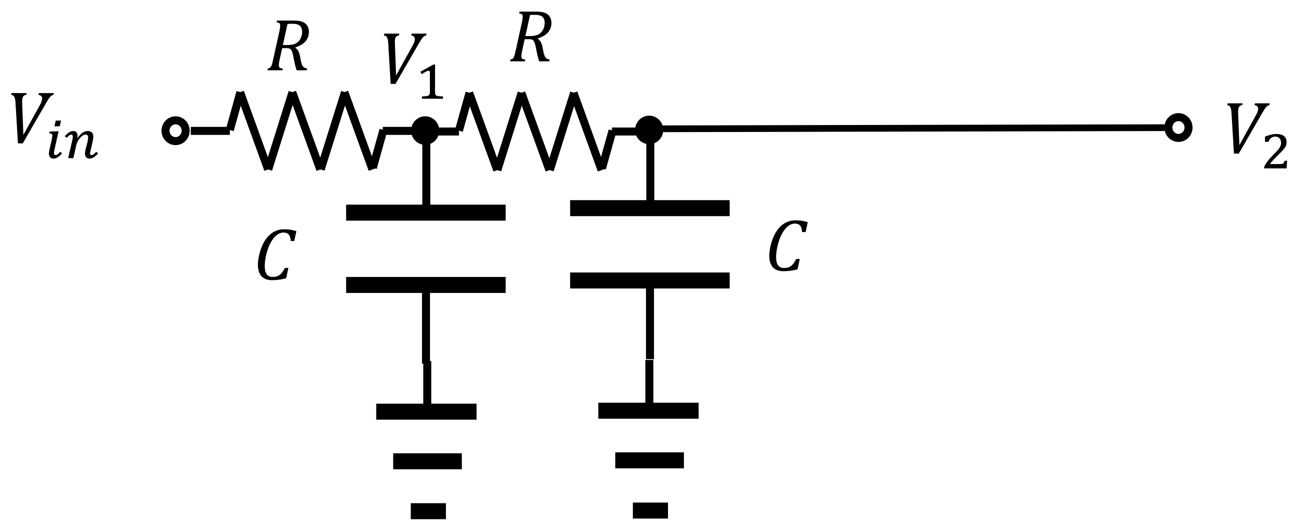
Digital Integrated Circuit
Lecture 13 Delay

Sung-Min Hong (smhong@gist.ac.kr)
Semiconductor Device Simulation Laboratory
School of Electrical Engineering and Computer Science
Gwangju Institute of Science and Technology

Review of Previous Lecture

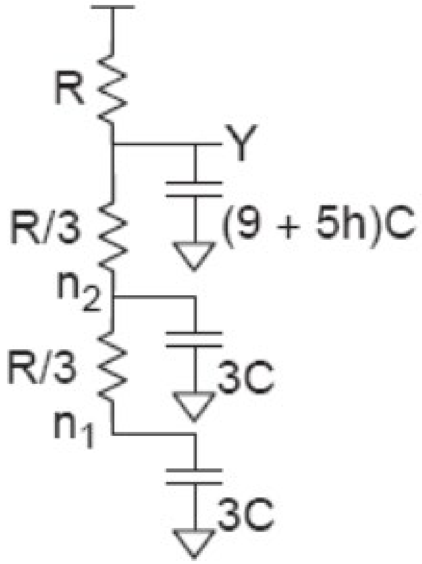
Lecture 12

- Elmore delay
  - When V_2 is the output voltage, $\tau = 3RC$.
  - When V_1 is the output voltage, $\tau = 2RC$.



Lecture 12

- Rising propagation delay
  - In the worst case, $\tau = (15 + 5h)RC$.



4.3 RC Delay Model

4.3. RC delay model (11)

- Delay components
  - *Parastic delay*: Time for a gate to drive its own internal diffusion capacitance
  - *Effort delay*: It depends on the ratio of external load capacitance to input capacitance.
  - The normalized delay, $d = \frac{t_{pd}}{3RC}$, can be written as

$$d = parastic\ delay + effort\ delay$$

4.3. RC delay model (12)

- Layout dependence of capacitance
  - A good layout minimizes the diffusion area.

