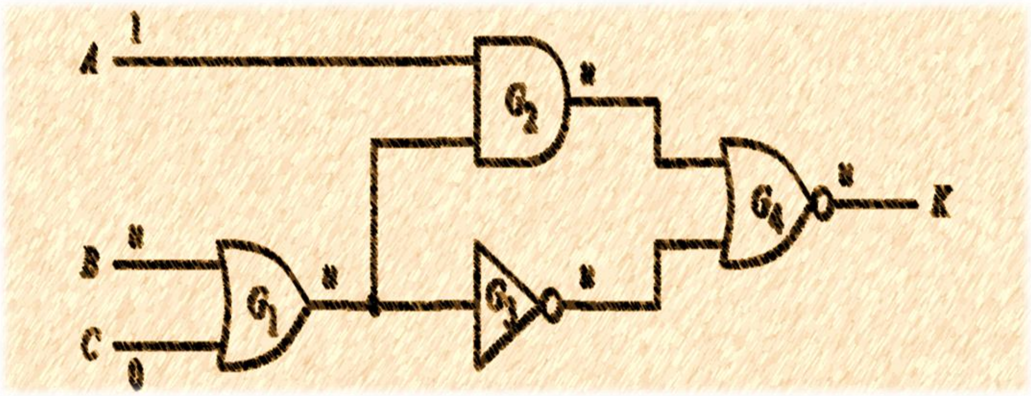
Logic Simulation

- Introduction
- **Simulation Models**
  - Logic States
  - Logic Gate Evaluation
  - Delay Models
- Logic Simulation Techniques
- Issues of Logic Simulations
- Conclusions



Logic States

- *Binary logic* (0,1)
- *Three-valued logic* (0,1, *u*) aka. *Ternary logic* [Eichelberger 65]
  - *u* (unknown) for logic value cannot be determined
    - aka. "x"
- *Four-valued logic* (0,1, *u,z*)
  - *z* = floating node without conducting path to VDD or GND
    - *aka. high impedance*
  - Note: do not confuse "*u*" and "*z*"

AND	0	1	u	z
0	0	0	0	0
1	0	1	u	u
u	0	u	u	u
z	0	u	u	u

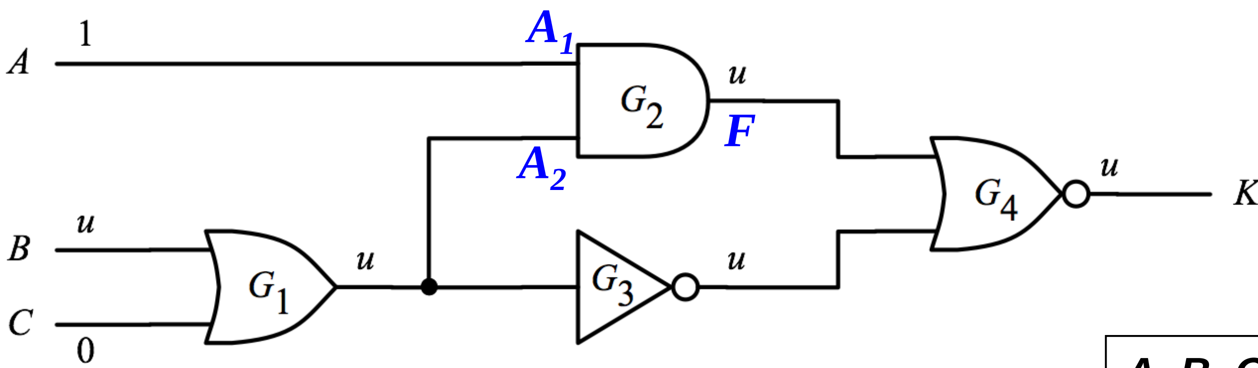
OR	0	1	u	z
0	0	1	u	u
1	1	1	1	1
u	u	1	u	u
z	u	1	u	u

NOT	0	1	u	z
	1	0	u	u

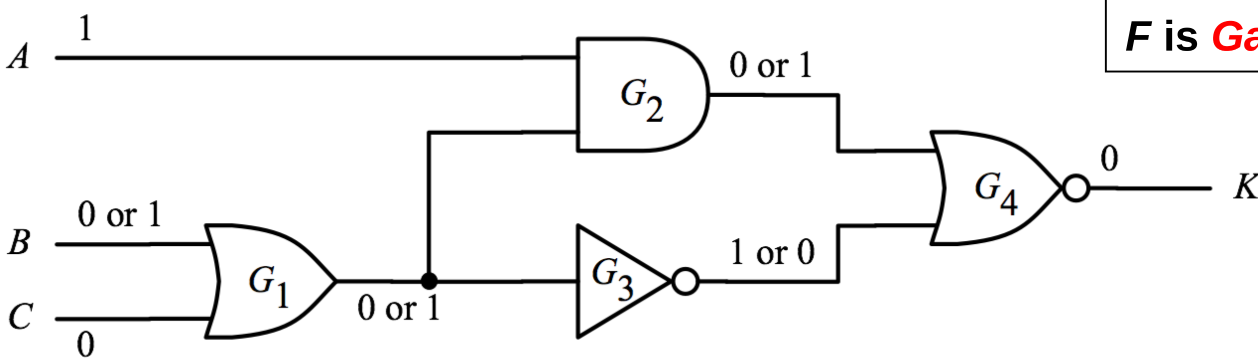
More States, More Accuracy, More CPU Time

