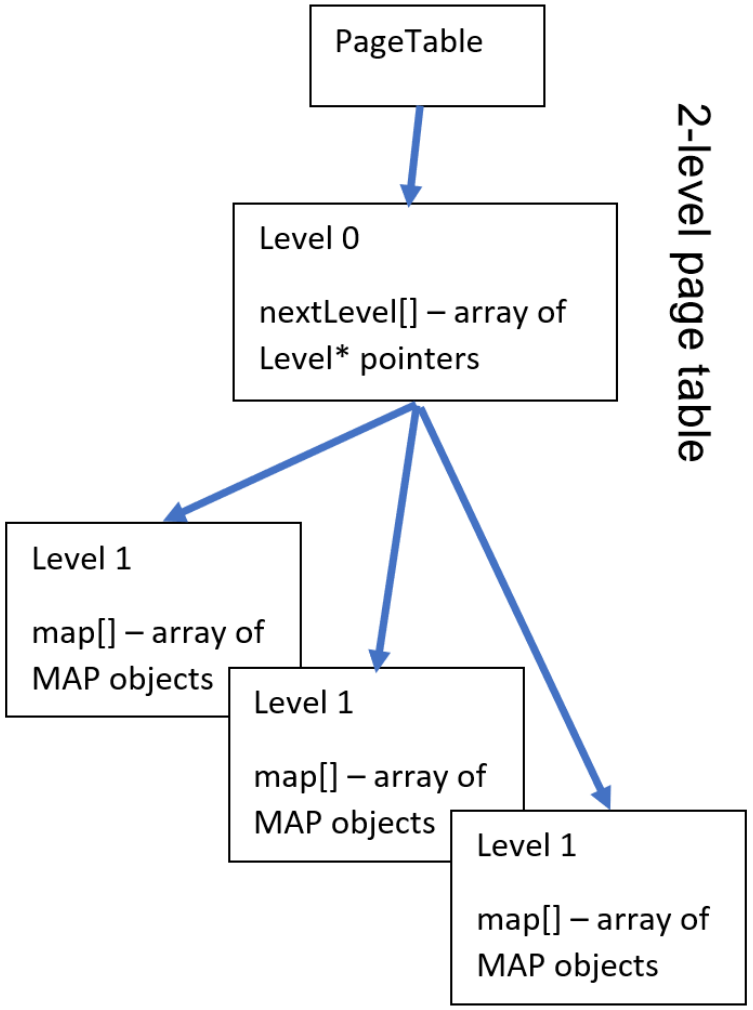
A sample data structure for N-level page tables

Sample Data Structure

- PageTable – Contains information about the tree
- Level – The page tree node representation. A structure describing a specific level of the page table.
  - nextLevel[ ] – Array of Level* pointers to the next level. (non-leaf or interior level), it is essentially a double Level**
  - map[ ] – Array of Map objects, each mapping a logical/virtual page to a physical frame. (leaf level)

    Map object can have a

    frame number and valid flag



PageTable

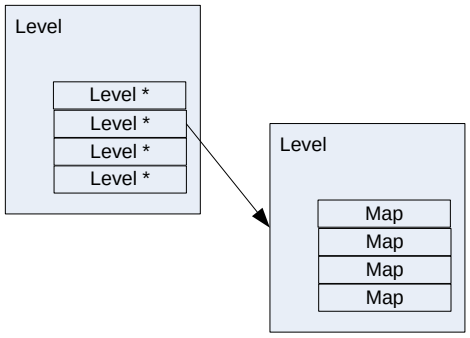
- Contains information about the tree:
  - levelCount: Number of levels
  - bitmask [i]: bit mask for level i
  - bitShift [i]: # of bits to shift level i page bits
  - entryCount [i]: # of possible pages for level i

Levels of the page table

- Each level of the page table is represented by a pair of structures:
  - Conceptually, Level contains an array of pointers to the next level (Level *) or Map entries
    - C/C++ does not permit variable size structures.
    - We circumnavigate this by using a pointer to a runtime allocated structure.
    - See the course FAQ for allocating arrays at runtime.
  - Interior levels use Level and nextLevel [ ] (NextLevelPtr, Level *[] or Level **), each element is a Level * pointer pointing to a next Level object
  - **Leaf** levels use Level and map[ ] (MapPtr, Map[] or Map*), each element is a Map object

