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# Chapter 1

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## **Disk Storage, Basic File Structures, and Hashing.**

Adapted from the slides of “Fundamentals of Database Systems”  
(Elmasri et al., 2006)

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# Chapter Outline

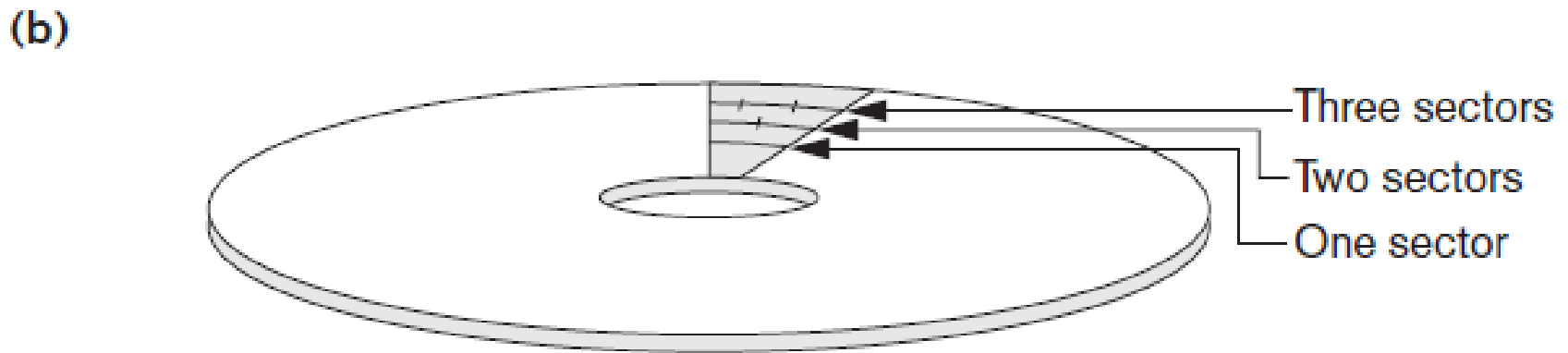
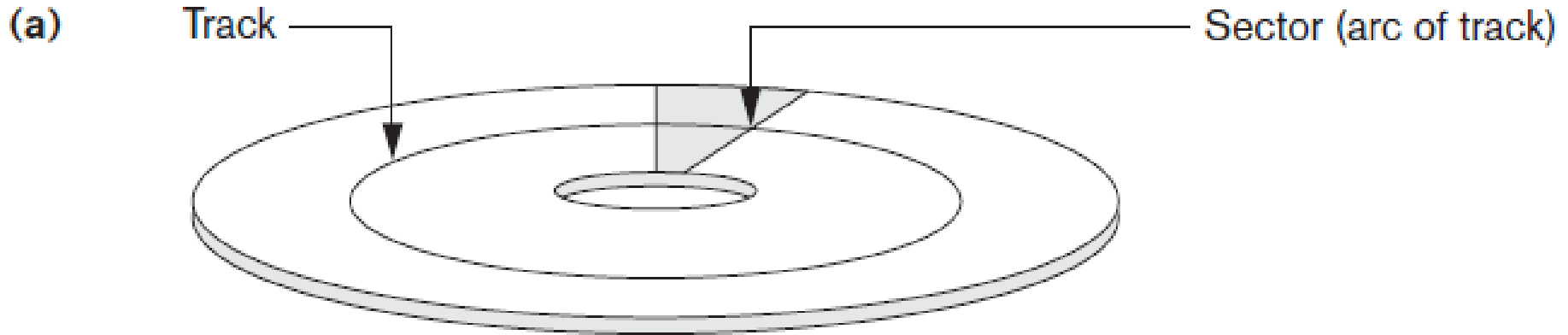
- Disk Storage Devices
- Files of Records
- Operations on Files
- Unordered Files
- Ordered Files
- Hashed Files
  - Dynamic and Extendible Hashing Techniques
- RAID Technology

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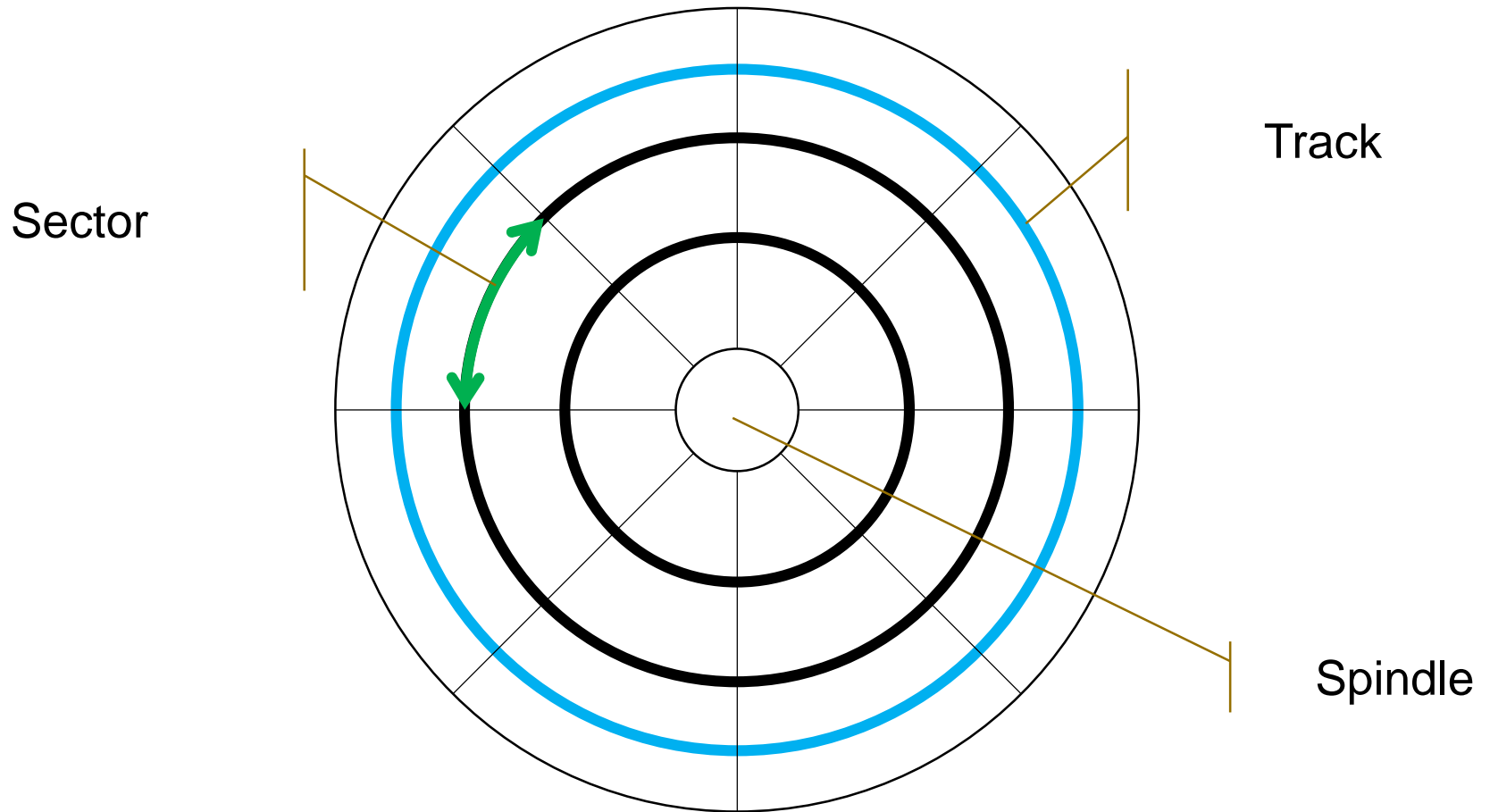
# Disk Storage Devices

- Preferred secondary storage device for high storage capacity and low cost.
- Data stored as magnetized areas on magnetic disk surfaces.
- A *disk pack* contains several magnetic disks connected to a rotating spindle.
- Disks are divided into concentric circular *tracks* on each disk *surface* .
  - Track capacities vary typically from 10 to 150 Kbytes.

# Disk Storage Devices (cont.)



# Disk Storage Devices (cont.)

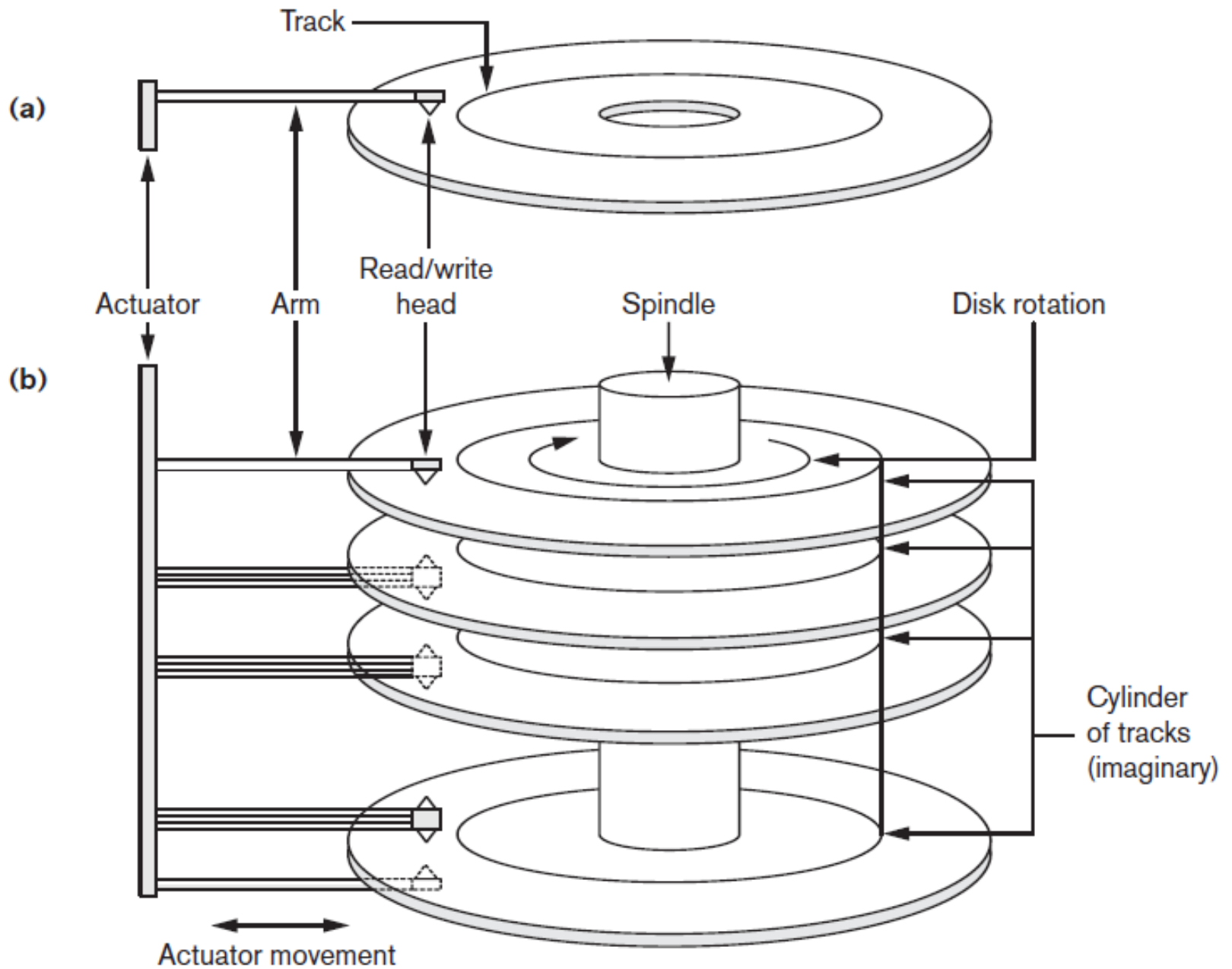


# Disk Storage Devices (cont.)

- A track is divided into smaller **blocks** or **sectors**.
  - because a track usually contains a large amount of information .
- A track is divided into **blocks**.
  - The block size  $B$  is fixed for each system.
    - Typical block sizes range from  $B=512$  bytes to  $B=8192$  bytes.
  - Whole blocks are transferred between disk and main memory for processing.

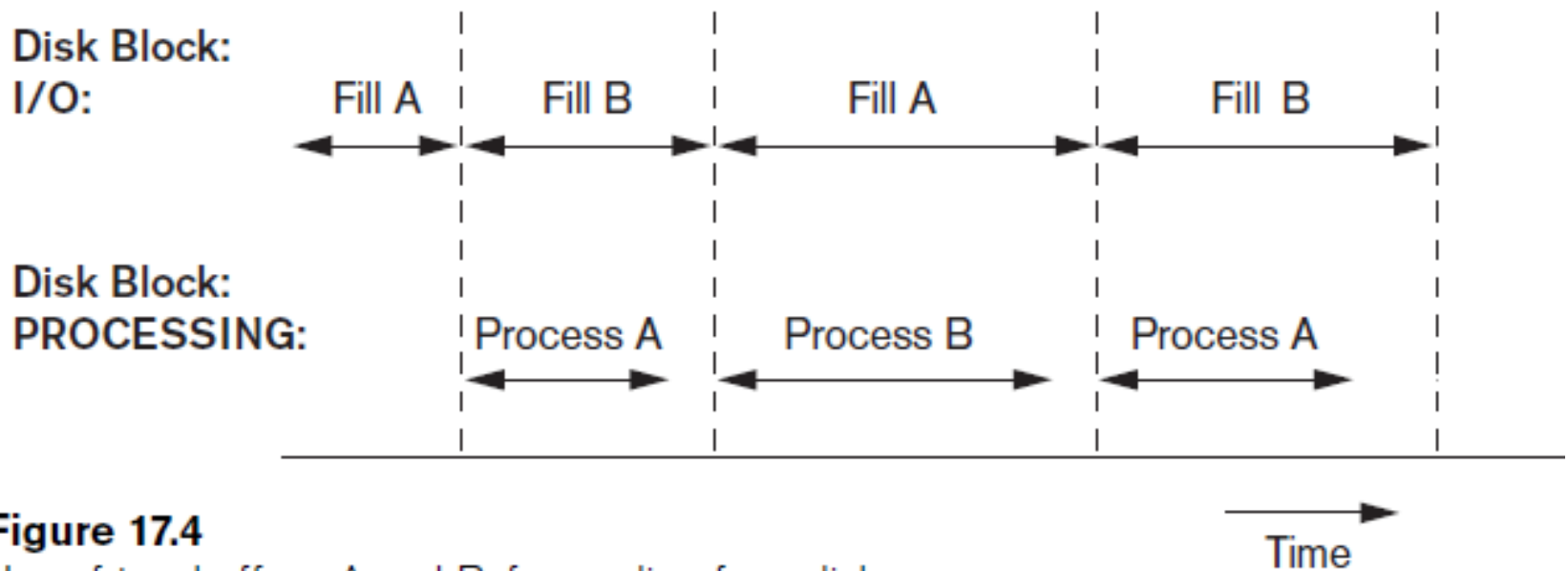
# Disk Storage Devices (cont.)

