Seminar on Coding for Non-Volatile Memories

236803/048704 – CS/EE Departments, Technion

INTRODUCTION

Coding

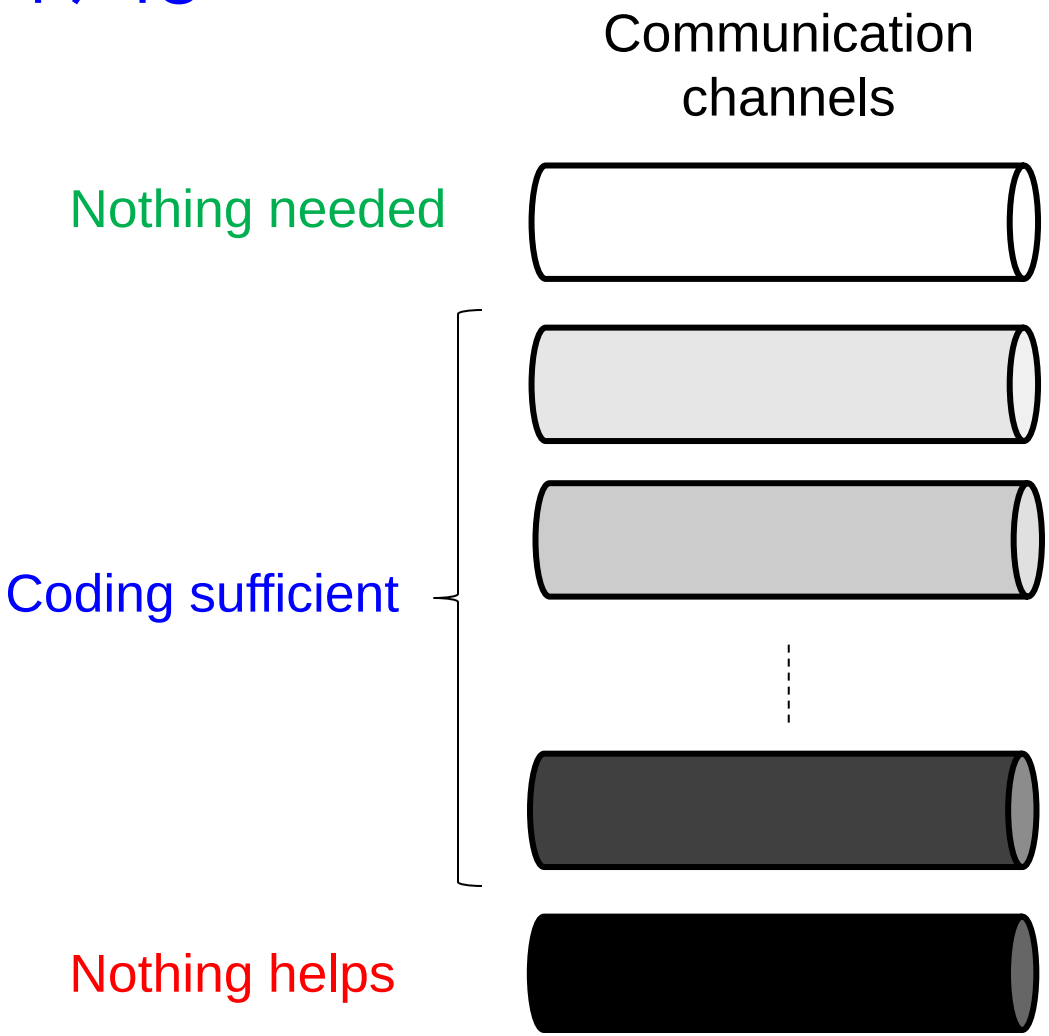
Definition:

Coding is a representation of information designed for some engineering objective.

- Classical examples:
  - Error-correcting codes
  - Data compression
  - Cryptographic codes (ciphers)
  - Software source code