Ternary Logic Simulation

- **Problem: output *K* should be zero**



(a) Ternary logic simulation: $K = u$

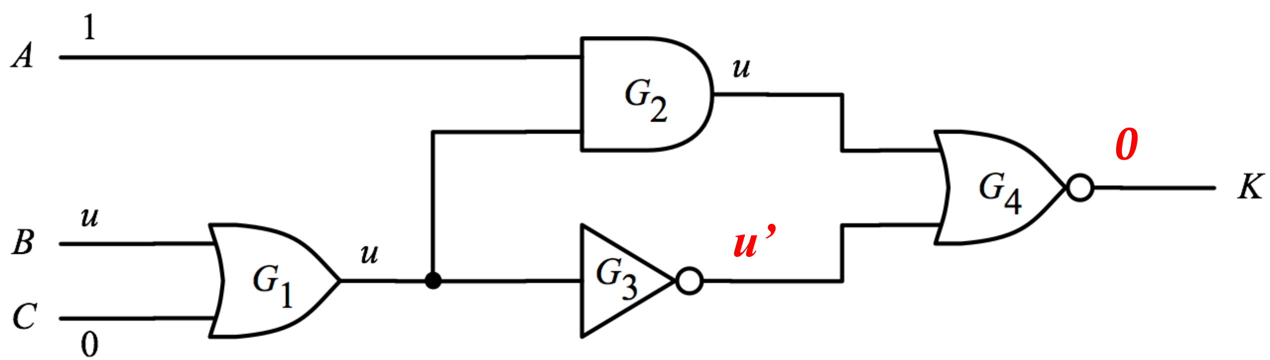


(b) Enumerate all possible cases ($B = 0$ and 1): $K = 0$

A, B, C **are** ***Primary Inputs (PI)***
A_1 A_2 are Gate Inputs ***for G_2***
K **is** ***Primary Output (PO)***
F **is** ***Gate Output*** ***for G_2***

Possible Solution

- Introduce *u*’ to represent inverse of *u*



- What is problem with this solution?
  - For every different source of *u*, need one unique *u*’
    - Too many *u*’s !
    - Need *symbolic simulation* to distinguish all *u*’s

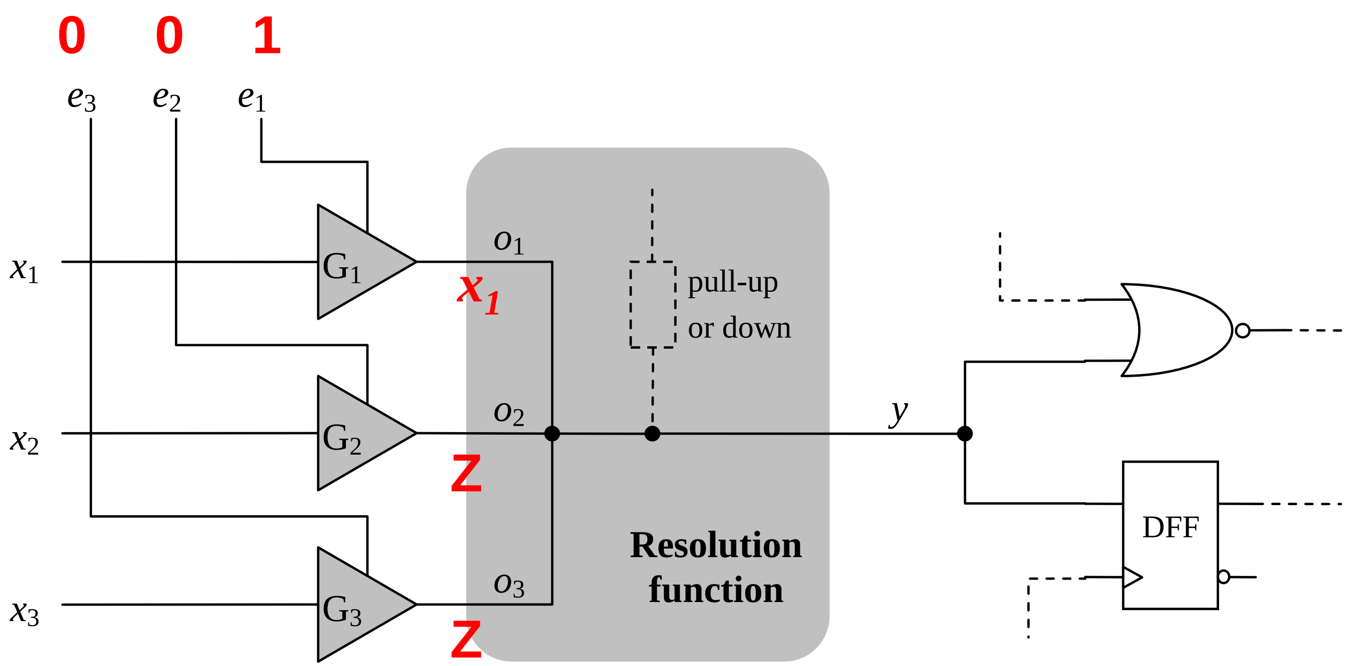
Moral: Simulation Results not 100% accurate.
Must Check!

