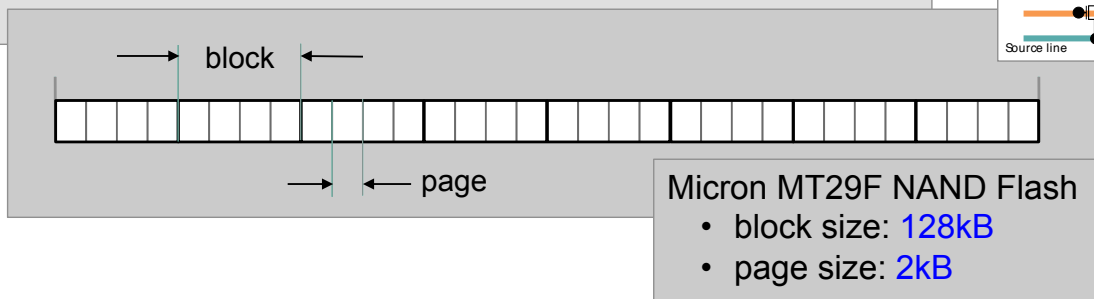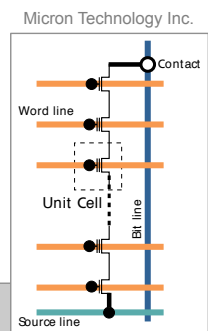# Solid State Storage Technology
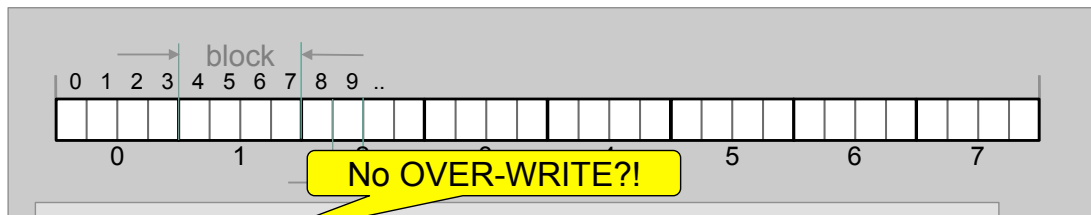
- Example: NAND Flash

- Characteristics and Performance

- Operations on NAND Flash

- The Flash Translation Layer (FTL)

NAND Flash Technology

- **Solid-state** persistent storage technology with **"disk-like"** user interface.
- READs/WRITEs are sector-based (**page-ba**sed)
- Suited for storage of **sequential data**.
- **Random access** can be "faked" by caching ("shadowing") data in RAM main memory.

Micron Technology Inc.

Contact
Word line
Unit Cell
Bit line
Source line

block

page

Micron MT29F NAND Flash
- block size: 128kB
- page size: 2kB

NAND Flash Operations

block

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | .. |

0   1   2   3   4   5   6   7

No OVER-WRITE?!

Operations: Latency (MT29F)

- **READ** (page-level)   75μsec
- **PROGRAM** (page-level)   220μsec
- **ERASE** (**block**-level)   500μsec

NAND Flash Operations
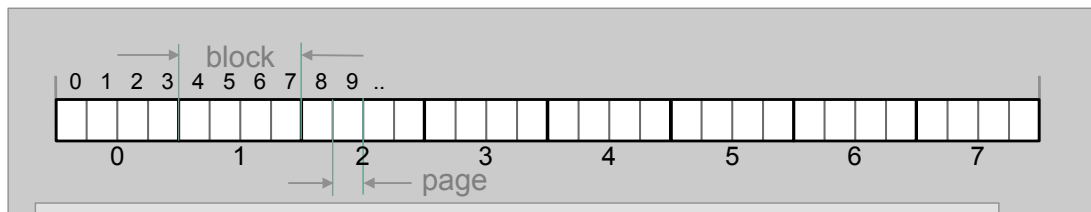
block

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | .. |

0   1   2   3   4   5   6   7

page

Operations: Latency (MT29F)

- **READ** (page-level)   75μsec
- **PROGRAM** (page-level)   220μsec
- **ERASE** (**block**-level)   500μsec

Erasing a block:

NAND Flash Operations

block

0 1 2 3 | 4 5 6 7 | 8 9 ..