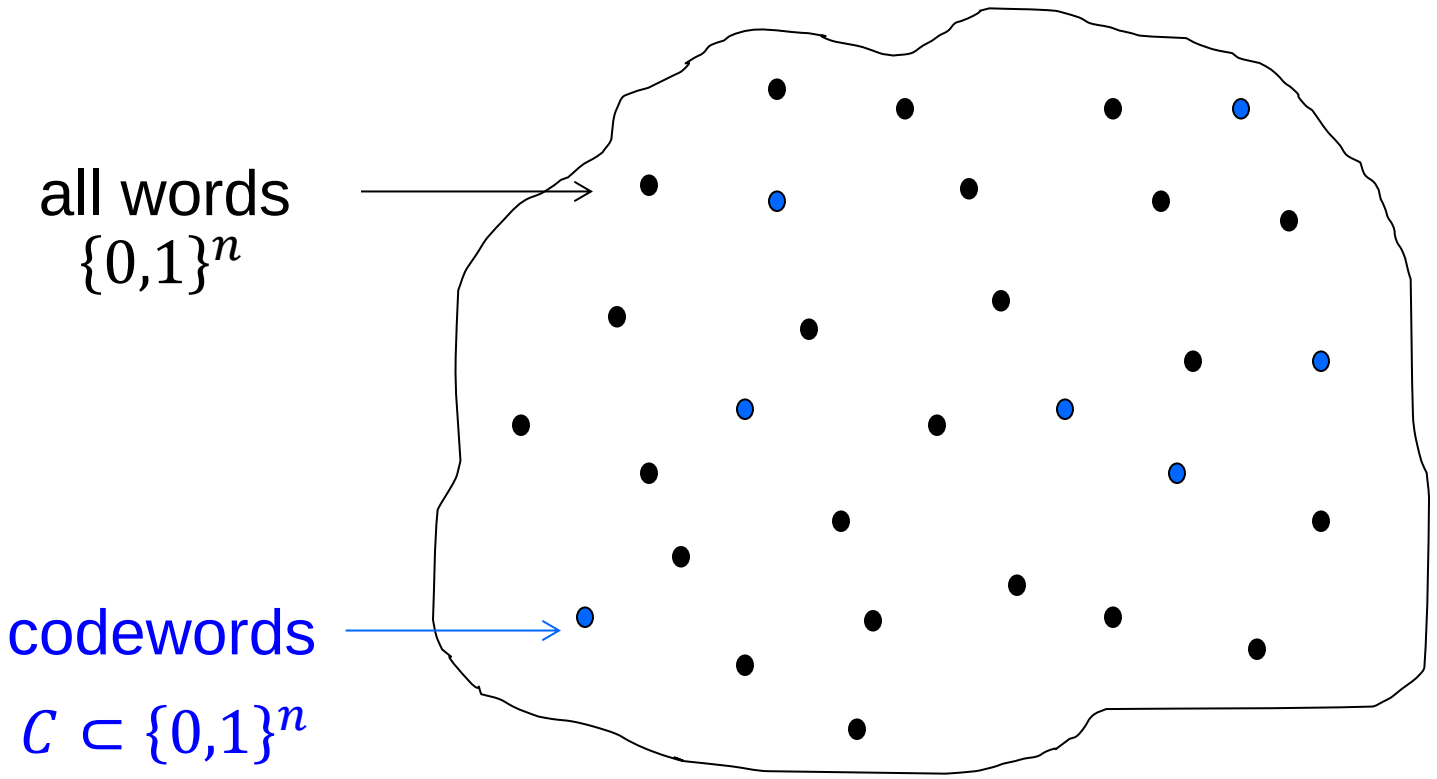
The Birth of Coding

- 1948



Shannon Codes

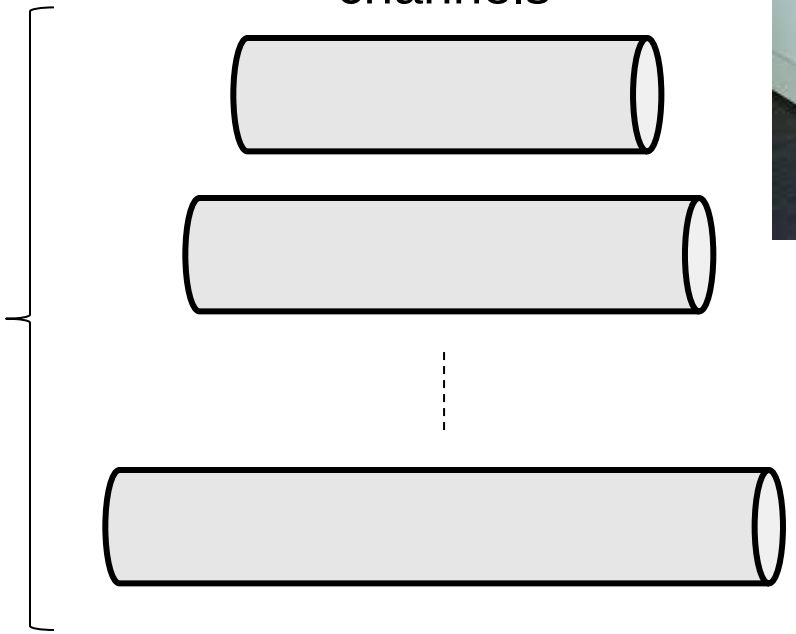
- Code = unstructured subset of $\{0,1\}^n$
  - Random!

