Department of Computer Science
University of Cyprus

EPL646 – Advanced Topics in Databases

Lecture 5

Indexing II: Hash-based Indexing

Chapter 11: Ramakrishnan & Gehrke

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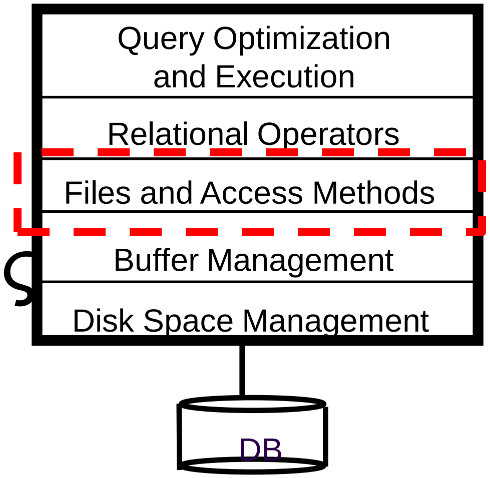
Lecture Outline

Hash Indexes (Ευρετήρια Κατακερματισμού)

- **11.1) Static Hashing (Στατικός Κατακερματισμός)**
- **Dynamic Hashing (Δυναμικός Κατακερματισμός)**
  - 11.2) Extendible Hashing (Επεκτατός Κατακερματισμός)
  - 11.3) Linear Hashing (Γραμμικός Κατακερματισμός)
  - 11.4) Extendible vs Linear Hashing

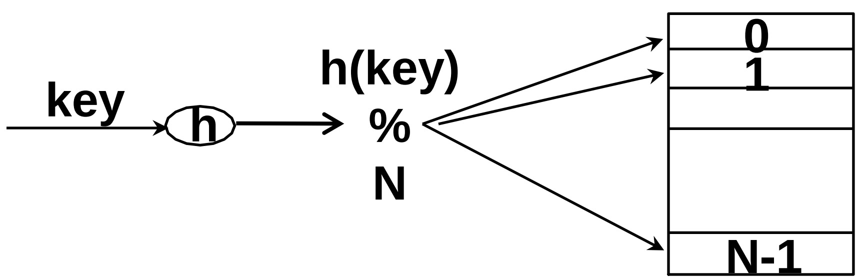


Introductory Remarks
(Εισαγωγικές Επισημάνσεις)

- *As for **any index**, 3 alternatives for data entries **k***:*
  - **Alternative 1: <k>**
  - **Alternative 2: <k, RID>**
  - **Alternative 3: <k, [RID_1, RID_2, …, RID_n]>**
  - **Choice orthogonal to the *indexing technique***
- **Hashing (Κατακερματισμός): key-to-address transformation:** involves **computing** the **address** of a **data item** by computing a **function** on the **search key value**.
- ***Hash* Indexes** (Ευρετήρια Κατακερματισμού) are best for ***equality queries (Επερωτήσεις Ισότητας)***. ***Cannot*** support **range queries**.

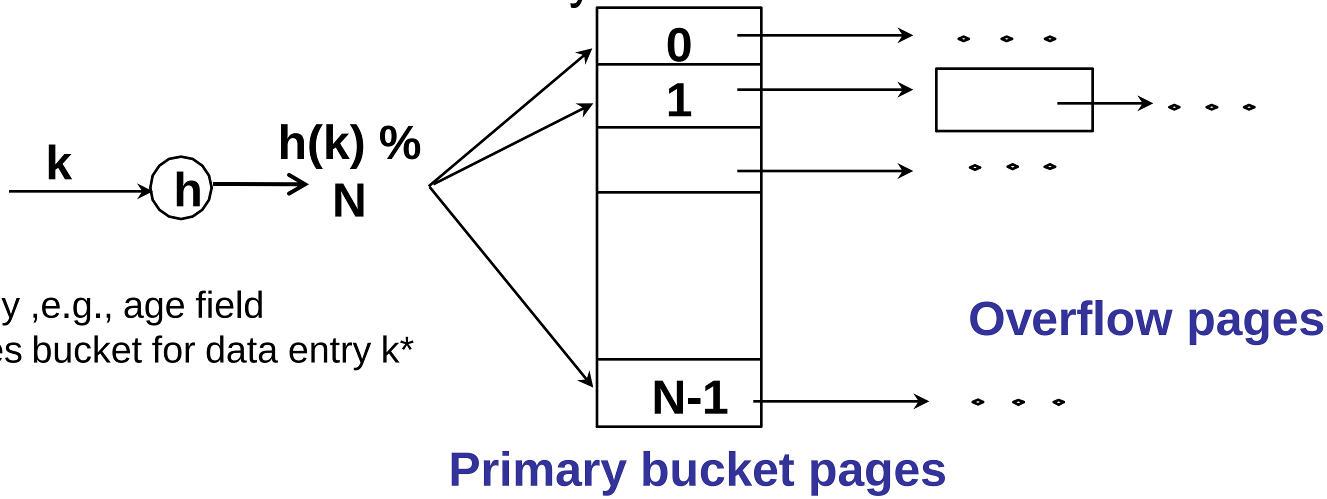
Hash Function *h(k)* (Συνάρτηση Κατακερματισμού)

