Practicum in Database Systems

Project 4 intro

Project 4 Introduction

- Add B+ tree indexing support to your SQL interpreter
  - build indexes
  - use indexes for selection

Project 4 Introduction

- Somewhat independent of P3
  - Same binary I/O format for data
  - Will be testing your queries only with TNLJ and in-memory sort implementations
  - But will need the others for P5, so you're not off the hook for those

Scope and length

- *Should* be significantly shorter than P3
- But don't take it lightly
  - since you have less time

Your TODOs

- Implement a bulk loading algorithm for B+-tree construction
  - And to serialize B+-tree to a file
- Implement an Index Scan operator that uses your tree index to retrieve records
- Integrate your index scan with your interpreter so it can be used for selection

B+ trees

- You are familiar with them from 4320
- But you know some details are implementation-specific
- Those may not be resolved the same way as in the 4320 homework
- Be sure to read the 4321 instructions, Section 2, very carefully!

On reusing 4320 code

- If you are reusing any 4320 H2 code
  - reuse of your own group's code is allowed
  - but you must acknowledge it explicitly!

What goes in the leaves

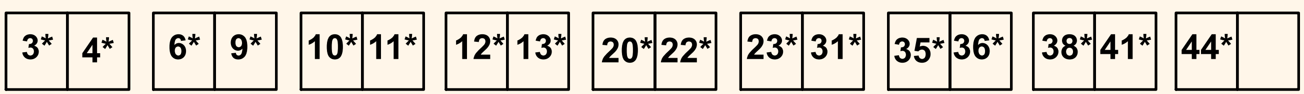
- Alternative 3
  - Every data entry is a key with a list of record ids
  - A record id is a (page id, tuple id) pair
- That way you won't need to worry about duplicate keys in the index
- But data entries are variable-length

Bulk loading

- Good news – no insert/delete needs to be implemented as your data is static
- But need to build the tree via bulk loading
- A number of different algorithms
  - Your textbook has one – don't use that one
  - The one you should use was covered in 4320 and is in the instructions

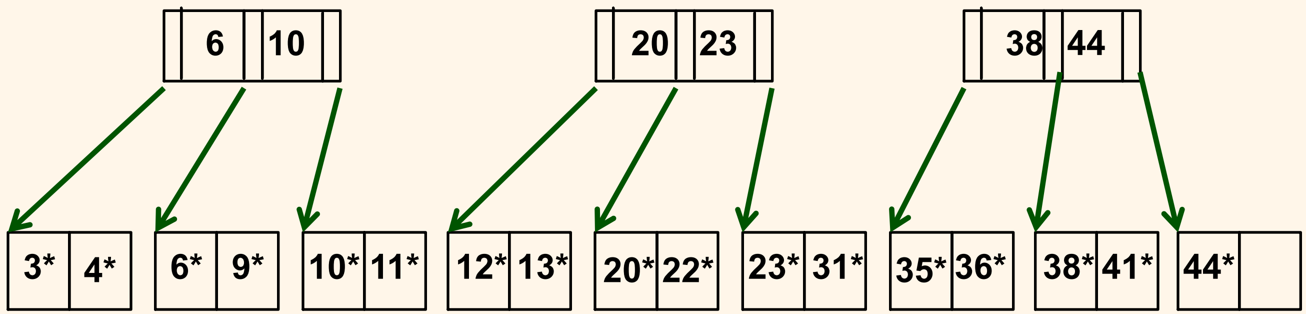
Bulk Loading of a B+ Tree

- *Initialization*:
- Create and sort all data entries
- Create all the leaf nodes



