# Database Management Systems

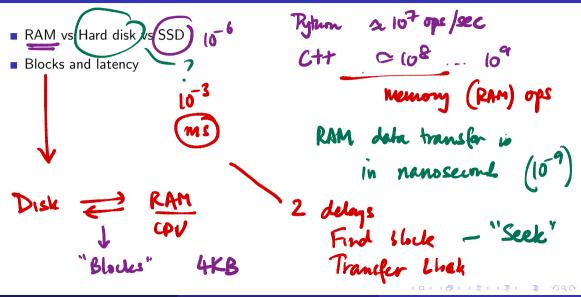
Madhavan Mukund

https://www.cmi.ac.in/~madhavan

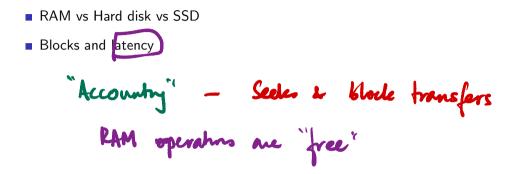
Lecture 8, 10 November 2023

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# Storing data



# Storing data



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# Fixed length records

Blocks and block boundaries

record 0	10101	Srinivasan	Comp. Sci.	65000
record 1	12121	Wu	Finance	90000
record 2	15151	Mozart	Music	40000
record 3	22222	Einstein	Physics	95000
record 4	32343	El Said	History	60000
record 5	33456	Gold	Physics	87000
record 6	45565	Katz	Comp. Sci.	75000
record 7	58583	Califieri	History	62000
record 8	76543	Singh	Finance	80000
record 9	76766	Crick	Biology	72000
record 10	83821	Brandt	Comp. Sci.	92000
record 11	98345	Kim	Elec. Eng.	80000

# Deleting a record

Delete Enstein



record 0	10101	Srinivasan	Comp. Sci.	65000
record 1	12121	Wu	Finance	90000
record 2	15151	Mozart	Music	40000
record 4	32343	El Said	History	60000
record 5	33456	Gold	Physics	87000
record 6	45565	Katz	Comp. Sci.	75000
record 7	58583	Califieri	History	62000
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record 10	83821	Brandt	Comp. Sci.	92000
record 11	98345	Kim	Elec. Eng.	80000

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# Deleting a record

Compress

Move last record

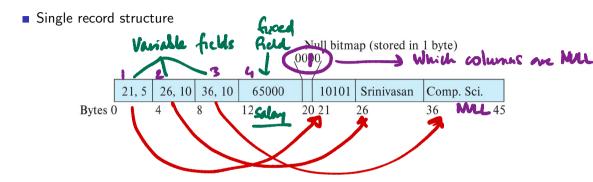
	record 0	10101	Srinivasan	Comp. Sci.	65000
	record 1	12121	Wu	Finance	90000
	record 2	15151	Mozart	Music	40000
	record 11	98345	Kim	Elec. Eng.	80000
	record 4	32343	El Said	History	60000
	record 5	33456	Gold	Physics	87000
	record 6	45565	Katz	Comp. Sci.	75000
	record 7	58583	Califieri	History	62000
<b>\</b>	record 8	76543	Singh	Finance	80000
<b>\</b>	record 9	76766	Crick	Biology	72000
	record 10	83821	Brandt	Comp. Sci.	92000

# Deleting a record

- Compress
- Move last record
- Maintain free list of empty slots

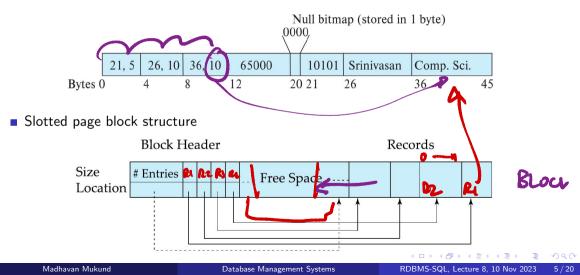
header					
record 0	10101	Srinivasan	Comp. Sci.	65000	$\geq$
record 1					
record 2	15151	Mozart	Music	40000	
record 3	22222	Einstein	Physics	95000	
record 4					
record 5	33456	Gold	Physics	87000	
record 6				4	
record 7	58583	Califieri	History	62000	
record 8	76543	Singh	Finance	80000	
record 9	76766	Crick	Biology	72000	
record 10	83821	Brandt	Comp. Sci.	92000	
record 11	98345	Kim	Elec. Eng.	80000	