- **Hash function [h(key)]:** Maps the **key** to a **bucket (κάδο**) where the key is expected to belong.
- A good hash function has the following properties:
  - **Distributes keys uniformly (ομοιόμορφα) -** all buckets are equally likely to be picked - and at **random (τυχαία) -** similar hash keys should be hashed to very different buckets.
  - **Low Cost.** Plain hash functions (rather than cryptographic hash functions such as MD5,SHA1) usually have a low computational cost.
  - **Determinism:** for a given input value it always generates same hashvalue.
- We shall utilize a **Trivial Hash Function (τετριμμένη συνάρτηση κατακερματισμού), i.e.,** the data itself (interpreted as an integer in binary notation). E.g., $\mathbf{44_{10} = 101100_2}$
- Which Bucket does key *k* belong to: **h(*k*) mod N (N = # of buckets)**. These are the **d least significant bits.**



Static Hashing (Στατικός Κατακερματισμός)

- Build a **fixed structure** at **index construction time**.
- Data Entries are stored on a number of **successive primary pages (πρωτοβάθμιες σελίδες).**
  - Primary pages are **fixed**, **allocated sequentially** during index construction. **Overflow pages** (σελίδες υπερχείλισης) are utilized when primary pages get full.
  - **Primary** Pages are never **de-allocated** during deletions.
  - That is similar to the way ISAM indexes are constructed…



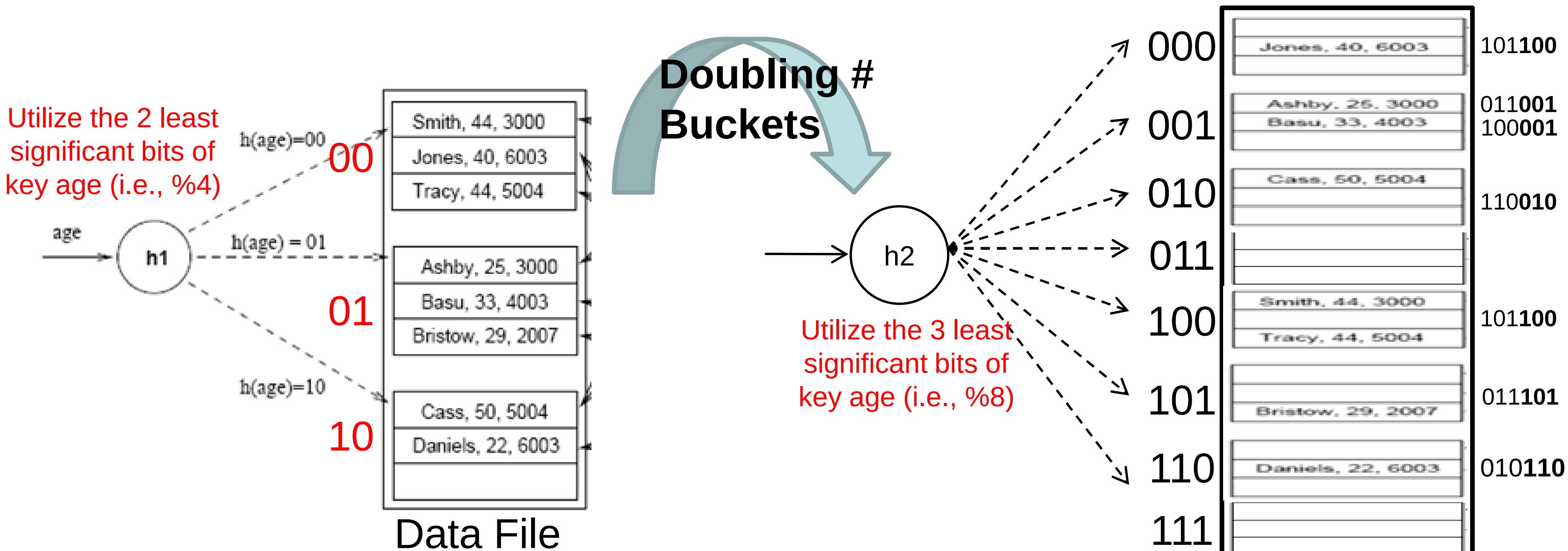
k: Search Key ,e.g., age field
h(k): Identifies bucket for data entry k*