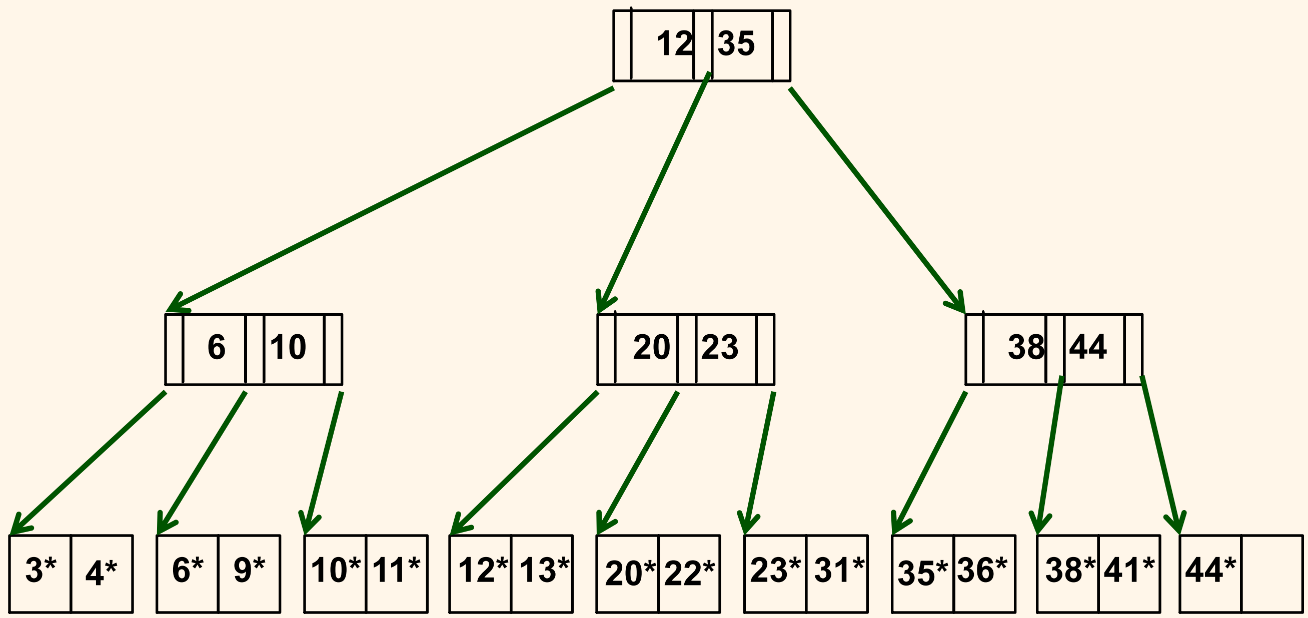
Bulk Loading of a B+ Tree

- Now create next layer above the leaf nodes
- Can control how full you want them to leave space for future inserts
  - In this project, we want them as full as possible



Bulk Loading of a B+ Tree

- Now build next layer above that
- Repeat until obtain a one-node layer – that's your root