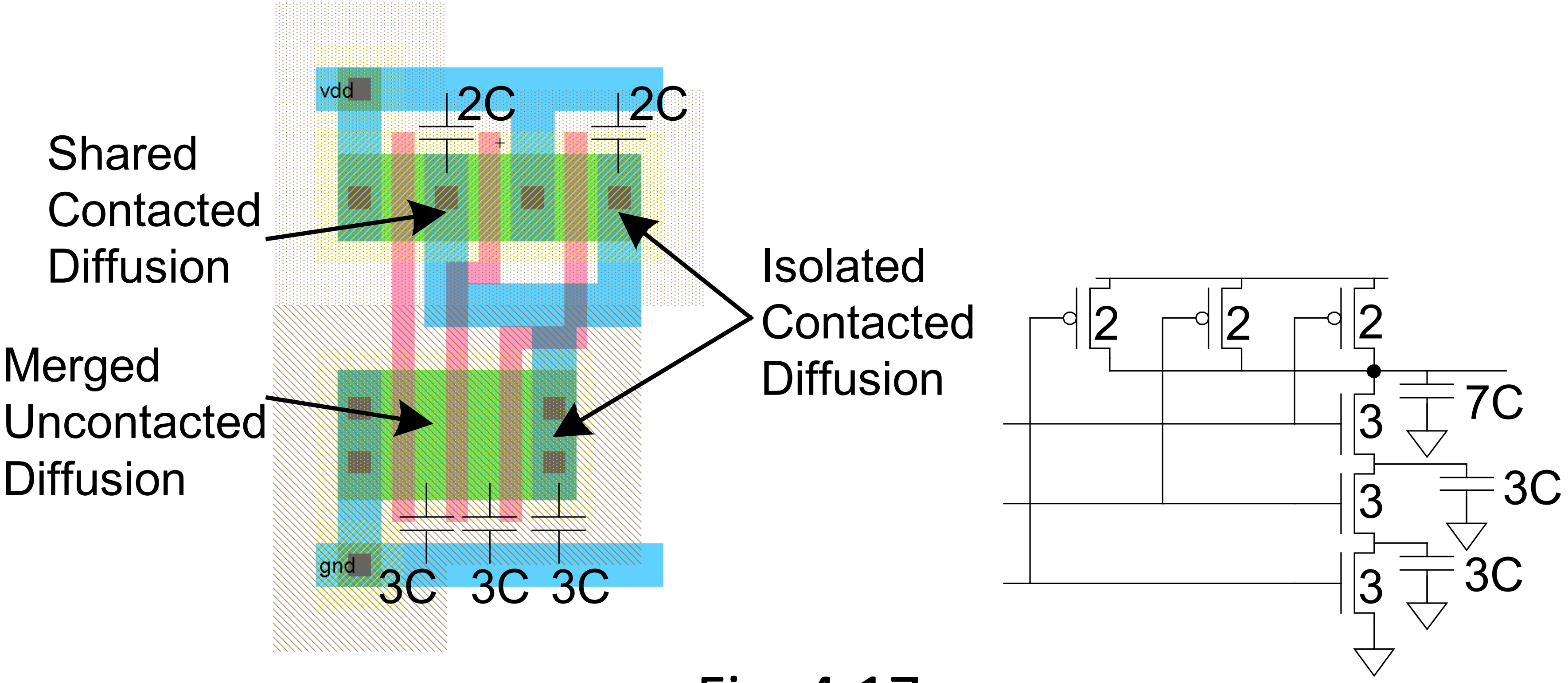


Fig. 4.17

4.4 Linear Delay Model

4.4. Linear delay model (1)

- Delay in a logic gate
  - Normalized delay

$$d = \frac{t_{pd}}{3RC}$$

  - Delay has two components:

$$d = f + p = gh + p$$

  - Effort delay:

$$f = gh$$

(g is the logical effort.)