Static Hashing (Στατικός Κατακερματισμός)

- **Search**: Ideally **1 I/O** (unless record is located in overflow chain). **Insert/Delete: 2 I/Os** (read and write) page.
- **Drawback: Long overflow chains (Αλυσίδες Σελίδων Υπερχείλισης)** can develop and degrade performance.
- **How to avoid overflow chains?**
  1. **80% Occupancy:** By initially keeping pages 80% full we can avoid overflow pages if the file does not grow too much.
  2. **Rehashing (Επανακερματισμός):** Hash the file with a different **hash function** (see next slide) to achieve 80% occupancy and no overflows. Drawback: Takes time (we need to rehash the complete DB)!
  3. **Dynamic Hashing:** Allow the **hash function** to be modified **dynamically** to accommodate the **growth**/shrink of the database (i.e., essentially rehash selected, rather than all, items)
     - Extendible Hashing (Επεκτακτό Κατακερματισμό)
     - Linear Hashing (Γραμμικό Κατακερματισμό)

Extendible Hashing (Επεκτατός Κατακερματισμός)

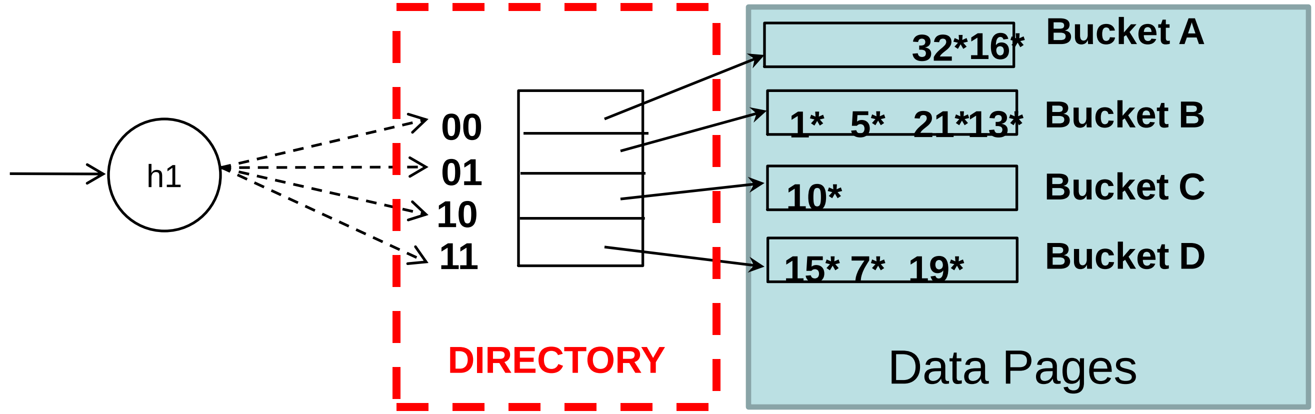
- To understand the motivation of Extendible Hashing consider the following **situation**:
- A Bucket (primary page) becomes full (e.g., page 00 on left).**Why not re-organize file by *doubling* # of buckets?**



- **Answer:** The entire file has to be **read** once and **written** back to disk to achieve the reorganization, which is **expensive**!