- Useful information to have in Level
  - Current depth
  - Pointer to the PageTable structure/object to access information

Conceptual organization



Initialization

- Suppose we wanted to create a 3 level page table with 8 bits per level on a 32 bit address space.
- We would allocate a PageTable structure and populate it with the following values:
  - levelCount = 3
  - bitmaskAry [] = {0xFF000000, 0x00FF0000, 0x0000FF00}
  - shiftAry [] = {24, 16, 8}
  - entryCount [] = {2^8, 2^8, 2^8}

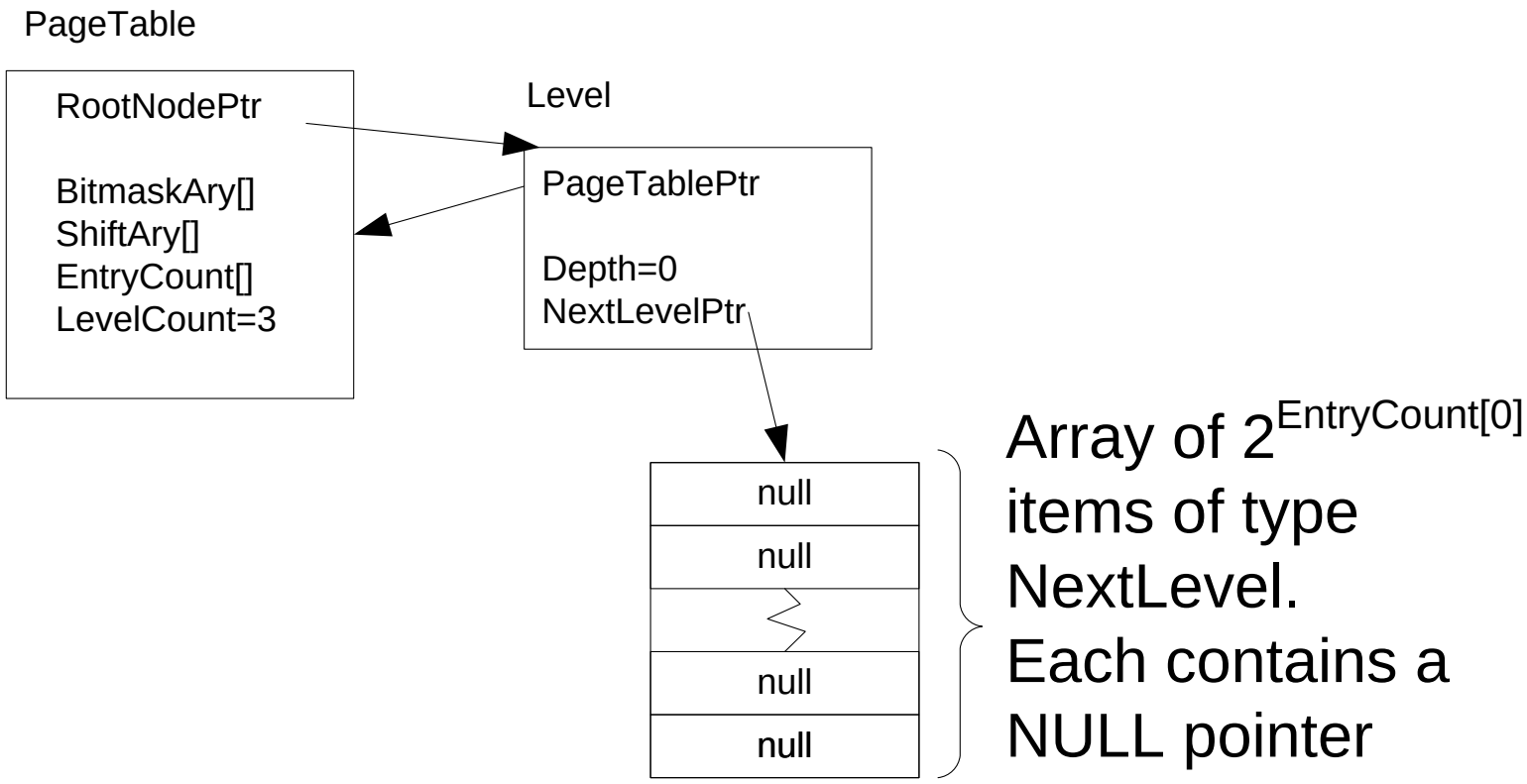
  bitmaskAry, shiftAry, and entryCount should all be computed dynamically based on your PageTable specification.

