Time-space Constrained Codes for Phase-change Memories

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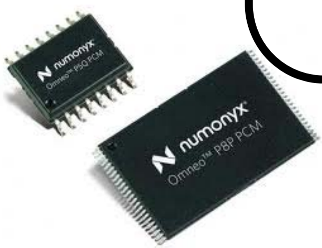
Outline

Introduction to Phase-Change Memories

Non-Volatile Memories



Electrically addressed systems:
- Read only memory (ROM)
- Flash memory (most widely used)
- Phase-change memory

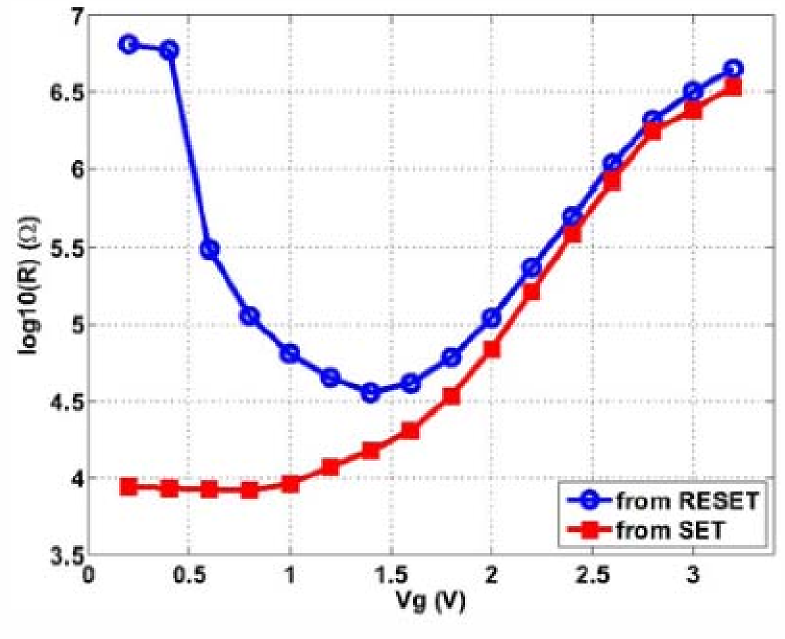
Mechanically addressed systems:
- Hard disk
- Optical disk
- Magnetic Tape

Introduction to Phase-Change Memories

- Why PCM could potentially replace flash?
  - Like flash, decreasing cell level is done first by RESET and then SET.
  - Different from flash, RESET can be performed to a single cell, instead of all block.
  - Faster writing/reading speed.
  - Degrade much more slowly. (~10^8 vs. ~10^6 cycles)
  - Less likely to "leak charges" than flash.
  - Higher resistance to radiation.

Introduction to Phase-Change Memories

- Cell states
  - Amorphous/RESET state (0) and Crystalline/SET state (1).
  - Multiple levels: intermediate states.
  - Cell programming (state-changing) is done by heating the cells.



Introduction to Phase-Change Memories

- Heat accumulation due to high temperatures
  - Degrades performance of the cells.
  - Affects adjacent cells by increasing their levels.
- Solution 1: Using Error Correction Codes (Flash)
- Solution 2: Using Modulation (Constrained) Codes (HDD)
  - (d,k)-runlength-limited codes
  - DC-free codes
- For PCM cells, we do not want too many cell-programmings
  - within a certain number of writes
  - among a span of consecutive cells.

Outline

Problem Setup

***Definition*[1]:** Let (α, β, p) be positive integers. A code is (α, β, p)-constrained if

- for any α consecutive writes, (time constraint)
- for any segment of β consecutive cells, (space constraint)

the total rewrite cost (the number of cell-programmings) of those cells over those rewrites is at most p.

***Remark*:** Here the rewrite cost is defined as the Hamming distance between the current state and the next state.

[1] A. Jiang, J. Bruck, and H. Li, "Constrained codes for phase-change memories," *Proc. IEEE Inform. Theory Workshop, Dublin, Ireland, August-September 2010.*

Problem Setup

***Example*:** Here is an (α=3, β=3,p=2)-constrained code of length 9 in 4 writes.

Constrained code

0:	0	0	0	0	0	0	0	0	0
1:	1	0	0	0	1	0	0	0	1
2:	1	0	1	0	1	1	0	0	0
3:	1	0	1	0	1	1	0	0	0
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- The number of cells programmed (red digits) in the rectangle of 3 by 3 is at most 2.

