Databases

Lectures 9-10*

The Physical Structure of Databases. Indexes

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Files of Records

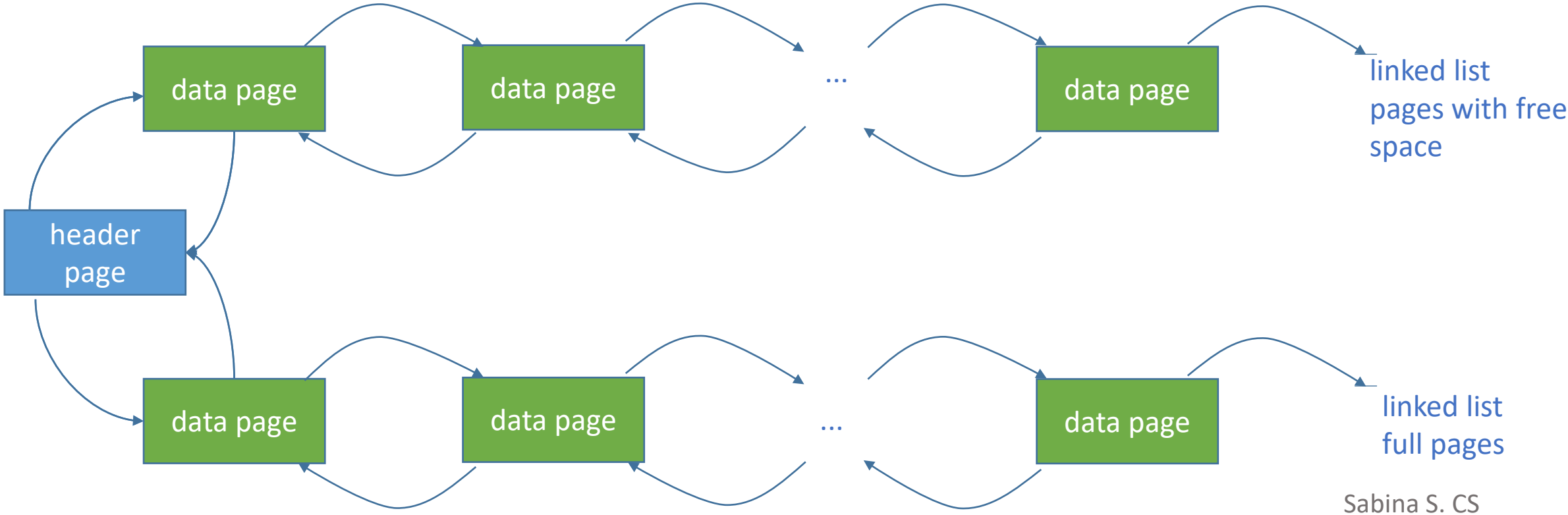
- higher level layers in the DBMS treat pages as collections of records
- file of records
  - collection of records; one or more pages
- different ways to organize a file's collection of pages
- every record has an identifier: the rid
- given the rid of a record, one can identify the page that contains the record

Heap Files

- the simplest file structure
- records are not ordered
- supported operations
  - create file
  - destroy file
  - insert a record
    - need to monitor pages with free space
  - retrieve a record given its rid
  - delete a record given its rid
  - scan all records
    - need to keep track of all the pages in the file
- appropriate when the expected pattern of use includes scans to obtain all the records

Heap Files - Linked List

- doubly linked list of pages
- DBMS stores the address of the first page (*header page*) of each file (a table holding pairs of the form <*heap_file_name*, *page1_address*>)
- 2 lists – pages with free space and full pages

