Technion

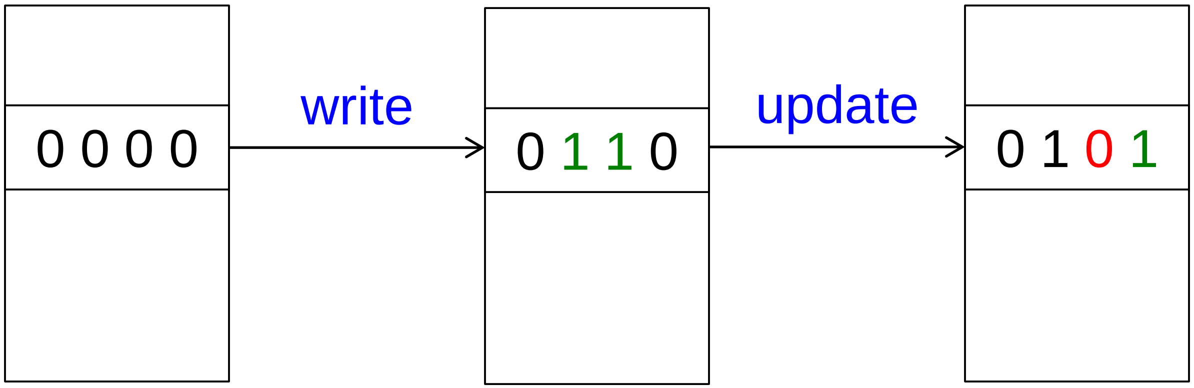
Electronics
Computers
Communications

Information in Storage Devices

049063 – EE Department, Technion

LECTURE 6: WRITE-ONCE MEMORY (WOM) – INTRODUCTION

The Erase Problem



0 → 1 easy

1 → 0 hard

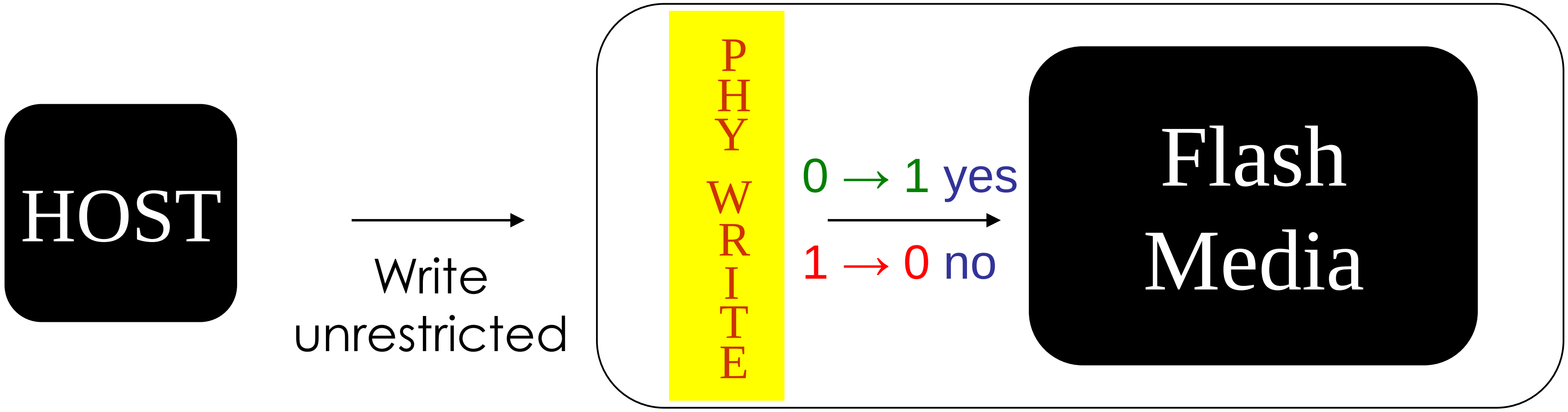
Good transitions 0 → 1

0 0 0 0 —w1→ 1 0 1 0 —w2→ 1 1 1 0 —w3→ 1 1 1 1

What if all transitions were like that?

Somebody will have to pay something…

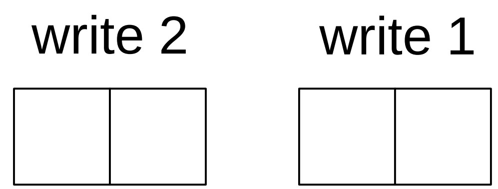
Solution: Re-write Codes



Write-Once Memory (WOM)

Example: write 2 bits, 2 times.
How many WOM bits are needed?

