

IF3140 – Sistem Basis Data Indexing

SEMESTER II TAHUN AJARAN 2024/2025



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Modified from [Silberschatz's slides](#),
“Database System Concepts”, 7th ed.



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“Database System Concepts”, 7th ed.

Sumber

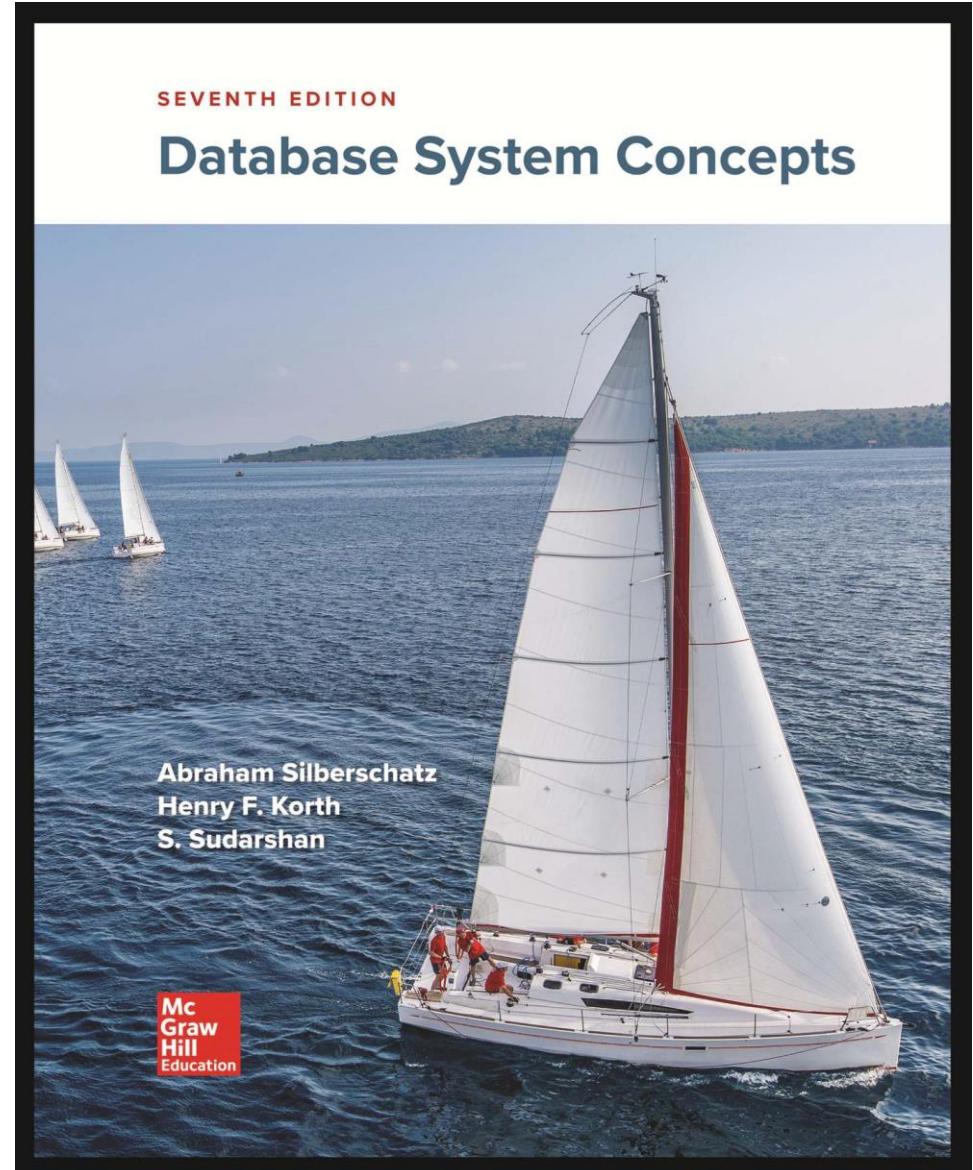
Silberschatz, Korth, Sudarshan:
“Database System
Concepts”, 7th Edition

- **Chapter 14:** Indexing



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“Database System Concepts”, 7th ed.



index terdiri dari records yg terdiri dari:

Index

records

search key
pointer

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



pointing untuk ke index berikutnya/record

- 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”.

tidak depends on keturunan indexnya,
melainkan dari hash functionnya.

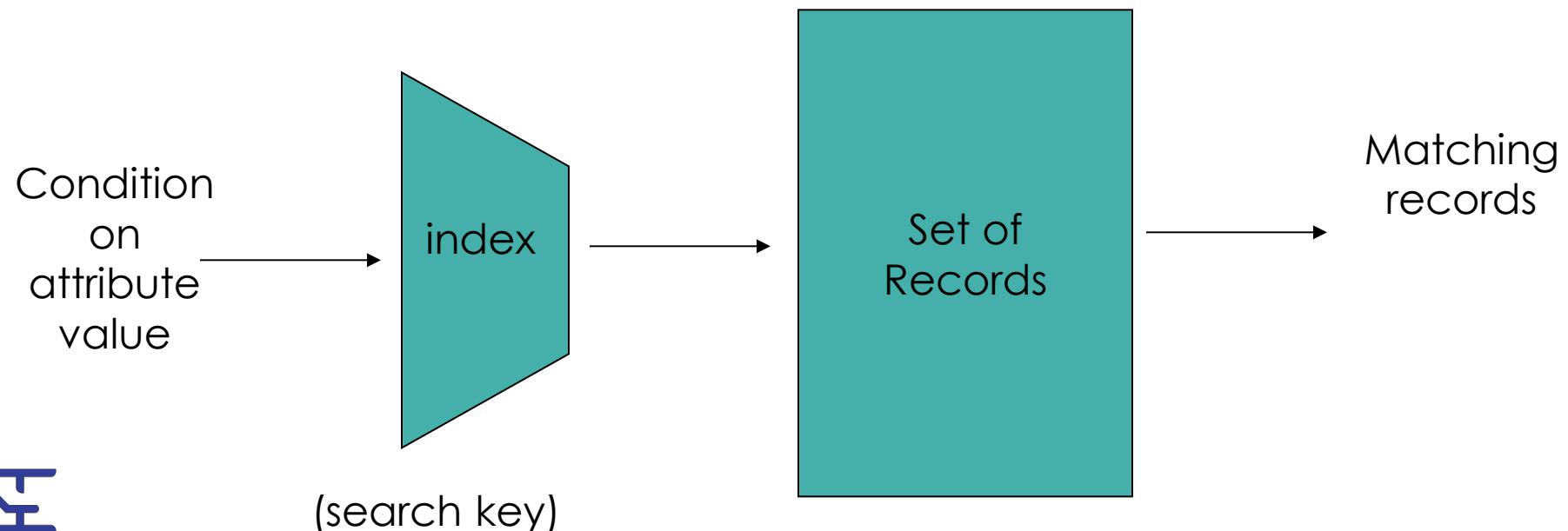


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Index

→ primary key is automatically indexed, sisanya manual by user

- An index is a data structure that **supports efficient access** to data
- It facilitates searching, sorting, join operation, etc., efficiently instead of scanning all table rows
- Index files are typically **much smaller** than the original file



Index Evaluation Metrics

- Access types supported efficiently. E.g.,
 - records with a **specified value** in the attribute where id = 1
 - or records with an attribute value falling in a specified **range of values**. where id > 1 and id < 10
- Access time → time to get the data / when the data has index (query read)
especially
- Insertion time → time taken when we insert new record to the table · ↗ may improve waktunya baca tp memperlambat insert/delete.
- Deletion time → time taken to delete a record.
- Space overhead
 - ↳ index is a new file so need more space.



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Several Index Methods

- Several index methods we will discuss:
 - Ordered indices ([index-sequential file](#))
 - B⁺-tree
 - Hash indexes
 - Bitmap indexes



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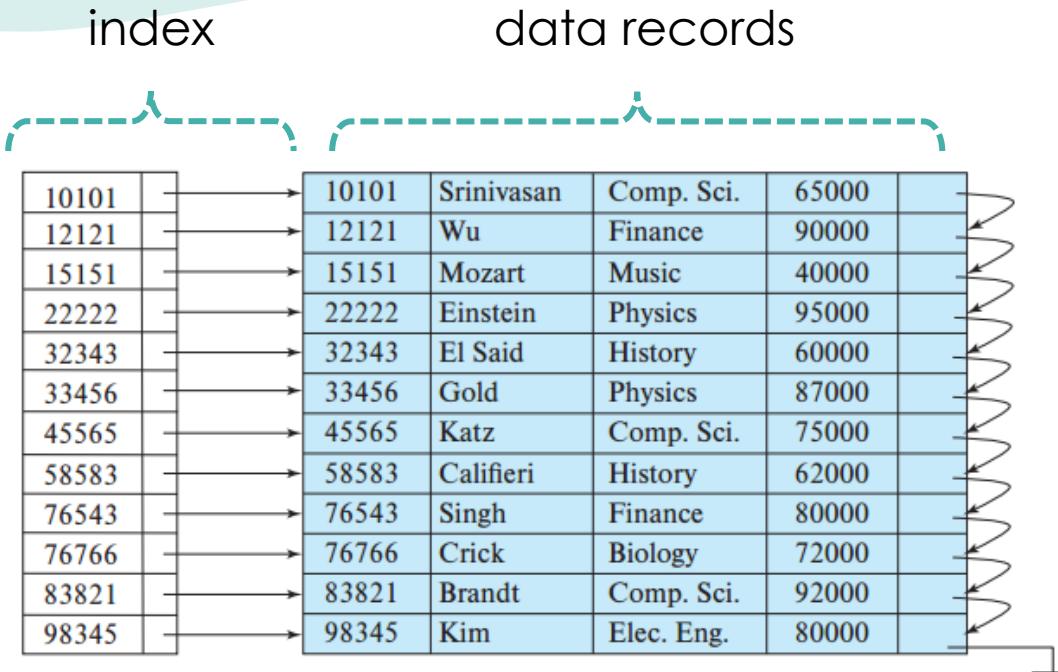
Ordered Indices

ada separate file of index yg contain value based on the search key.