0   1   2   3   4   5   6   7

page

Operations: Latency (MT29F)

- **READ** (page-level)   75μsec
- **PROGRAM** (page-level)   220μsec
- **ERASE** (**block**-level)   500μsec

Problem:
After about 100,000 PROGRAM/
ERASE cycles, blocks start **failing**.

Erasing a block:

NAND Flash Operations

block

0 1 2 3 | 4 5 6 7 | 8 9 ..

0   1   2   3   4   5   6   7
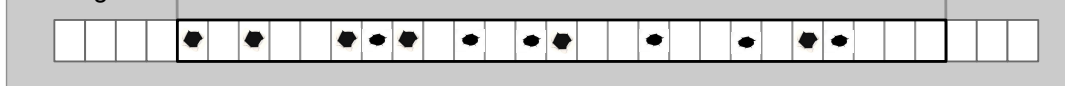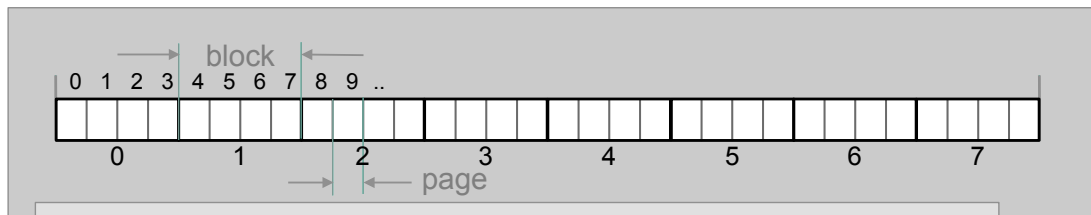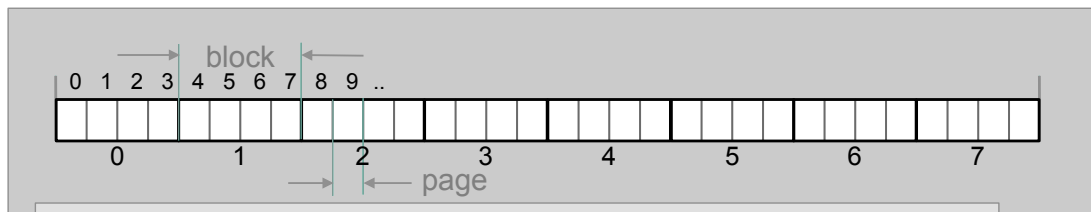
page

Operations: Latency (MT29F)

- **READ** (page-level)   75μsec
- **PROGRAM** (page-level)   220μsec
- **ERASE** (**block**-level)   500μsec

Problem:
After about 100,000 PROGRAM/
ERASE cycles, blocks start **failing**.

Erasing a block:

NAND Flash: Naïve Writing

W 9

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | . |

0   1   2   3   4   5   6   7

NAND Flash: Naïve Writing

Cost:
- Latency: **~1msec**
- Wear-out: 1 ERASE per Over-WRITE
  (recall: 100'000 ERASE cycles max!)
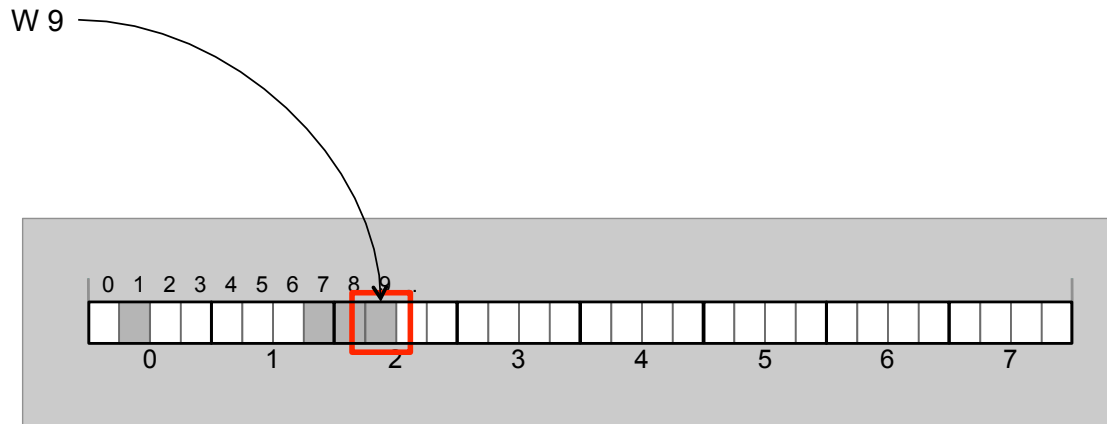
Analysis:
1 Over-WRITE causes:
- 1 READ operation
- **1 Block ERASE** operation
- 2 PROGRAM operations