Trivial solution: 4 bits



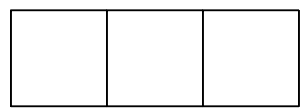
info	write 1	write 2
00	00 00	00 XX
01	00 01	01 XX
10	00 10	10 XX
11	00 11	11 XX

Write-Once Memory (WOM)

Example: write 2 bits, 2 times.
How many WOM bits are needed?

Clever solution: **3** bits

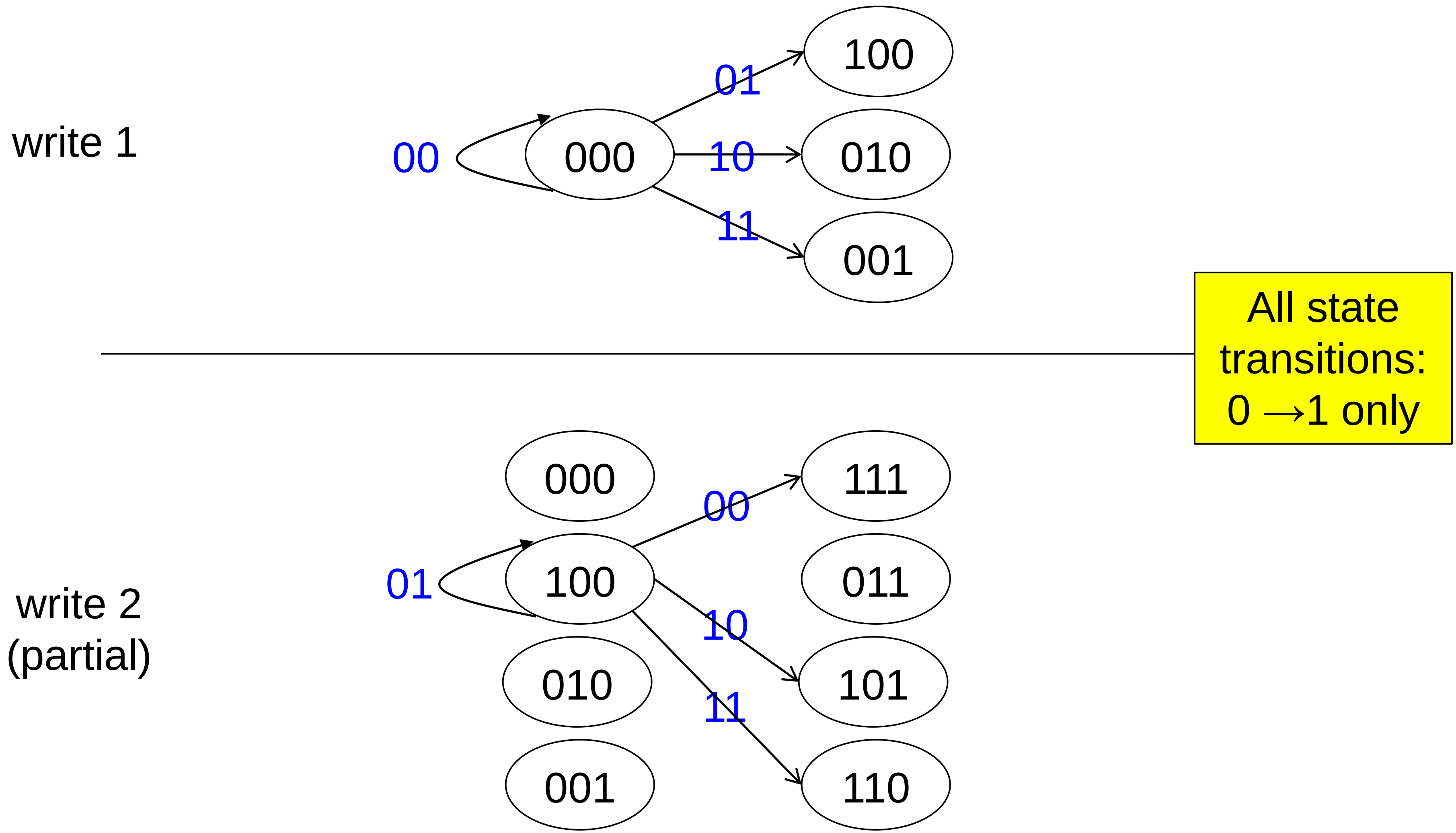
writes 1,2



info	write 1	write 2
00	000	111
01	001	110
10	010	101
11	100	011

Read only the last write!

