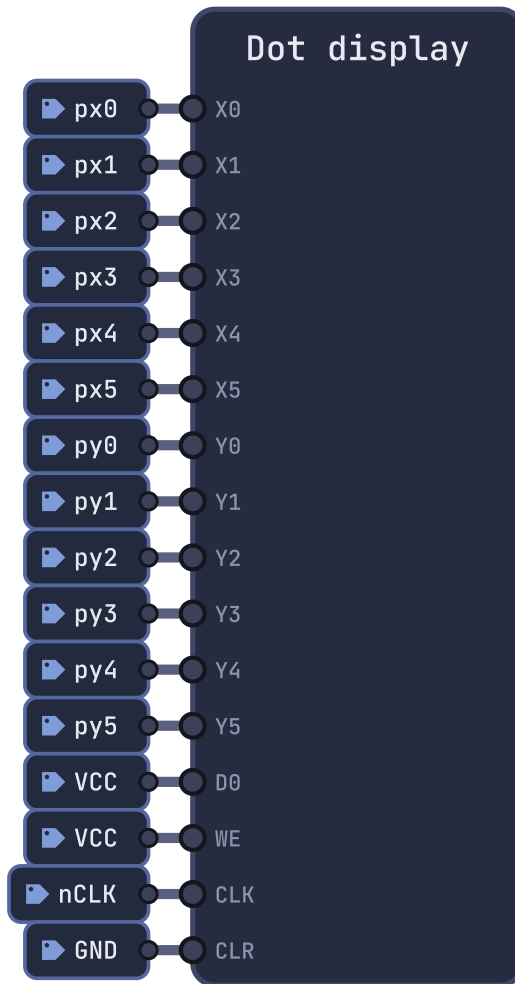
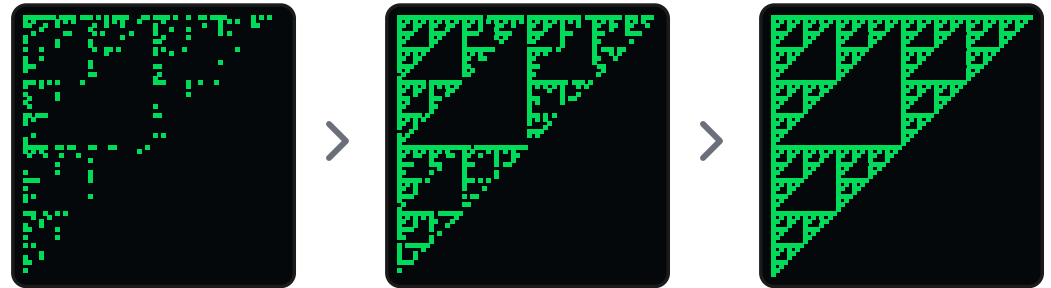
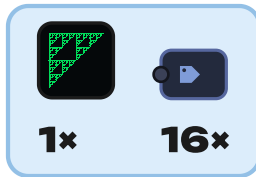
Dot display → ⦿: Layout Dots, 64 × 64, Port width 1 dot