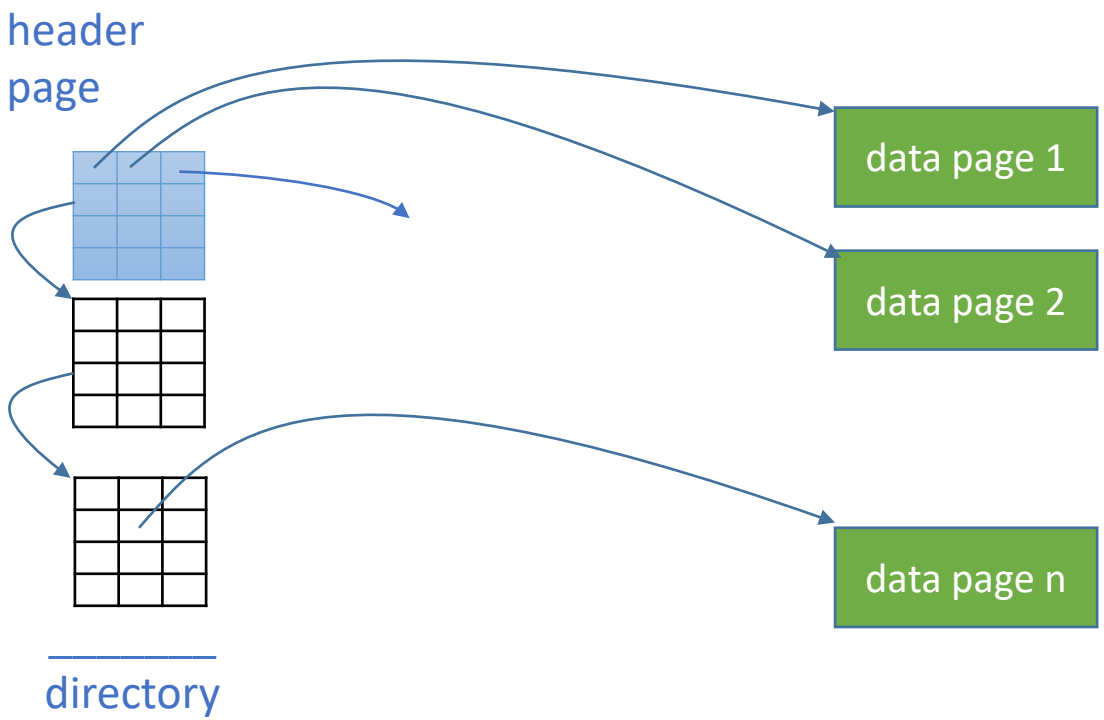


Heap Files - Linked List

- drawback
  - variable-length records => most of the pages will be in the list of pages with free space
  - when adding a record, multiple pages have to be checked until one is found that has enough free space

Heap Files - Directory of Pages

- DBMS stores the location of the header page for each heap file
- directory - collection of pages (e.g., linked list)
- directory entry - identifies a page in the file
- directory entry size - much smaller than the size of a page
- directory size - much smaller than the size of the file
- free space management
  - 1 bit / directory entry - corresponding page has / doesn't have free space
  - count / entry - available space on the corresponding page => efficient search of pages with enough free space when adding a variable-length record

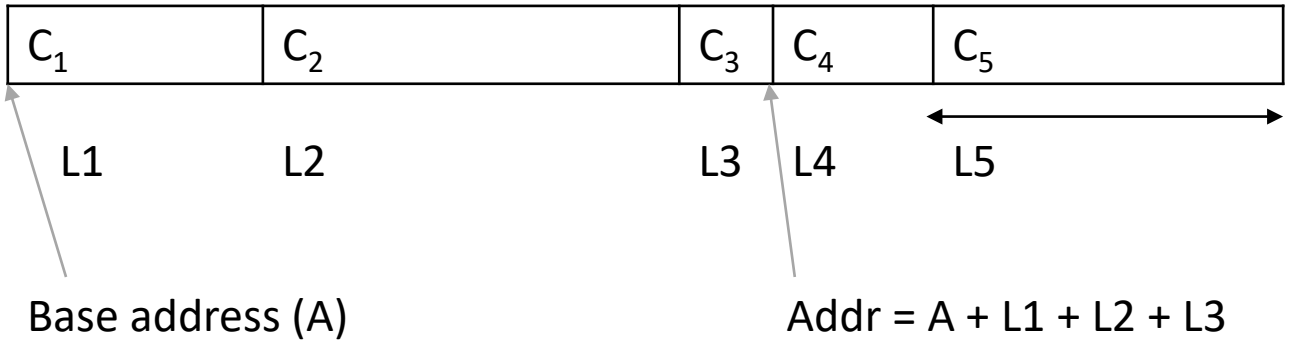


Other File Organizations

- sorted files
  - suitable when data must be sorted, when doing range selections
- hashed files
  - files that are hashed on some fields (records are stored according to a hash function); good for equality selections

Record Formats

- fixed-length records



  - each field has a fixed length
  - fixed number of fields
  - fields - stored consecutively
  - computing a field's address
    - record address, length of preceding fields (from the system catalog)

