CMSC 424 – Database design
Lecture 13
Storage: Files

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Recap

- Databases are stored on disk
  - cheaper than memory
  - non-volatile (survive power loss)
  - large capacity
- Operating systems are designed for “general” use – do not perform optimally when used to manage database storage
- Most DBMSs replace the OS and manage disk storage directly
  - Specialized buffer management (MRU policy might be better than LRU, pinned records, etc.)
  - Specialized storage of files (today)

File Organization

- The database is stored as a collection of *files*. Each file is a sequence of *records*. A record is a sequence of fields.
- One approach:
  - assume record size is fixed
  - each file has records of one particular type only
  - different files are used for different relations

  This case is easiest to implement; will consider variable length records later.

Fixed-Length Records

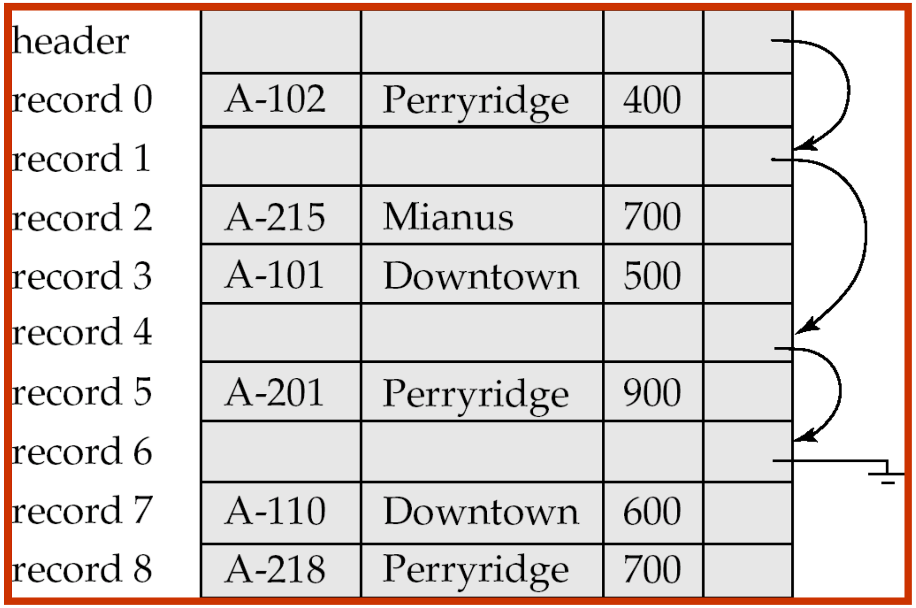
- Simple approach:
  - Store record i starting from byte $n * (i - 1)$, where n is the size of each record.
  - Record access is simple but records may cross blocks
    - Modification: do not allow records to cross block boundaries

record 0	A-102	Perryridge	400
record 1	A-305	Round Hill	350
record 2	A-215	Mianus	700
record 3	A-101	Downtown	500
record 4	A-222	Redwood	700
record 5	A-201	Perryridge	900
record 6	A-217	Brighton	750
record 7	A-110	Downtown	600
record 8	A-218	Perryridge	700

- Deletion of record i: alternatives:
  - move records $i + 1, \ldots, n$ to $i, \ldots, n - 1$
  - move record n to i
  - do not move records, but link all free records on a *free list*

Free Lists

- Store the address of the first deleted record in the file header.
- Use this first record to store the address of the second deleted record, and so on
- Can think of these stored addresses as pointers since they "point" to the location of a record.
- More space efficient representation: reuse space for normal attributes of free records to store pointers. (No pointers stored in in-use records.)