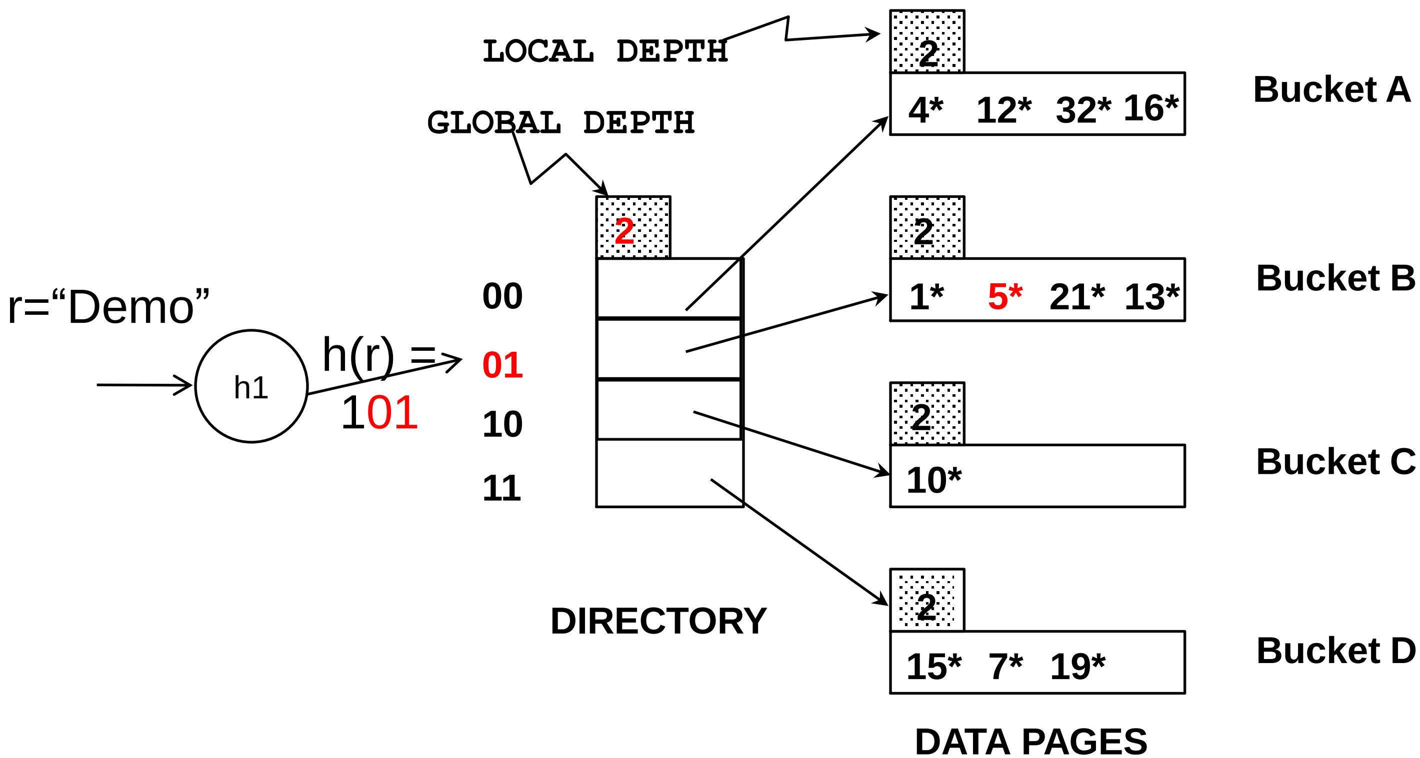
Extendible Hashing (Επεκτατός Κατακερματισμός)

- *<u>Basic Idea:</u>* ***Use directory of pointers to buckets and double the directory*** **instead of Doubling the Data file.**
  - Directory much smaller than file, so doubling is much cheaper.
- Just split the bucket that overflowed NOT ALL of them
  - Only one page of data entries is split.
  - Additionally, no overflow pages are constructed!



