COMP 3311
DATABASE MANAGEMENT SYSTEMS

TUTORIAL 6
INDEXING

INDEX: REVIEW

Clustering index
An index in which the records in the file are ordered (sequentially) by the search-key values. Primary index if search key=primary key.

Non-clustering index (secondary index)
An index in which the records in the file are not ordered by the search-key values.

Sparse Index: One index entry for many records; only applies to a clustering index.

Dense index: One index entry for each record in the file.

Single-level Index: Each index entry points to records.

Multilevel Index: An index entry points to another index entry except for the bottom level, which points to records.

EXERCISE 1

Assume that a school keeps the following file with the records of its students:

Student(studentId: 4 bytes, name: 10 bytes, deptId: 4 bytes)

where deptId is the department id to which a student belongs.

There exist 10,000 student records and 50 departments.

A page is 128 bytes and a pointer is 4 bytes.

The data file is sorted sequentially on studentId.

Record size: 18 bytes

$\boldsymbol{bf_{Student}}$: $\lfloor$128 bytes per page / 18 bytes per record$\rfloor$ = 7 records/page

Pages needed: $\lceil$10,000 records / 7 records per page$\rceil$ = 1429

EXERCISE 1 (CONT'D)

Student records: 10,000
Departments: 50
Page size: 128 bytes
Pointer size: 4 bytes
Record size: 18 bytes
$bf_{Student}$: 7 records/page
Pages: 1429

a) **Given the data file only, what is the cost of finding students in a particular department (e.g., CSE)?**

Search cost: 1429 page I/Os **Why?**

The records are sorted on studentId, instead of deptId. Thus, the only way to answer the query is to sequentially scan the file.

b) **How can we reduce the cost of this search?**

Build an ordered, single-level index on deptId.

Index entry size: 8 bytes **Why?**

Each index entry is of the form (deptId, *pointer*) and requires 4 bytes for deptId and 4 bytes for the pointer.

$bf_{deptIdindex}$: $\lfloor$128 bytes per page / 8 bytes per record$\rfloor$
= 16 index entries/page

EXERCISE 1 (CONT'D)

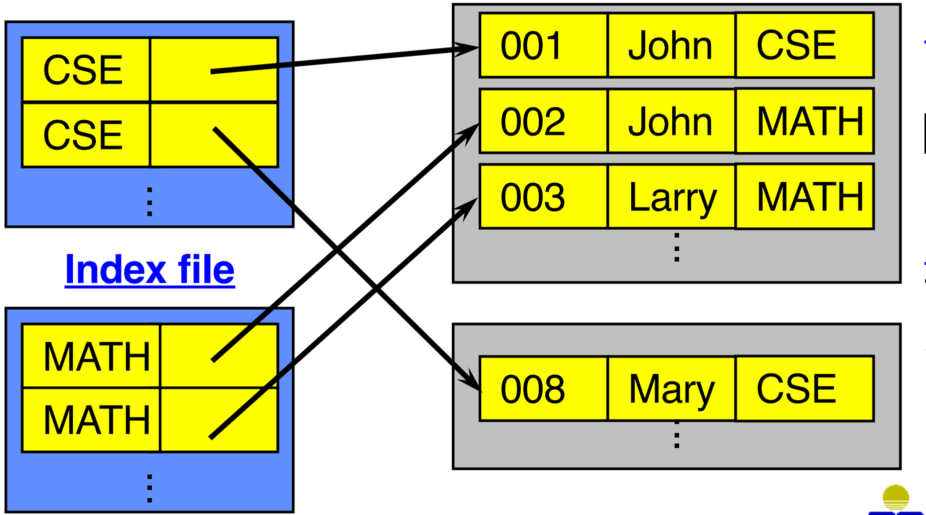
Student records: 10,000
Departments: 50
Page size: 128 bytes
Pointer size: 4 bytes
Record size: 18 bytes
$bf_{Student}$: 7 records/page
Pages: 1429

For simplicity, we assume each department has exactly 10,000 students/50 departments = 200 students and *a page can only contain index entries for students in the same department*.

i. Build an ordered, single-level index.

Index pages: $\lceil$(200 students per dept / 16 index entries per page)$\rceil$ * 50 departments = 650 (13 index pages per department)

Index search cost: $\lceil \log_2 650 \rceil$ (to find the first index page) + 12 additional index pages = 22 page I/Os



Data file

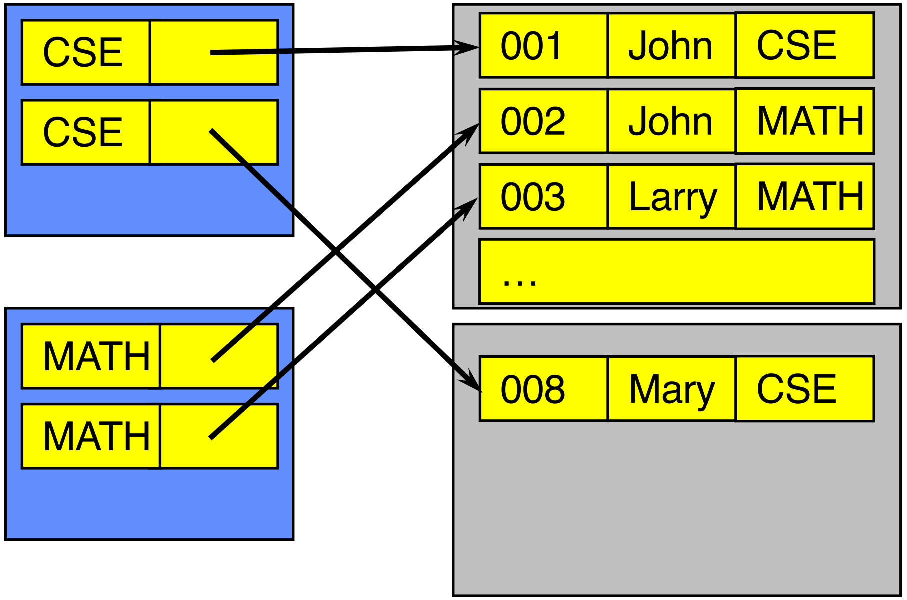
Pages needed:
$\lceil$(10,000 records / 7 records per page)$\rceil$ = 1429

Data file search cost:
200 page I/Os **Why?**
The file is not ordered by deptId. Thus, for each student we may need to access one page.

