

# DOGGO 151/251A SP2022 Discussion 8

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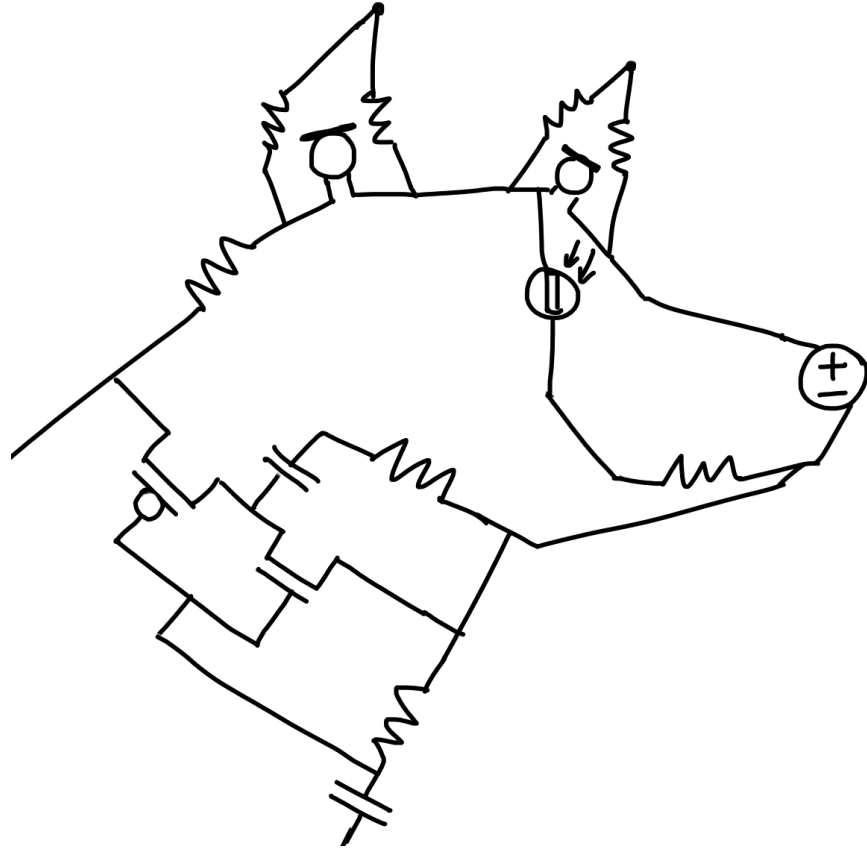
GSI: DIMA NIKIFOROV, YIKUAN CHEN



