Discussion Section 12

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Faults

- Design Fault
  - Systematic issue with design
  - Affects all instances equally
- Manufacturing Fault
  - Issue at manufacturing stage
  - Affects particular batch of devices
- Runtime Fault
  - Caused by random events (e.g. particle strike)
  - Affects devices randomly depending on history of use

Failure Mechanisms

- Hot Carrier Injection
  - Strong current + gate field can embed carriers into oxide
  - Eventually builds up voltage, renders device unusable
- Time-Delayed Dielectric Breakdown (TDDB)
  - Over time, a shorting path forms in gate oxide
- Electromigration
  - Electron drift current pushes metal atoms out of position, eventually breaking connections

Error Correction Codes

- Runtime errors are unpredictable, but can guard against them
- Can introduce encoding schemes that help detect and correct errors

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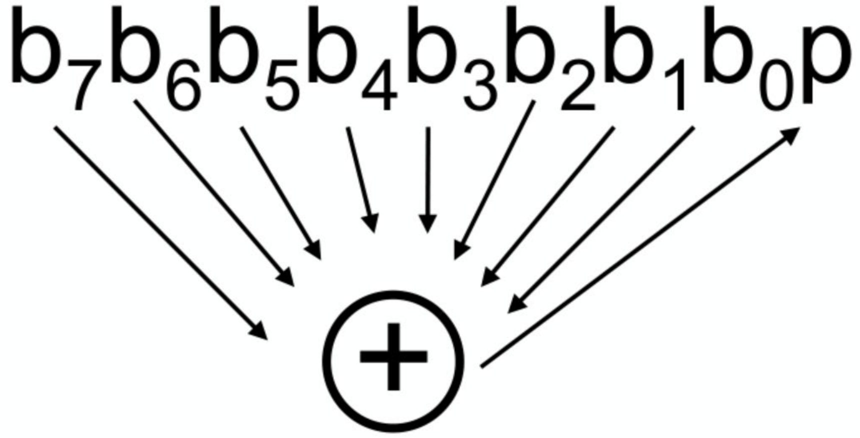
Error Correction Codes

- Simplest ECC is a single parity bit
- Can detect an odd number (1-bit, 3-bit, etc.) of errors
- Indicates that an error occurred, but no way to determine which bit flipped
- Can we combine parity bits?



Hamming Code

- Use a set of parity bits to determine the error bit
- Choose parity bits to represent different groups of bits
- Each bit of data covered by a unique combination of parity bits
- Can identify and correct a single bit of error (SECSED)

1	2	3	4	5	6	7
p_1	p_2	d_1	p_3	d_2	d_3	d_4

Bit position number

$$\left.\begin{array}{l} 001 = 1_{10} \\ 011 = 3_{10} \\ 101 = 5_{10} \\ 111 = 7_{10} \end{array}\right\} p_1$$

$$\left.\begin{array}{l} 010 = 2_{10} \\ 011 = 3_{10} \\ 110 = 6_{10} \\ 111 = 7_{10} \end{array}\right\} p_2$$

$$\left.\begin{array}{l} 100 = 4_{10} \\ 101 = 5_{10} \\ 110 = 6_{10} \\ 111 = 7_{10} \end{array}\right\} p_3$$

Hamming Code Example

- Index the bits starting at 1

10110110

Hamming Code Example

- Index the bits starting at 1
- Add parity bits to the places at powers of 2
  - Parity bits would be in positions 1,2,4,8,16, …

$$p_1 p_2 1 p_4 011 p_8 0110$$

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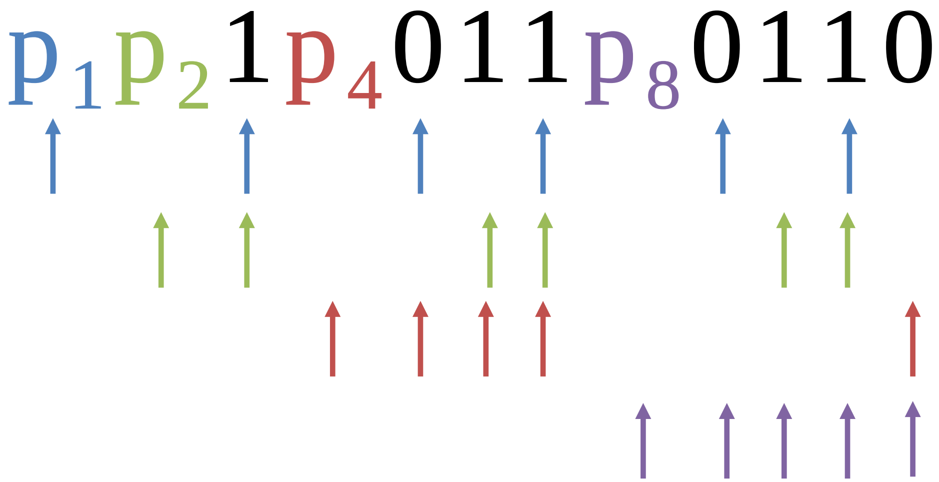
Hamming Code Example