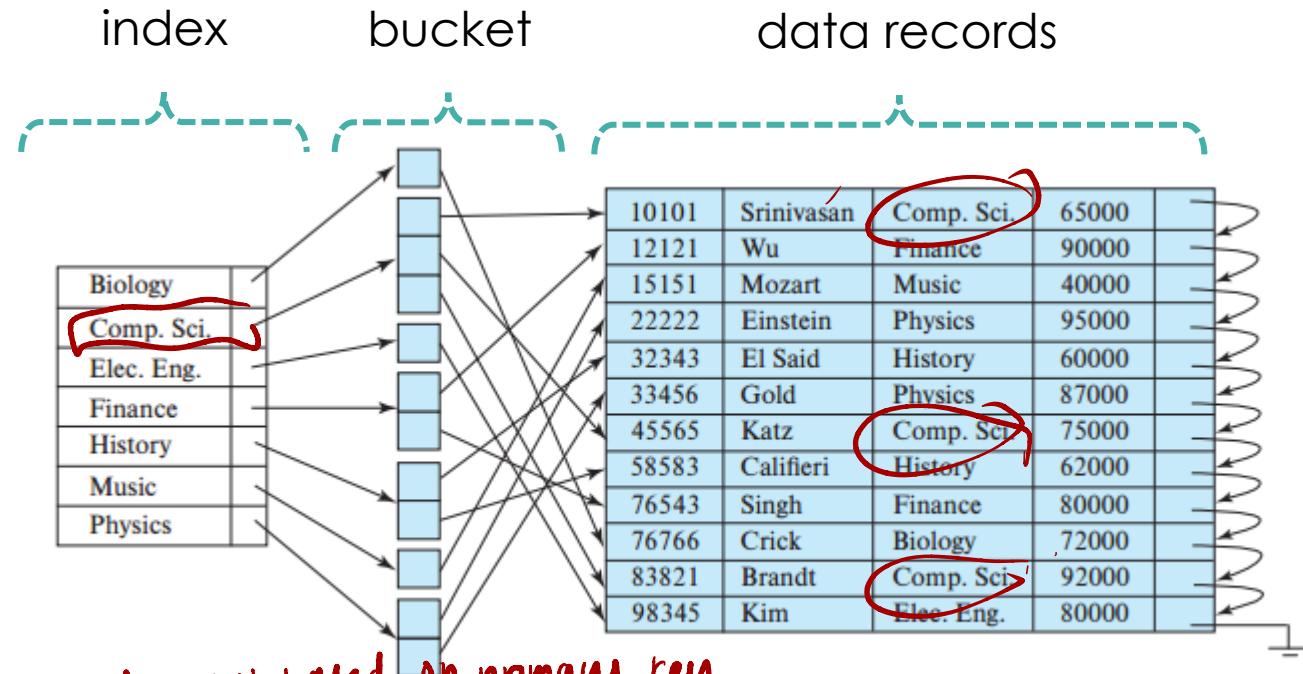
- In an **ordered index**, index entries are stored sorted on the search key value. E.g., author catalog in library.
- **Primary index:** an index whose search key specifies the sequential order of the file. Also called clustering index.
 - A table can **have only one clustered index**
 - The search key of a primary index is **usually** but not necessarily the primary key.
urutan index menentukan urutan physical
- **Secondary index:** an index whose search key specifies an order different from the sequential order of the file. Also called non-clustering index.
search key of index ≠ search key of file.
urutan index tidak menentukan urutan physical
- Index-sequential file: ordered sequential file with a primary index.



Primary (clustering) vs. Secondary (non-clustering) Index



Primary index (clustering index) on **ID**



index not based on primary key

Secondary index (non-clustering index) on **dept_name**

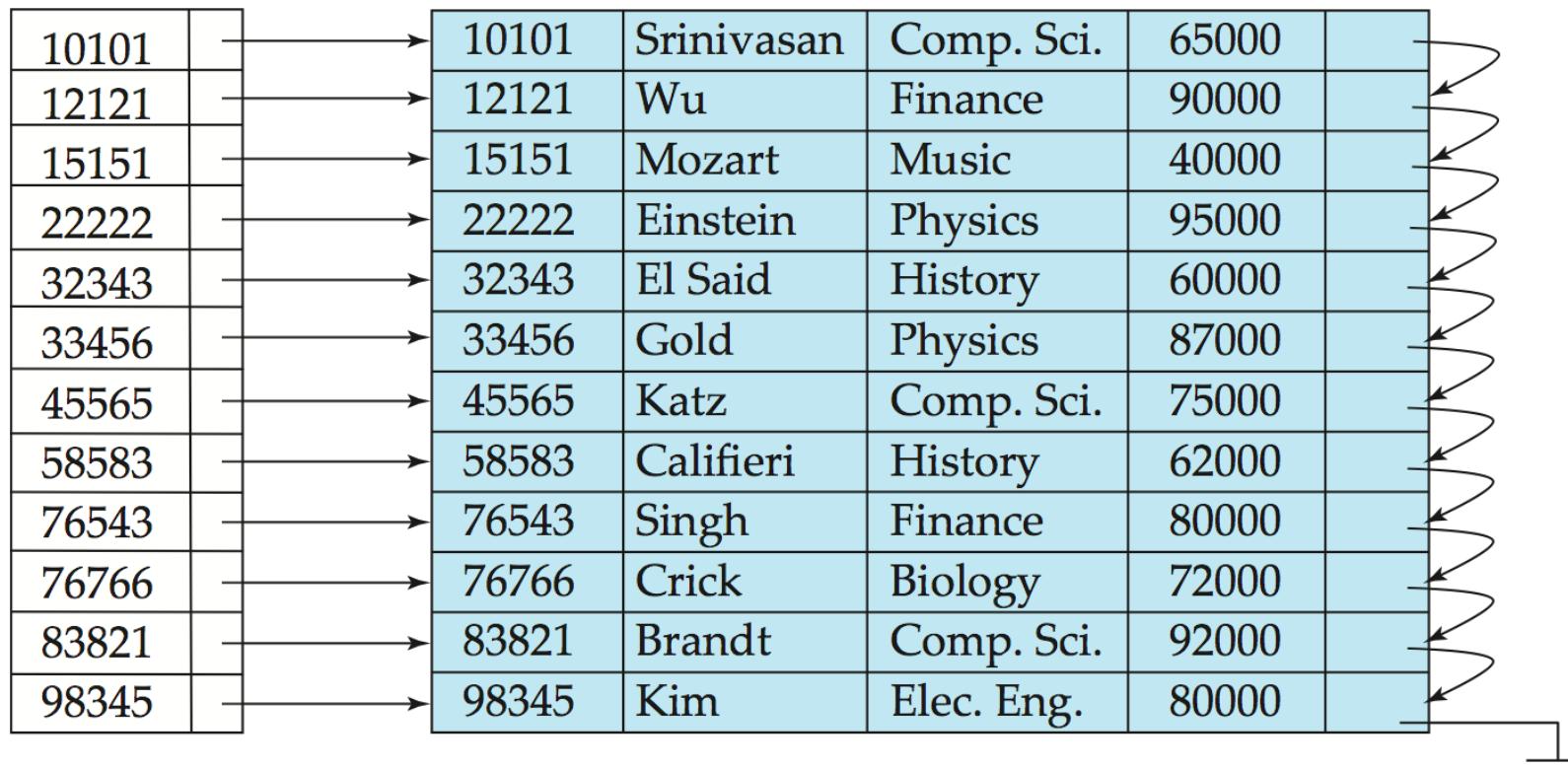
- Thus, a table can **have only one clustered index**
- E.g., SQL Server 2005 supports up to 249 non-clustering indices on a table

Ordered indices - Dense Index

semua value yg ada
di atribut search key
ada di index

- **Dense index** — Every search-key appears in the index records.
- E.g. index with search key on **ID** attribute of **instructor** relation

1 search key menunjuk 1 record



Note:

- Record is sorted based on the search key in a linked-list structure
- Locating index record is done by binary search (complexity = $\log_2 n$)

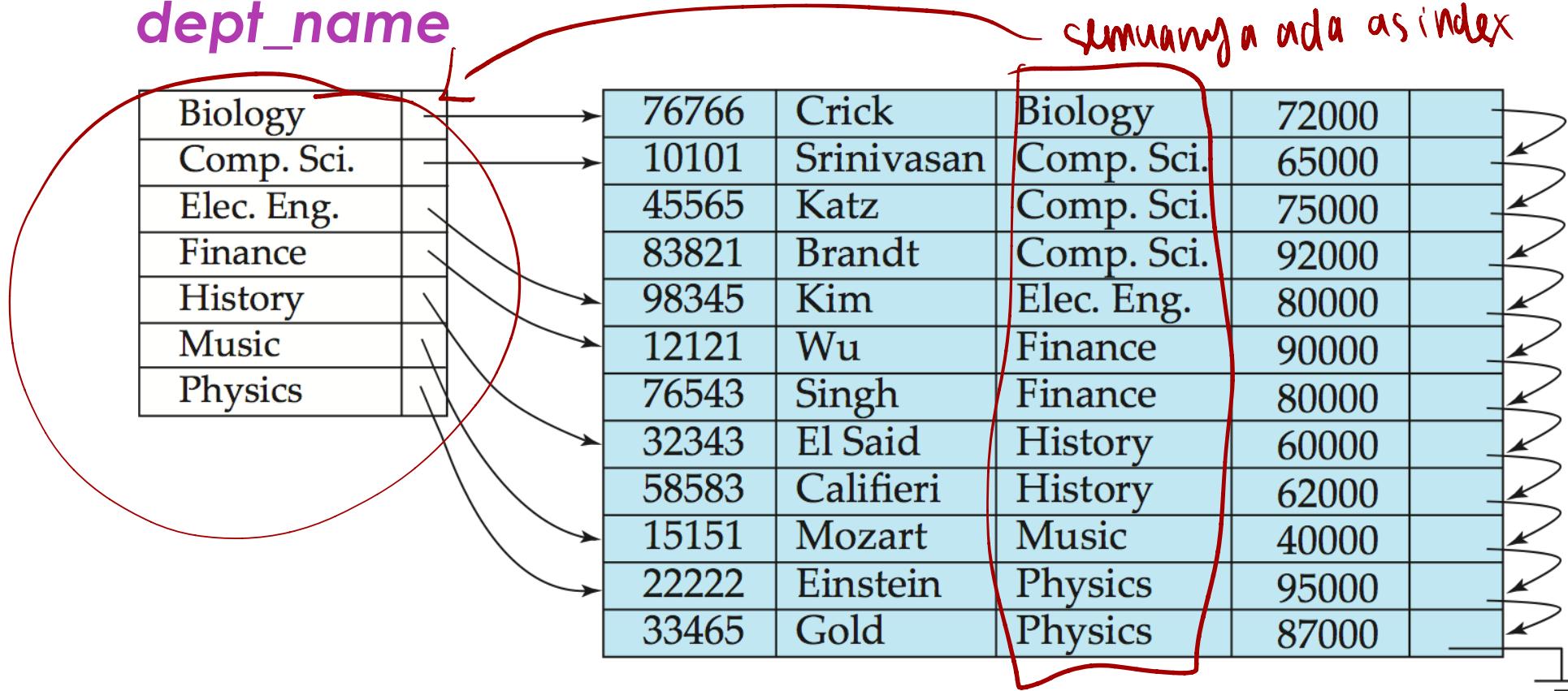


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"Database System Concepts", 7th ed.

Ordered indices - Dense Index (Cont.)