Record Formats

- variable-length records
  - variable-length fields

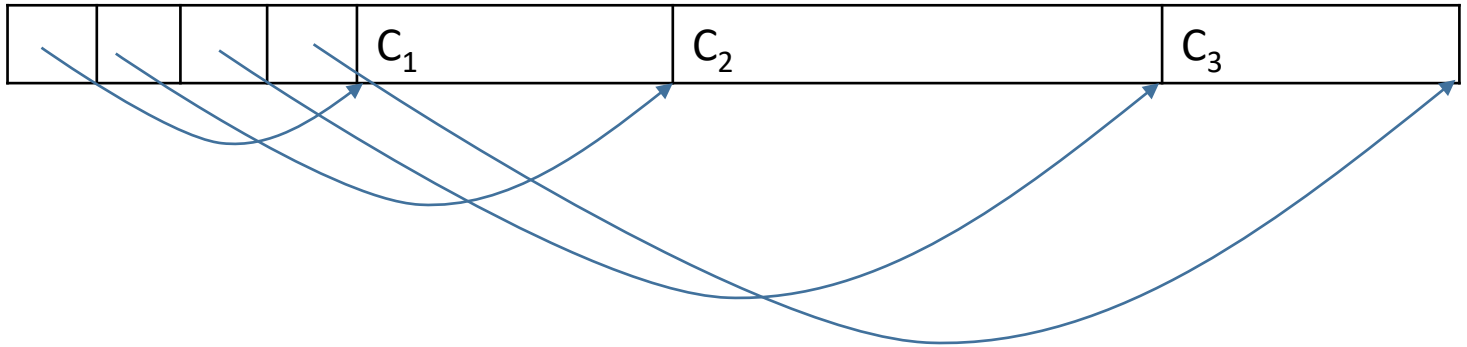
v1

  - fields
    - stored consecutively, separated by delimiters
  - finding a field
    - a record scan

Record Formats

- variable-length records

v2



  - reserve space at the beginning of the record
    - array of fields offsets, offset to the end of the record
  - array overhead, but direct access to every field

Page Formats

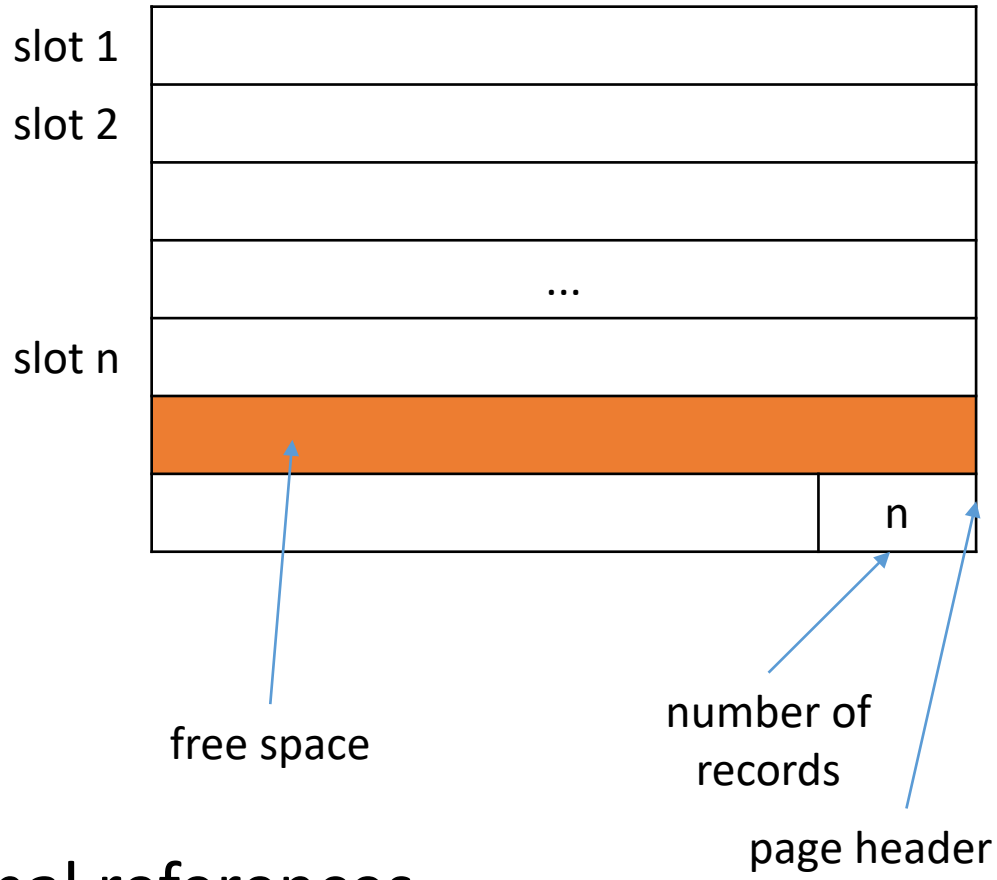
- page
  - collection of slots
  - 1 record / slot
- identifying a record
  - record id (rid): <page id, slot number>
- how to arrange records on pages
- how to manage slots

Page Formats

- fixed-length records
  - records have the same size
  - uniform, consecutive slots
  - adding a record
    - finding an available slot
  - problems
    - keeping track of available slots
    - locating records