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | .. |

0   1   2   3   4   5   6   7

Solution: Log-Structured Flash Translation Layer

Flash Translation Layer (FTL)

Page State:
- E: empty
- V: valid
- I: invalid

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0	1	2	3	4	5	6	7	8	9	10	11												

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
V	V	V	V	V	V	V	V	V	V	V	V	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E

0   1   2   3   4   5   6   7
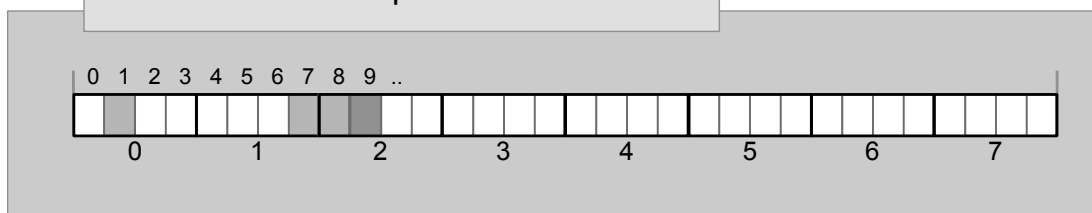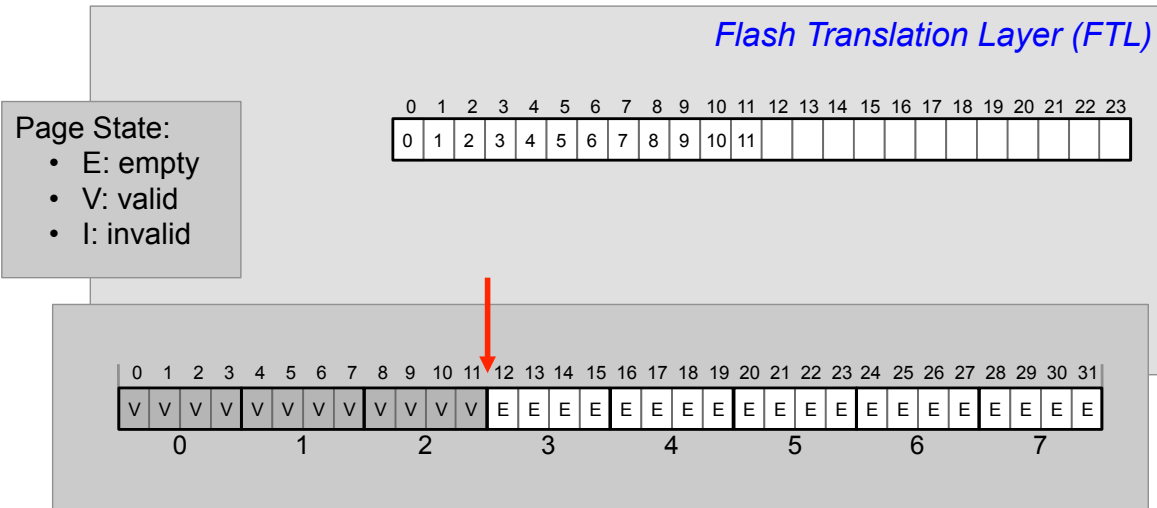
Garbage Collection in the Flash Translation Layer
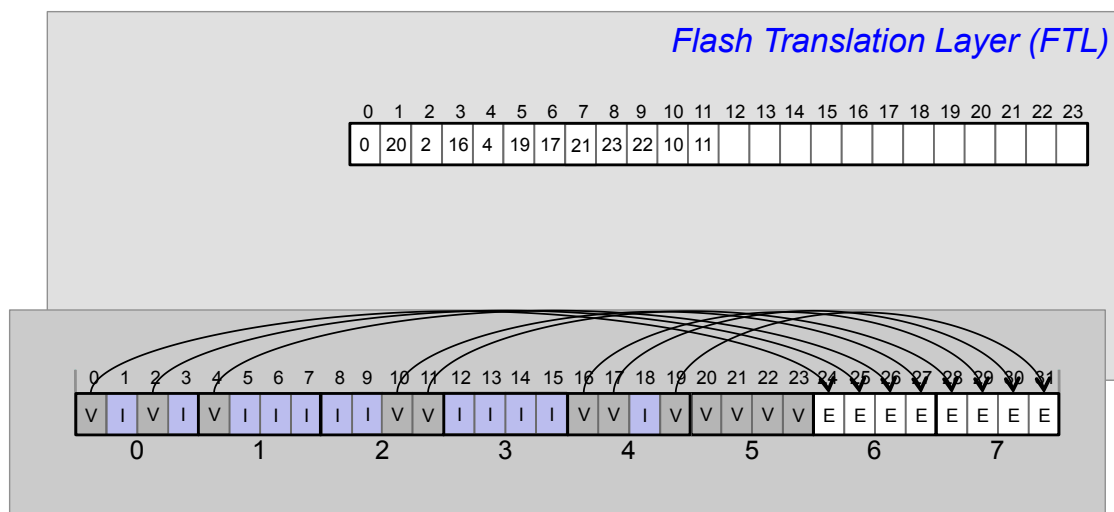
Flash Translation Layer (FTL)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0	20	2	16	4	19	17	21	23	22	10	11												