Initialize Data Structure

- In addition, we would allocate the level 0 information:
  - Allocate a Level structure
    - Set its depth to 0
    - Have it point back to the PageTable
    - Allocate an array of 256 (2^8) pointers to Level structures.
      - Initialize all to NULL (number of level 1 entries)
      - If this had been a 1 level page table we would have allocated Map structures instead of pointers to Levels

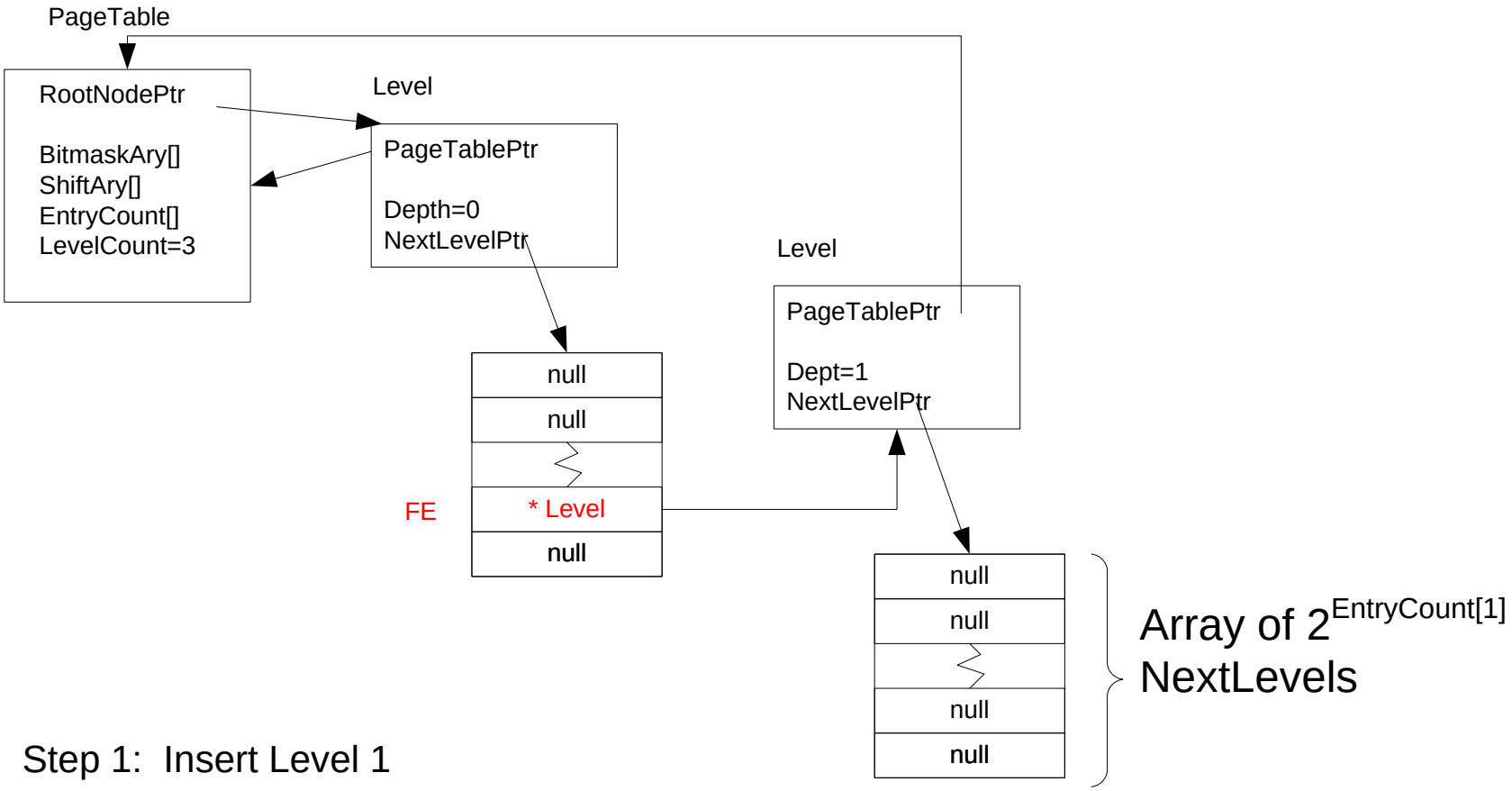
3 level example

- Empty table (Note Level is the node, NextLevelPtr is the children Level / node array, i.e.: Level*[] or Level **)