- A **read-write head** moves to the track that contains the block to be transferred.
  - Disk rotation moves the block under the read-write head for reading or writing.
- A physical disk block (hardware) address consists of:
  - a cylinder number (imaginary collection of tracks of same radius from all recorded surfaces)
  - the track number or surface number (within the cylinder)
  - and block number (within track).
- Reading or writing a disk block is time consuming because of the seek time  $s$  and rotational delay (latency) **rd**.
- *Double buffering* can be used to speed up the transfer of contiguous disk blocks.





# Double Buffering



**Figure 17.4**

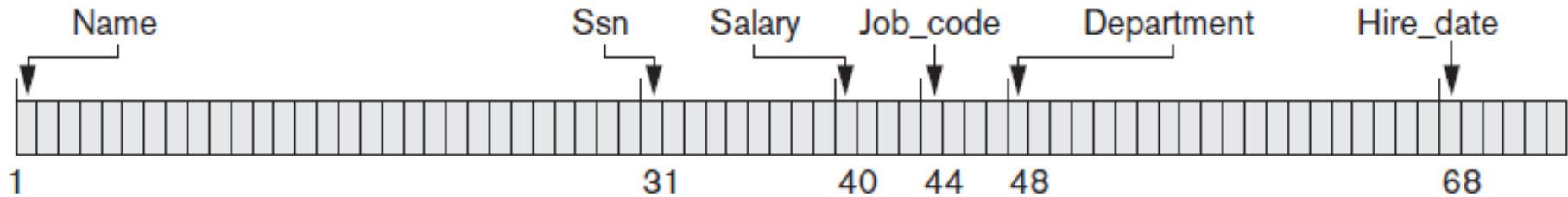
Use of two buffers, A and B, for reading from disk.

# Records

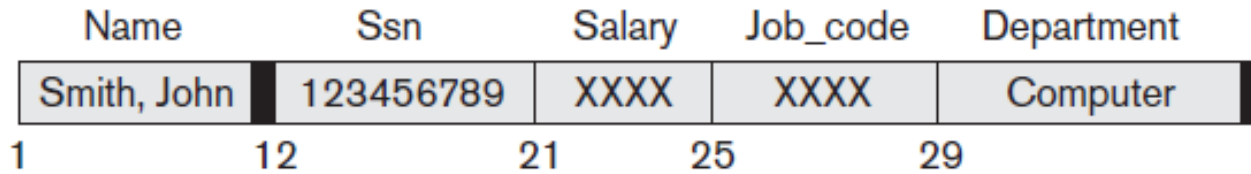
- Fixed and variable length records.
- Records contain fields which have values of a particular type.
  - E.g., amount, date, time, age.
- Fields themselves may be fixed length or variable length.
- Variable length fields can be mixed into one record:
  - Separator characters or length fields are needed so that the record can be “parsed”.

# Records (cont.)

(a)



(b)



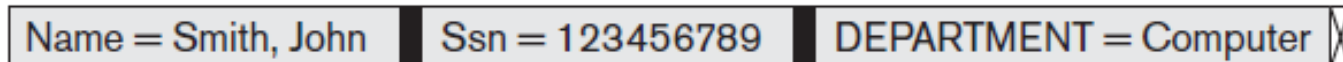
## Separator Characters

= Separates field name from field value

■ Separates fields

⊠ Terminates record

(c)

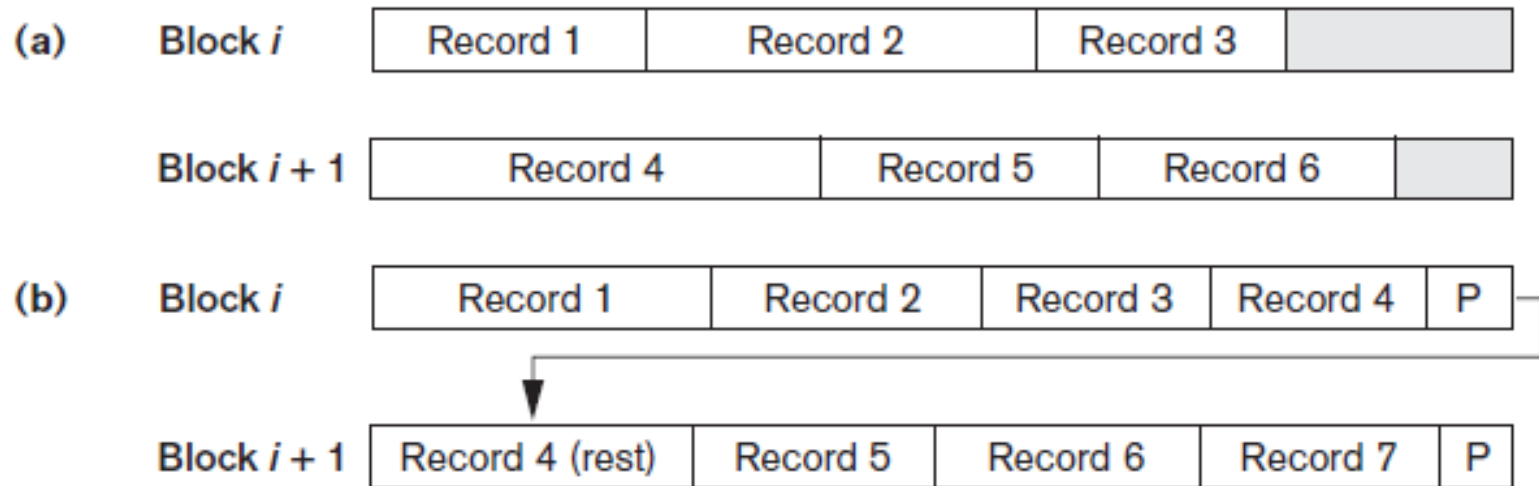


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# Blocking

- **Blocking:** refers to storing a number of records in one block on the disk.
- **Blocking factor (*bfr*):** refers to the number of records per block.
- There may be empty space in a block if an integral number of records do not fit in one block.
- **Spanned Records:** refer to records that exceed the size of one or more blocks and hence span a number of blocks.

# Blocking (cont.)



(a) Unspanned.

(b) Spanned.

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# Files of Records

- A **file** is a *sequence* of records, where each record is a collection of data values (or data items).
- A **file descriptor** (or **file header**) includes information that describes the file, such as the *field names* and their *data types*, and the addresses of the file blocks on disk.
- Records are stored on disk blocks.
- The **blocking factor bfr** for a file is the (average) number of file records stored in a disk block.
- A file can have **fixed-length** records or **variable-length** records.

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# Files of Records (cont.)

- File records can be **unspanned** or **spanned**:
  - **Unspanned**: no record can span two blocks
  - **Spanned**: a record can be stored in more than one block
- The physical disk blocks that are allocated to hold the records of a file can be *contiguous, linked, or indexed*.
- In a file of fixed-length records, all records have the same format. Usually, unspanned blocking is used with such files.
- Files of variable-length records require additional information to be stored in each record, such as **separator characters** and **field types**.
  - Usually spanned blocking is used with such files.

# Operation on Files

Typical file operations include:

- **OPEN:** Reads the file for access, and associates a pointer that will refer to a *current* file record at each point in time.
- **FIND:** Searches for the first file record that satisfies a certain condition, and makes it the current file record.
- **FINDNEXT:** Searches for the next file record (from the current record) that satisfies a certain condition, and makes it the current file record.
- **READ:** Reads the current file record into a program variable.
- **INSERT:** Inserts a new record into the file, and makes it the current file record.



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# Operation on Files (cont.)

- **DELETE:** Removes the current file record from the file, usually by marking the record to indicate that it is no longer valid.
- **MODIFY:** Changes the values of some fields of the current file record.
- **CLOSE:** Terminates access to the file.
- **REORGANIZE:** Reorganizes the file records. For example, the records marked deleted are physically removed from the file or a new organization of the file records is created.
- **READ\_ORDERED:** Read the file blocks in order of a specific field of the file.

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# Unordered Files

- Also called a **heap** or a **pile** file.
- New records are inserted at the end of the file.
- A **linear search** through the file records is necessary to search for a record.
  - This requires reading and searching half the file blocks on the average, and is hence quite expensive.
- Record insertion is quite efficient.
- Reading the records in order of a particular field requires sorting the file records.

# Ordered Files

- Also called a **sequential** file.
- File records are kept sorted by the values of an *ordering field*.
- Insertion is expensive: records must be inserted in the correct order.
  - It is common to keep a separate unordered *overflow* (or *transaction*) file for new records to improve insertion efficiency; this is periodically merged with the main ordered file.
- A **binary search** can be used to search for a record on its *ordering field* value.
  - This requires reading and searching  $\log_2$  of the file blocks on the average, an improvement over linear search.
- Reading the records in order of the ordering field is quite efficient.

# Ordered Files (cont.)

	NAME	SSN	BIRTHDATE	JOB	SALARY	SEX
block 1	Aaron, Ed					
	Abbott, Diane					
	⋮					
	Acosta, Marc					

block 2	Adams, John					
	Adams, Robin					
	⋮					
	Akers, Jan					

block 3	Alexander, Ed					
	Alfred, Bob					
	⋮					
	Allen, Sam					

⋮

block n - 1	Wong, James					
	Wood, Donald					
	⋮					
	Woods, Manny					

block n	Wright, Pam					
	Wyatt, Charles					
	⋮					
	Zimmer, Byron					

# Average Access Times

- The following table shows the average access time to access a specific record for a given type of file:

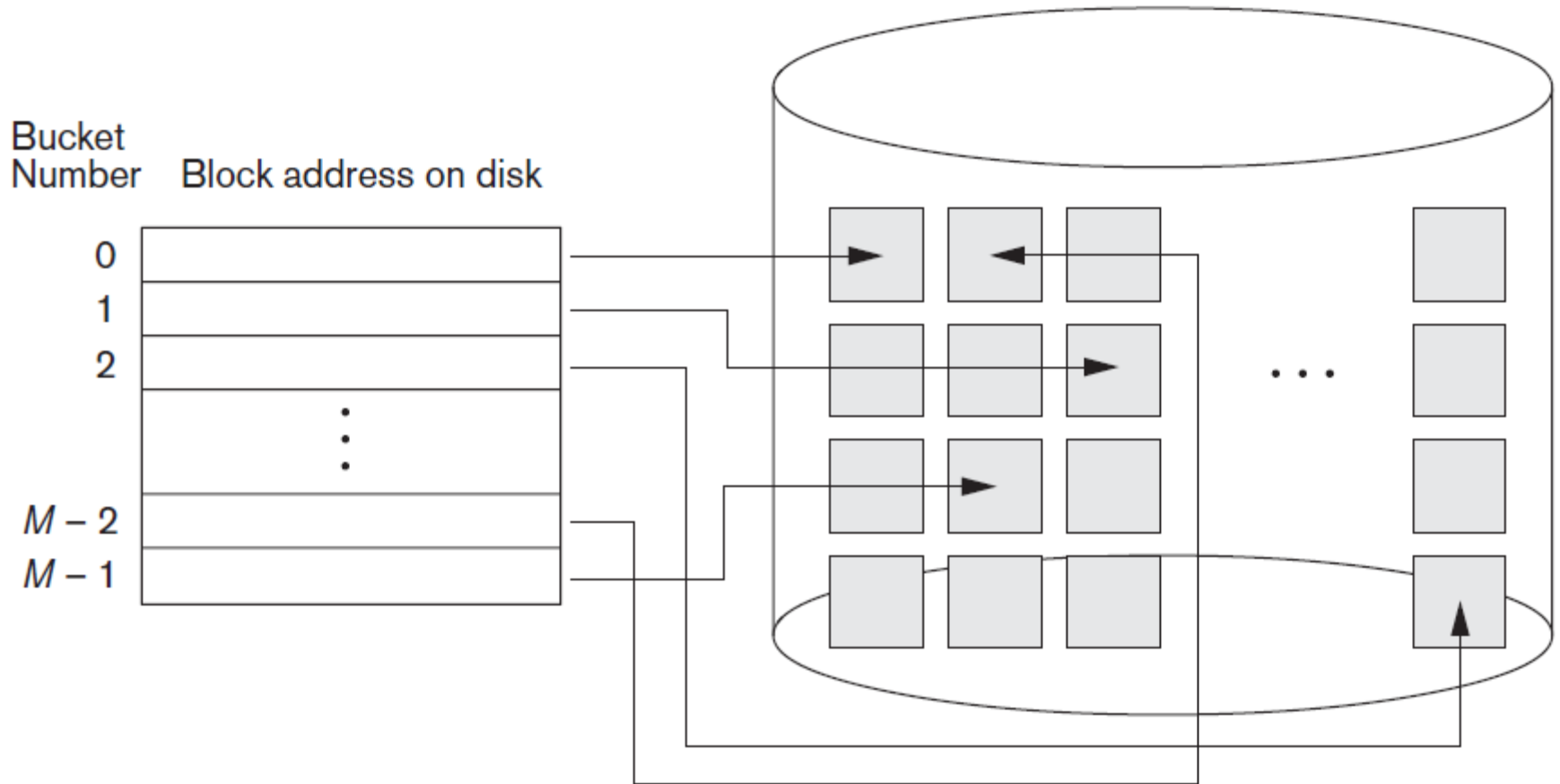
**Table 17.2** Average Access Times for a File of  $b$  Blocks under Basic File Organizations

Type of Organization	Access/Search Method	Average Blocks to Access a Specific Record
Heap (unordered)	Sequential scan (linear search)	$b/2$
Ordered	Sequential scan	$b/2$
Ordered	Binary search	$\log_2 b$

# Hashed Files

- Hashing for disk files is called **External Hashing**.
- The file blocks are divided into  $M$  equal-sized **buckets**, numbered  $\text{bucket}_0, \text{bucket}_1, \dots, \text{bucket}_{M-1}$ .
  - Typically, a bucket corresponds to one (or a fixed number of) disk block.
- One of the file fields is designated to be the **hash key** of the file.
- The record with hash key value  $K$  is stored in bucket  $i$ , where  $i=h(K)$ , and  $h$  is the **hashing function**.
- Search is very efficient on the hash key.
- Collisions occur when a new record hashes to a bucket that is already full.
  - An overflow file is kept for storing such records.
  - Overflow records that hash to each bucket can be linked together.