# Agenda

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- Power/Energy
- Adders

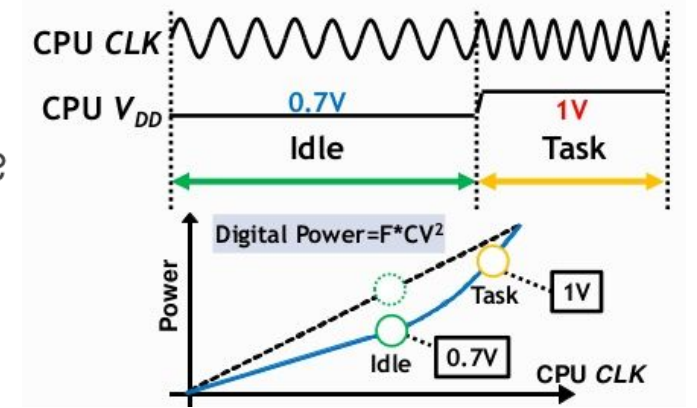


# Energy

# Power/Energy in Digital Circuits

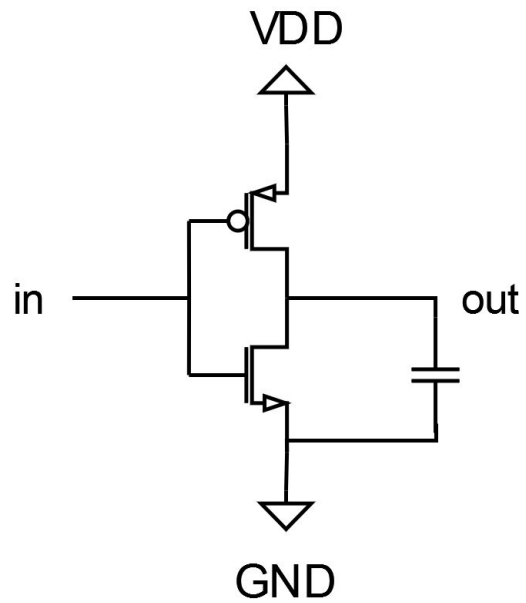
- Fundamentally, charging/discharging capacitors (gate, parasitic, load) through resistances (PMOS, NMOS, wires)
  - Capacitors draw  $CV^2$  joules from supply over 1 charge/discharge cycle
    - $\frac{1}{2}CV^2$  dissipated in PMOS as heat when charging
    - $\frac{1}{2}CV^2$  stored on capacitor, then dissipated in NMOS when discharging
- Dynamic power =  $P_{\text{switching}} = aCV^2f$ 
  - How to minimize each term?
  - Minimizing which terms reduces total energy consumed?
- Static power = leakage  $\rightarrow$  wasted energy!

Dynamic Voltage and Frequency Scaling (DVFS)

