Storage Coding for Wear Leveling in Flash Memories

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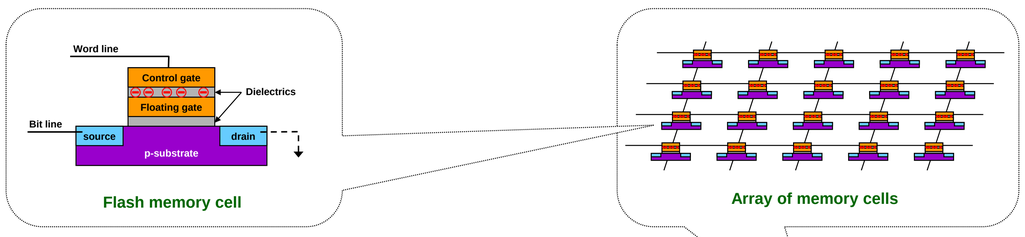
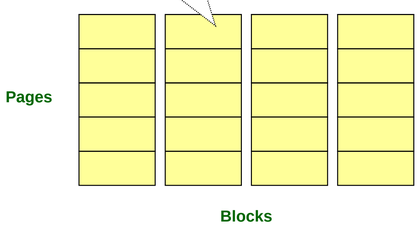
Flash Memory





NVM Non-Volatile Memory

EEPROM Electrically Erasable Programmable Read-Only Memory

Erasing Data

ERASE by BLOCKS

ERASURE is DESTRUCTIVE for the physical substrate (10^4 ~ 10^5 erasures)

Challenge

Given the destination block for each page, reorganize data

while MINIMIZING BLOCK ERASURES

5	6	8	6	1	1	4	8
3	7	6	3	2	4	3	5
2	7	2	1	4	5	8	7

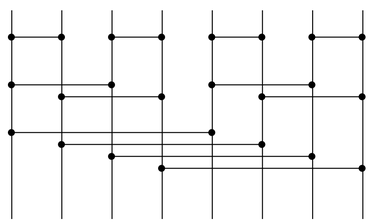
→

1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8

Hall Theorem Decomposition

5	6	8	6	1	1	4	8
3	7	6	3	2	4	3	5
2	7	2	1	4	5	8	7

	6	8				4	
3				2			
			1		5		7



Sorting network

We can pick one number from each column such that they are all different and form a permutation

With **two** extra blocks, **O(n log n)** erasures can be achieved with an AKS [Ajtai,Komlós,Szemerédi 1983] sorting network, and no coding techniques.

Simple Coding Techniques - XOR

Hall theorem decomposition of matrix into "lines" - permutations of {1,…,n}

Process blocks in a fixed order, forward and backward:

Forward: each page maintains old + new (XOR) information

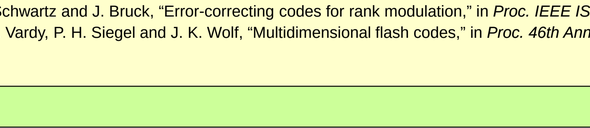
Backward: decode new information for each page

With **one** extra block, **2n** erasures can be achieved with efficient XOR coding techniques.

Permutation decomposition into cycles

	6	8				4	
3				2			
			1		5		7

Each "line" is a permutation made of cycles



b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	
	3	6	8	1	2	5	4	7	
3+1		6	8	1	2	5	4	7	$b_1 + b_4$
3+1	6+2		8	1	2	5	4	7	$b_2 + b_5$
3+1	6+2	8+3		1	2	5	4	7	$b_3 + b_0 + b_4$
3+1	6+2	8+3	1+4		2	5	4	7	$b_4 + b_7$
3+1	6+2	8+3	1+4	2+5		5	4	7	$b_5 + b_6$
3+1	6+2	8+3	1+4	2+5	5		4	7	copy b_6
3+1	6+2	8+3	1+4	2+5	5	4+7		7	$b_7 + b_8$
3+1	6+2	8+3	1+4	2+5	5	4+7	7		copy 8
3+1	6+2	8+3	1+4	2+5	5	4+7	7		$b_7 + b_6 + b_3 + b_0 + b_2$
3+1	6+2	8+3	1+4	2+5	5	4+7		8	$b_6 + b_3 + b_0 + b_2 + b_8$
3+1	6+2	8+3	1+4	2+5	5		7	8	$b_5 + b_4 + b_1$
3+1	6+2	8+3	1+4	2+5		6	7	8	$b_4 + b_1 + b_6$
3+1	6+2	8+3	1+4		5	6	7	8	$b_3 + b_0 + b_2 + b_8$
3+1	6+2	8+3		4	5	6	7	8	$b_2 + b_8$
3+1	6+2		3	4	5	6	7	8	$b_1 + b_6$
3+1		2	3	4	5	6	7	8	$b_0 + b_3$
	1	2	3	4	5	6	7	8	

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