# Hashed Files (cont.)



# Hashed Files (cont.)

There are numerous methods for **collision resolution**:

- **Open addressing:** Proceeding from the occupied position specified by the hash address, the program checks the subsequent positions in order until an unused (empty) position is found.

- $h(K) = K \bmod 7$

0	1	2	3	4	5	6
	1		3	11		6

- Insert 8

	1	8	3	11		6
--	---	---	---	----	--	---

- Insert 15

	1	8	3	11	15	6
--	---	---	---	----	----	---

- Insert 13

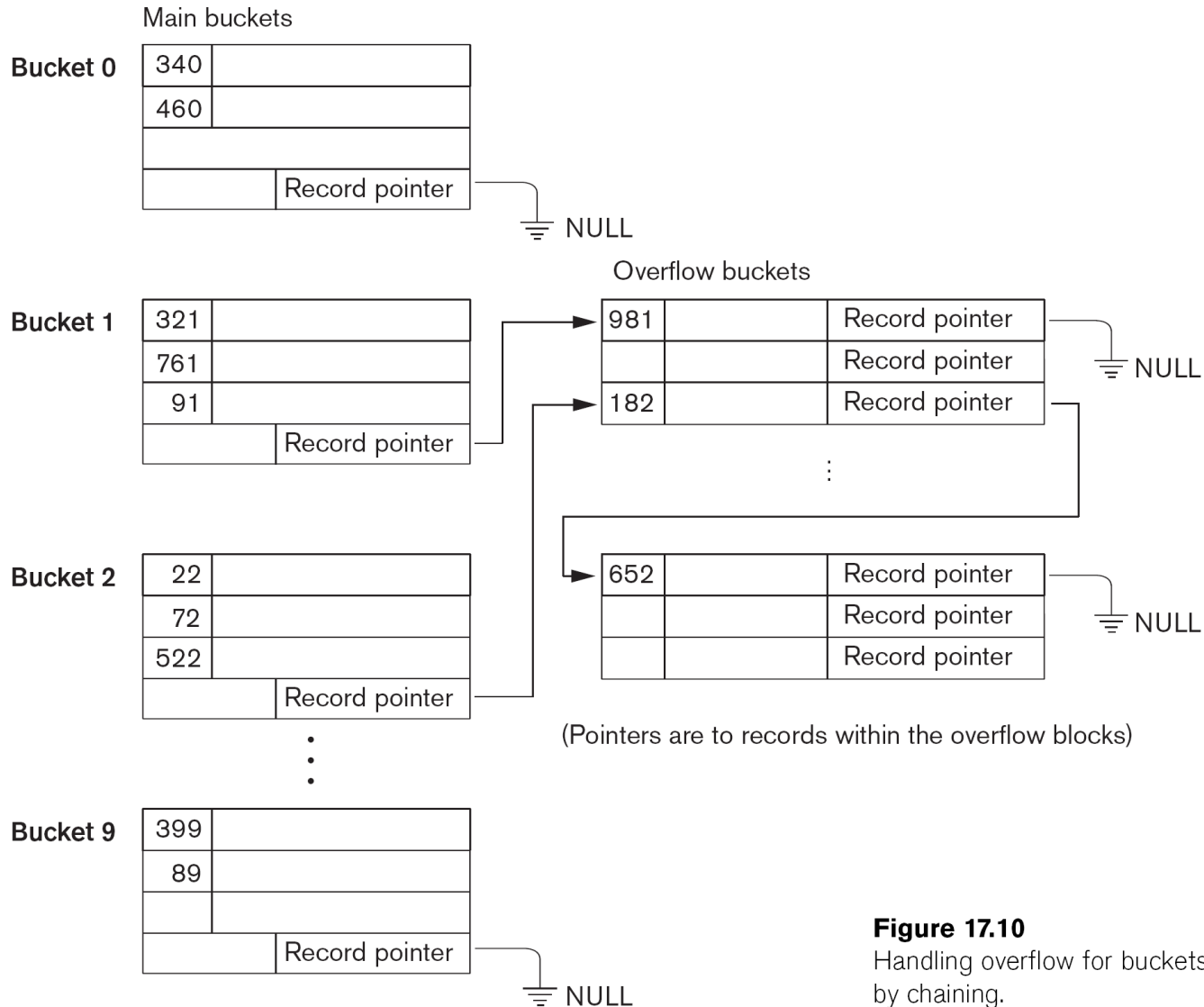
13	1	8	3	11	15	6
----	---	---	---	----	----	---



# Hashed Files (cont.)

- There are numerous methods for collision resolution, including the following:
  - **Chaining:**
    - Various overflow locations are kept: extending the array with a number of overflow positions.
    - A pointer field is added to each record location.
    - A collision is resolved by placing the new record in an unused overflow location and setting the pointer of the occupied hash address location to the address of that overflow location.
  
  - **Multiple hashing:**
    - The program applies a second hash function if the first results in a collision.
    - If another collision results, the program uses open addressing or applies a third hash function and then uses open addressing if necessary.

# Hashed Files (cont.) - Overflow handling



**Figure 17.10**  
Handling overflow for buckets  
by chaining.

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# Hashed Files (cont.)

- To reduce overflow records, a hash file is typically kept 70-80% full.
- The hash function  $h$  should distribute the records uniformly among the buckets;
  - Otherwise, search time will be increased because many overflow records will exist.
- Main disadvantages of static external hashing:
  - Fixed number of buckets  $M$  is a problem if the number of records in the file grows or shrinks.
  - Ordered access on the hash key is quite inefficient (requires sorting the records).

# Dynamic And Extendible Hashed Files

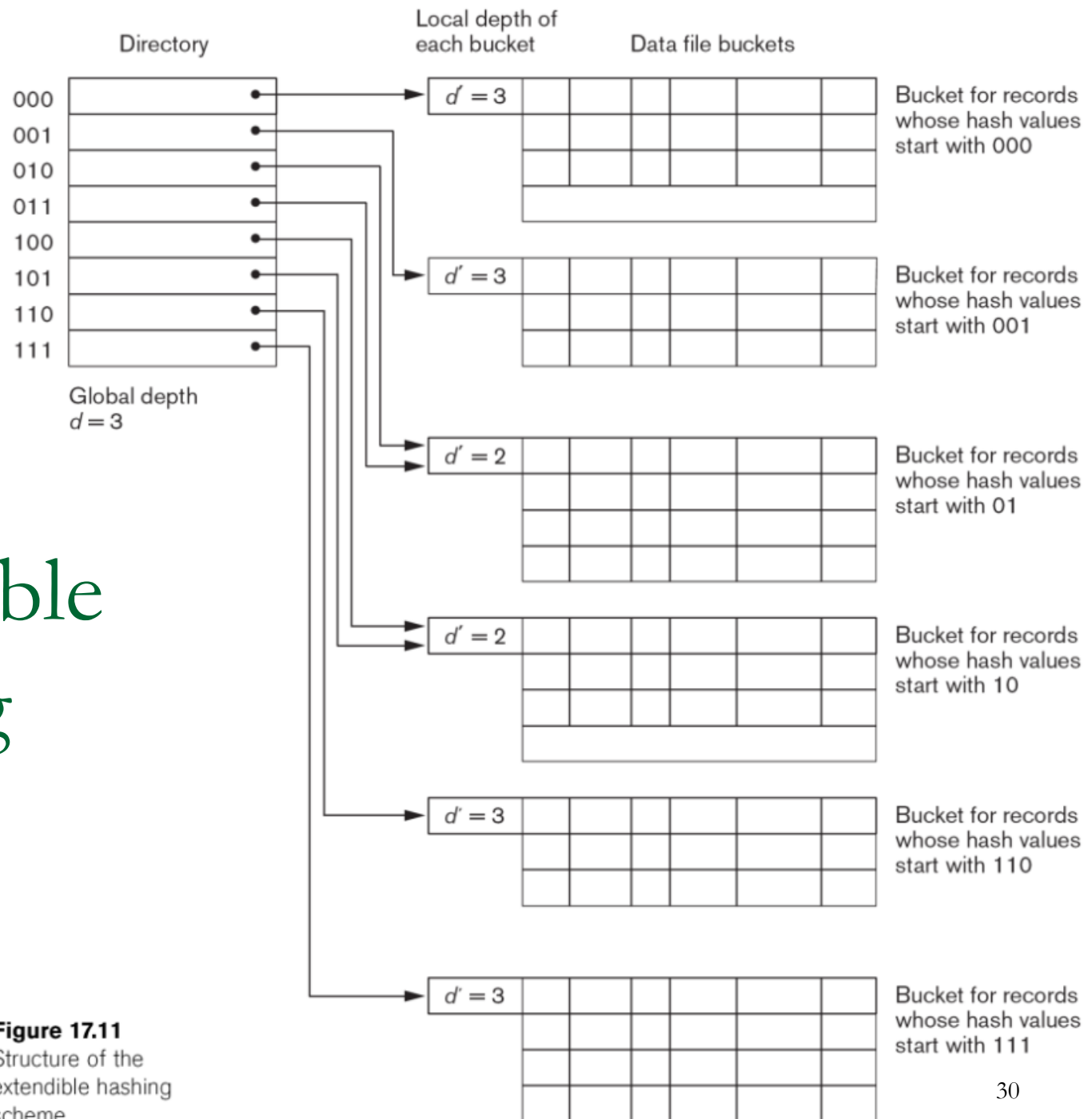
- Dynamic and Extendible Hashing Techniques
  - Hashing techniques are adapted to allow the dynamic growth and shrinking of the number of file records.
  - These techniques include the following: **dynamic hashing**, **extendible hashing**, and **linear hashing**.
- Both dynamic and extendible hashing use the **binary representation** of the hash value  $h(K)$  in order to access a **directory**.
  - In dynamic hashing the directory is a binary tree.
  - In extendible hashing the directory is an array of size  $2^d$  where  $d$  is called the **global depth**.

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## Dynamic And Extendible Hashing (cont.)

- The directories can be stored on disk, and they expand or shrink dynamically.
  - Directory entries point to the disk blocks that contain the stored records.
- An insertion in a disk block that is full causes the block to split into two blocks and the records are redistributed among the two blocks.
  - The directory is updated appropriately.
- Dynamic and extendible hashing do not require an overflow area.
- Linear hashing does require an overflow area but does not use a directory.
  - Blocks are split in *linear order* as the file expands.

# Extendible Hashing



**Figure 17.11**  
Structure of the extendible hashing scheme.

# Extendible Hashing – Example

Record	K	$h(K) = K \% 32$	$h(K)B$
r1	2657	1	00001
r2	3760	16	10000
r3	4692	20	10100
r4	4871	7	00111
r5	5659	27	11011
r6	1821	29	11101
r7	1074	18	10010
r8	2123	11	01011
r9	1620	20	10100
r10	2428	28	11100
r11	3943	7	00111
r12	4750	14	01110
r13	6975	31	11111
r14	4981	21	10101
r15	9208	24	11000

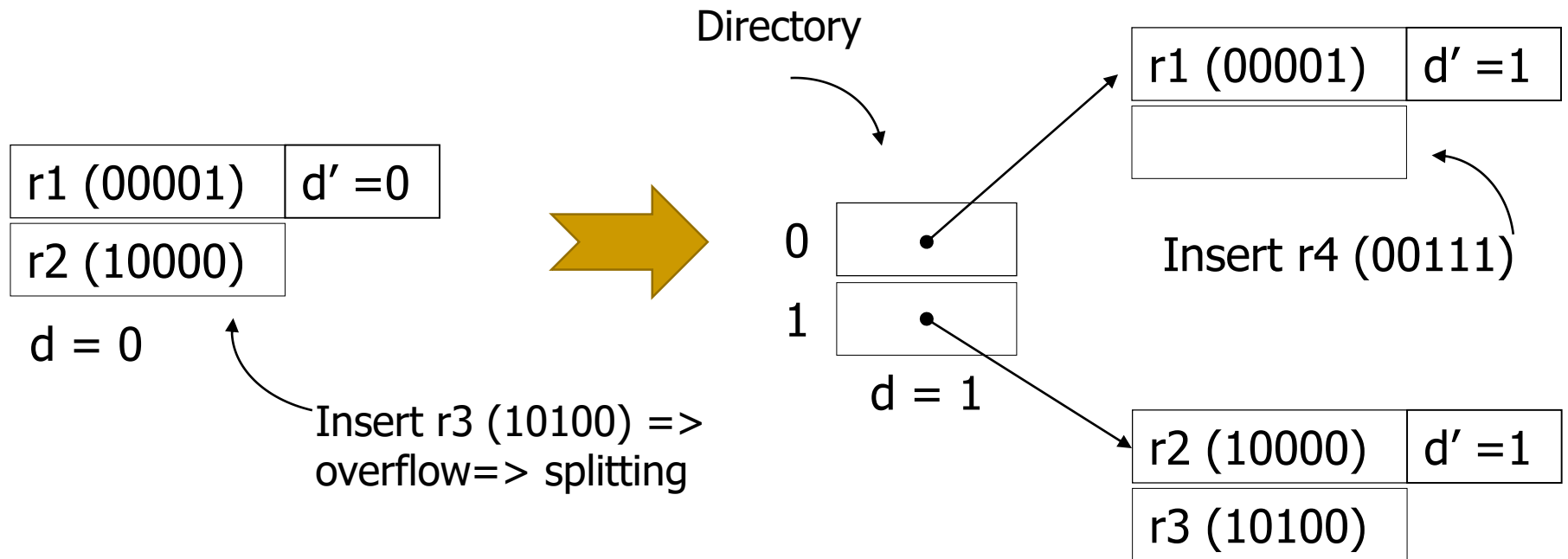
$d'$  = local depth  
 $d$  = global depth

r1 (00001)	$d' = 0$
r2 (10000)	