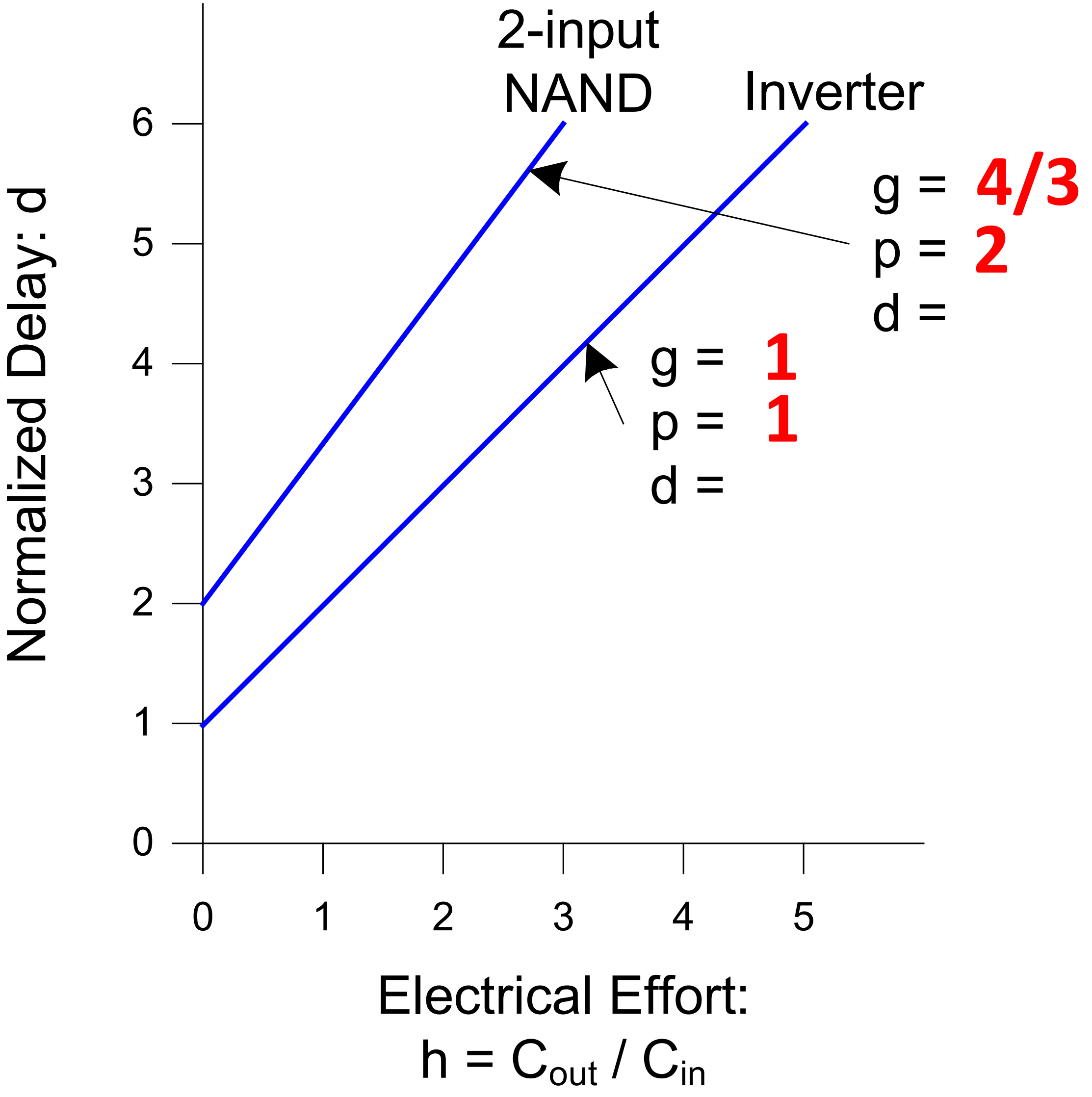
4.4. Linear delay model (2)

- Delay in a logic gate
  - Fanout (or electrical effort)

$$h = \frac{C_{out}}{C_{in}}$$

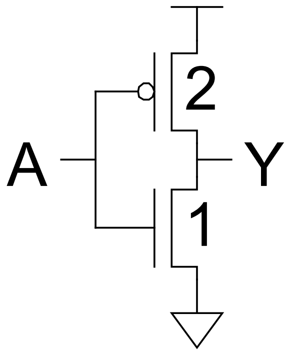
(Ratio of output to input capacitance)

  - Parasitic delay, p, represents delay of gate driving no load.
  - p is set by internal parasitic capacitance.

