1. BST, AVL trees, and hash tables can all be used to implement a dictionary ADT.

<p>| Dictionary Successful Search Comparisons with 10,000 integer items (Time in seconds) |
|-----------------------------------|---------------------------------|-----------------|----------------|----------------|
|                                   | Items added in sorted order     | Items added in random order | Order did not matter |</p>
<table>
<thead>
<tr>
<th></th>
<th>BST</th>
<th>AVL Tree</th>
<th>BST</th>
<th>AVL Tree</th>
<th>Open Addr. (Quadratic)</th>
<th>Closed Addr. (Chaining)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total add/put time</td>
<td>47.785</td>
<td>0.205</td>
<td>0.119</td>
<td>0.195</td>
<td>0.064</td>
<td>0.074</td>
</tr>
<tr>
<td>Total search time</td>
<td>38.100</td>
<td>0.060</td>
<td>0.079</td>
<td>0.062</td>
<td>0.044</td>
<td>0.039</td>
</tr>
<tr>
<td>Height of resulting tree</td>
<td>9,999</td>
<td>13</td>
<td>30</td>
<td>15</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

a) The puts of these 10,000 randomly ordered items into the BST took 0.119 seconds and 0.195 seconds into the AVL tree. Why did the BST puts take less time eventhough the final height was 30 vs. a final AVL tree height of 15? **AVL need to rebalance the tree periodically (rotations) so more work to keep tree balanced than BST.**

b) With a very, very poor hash function or very, very bad choice of keys all keys could hash to the same home address.

- What would be the worst-case big-oh of open-address hashing with quadratic probing? \( O(n) \)

- What would be the worst-case big-oh of chaining using a linked list at each home address (i.e., ChainingDict)? \( O(n) \)

- What would be the worst-case big-oh of chaining using an AVL tree at each home address?

```
    Hash Table
      0
      1
      2
      3
      4
      5
      \[ AVL Tree containing all "n" items in the hash table \]
```

\[ O(\log n) \]

2. The data structures we have discussed so far are all in-memory, i.e., data is stored in main/RAM memory. Data can also be stored on secondary storage in a file (e.g., movieData.txt file). Currently, most secondary storage consists of hard-disks.

a) Complete the following table comparing main/RAM memory vs. hard-disk:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Main/RAM memory</th>
<th>Hard-disk Drive</th>
<th>Solid-State Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size on a typical desktop computer</td>
<td>12 GB</td>
<td>1 TB</td>
<td>256 GB</td>
</tr>
<tr>
<td>Average access time</td>
<td>10 ns</td>
<td>10 ms</td>
<td>100 ms</td>
</tr>
<tr>
<td></td>
<td>( 10 \times 10^{-9} ) sec</td>
<td>( 10 \times 10^{-9} ) sec</td>
<td>( 100 \times 10^{-6} ) sec</td>
</tr>
</tbody>
</table>

b) Which criterion seems to be the most important difference between the main and secondary memories?
Logical View of Disk as Linear Collection of Blocks

(0,0,0) | (0,0,1) | (0,0,2) | ... | ... 
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All of cylinder 0</td>
<td>All of cylinder 1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bits of linear block #: track # | surface # | sector #

3. Disk-access time = \( (\text{seek time}) + (\text{rotational delay}) + (\text{data transfer time}) \). How is each component of the disk-access time effected by increasing the disk's RPMs (revolutions per minute)?

- Seek-time (moving of R/W head) is unaffected by faster disk rotation.

b) If we want fast access to a collection of sectors, where can we place them to minimize seek time and rotational delay? On same track/cylinder to eliminate seek time. Consecutive sectors to eliminate rotational delay for all but the first sector.
User Program - HLL programming language makes system calls to OS to:
1. open file - establish a link between file variable and file for either reading, writing, or both
2. access file - read or write one piece of data at a time (e.g., char., record, etc.)
3. close file - flush changes to disk

Operating System - manage and control access to secondary storage through its file system which contains information about every file: location on disk, ownership and security/protection
- OS views disk as linear sequence of blocks (block 0, block 1, etc.), but assumes closeness in block # means close with respect to access time.
- OS buffers some blocks in memory to improve efficiency
- OS maintains free disk space "list"

Secondary Storage - accepts R/W requests from OS for block# and maps block# to internals physical address
Device (e.g., (track #, surface #, sector #) - more complex than above picture!)

Kinds of File Access:
- serial/sequential files - open at the beginning and read sequentially from beginning to end linearly
- random-access files - "seek" to any position by specifying a byte-offset from the beginning of the file, record #, etc.
- random-access of a record by key - 1 2 3 4 5 6

Implementation of Files on Disk - how are blocks allocated?

4. non-contiguous - scattered across linear address space of OS and disk

File system meta-data for file

linked-list of blocks on disk

a) What types of file access are supported efficiently?

b) How easy is it for the file to grow in size?

5. contiguous - sequential collection of blocks from OS linear view of disk

File system meta-data for file

a) What types of file access are supported efficiently?

b) How easy is it for the file to grow in size??
6. File descriptor blocks - list of blocks hold the address of the physical location of data blocks

- File system meta-data for file
- File descriptor block(s)
- Pointer to next file descriptor block
- 0th data block in file
- 1st data block in file
- 2nd data block in file
- 3rd data block in file

a) What types of file access are supported efficiently?
   - serial/sequential
   - random-seek
   - random-key

b) How easy is it for the file to grow in size?
   - easy

7. To implement "random-access of a record by key" in a file how might we use hashing?
   - Contiguously allocate blocks for the file and use it like a hash table:
     - Run key thru hash function to get a home addr.
     - Read disk at home addr. Where we hopefully find the key

8. To implement "random-access of a record by key" in a file why would an AVL tree not work well?

   - Logarithmic too large given slow access from disk.
9. A B+ Tree is a multi-way tree (typically in the order of 100s children per node) used primarily as a file-index structure to allow fast search (as well as insertions and deletions) for a target key on disk. Two types of pages (B+ tree "nodes") exist:

- Data pages - which always appear as leaves on the same level of a B+ tree (usually a doubly-linked list too)
- Index pages - the root and other interior nodes above the data page leaves. Index nodes contain some minimum and maximum number of keys and pointers bases on the B+ tree's branching factor (b) and fill factor. A 50% fill factor would be the minimum for any B+ tree. All index pages must have \( \lceil \frac{b}{2} \rceil \leq \# \text{child} \leq b \), except the root which must have at least two children.

Consider an B+ tree example with \( b = 5 \).

a) How would you find 88?

b) The insert algorithm for a B+ tree is summarized by the below table. Where would you insert 50, 100, 105, 110, 180, 200, 210?

<table>
<thead>
<tr>
<th>Situation</th>
<th>insertion Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data Page Full?</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>