Error Control Strategies for NVM: Extending Memory Lifetime Using Coding

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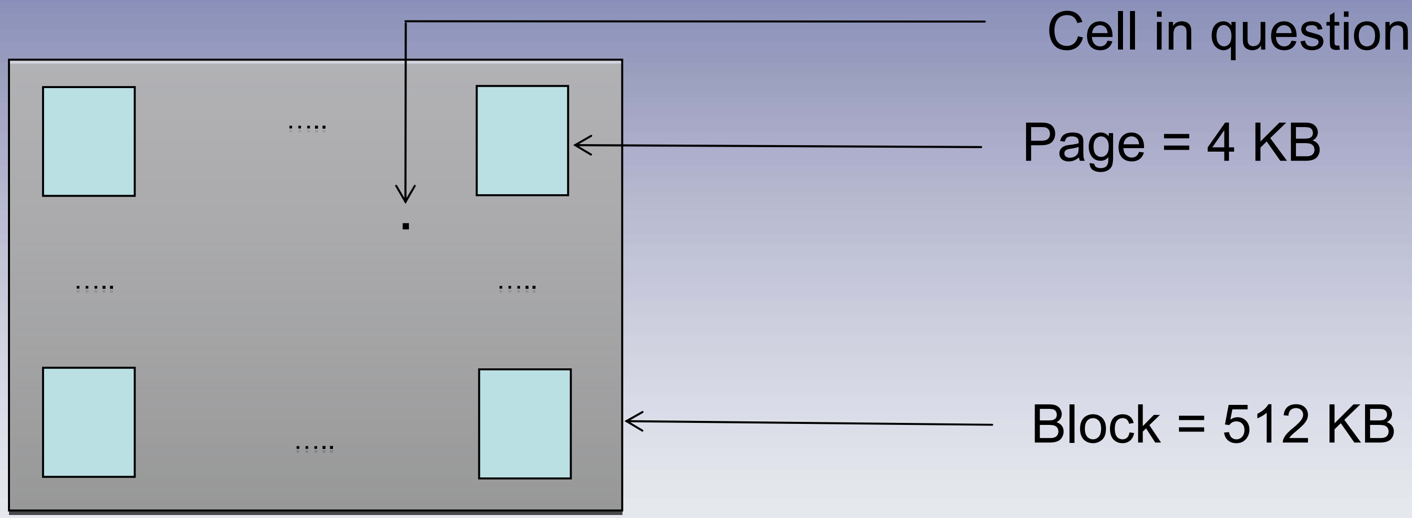
Outline

- Problem:
  - o Cell erasures and memory wearout.
- Proposed approach:
  - o Data self-repair to minimize number of erasures based on algebraic techniques.
- Summary and outlook:
  - o Overcome physical degradation by novel mathematical solutions.

Memory Lifetime and Write/Erase Operations

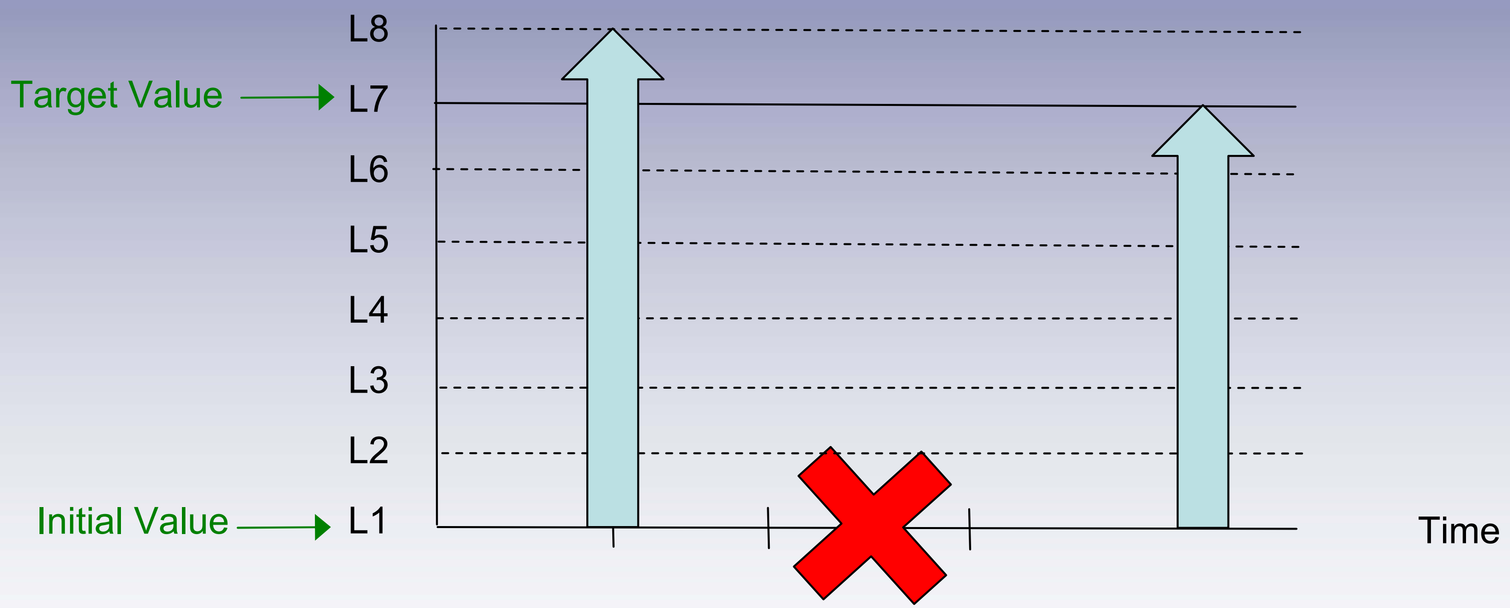
- When only one cell needs to be erased, the whole block needs to be reset.



