Joint Rewriting and Error Correction in Flash Memories

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joint work with

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The Problem of Block Erasure

- Erasing a cell requires block erasure
  - Block erasure slows down programming
  - Degrades flash cells
- Solutions
  - Flash translation layer (FTL)
  - Coding for rewriting data
    - Floating codes
    - Buffer codes
    - Rank modulation codes
    - Write-once memory (WOM) codes

What is a “rewrite” ?

- Store data by programming cells which have been programmed before without erasing a cell.
- Constraint: *a cell previously at level 1 (high threshold voltage) has to stay at level 1 after rewriting.*
  - e.g. 101 -> 111
- After rewriting, the data stored by the previous writes no longer need to be recovered.

The first write-once memory (WOM) code

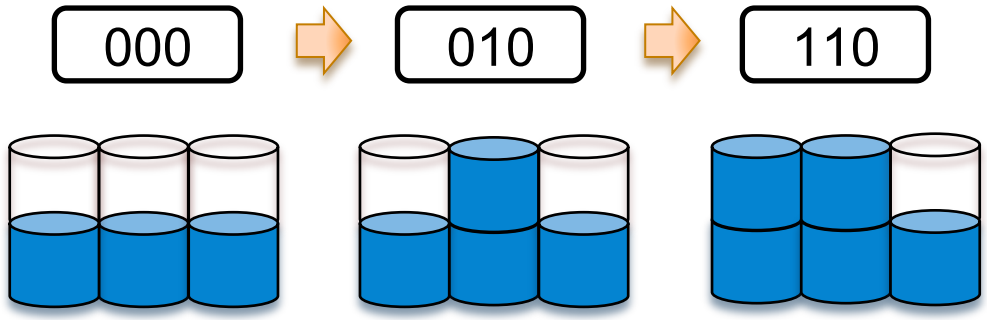
R. L. Rivest and A. Shamir, "How to reuse a 'Write-Once' memory," Information and Control, vol. 55, pp. 1–19, 1982 (also published in STOC)

Data	Codeword (1st write)	Codeword (2nd write)
00	000	111
01	001	110
10	010	101
11	100	011

Write 2 bits twice using 3 cells

Rate = 4/3 = 1.33 bits/cell

Example (with SLC): we first write data 10, then rewrite the data to 01.



WOM codes

Capacities have been derived

[1] **C. Heegard**, "On the capacity of permanent memory", IEEE Transactions on Information theory, vol. 31, no. 1, 1985

Different WOM codes have been proposed.
Capacity-achieving codes have been proposed

[1] **A. Shipilka**, "Capacity achieving multiwrite WOM codes", 2012.
[2] **D. Burshtein and A. Strugatski**, "*Polar write-once memory codes*," ISIT 2012.

However, WOM codes for noisy channels are limited.

[3] **G. Zemor and G. D. Cohen**, "Error-Correcting WOM-Codes", IEEE Transactions on Information Theory, vol. 37, no. 3, pp. 730-734, 1991.
[4] **E. Yaakobi, P. Siegel, A. Vardy, and J. Wolf**, "Multiple Error-Correcting WOM-Codes", in IEEE Transactions on Information Theory, vol. 58, no. 4, pp. 2220-2230, 2012.

We study WOM codes which correct many errors.

Polar WOM Codes[1]

- Views a write as the decoding of a polar code:
  - Views the cells' state before the write as a noisy Polar codeword.
  - Views the cells' state after the write as the corrected (i.e., error-free) Polar codeword.

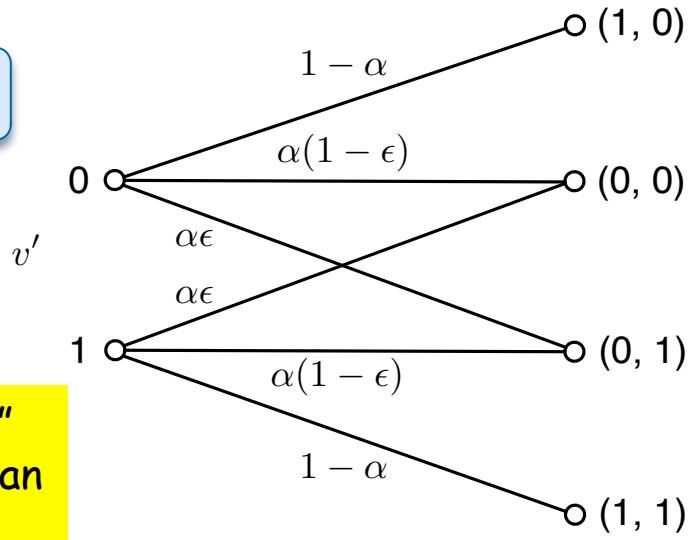
- More precisely, write/rewrite can be considered as lossy data compression.