- Dense index on **dept_name**, with *instructor* file **sorted on dept_name**



See! All the search-keys appear in the index file

Ordered indices – Sparse Index

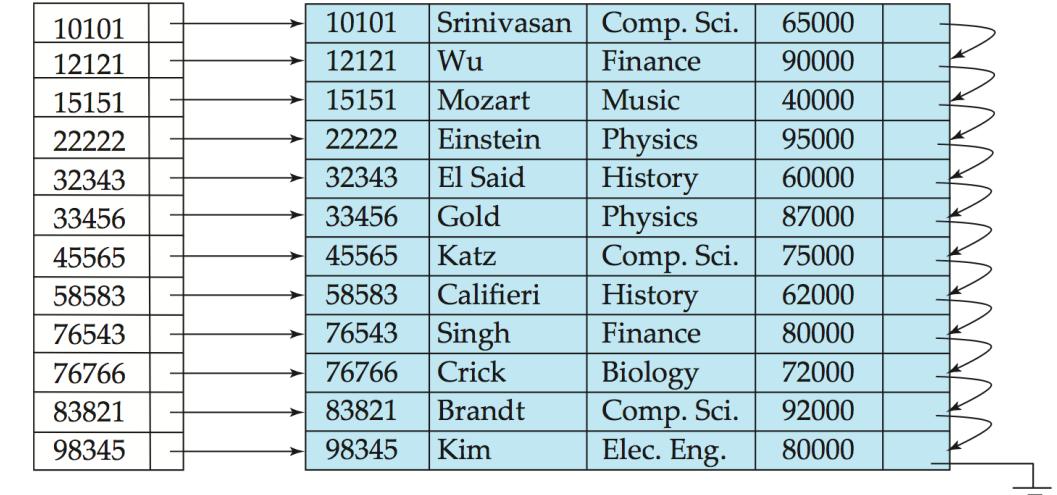
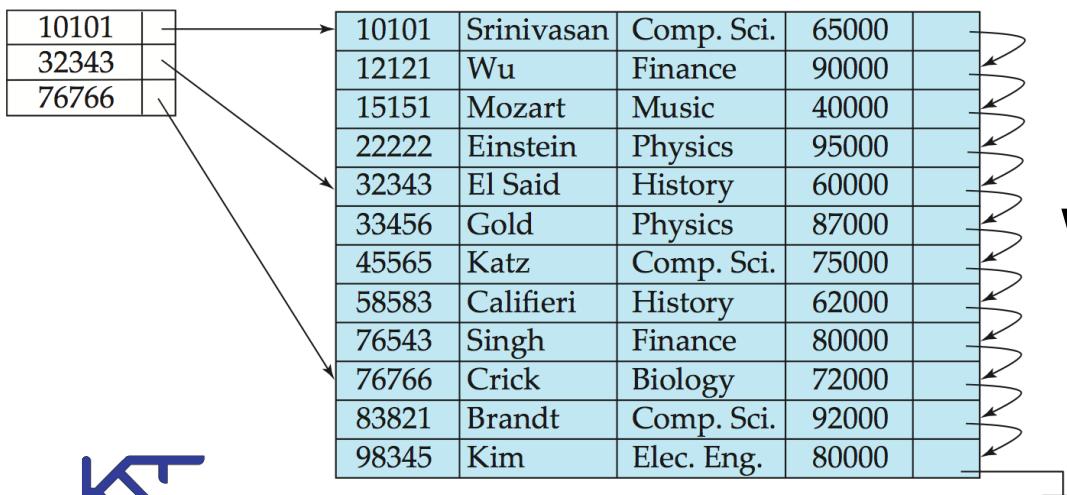
- **Sparse Index:** only some search-key values appear in the index records.
 - Applicable when **records are sequentially ordered on search-key**
- To locate a record with search-key value **K**, we:
 - Find index record with **largest search-key value that is $\leq K$**
 - **Search file sequentially** starting at the record to which the index record points

value palin
besar dari yg
lebih kecil dari
yg kita cari
mau yg ga
ada di search
key

10101	Srinivasan	Comp. Sci.	65000	
12121	Wu	Finance	90000	
15151	Mozart	Music	40000	
22222	Einstein	Physics	95000	
32343	E. Said	History	60000	
33456	Gold	Physics	87000	
45565	Katz	Comp. Sci.	75000	
58583	Califieri	History	62000	
76543	Singh	Finance	80000	
76766	Crick	Biology	72000	
83821	Brandt	Comp. Sci.	92000	
98345	Kim	Elec. Eng.	80000	

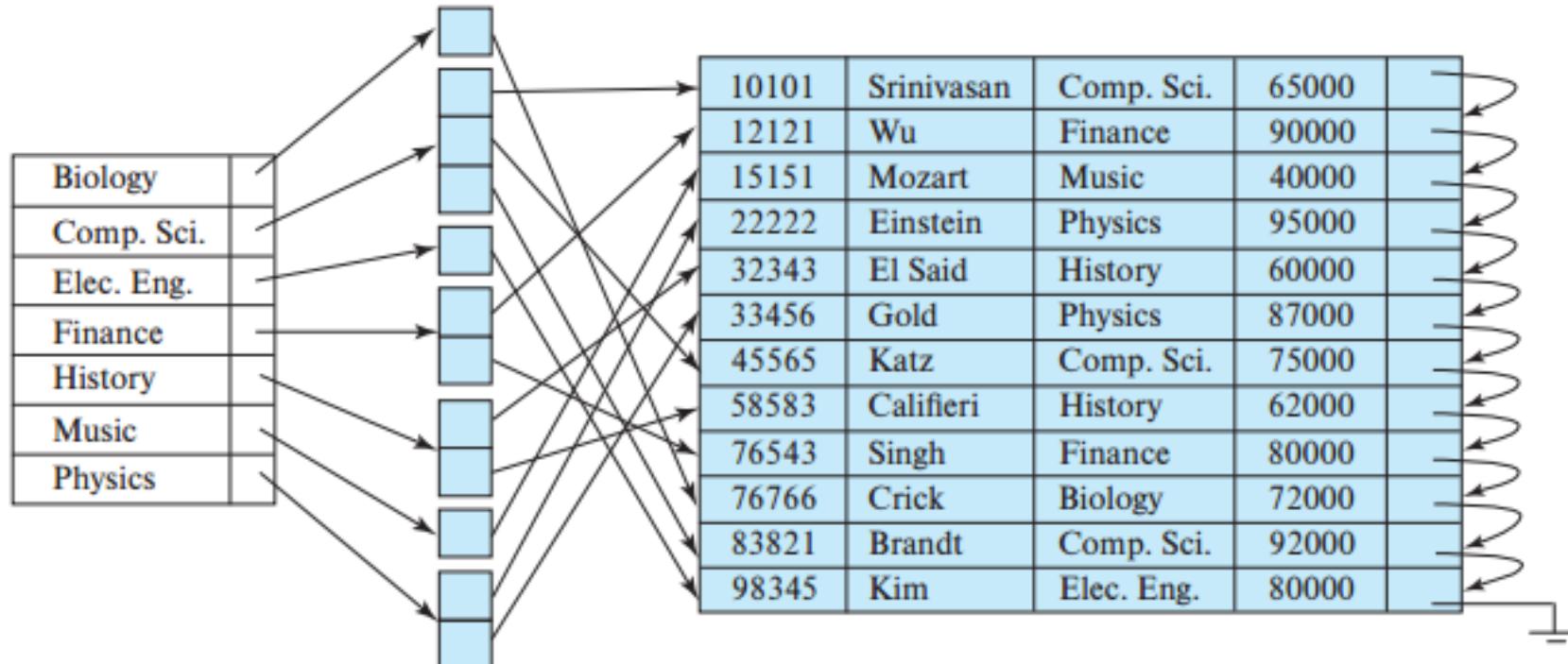
Ordered indices – Sparse Index (Cont.)

- 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.



Ordered indices – Secondary Index (revisit)

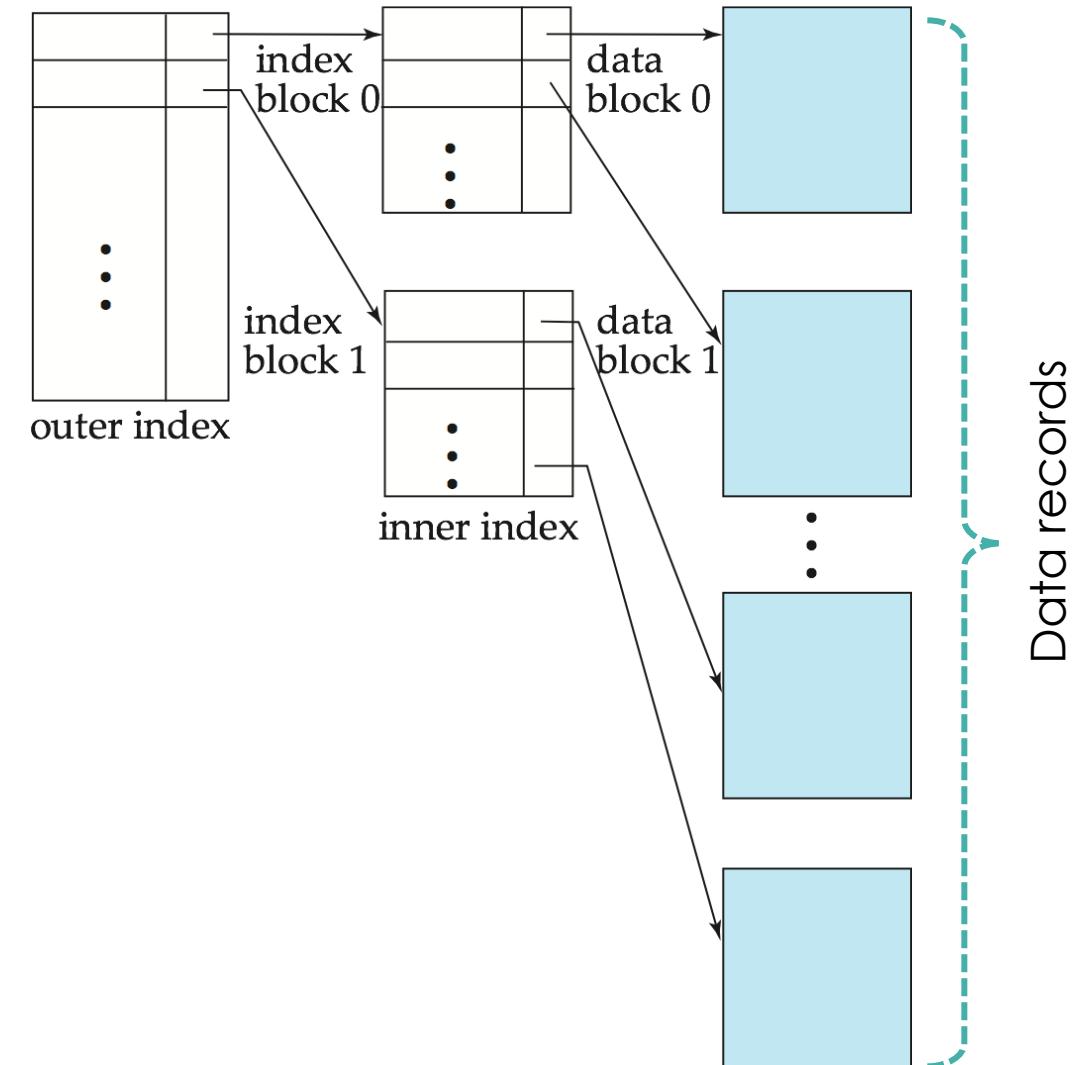
- Index record **points to a bucket** that contains pointers to all the actual records with that particular search-key value.
- Secondary indices **have to be dense**