- For SLC ~ 10^6 writes,
- For MLC ~ 10^4 – 10^5 writes (serious)
- For TLC ~ 10^3 – 10^4 writes (more serious).

Memory Lifetime and Write/Erase Operations

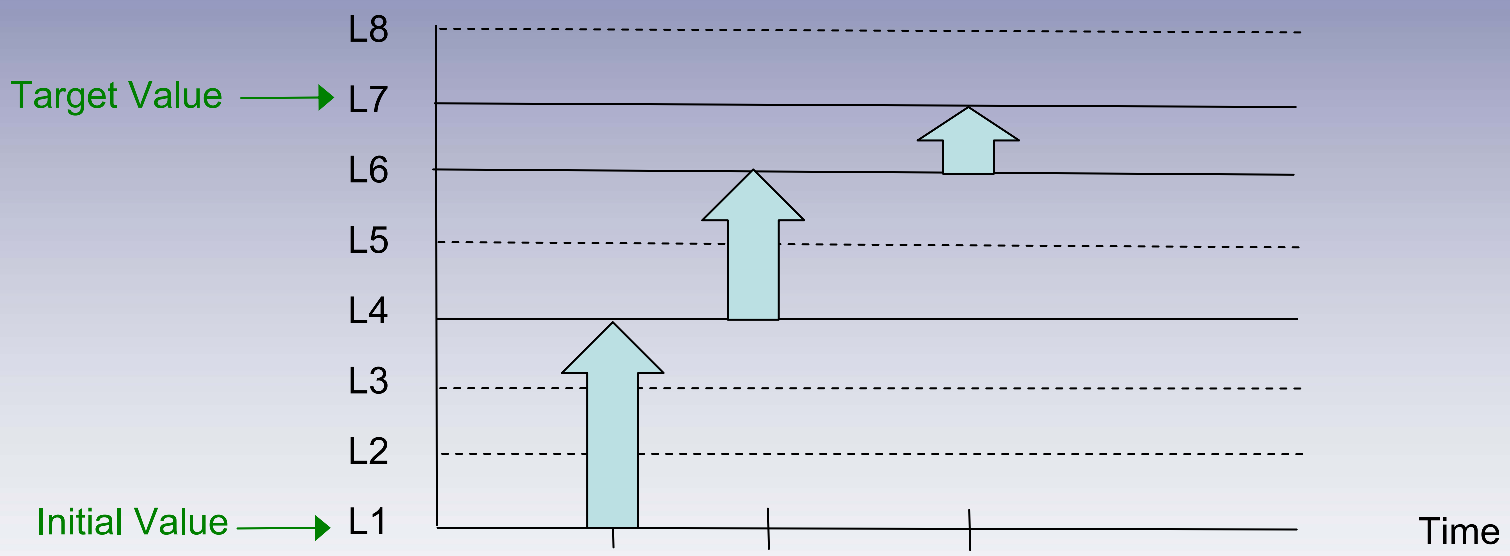
- Programming (write) error is very costly.



- Wastes erase cycles.

Memory Lifetime and Write/Erase Operations

- Write is incremental step pulse programming a.k.a. “guess-and-verify”.



- Being cautious affects latency.