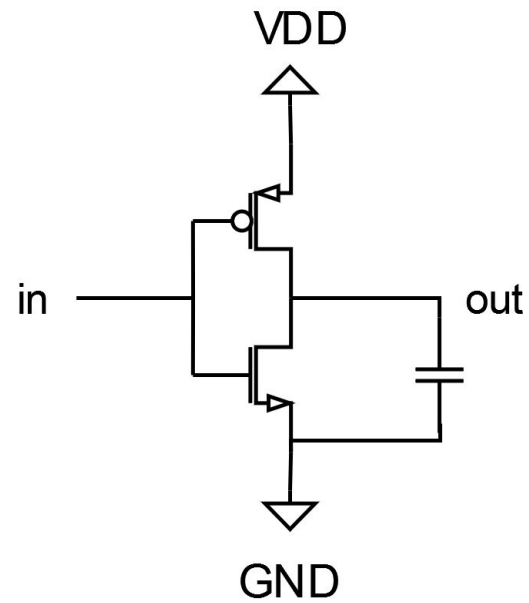


# Power/Energy in Digital Circuits Causes

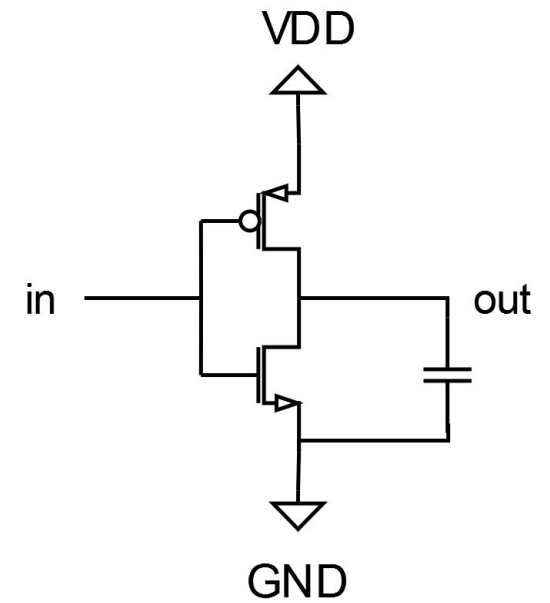
Dynamic Power



Switching Power

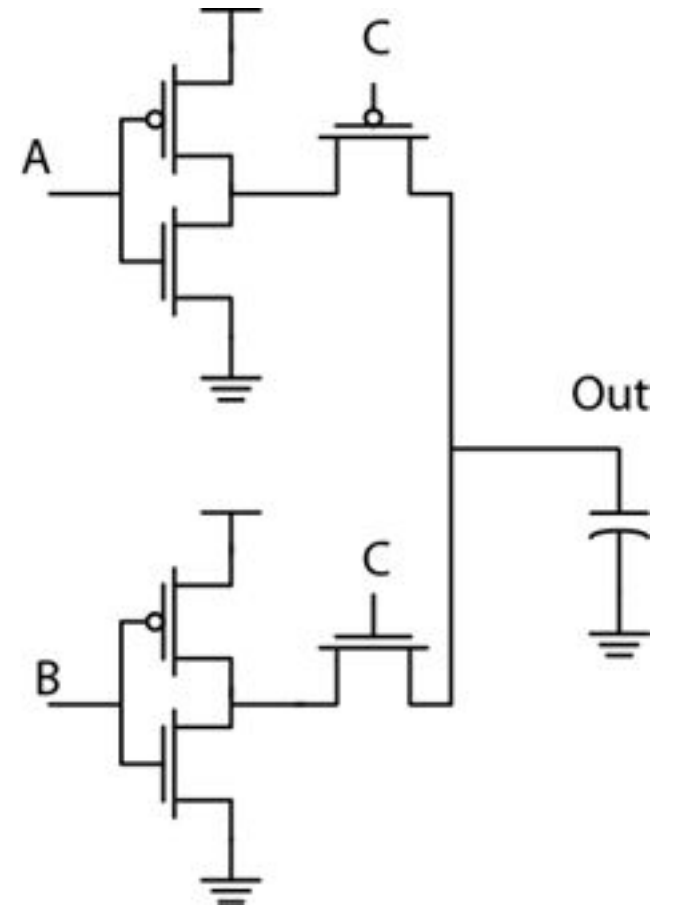


Leakage Power



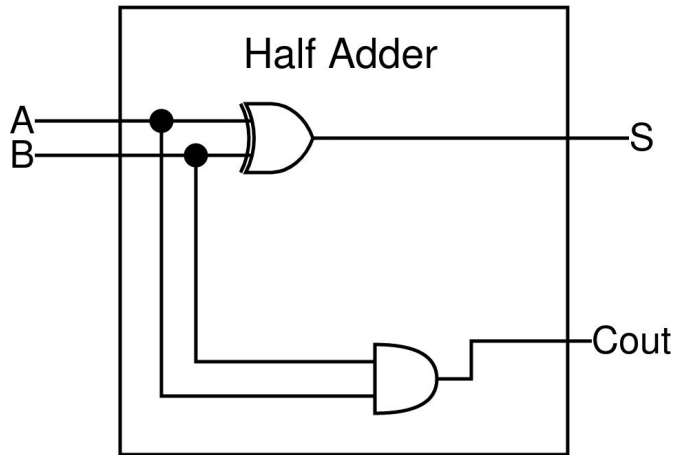
# Energy Example

- Initially:  $A = 1, C = 1, \text{Out} = 0$
- Energy pulled from supply when  $B = 1 \rightarrow 0$ ?
  
- Then, how much energy dissipated when  $C = 1 \rightarrow 0$ ?