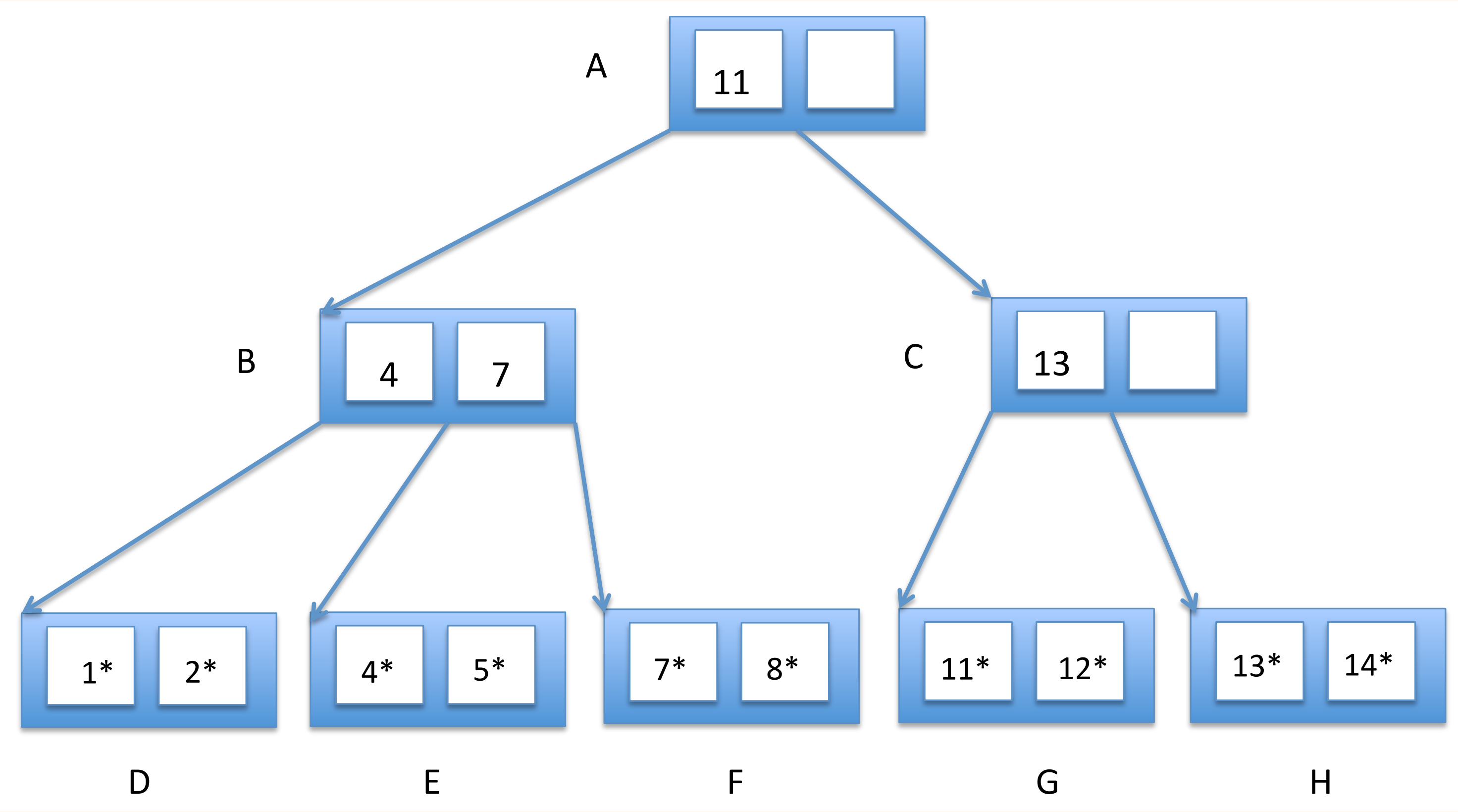
Serializing a B+-tree to a file

- Indexes don't sit in memory all the time
- So we need a binary format to serialize them
- One node = one page
  - Whether index node or leaf node
  - May assume every node will fit on a 4096-byte page when serialized in our format