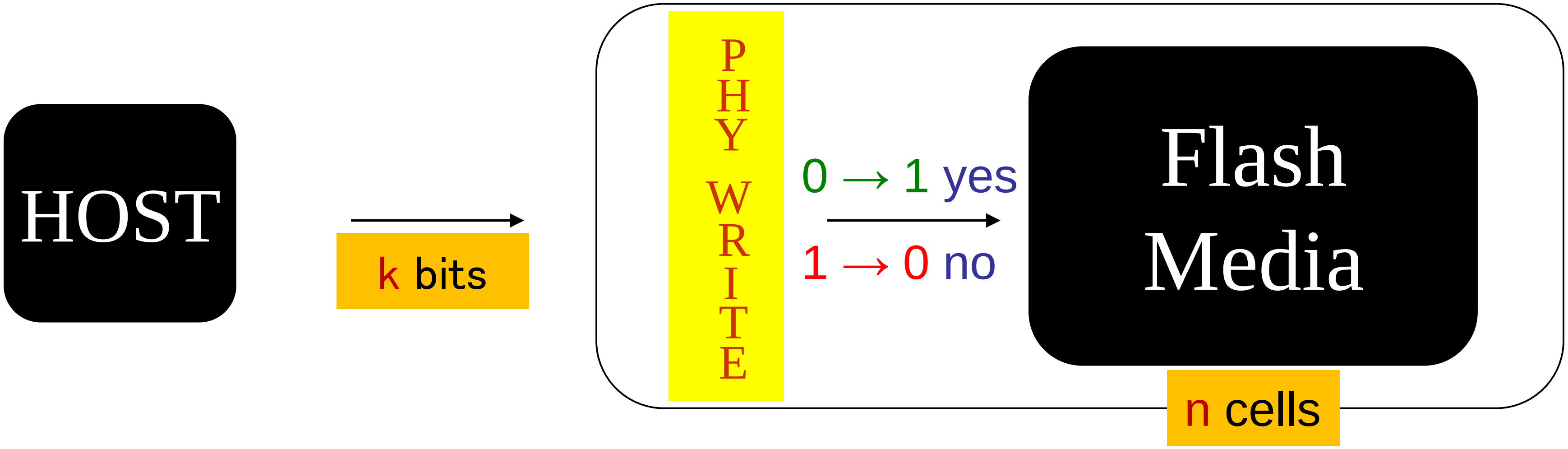
WOM State Diagram

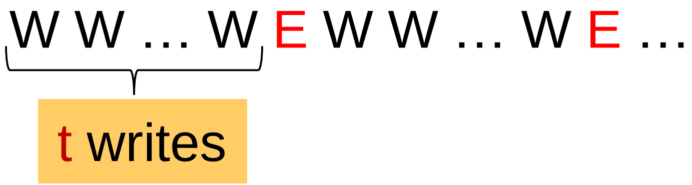


WOM Code Specification

(n,k,t) WOM code:

Write k bits t times, on n cells





WOM = Speed + Long Life in Flash

0 → 1 Write, 1 → 0 Erase

IF

Time(Erase) ≫ Time(Write)

Wear(Erase) ≫ Wear(Write)

THEN

WOM speeds up by factor t

WOM extends life by factor t

Issues

Issues:

1. Redundancy
2. Read before write

WOM Code Definition

1) Decoding Function

$$\psi(c_1, \ldots, c_n) = (y_1, \ldots, y_k)$$

$$c_i \in \{0,1\}$$

2) Update Function

legal

$$\mu(c_1, \ldots, c_n \,;\, y_1, \ldots, y_k) = (c'_1, \ldots, c'_n)$$

current cell values — new data — new cell values

Requirements

- Consistency

$$\psi\left[\mu\left(c_1, \dots, c_n; \underline{y}\right)\right] = \underline{y}$$

- Adherence

If $(c'_1, \dots, c'_n) = \mu\left(c_1, \dots, c_n; \underline{y}\right)$, then $\forall i, c'_i \geq c_i$

- Completeness

$\mu\left(c_1, \dots, c_n; \underline{y}\right)$ is defined and consistent for every $\underline{y} \in \{0,1\}^k$

Alternative Definition

(n,k,t) WOM code $\rightarrow$ $\langle v \rangle^t / n$ WOM code

$k = \log_2(v)$, but v not necessarily an integer power of 2.

Definition:

$w(\langle v \rangle^t)$: number of cells in an optimal $\langle v \rangle^t$ WOM code.