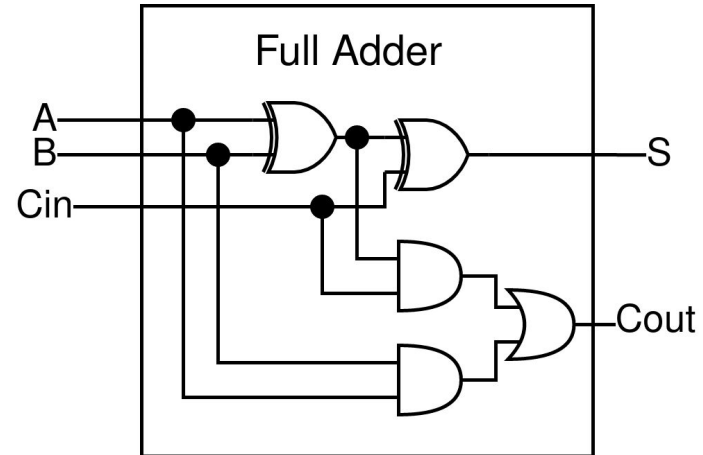
# Adders

# Adder Components



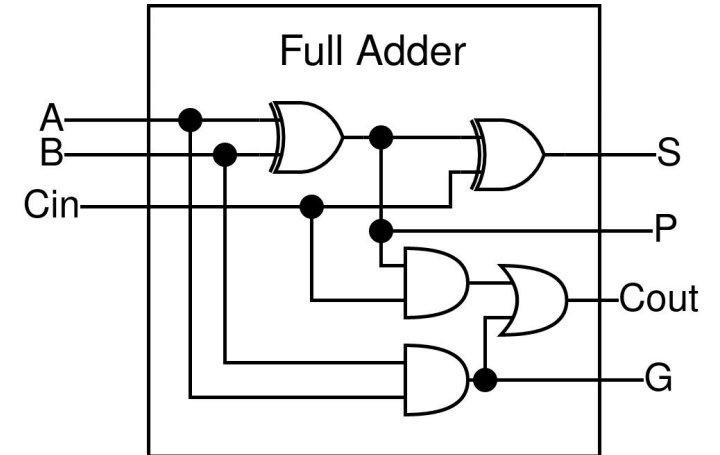
$$S = A \oplus B$$

$$C_o = A B$$



$$S = A \oplus B \oplus C_i$$

$$C_o = A B + B C_i + A C_i$$