# Variable length records



# Variable length records

Single record structure



# Storing tables — heap file organization

Use first available free slot

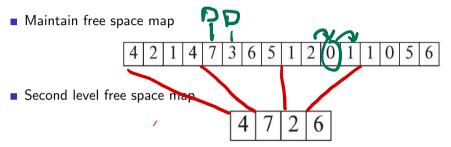
# Storing tables — heap file organization

- Use first available free slot
- Maintain free space map

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# Storing tables — heap file organization

Use first available free slot



# Storing tables — sequential file organization

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

#### Overflow block

		0		
10101	Srinivasan	Comp. Sci.	65000	
12121	Wu	Finance	90000	$ \leq $
15151	Mozart	Music	40000	
22222	Einstein	Physics	95000	
32343	El Said	History	60000	5
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	$ \prec$
98345	Kim	Elec. Eng.	80000	
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32222	Verdi	Music	48000	



• Why build an index?

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# Indexing

Why build an index?

## Search key

- As opposed to superkey, candidate key, ...
- May need multiple search keys for a table

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# Indexing

Why build an index?

## Search key

- As opposed to superkey, candidate key, ...
- May need multiple search keys for a table
- Types of queries point vs range
  - ID = "10102"
  - **salary** > 75000

-

# Indexing

Why build an index?

## Search key

- As opposed to superkey, candidate key, ...
- May need multiple search keys for a table
- Types of queries point vs range
  - ID = "10102"
  - salary > 75000
- Maintaining an index
  - Inserts, deletes
  - Space

# Clustering index

- File is ordered with respect to index values
- Index sequential file

Madhavan Mukund

Dense index — every value is present in the index

10101	-	<b>—</b>	10101	Srinivasan	Comp. Sci.	65000	
12121	-		12121	Wu	Finance	90000	$\leq$
15151	-		15151	Mozart	Music	40000	$\leq$
22222	-		22222	Einstein	Physics	95000	$ \leq$
32343	-		32343	El Said	History	60000	$\prec$
33456	1		33456	Gold	Physics	87000	K
45565	-		45565	Katz	Comp. Sci.	75000	-
58583	1-		58583	Califieri	History	62000	$\prec$
76543	-	<b>&gt;</b>	76543	Singh	Finance	80000	-
76766	-	<b>&gt;</b>	76766	Crick	Biology	72000	-
83821	-		83821	Brandt	Comp. Sci.	92000	-
98345	-		98345	Kim	Elec. Eng.	80000	

r to blocks

- File is ordered with respect to index values
- Index sequential file
- Dense index every value is present in the index
  - Index value may match multiple records

					Sortes	)	
Biology	-		76766	Crick	Biology	72000	
Comp. Sci.	-	<b>→</b>	10101	Srinivasan	Comp. Sci.	65000	-
Elec. Eng.	~		45565	Katz	Comp. Sci.	75000	$\prec$
Finance	~	$\searrow$	83821	Brandt	Comp. Sci.	92000	$\checkmark$
History		1	98345	Kim	Elec. Eng.	80000	$\sim$
Music	$\backslash$		12121	Wu	Finance	90000	
Physics	1		76543	Singh	Finance	80000	$\sim$
	/	1 >	32343	El Said	History	60000	
		$\backslash \backslash$	58583	Califieri	History	62000	$\sim$
		$\langle \rangle$	15151	Mozart	Musie	40000	
		$\searrow$	22222	Einstein	Physics	95000	
			33465	Gold	Physics	87000	~
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# Indexing — sparse indices

- Maintain indices for a subset of values
  - Page headers in a dictionary



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#### Database Management Systems