EXERCISE 1 (CONT'D)

Student records: 10,000
Departments: 50
Page size: 128 bytes
Pointer size: 4 bytes
Record size: 18 bytes
$bf_{Student}$: 7 records/page
Pages: 1429

ii. Build an ordered, single-level index.



Primary index or secondary index?
Secondary index.

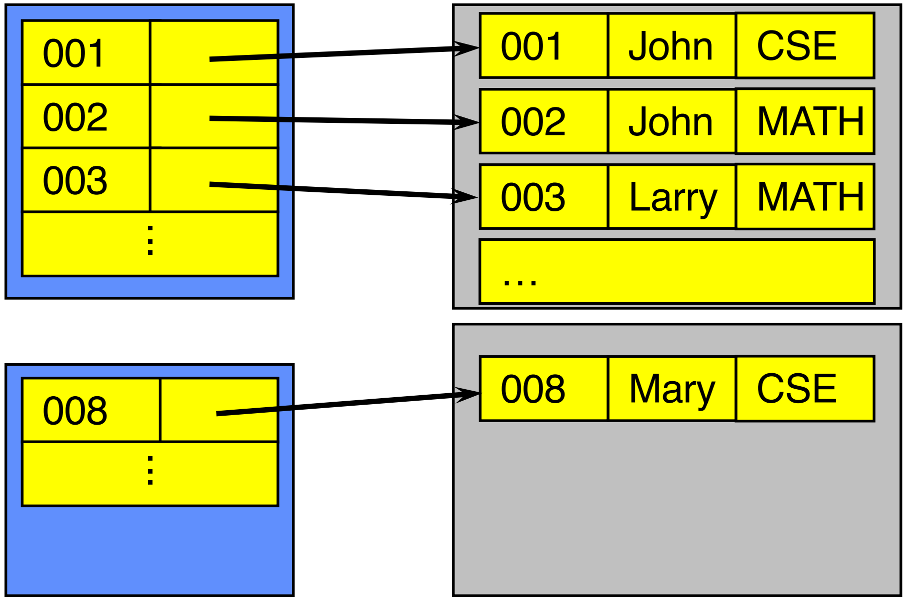
Dense index or sparse index?
Dense index. Why?

A secondary index must be a dense index.

EXERCISE 1 (CONT'D)

iii. Build an ordered, single-level index.

Suppose we create an index as shown below.



Primary index or secondary index?
Primary index.

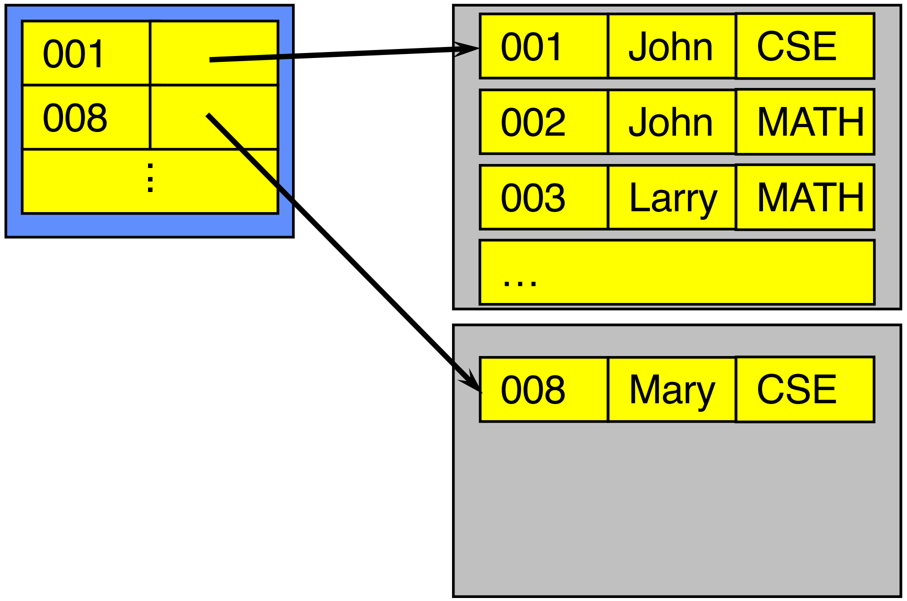
Dense index or sparse index?
Dense index.

EXERCISE 1 (CONT'D)

Student records: 10,000
Departments: 50
Page size: 128 bytes
Pointer size: 4 bytes
Record size: 18 bytes
$bf_{Student}$: 7 records/page
Pages: 1429

iv. Build an ordered, single-level index.

Suppose we create an index as shown below.



Primary index or secondary index?
Primary index.