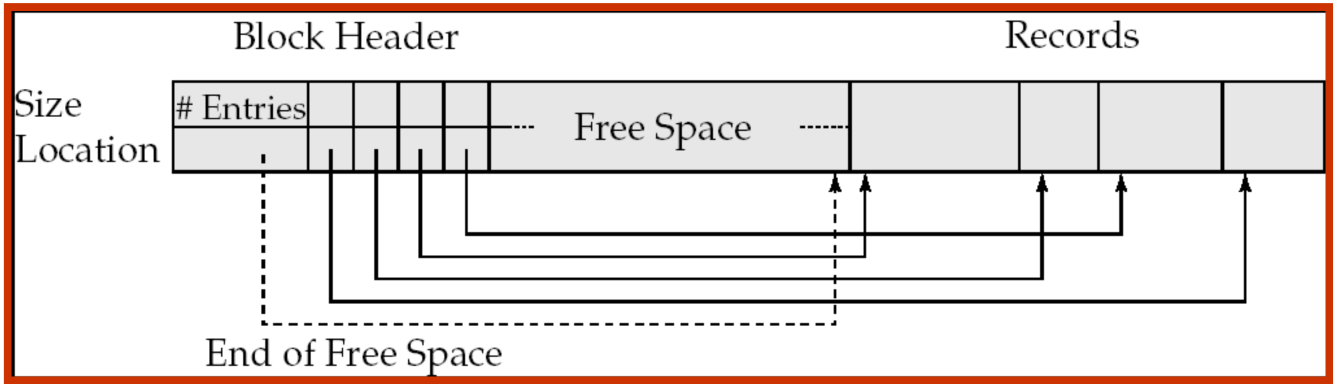


header				
record 0	A-102	Perryridge	400	
record 1				
record 2	A-215	Mianus	700	
record 3	A-101	Downtown	500	
record 4				
record 5	A-201	Perryridge	900	
record 6				
record 7	A-110	Downtown	600	
record 8	A-218	Perryridge	700	

Variable-Length Records

- Variable-length records arise in database systems in several ways:
  - Storage of multiple record types in a file.
  - Record types that allow variable lengths for one or more fields.
  - Record types that allow repeating fields (used in some older data models).

Variable-Length Records: Slotted Page Structure



- Slotted page header contains:
  - number of record entries
  - end of free space in the block
  - location and size of each record
- Records can be moved around within a page to keep them contiguous with no empty space between them; entry in the header must be updated.
- Pointers should not point directly to record — instead they should point to the entry for the record in header.

Organization of Records in Files

- **Heap** – a record can be placed anywhere in the file where there is space
- **Sequential** – store records in sequential order, based on the value of the search key of each record
- **Hashing** – a hash function computed on some attribute of each record; the result specifies in which block of the file the record should be placed
- Records of each relation may be stored in a separate file. In a **multitable clustering file organization** records of several different relations can be stored in the same file
  - Motivation: store related records on the same block to minimize I/O

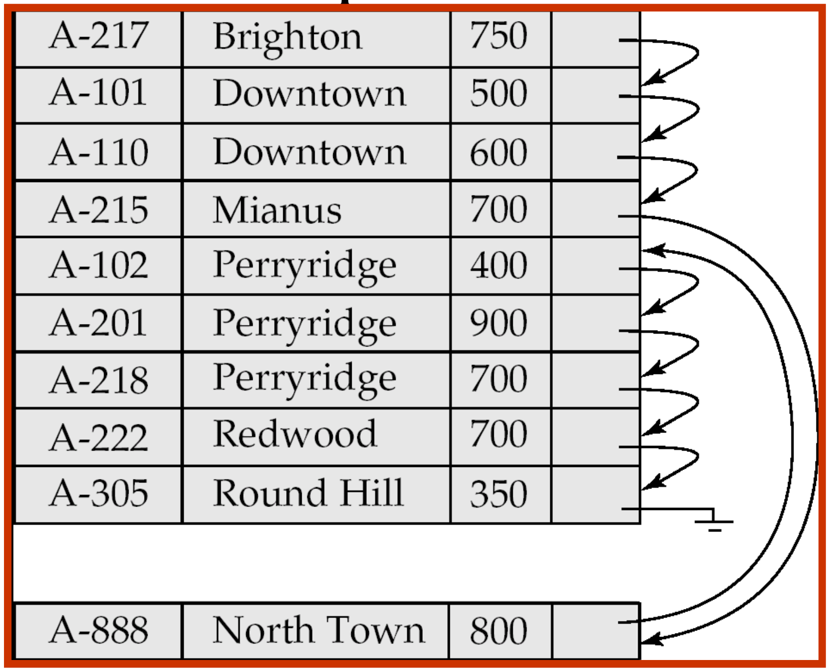
Sequential File Organization

- Suitable for applications that require sequential processing of the entire file
- The records in the file are ordered by a search-key

A-217	Brighton	750	
A-101	Downtown	500	
A-110	Downtown	600	
A-215	Mianus	700	
A-102	Perryridge	400	
A-201	Perryridge	900	
A-218	Perryridge	700	
A-222	Redwood	700	
A-305	Round Hill	350	

Sequential File Organization (Cont.)