High Impedance State (Z)

- **Tri-state bus driver**

$$o_i = \begin{cases} x_i & if\ e_i = 1 \\ Z & if\ e_i = 0 \end{cases}$$

- **Only one driver enabled at a time**
  - ***e_1,e_2, e_3* are *one-hot signals***

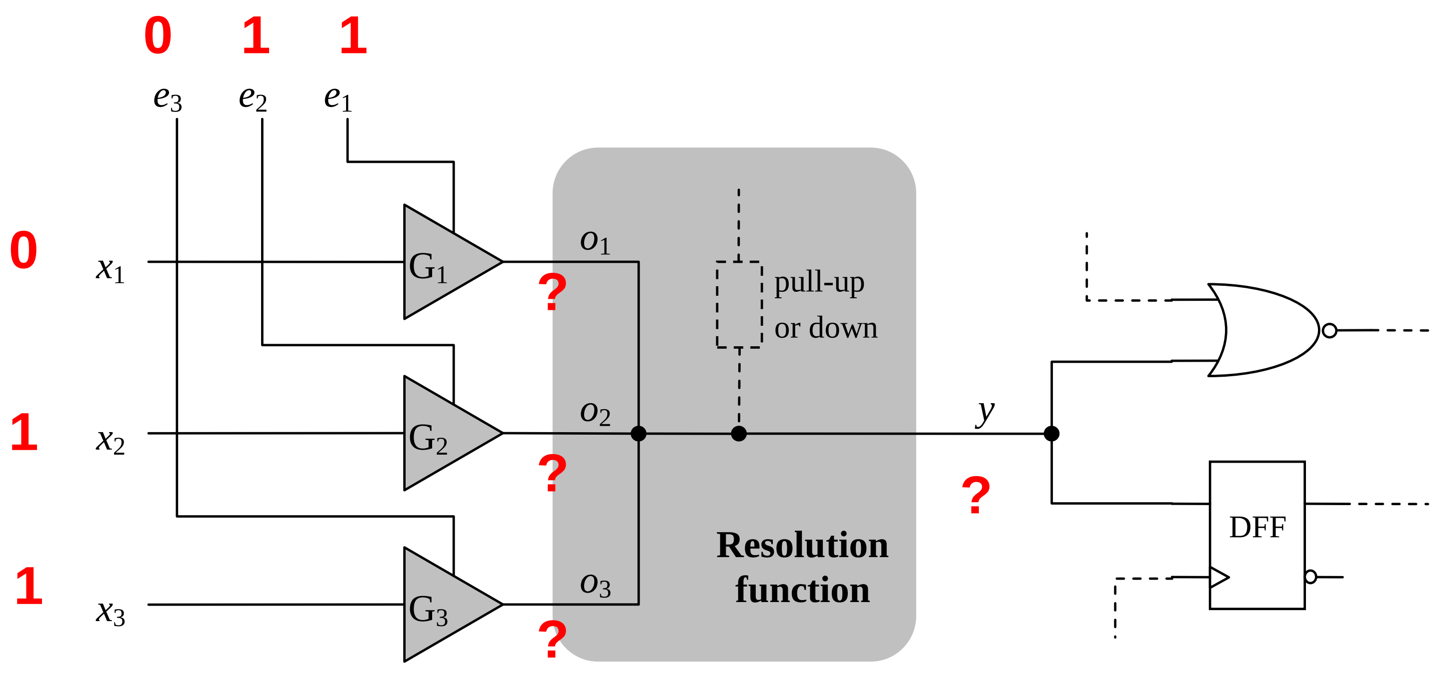


(WWW Fig 3.6)

Quiz

Q: If e_1,e_2, e_3 are NOT one-hot signals what is y?