- Index the bits starting at 1
- Add parity bits to the places at powers of 2
  - Parity bits would be in positions 1,2,4,8,16, …
- Each parity bit is responsible for a different group of bits
  - Each bit covers its respective power of 2 in the bit index starting from itself (slide 6)



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Hamming Code Example

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- Add parity bits to the places at powers of 2
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1	p_1	p_2	
0	p_1	p_4	
1	p_2	p_4	
1	p_1	p_2	p_4
0	p_1	p_8	
1	p_2	p_8	
1	p_1	p_2	p_8
0	p_4	p_8	

Hamming Code Example

- Index the bits starting at 1
- Add parity bits to the places at powers of 2
  - Parity bits would be in positions 1,2,4,8,16, …
- Each parity bit is responsible for a different group of bits
  - Each bit covers its respective power of 2 in the bit index starting from itself (slide 6)
- Set parity bits by taking XOR of all the data bits they cover

1 1 1 0 0 1 1 0 0 1 1 0

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Hamming Code Example

- Identify the wrong bit using the parity bits

1 1 1 0 0 0 1 0 0 1 1 0

Hamming Code Example

- Identify the wrong bit using the parity bits
- Check all parity bits to see which ones are invalid
  - p_2 and p_4

$$1\,1\,1\,0\,0\,0\,1\,0\,0\,1\,1\,0$$

$$p_1 \quad 1 = 1 \oplus 0 \oplus 1 \oplus 0 \oplus 1 \oplus 0$$

$$p_2 \quad 1 \neq 1 \oplus 0 \oplus 1 \oplus 1 \oplus 1$$

$$p_4 \quad 0 \neq 0 \oplus 0 \oplus 1 \oplus 0$$

$$p_8 \quad 0 = 0 \oplus 1 \oplus 1 \oplus 0$$

Hamming Code Example

- Identify the wrong bit using the parity bits
- Check all parity bits to see which ones are invalid
  - p_2 and p_4
- Find bit covered by these parity bits

1	p_1	p_2	
0	p_1	p_4	
$\boxed{0}$	$\boxed{p_2}$	$\boxed{p_4}$	
1	p_1	p_2	p_4
0	p_1	p_8	
1	p_2	p_8	
1	p_1	p_2	p_8
0	p_4	p_8	

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Hamming Code Example

- Identify the wrong bit using the parity bits
- Check all parity bits to see which ones are invalid
  - p_2 and p_4
- Find bit covered by these parity bits
- Identified error bit and can correct

1	p_1	p_2	
0	p_1	p_4	
$\boxed{1}$	$\boxed{p_2}$	$\boxed{p_4}$	
1	p_1	p_2	p_4
0	p_1	p_8	
1	p_2	p_8	
1	p_1	p_2	p_8
0	p_4	p_8	

Extended Hamming Code (SECDED)

- What if there are 2 error bits?

1 1 1 0 0 0 1 0 0 0 1 0

Extended Hamming Code (SECDED)

- What if there are 2 error bits?
- Parity bit p_2 would not detect this error
  - This would appear like the last data bit had the bit error!

1	p_1	p_2	
0	p_1	p_4	
0	p_2	p_4	
1	p_1	p_2	p_4
0	p_1	p_8	
0	p_2	p_8	
1	p_1	p_2	p_8
0	p_4	p_8	

Extended Hamming Code (SECDED)

- What if there are 2 error bits?
- Parity bit p_2 would not detect this error
  - This would appear like the last data bit had the bit error!
- Solution: Add one more parity bit checking entire word

1 1 1 0 0 0 1 0 0 0 1 0 1

Extended Hamming Code (SECDED)

- Check all parity bits to see which ones are invalid
  - p_4 and p_8
  - p_2 does not catch the error
- If this was a single error situation, detector would assume last data bit had error
- However, final parity bit check should also fail on single bit error
- Final parity bit check passes, but other parity bits fail → double bit error!

1 1 1 0 0 0 1 0 0 0 1 0 1

p_1 $1 = 1 \oplus 0 \oplus 1 \oplus 0 \oplus 1 \oplus 0$

p_2 $1 = 1 \oplus 0 \oplus 1 \oplus 0 \oplus 1$

p_4 $0 \neq 0 \oplus 0 \oplus 1 \oplus 0$

p_8 $0 \neq 0 \oplus 0 \oplus 1 \oplus 0$