Page Formats

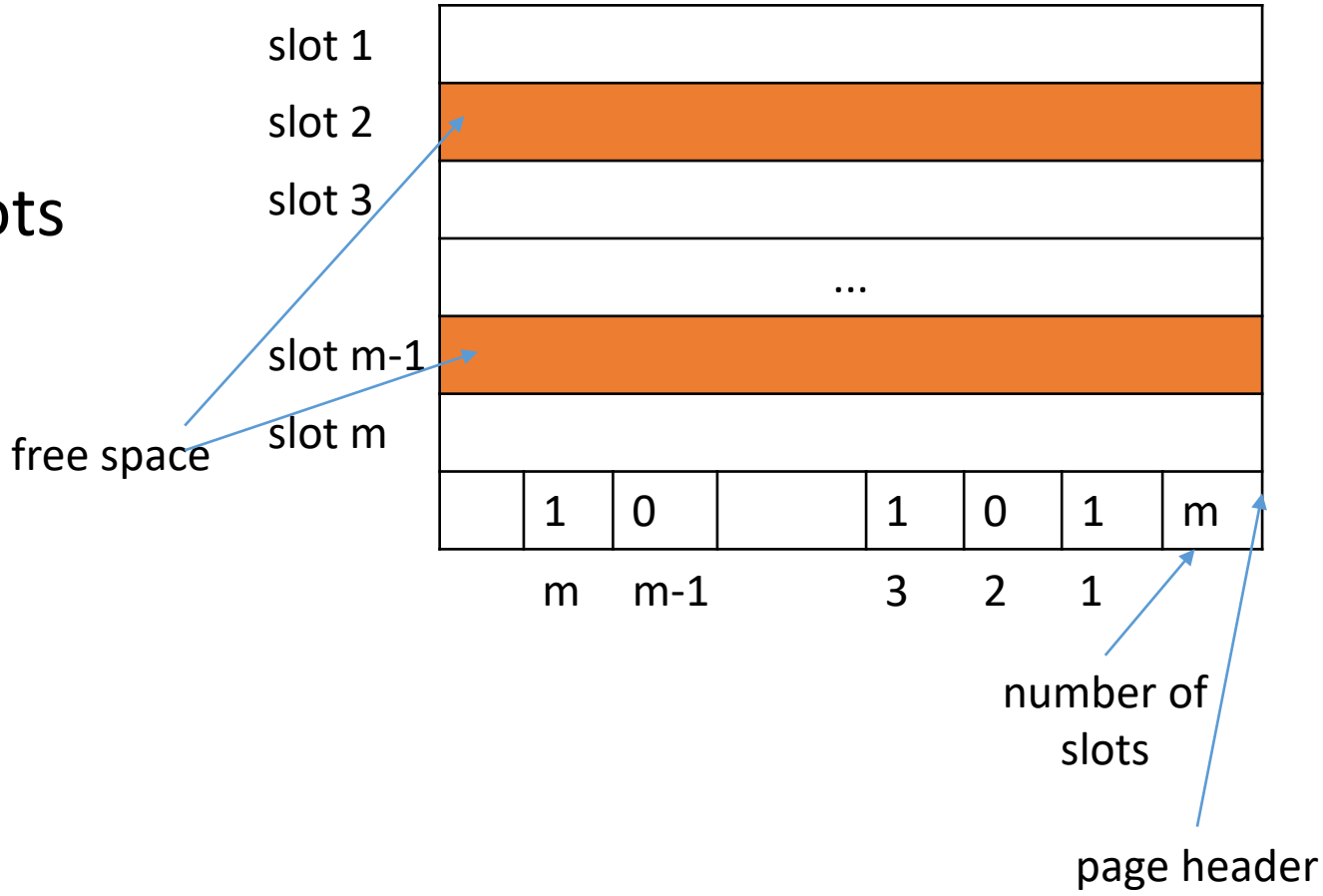
- fixed-length records - v1
  - *n* – number of records on the page
  - records are stored in the first *n* slots
  - locating record *i* - compute corresponding offset
  - deleting a record - the last record on the page is moved into the empty slot
  - empty slots - at the end of the page



  - problems when a moved record has external references
    - the record's slot number would change, but the rid contains the slot number!

Page Formats

- fixed-length records - v2
- array of bits to monitor available slots
- 1 bit / slot
- deleting a record - turning off the corresponding bit