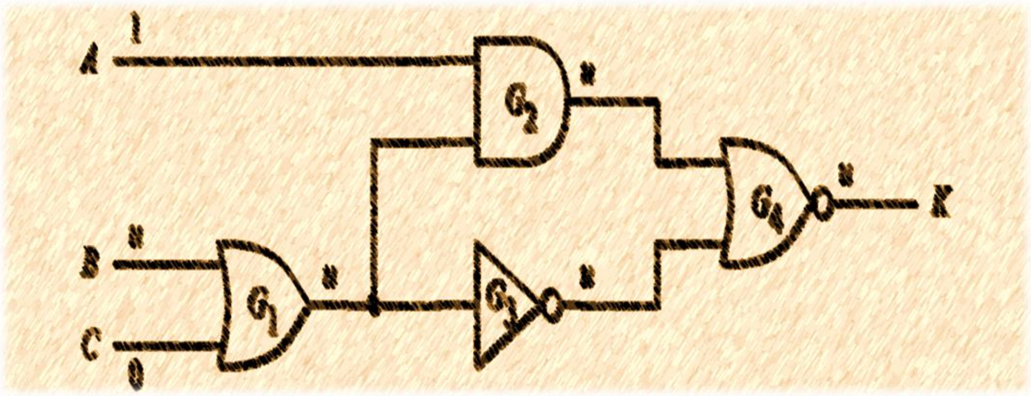
A:



(WWW Fig 3.6)

Logic Simulation

- Introduction
- <u>Simulation Models</u>
  - Logic States
  - <u>Logic Gate Evaluation</u>
    - <u>Truth table</u>
    - Input scanning
  - Delay Models
- Logic Simulation Techniques
- Issues of Logic Simulations
- Conclusions



Gate Evaluation Using Truth Table

- **Determine output value based on a pre-stored truth table**
- **Example: 4-valued logic truth table**

AND	0	1	u	z
0	0	0	0	0
1	0	1	u	u
u	0	u	u	u
z	0	u	u	u

OR	0	1	u	z
0	0	1	u	u
1	1	1	1	1
u	u	1	u	u
z	u	1	u	u

NOT	0	1	u	z
	1	0	u	u

Quiz:

What is size of truth table for n-input gate using 4 valued-logic?

A:

- **Practical implementation**
  - **Break n-input gate into multiple 2-input gates**
  - **Use for-loop to evaluate gate one by one**

Input Scanning

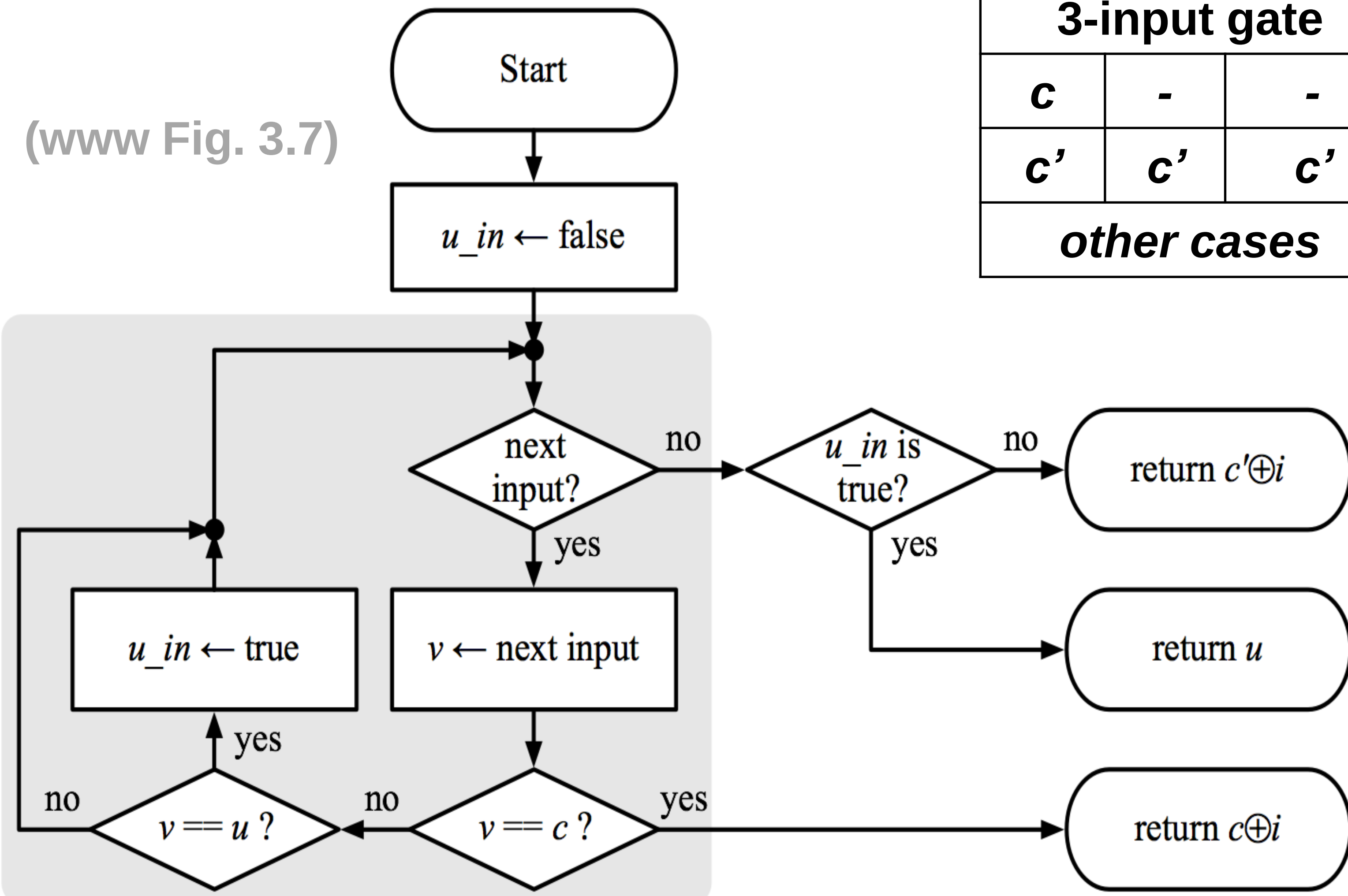
- Idea: check gate inputs one by one
  - Determine gate output by number of *c, i, u*
- Gates can be characterized by *
  - *Controlling value, c*
    - *c* = input value that decides gate output
    - regardless of other gate inputs
  - Inversion, *i*
    - *i* =1, gate output is inverted w.r.t. gate input
    - *i* =0, otherwise