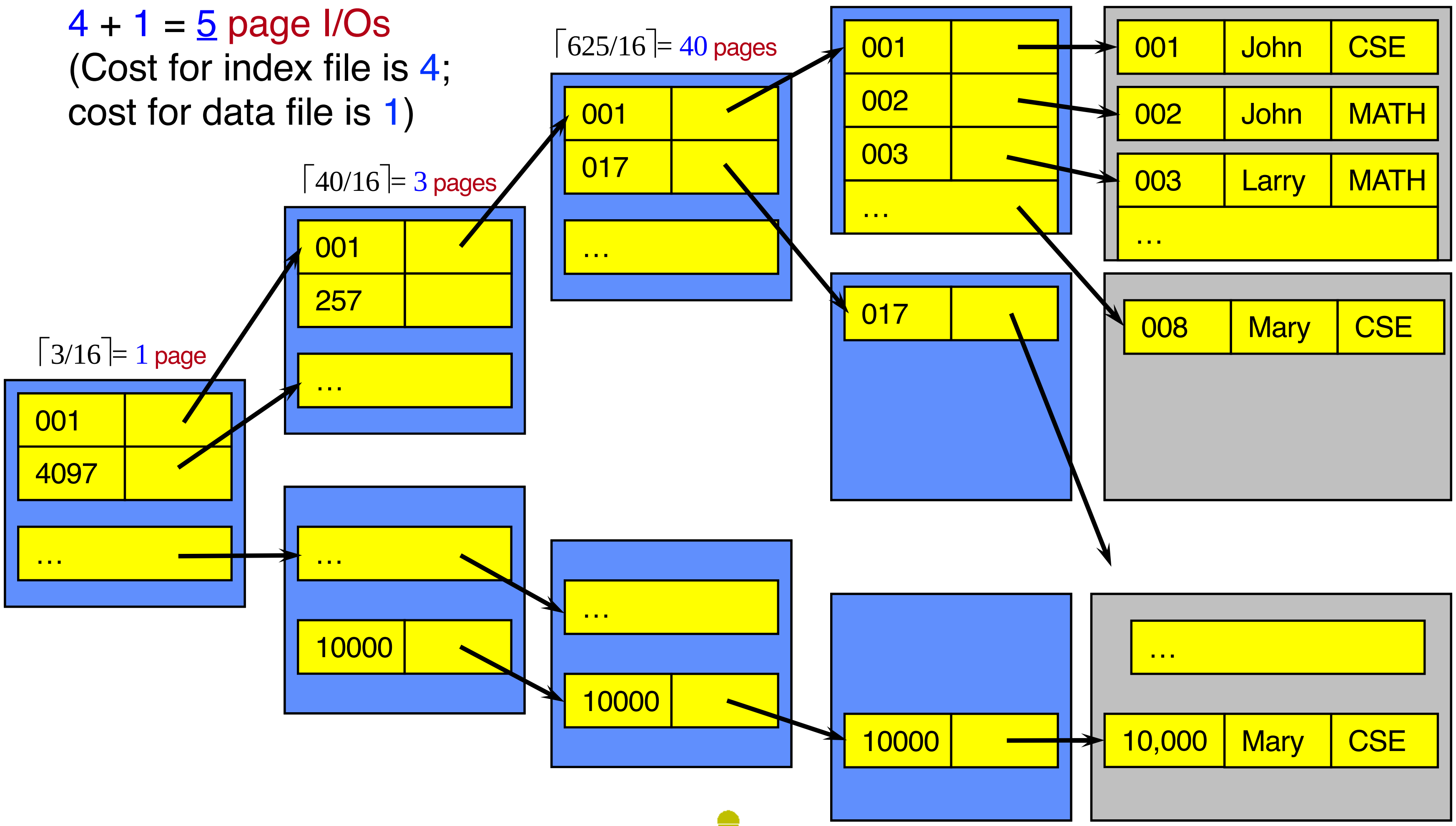
Dense index or sparse index?
Sparse index.

EXERCISE 1 (CONT'D)

Student records: 10,000	
Departments: 50	
Page size: 128 bytes	
Pointer size: 4 bytes	
Record size: 18 bytes	
$bf_{Student}$: 7 records/page	
Pages: 1429	

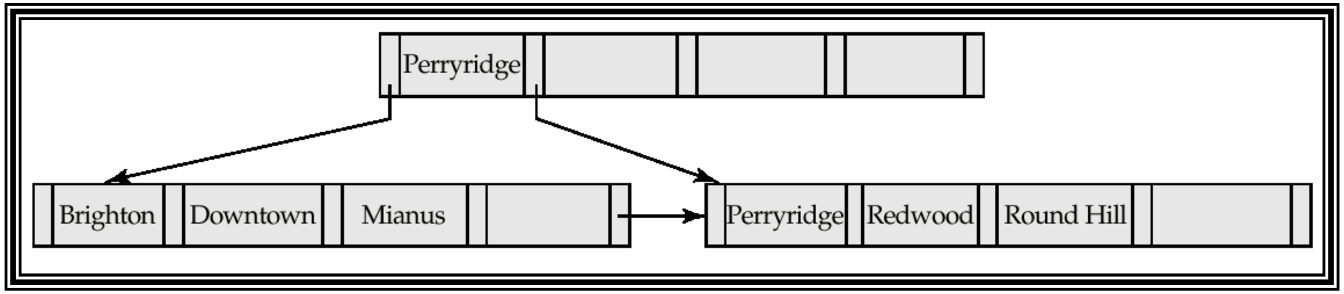
c) **Assume the main memory size is only one page. What is the cost to look up a particular student using this index?**

4 + 1 = 5 page I/Os
(Cost for index file is 4;
cost for data file is 1)



REVIEW: B+-TREE INDEX

- A balanced tree.
- Use pointers to access records; no need for sequential storage.
- The height of the tree is in logarithmic order.
- Space overhead – additional space is needed for the index.
- Insertion and deletion overhead. However, can be handled in logarithmic time.