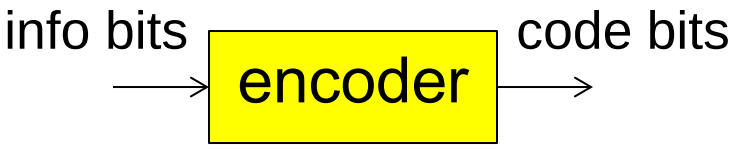


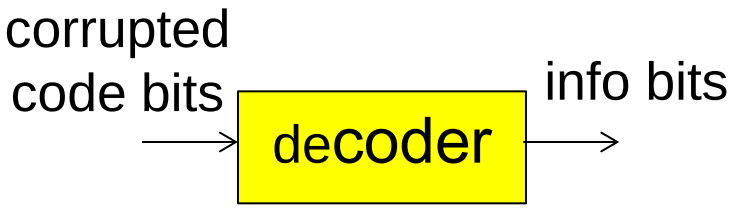
The Birth of Structured Coding

- 1950

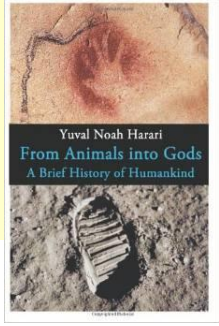
Optimal redundancy, and







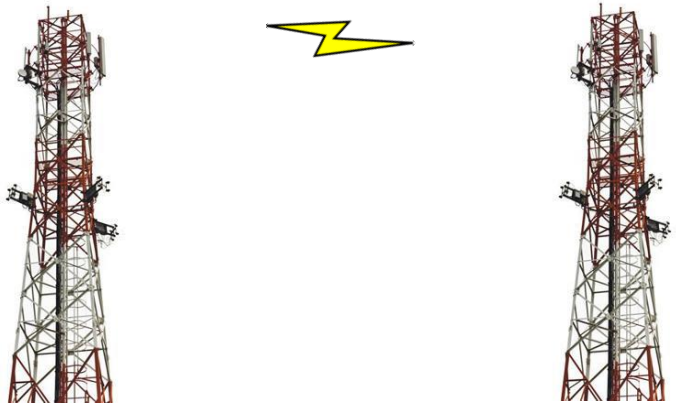
A Brief History of Coding



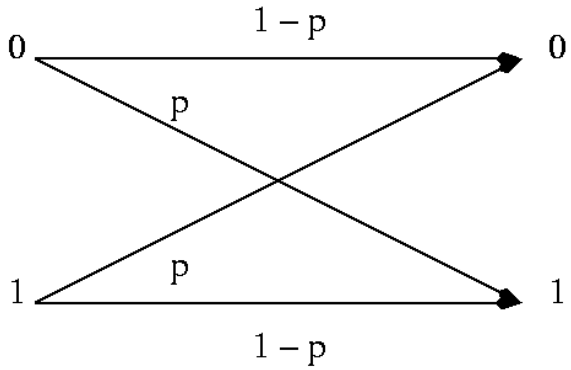
t=1	t=const	any t (but non-binary)	whp	whp, low complexity	whp, low complexity, low error floor	Capacity achieving (but need long blocks)
1950	1959	1960	1967	1993	1998	2009
Hamming	BCH	Reed Solomon	Convolutional codes (Viterbi decoder)	Turbo codes	LDPC codes (showtime)	Polar codes

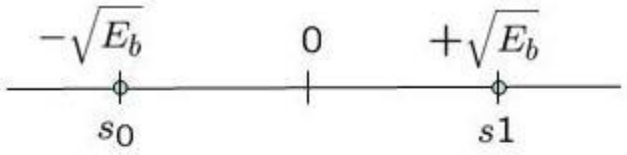
What is Common?

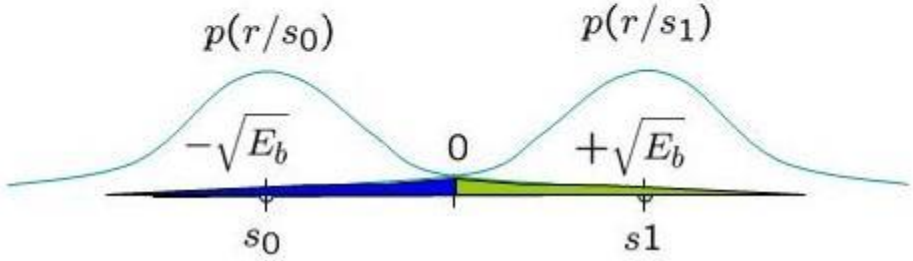
1) Communications:



2) Symmetric errors:

