4.13.1
5-stage pipelined datapath
No forwarding or hazard detection

```
add r5, r2, r1      IF ID EX M WB
nop                    IF ID EX M WB
nop                       IF ID EX M WB
lw r3, 4(r5)                 IF ID EX M WB
lw r2, 0(r2)                    IF ID EX M WB
nop                                IF ID EX M WB
or r3, r5, r3                         IF ID EX M WB
nop                                      IF ID EX M WB
nop                                         IF ID EX M WB
sw r3, 0(r5)                                   IF ID EX M WB
```

4.14.1
Pipelined processor w/ a 5-stage pipeline, full forwarding, and a predict-taken branch predictor
Draw pipeline execution diagram assuming BR execute in EX stage

```
lw r3, 0(r1)    IF ID EX M WB
label1  beq r2, r0, label2   IF ID ID EX M WB   # first, not taken; predict taken
label2  sw r1, 0(r2)            IF IF ID
        Ins After SW               IF
```

flush

branch resolved and should not have been taken

```
lw r3, 0(r2)                    IF ID EX M WB
beq r3, r0, label1 # taken      IF ID ID EX M WB   resolved
beq r2, r0, label2 # now taken     IF IF ID EX M WB   resolved
sw, r1, 0(r2) # successful prediction     IF ID EX M WB
!
next instructions
```

successful prediction → goto label1

4.16.1 – 4.16.3 Accuracy of various branch predictors for repeating pattern T, NT, T, T, NT

4.16.1

Always-taken predictor:

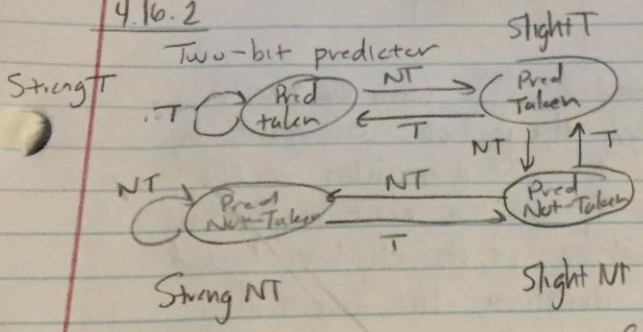
$\frac{3 \text{ taken}}{5 \text{ total branches}} = 60\%$

Always-not-taken predictor

$\frac{2 \text{ not-taken}}{5 \text{ total branches}} = 40\%$

4.16.2

Two-bit predictor



First 4 branches, starting from bottom-left state

Guess	Actual	Correct	State
NT	T	X	Strong NT → Slight NT
NT	NT	✓	Slight NT → Strong NT
NT	T	X	Strong NT → Slight NT
NT	T	X	Slight NT → Slight T

Our branch prediction was successful $\frac{2}{4} = 50\%$ of the time

4.16.3 Accuracy if repeated forever

Guess	Actual	Correct	State
NT	T	X	Strong NT → Slight NT
NT	NT	✓	Slight NT → Strong NT
NT	T	X	Strong NT → Slight NT
NT	T	✓	Slight NT → Slight T
T	NT	X	Slight T → Slight NT
NT	T	X	Slight NT → Slight T
T	NT	X	Slight T → Slight NT
NT	T	X	Slight NT → Slight T
T	T	✓	Slight T → Strong T
T	NT	X	Strong T → Slight T

Guess	Actual	Correct	State
T	T	✓	Slight T → Strong T
T	NT	✗	Strong T → Slight T
T	T	✓	Slight T → Strong T
T	T	✓	Strong T → Strong T
T	NT	✗	Strong T → Slight T
T	T	✓	Slight T → Strong T
T	NT	✗	Strong T → Slight T
T	T	✓	Slight T → Strong T
T	T	✓	Strong T → Strong T
T	NT	✗	Strong T → Slight T

Since there are 3 T's and 2 NT's (where the 2 NT's don't occur consecutively), the predictor will eventually always become biased to T. If it encounters an NT, it will be slightly bias to T, but the next instruction will always be a T, making it strongly bias toward T again. With infinite iterations, this essentially mimics the always-taken predictor

$\frac{3}{5} = 60\%$