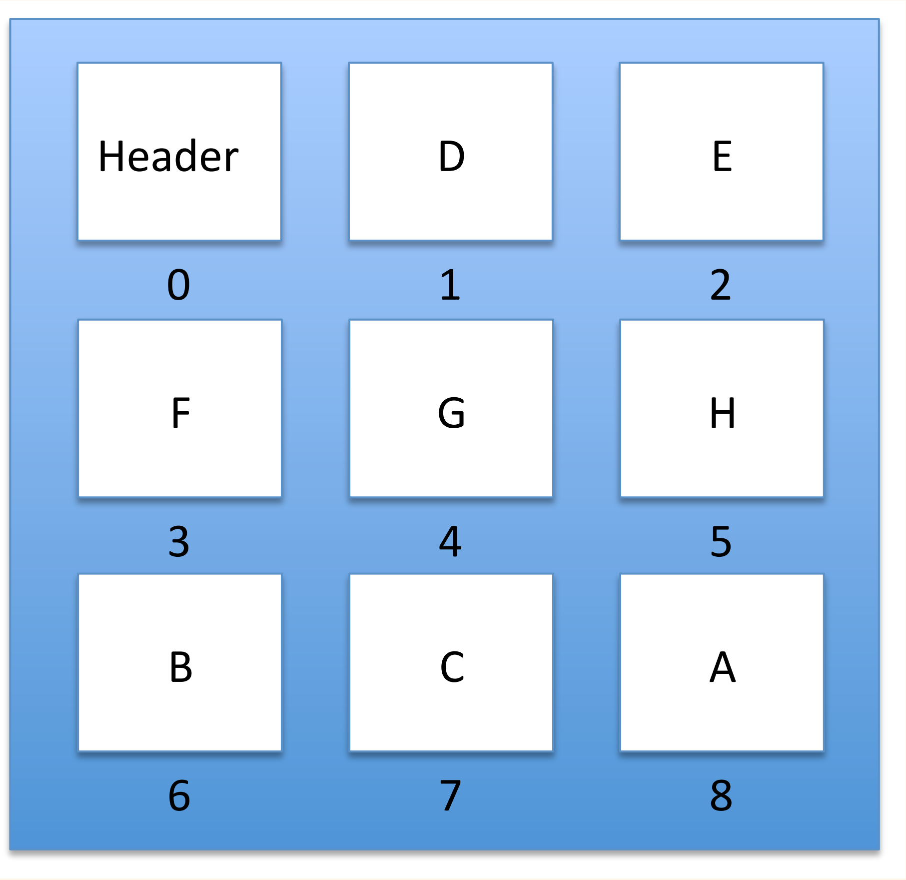
Overall file format for a tree

- Header page
- Leaf pages in order left-to-right
- Index pages from layer immediately above leaves
- Etc
- Root is on last page

Example tree



Serialization in file



Layout and addresses

- Leaf nodes sequential in file, so no need for next/prev pointers in leaves
- A node's *address* is the page it is stored on
  - Not known until the node is serialized
  - Index nodes store the addresses of their children
  - Suggests why the leaf nodes are serialized first in the file (serialize one layer at a time, setting addresses in parent layer as you go)

Header page

- Basic info about the tree:
  - Address of the root
  - Number of leaves
  - Order (parameter *d*)
- In a "real" system this might store more info such as the type of the key (string, integer etc)