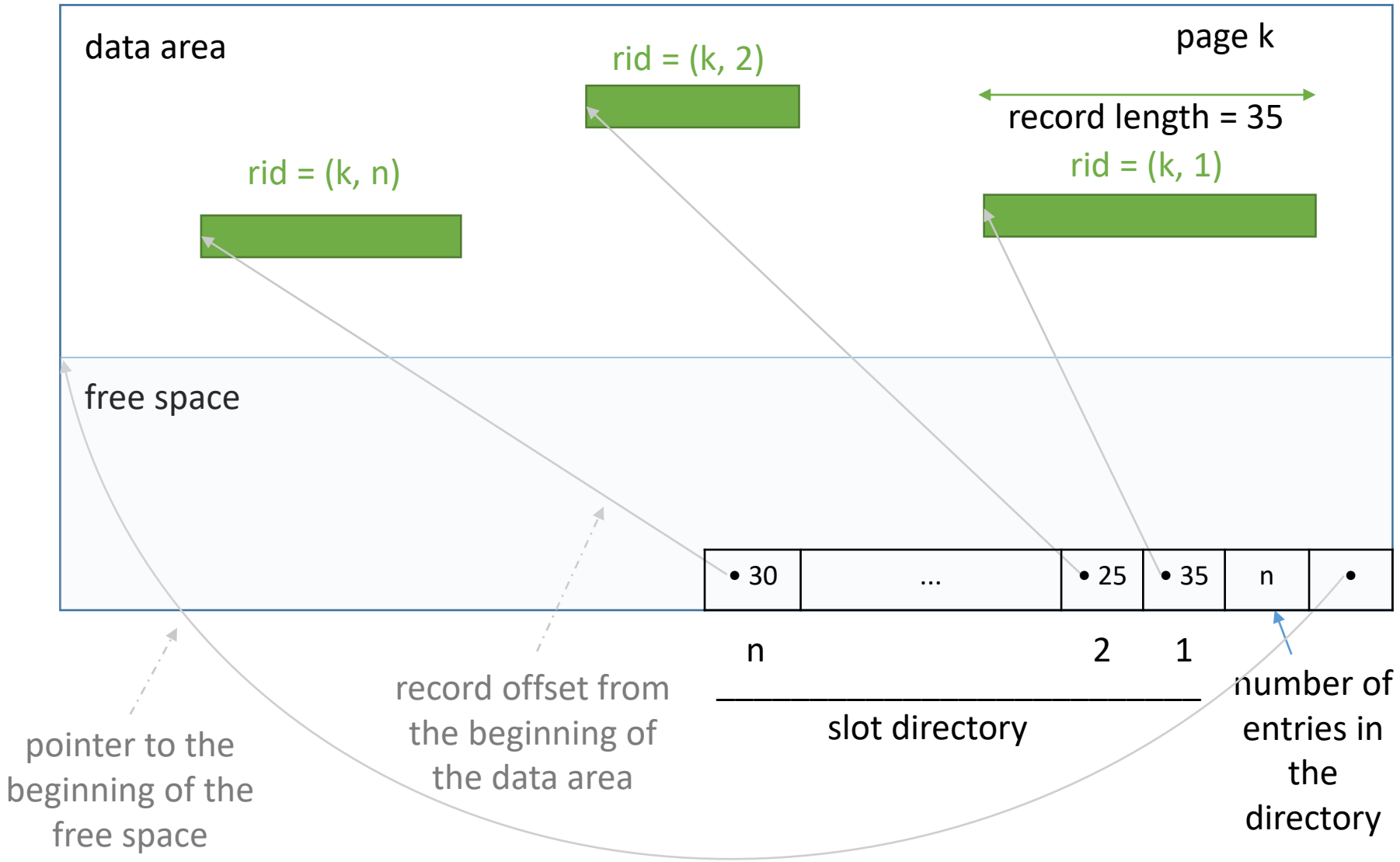


Page Formats

- variable-length records
  - adding a record
    - finding an empty slot of the right size
  - deleting a record
    - contiguous free space
  - a directory of slots / page
  - a pair <record offset , record length> / slot
  - a pointer to the beginning of the free space area on the page
  - moving a record on the page
    - only the record's offset changes
    - its slot number remains unmodified
  - can also be used for fixed-length records (when records need to be kept sorted)

Page Formats

- variable-length records



Indexes

- motivating example
  - file of students records sorted by name
    - good file organization
      - retrieve students in alphabetical order
    - not a good file organization
      - retrieve students whose age is in a given range
      - retrieve students who live in Timișoara
- index
  - auxiliary data structure that speeds up operations which can't be efficiently carried out given the file's organization
  - enables the retrieval of the rids of records that meet a selection condition (e.g., the rids of records describing students who live in Timișoara)

Indexes

- *search key*
  - set of one or more attributes of the indexed file (different from the *key* that identifies records)
- an index speeds up queries with equality / range selection conditions on the search key
- *entries*
  - records in the index (e.g., <search key, rid>)
  - enable the retrieval of records with a given search key value

Indexes

- example
  - files with students records
  - index built on attribute *city*
  - entries: <city, rid>, where rid identifies a student record
  - such an index would speed up queries about students living in a given city:
    - find entries in the index with city = *'Timișoara'*
    - follow rids from obtained entries to retrieve records describing students who live in Timișoara

Indexes

- an index can improve the efficiency of certain types of queries, not of all queries (analogy - when searching for a book at the library, index cards sorted on author name cannot be used to efficiently locate a book given its title)

- organization techniques (access methods) - examples
  - B+ trees
  - hash-based structures

- changing the data in the file => update the indexes associated with the file (e.g., inserting records, updating search key columns, updating columns that are not part of the key, but are included in the index)
- index size
  - as small as possible, as indexes are brought into main memory for searches

Indexes - Data Entries

- problems
  - what does a data entry contain?
  - how are the entries of an index organized?