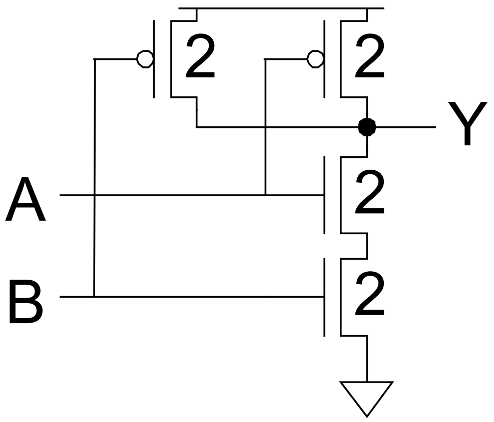


4.4. Linear delay model (3)

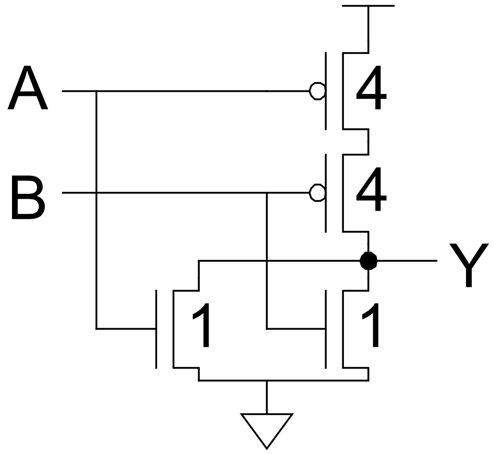
- Computing logical effort
  - *Logical effort is the ratio of the input capacitance of a gate to the input capacitance of an inverter delevering the same output current.*



C_{in} = 3
g = 3/3



C_{in} = 4
g = 4/3



C_{in} = 5
g = 5/3

4.4. Linear delay model (4)

- Logical effort of common gates

Gate type	Number of inputs				
	1	2	3	4	n
Inverter	1				
NAND		4/3	5/3	6/3	(n+2)/3
NOR		5/3	7/3	9/3	(2n+1)/3
Tristate / mux	2	2	2	2	2
XOR, XNOR		4, 4	6, 12, 6	8, 16, 16, 8	

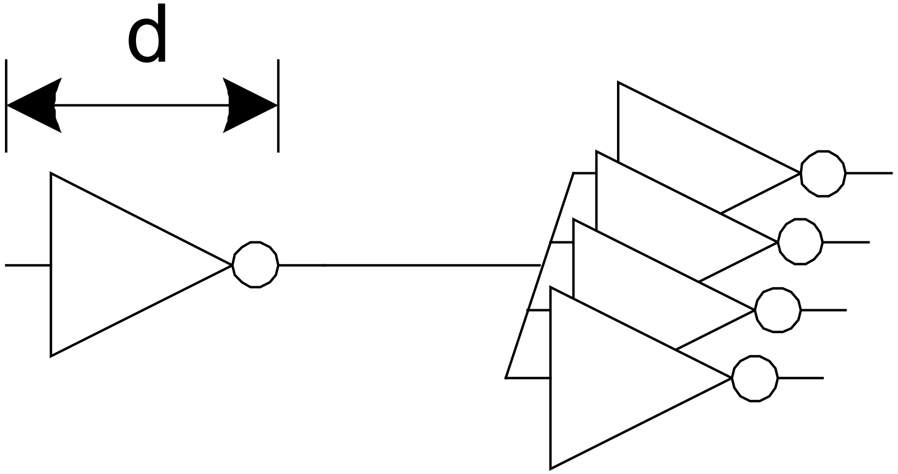
4.4. Linear delay model (5)

