CSE 100: B TREES
B- Trees

• Data structures for efficient search on secondary storage
Typical memory hierarchy: a picture

<table>
<thead>
<tr>
<th>AMOUNT OF STORAGE (approx!)</th>
<th>CPU</th>
<th>TIME TO ACCESS (approx!)</th>
</tr>
</thead>
<tbody>
<tr>
<td>hundreds of bytes</td>
<td>CPU registers</td>
<td>1 nanosecond</td>
</tr>
<tr>
<td>hundreds of kilobytes</td>
<td>cache</td>
<td>10 nanoseconds</td>
</tr>
<tr>
<td>hundreds of megabytes</td>
<td>main memory</td>
<td>100 nanoseconds</td>
</tr>
<tr>
<td>hundreds of gigabytes</td>
<td>disk</td>
<td>10 milliseconds</td>
</tr>
</tbody>
</table>

1 sec = 1,000 millisec = 1,000,000 microsec = 1,000,000,000 nanosec
Consequences of the memory hierarchy

• Accessing a variable can be fast or slow, depending on various factors

• If a variable is in slow memory, accessing it will be slow

• However, when it is accessed, the operating system will typically move that variable to faster memory (“cache” or “buffer” it), along with some nearby variables
  • The idea is: if a variable is accessed once in a program, it (and nearby variables) is likely to be accessed again

• So it is possible for one access of a variable to be slow, and the next access to be faster; possibly orders of magnitude faster

  \[
  x = z[i]; \quad // \text{if } z[i] \text{ is on disk this takes a long time}
  z[i] = 3; \quad // \text{now } z[i] \text{ is in cache, so this is very fast!}
  z[i+1] = 9; \quad // \text{nearby variables also moved, so this is fast}
  \]

• The biggest speed difference is between disk access and semiconductor memory access, so that’s what we will pay most attention to
Accessing data on disk

• Because disk accesses are many (thousands!) of times slower than semiconductor memory accesses, if a data structure is going to reside on disk, it is important that it can be used with very few disk accesses.

• The most commonly used data structure for large disk databases is a B-tree, which can be designed to use disk accesses very efficiently.

• Operations that we are interested in:
  • Insert
  • Delete
  • Find

   All of them should be done with fewest disk accesses as possible.
B-trees and storage

- Each node in a B-tree fits into a block (i.e., if you get part of the node, you get it all)
- Search tree property
- Keys in each node are sorted
The goal of B-Trees

- Always at least half full
- Perfectly Balanced
- Few levels
Properties of an m-order B trees

1. The root has at least 2 sub-trees, unless it is a leaf
2. All leaves are at the same level
3. Each node (leaf as well as non leaf) holds k-1 keys where \(\text{ceil}(m/2) \leq k \leq m\)
4. Each non-leaf node additionally holds k pointers to subtrees where \(\text{ceil}(m/2) \leq k \leq m\).
Order of B-trees

What order is this B-tree?
A. 2
B. 3
C. 4
D. 5
E. 6
What is the minimum number of keys each non-root node in this B-tree is allowed to store?
A. 0
B. 1
C. 2
D. 3
E. 4

How can we guarantee this?
Insertion and properties of B-trees

Insert 21 into this B-tree. Then insert 50
Insertion and properties of B-trees

Insert 15 into this B-tree
Insertion and properties of B-trees

Insert 22 and 23
Insertion and properties of B-trees

Insert 16
Insertion and properties of B-trees

Insert 16, after
Insertion and properties of B-trees

Which key will be promoted up?
A. 61    B. 62    C. 68    D. 75    E. 80
Insertion and properties of B-trees

Insert 62

Which key will be promoted up?
A. 13   B. 25   C. 60   D. 85   E. 68
Insertion and properties of B-trees

Insert 62
Insertion and properties of B-trees

B-trees grow up! (Which is why all their leaves are always at the same level)
B-Tree performance

• The time savings in a B-Tree comes from *efficiently reading lots of data from disk*
• When B-Trees are stored in memory they are typically comparable to other search trees
• When they have to access disk they are a big win

(For details see the slides here: [http://cseweb.ucsd.edu/users/kube/cls/100/Lectures/lec17/lec17.pdf](http://cseweb.ucsd.edu/users/kube/cls/100/Lectures/lec17/lec17.pdf)

You will be responsible for the general ideas behind the tradeoffs of their design, but not the details. Example questions next class.)