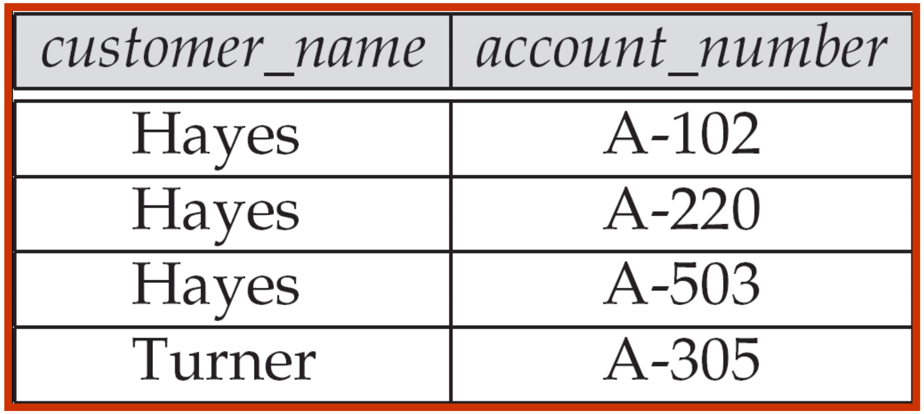
- Deletion – use pointer chains
- Insertion –locate the position where the record is to be inserted
  - if there is free space insert there
  - if no free space, insert the record in an overflow block
  - In either case, pointer chain must be updated
- Need to reorganize the file from time to time to restore sequential order



A-217	Brighton	750
A-101	Downtown	500
A-110	Downtown	600
A-215	Mianus	700
A-102	Perryridge	400
A-201	Perryridge	900
A-218	Perryridge	700
A-222	Redwood	700
A-305	Round Hill	350
A-888	North Town	800

Multitable Clustering File Organization

Store several relations in one file using a **multitable clustering** file organization



customer_name	*account_number*
Hayes	A-102
Hayes	A-220
Hayes	A-503
Turner	A-305

customer_name	*customer_street*	*customer_city*
Hayes	Main	Brooklyn
Turner	Putnam	Stamford

Multitable Clustering File Organization (cont.)

Multitable clustering organization of *customer* and *depositor:*

Hayes	Main	Brooklyn
Hayes	A-102	
Hayes	A-220	
Hayes	A-503	
Turner	Putnam	Stamford
Turner	A-305	

- good for queries involving *depositor* $\bowtie$ *customer*, and for queries involving one single customer and his accounts
- bad for queries involving only customer
- results in variable size records
- Can add pointer chains to link records of a particular relation

Data Dictionary Storage

- Data dictionary (also called system catalog) stores metadata; that is, data about data, such as:
- Information about relations
  - names of relations
  - names and types of attributes of each relation
  - names and definitions of views
  - integrity constraints
- User and accounting information, including passwords
- Statistical and descriptive data
  - number of tuples in each relation
- Physical file organization information
  - How relation is stored (sequential/hash/…)
  - Physical location of relation
- Information about indices (Chapter 12)

Data Dictionary Storage (Cont.)

- Catalog structure
  - Relational representation on disk
  - specialized data structures designed for efficient access, in memory
- A possible catalog representation:

Relation_metadata = (*relation_name, number_of_attributes,*
storage_organization, location)
Attribute_metadata = (*attribute_name, relation_name, domain_type,*
position, length)
User_metadata = (*user_name, encrypted_password, group*)
Index_metadata = (*index_name, relation_name, index_type,*
index_attributes)
View_metadata = (*view_name, definition*)

Indexing...rationale

- Remember the “join” function
  - assume tables R1(<u>A1</u>, B), R2(<u>A2</u>, C)

```
for t1 in R1
  for t2 in R2
    if (t1[A1] == t2[A2])
      output (t1[A1], t1[B], t2[C])
    end
  end
end
```

  running time - #tuples in R1 * # tuples in R2

- Can we do better?
  - what if the tables were written in sorted files

Indexing...rationale

- Better algorithm

```
while not end of R1 or R2
  while (t1[A1] < t2[A2])
     t1 = next
  end
  while (t1[A1] > t2[A2])
     t2 = next
  end
 foreach t1 & t2 st. t1[A1] == t2[A2]
   output (t1[A1], t1[B], t2[C])
 end
 advance t1 and t2 to next difference
end
```

running time min (# tuples in R1, # tuples in R2) + “size of largest cluster of equal keys”

Indexing...rationale

- Sorting makes things faster
- What if we have more than one key on which we join?
- Store a separate index for each key
  - file of pointers to the records
  - order of pointers in the index corresponds to ordering of key values
- Multiple indices – we can sort the same file in different ways

Basic Concepts

- Indexing mechanisms used to speed up access to desired data.
  - E.g., author catalog in library
- **Search Key** - attribute to set of attributes used to look up records in a file.
- An **index file** consists of records (called **index entries**) of the form

search-key	pointer

- Index files are typically much smaller than the original file
- Two basic kinds of indices:
  - **Ordered indices:** search keys are stored in sorted order
  - **Hash indices:** search keys are distributed uniformly across “buckets” using a “hash function”.