Page Insertion

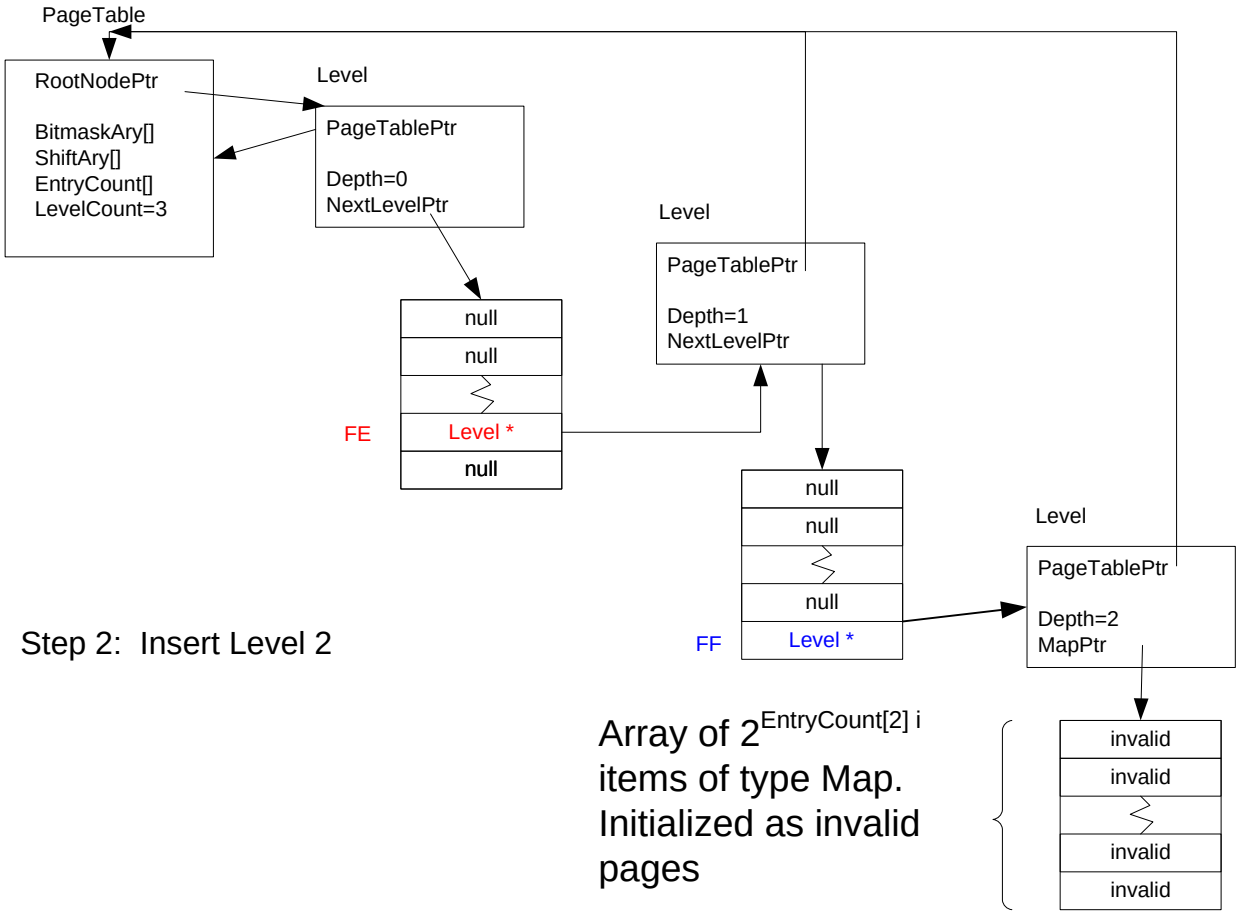
Assume 32 bit word, 8 bit pages for each level
Insert address 0xFEFFFEC2 mapping to frame 3