	c	*i*
AND	0	0
OR	1	0
NAND	0	1
NOR	1	1

*Assumes only elementary gates : AND, OR, NAND, and NOR

Input Scanning Algorithm

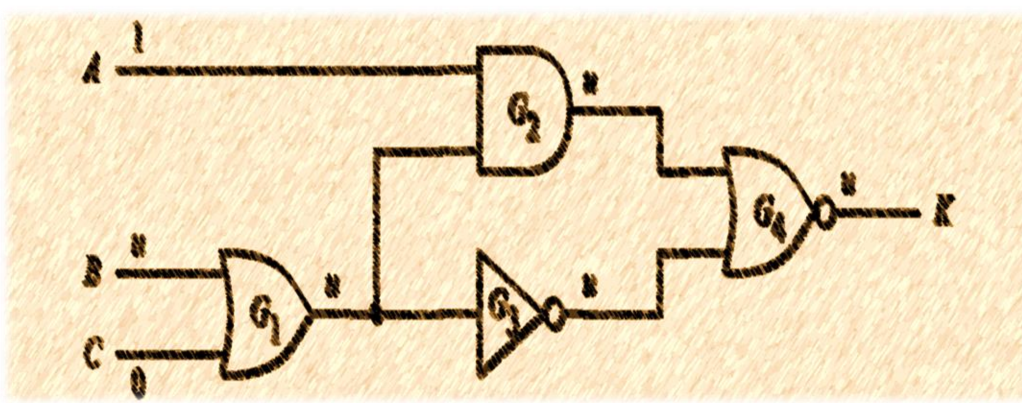
(www Fig. 3.7)



3-input gate			O/P
c	-	-	*c*⊕*i*
c'	*c'*	*c'*	*c'*⊕*i*
other cases			*u*

Logic Simulation

- Introduction
- Simulation Models
    - Logic States
    - Logic Gate Evaluation
    - Delay Models
        - Gate delay model
        - Wire delay (not in lecture)
- Logic Simulation Techniques
- Issues of Logic Simulations
- Conclusions