REVIEW: EXTENDABLE HASHING

- Allows the number of buckets to be modified dynamically.
- If insert of data entry is to a full bucket, split it.
  - If necessary, double the directory.
  - Before inserting, local depth of bucket = global depth.
  - Insert causes local depth > global depth.
- If removal of data entry makes bucket empty, merge with its "split image".
  - Each directory entry points to the same bucket as its split image.
  - If necessary, halve the directory.

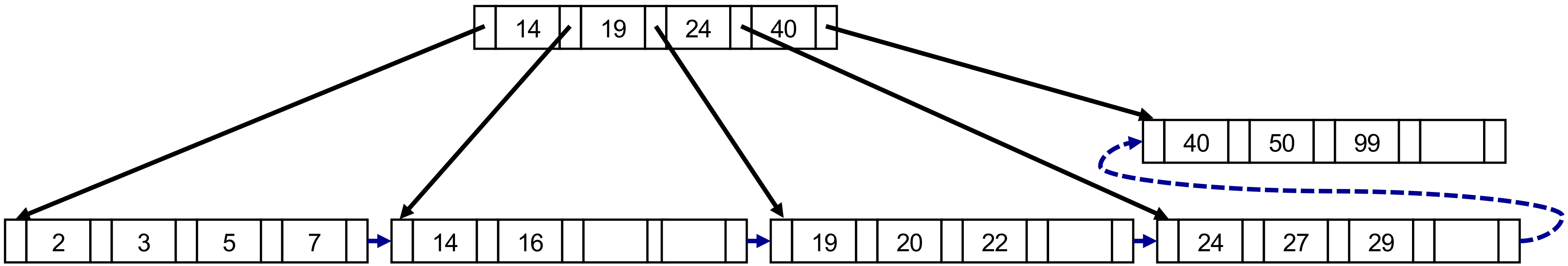
EXERCISE 2

For the B$^+$-tree shown below, show the tree that would result after *successively* applying the following operations.

i. insert 8

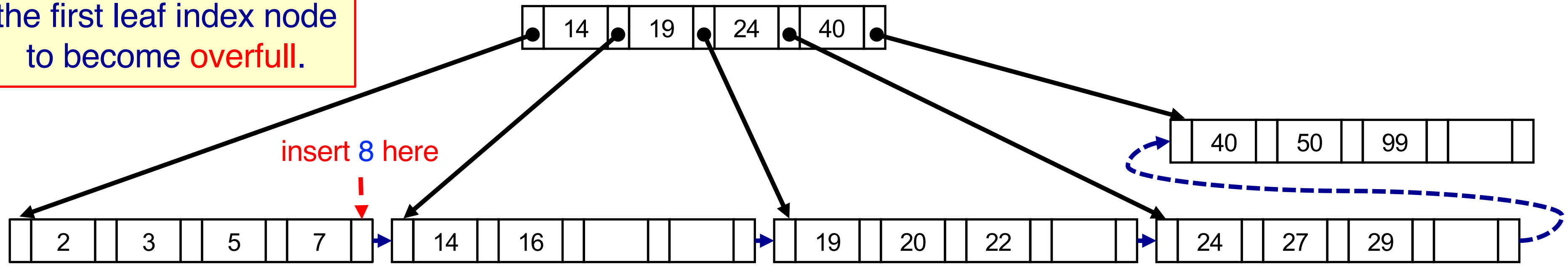
ii. delete 2

iii. delete 3



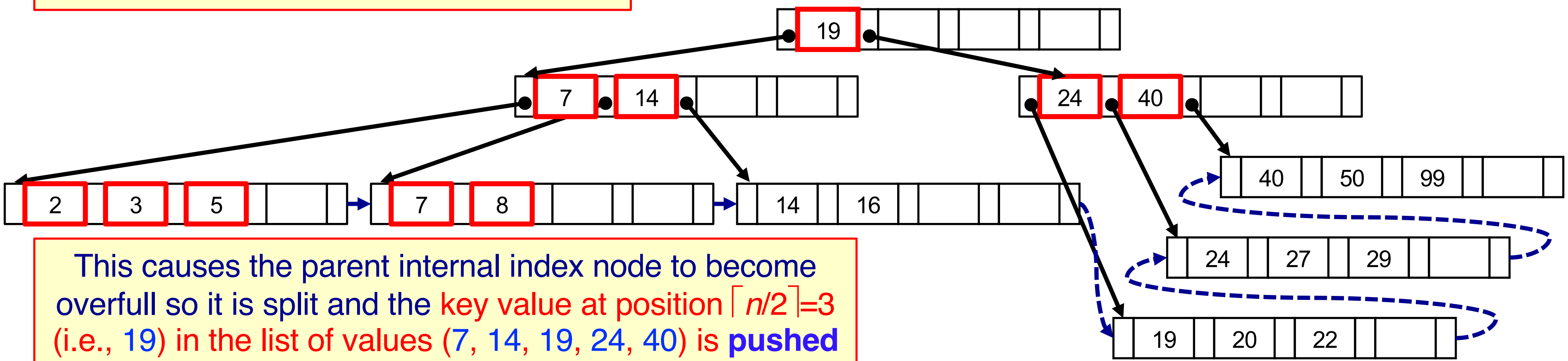
EXERCISE 2 (CONT'D)

The insertion causes the first leaf index node to become overfull.