Index Evaluation Metrics

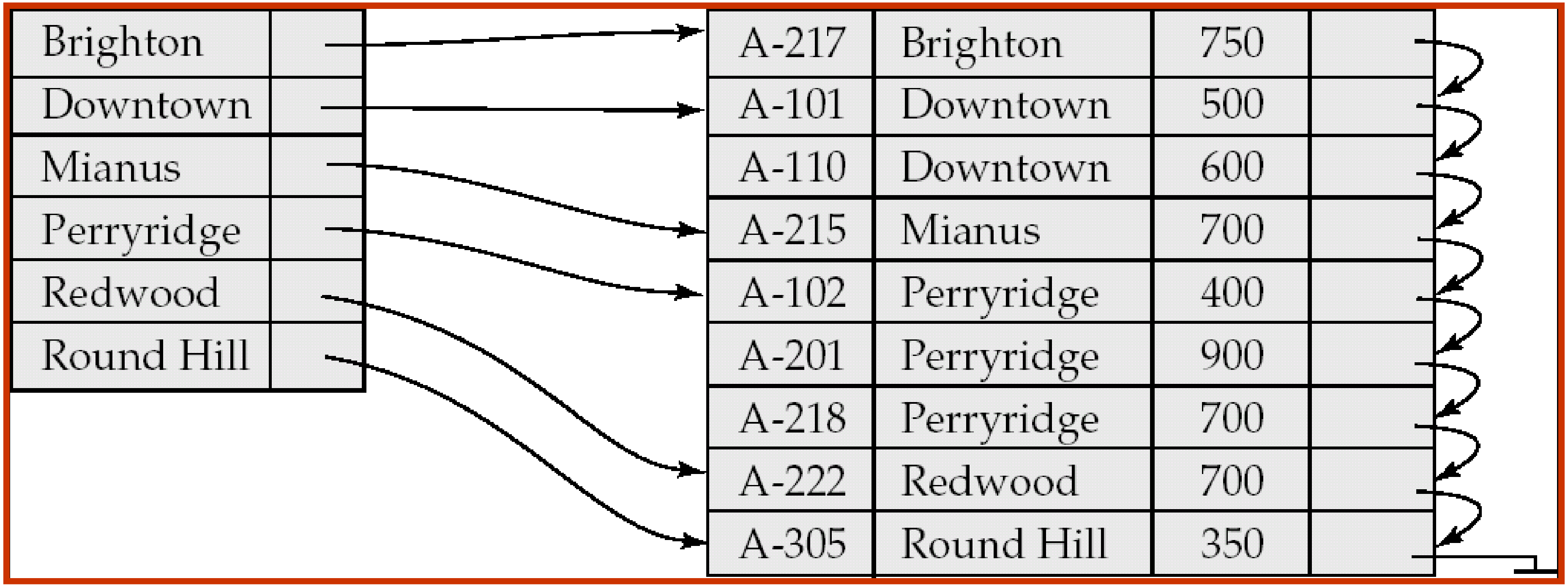
- Access types supported efficiently. E.g.,
  - records with a specified value in the attribute
  - or records with an attribute value falling in a specified range of values.
- Access time
- Insertion time
- Deletion time
- Space overhead

Ordered Indices

- In an **ordered index**, index entries are stored sorted on the search key value. E.g., author catalog in library.
- **Primary index**: in a sequentially ordered file, the index whose search key specifies the sequential order of the file.
  - Also called **clustering index**
  - The search key of a primary index is usually but not necessarily the primary key.
- **Secondary index**: an index whose search key specifies an order different from the sequential order of the file. Also called
  non-clustering index.
- Index-sequential file: ordered sequential file with a primary index.

Dense Index Files

- **Dense index** — Index record appears for every search-key value in the file.