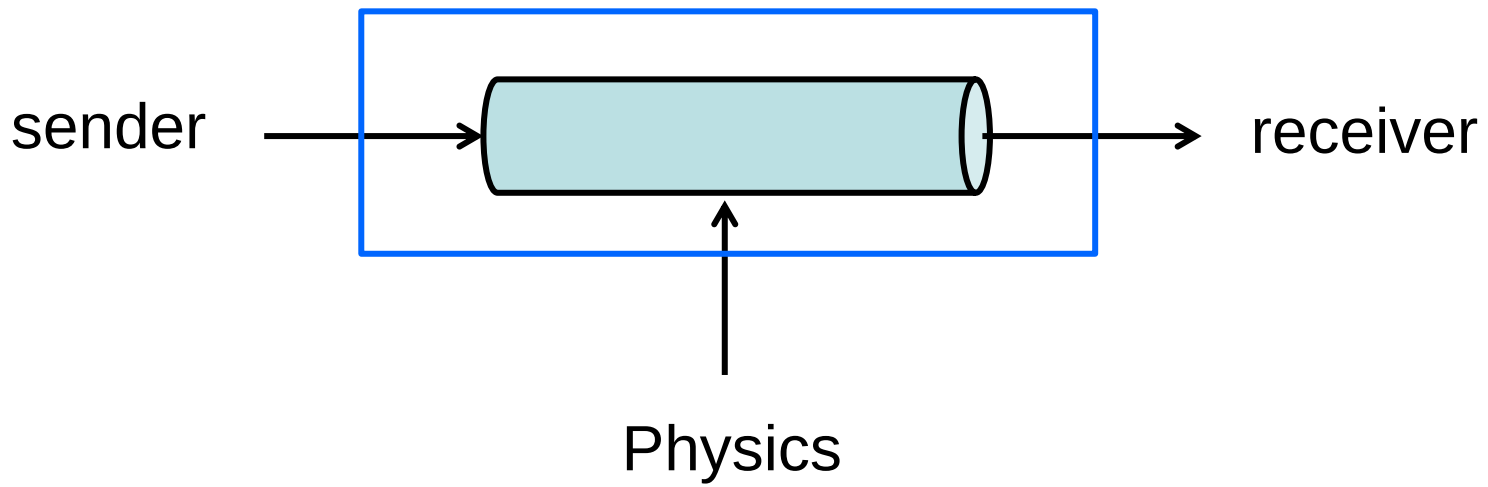






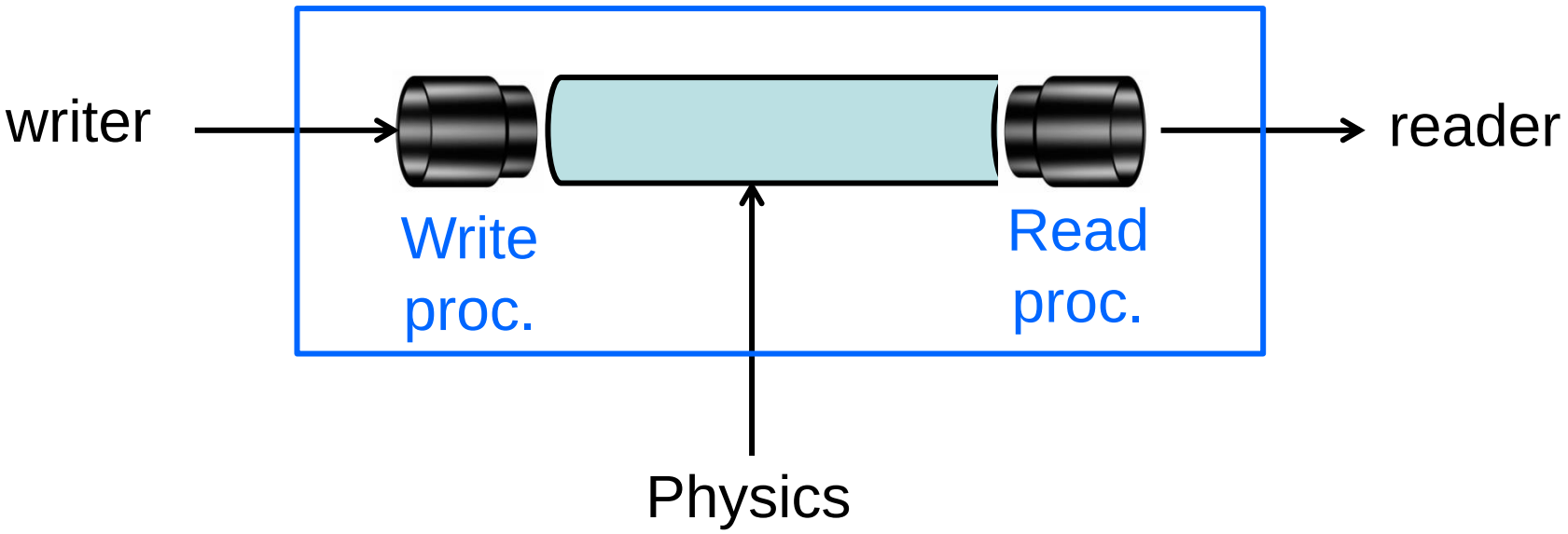
Coding for Communications

Communication



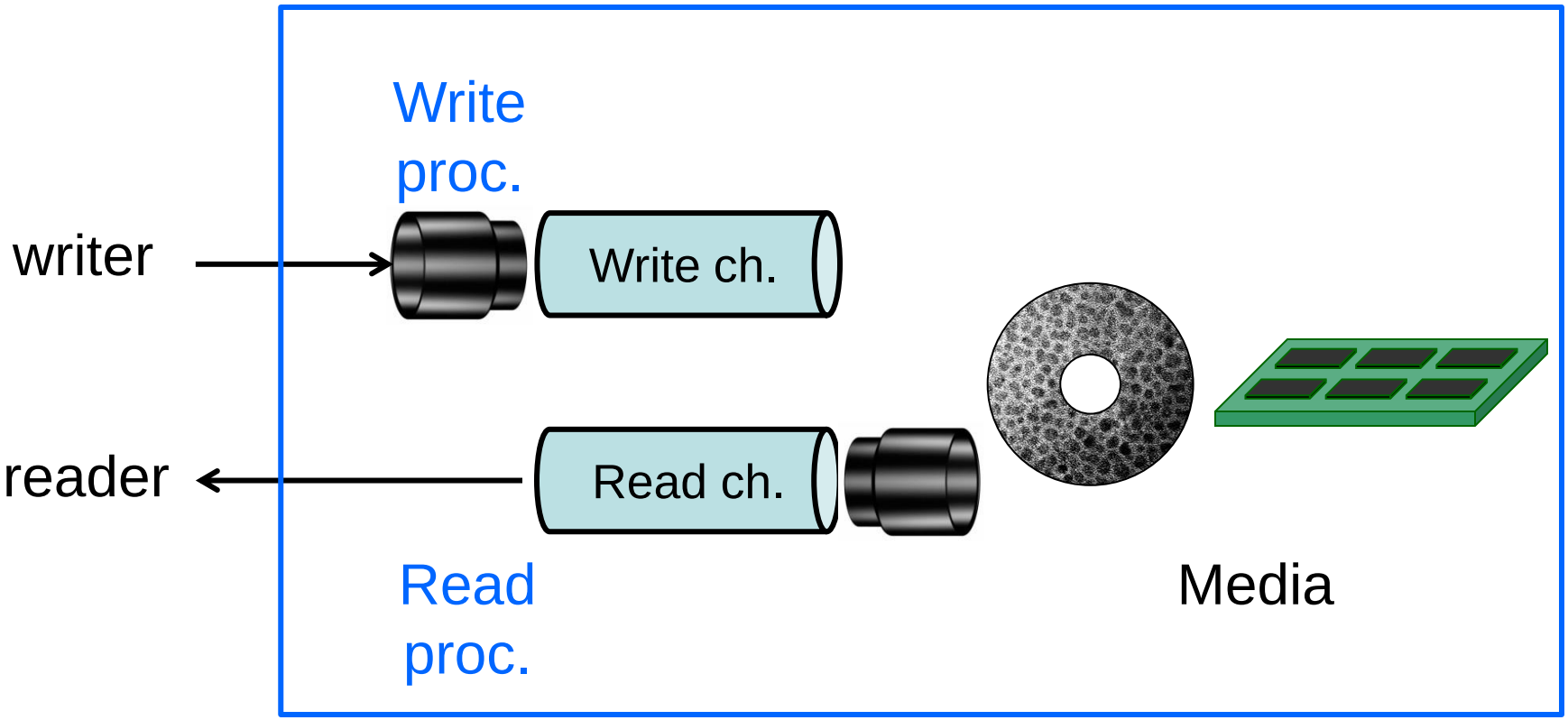
Coding for Storage

Storage



Storage → 2 Channels

Storage



Coding under the reign of HDD

- 1956-2006: Storage = Hard-Disk Drive
- Read channel similar to a communication channel

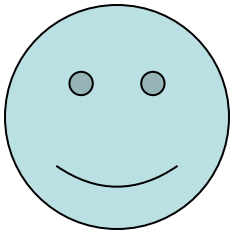
- Write/read synchronization issues
  - Run-Length Limited (RLL) codes