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Problem Setup

Physical limit (number of cell-programs in time and in space)

→

Constrained system:

- Shannon Capacity
- Encoder and decoder (rate vs. complexity)

Problem Setup

***Definition*:** Suppose the number of bits on each write is M , the rate of the constrained code is $R = M / n$.

The Shannon capacity of the constraint is

$$C(\alpha, \beta, p) = \lim_{n\to\infty} \sup \left\{ R : R \text{ is a rate of an } (\alpha, \beta, p)\text{-constrained code of length } n \right\}$$

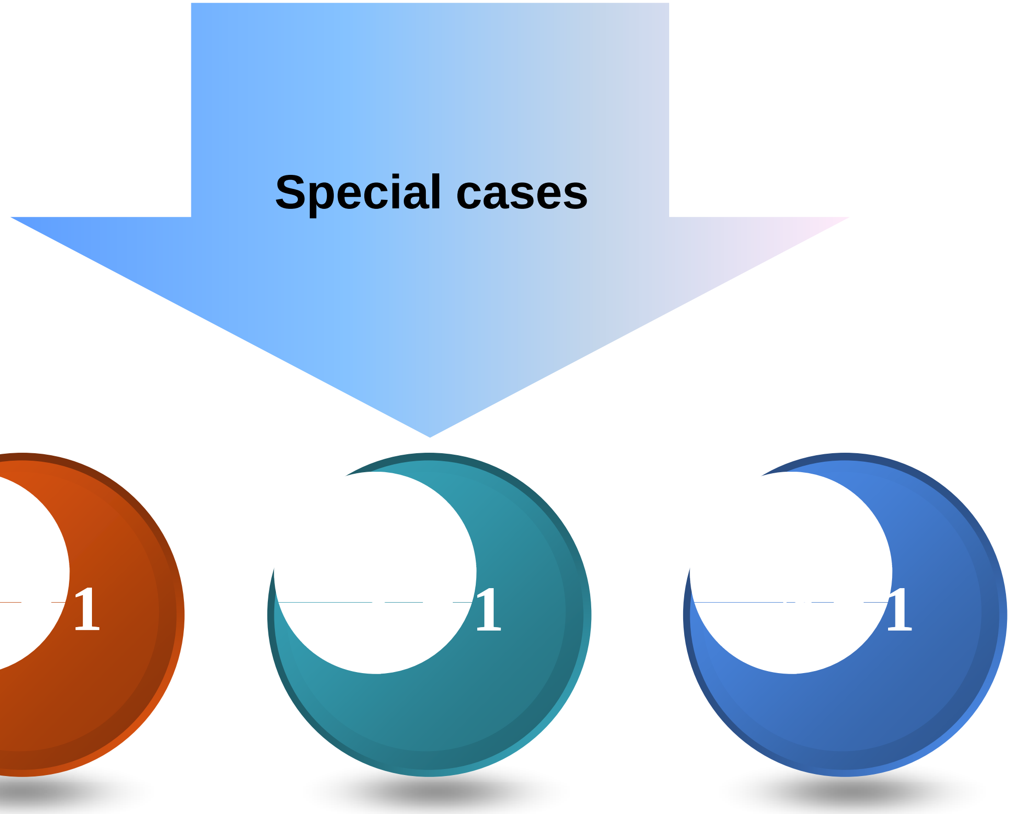
Question: Given (α, β, p), what is $C(\alpha, \beta, p)$?