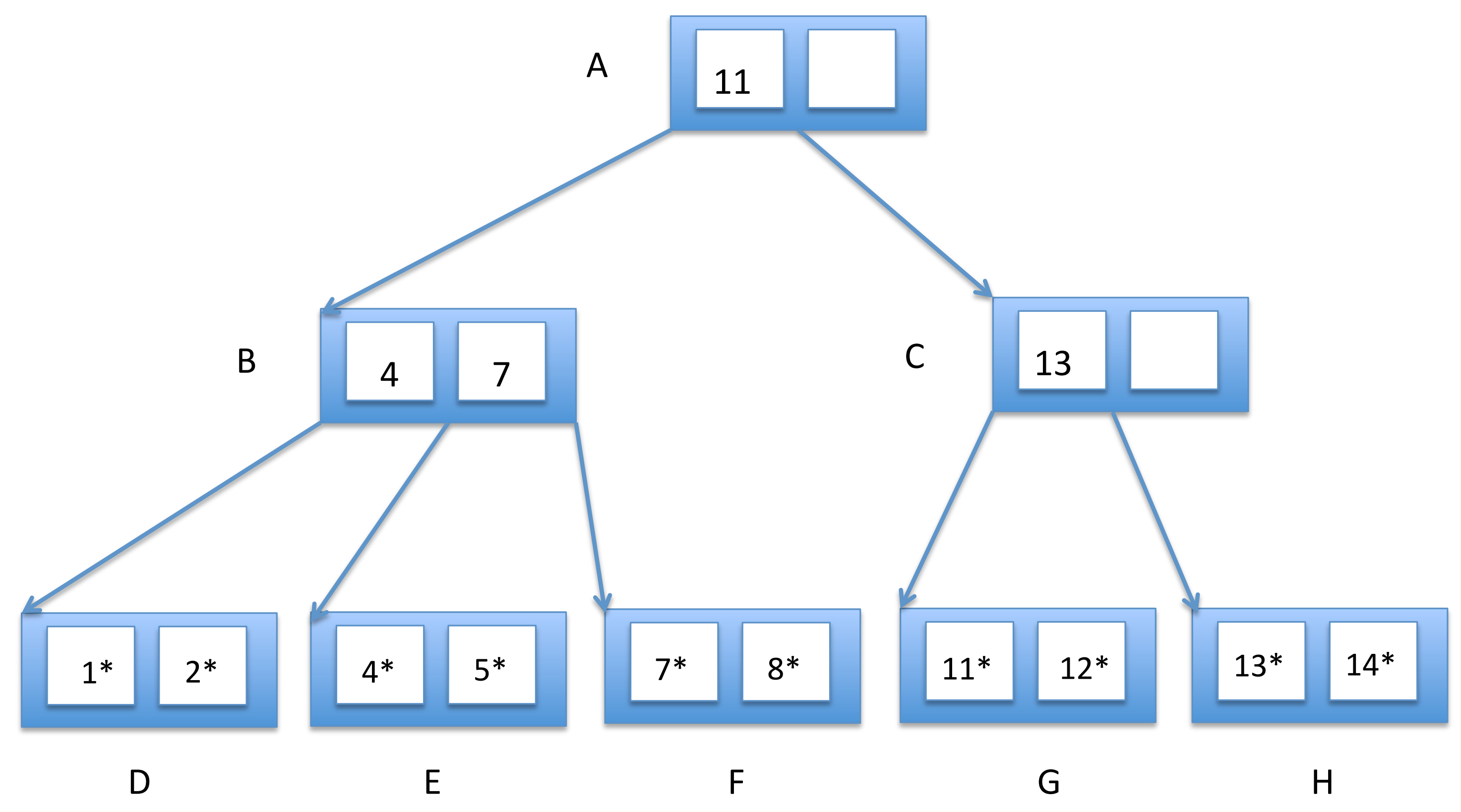
Serializing a node to a page

- Format depends on whether node is an index node or a leaf node

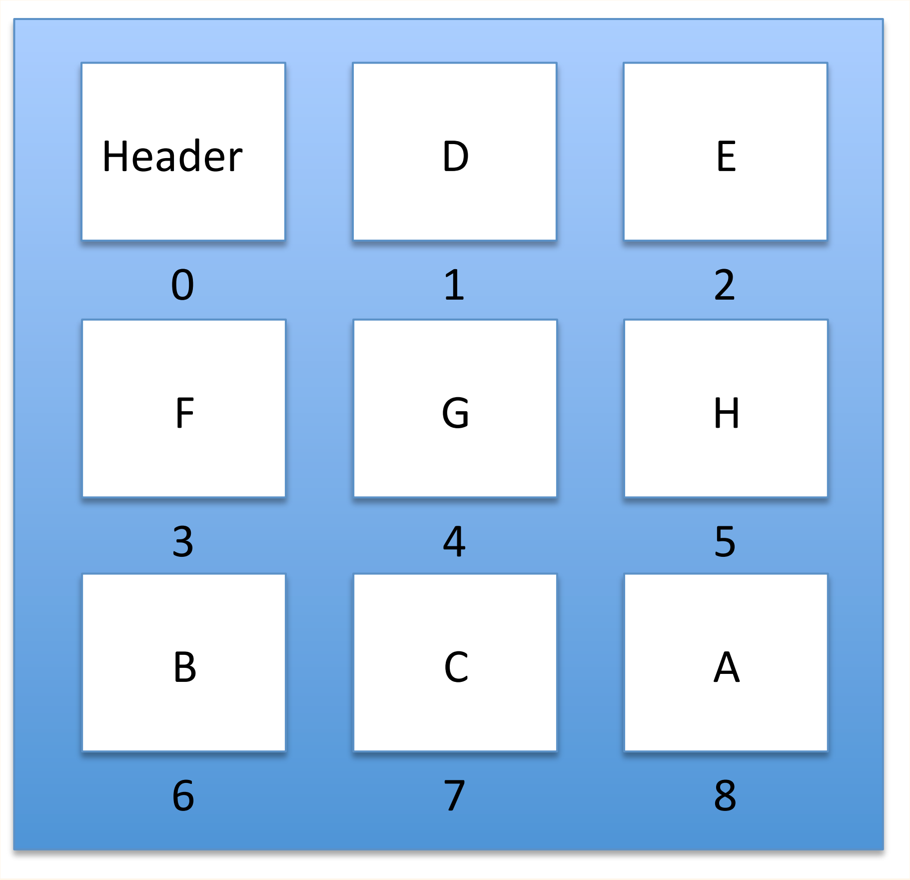
Serializing an index node

- Flag 1 to indicate it's an index node
- Number of keys
- Keys
- Addresses of children