Secondary index on `dept_name` attribute of `instructor`

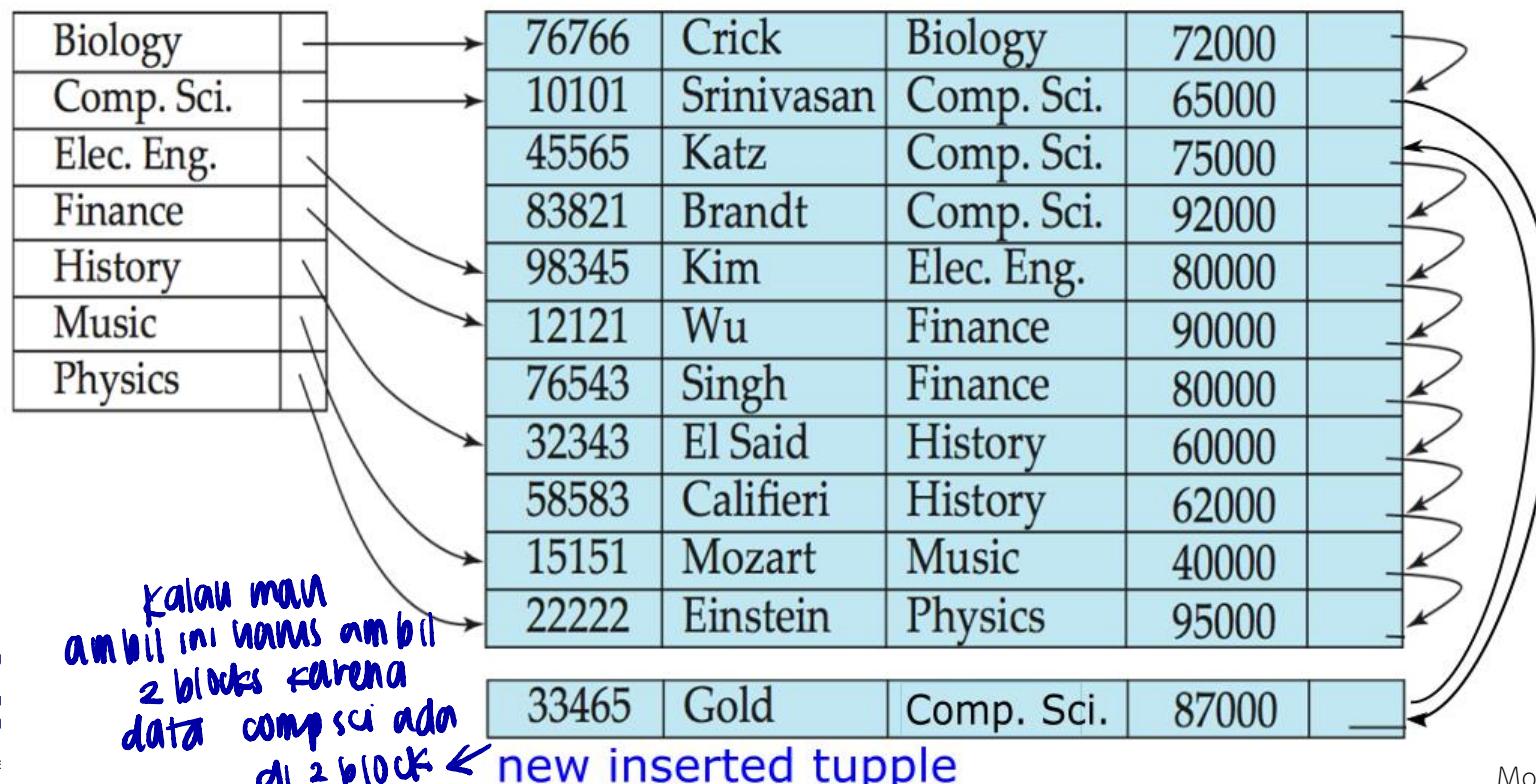
Ordered indices – Multilevel Index

- If primary index does not fit in memory, access becomes expensive. → *index also file stored in blocks*
- **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



Ordered indices on Insert, Delete, Update

- In **index-sequential file**, as file grows with insert, delete and update, many **overflow blocks get created**.
- **Periodic reorganization** of entire file is required, otherwise, **more random disk I/O is needed**.



kalan misal dia dih aurut jd gaperlu 2 blocks karena compsi nya dah keurut .

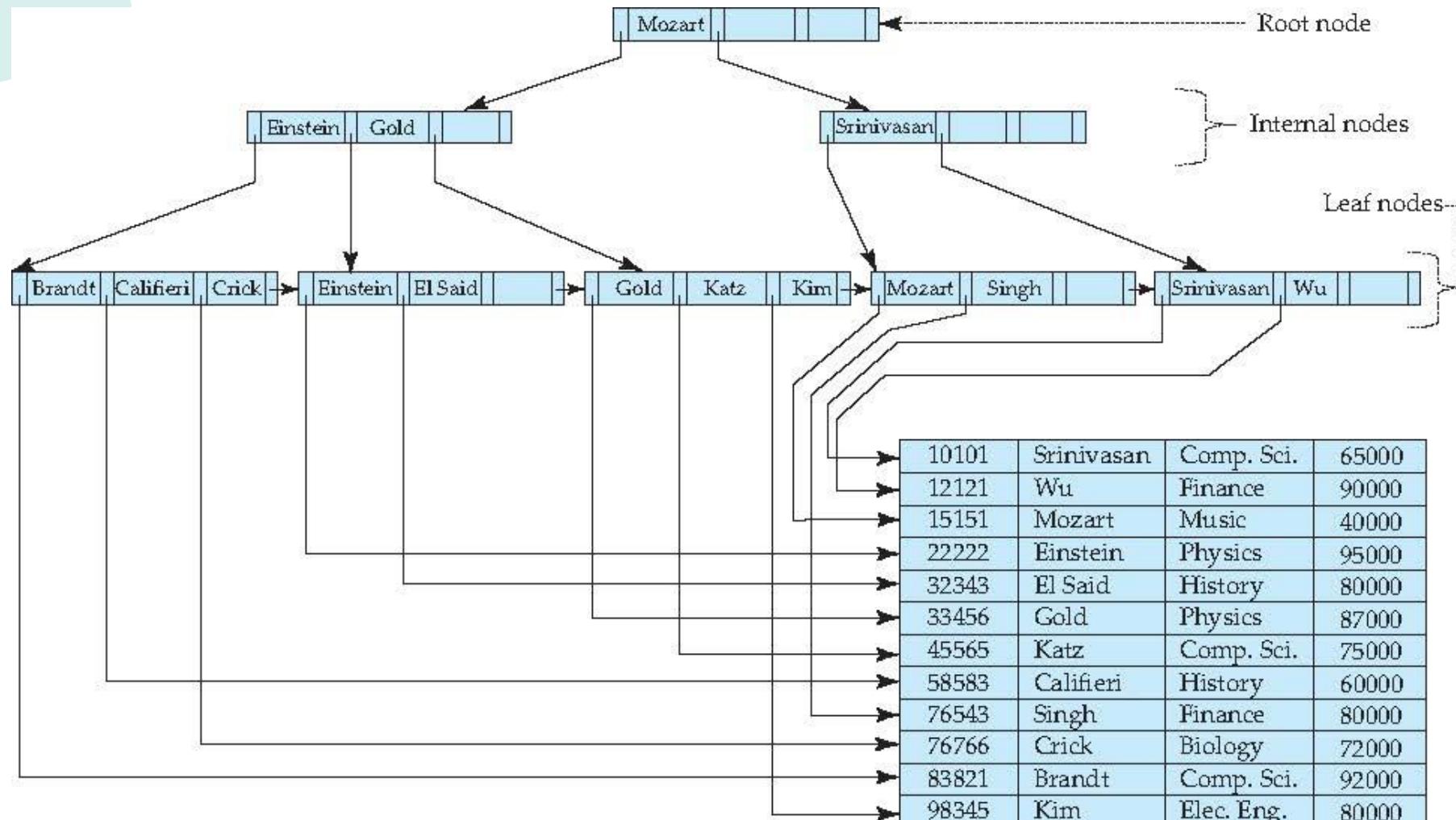
E.g., querying records whose **dept_name** is "Comp. Sci." now needs more disk I/O

B⁺-Tree Index

B⁺-tree indices are **an alternative to indexed-sequential files**.

- Disadvantage of indexed-sequential files
 - **performance degrades** as file grows, since **many overflow blocks get created**.
 - **Periodic reorganization** of entire file is required.
 - Searching using binary search has **(log₂ n) cost**, later, we will know a cheaper cost using B⁺-tree
- Advantage of B⁺-tree index files:
 - automatically reorganizes itself with small, local, changes, in the face of insertions and deletions.
 - **Reorganization of entire file is not required** to maintain performance.
- (Minor) disadvantage of B⁺-trees:
 - extra insertion and deletion overhead, space overhead.
- Advantages of B⁺-trees **outweigh** disadvantages
 - **B⁺-trees are used extensively**

Example of B^+ -Tree



B+-Tree Index (Cont.)

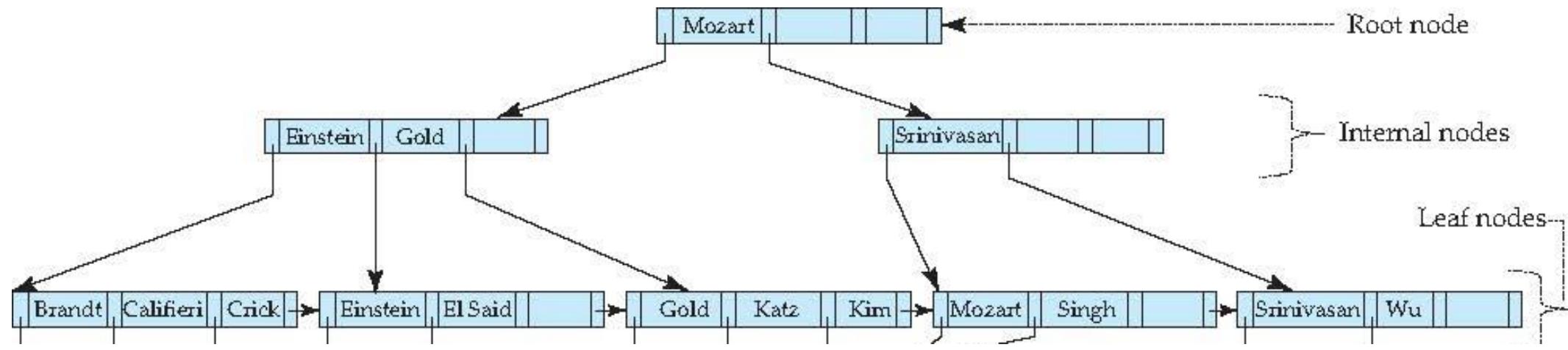
- A B+-tree with max degree n is a rooted tree satisfying the following properties:
 - All paths from root to leaf are of the same length
 - Each node that is not a root or a leaf has between $\lceil n/2 \rceil$ and n children
 - A leaf node has between $\lceil (n-1)/2 \rceil$ and $n-1$ values
 - Special cases:
 - If the root is not a leaf, it has at least 2 children.
 - If the root is a leaf (that is, there are no other nodes in the tree), it can have between 0 and $(n-1)$ values.



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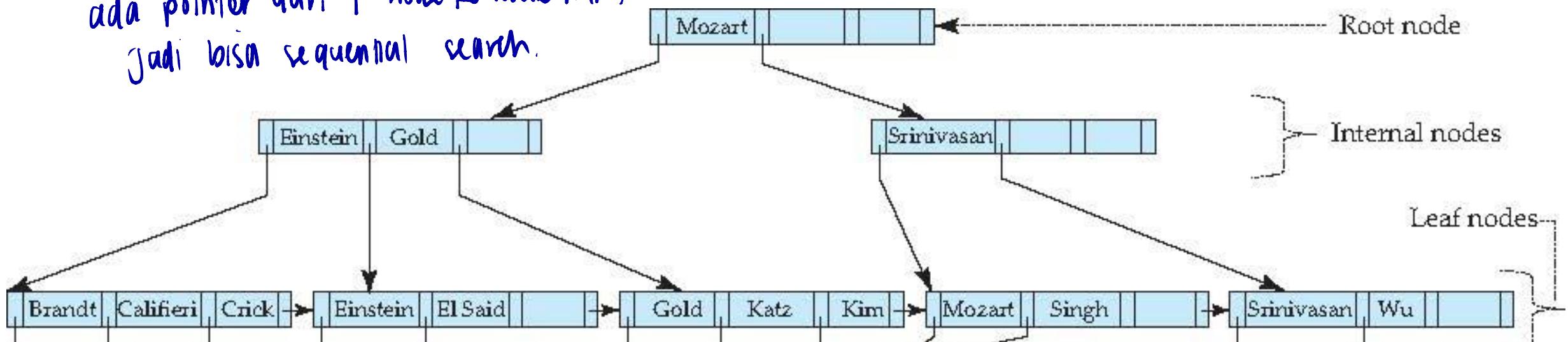
B+-Tree Index (Cont.)