Insert 8

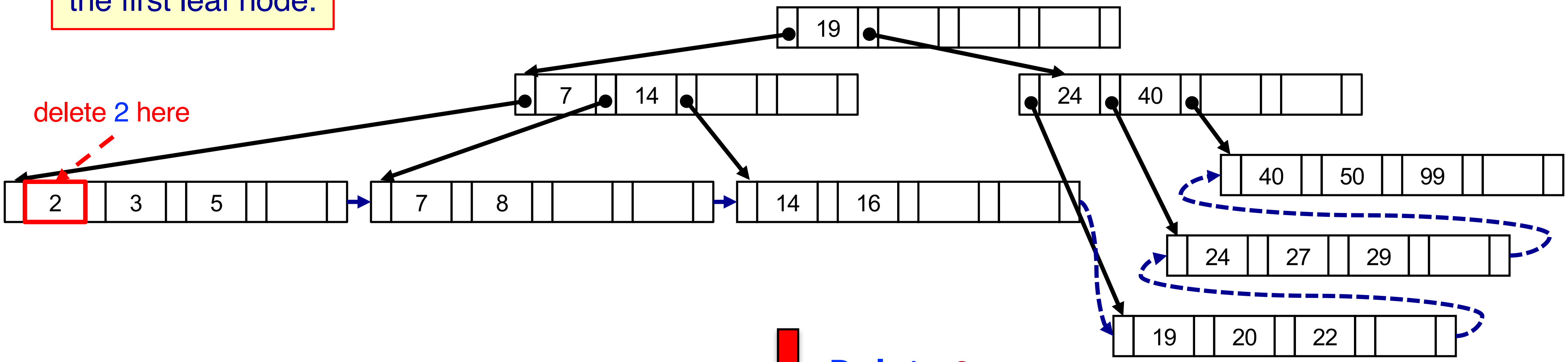
The leaf index node is split and the key value at position ⌈$n/2$⌉+1=4 (i.e., 7) of the list of values (2, 3, 5, 7, 8) is **copied up** to the parent internal index node.



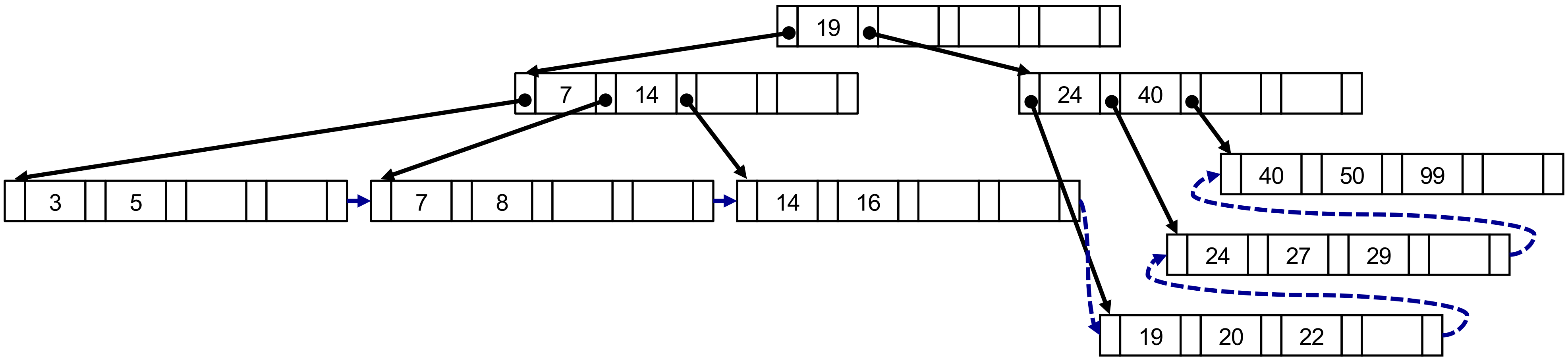
This causes the parent internal index node to become overfull so it is split and the key value at position ⌈$n/2$⌉=3 (i.e., 19) in the list of values (7, 14, 19, 24, 40) is **pushed up** to the new parent (root) internal index node.

EXERCISE 2 (CONT'D)

2 is deleted from the first leaf node.