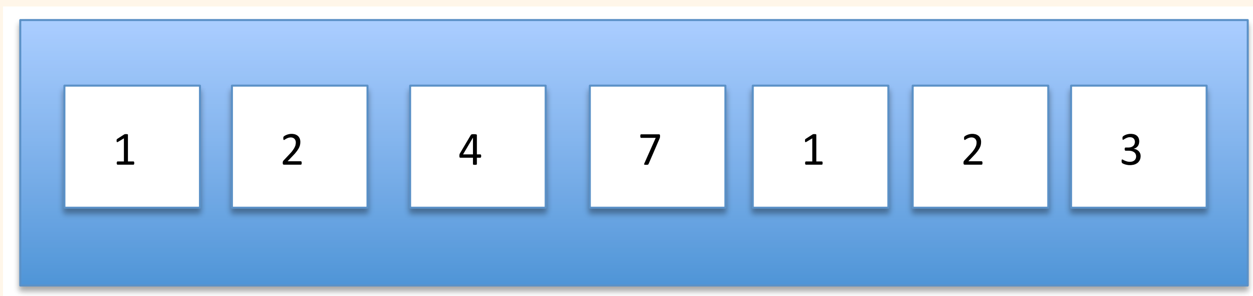
Example tree



Serialization in file



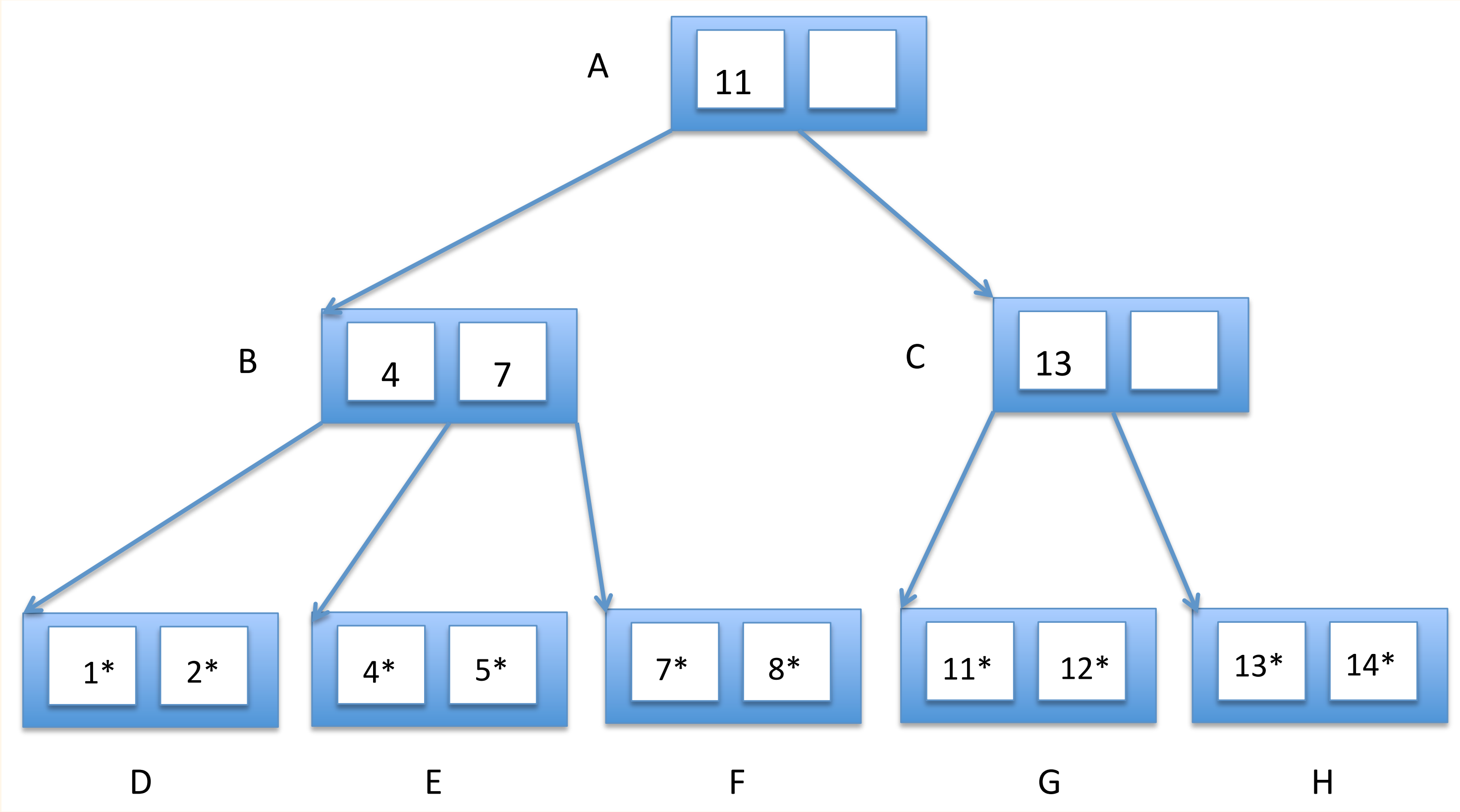
Serializing node B



Serializing a leaf node