- Parasitic delay of common gates

Gate type	Number of inputs				
	1	2	3	4	n
Inverter	1				
NAND		2	3	4	n
NOR		2	3	4	n
Tristate / mux	2	4	6	8	2n
XOR, XNOR		4	6	8	

4.4. Linear delay model (6)

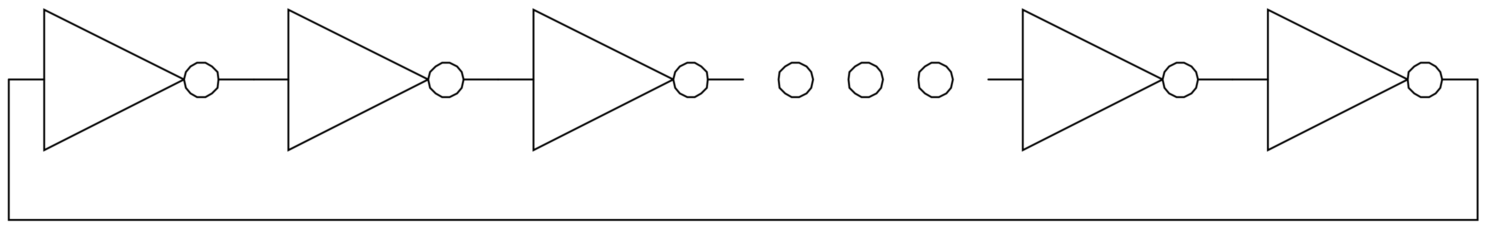
- Example 4.10



  - Logical effort: g = 1
  - Electrical effort: h = 4
  - Parasitic delay: p = 1
  - Stage delay: d = 5
  - When $\tau = 3RC = 3\ \mathrm{ps}$, the total delay is 15 ps.

4.4. Linear delay model (7)

- Example 4.11



  - A ring oscillator with an odd number (N) of inverters
  - Logical effort: g = 1
  - Electrical effort: h = 1
  - Parasitic delay: p = 1
  - Stage delay: d = 2
  - Frequency: $f_{osc} = \frac{1}{2Nd} = \frac{1}{4N}$

4.5 Logical Effort of Paths

4.5. Logical effort of paths (1)

- Multistage logic networks
  - Logical effort is independent of size.
  - Electrical effort depends on sizes.

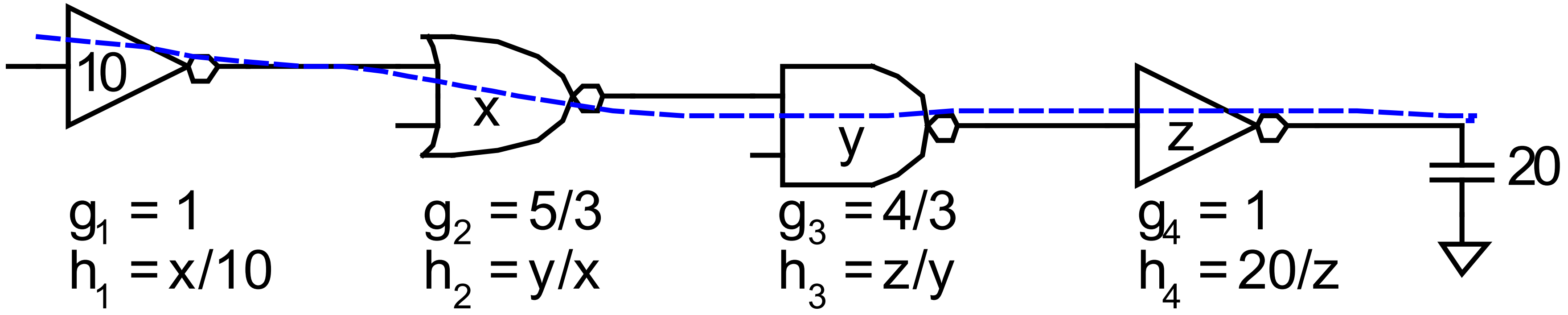


Fig. 4.29

  - What is the total propagation delay?