- let k* be a data entry in an index; the data entry:
  - alternative 1

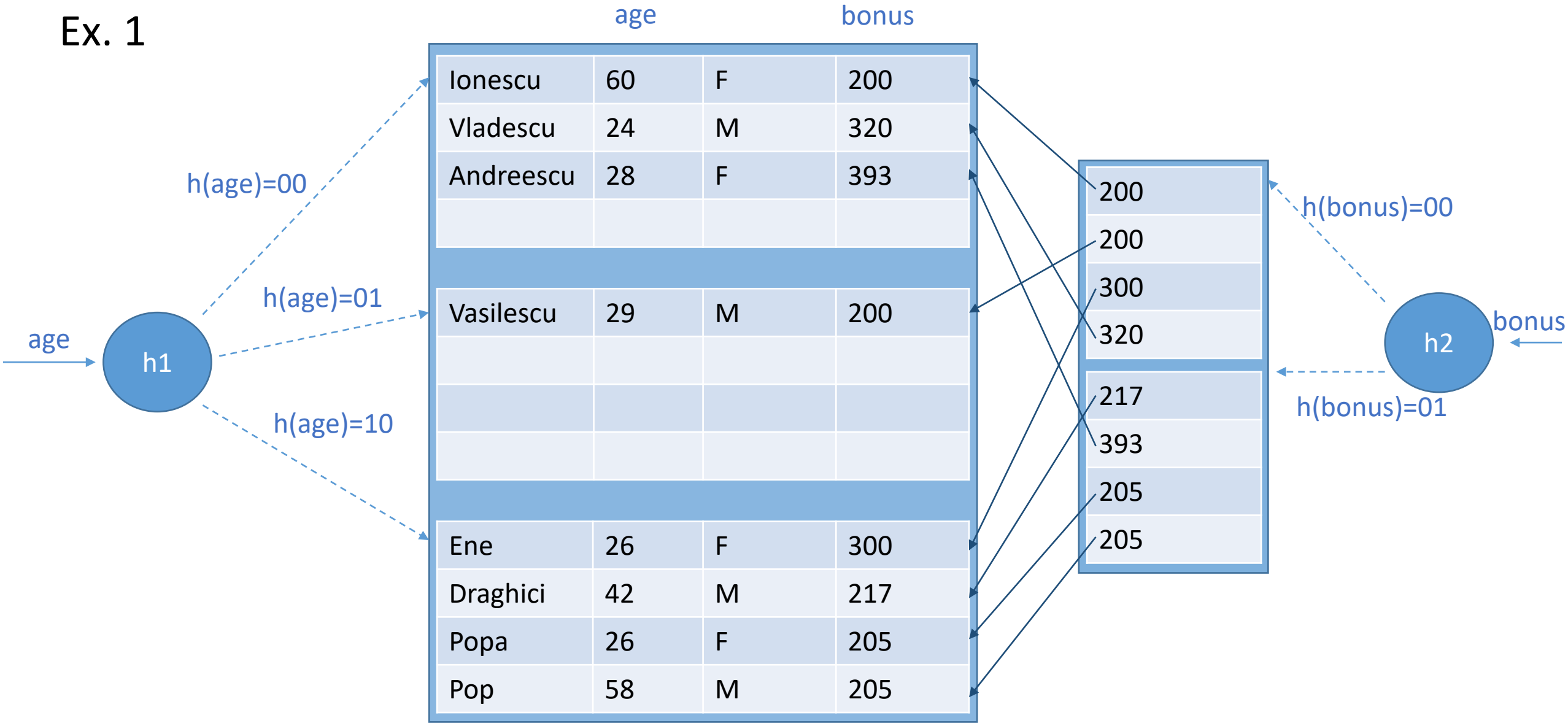
    is an actual data record with search key value = k
  - alternative 2
    - is a pair <k, rid> (rid – id of a data record with search key value = k)
  - alternative 3
    - is a pair <k, rid_list> (rid_list – list of ids of data records with search key value = k)

Indexes - Data Entries

- a1
  - the file of data records needn't be stored in addition to the index
  - the index is seen as a special file organization
  - at most 1 index / collection of records should use alternative a1 (to avoid redundancy)
- a2, a3
  - data entries point to corresponding data records
  - in general, the size of an entry is much smaller than the size of a data record
  - a3 is more compact than a2, but can contain variable-length records
  - can be used by several indexes on a collection of records
  - independent of the file organization