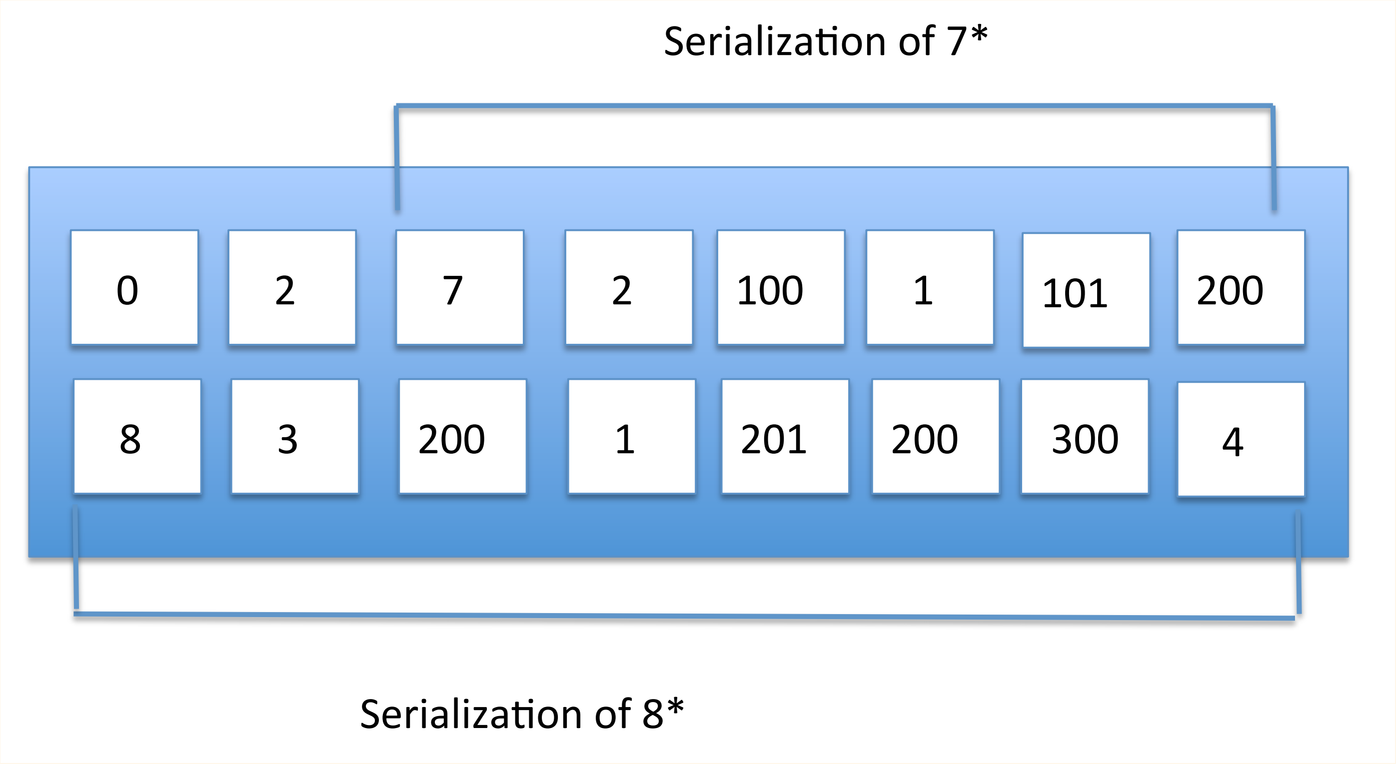
- Flag 0 to indicate it's a leaf node
- Number of data entries
- A serialized representation of each data entry