21



22**23****24**

25

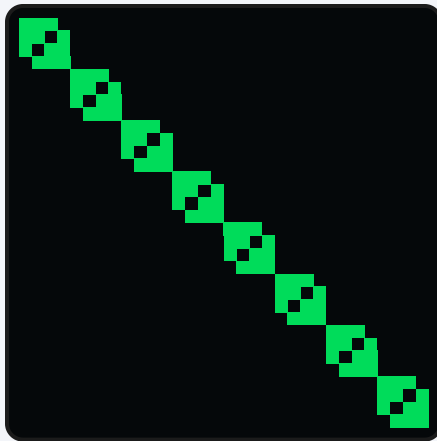




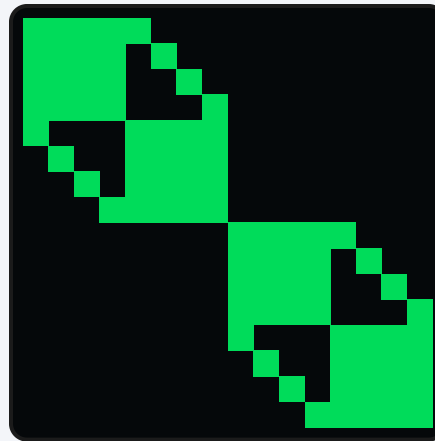
Bonus: Munching Squares

a living pattern from 1962

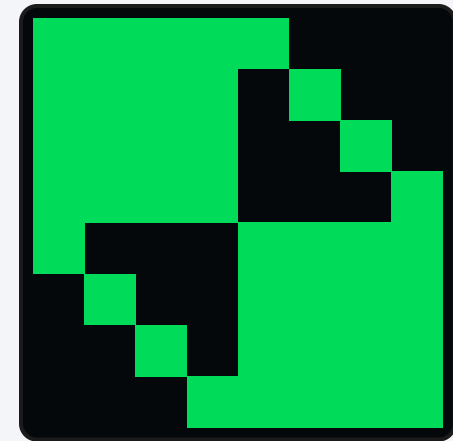
t = 6



t = 20



t = 40



▶ IN

▶ OUT

NOT

AND

XOR

OR

CNT6

▶

3×

1×

2×

2×

7×

1×