B⁺-Tree Index (Cont.)

- Search **key is in sorted order**, having properties of n-ary search tree
- There is a **pointer** in the end of leaf pointing to the **next leaf**
- The non-leaf levels of the B⁺-tree form a hierarchy of sparse indices.

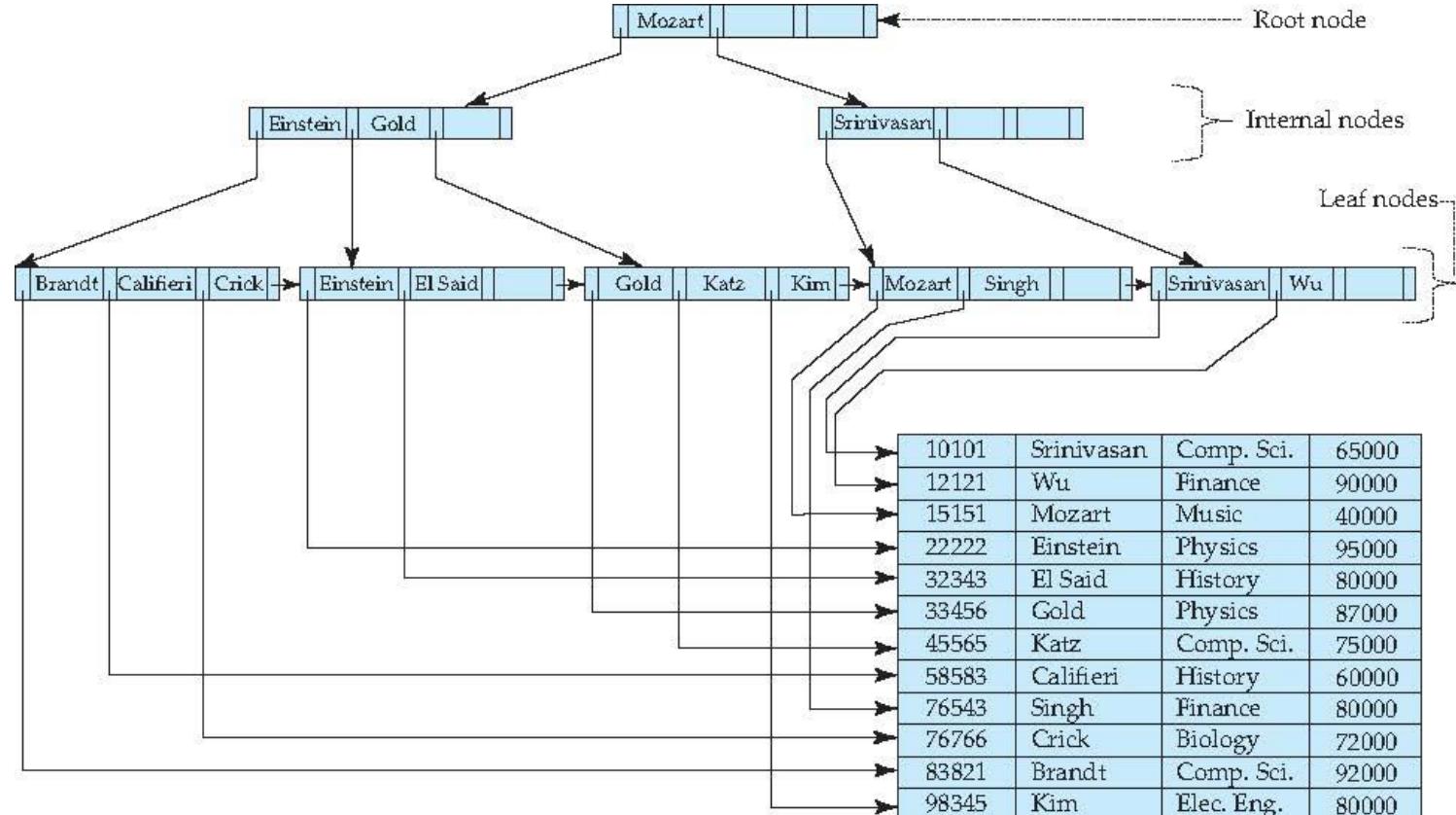
internal node
ada pointer dari 1 node ke node lain,
jadi bisa sequential search.



A B⁺-tree example with $n = 4$

Queries on B^+ -Trees

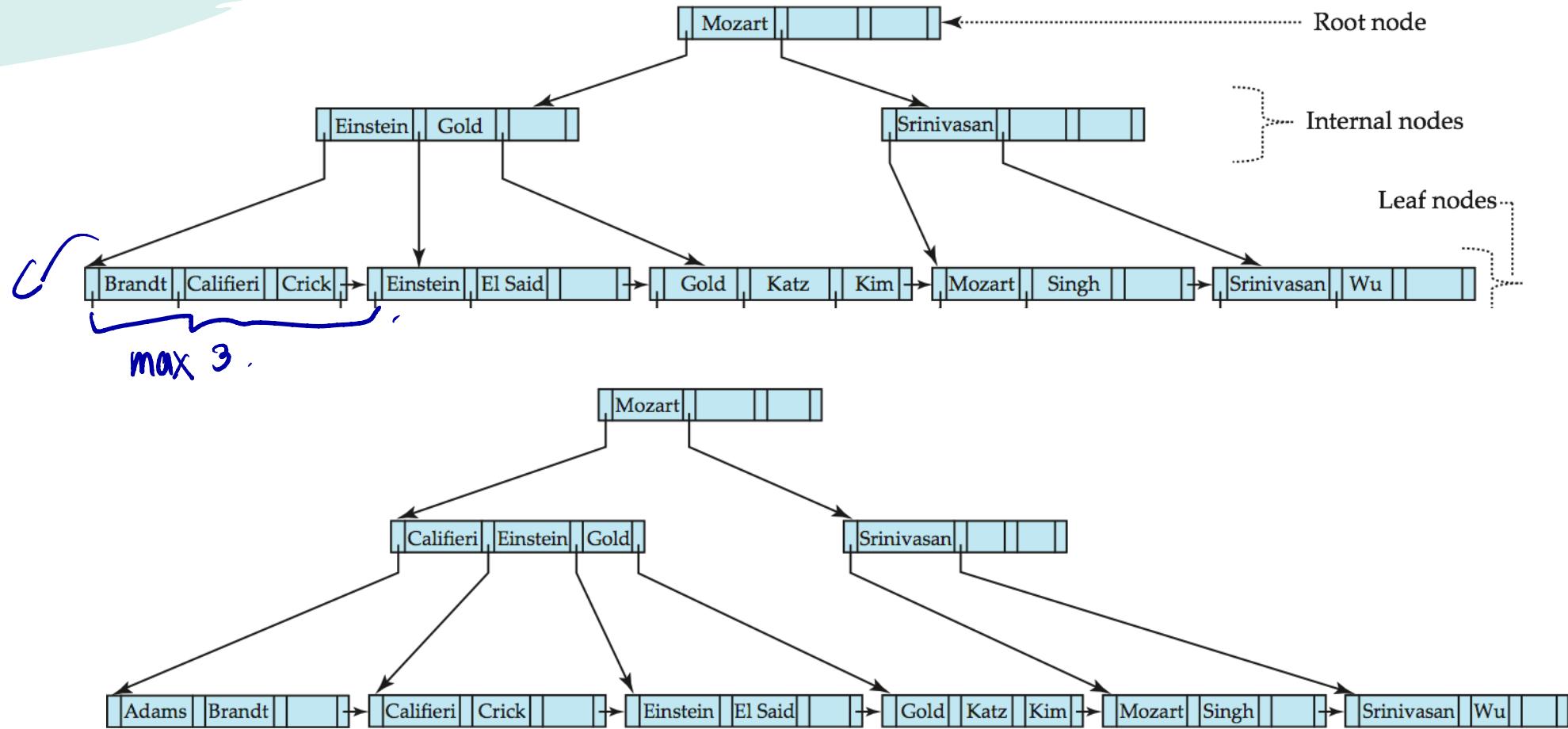
- With K search-key values, the tree height is no more than $\lceil \log_{\lceil n/2 \rceil}(K) \rceil$.
- A node is generally the same size as a disk block, typically 4 KB
 - and n is typically around 100 (40 bytes per index entry).
- With 1 million search key values and $n = 100$
 - at most $\log_{50}(1,000,000) = 4$ nodes are accessed in a lookup.



- It handles efficiently **range query!**

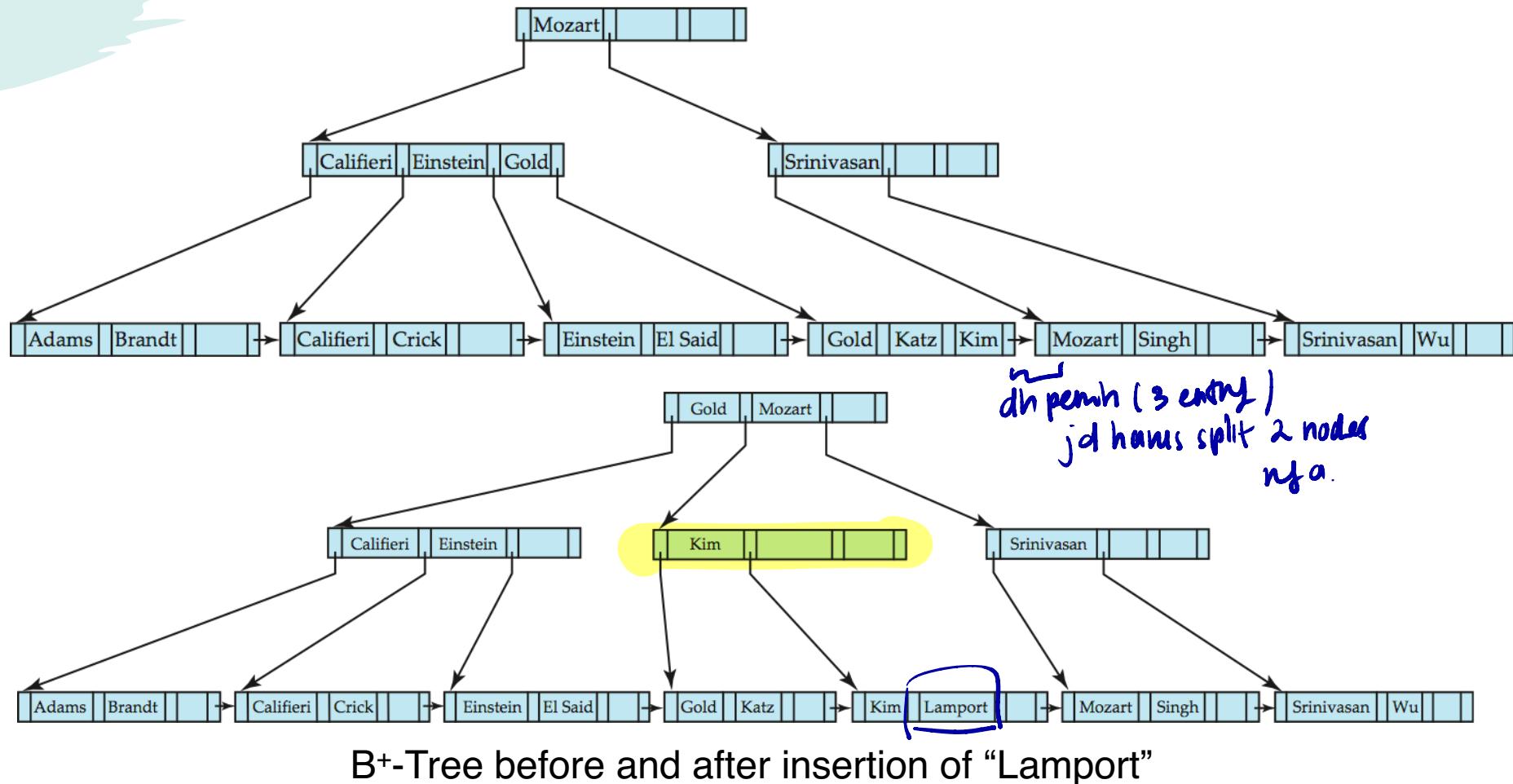
\rightarrow until access leaf, \rightarrow root, internal nodes 2x , and leaf..