$$D = \frac{x}{10} + 1 + \frac{5}{3}\frac{y}{x} + 2 + \frac{4}{3}\frac{z}{y} + 2 + \frac{20}{z} + 1$$

4.5. Logical effort of paths (2)

- Minumum propagation delay?
  - Parasitic delay is given as 6.

$$D = 6 + \frac{x}{10} + \frac{5}{3}\frac{y}{x} + \frac{4}{3}\frac{z}{y} + \frac{20}{z}$$

  - Minimize the effort delay.
  - Recall the inequality of arithmetic and geometric means

$$f_1 + f_2 + \cdots + f_N \geq N \sqrt[N]{f_1 f_2 \ldots f_N}$$

The equality holds if and only if $f_1 = f_2 = \cdots = f_N$.

4.5. Logical effort of paths (3)

- Product of effort delays is a constant.
  - In our example,

$$D = 6 + \frac{x}{10} + \frac{5}{3}\frac{y}{x} + \frac{4}{3}\frac{z}{y} + \frac{20}{z} \geq 6 + 4\sqrt[4]{\frac{40}{9}}$$

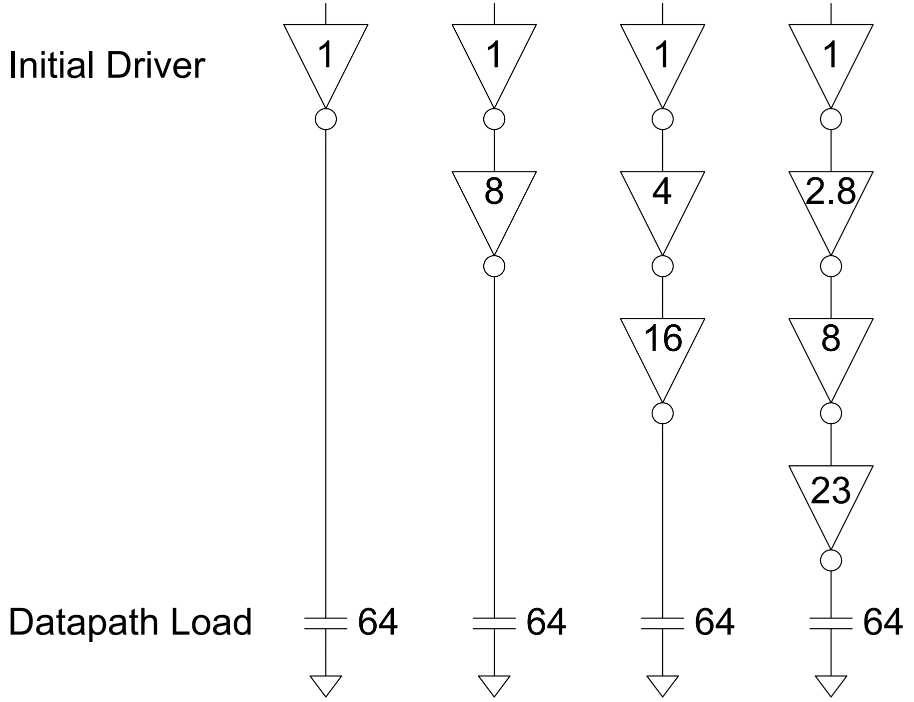
  - The equality holds when $\frac{x}{10} = \frac{5}{3}\frac{y}{x} = \frac{4}{3}\frac{z}{y} = \frac{20}{z} = \sqrt[4]{\frac{40}{9}} \approx 1.45.$
- Minimum possible delay of an N–state path

$$D = N\sqrt[N]{F} + P$$

  - F: Path effort
  - P: Path parasitic delay

4.5. Logical effort of paths (4)

- Exampe 4.14
  - Determine the number of stages.
  - $N = 1: D = 1 + 64$
  - $N = 2: D = 2 + 2\sqrt{64}$
  - $N = 3: D = 3 + 3\sqrt[3]{64}$



N:	1	2	3	4
f:	64	8	4	2.8
D:	65	18	15	15.3

Fastest

Thank you!