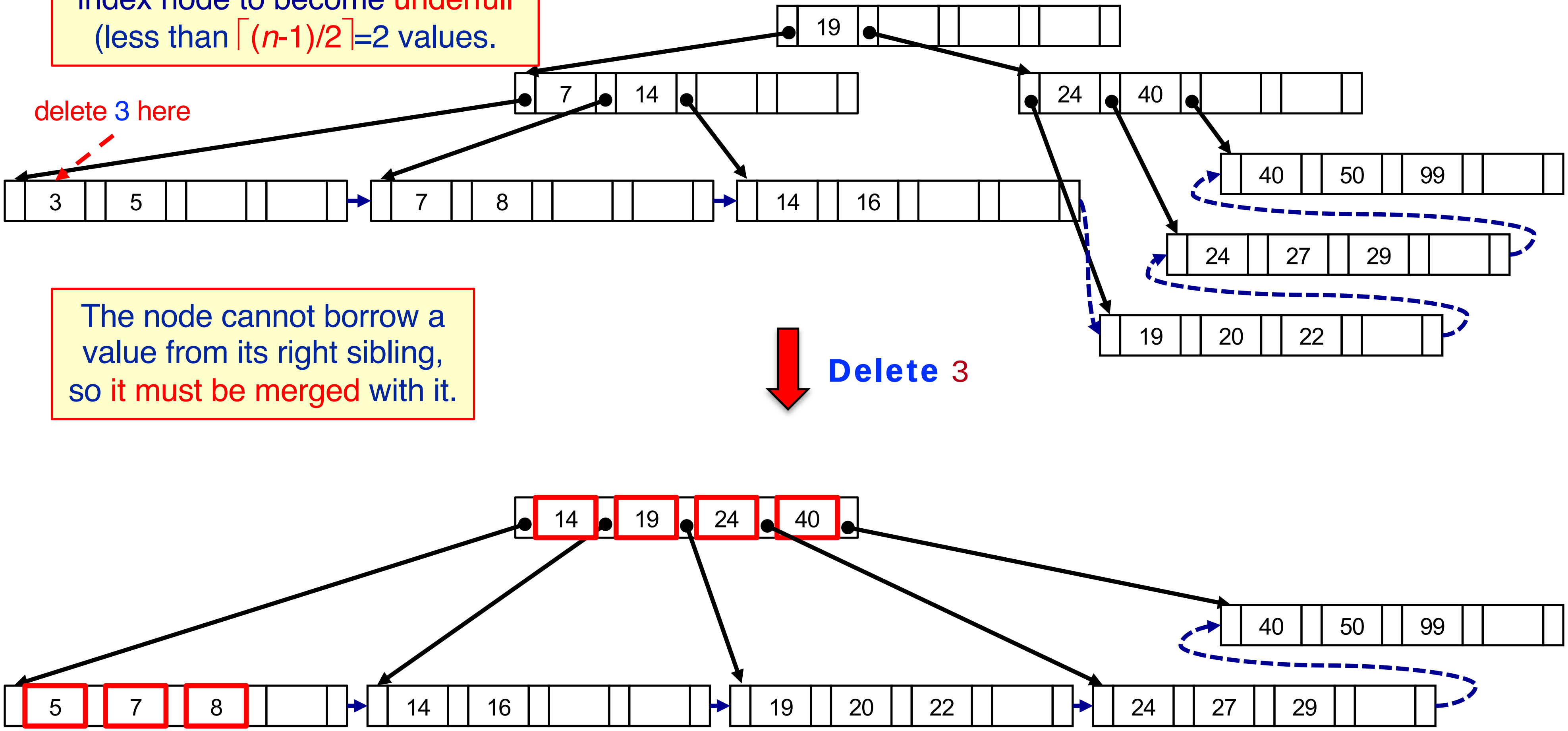


Delete 2



EXERCISE 2 (CONT'D)

The deletion causes the first leaf index node to become underfull (less than ⌈(*n*-1)/2⌉=2 values.



The node cannot borrow a value from its right sibling, so it must be merged with it.

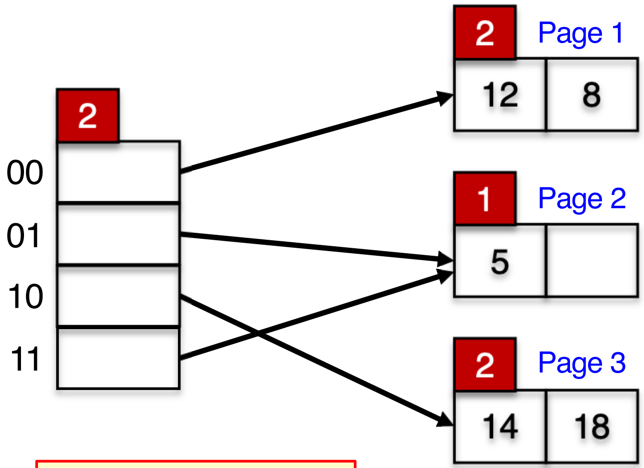
This causes the parent internal index node to now have only 2 pointers, but it needs 3. Therefore, it is merged with its sibling and the index values adjusted.

The merge of the internal index nodes causes the root index node to now have only 1 pointer, so it is merged with the internal index node below it and the tree shrinks one level.

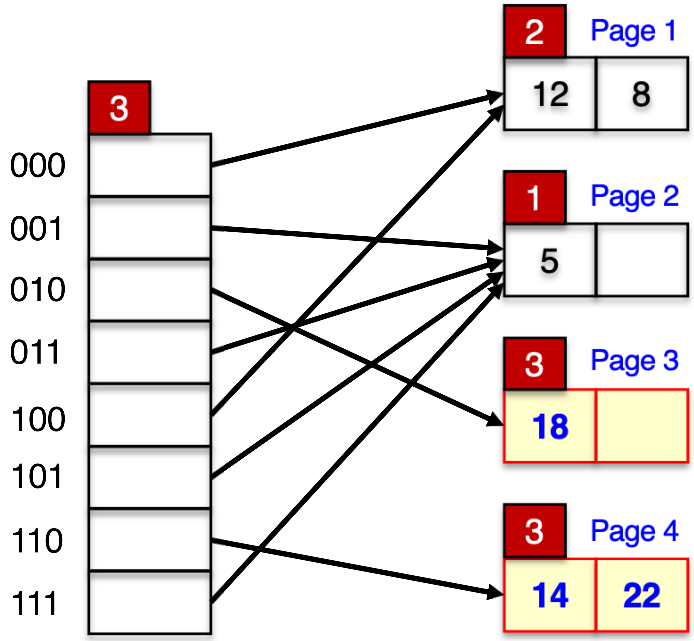
EXERCISE 3

For the directory and buckets shown below, use extendable hashing and show what the directory and buckets would be after the following operations.