$d = 0$

Each bucket has  
maximum 2 records

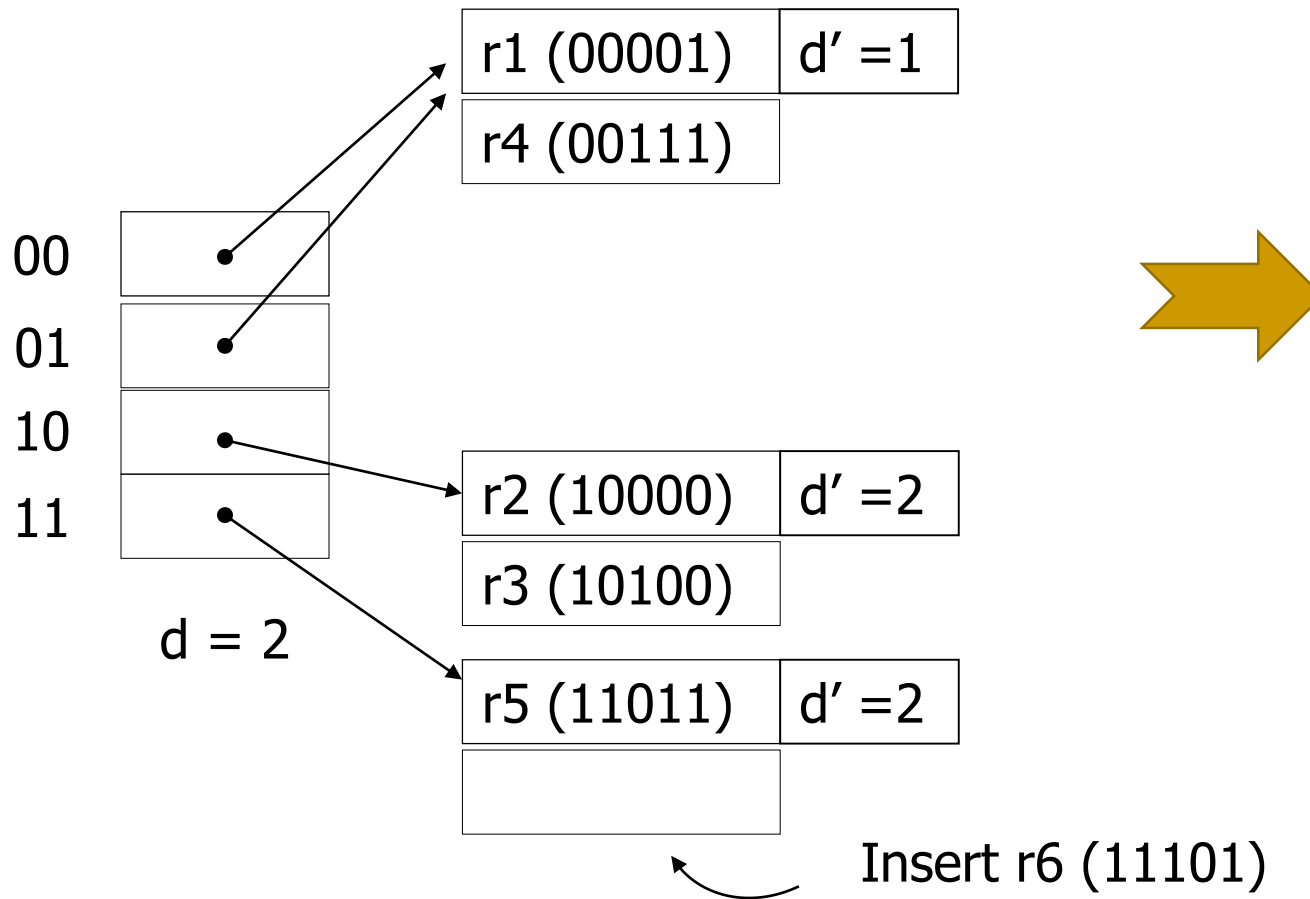
# Extendible Hashing – Example(cont.)



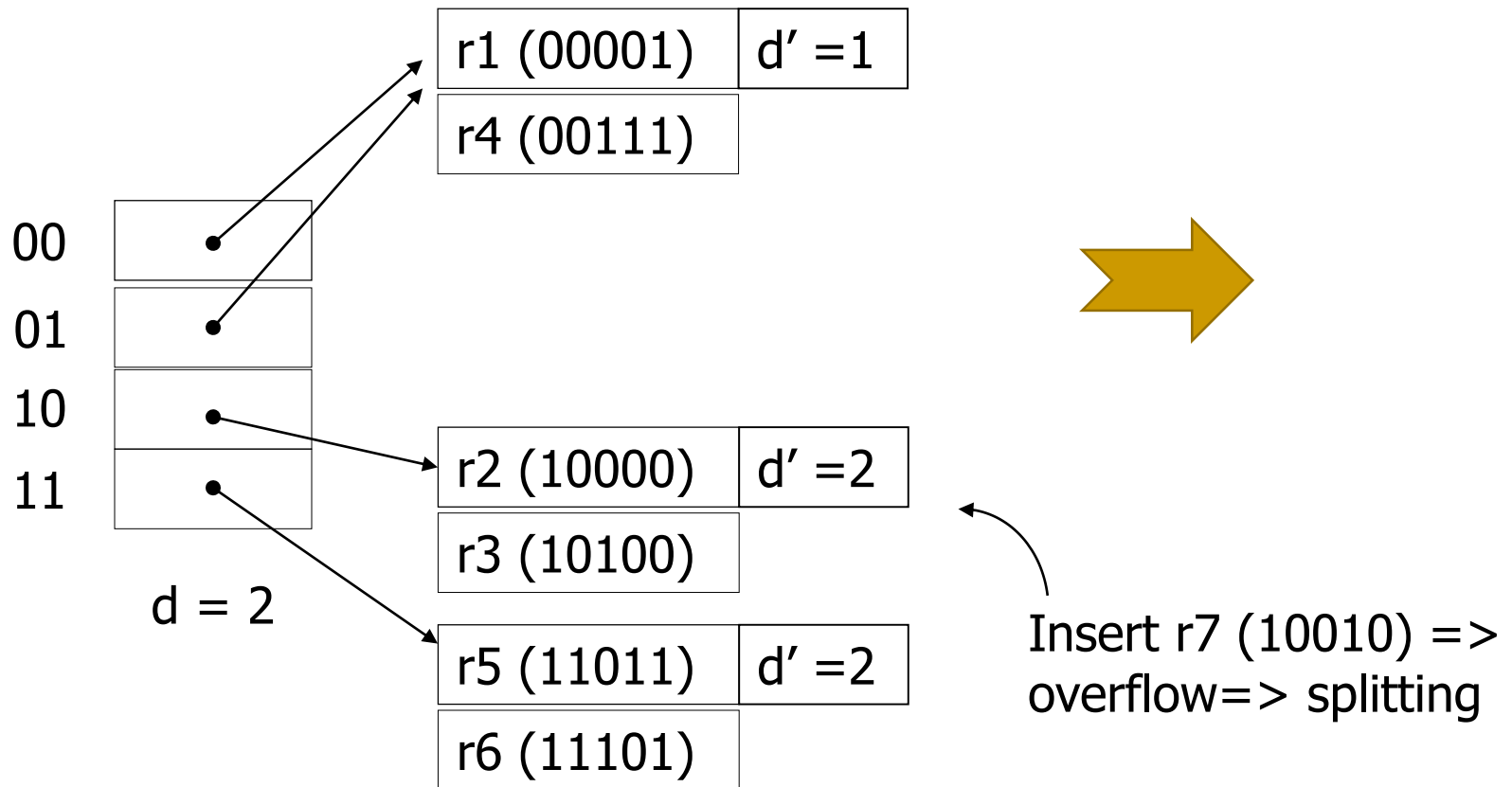




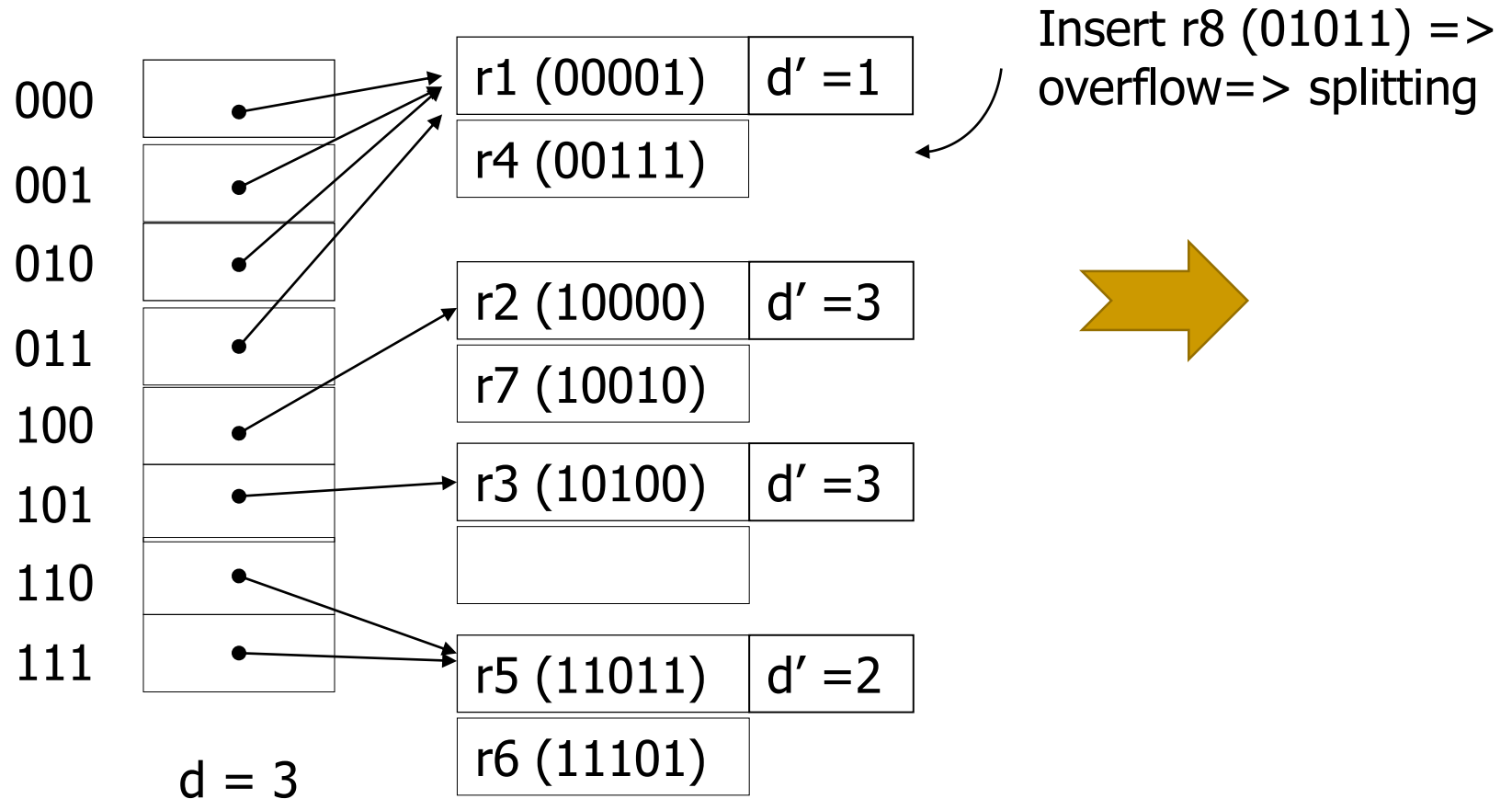
# Extendible Hashing – Example(cont.)



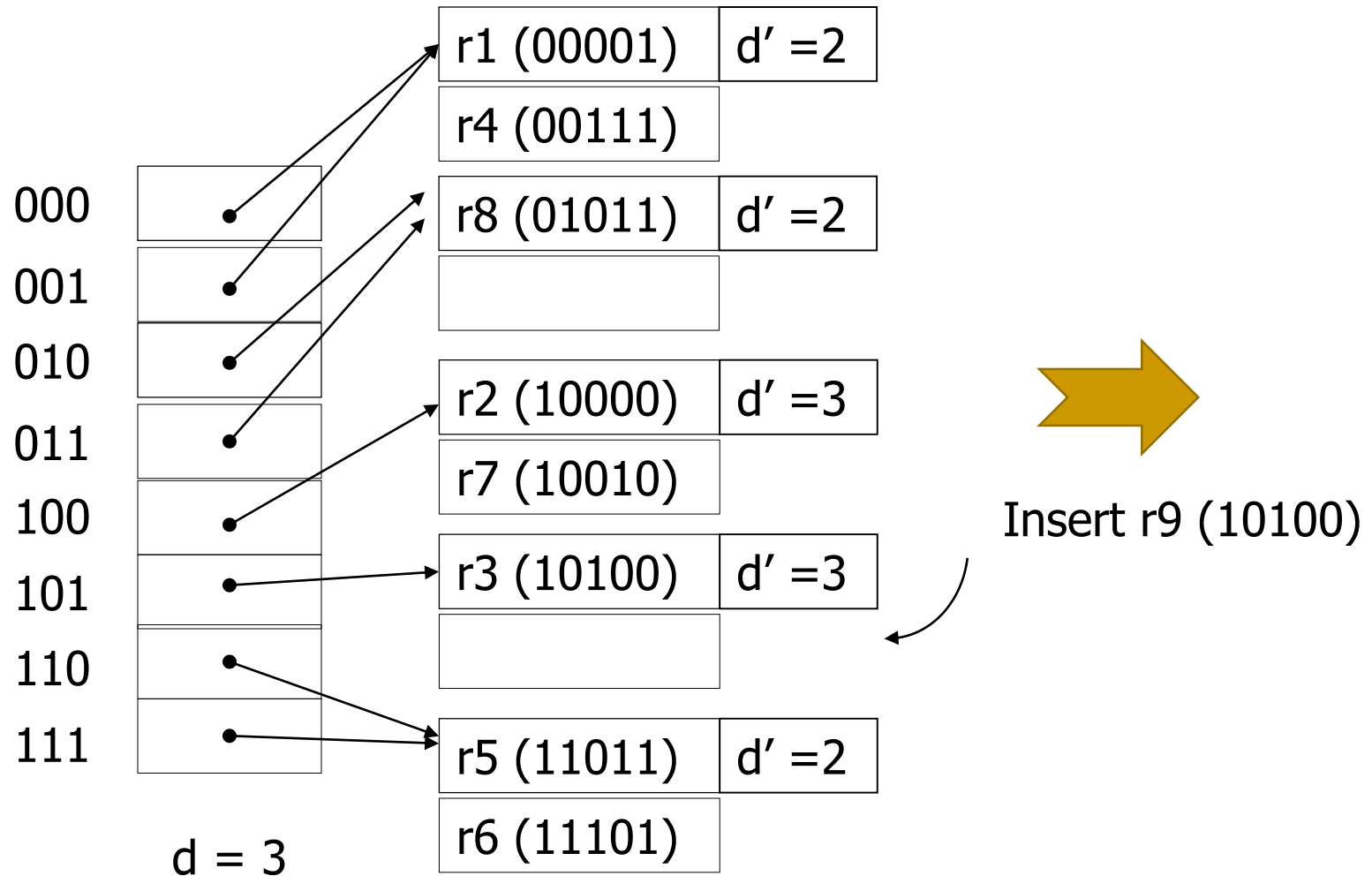
# Extendible Hashing – Example(cont.)