B⁺-Tree Insertion



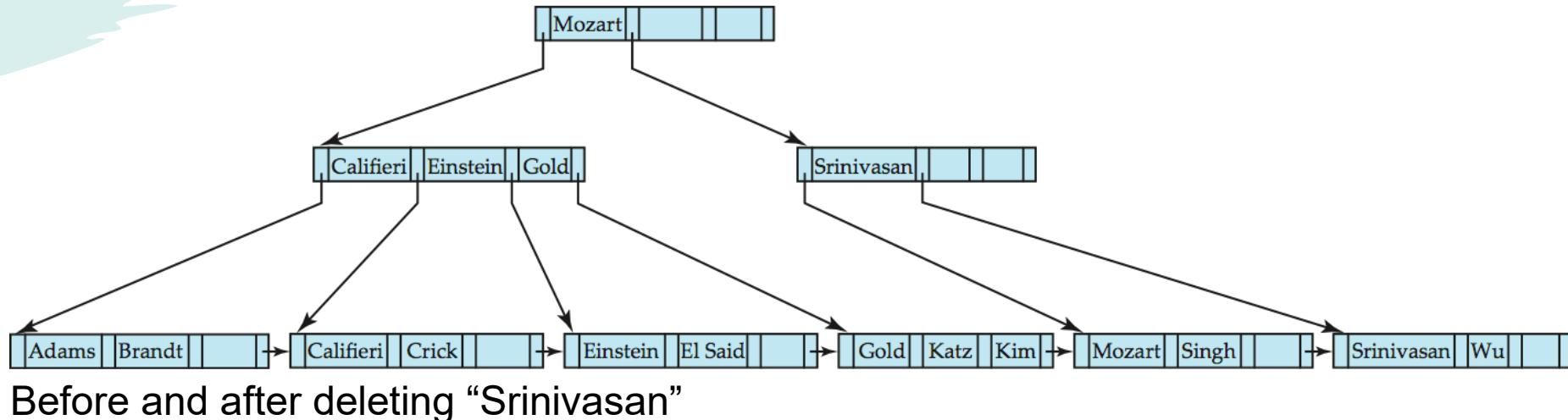
B⁺-Tree before and after insertion of “Adams”

B⁺-Tree Insertion (Cont.)

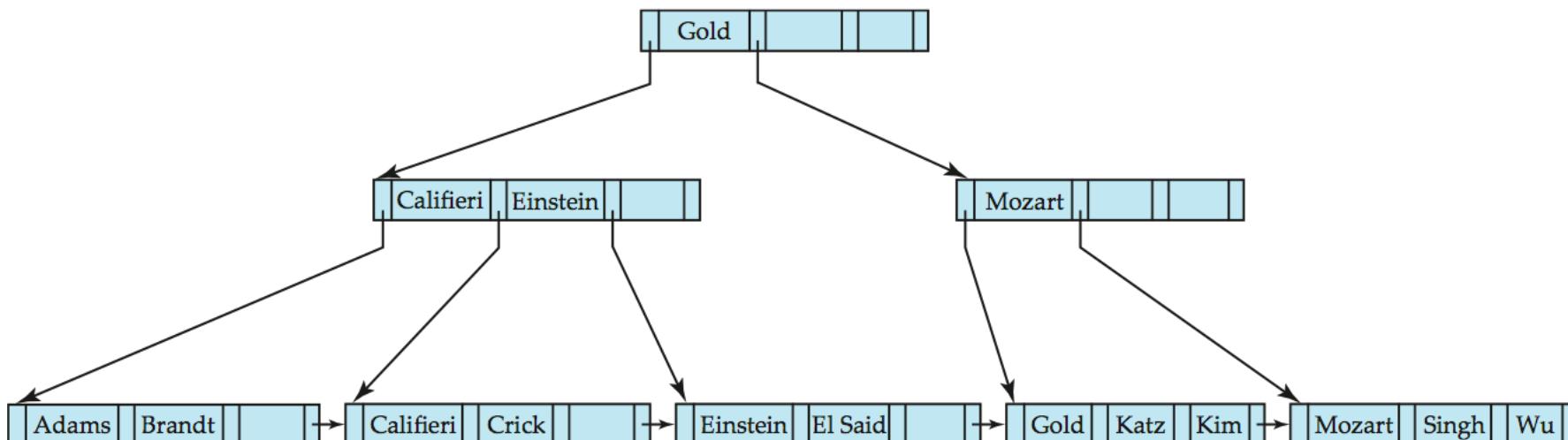


- There is **split** and **merge** mechanisms to maximize the number of search-keys in each node. Read the detail in the textbook!

Examples of B^+ -Tree Deletion

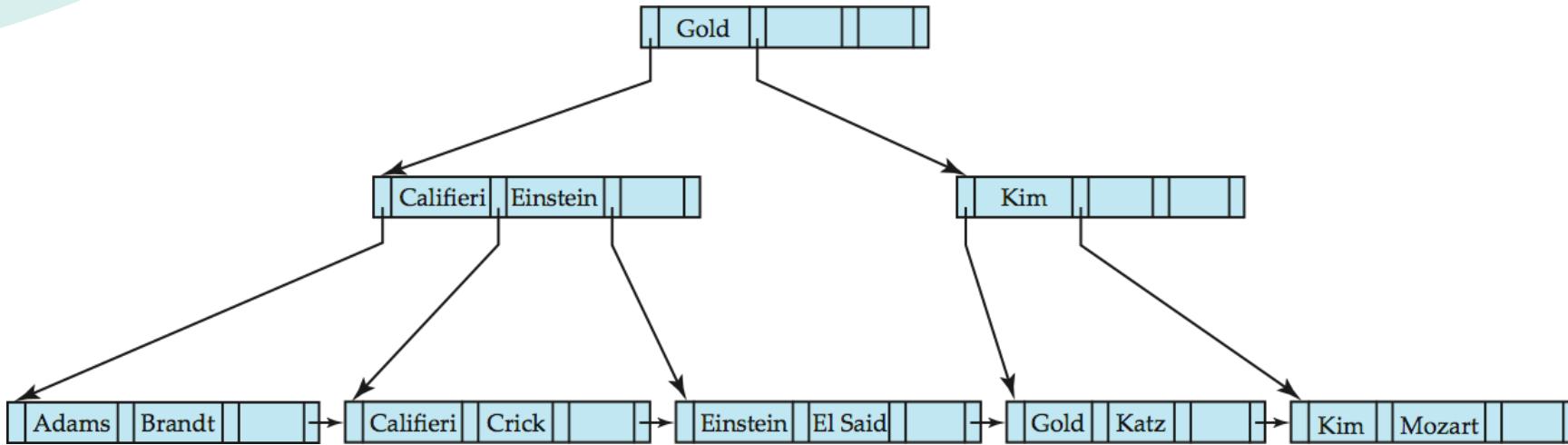


Before and after deleting “Srinivasan”



- Deleting “Srinivasan” causes merging of under-full leaves

Examples of B+-Tree Deletion (Cont.)



Deletion of “Singh” and “Wu” from result of previous example

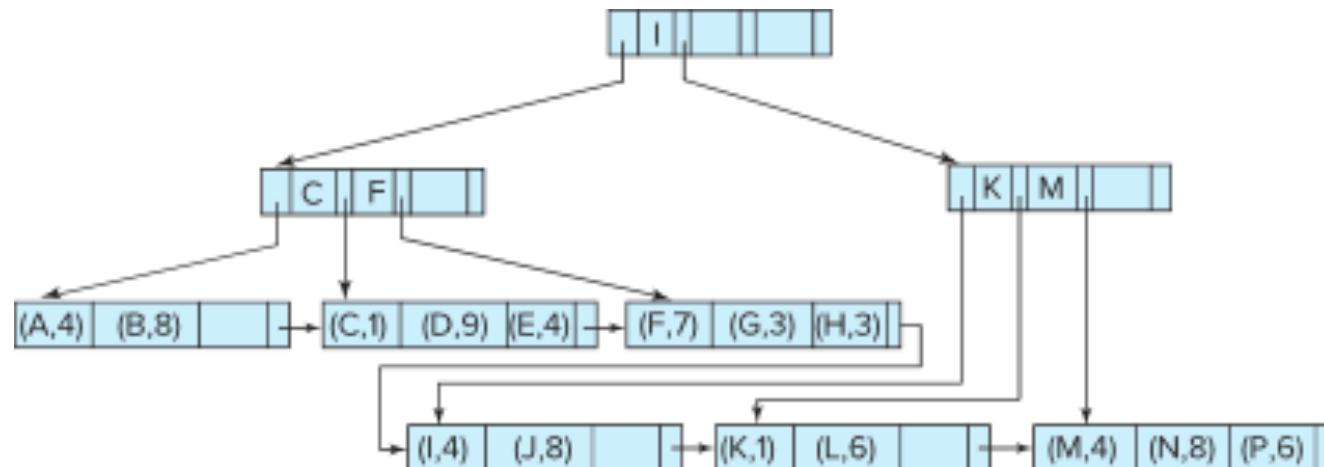
- Leaf containing Singh and Wu became underfull, and borrowed a value Kim from its left sibling
- Search-key value in the parent changes as a result

B+-Tree File Organization

- B+-Tree File Organization:
 - Leaf nodes in a B+-tree file organization store records, instead of pointers
 - Helps keep data records clustered even when there are insertions/deletions/updates
- Leaf nodes are still required to be half full
 - Since records are larger than pointers, the maximum number of records that can be stored in a leaf node is less than the number of pointers in a nonleaf node.
- Insertion and deletion are handled in the same way as insertion and deletion of entries in a B+-tree index.

B+-Tree File Organization (Cont.)