Outline

1. Introduction to Phase-Change Memories
2. Problem Setup
3. Upper Bounds on Capacity
4. Lower Bounds on Capacity

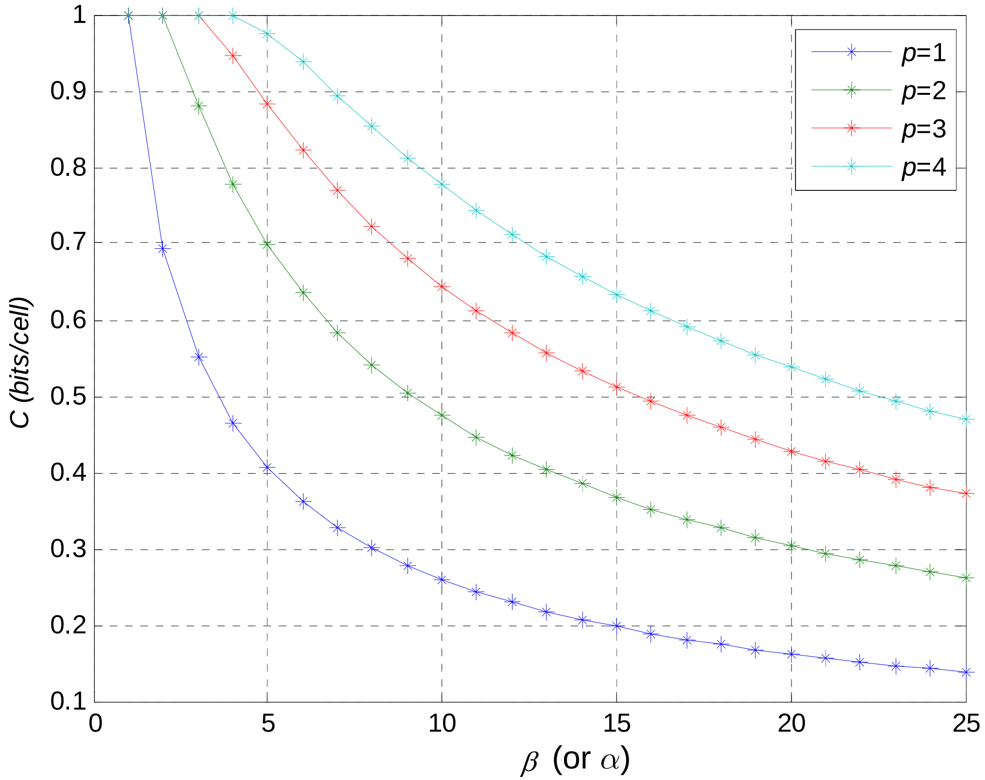
Upper Bound on *C*(α, β, *p*)

General statement of $C(\alpha, \beta, p)$



Upper Bound on *C*(α, β, *p*)

Upper Bounds on the capacity of (1, β, p) or (α, 1, p)-constraint.



[1]. M. Qin, E. Yaakobi, and P. H. Siegel, "Time-space constrained codes for phase-change memories," *Globecom, 2011*

Outline

Lower Bounds on $C(\alpha, \beta, p)$

Special Cases

$(\alpha = 1, \beta, p)$-code

$(\alpha, \beta = 1, p)$-code

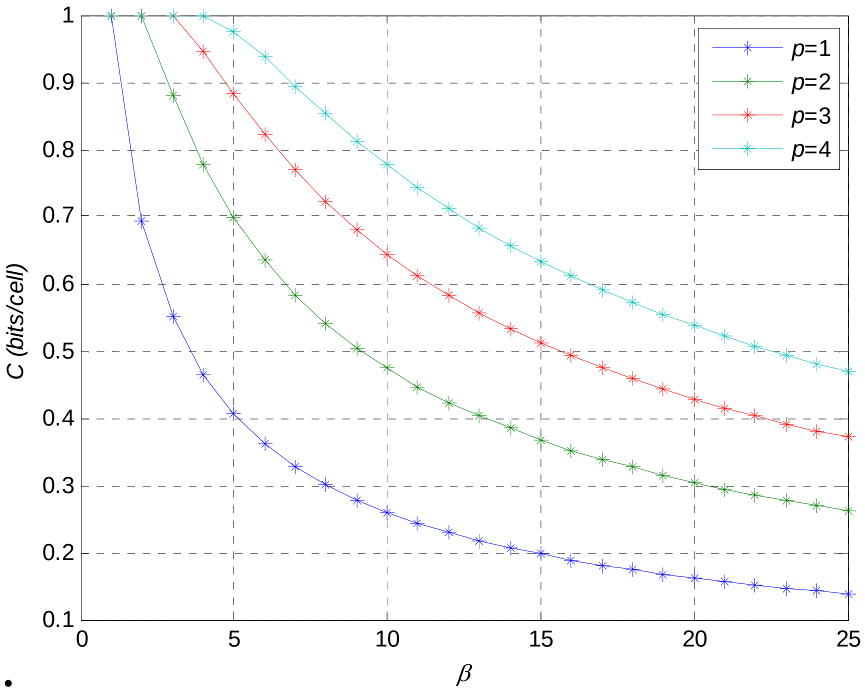
General

(α, β, p)-code

Space Constraint Construction: C(α = 1, β, *p*)