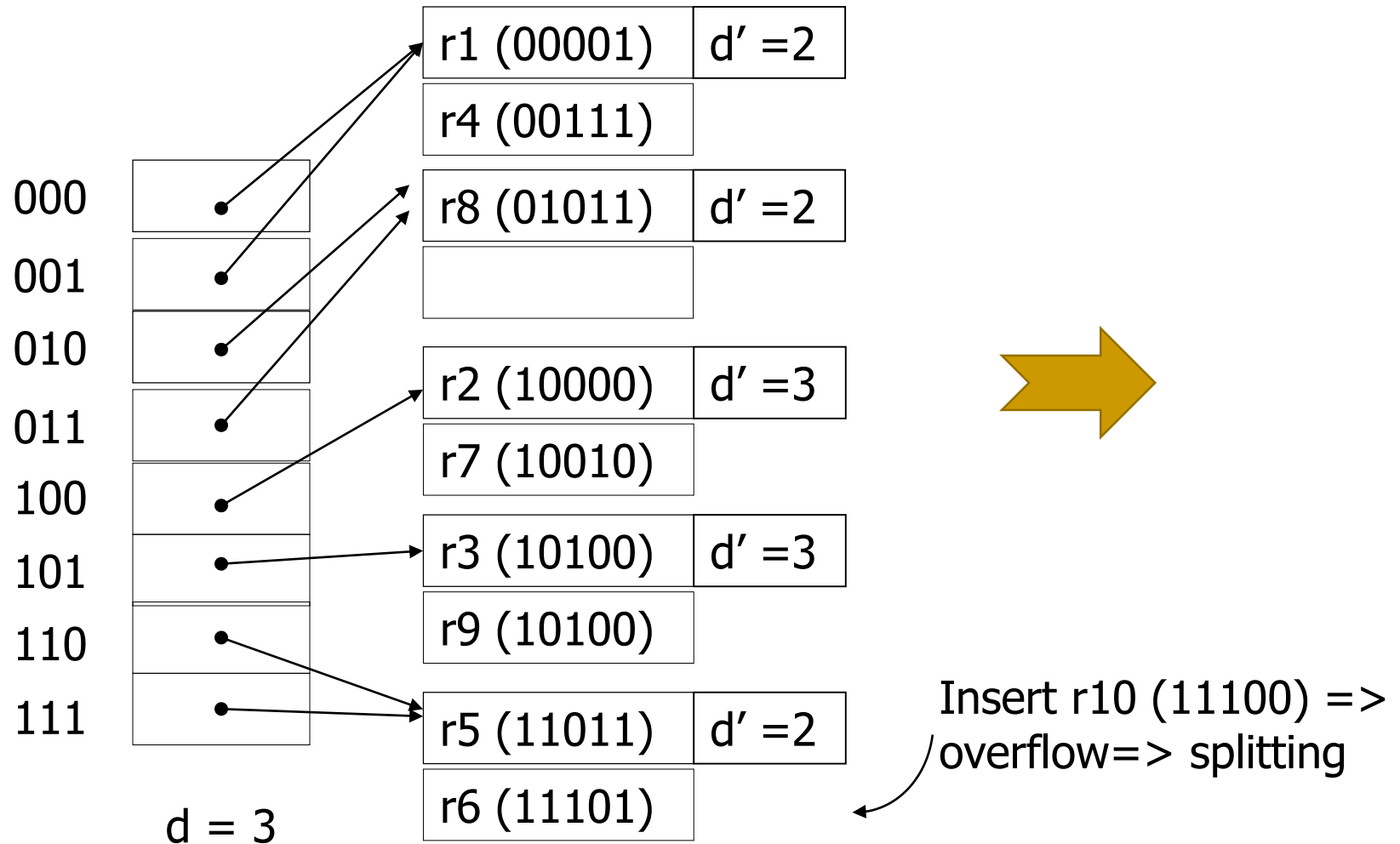
# Extendible Hashing – Example(cont.)



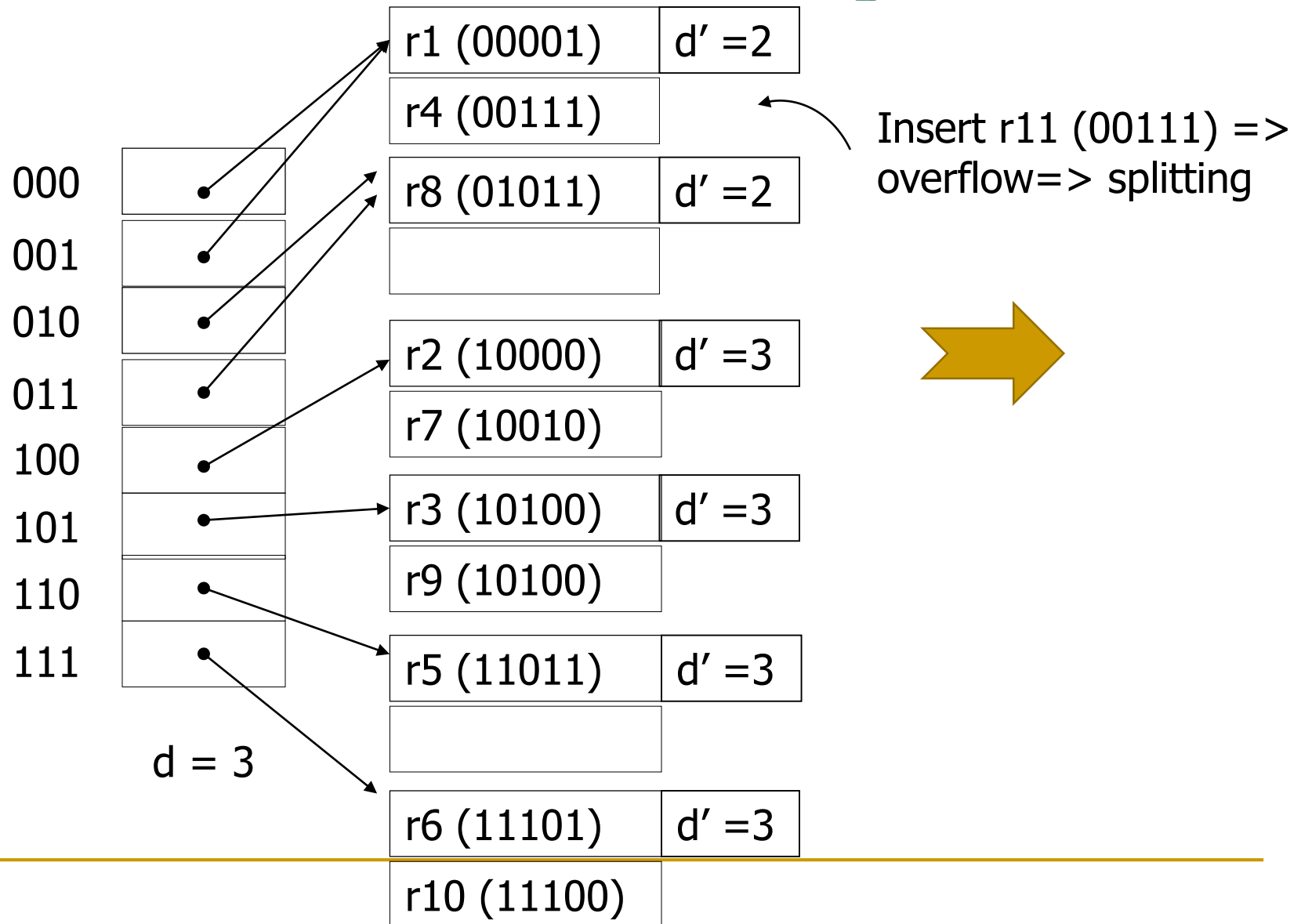
# Extendible Hashing – Example(cont.)



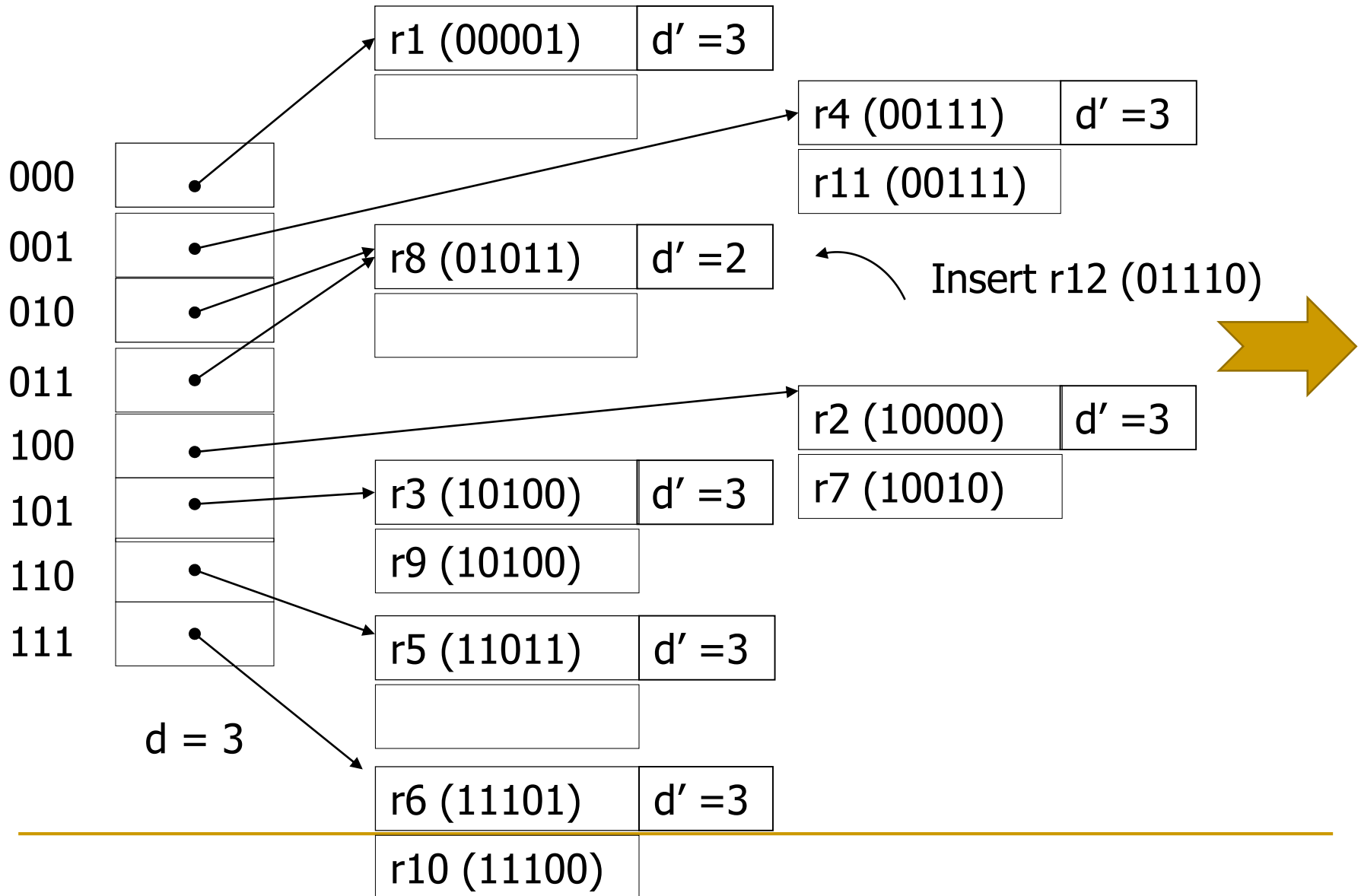
# Extendible Hashing – Example(cont.)