[1] **D. Burshtein and A. Strugatski**, "*Polar write-once memory codes*," ISIT 2012.

The Channel for Rewriting

- Smart idea by Burshtein and Strugatski:
  - Add dither to cell levels:
    - Let $s \in \{0, 1\}$ be the level of a cell.
    - Let $g \in \{0, 1\}$ be a pseudo-random number known to the WOM encoder and the WOM decoder.
    - Let $v = s \oplus g$ be called the value of the cell.
  - Build a test channel for the write, which we shall call the WOM channel

Cell value after rewrite



Cell states and values before rewrite

(s, v)

α: fraction of the cells at "0"
ε: fraction of the cells you can program

Model for WOM codes

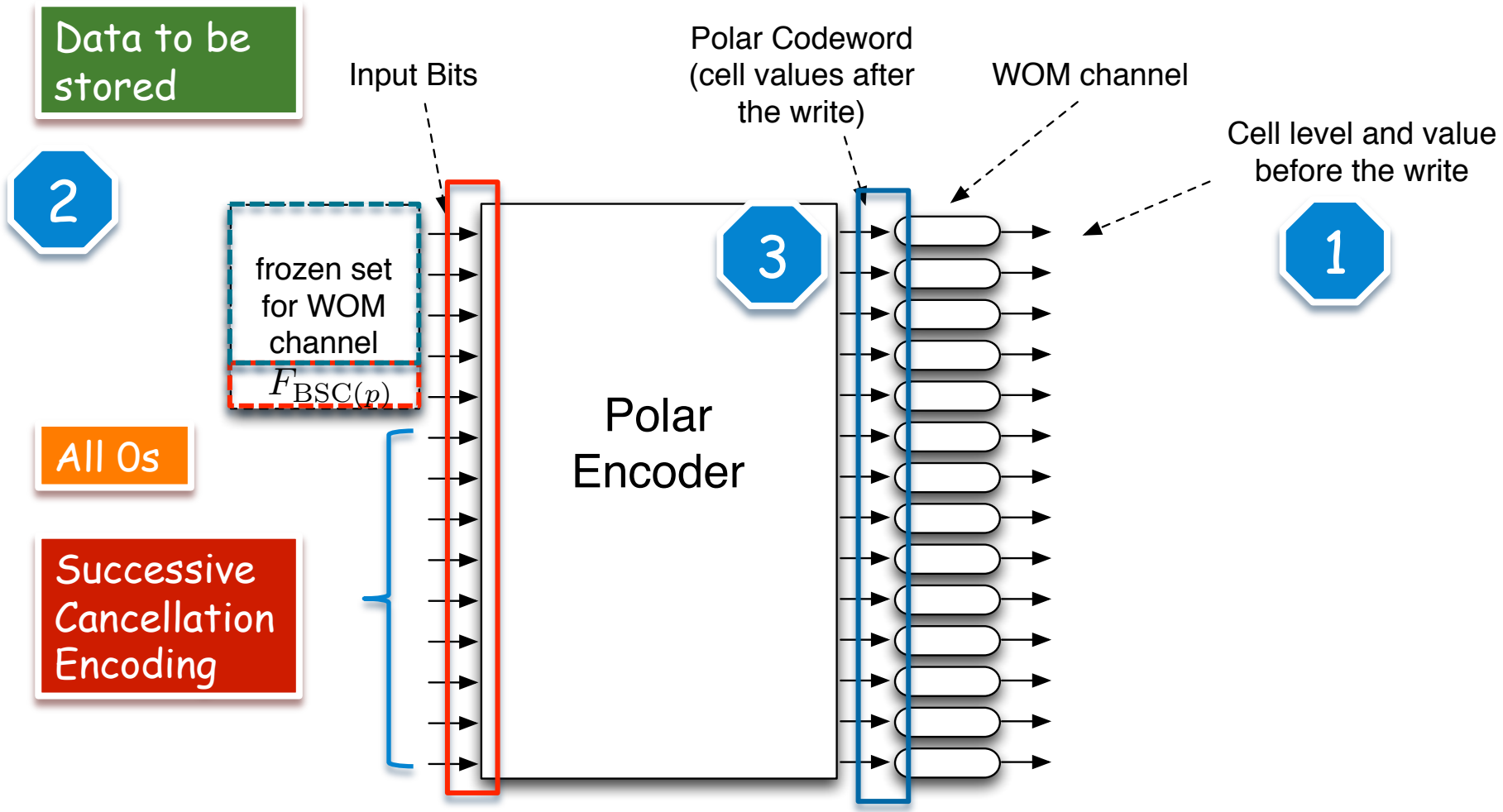
ECC WOM codes

- We would like to construct a nested code.
  - A WOM codeword is also a channel codeword
- Consider two channels
  - WOM channel. Let its frozen set be $F_{\mathrm{WOM}(\alpha,\epsilon)}$
  - BSC/noise channel. Let its frozen set be $F_{\mathrm{BSC}(p)}$