Step 1: Insert Level 1

Page Insertion

Assume 32 bit word, 8 bit pages for each level
Insert address 0xFEFFFEC2 mapping to frame 3

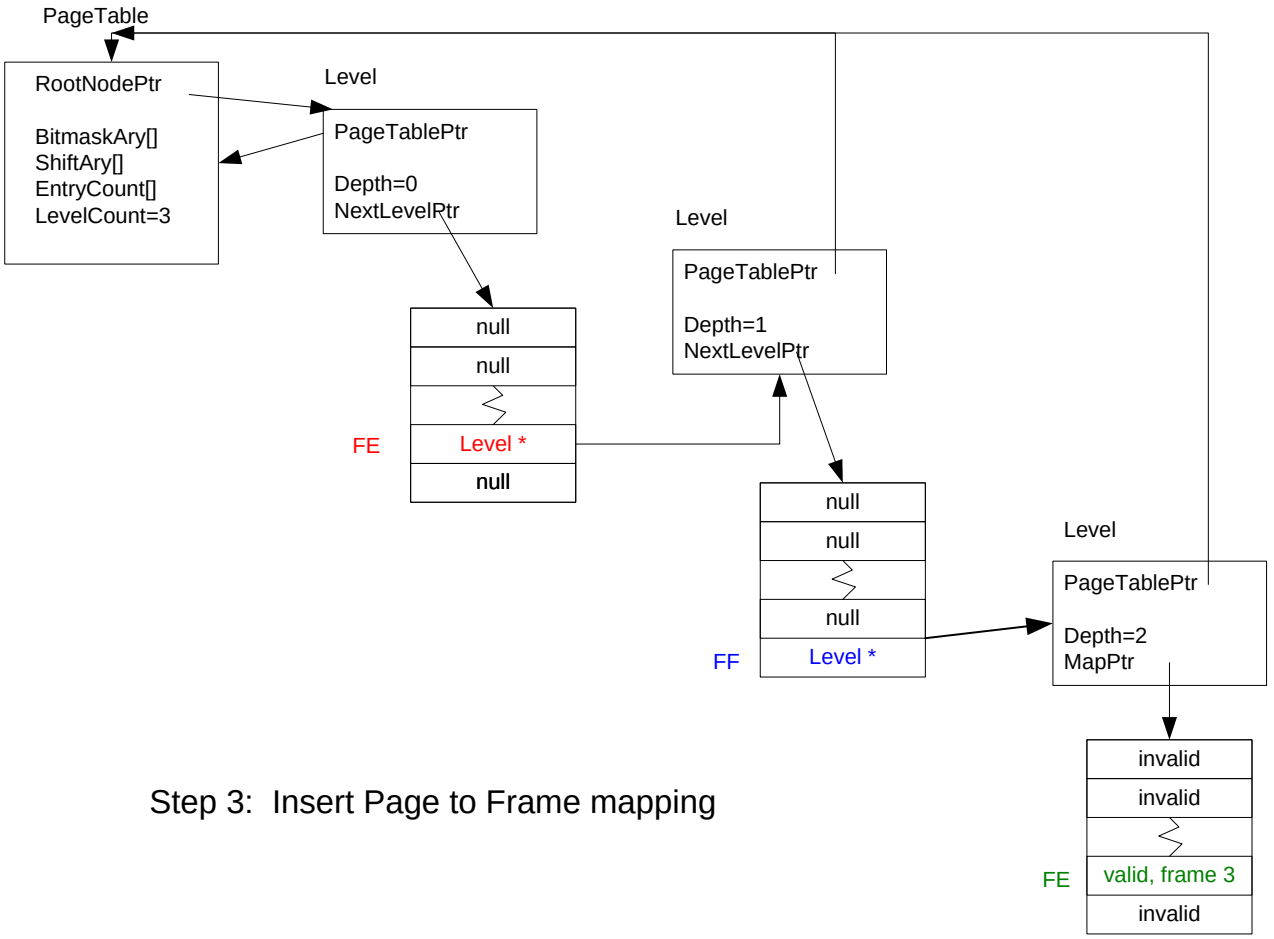


Inserting leaf nodes

- Next, we insert the level 2 node which is a leaf in a 3 level page table.
- This time, we allocate Maps instead of pointers to next Level.
- Initialize the pages (maps) to invalid.
- Set the level 2 pages (maps) to valid and store the frame.