# Extendible Hashing – Example(cont.)

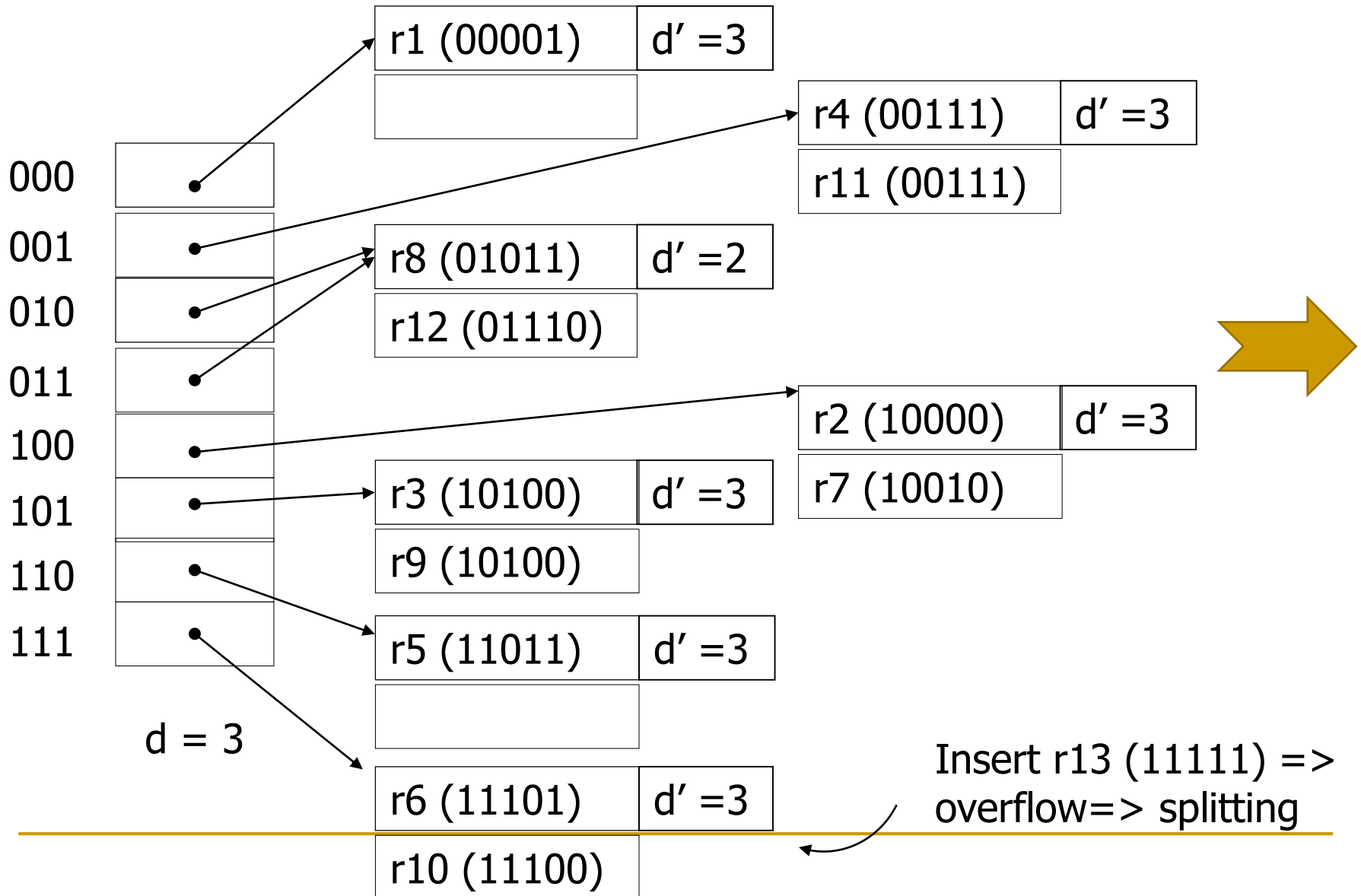


# Extendible Hashing – Example(cont.)

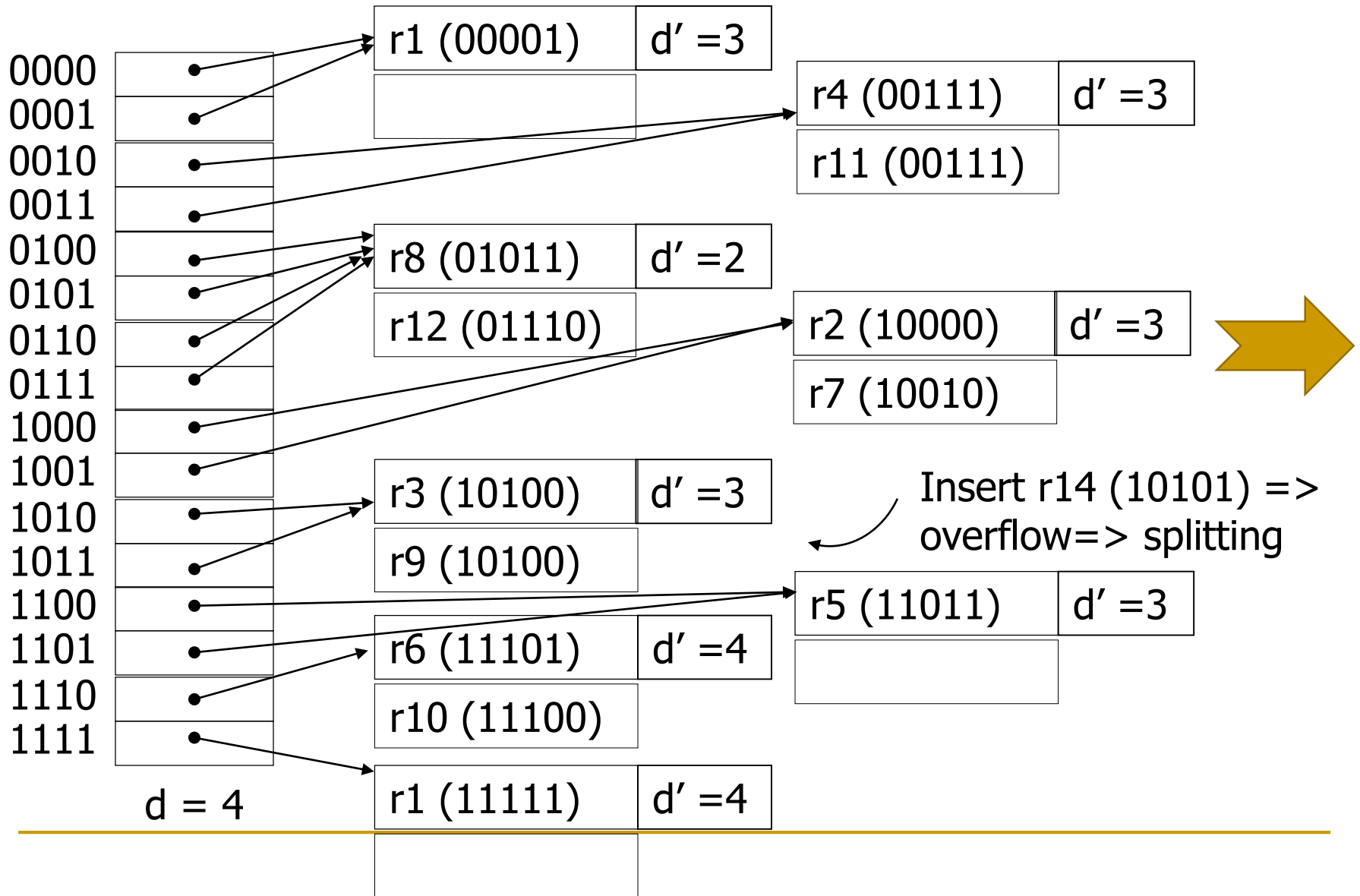




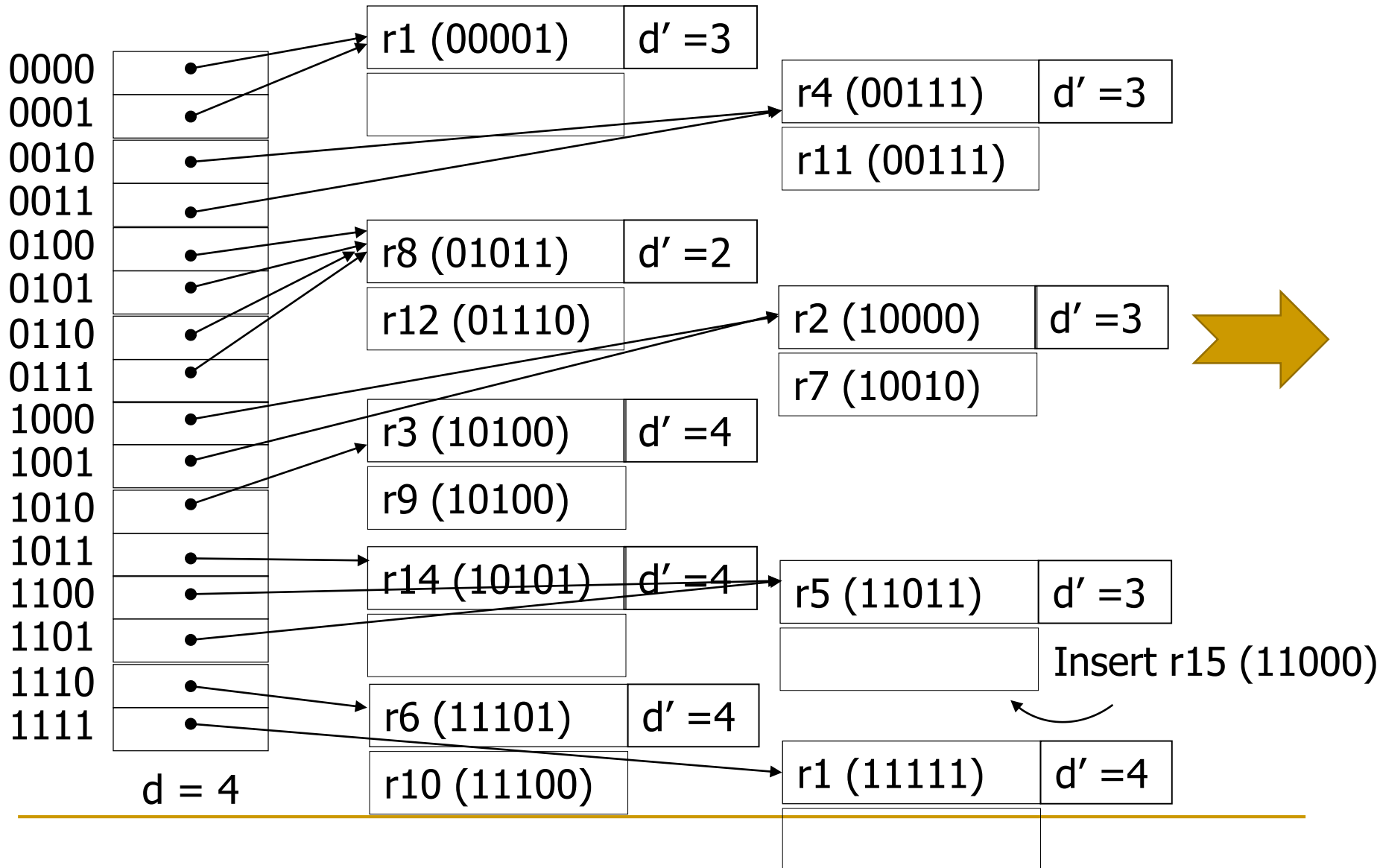
# Extendible Hashing – Example(cont.)



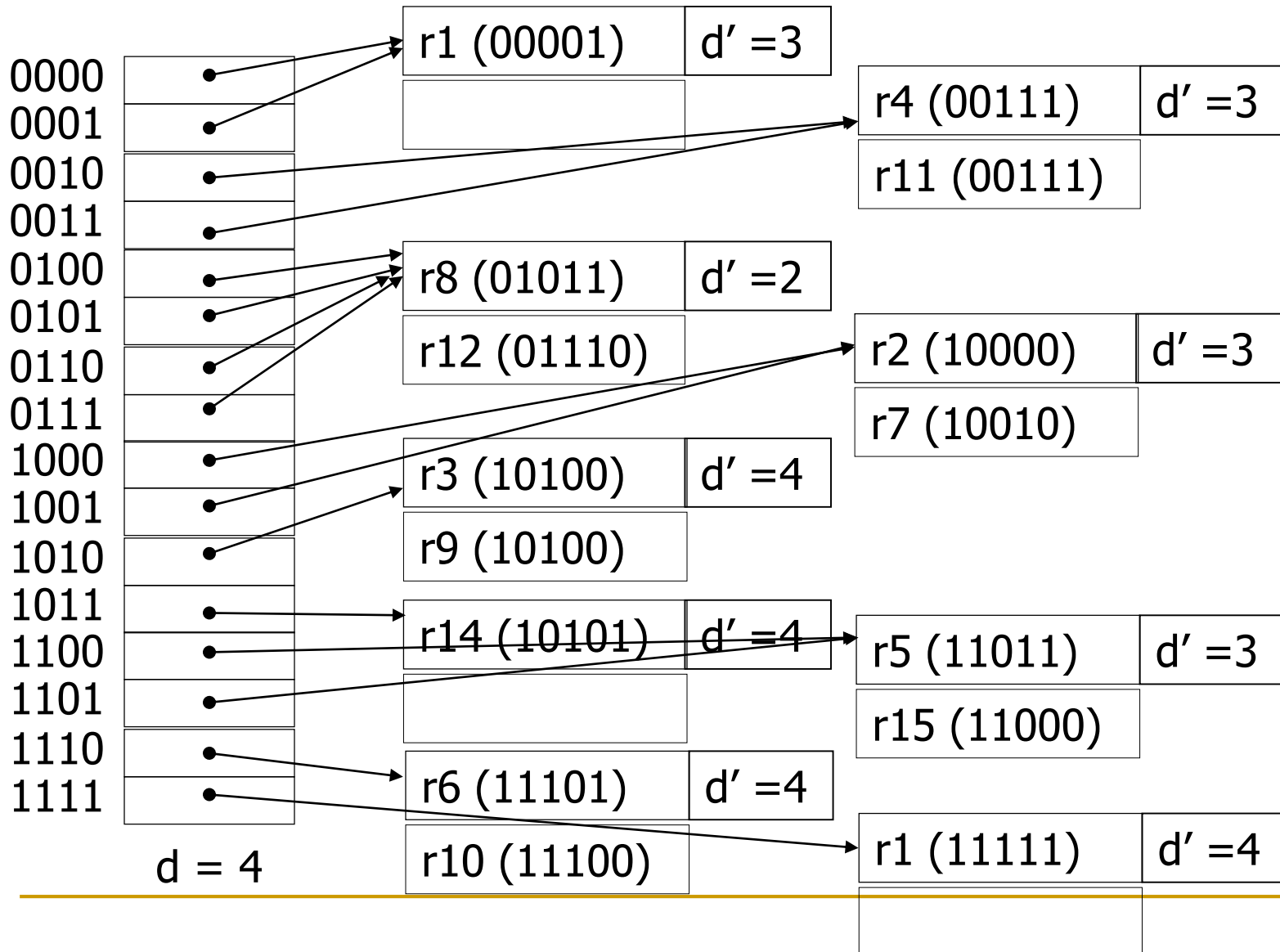
# Extendible Hashing – Example(cont.)