Brighton	
Downtown	
Mianus	
Perryridge	
Redwood	
Round Hill	

A-217	Brighton	750	
A-101	Downtown	500	
A-110	Downtown	600	
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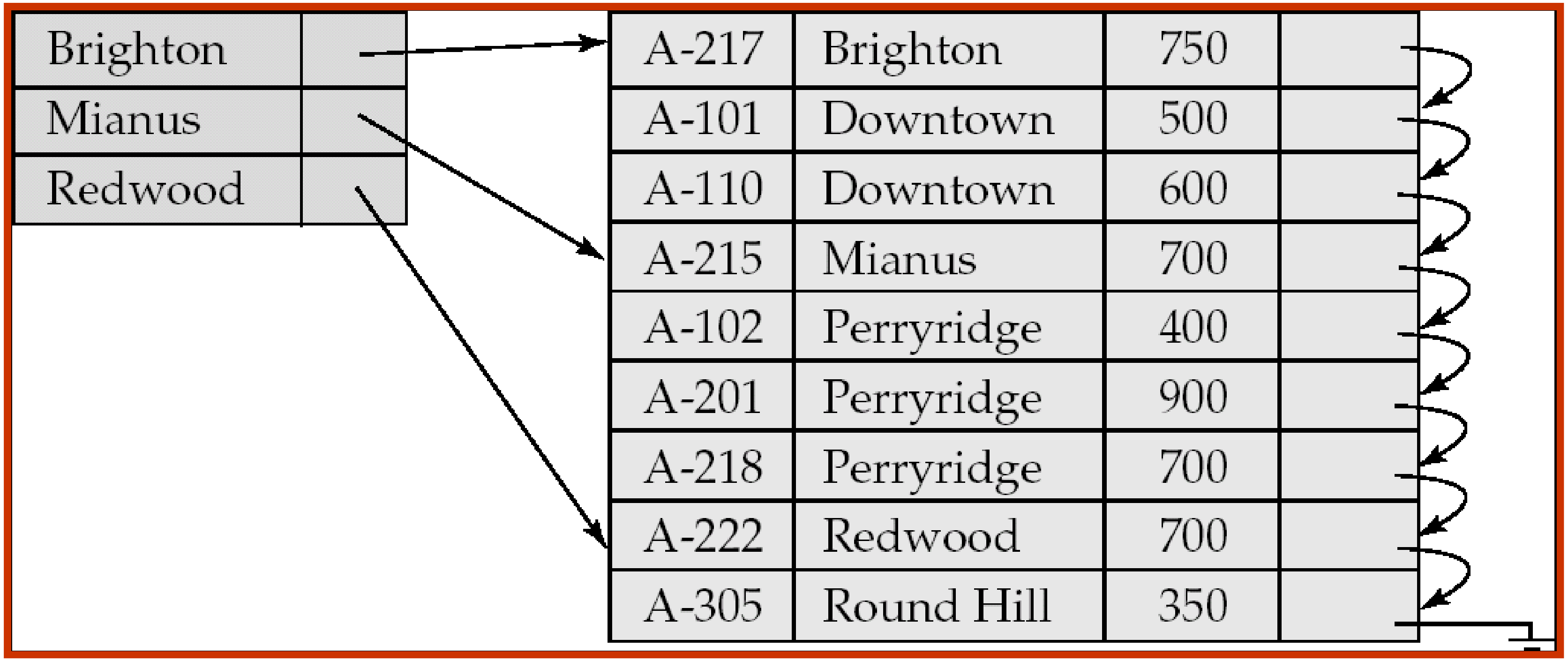
A-222	Redwood	700	
A-305	Round Hill	350	

Sparse Index Files

- Sparse Index: contains index records for only some search-key values.
  - Applicable when records are sequentially ordered on search-key
- To locate a record with search-key value *K* we:
  - Find index record with largest search-key value < *K*
  - Search file sequentially starting at the record to which the index record points