Page Insertion

Assume 32 bit word, 8 bit pages for each level
Insert address 0xFEFFFEC2 mapping to frame 3



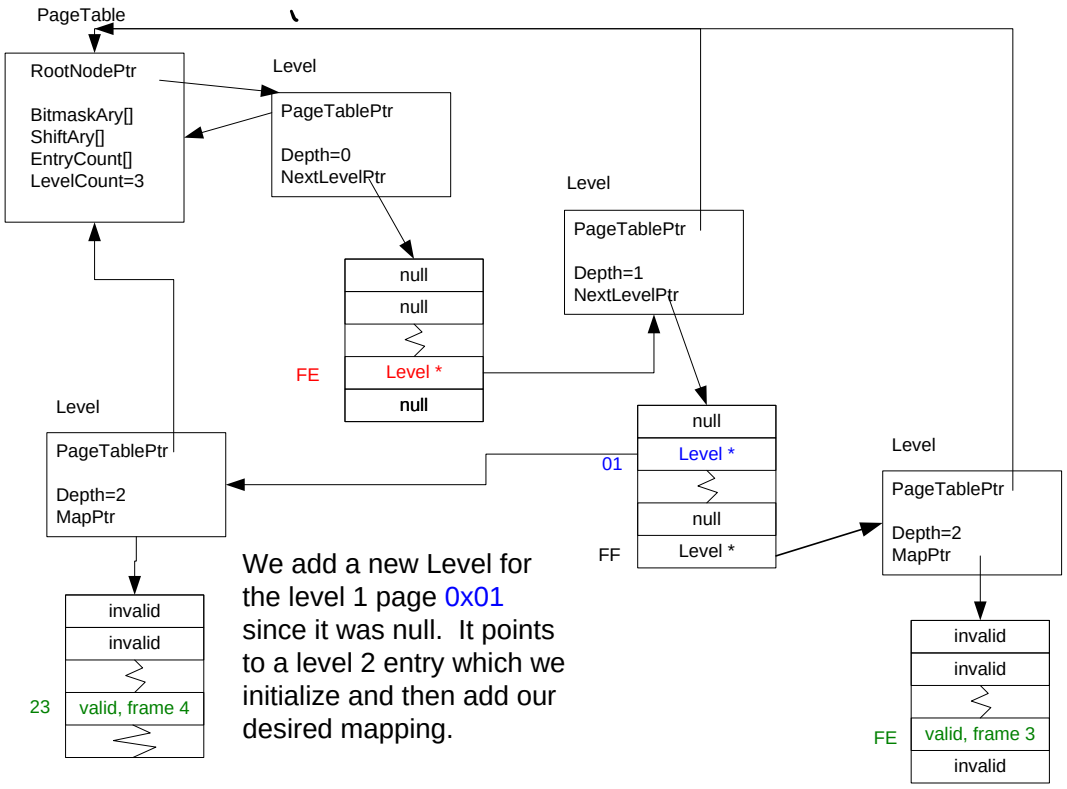
Step 3: Insert Page to Frame mapping

Another example

- Next, add a mapping between the page associated with address 0xFE0123C2 and frame 4.
- Pay attention to the fact that the level 0 page, 0xFE, already exists and note how the new entries are added.

Adding a second page

Assume 32 bit word, 8 bit pages for each level
Insert address 0xFE01123C2 mapping to frame 4



We add a new Level for the level 1 page 0x01 since it was null. It points to a level 2 entry which we initialize and then add our desired mapping.

Insert_vpn2pfn Pseudo-Code (a recursive approach, you are free to use an iterative approach)

```
PageTable class
    insert_vpn2pfn(pageTablePtr, address, frame) {
        // C users, you would have to rename the 2nd insert_vpn2pfn
        // function since C cannot distinguish two functions with
        // the same name and different signatures.
        insert_vpn2pfn(pageTablePtr->rootNodePtr, address, frame)
    }

Level class
    insert_vpn2pfn(levelPtr, address, frame) {
        Find index into current page level
        if leaf node(levelPtr) {
            Set appropriate page index to valid and store Frame
        } else {
            Create a new Level and set level to current depth + 1
            Create an array of Level * entries based upon the number of entries in the
              new level and initialize to null/invalid as appropriate
            insert_vpn2pfn(pointer to new Level, address, frame)
        }
    }
```