# Extendible Hashing – Example(cont.)

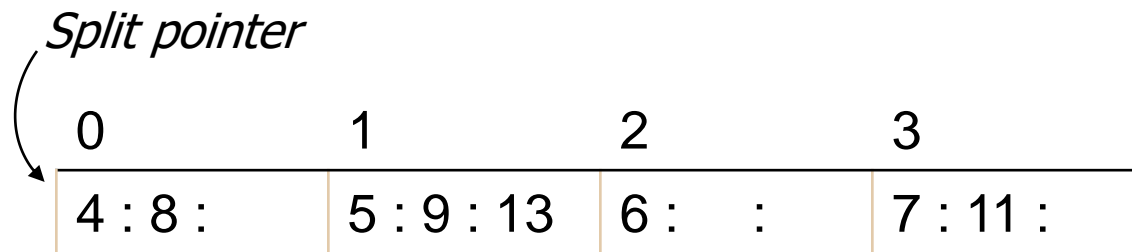


# Extendible Hashing – Example(cont.)



# Linear Hashing – Example

- $M=4$ ,  $h_0(K) = K \bmod M$ , each bucket has 3 records.
- Initialization:



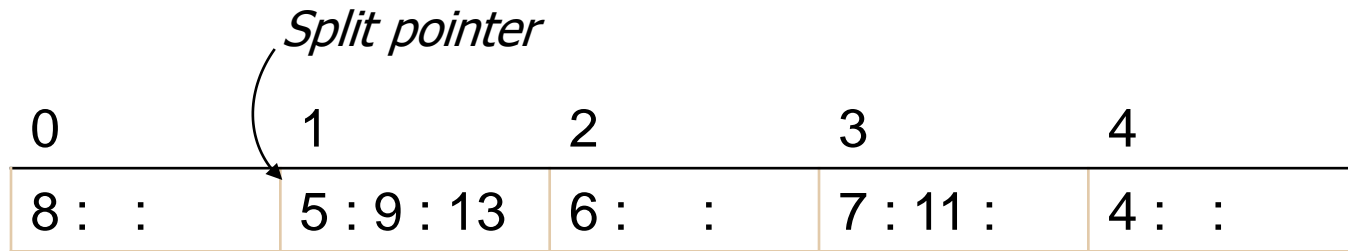
Insert 17  
( $17 \bmod 4 = 1$ )

Bucket 1: overflow

Split bucket 0

$$h_1(K) = K \bmod 2 * M$$

# Linear Hashing – Example(cont.)



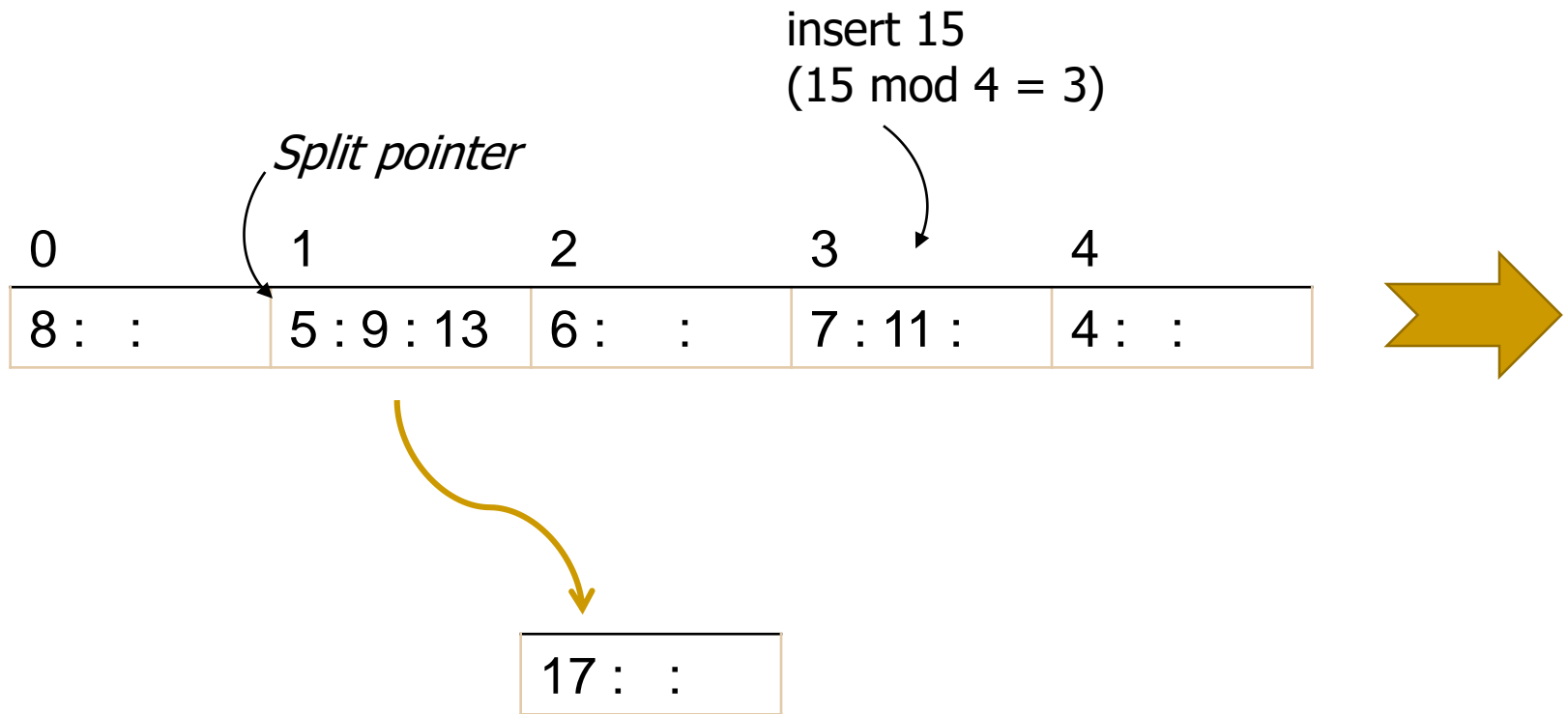
17 : :

4: bucket ( $4 \bmod 2*4 =$ ) 4

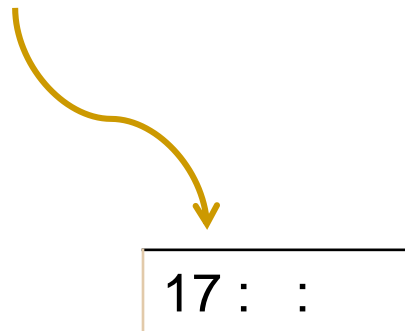
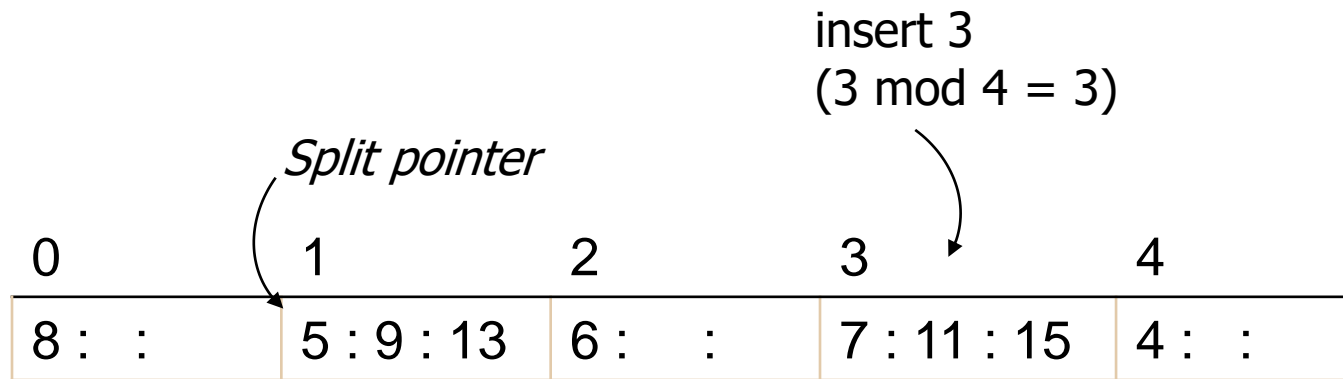
8: bucket ( $8 \bmod 2*4 =$ ) 0

17: overflow records

# Linear Hashing – Example(cont.)



# Linear Hashing – Example(cont.)



Bucket 3: overflow

Split bucket 1.

=> Overflow records: Redistributed



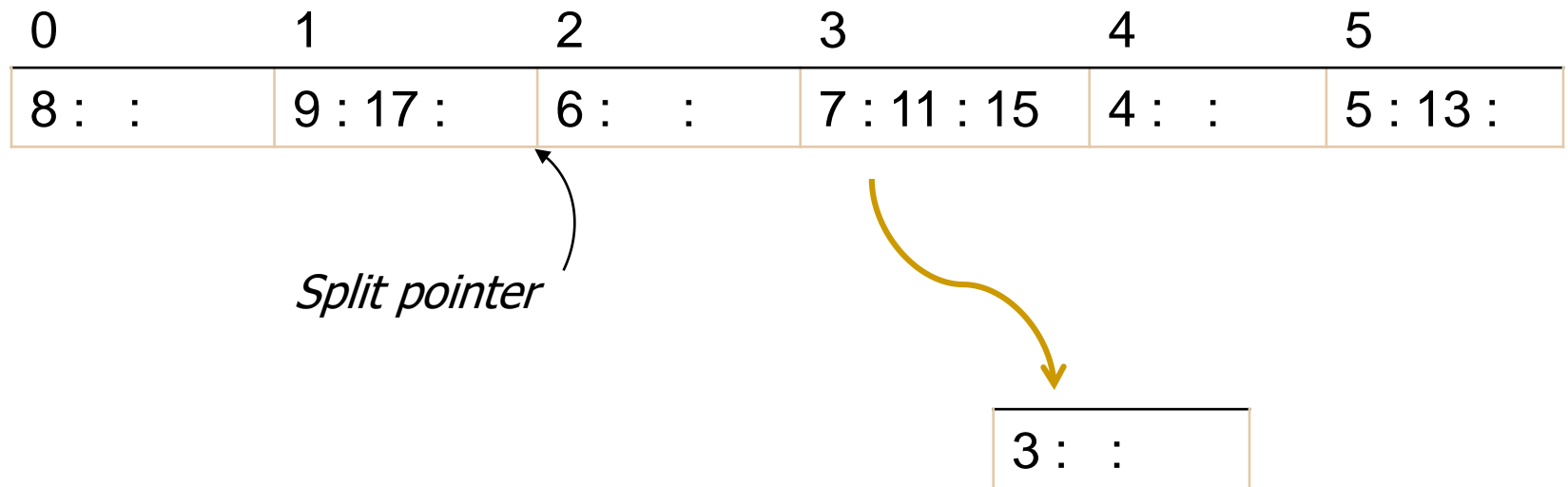
# Linear Hashing – Example(cont.)

5: bucket  $(5 \bmod 2^4 = ) 5$

9: bucket  $(9 \bmod 2^4 = ) 1$

13: bucket  $(13 \bmod 2^4 = ) 5$

17: bucket  $(17 \bmod 2^4 = ) 1$



# Linear Hashing – Example(cont.)

Bucket 3: overflow.

Split bucket 2.

Insert 23  
( $23 \bmod 4 = 3$ )

0	1	2	3	4	5
8 : :	9 : 17 :	6 : :	7 : 11 : 15	4 : :	5 : 13 :

*Split pointer*

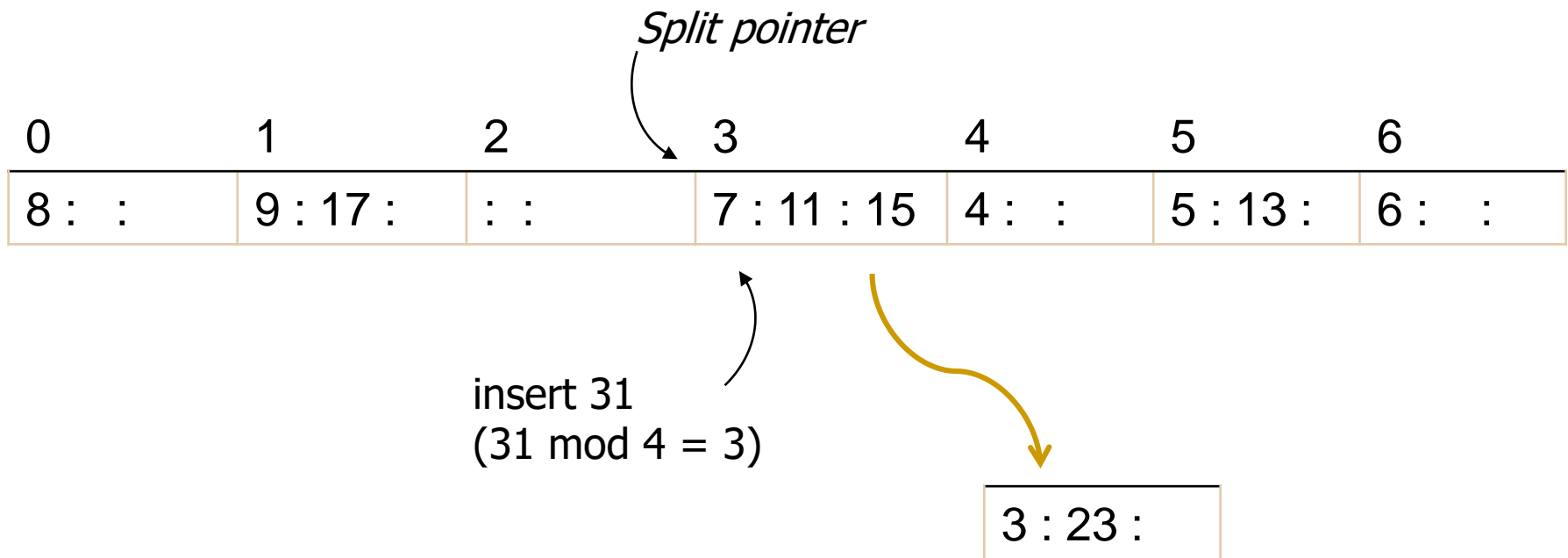
3 : :