Indexes - Data Entries

Ex. 1



Indexes - Data Entries

Ex. 1

- file with Employee records hashed on *age*
  - record <Ionescu, 60, F, 200>:
    - apply hash function to *age:* convert 60 to its binary representation, take the 2 least significant bits as the bucket identifier for the record
- index file that uses alternative 1 (data entries are the actual data records), search key *age*
- index that uses alternative 2 (data entries have the form <search key, rid>), search key *bonus*
- both indexes use hashing to locate data entries

Indexes - Data Entries

Ex. 2

	Name	Score	Age
rid_1	Popescu	3	44
rid_2	Ionescu	95	80
rid_3	Vladescu	3	45
...		...	
rid_p	Xulescu	90	14

search key

rid_1	3
rid_2	95
rid_3	3
...	
rid_p	90

3	rid_1, rid_3 ...
95	rid_2 ...
...	
90	rid_p ...
	...

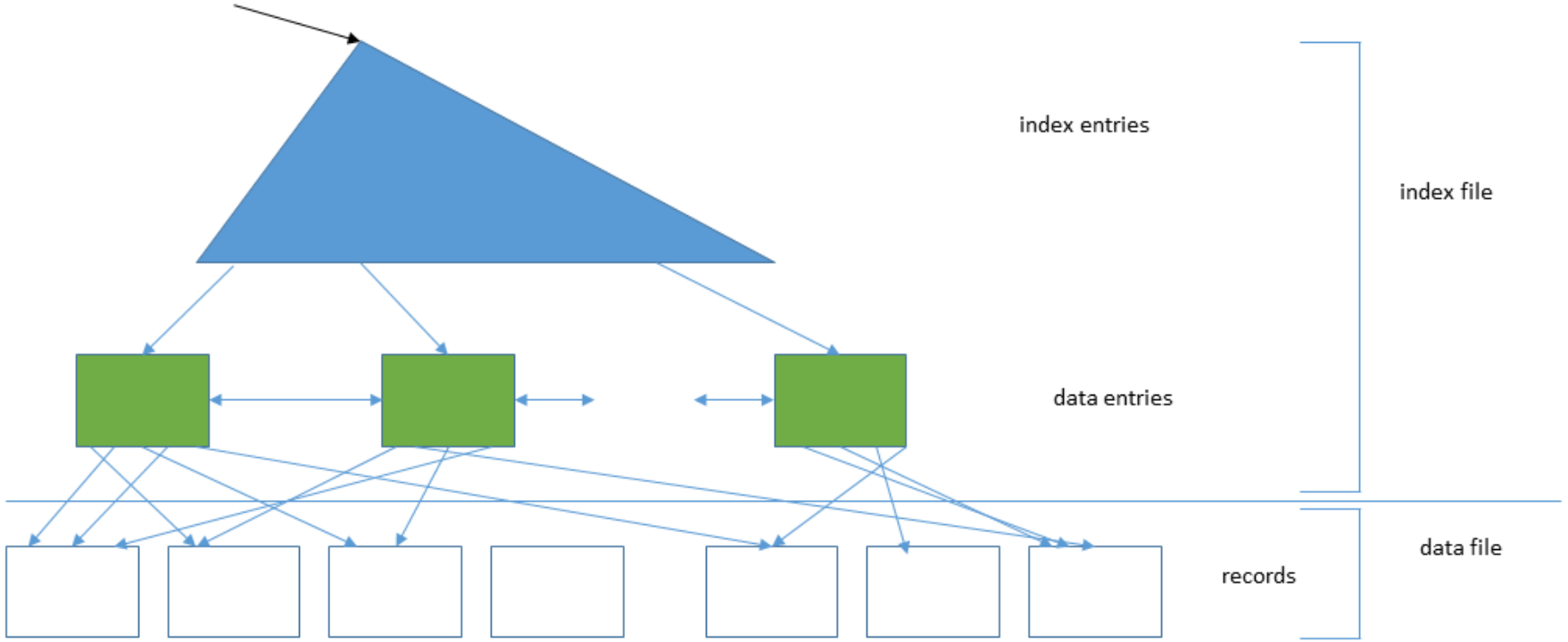
data entry

...	
3	rid_1, rid_3 ...
...	
90	rid_p ...
...	
95	rid_2 ...
...	

index file

Clustered / Unclustered Indexes

- clustered index: the order of the data records is close to / the same as the order of the data entries
- unclustered index: index that is not clustered



index entries guide the search for data entries

unclustered index, alternative 2

Clustered / Unclustered Indexes

- index that uses alternative 1 - clustered (by definition, since the data entries are the actual data records)
- indexes using alternatives 2 / 3 are clustered only if the data records are ordered on the search key
- in practice:
  - expensive to maintain the sort order for files, so they are rarely kept sorted
  - a clustered index is an index that uses alternative 1 for data entries
  - an index that uses alternative 2 or 3 for data entries is unclustered
- on a collection of records:
  - there can be at most 1 clustered index
  - and several unclustered indexes