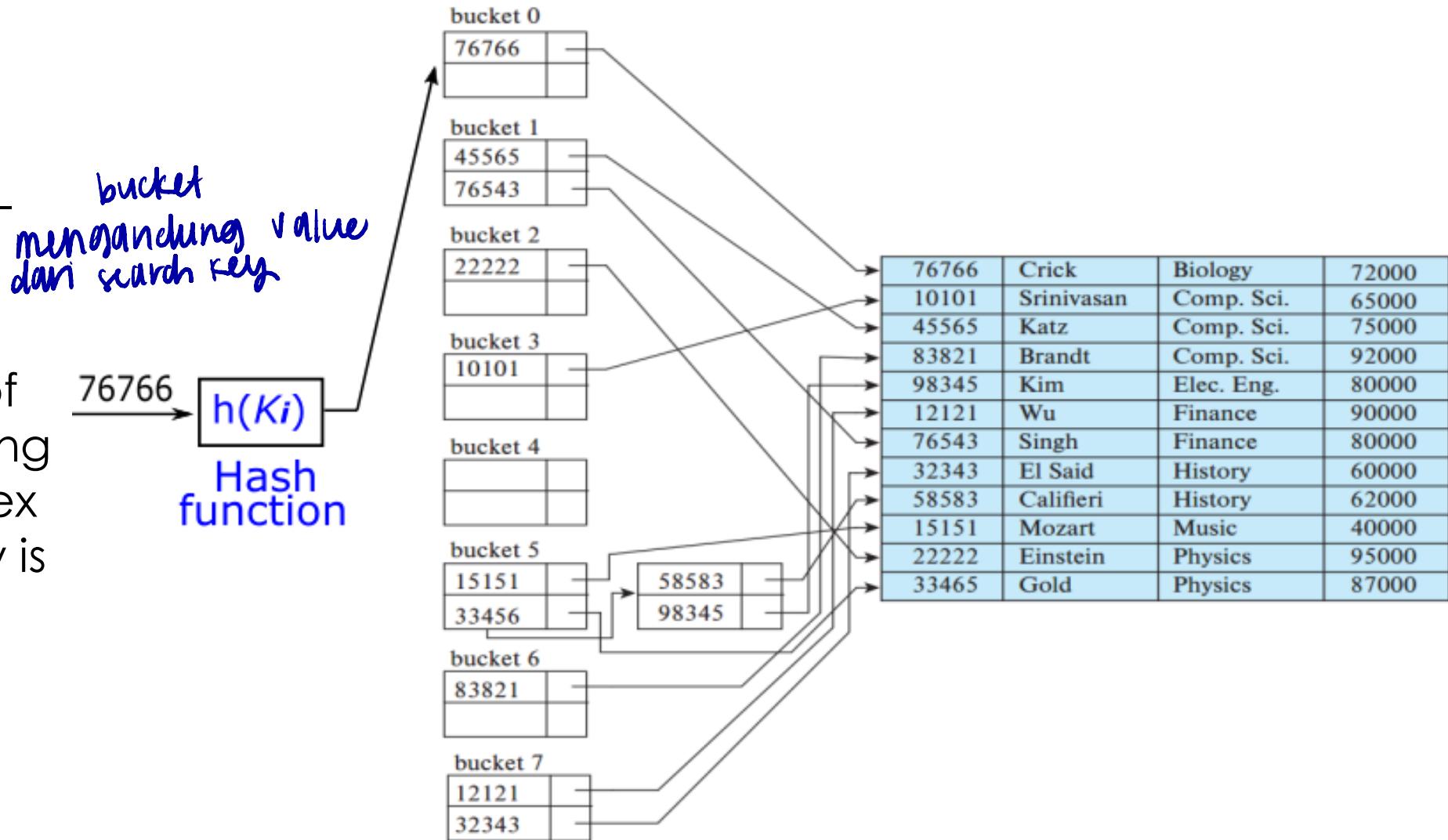
- Example of B+-tree File Organization



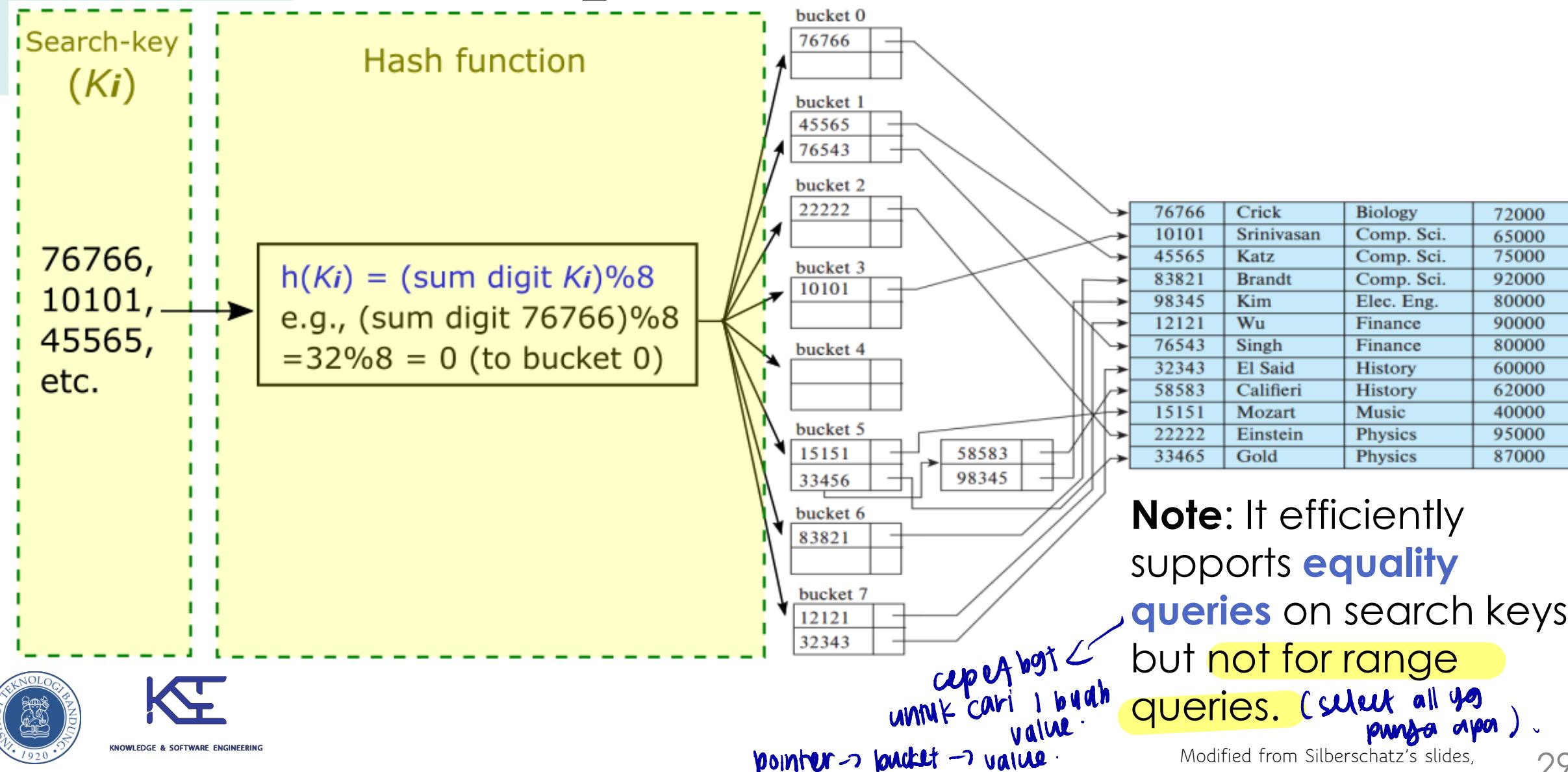
- Good space utilization important since records use more space than pointers.
- To improve space utilization, involve more sibling nodes in redistribution during splits and merges
 - Involving 2 siblings in redistribution (to avoid split / merge where possible) results in each node having at least $\lfloor 2n/3 \rfloor$ entries

Hash Index

- Hash index uses function $h(k_i)$ mapping search key value K_i to bucket.
- **Bucket** is a unit of storage containing one or more index records, typically is one block
- Bucket **contains search-key and pointer to record**