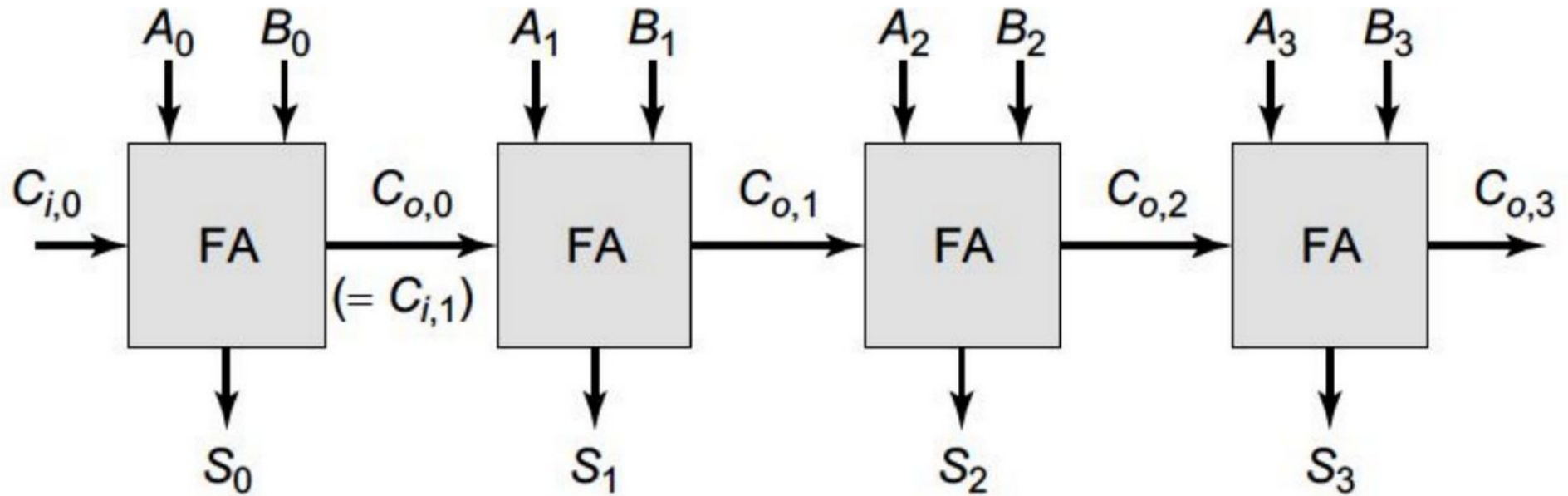


$$P = A \oplus B$$

$$G = A B$$

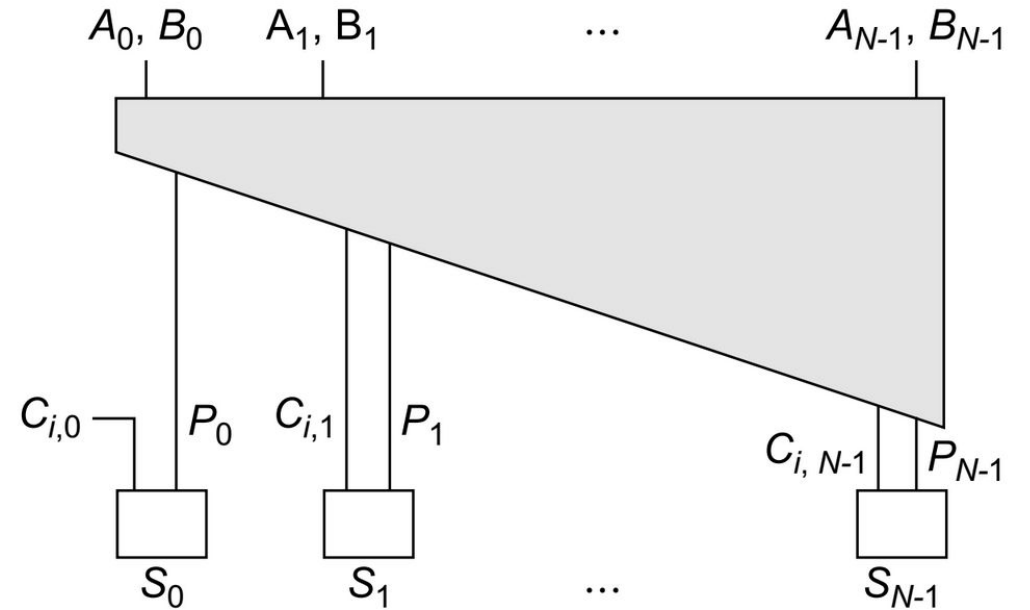
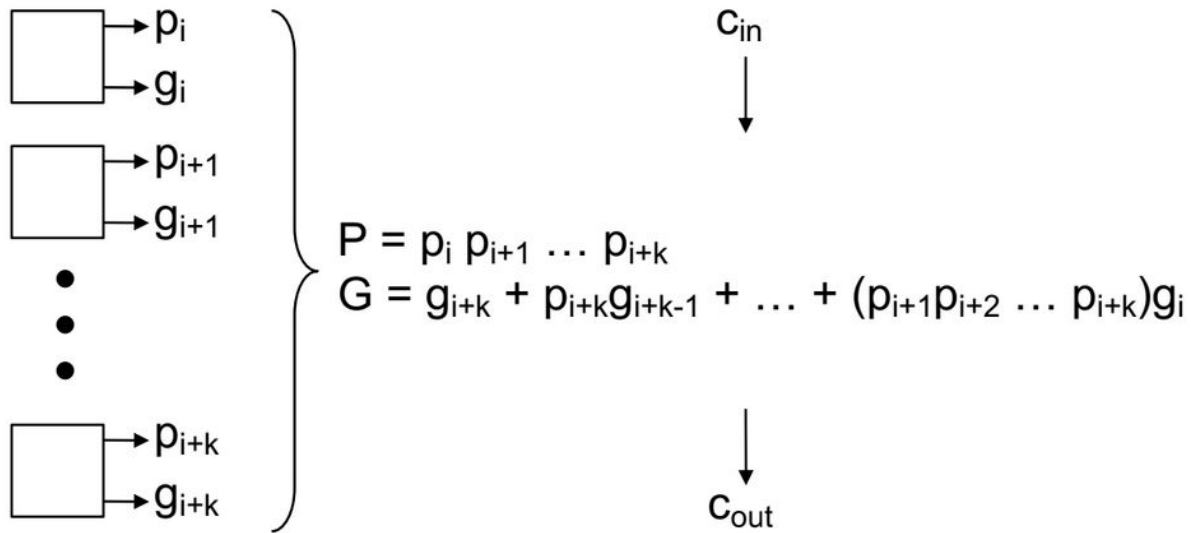


# Ripple-Carry Adder



- Time Complexity?
- Area Complexity?