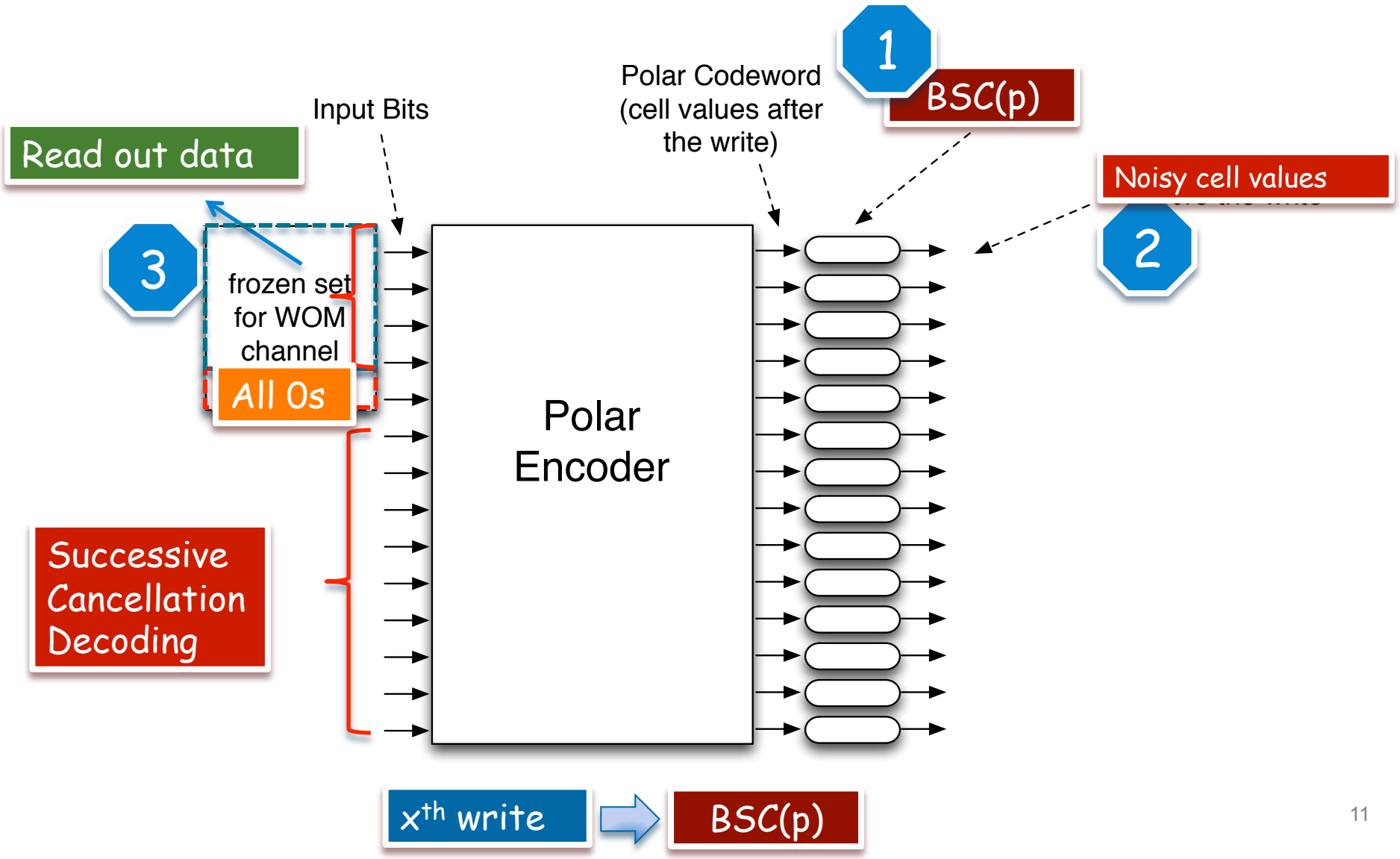
- A codeword of polar codes for WOM channel is also a codeword of the codes for BSC channel under the condition