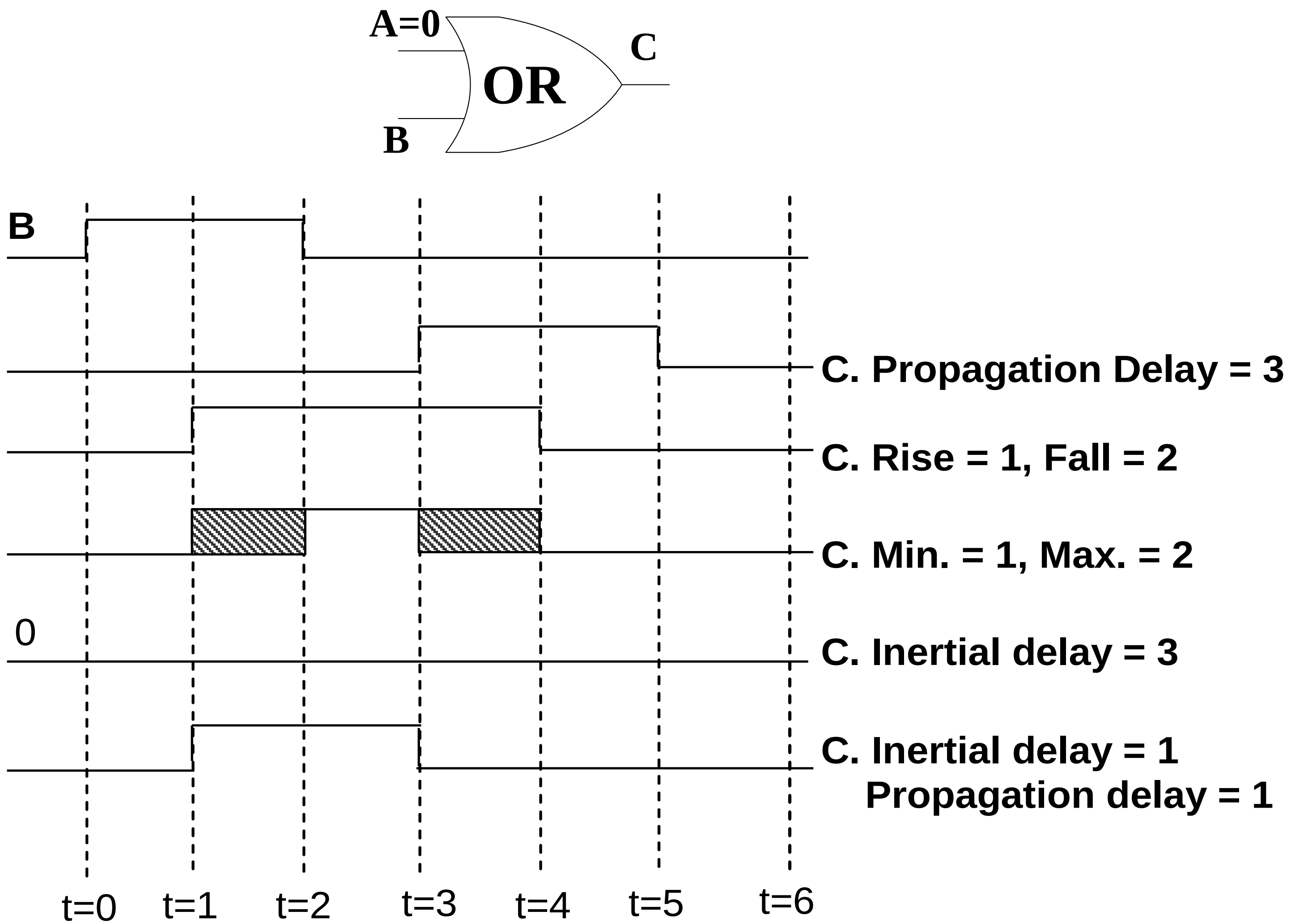
Gate Delay Models

- ***Propagation delay* (aka. *Transport delay*)**
  - **DEF: time from gate input change to output change**
    - ***Zero delay*: prop. delay of all gates is zero**
    - ***Unit delay:* prop. delay of all gates is 1 time unit**
    - ***Multiple delay:* prop. delay is multiple of some time unit**
    - ***Rise delay, fall delay***

- ***Ambiguous delay model***
  - ***Max delay, Min delay*, *Typical (nominal) delay***
- ***Inertial delay model***
  - **Minimum amount of time during which a signal must persist at gate input in order to change gate output**