1×

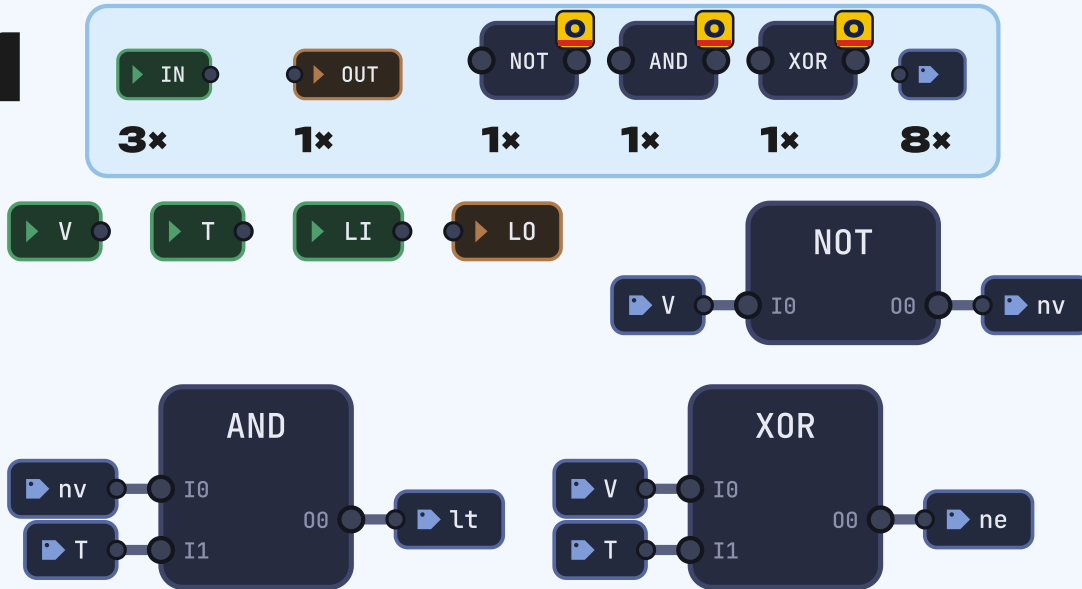
1×

∞

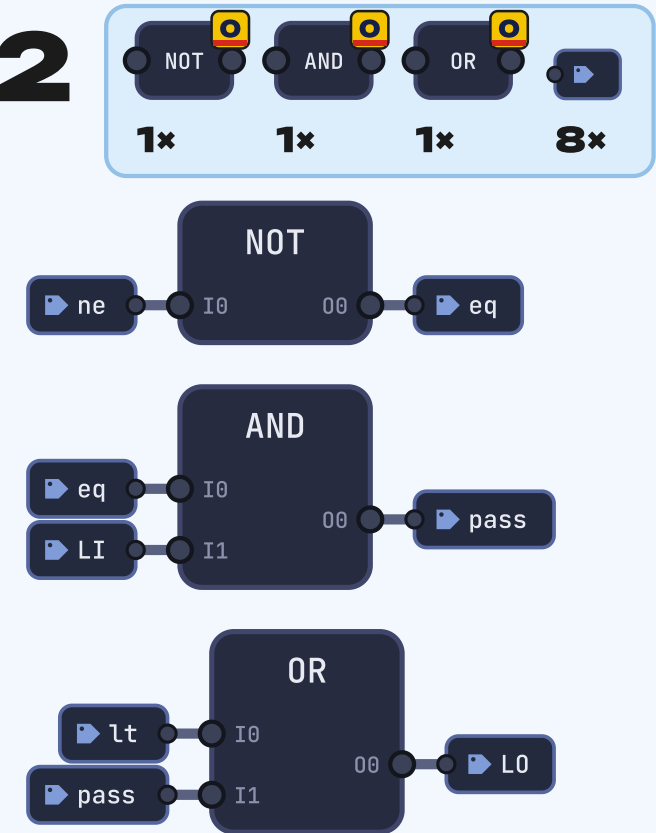
Ctrl + G > CMP1

CMP1

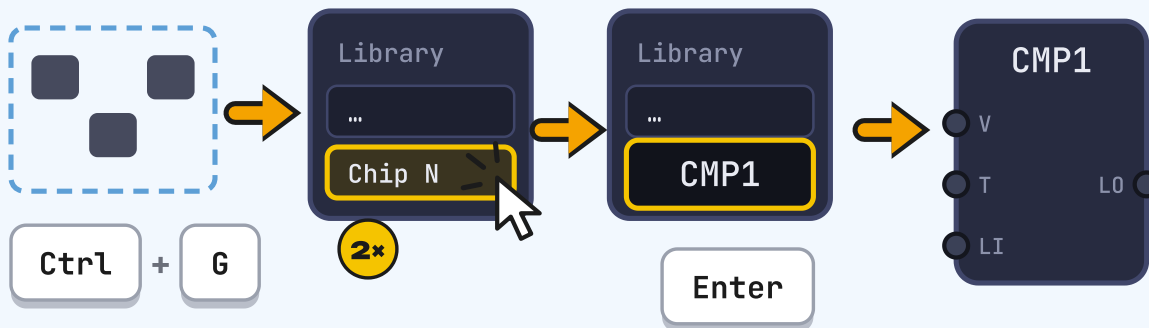
1



2



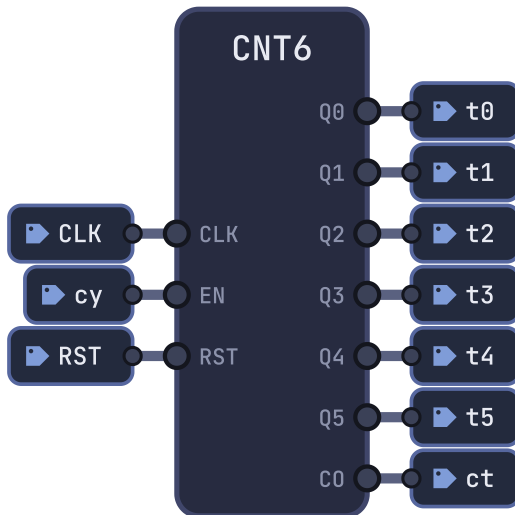
3



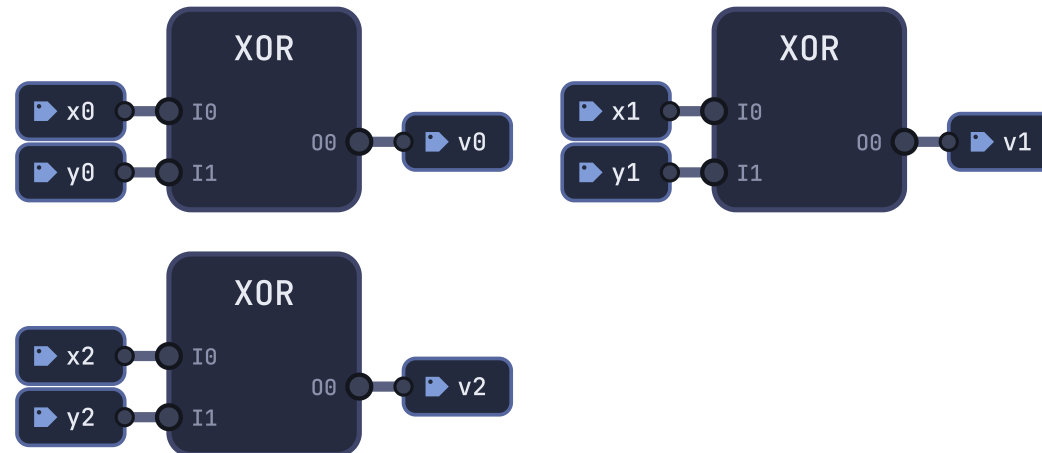
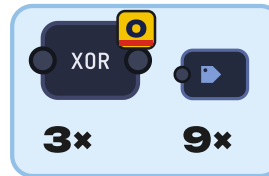
4