Brighton	
Mianus	
Redwood	

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A-215	Mianus	700	
A-102	Perryridge	400	
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A-218	Perryridge	700	
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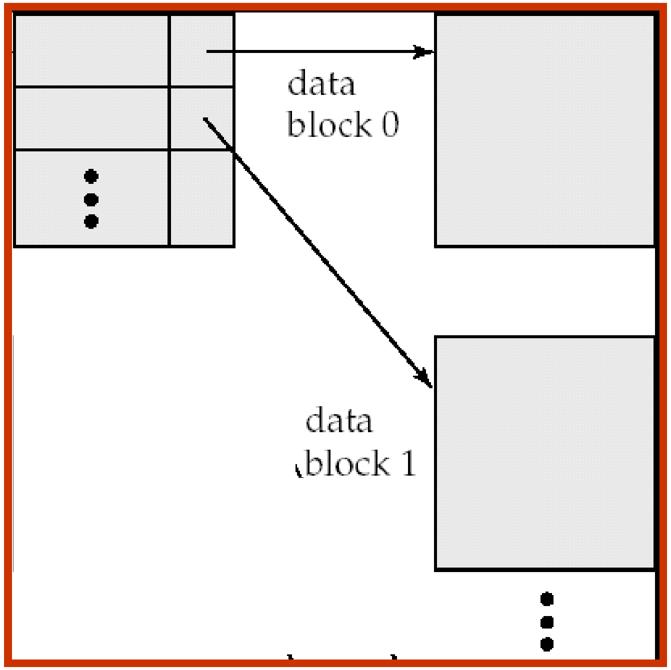
A-305	Round Hill	350	

Sparse Index Files (Cont.)

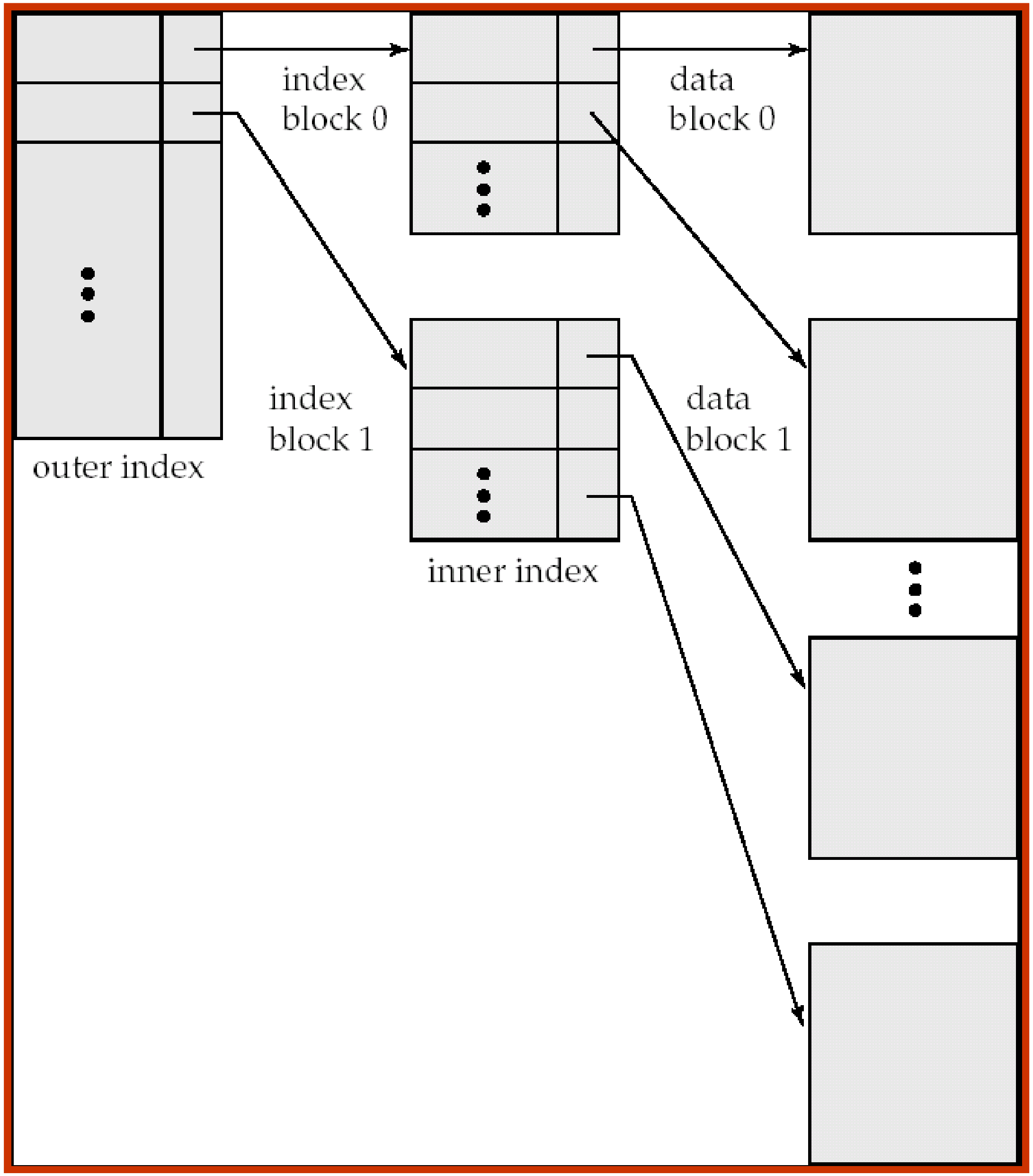
- Compared to dense indices:
  - Less space and less maintenance overhead for insertions and deletions.
  - Generally slower than dense index for locating records.
- **Good tradeoff**: sparse index with an index entry for every block in file, corresponding to least search-key value in the block.