Insert 22 (0001 0110)



← insert 22 here
⇒ split bucket;
double directory



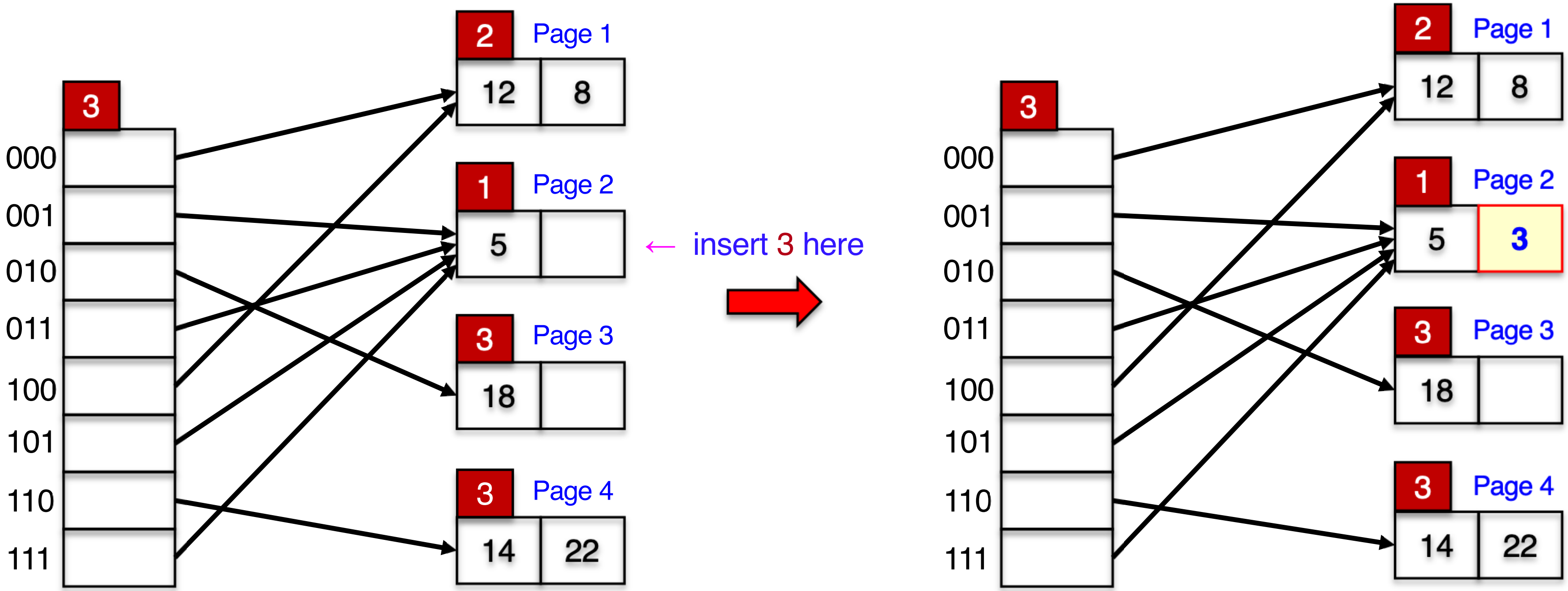
Hash values

8	(0000 1000)
5	(0000 0101)
12	(0000 1100)
14	(0000 1110)
18	(0001 0010)

Page 4 is a "split image" of Page 3.

EXERCISE 3 (CONT'D)

Insert 3 (0000 0011)