# Carry-Lookahead Adder



$$C_{o,k} = f(A_k, B_k, C_{o,k-1}) = G_k + P_k C_{o,k-1}$$

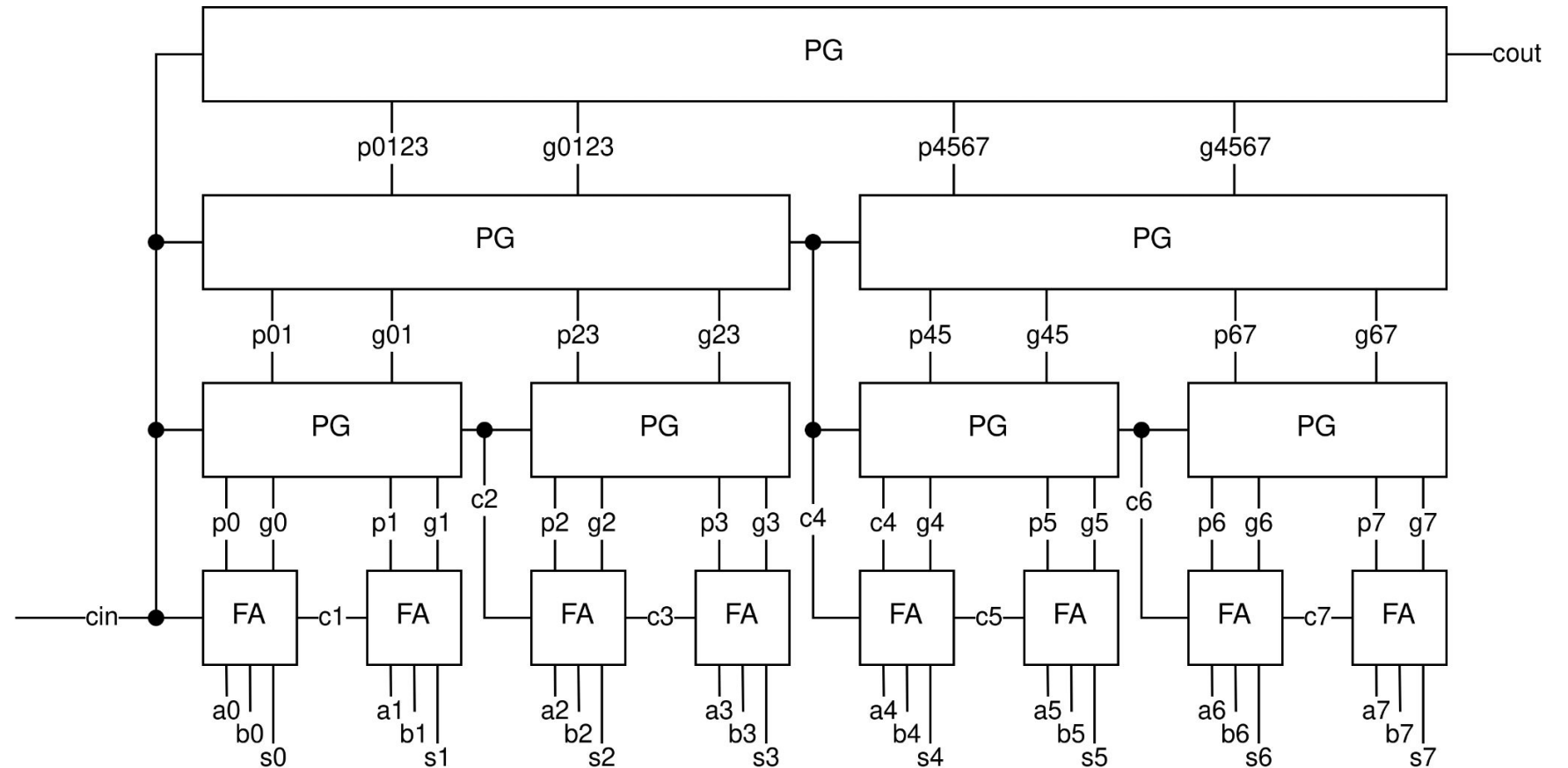
- Time Complexity?
- Area Complexity?