Multilevel Index

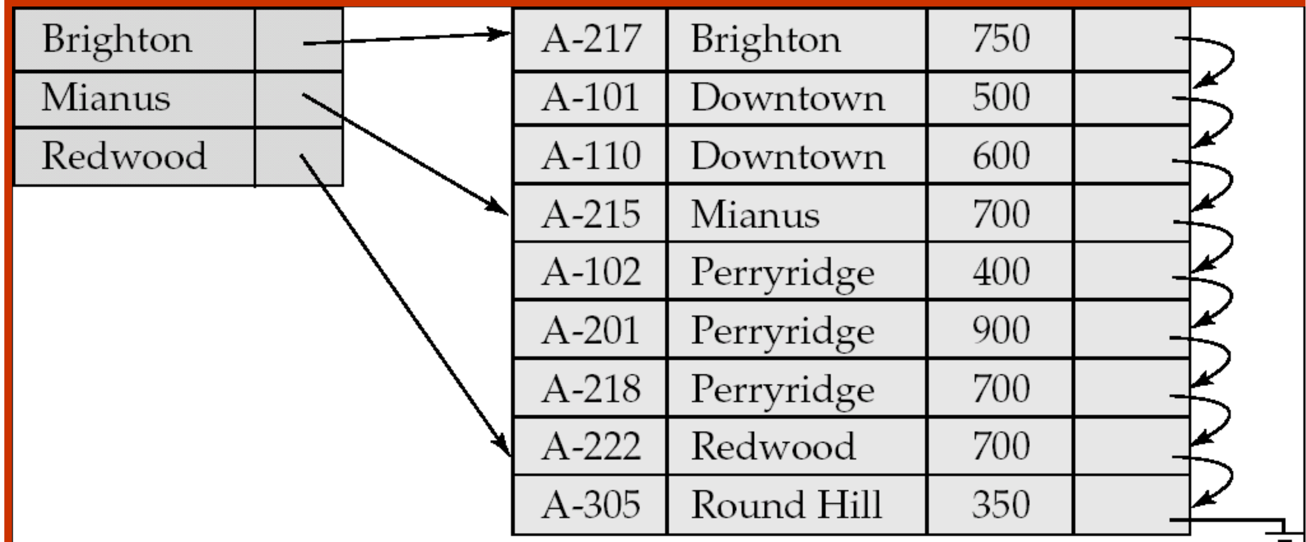
- If primary index does not fit in memory, access becomes expensive.
- Solution: treat primary index kept on disk as a sequential file and construct a sparse index on it.
  - outer index – a sparse index of primary index
  - inner index – the primary index file
- If even outer index is too large to fit in main memory, yet another level of index can be created, and so on.
- Indices at all levels must be updated on insertion or deletion from the file.

Multilevel Index (Cont.)



Index Update: Deletion

- If deleted record was the only record in the file with its particular search-key value, the search-key is deleted from the index also.
- Single-level index deletion:
  - **Dense indices** – deletion of search-key:similar to file record deletion.
  - **Sparse indices** –
    - if an entry for the search key exists in the index, it is deleted by replacing the entry in the index with the next search-key value in the file (in search-key order).
    - If the next search-key value already has an index entry, the entry is deleted instead of being replaced.