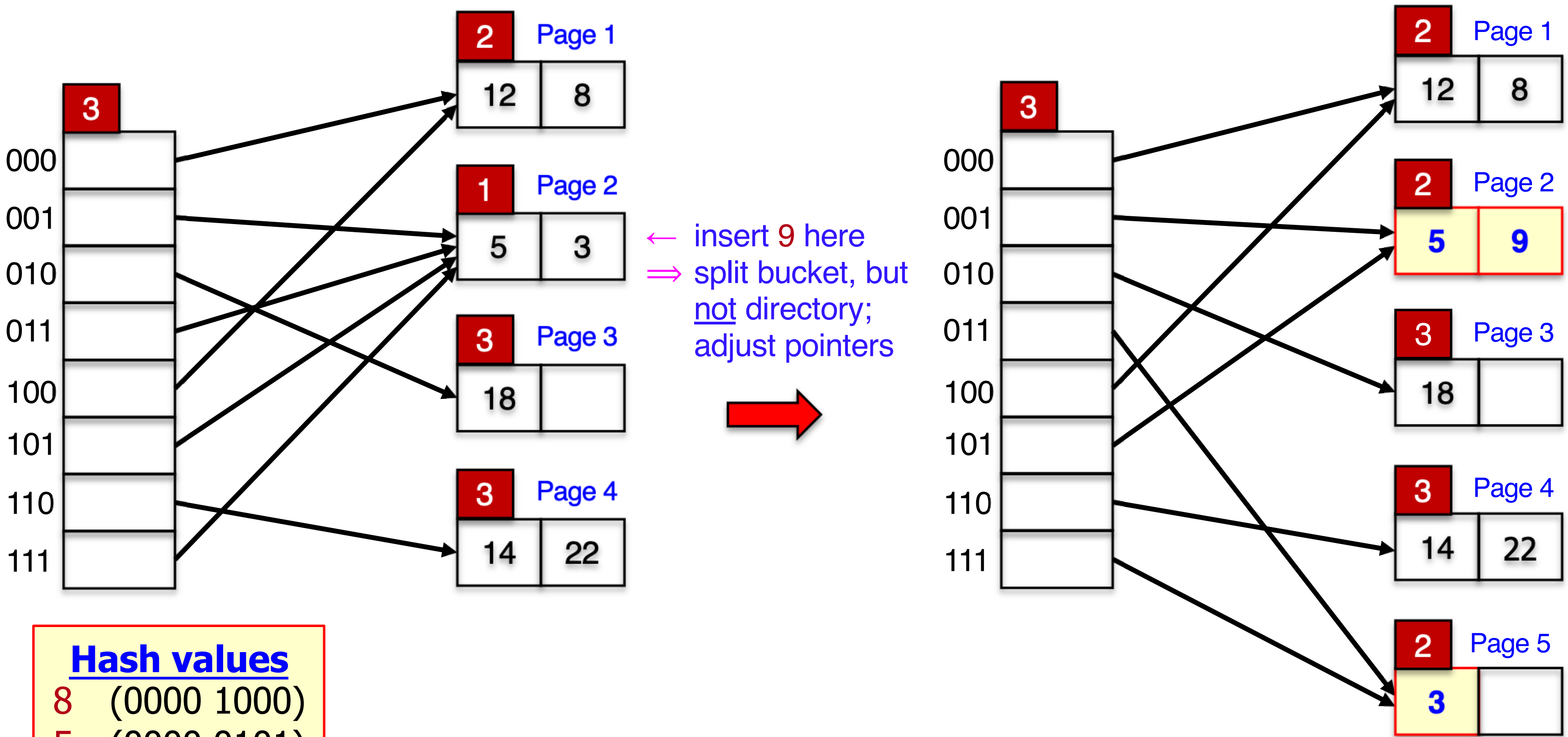


Hash values

8 (0000 1000)
5 (0000 0101)
12 (0000 1100)
14 (0000 1110)
18 (0001 0010)

EXERCISE 3 (CONT'D)

Insert 9 (0000 1001)

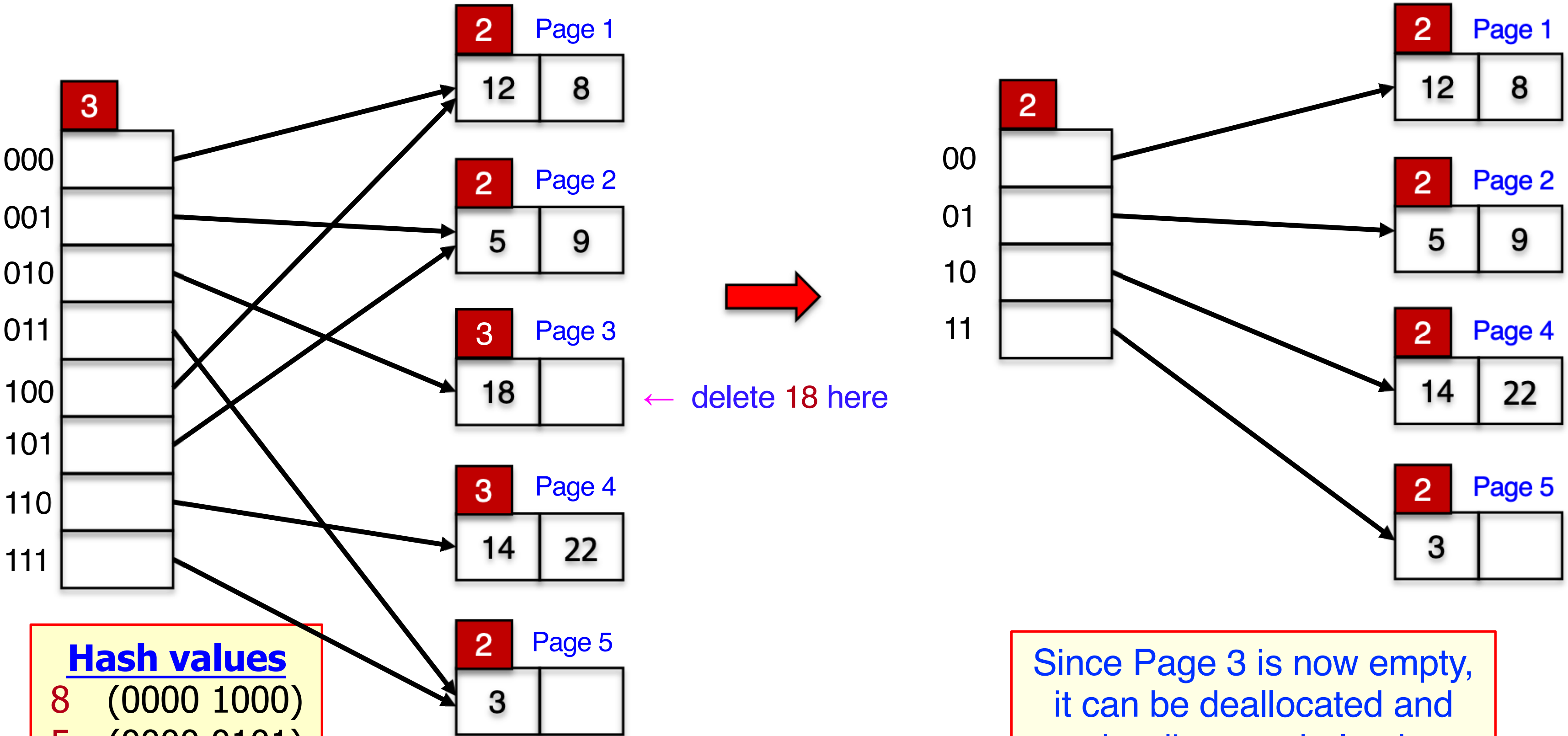


Hash values
8 (0000 1000)
5 (0000 0101)
12 (0000 1100)
14 (0000 1110)
18 (0001 0010)

Page 5 is a "split image" of Page 2.

EXERCISE 3 (CONT'D)

delete 18 (0001 0010)



Hash values

8 (0000 1000)
5 (0000 0101)
12 (0000 1100)
14 (0000 1110)
18 (0001 0010)

Since Page 3 is now empty, it can be deallocated and the directory halved.