Clustered / Unclustered Indexes

- range search query (e.g., *where age between 20 and 30*)
  - cost of using an unclustered index
    - each data entry that meets the condition in the query could contain a rid pointing to a distinct page
    - the number of I/O operations could be equal to the number of data entries that satisfy the query's condition

Primary / Secondary Indexes

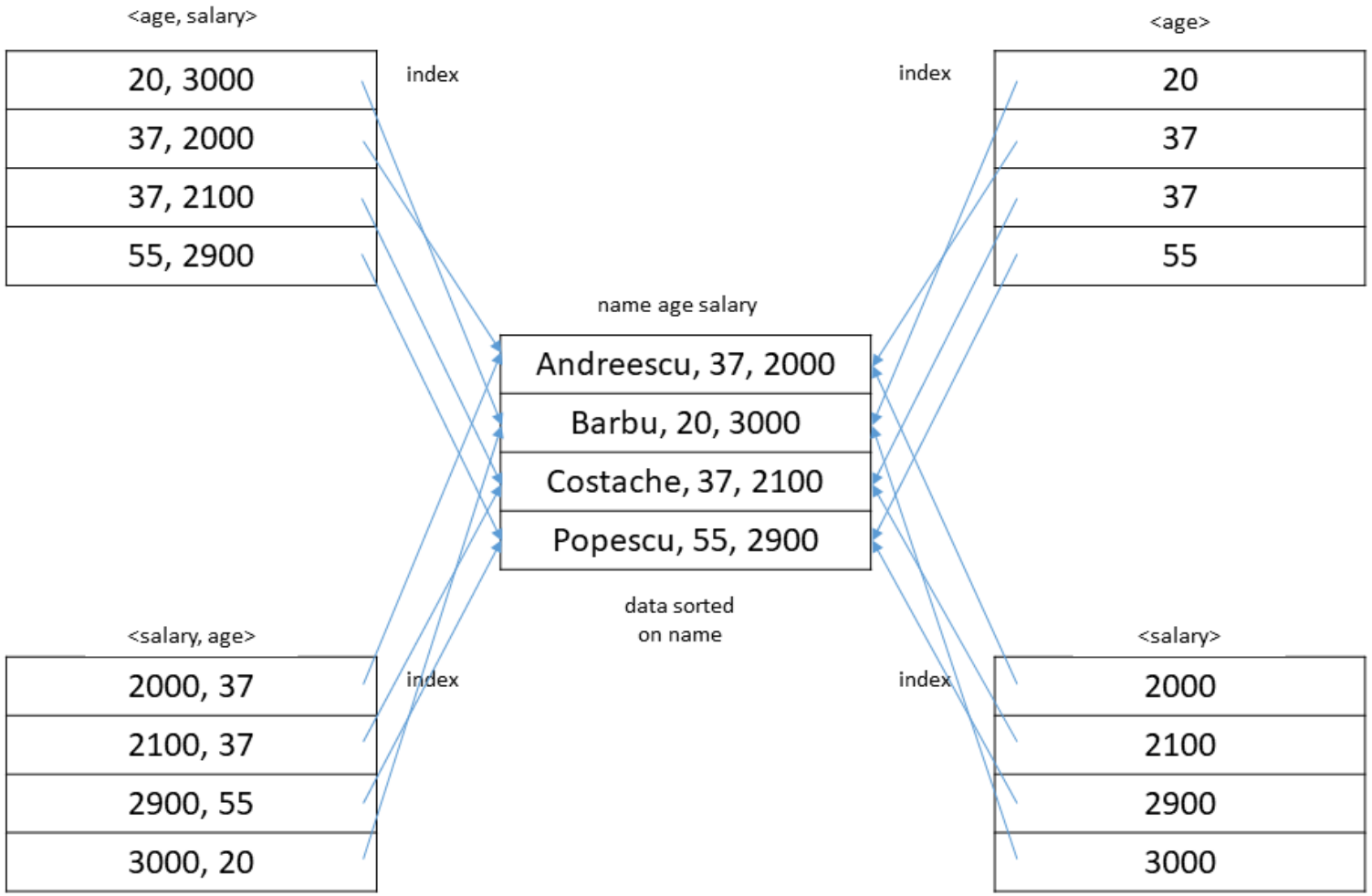
- primary index
  - the search key includes the primary key
- secondary index
  - index that is not primary
- unique index
  - the search key contains a candidate key

- duplicates
  - data entries with the same search key value

- primary indexes, unique indexes cannot contain duplicates

Composite Search Keys

- composite (concatenated) search key - search key that contains several fields
  - examples



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