Dot display → ⦿: Layout Dots, 64 × 64, Port width 1 dot

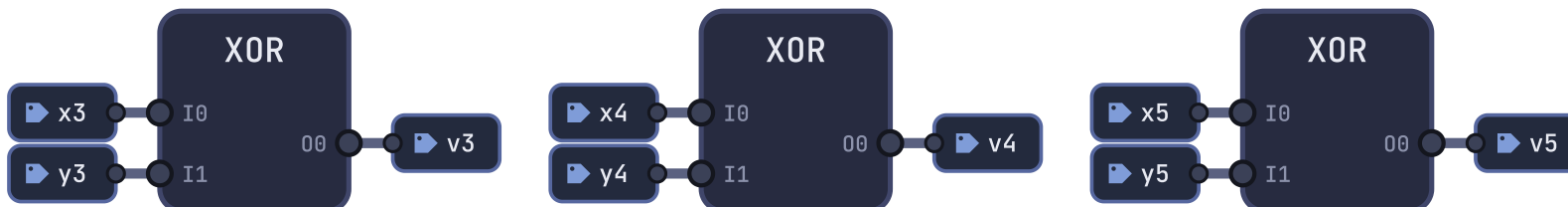
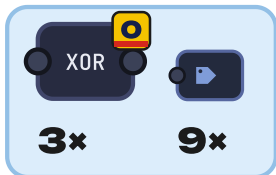
5



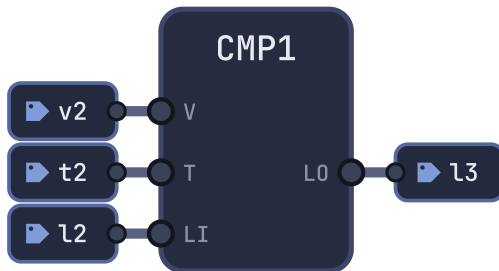
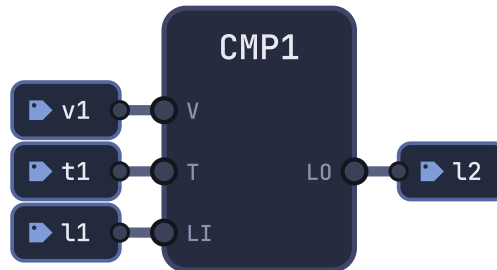
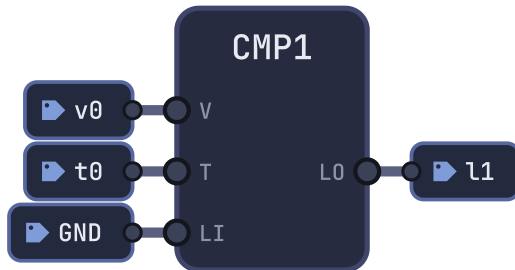
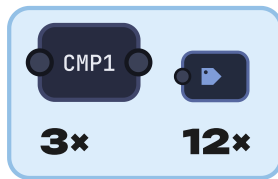
6



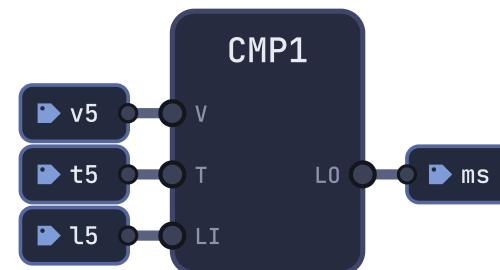
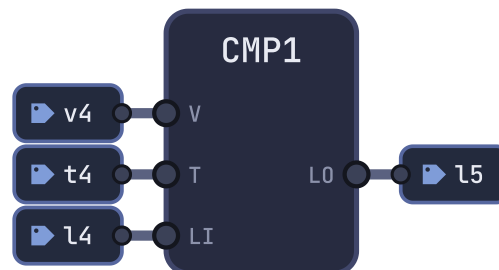
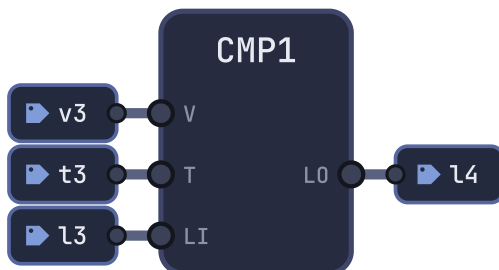
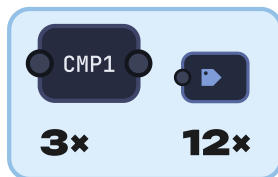
7