# Carry-Lookahead Tree Adder

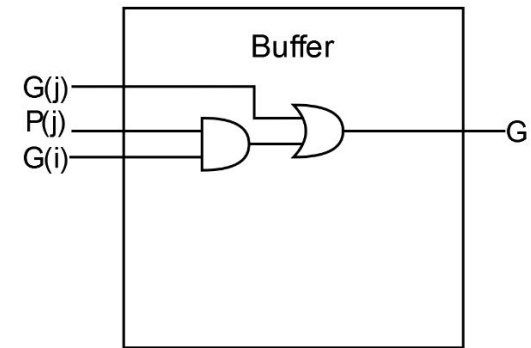
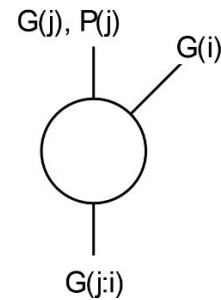
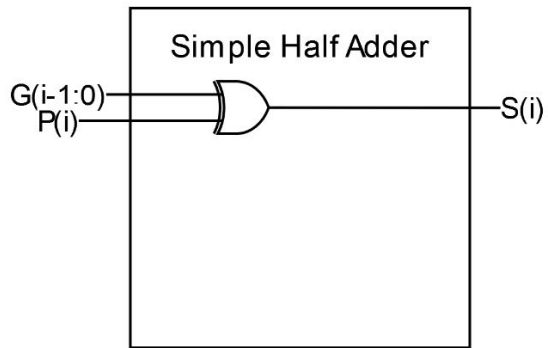
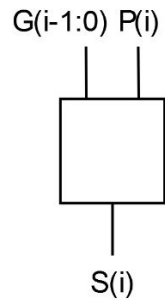
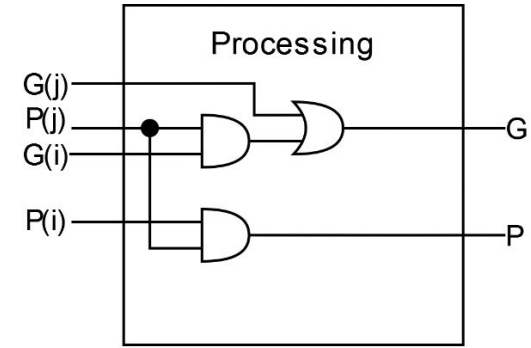
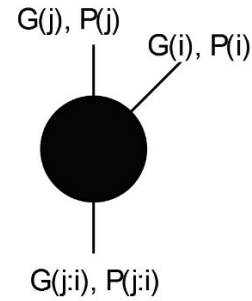
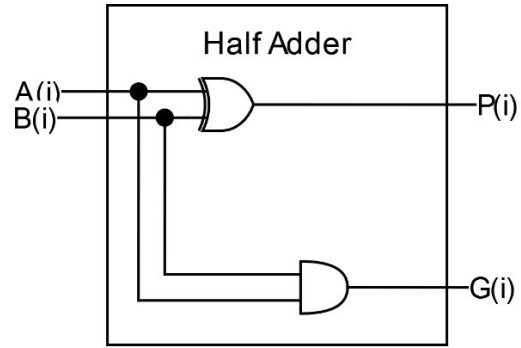
- Time Complexity?

$$P_{1:0} = P_1 \cdot P_0, G_{1:0} = G_1 + P_1 \cdot G_0, \rightarrow C_{out1} = G_{1:0} + P_{1:0} \cdot C_{0,in}$$