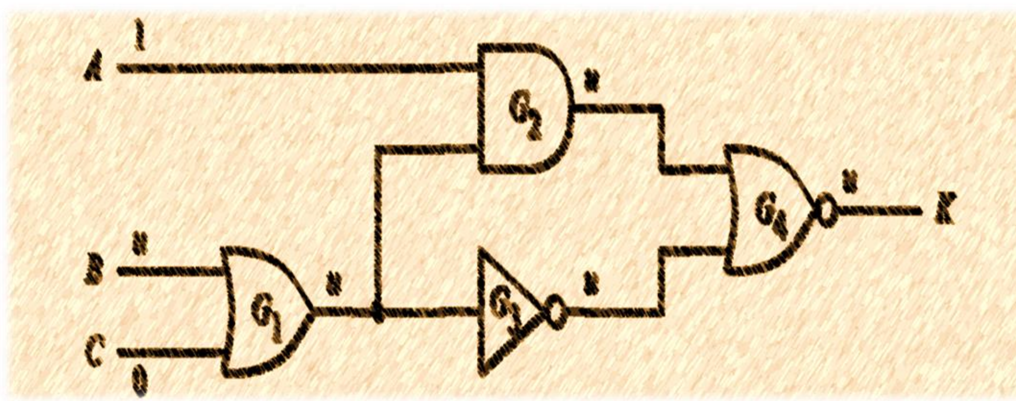
Different Delay Model, Different Usage

Example


A=0
B
OR
C
B
C. Propagation Delay = 3
C. Rise = 1, Fall = 2
C. Min. = 1, Max. = 2
0
C. Inertial delay = 3
C. Inertial delay = 1
Propagation delay = 1
t=0
t=1
t=2
t=3
t=4
t=5
t=6

Summary

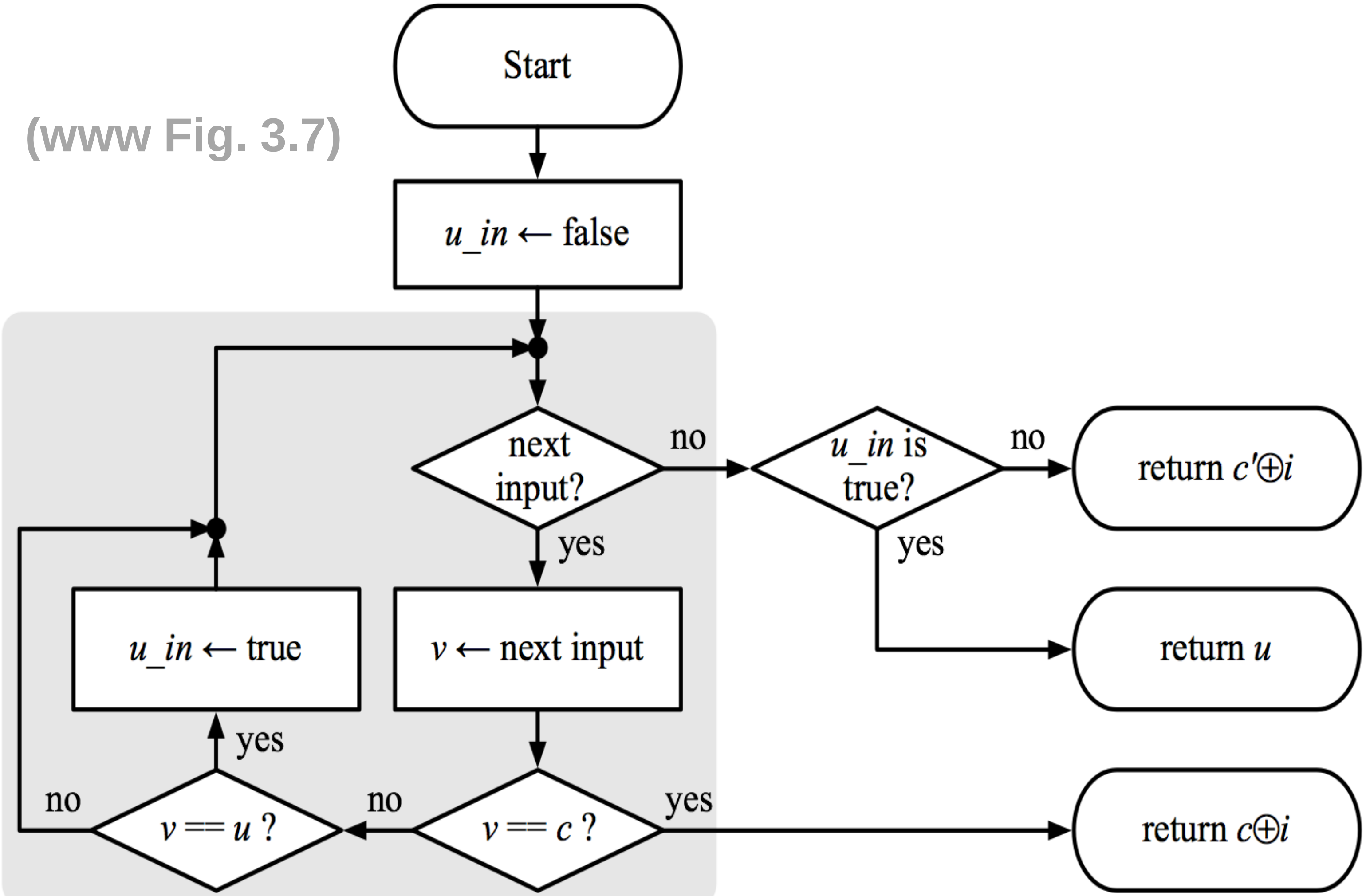
- Simulation Models
  - Logic States
    - 0,1,u,z
  - Logic Gate Evaluation
    - Truth table, Input scanning
  - Delay Models
    - propagation, ambiguous, inertial delay