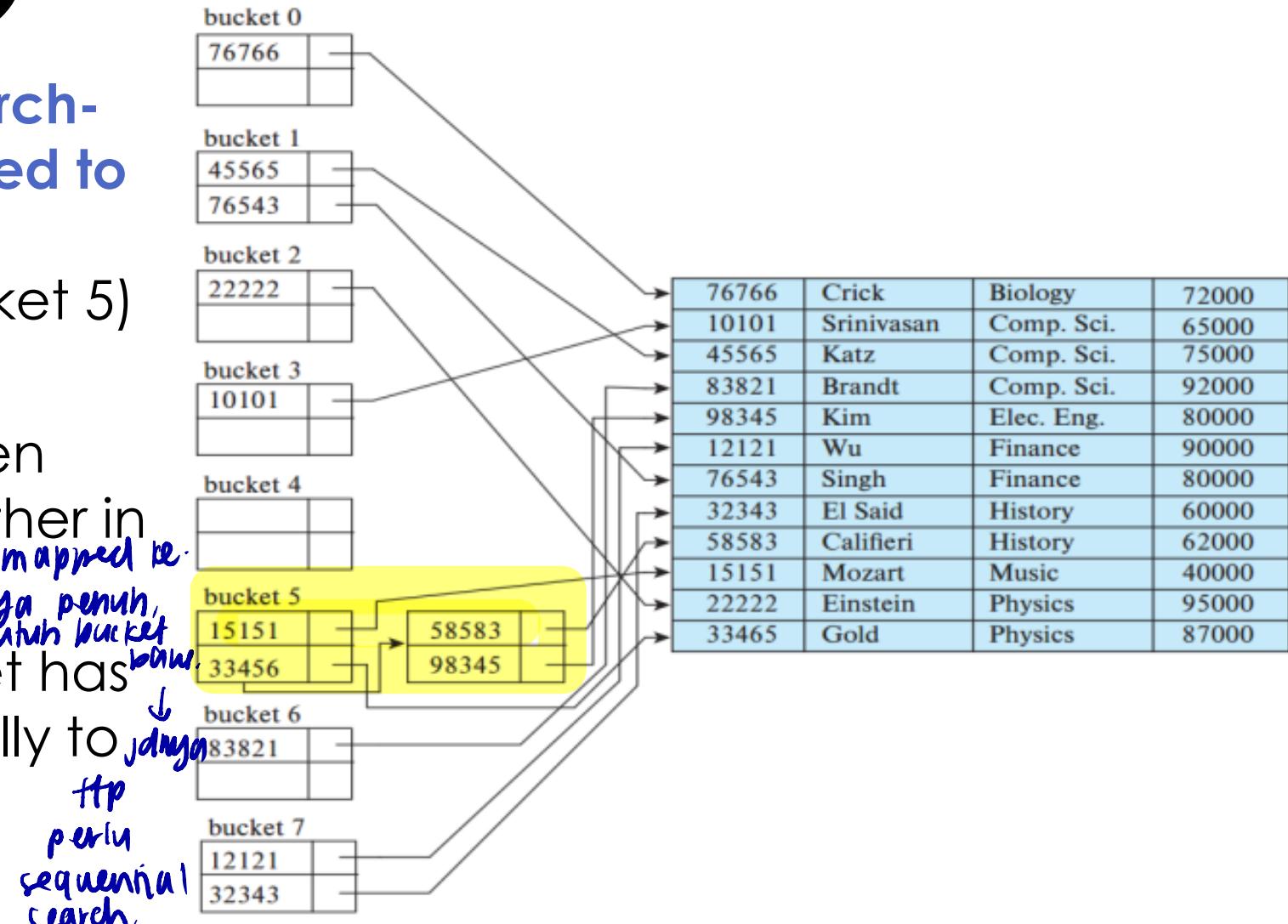


Hash Index Example



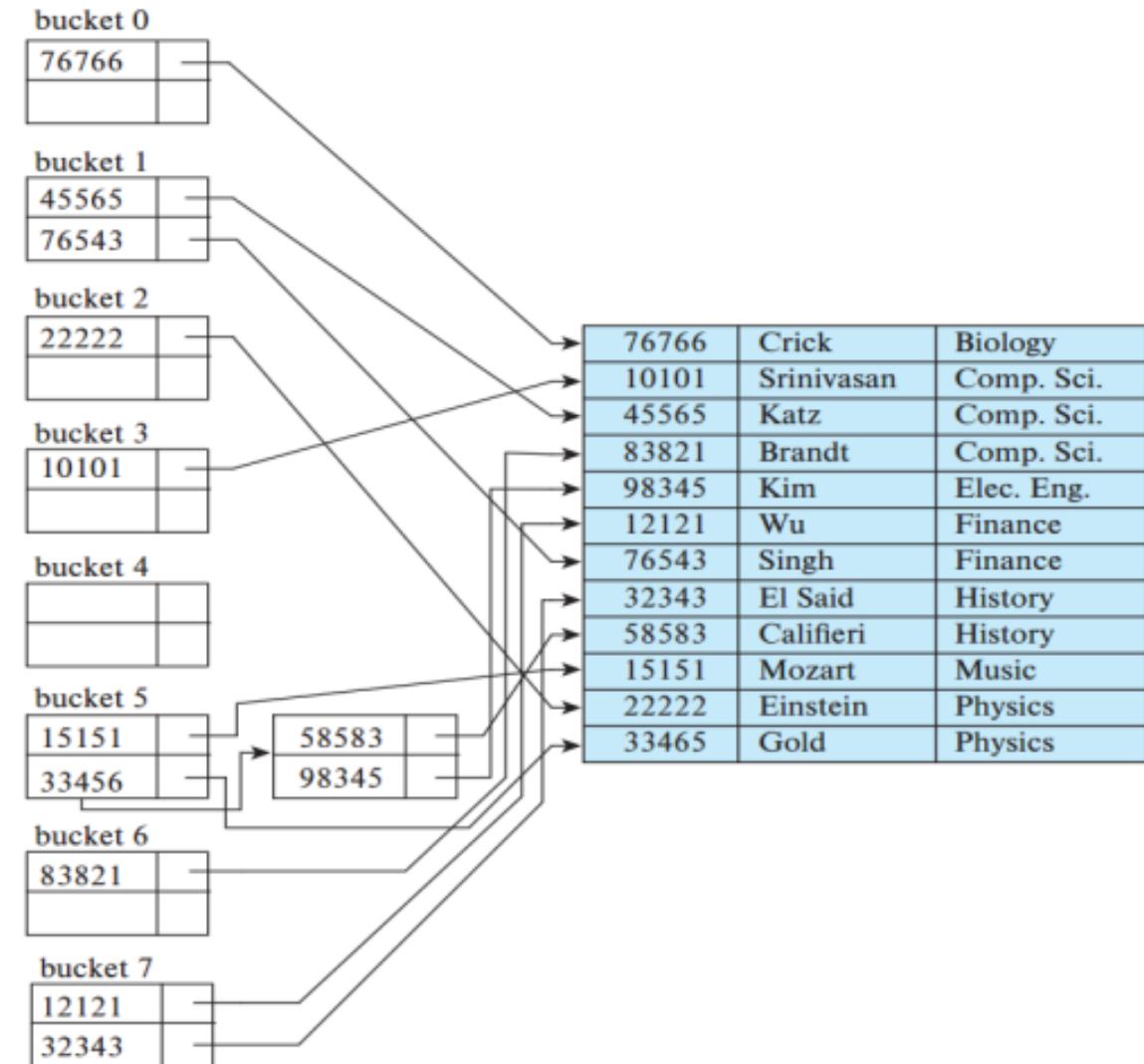
Hash Index (Cont.)

- Records with **different search-key** values may be **mapped to the same** bucket causing **overflow** bucket (see bucket 5)
- Overflow chaining** – the overflow buckets of a given bucket are chained together in a linked list.
*too many records mapped ke...
bucket dan bucket nya penuh,
butuh bucket bawah*
- In such case, entire bucket has to be searched sequentially to locate a record.



Hash Index (Cont.)

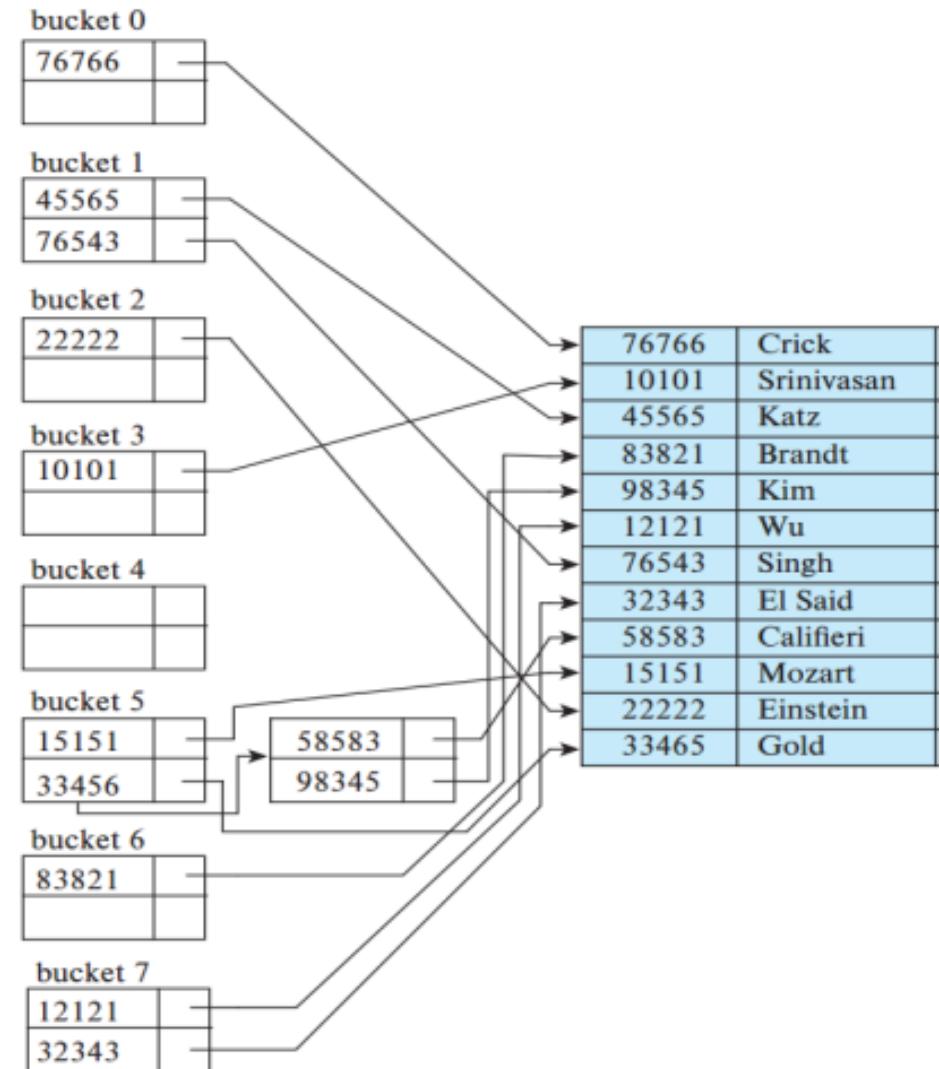
- Ideal hash function has these properties to minimize overflow bucket
 - **Uniform:** the hash function assigns each bucket the **same number** of index records
 - **Random:** each bucket will have nearly the same number of index records, **regardless of the actual distribution** of search-key values



Hash Index (Cont.)

- Type of hashing methods:
 - **Static hashing:** the set of buckets is fixed at the time the index is created → need to know how many records in advance
 - **Dynamic hashing:** the hash index can be rebuilt with an increased number of buckets

More details, read in the book



Hash File Organization

- A **bucket** is a unit of storage containing one or more records (a bucket is typically a disk block).
- In a **hash file organization** we obtain the bucket of a record directly from its search-key value using a **hash function**.
- Hash function h is a function from the set of all search-key values K to the set of all bucket addresses B .
- Hash function is used to locate records for access, insertion as well as deletion.
- Records with different search-key values may be mapped to the same bucket; thus entire bucket has to be searched sequentially to locate a record.

Example of Hash File Organization

Hash file organization of *instructor* file, using *dept_name* as key
(See figure in next slide.)

- There are 10 buckets,
- The binary representation of the i th character is assumed to be the integer i .
- The hash function returns the sum of the binary representations of the characters modulo 10
 - E.g. $h(\text{Music}) = 1 \quad h(\text{History}) = 2$
 $h(\text{Physics}) = 3 \quad h(\text{Elec. Eng.}) = 3$

Example of Hash File Organization (cont.)

bucket 0

bucket 1

15151	Mozart	Music	40000

bucket 2

32343	El Said	History	80000
58583	Califieri	History	60000

bucket 3

22222	Einstein	Physics	95000
33456	Gold	Physics	87000
98345	Kim	Elec. Eng.	80000

bucket 4

12121	Wu	Finance	90000
76543	Singh	Finance	80000

bucket 5

76766	Crick	Biology	72000

bucket 6

10101	Srinivasan	Comp. Sci.	65000
45565	Katz	Comp. Sci.	75000
83821	Brandt	Comp. Sci.	92000

bucket 7

Hash file organization of *instructor* file, using *dept_name* as key (see previous slide for details).



Bitmap Indices

→ COOK untuk
yg varietynya
dikit

- Special type of index designed for **efficient querying on multiple keys**
- Applicable on attributes having relatively **small number of distinct values**
 - E.g., gender, country, state, etc.
 - E.g., income-level (broken up into a small number of levels, such as 0-9999, 10000-19999, 20000-50000, 50000-infinity)

record number	<i>ID</i>	<i>gender</i>	<i>income_level</i>
0	76766	m	L1
1	22222	f	L2
2	12121	f	L1
3	15151	m	L4
4	58583	f	L3

	Bitmaps for <i>gender</i>	Bitmaps for <i>income_level</i>
m	10010	L1
f	01101	L2
		01000
		00001
		00010
		00000



Bitmap Indices (Cont.)

- Bitmap indices are useful for queries on **multiple attributes**
 - not particularly useful for single attribute queries
- Queries are answered using bitmap operations
 - Intersection (and)
 - Union (or)
 - Complementation (not)
 - E.g., query for **males** with income **level L1**: 10010 AND 10100 = 10000
 - Can then retrieve required tuples.
 - Counting number of matching tuples is even faster



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Index Definition in SQL

- Create an index:

create index <index-name> **on** <relation-name>(<attribute-list>)

E.g.: **create index** b-index **on** branch(branch_name)

- Use **create unique index** to indirectly specify and enforce the condition that the search key is a candidate key.
 - Not really required if SQL **unique** integrity constraint is supported
- To drop an index

drop index <index-name>

- Most database systems allow specification of type of index, and clustering.

End of Topic



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