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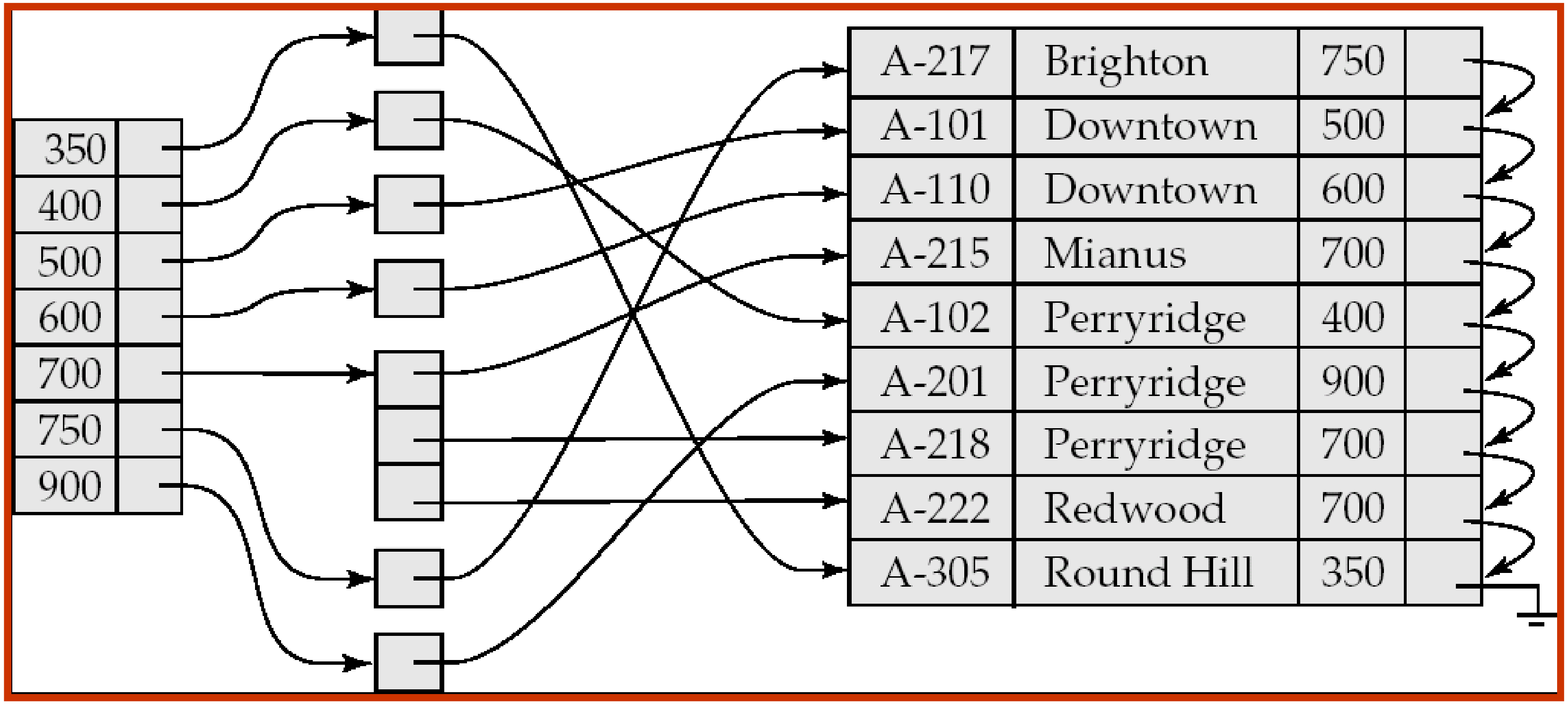
Index Update: Insertion

- Single-level index insertion:
  - Perform a lookup using the search-key value appearing in the record to be inserted.
  - **Dense indices** – if the search-key value does not appear in the index, insert it.
  - **Sparse indices** – if index stores an entry for each block of the file, no change needs to be made to the index unless a new block is created.
    - If a new block is created, the first search-key value appearing in the new block is inserted into the index.
- Multilevel insertion (as well as deletion) algorithms are simple extensions of the single-level algorithms

Secondary Indices

- Frequently, one wants to find all the records whose values in a certain field (which is not the search-key of the primary index) satisfy some condition.
  - Example 1: In the *account* relation stored sequentially by account number, we may want to find all accounts in a particular branch
  - Example 2: as above, but where we want to find all accounts with a specified balance or range of balances
- We can have a secondary index with an index record for each search-key value

Secondary Indices Example



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A-222	Redwood	700
A-305	Round Hill	350

Secondary index on *balance* field of *account*

- Index record points to a bucket that contains pointers to all the actual records with that particular search-key value.
- Secondary indices have to be dense

Primary and Secondary Indices

- Indices offer substantial benefits when searching for records.
- BUT: Updating indices imposes overhead on database modification --when a file is modified, every index on the file must be updated,
- Sequential scan using primary index is efficient, but a sequential scan using a secondary index is expensive
  - Each record access may fetch a new block from disk
  - Block fetch requires about 5 to 10 milliseconds
    - versus about 100 nanoseconds for memory access

Next...

- B+-trees
- Hashing

- Have a good break!