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# Indexing — sparse indices

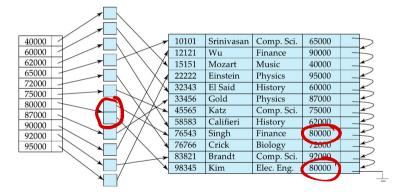
- Maintain indices for a subset of values
  - Page headers in a dictionary
- Align to block boundaries
  - Records are still sequential with respect to index
  - Sparse index identifies first record in each block

10101	10101	Srinivasan	Comp. Sci.	65000	
32343	12121	Wu	Finance	90000	
76766	15151	Mozart	Music	40000	$\sim$
	22222	Einstein	Physics	95000	_
	32343	El Said	History	60000	$\sim$
$\backslash$	33456	Gold	Physics	87000	$\sim$
$\backslash$	45565	Katz	Comp. Sci.	75000	$\sim$
$\backslash$	58583	Califieri	History	62000	-
$\backslash$	76543	Singh	Finance	80000	
×	76766	Crick	Biology	72000	
	83821	Brandt	Comp. Sci.	92000	
	98345	Kim	Elec. Eng.	80000	
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# Indexing — secondary index

 Index for an attribute that does not match sequence in which table is stored

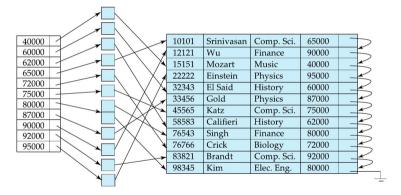


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# Indexing — secondary index

- Index for an attribute that does not match sequence in which table is stored
- Key points to block that contains pointers to matching records
  - Can have multiple records for same search key





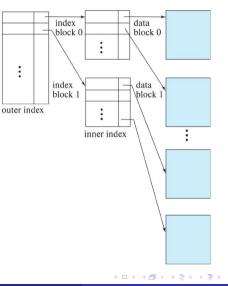
 Typically, index will not fit in RAM

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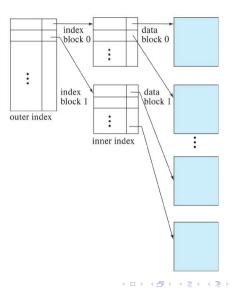


- Typically, index will not fit in RAM
- Store index as a sequential file
  - Build a sparse index for the index file
  - Multi-level, till sparse index fits in one block



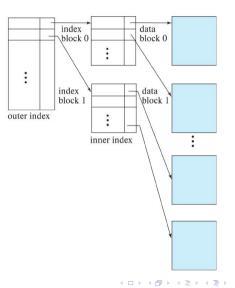


- Typically, index will not fit in RAM
- Store index as a sequential file
  - Build a sparse index for the index file
  - Multi-level, till sparse index fits in one block
- Binary search to find required key





- Typically, index will not fit in RAM
- Store index as a sequential file
  - Build a sparse index for the index file
  - Multi-level, till sparse index fits in one block
- Binary search to find required key
- Idea leads to a more efficient structure



- Binary search trees
  - Binary search on dynamic data
  - Balanced tree has logarithmic height



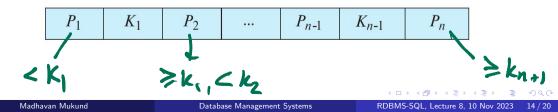
# Node size = 1 block

#### Binary search trees

- Binary search on dynamic data
- Balanced tree has logarithmic height
- Block-based access
  - Binary tree node has one search key value, two pointers
  - Block can hold much more

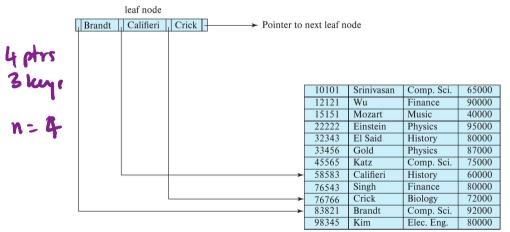
- Binary search trees
  - Binary search on dynamic data
  - Balanced tree has logarithmic height
- Block-based access
  - Binary tree node has one search key value, two pointers
  - Block can hold much more
- Generalize to multiple key values, multiple pointers