FFT 1

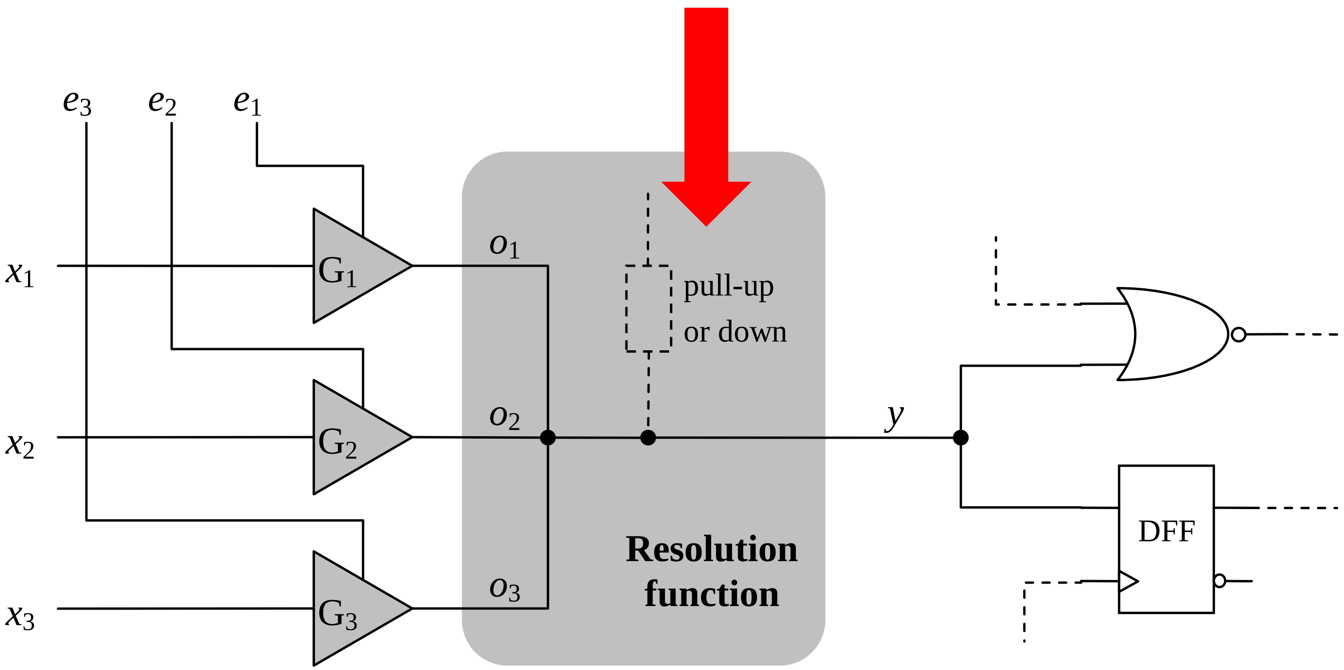
- **Q: From truth table to input scanning, what do we gain/loose?**
  - **HINT: CPU time vs memory**

(www Fig. 3.7)



FFT 2

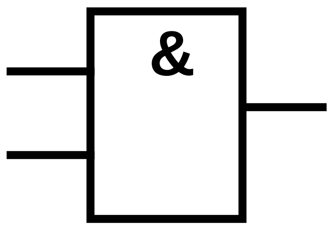
- **Q: What is the use of pull-up or pull-down?**
  - **HINT: what happens when e_1=e_2=e_3=0**

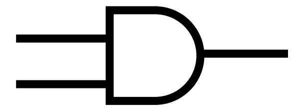


(WWW Fig 3.6)

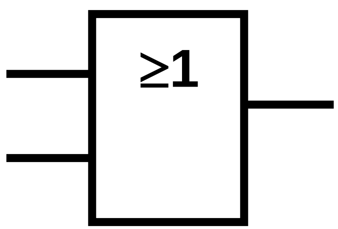
Appendix: Logic Symbols

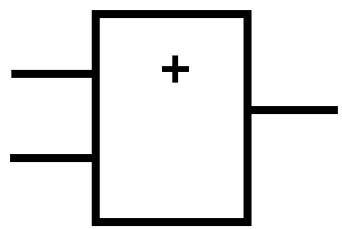
- IEEE logic symbols: rectangular shape v.s. distinctive shape
- AND

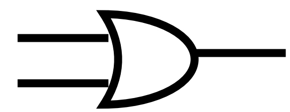




- Or







- inverter