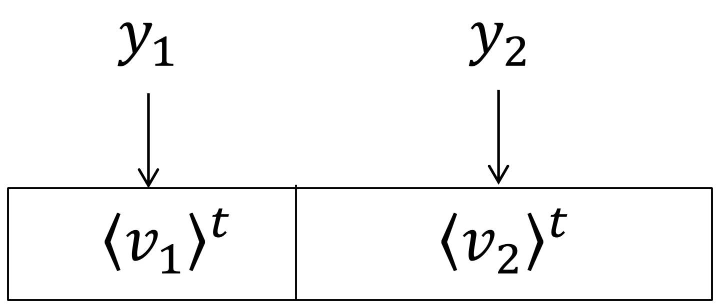
Reduction on Input

Lemma 1:

$$w(\langle v_1 \cdot v_2 \rangle^t) \leq w(\langle v_1 \rangle^t) + w(\langle v_2 \rangle^t)$$

Proof:

Given $y \in \{0, \ldots, v_1 v_2 - 1\}$, split to $y = (y_1, y_2)$, where $y_1 \in \{0, \ldots, v_1 - 1\}$, and $y_2 \in \{0, \ldots, v_2 - 1\}$. Then concatenate

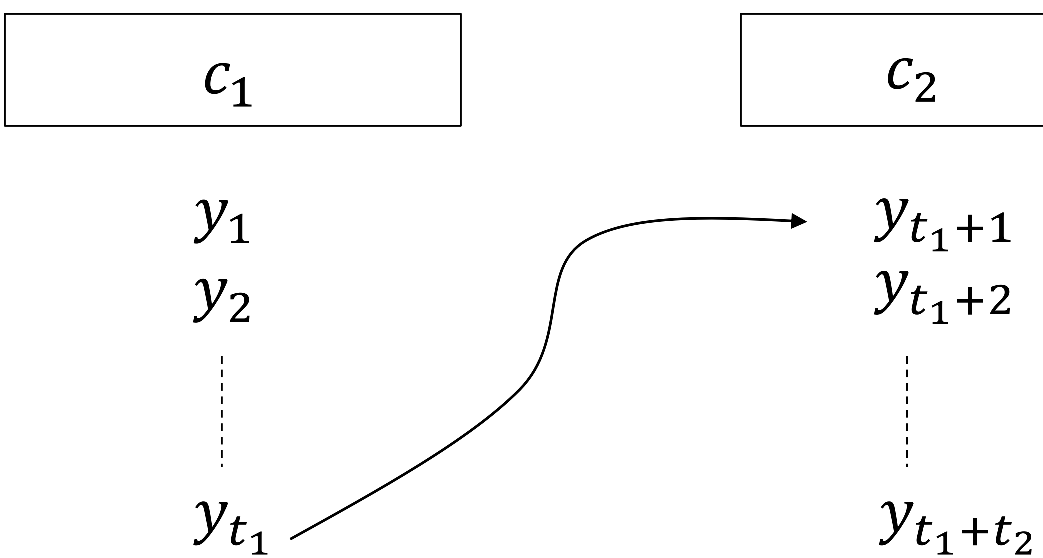


Reduction on Writes

Lemma 2:

$$w(\langle v \rangle^{t_1+t_2}) \leq w(\langle v \rangle^{t_1}) + w(\langle v \rangle^{t_2})$$

Proof:



Are you sure?

Write-Count Issue

c_1

0 1 0 1 1 0

c_2

0 0 0 0 0 0

Option 1: $y = \psi(c_1)$, if t_1 writes or less

Option 2: $y = \psi(\underline{0})$, if $t_1 + 1$ writes

Must know the number of writes!

Avoiding Write Counters

Lemma 2:

$$w(\langle v\rangle^{t_1+t_2}) \leq w(\langle v\rangle^{t_1}) + w(\langle v\rangle^{t_2})$$

Proof:

$$\psi(c) \triangleq \psi(c_1) - \psi(c_2)$$

← Move to c_2 only with non-zero!

c_1	c_2
y_1	$y_{t_1} - y_{t_1+1}$
y_2	$y_{t_1} - y_{t_1+2}$
⋮	⋮
y_{t_1}	$y_{t_1} - y_{t_1+t_2}$

Reduction on Input and Writes

Theorem:

$$w(\langle 2^k \rangle^t) \leq kt$$

Proof:

$$w(\langle 2^k \rangle^t) \underset{\text{Lemma 1}}{\leq} k \cdot w(\langle 2 \rangle^t) \underset{\text{Lemma 2}}{\leq} kt \cdot \underbrace{w(\langle 2 \rangle^1)}_{=1} = kt$$