Non-Volatile Storage

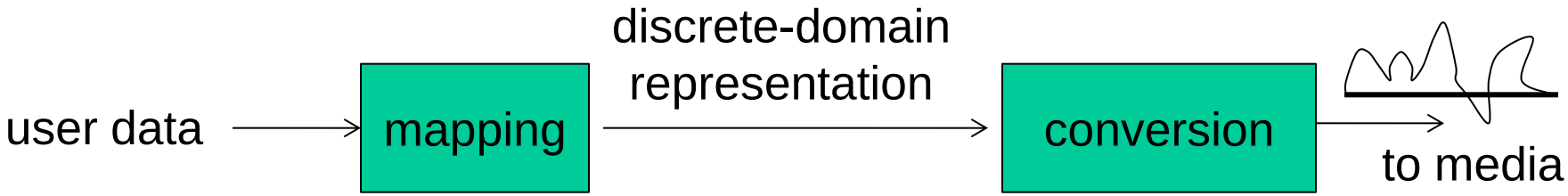
- Solid-State Drive
  - silicon-based cells in 2D/3D matrix
- Leading technology: NAND flash
- More expensive, but much faster
- Capacity scales by "Moore's law"

Coding for Non-Volatile Storage

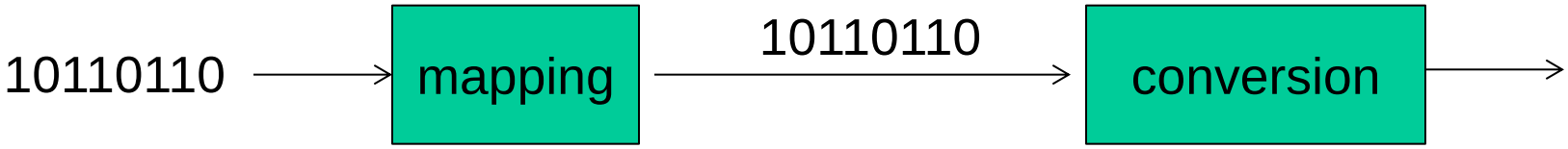
- Early days: SSD is memory
  - Primitive error-correction, e.g. Hamming codes
- Channel very different from communications!