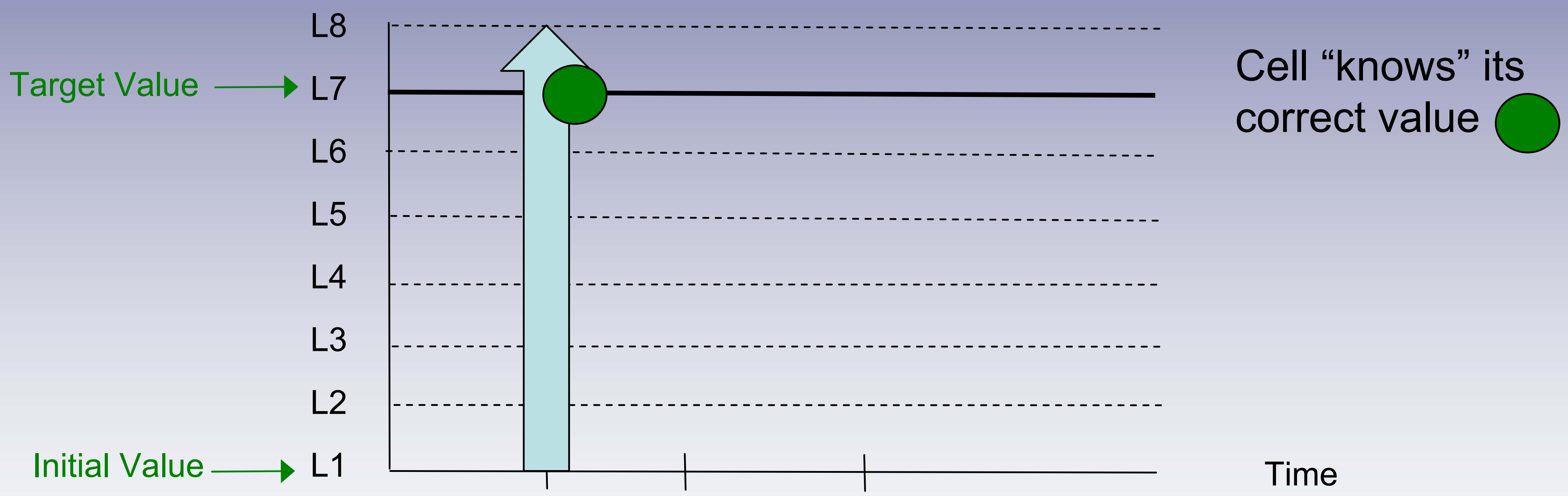
Sloppy Writes and Data Self-Repair

- Idea 1: Allow for sloppy writes.
  - Improves latency.
  - Not wasting erase/write budget.
  - Reliability ?

- Idea 2: Figure out what was intended to be written based on other cells.
  - Overshot values stay intact (for the time being).
  - Redundancy ?

Sloppy Writes and Data Self-Repair

- Allow writing overshoot, a.k.a. sloppy writes.



- Key: unidirectional error correction scheme.

A Scheme Based on Number Theory

- Varshamov-Tenengolts codes [1]:

$$\sum_{i=1}^{n} i x_i \equiv a \bmod (n+1)$$

  - o n is block size,
  - o x_i is value in cell i,
  - o a is arbitrary integer.

- VT code corrects one unidirectional error.

[1] R. R. Vashamov and G. M. Tenengolts, 1965.

A Generalized Scheme Based on Number Theory

- Proposed scheme:

$$\sum_{i=1}^{n} i\, x_i \equiv a_1 \mod p$$

$$\sum_{i=1}^{n} i^2 x_i \equiv a_2 \mod p$$

$$\dots$$

$$\sum_{i=1}^{n} i^{2k} x_i \equiv a_{2k} \mod p$$

- Parameters:
  - o *k* is target error correction
  - o *n* is block size
  - o x_i is value in cell *i*,
  - o $a_1 \ldots a_{2k}$ *are* arbitrary integers.
  - o *p* is some prime, $p > n$

- Guaranteed to correct *k* unidirectional errors.

A Generalized Scheme Based on Number Theory

- Encoding:

1. Compute congruency contribution from data.
2. Add values in anchors for overall congruency.
   - With careful indexing, redundancy is minimal.
   - Systematic construction.

- Example:

target: $\sum i \, x_i = 0 \bmod p$

index	1	2	3	4	5	6	7	8	9	10
values	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**1**

Legend
Data
Anchors

A Generalized Scheme Based on Number Theory

- Decoding
  1. Test if congruency constraints are violated.
  2. Solve equations to figure out the correct values.
     - o Computations can be efficiently implemented.

- Example:

  target: $\sum i\, x_i = 0 \bmod 11$

  index 1 2 3 4 5 6 7 8 9 10

  values **1 1 1 1 0 1 1 0 1 1**

A Generalized Scheme Based on Number Theory

- Decoding
  1. Test if congruency constraints are violated.
  2. Solve equations to figure out the correct values.
     - o Computations can be efficiently implemented.

- Example:

  computed: $\sum i\, x_i = 9 \bmod 11$

index	1 2 3 4 5 6 7 8 9 10
values	**1 1 1 1 0 1 1 0 1 1**

Conclusion and Outlook

- Data self-repair can improve write latency and extend memory lifetime.
- Efficient methods are developed based on number-theoretic ideas.
  - Very low redundancy
  - Implementable algorithms
  - For SLC/MLC/TLC
- Rich opportunity to develop new data correction algorithms and methodologies tailored for Flash.

Thank you

- Thank you for your attention!

- For more information

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