**Discussion 13: I/O, ECC/Parity, RAID**

**Hamming ECC**

Recall the basic structure of a Hamming code. Given bits 1, \ldots, m, the bit at position 2n is parity for all the bits with a 1 in position n. For example, the first bit is chosen such that the sum of all odd-numbered bits is even.

<table>
<thead>
<tr>
<th>Bit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>P1</td>
<td>P2</td>
<td>D1</td>
<td>P4</td>
<td>D2</td>
<td>D3</td>
<td>D4</td>
<td>P8</td>
<td>D5</td>
<td>D6</td>
<td>D7</td>
<td>D8</td>
<td>D9</td>
<td>D10</td>
<td>D11</td>
</tr>
<tr>
<td>P1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>P4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>P8</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

i. How many bits do we need to add to 00112 to allow single error correction?
   
   Parity Bits: 3

ii. Which locations in 00112 would parity bits be included?
   
   Using P for parity bits: PP0P0112

iii. Which bits does each parity bit cover in 00112?
   
   Parity bit #1: 1, 3, 5, 7
   Parity bit #2: 2, 3, 6, 7
   Parity bit #3: 4, 5, 6, 7

iv. Write the completed coded representation for 00112 to enable single error correction.
   
   10000112

v. How can we enable an additional double error detection on top of this?
   
   Add an additional parity bit over the entire sequence.

vi. Find the original bits given the following SEC Hamming Code: 01101112
   
   Parity group 1: error
   Parity group 2: okay
   Parity group 4: error
   Incorrect bit: 1 + 4 = 5, change bit 5 from 1 to 0: 01100112
   01100112 → 10112
vii. Find the original bits given the following SEC Hamming Code: 1001000₂
Parity group 1: error
Parity group 2: okay
Parity group 4: error
Incorrect bit: 1 + 4 = 5, change bit 5 from 1 to 0: 1001100₂
1001100₂ → 0100₂

viii. Find the original bits given the following SEC Hamming Code: 010011010000110₂
Parity group 1: okay
Parity group 2: error
Parity group 4: okay
Parity group 8: error
Incorrect bit: 2 + 8 = 10, change bit 10 from 0 to 1: 010011010100110₂
010011010100110₂ → 01100100110₂

**RAID**

Fill out the following table:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Pro / Good for…</th>
<th>Con / Bad for…</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAID 0</td>
<td>Data disks without check information</td>
<td>No overhead Fast read / write</td>
</tr>
<tr>
<td>RAID 1</td>
<td>Mirrored Disks: Extra copy of disks</td>
<td>Fast read / write Fast recovery</td>
</tr>
<tr>
<td>RAID 2</td>
<td>Hamming ECC: One check disk per parity group</td>
<td>Smaller overhead</td>
</tr>
<tr>
<td>RAID 3</td>
<td>Single check disk for error correction (Disk controllers can detect failures) Transfer units are spread over all disks in a group (bit interleaving)</td>
<td>Smallest check information overhead</td>
</tr>
<tr>
<td>RAID 4</td>
<td>Transfer units = a sector within a single disk. Errors are detected within a single transfer unit Can handle independent reads/writes per disks</td>
<td>Higher throughput of small reads</td>
</tr>
<tr>
<td>RAID 5</td>
<td>Check information is distributed across all disks in a group.</td>
<td>Higher throughput of small writes</td>
</tr>
</tbody>
</table>

Small accesses = an access to a single disk in a group