Example tree



Serializing node F

- Suppose 7* is <7, [(100, 1), (101, 200)]>
- Suppose 8* is <8, [(200,1), (201, 200), (300,4)]>



Where do your indexes go?

- Some new files and folders in your directory structure
- *index_info.txt* specifies what indexes to build
- *indexes* subdirectory contains the serialized indexes
- At most one index per relation
  - will change in P5
- Only build indexes on a single attribute
  - will not change in P5

Configurations

- We want to run your code in three different ways:
  - Build indexes (only)
  - Run queries using provided indexes (our indexes)
    - index_info file provides guidance to the DB catalog as to what indexes are available for use in selection
  - Build indexes and run queries

Yet another config file…

- Your interpreter now takes a config file instead of command-line arguments
- First 3 lines specify the 3 arguments from P3 (input/output/temporary sort)
- Next 2 lines are flags for whether to build indexes and whether to run queries

Plan builder config file

- Previously, this specified the join and sort implementations
- Now it also specifies whether or not to try using an index for selection

Your first task

- Implement an algorithm that builds a tree index and serializes it to a file
- If we desire a clustered index, should start by sorting the relation file by the indexed attribute
- Should be relatively straightforward once you understand the format
- Connect your algorithm to your interpreter so you can build all the desired indexes from index_info.txt

Your second task

- Now, time to use your indexes for selection
- Implement a new physical operator: IndexScan
  - You had a scan previously that read the whole file
  - Now you're going to retrieve tuples using the index instead!

IndexScan

- Every IndexScan has a lowKey and a highKey
- These specify the scan range you want
  - e.g from 1 to 2000
  - one (or theoretically both) may be null, to indicate you want to scan from the beginning or to the end of the key space

What does the IndexScan do?

- On initialization, grab the index file and deserialize nodes from the root to the first relevant leaf based on lowKey
  - Do NOT deserialize the whole tree!!!
- Upon calls to getNextTuple(), obtain the next tuple using the appropriate info from your index
  - until you run out of tuples or reach highKey

Implementing IndexScan

- If your index is *clustered,* don't read any leaves after the first one
  - Jump into the data file which is sorted and read tuples from there
- If your index is *unclustered,* you'll have to scan the leaves and resolve the rid to a particular tuple in the data file
  - I push the implementation of this to my TupleReader, so it can now effectively do "random access" into the file based on rid

Using IndexScan for selection

- Your third task: make your PhysicalPlanBuilder use indexes for selection
- Assume you are pushing selections so your logical selection operators all have leaves as children
- A general selection may need to be implemented as two operators:
  - an IndexScan to handle whatever portion of the selection can be dealt with using index
  - followed by a "regular" full-scan selection for the remainder

What your PlanBuilder needs to do

- Check whether there is an index on the relation in question and whether it's clustered
- Partition the selection condition into the part that can be handled via the index and the part that cannot
  - E.g. R.A < 5 AND R. C >= 10 AND R.B = 3, index on R.B…
  - Visitor pattern !!

What your PlanBuilder needs to do

- Translate the selection condition into:
  - A lowkey/highkey pair for your IndexScan
  - The "remainder" that cannot be handled via the index
  - One of those may be null
- Create appropriate physical operators

Finally

- Like in P3, we want you to do some performance benchmarking to see if indexing helps your queries run faster

Must–have requirements

- Implement IndexScan following our logic/instructions
  - lowKey and highKey
  - don't deserialize entire tree
  - handle clustered/unclustered indexes differently
- Use IndexScans to implement selection
  - handle maximal possible portion of selection via index
- As in P3, give a good-faith implementation of everything we request or tell us in the README if you don't