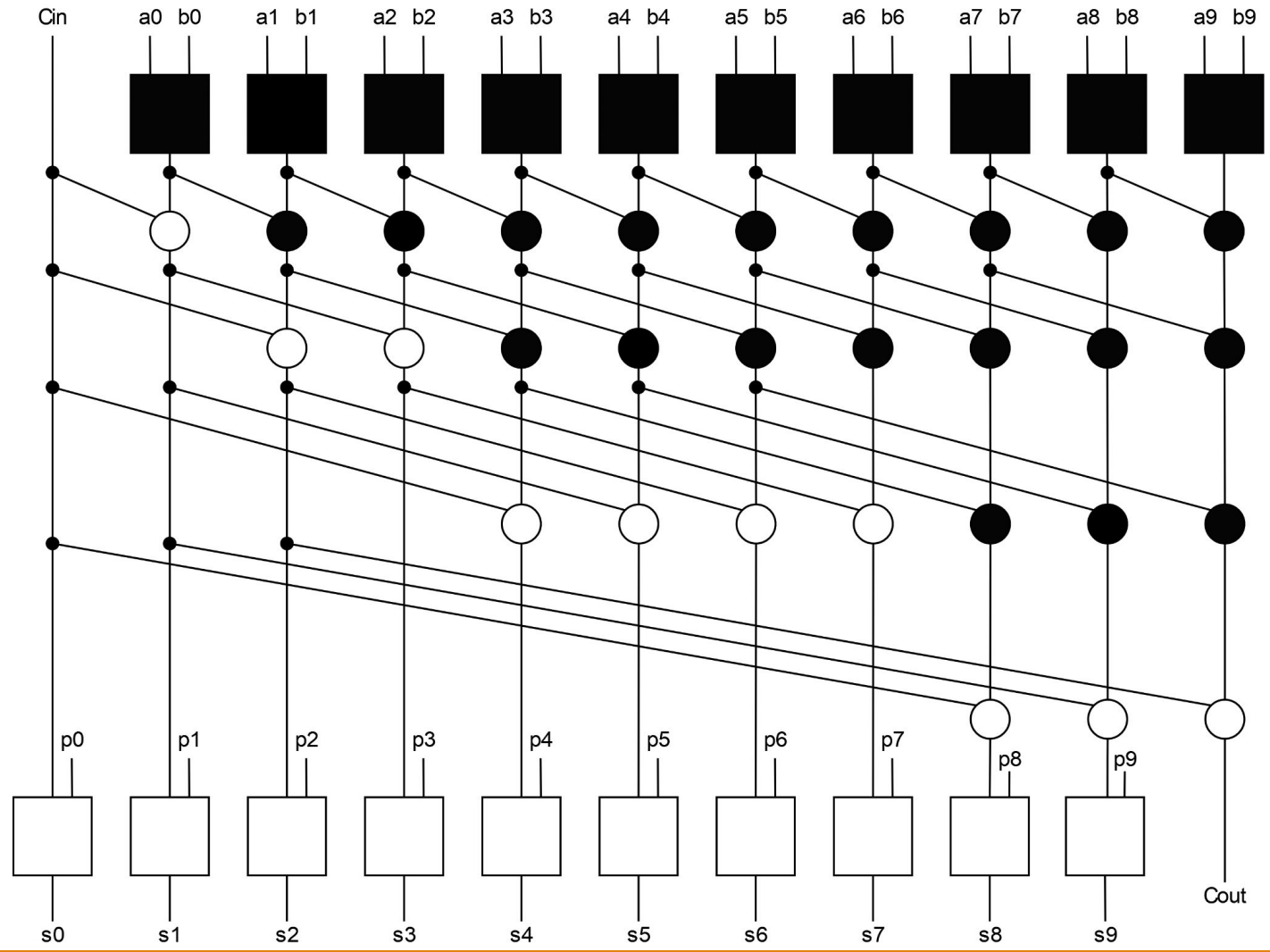
- Area Complexity?



# Kogge-Stone Tree Adder (Components)



# Kogge-Stone Tree Adder



# Doggo Adder



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# Questions?