***Theorem*:** The upper bounds of $C(1, \beta, p)$ in the previous section are tight.

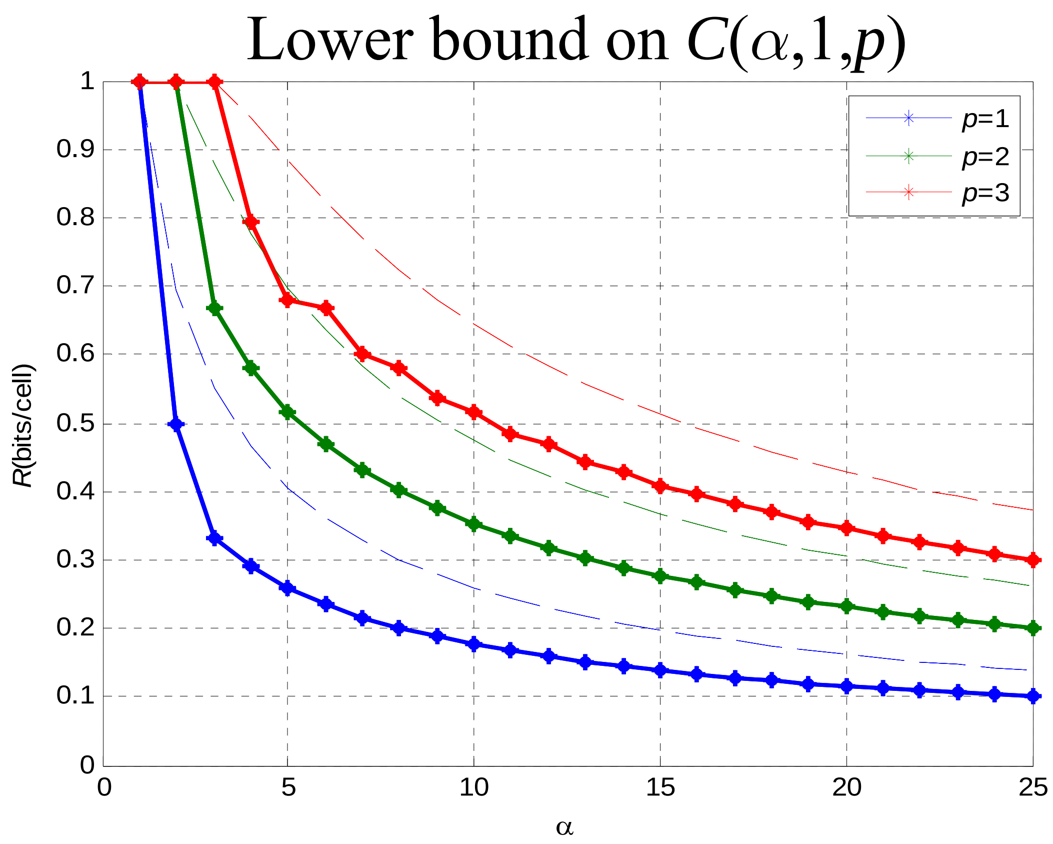
$C(1, \beta, p)$



Key points:

- Probabilistic approach.
- Property of group codes.
- Exponential complexity in encoding.

Time Constraint Construction: $C(\alpha, \beta = 1, p)$



- Constructions based on Write-once memories (WOM) codes[1].

[1]. R.L.Rivest and A. Shamir, "How to reuse a write-once memory," *Inform. and Contr., vol. 55, no. 1–3, pp. 1–19, December 1982.*

Summary

- Motivation
  - Cell programming (State changes) → Heat accumulation → Errors in read/write
  - Modulation (Constrained) codes
    - Time-constraint
    - Space-constraint
- Upper bounds
- Lower bounds

Thank You !