# Linear Hashing – Example(cont.)

Bucket 3: overflow

Split bucket 3

=> Overflow records: Redistributed



# Linear Hashing – Example(cont.)

7: bucket ( $7 \bmod 2^4 =$ ) 7

11: bucket ( $11 \bmod 2^4 =$ ) 3

15: bucket ( $15 \bmod 2^4 =$ ) 3

3: bucket ( $3 \bmod 2^4 =$ ) 3

23: bucket ( $23 \bmod 2^4 =$ ) 7

31: bucket ( $31 \bmod 2^4 =$ ) = 7

$$h_1(K) = K \bmod 8$$

0	1	2	3	4	5	6	7
8 : :	9 : 17 :	: :	11 : 15 : 3	4 : :	5 : 13 :	6 : :	7 : 23 : 31

 *Split pointer*

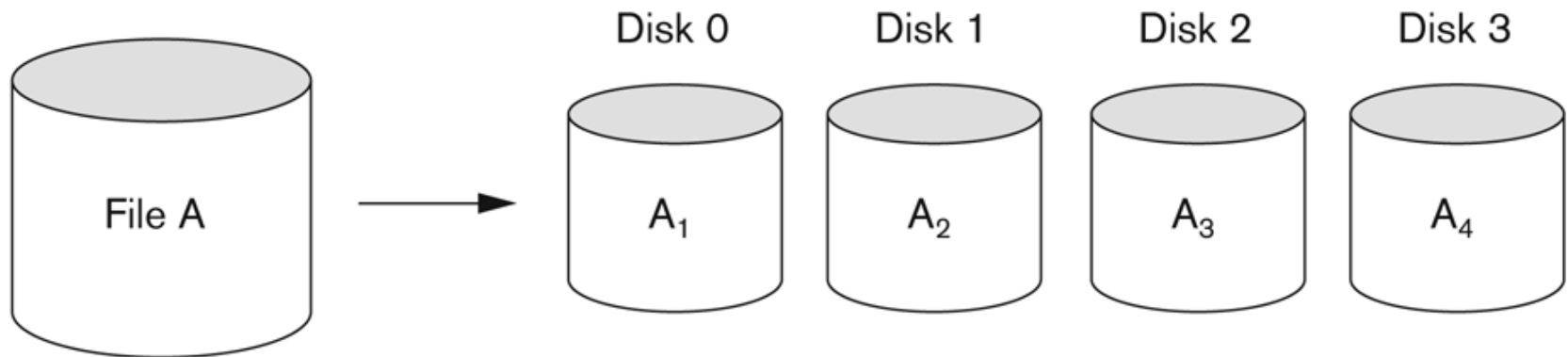
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# Parallelizing Disk Access using RAID Technology.

- Secondary storage technology must take steps to keep up in performance and reliability with processor technology.
- A major advance in secondary storage technology is represented by the development of **RAID**, which originally stood for **Redundant Arrays of Inexpensive Disks**.
- The main goal of RAID is to even out the widely different rates of performance improvement of disks against those in memory and microprocessors.

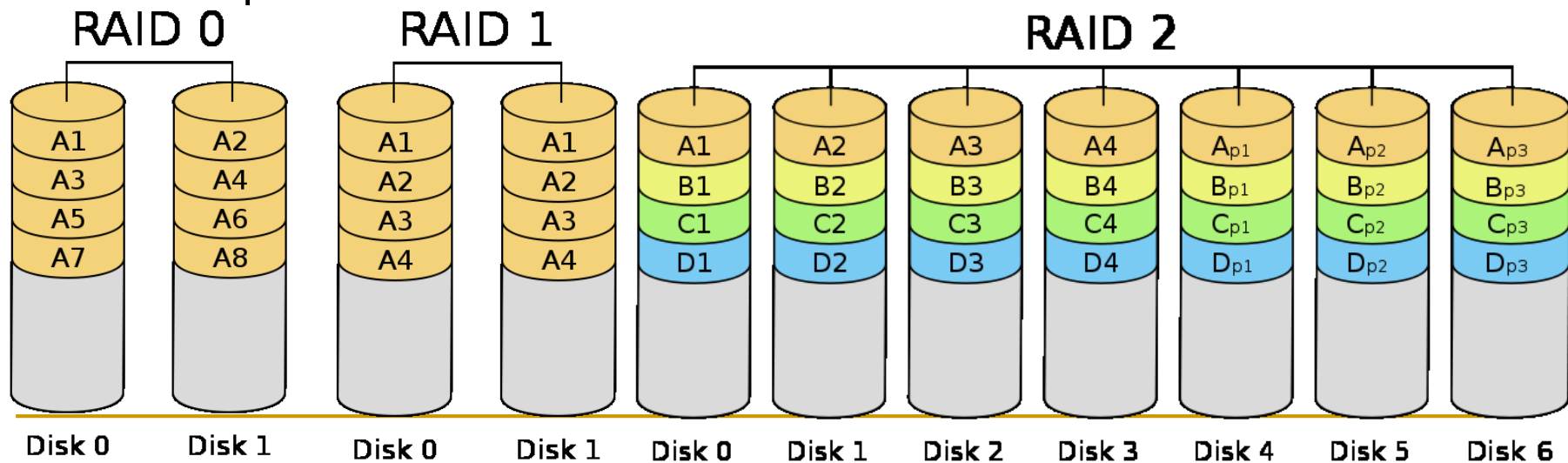
# RAID Technology (cont.)

- A natural solution is a large array of small independent disks acting as a single higher-performance logical disk. A concept called **data striping** is used, which utilizes *parallelism* to improve disk performance.
- Data striping distributes data transparently over multiple disks to make them appear as a single large, fast disk.



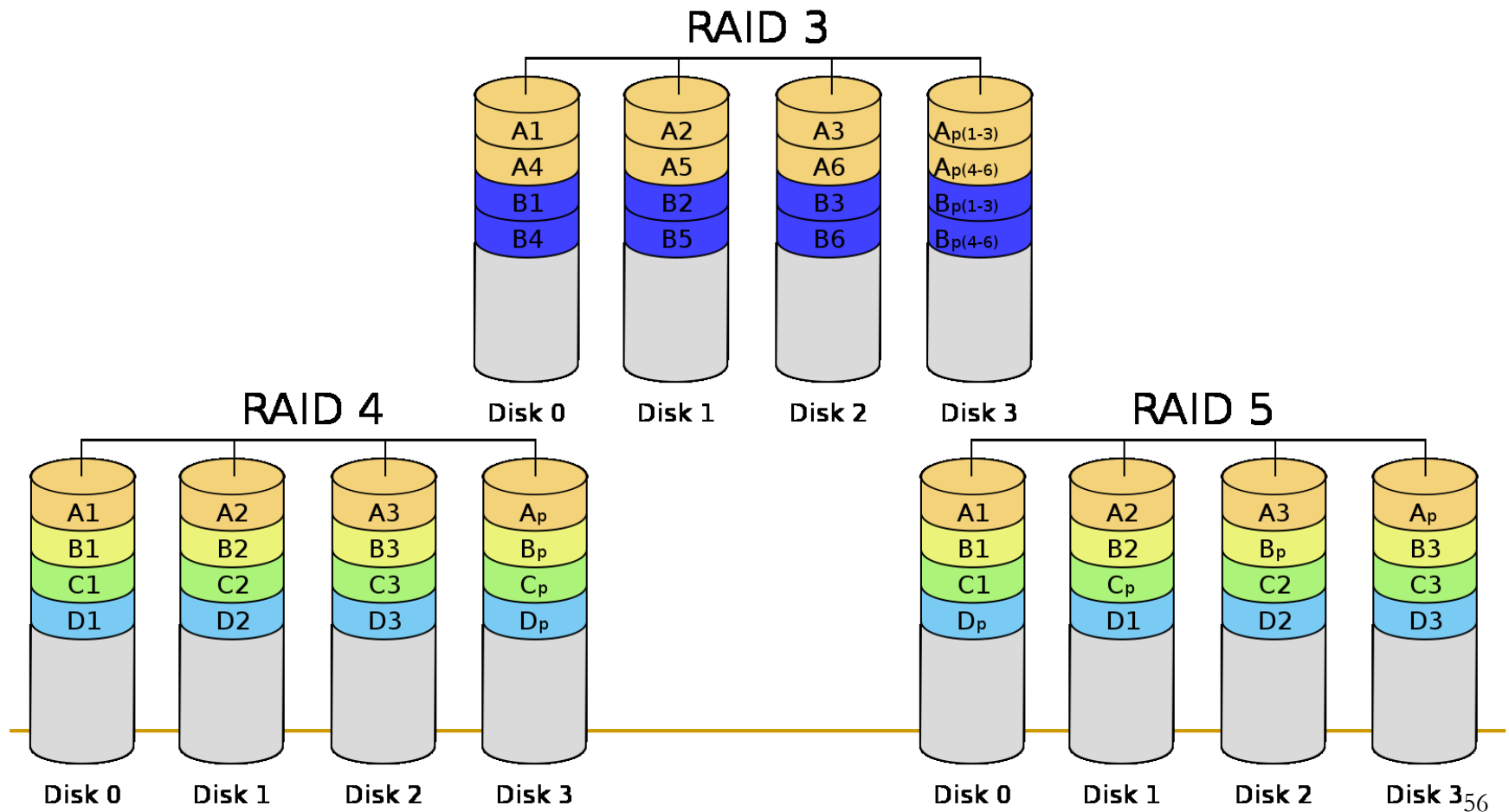
# RAID Technology (cont.)

- Different raid organizations were defined based on different combinations of the two factors of granularity of data interleaving (striping) and pattern used to compute redundant information.
  - **Raid level 0** has no redundant data and hence has the best write performance.
  - **Raid level 1** uses mirrored disks.
  - **Raid level 2** uses memory-style redundancy by using Hamming codes, which contain parity bits for distinct overlapping subsets of components. Level 2 includes both error detection and correction.



# RAID Technology (cont.)

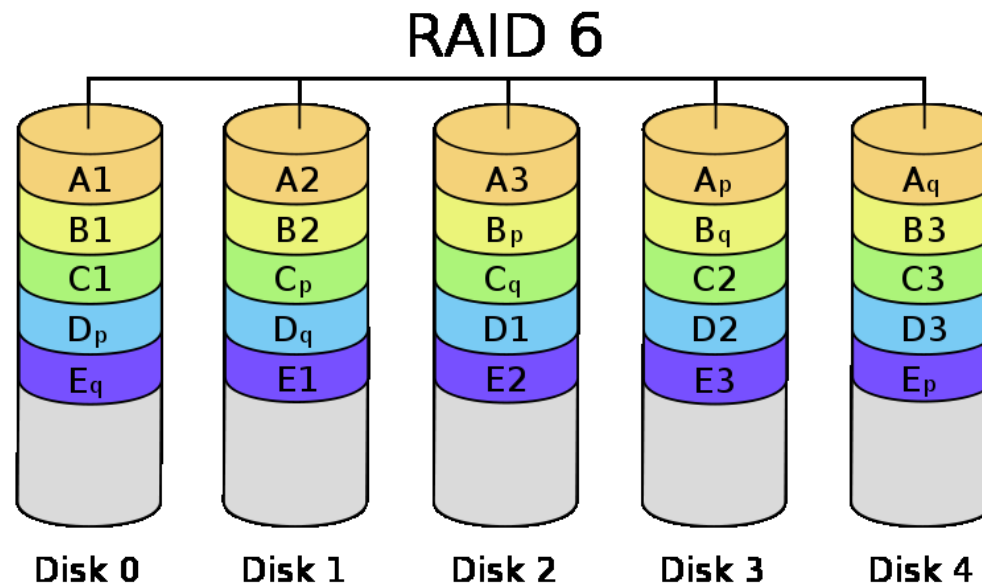
- ❑ **Raid level 3** uses a single parity disk relying on the disk controller to figure out which disk has failed.
- ❑ **Raid levels 4 and 5** use block-level data striping, with level 5 distributing data and parity information across all disks.





# RAID Technology (cont.)

- ❑ **Raid level 6** applies the so-called  $P + Q$  redundancy scheme using Reed-Soloman codes to protect against up to two disk failures by using just two redundant disks.



# Use of RAID Technology (cont.)

- Different raid organizations are being used under different situations:
  - **Raid level 1** (mirrored disks) is the easiest for rebuild of a disk from other disks
    - It is used for critical applications like logs.
  - **Raid level 2** uses memory-style redundancy by using Hamming codes, which contain parity bits for distinct overlapping subsets of components. Level 2 includes both error detection and correction.
  - **Raid level 3** (single parity disks relying on the disk controller to figure out which disk has failed) and **level 5** (block-level data striping) are preferred for large volume storage, with level 3 giving higher transfer rates.
  - Most popular uses of the RAID technology currently are: Level 0 (with striping), Level 1 (with mirroring) and Level 5 with an extra drive for parity.
  - Design decisions for RAID include – level of RAID, number of disks, choice of parity schemes, and grouping of disks for block-level striping.

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# Storage Area Networks

- The demand for higher storage has risen considerably in recent times.
- Organizations have a need to move from a static fixed data center oriented operation to a more flexible and dynamic infrastructure for information processing.
- Thus they are moving to a concept of Storage Area Networks (SANs).
  - In a SAN, online storage peripherals are configured as nodes on a high-speed network and can be attached and detached from servers in a very flexible manner.
- This allows storage systems to be placed at longer distances from the servers and provide different performance and connectivity options.

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# Storage Area Networks (cont.)

## ■ Advantages of SANs are:

- ❑ Flexible many-to-many connectivity among servers and storage devices using fiber channel hubs and switches.
- ❑ Up to 10km separation between a server and a storage system using appropriate fiber optic cables.
- ❑ Better isolation capabilities allowing nondisruptive addition of new peripherals and servers.

## ■ SANs face the problem of:

- ❑ combining storage options from multiple vendors
- ❑ dealing with evolving standards of storage management software and hardware.

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# Review questions

- 1) What is the difference between a file organization and an access method?
- 2) What is the difference between static and dynamic files?
- 3) What are the typical record-at-a-time operations for accessing a file? Which of these depend on the current record of a file?
- 4) Discuss the advantages and disadvantages of (a) unordered file, (b) ordered file, and (c) static hash file with buckets and chaining. Which operations can be performed efficiently on each of these organizations, and which operations are expensive?
- 5) Discuss the techniques for allowing a hash file to expand and shrink dynamically. What are the advantages and disadvantages of each?