$$F_{\mathrm{BSC}(p)} \subseteq F_{\mathrm{WOM}(\alpha,\epsilon)}$$

The Encoding Scheme

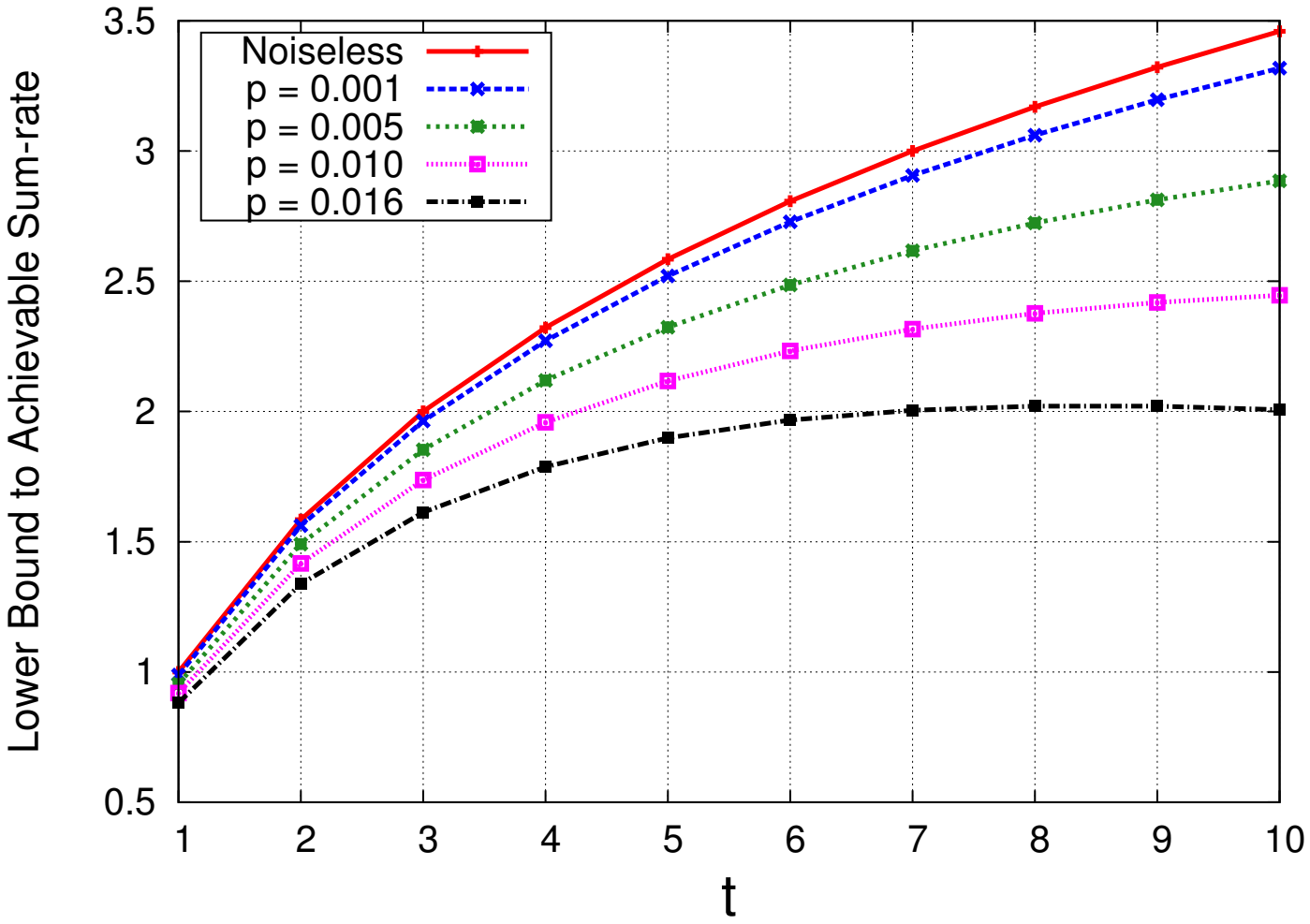


The Decoding Scheme



Lower Bounds to Achievable Sum-Rates

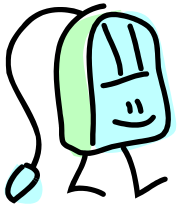
Sum-rate: total number of bits that can be stored using one cell through t writes.



Conclusions

- We proposed a coding scheme
  - allows multiple rewrites in one P/E cycle.
  - corrects a significant number of errors
  - Uses polar lossy source coding and channel coding

A. Jiang, Y. Li, E. En Gad, M. Langberg and J. Bruck. Joint Rewriting and Error Correction in Write-Once Memories. ISIT 2013.



THANK YOU