# B+ trees

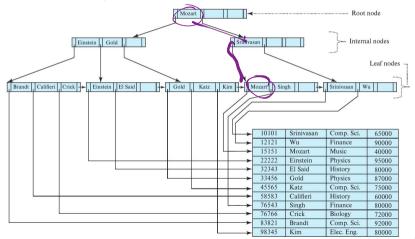
Leaf nodes form a dense index — linked list of leaves, each one block



instructor file

# B+ trees

- Leaf nodes form a dense index linked list of leaves
- Non-Leaf nodes form a sparse index

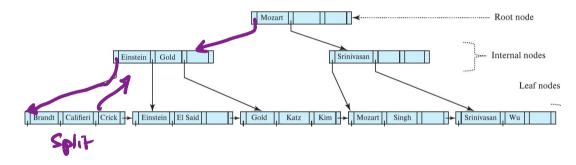


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- Leaf nodes form a dense index linked list of leaves
- Non-leaf nodes form a sparse index
- Constraints assume *n* keys and pointers can fit in a block
  - Each leaf has at least  $\lceil (n-1)/2 \rceil$  key values
  - Each non-leaf has at least  $\lceil n/2 \rceil$  pointers
  - Height of the tree is proportional to  $\log_{n/2}(n)$

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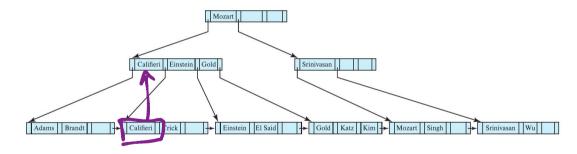
Insert Adams



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Insert Adams

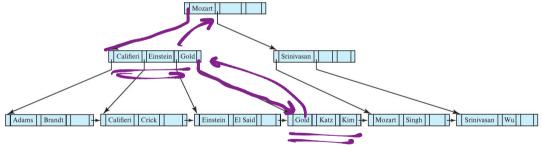


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Insert Adams

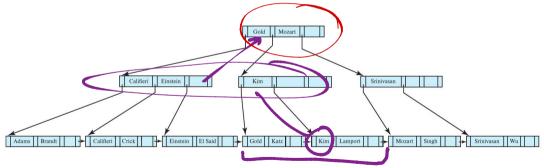


Insert Lamport

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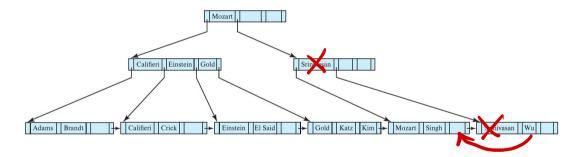
- Insert Adams
- Insert Lamport



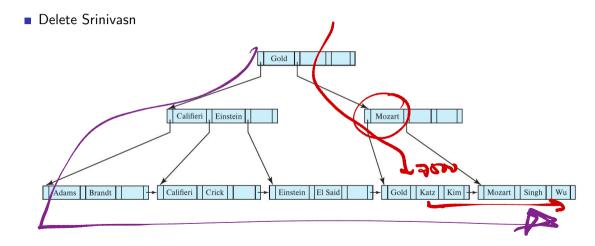
- Insert Adams
- Insert Lamport
- Recursively insert from leaf level upwards
  - Split nodes when needed and adjust search keys and pointers

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Delete Srinivasn 



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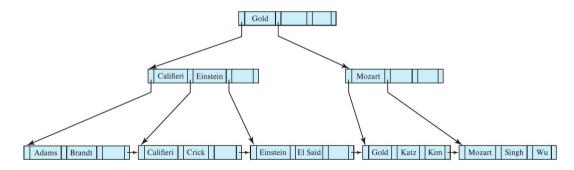
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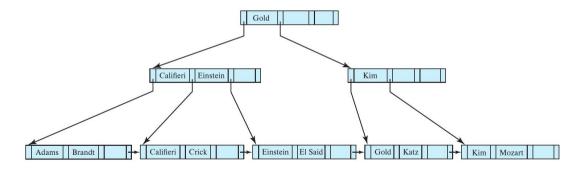
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Delete Srinivasn 



Delete Singh and Wu

- Delete Srinivasn
- Delete Singh and Wu



- Delete Srinivasn
- Delete Singh and Wu
- Recursively delete from leaf level upwards
  - Merge or redistribute with neighbour