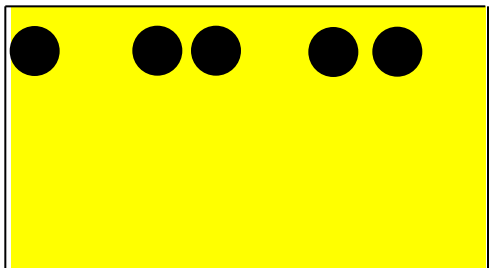
Data Representation



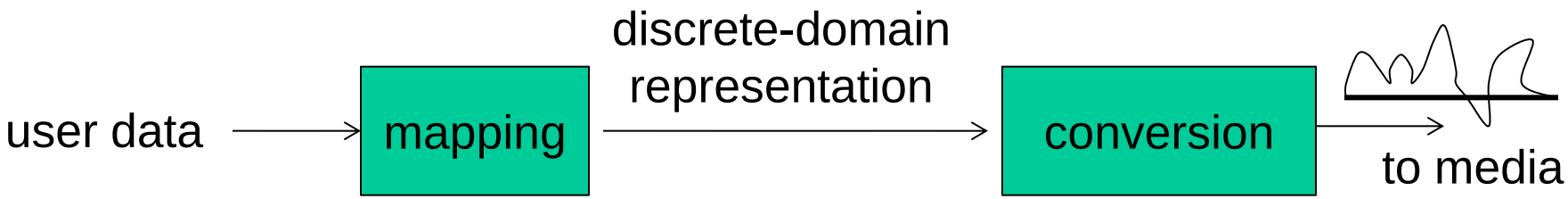
Example: trivial mapping



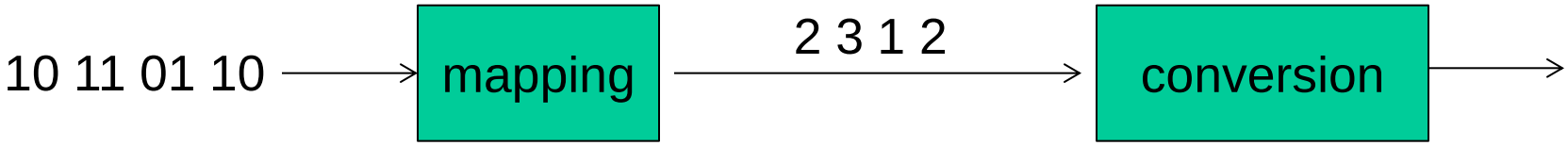
media:
punch tape



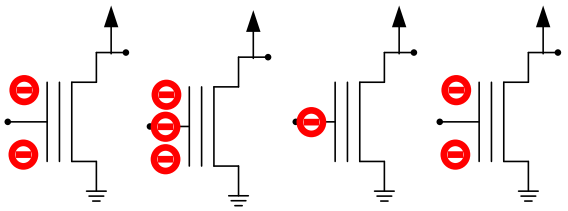
Data Representation



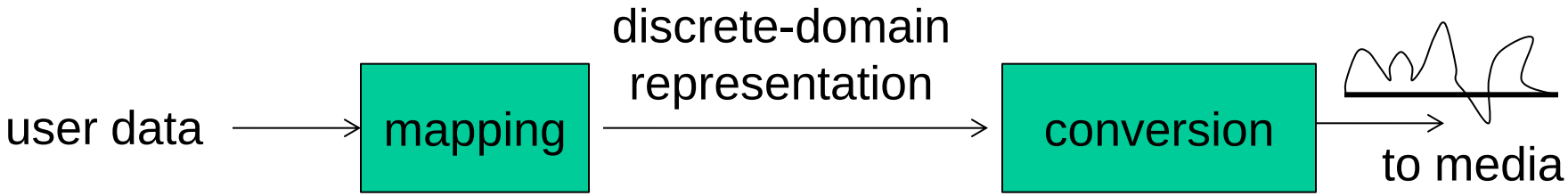
Example: multi-level flash



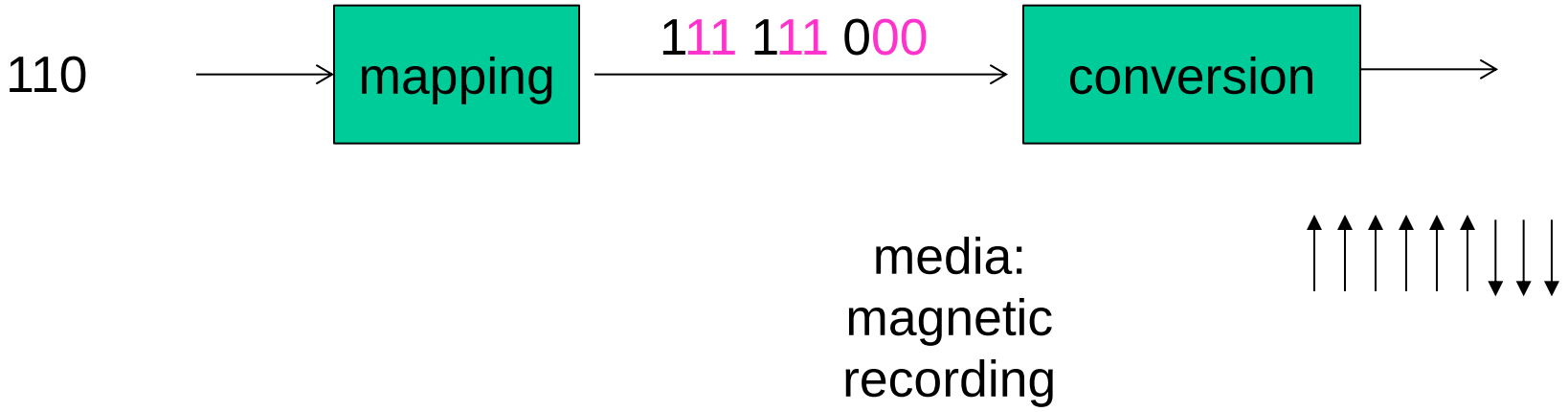
media:
4-level flash



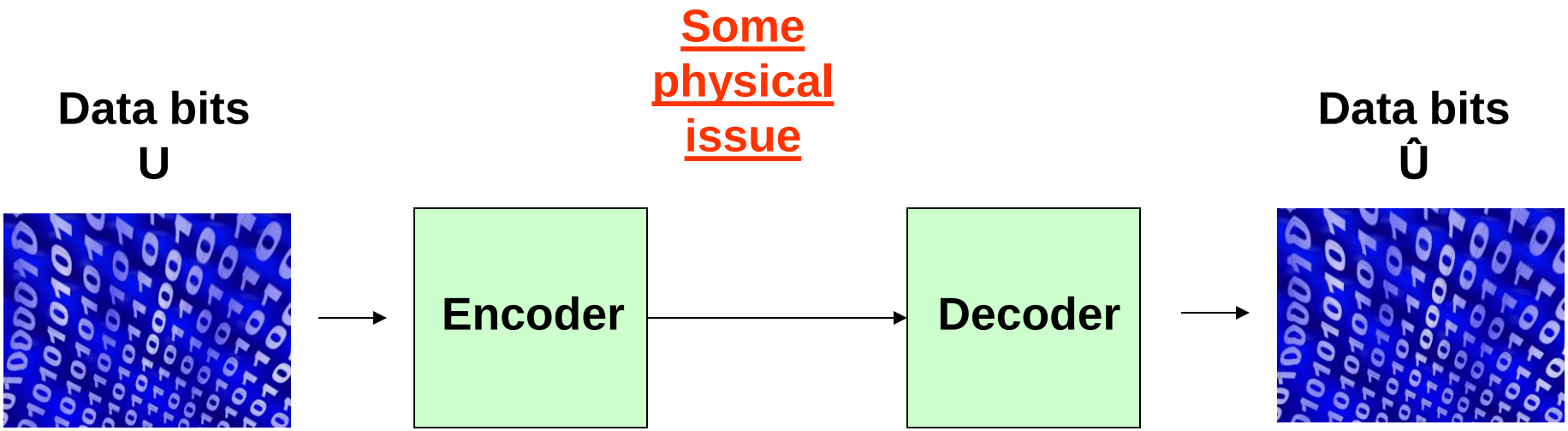
Data Representation



Example: error-correcting codes

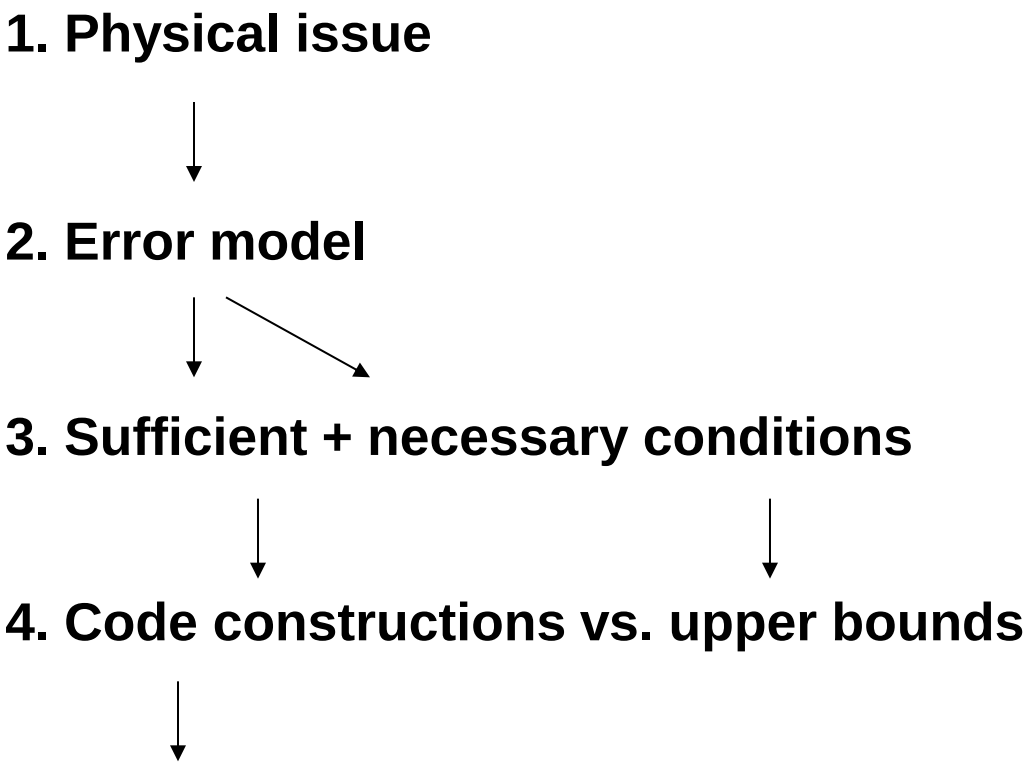


Coding: The General Problem



Find good codes that overcome physical issue and give U = Û

The General Coding Method



Example 1

1. Channel with 0→1 and 1→0

2. At most t 0→1 and 1→0 combined

3. $D_H(x,y)>2t$ for all x,y in C (necessary and sufficient)

4. Hamming code vs. Hamming bound

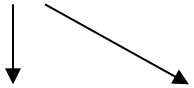
5. Find codewords at Hamming distance t or less from received word

The General Problem

Examples 2,3,4,…

1. Physical impairment

2. Error model



3. Sufficient + necessary conditions

4. Code constructions vs. upper bounds

5. Decoding

Coding for NVMs

About the Course

- URL
  - http://ycassuto.eew.technion.ac.il/teaching/048704-2/
- Some notes
  - 2 Units. Graduate course, open to excellent undergraduates in their last year upon instructor approval.
  - Strong mathematical scope
  - Lectures by students
  - Weekly paper summaries