Given:

- Replacement Algorithm: Intel 486 pseudo-LRU (Least Recently Used)
- Cache Organization: 128 sets
- Each set has: 4 lines (L0, L1, L2, L3)
- Replacement Metadata: Each set is associated with 3 bits (B0, B1, B2)
- Replacement Strategy:
    - Cache first distinguishes between pairs: (L0, L1) vs (L2, L3)
    - Then within the selected pair, identifies the least recently used block to evict

Solution:

a/ In what way are bits B0, B1, B2 used

In the pseudo-LRU replacement algorithm, these three bits (B0, B1, B2) form a binary tree structure to determine which line should be replaced:

- **B0 bit**: Makes the selection between lines L0 and L1 versus lines L2 and L3
    - If B0 = 0, it means lines L0 and L1 were more recently used (and L2, L3 were less recently used)
    - If B0 = 1, it means lines L2 and L3 were more recently used (and L0, L1 were less recently used)
- **B1 bit**: Makes the selection between lines L0 and L1
    - If B1 = 0, it means line L0 was more recently used than L1
    - If B1 = 1, it means line L1 was more recently used than L0
- **B2 bit**: Makes the selection between lines L2 and L3
    - If B2 = 0, it means line L2 was more recently used than L3
    - If B2 = 1, it means line L3 was more recently used than L2

The replacement algorithm works as follows:

1. First, the B0 bit is checked
2. If B0 = 0, the B2 bit is used to choose between L2 and L3 (if B2 = 0, replace L3; if B2 = 1, replace L2)

3. If B0 = 1, the B1 bit is used to choose between L0 and L1 (if B1 = 0, replace L1; if B1 = 1, replace L0)

When a line is accessed, the bits are updated as follows:

- When L0 is accessed: B0 = 0, B1 = 0
- When L1 is accessed: B0 = 0, B1 = 1
- When L2 is accessed: B0 = 1, B2 = 0
- When L3 is accessed: B0 = 1, B2 = 1

b/ How many bits need each set to implement full LRU algorithm

A full LRU implementation for a 4-way set requires tracking the exact order of usage for all 4 lines. The number of possible permutations of 4 lines is:

- 4! = 24 unique usage orders
- To encode 24 states, you need: log2(24) ≈ 4.58 ⇒ at least 5 bits

Answer: 5 bits are required per set to implement a true/full LRU algorithm for 4 lines.