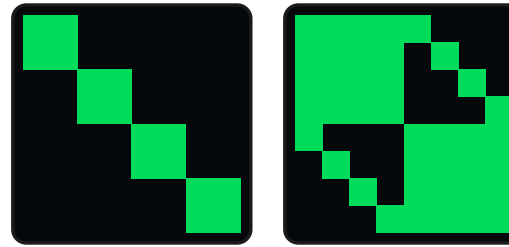
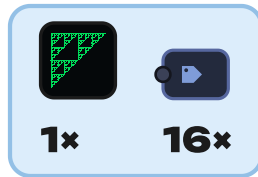
8



9



10



Kit parts

how many times you place each part over all the lessons



11×



11×



1×



1×



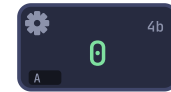
5×



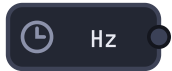
8×



3×



1×



2×



28×



28×



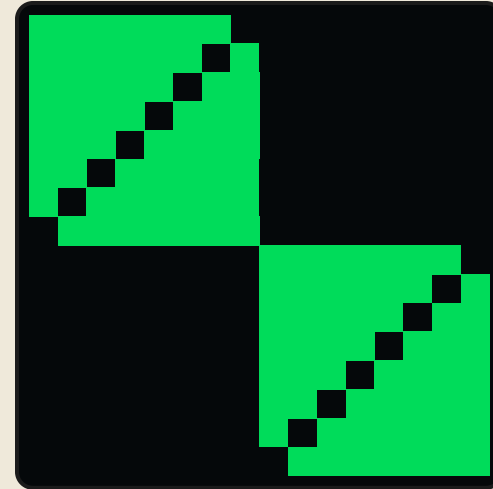
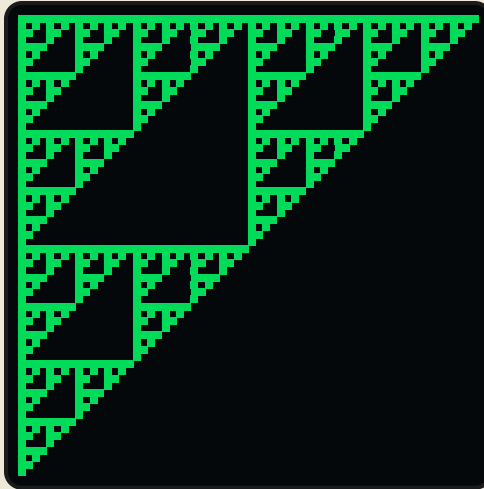
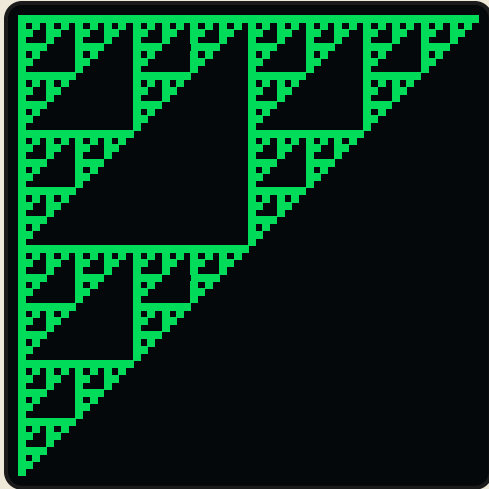
543×

Kit chips

you build them yourself: each one is made of the ones before



Done!



a machine of 3,064 transistors draws three screens

next: "Worlds of Mandelbrot and Julia"

Copyright

© 2026 Daniil Khanin, khanin.info. All rights reserved.

These instructions, the drawings and circuits are original work.
Reprinting, publishing online, selling or passing it on to others,
in whole or in part, is prohibited without the written permission of the author.

The latest version is at khanin.info.



khanin.info

HB-03