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
V	I	V	I	V	I	I	I	I	I	V	V	I	I	I	I	V	V	I	V	V	V	V	V	E	E	E	E	E	E	E	E

0   1   2   3   4   5   6   7

Solution: Log-Structured Flash Translation Layer

Flash Translation Layer (FTL)

W 6

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
24	20	25	29	26	31	0	21	23	22	27	28												

V	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	V	V	V	V	V	V	V	V	V	V	I	V

0   1   2   3   4   5   6   7   8   9   10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

0   1   2   3   4   5   6   7

Solution: Log-Structured Flash Translation Layer
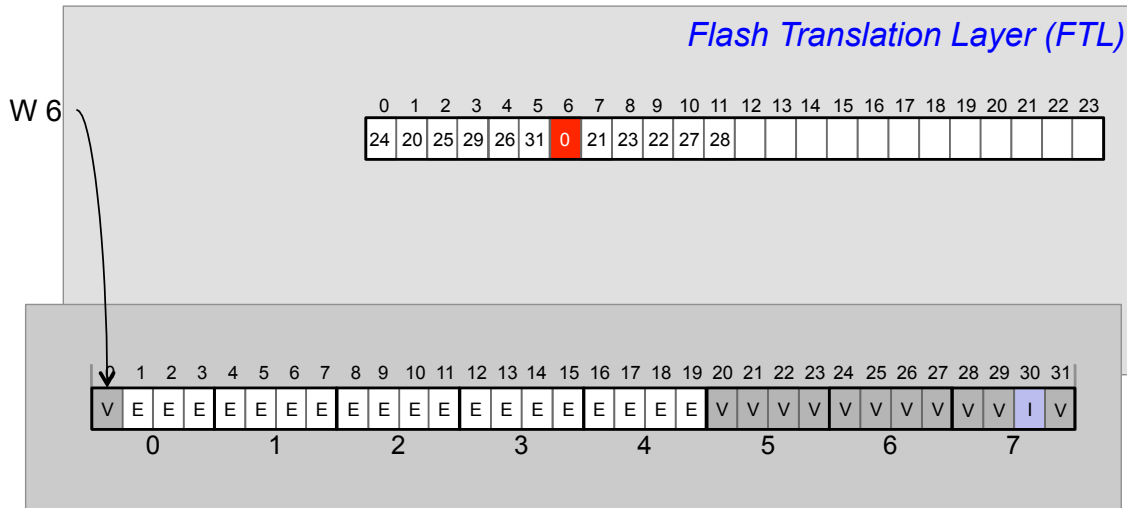
Flash Translation Layer (FTL)

Analysis:

N Over-WRITEs cause

N/(block size)

Block ERASE operations.

3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
29	26	31	0	21	23	22	27	28												

V	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	V	V	V	V	V	V	V	V	V	V	I	V

0   1   2   3   4   5   6   7   8   9   10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

0   1   2   3   4   5   6   7

Solid State Storage Technology

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