Extendible Hashing: **Search**
(Επεκτατός Κατακερματισμός: **Αναζήτηση**)

- **Example:** Locate data entry **r** with hash value **h(r)=5 (binary 101)**. Look at directory element 01 (i.e., **"Global-depth least-significant bits of h(r), δηλ., 2 λιγότερα σημαντικά ψηφία"**)
- We then follow the pointer to the data page (bucket B in figure)



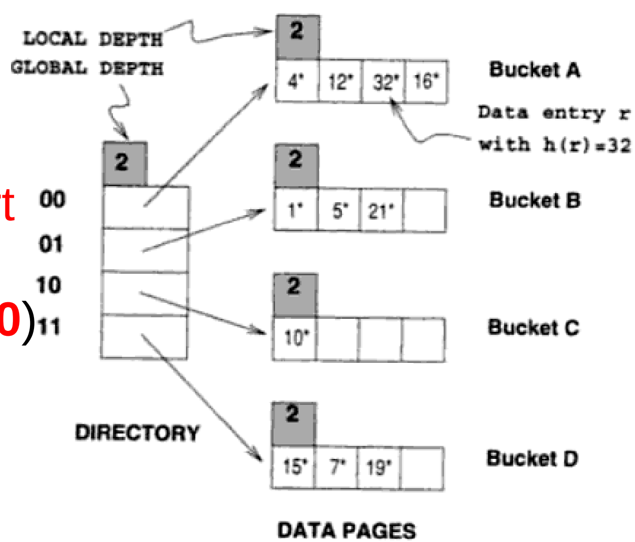
Global/Local Depths to be described more carefully next

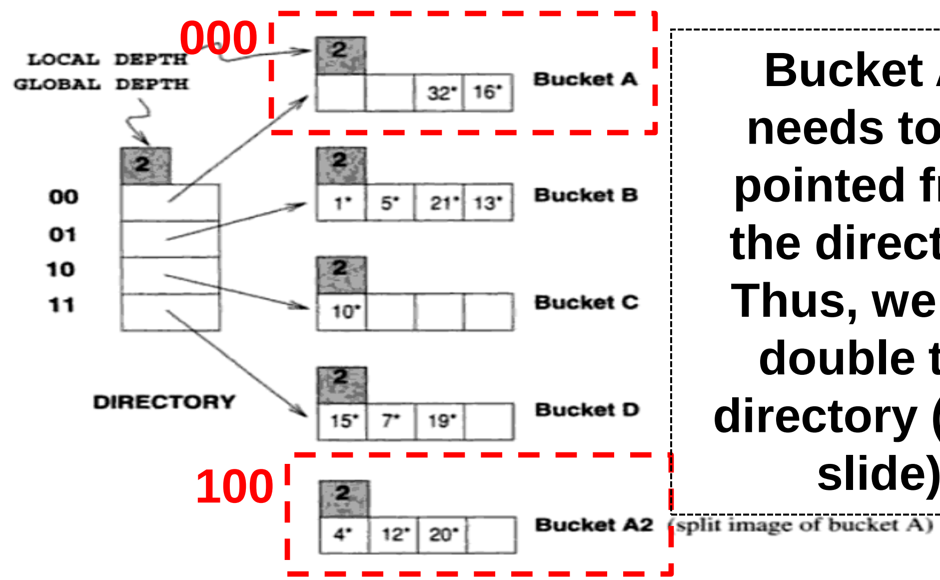
Extendible Hashing: **Insert**
(Επεκτατός Κατακερματισμός: **Εισαγωγή**)

Insert Algorithm Outline

- Find target buffer: Done similarly to Search
- If target bucket is **NOT full**, insert and finish (e.g., insert h(r)=9, which is binary 10**01**, can be inserted to bucket B).
- If target bucket is full, **split** it (allocate new page and re-distribute). E.g., insertion of **h(r)=20** (101**00**) causes the split of bucket A and redistribution between **A** and **A2**

Insert 20 (101**00**)

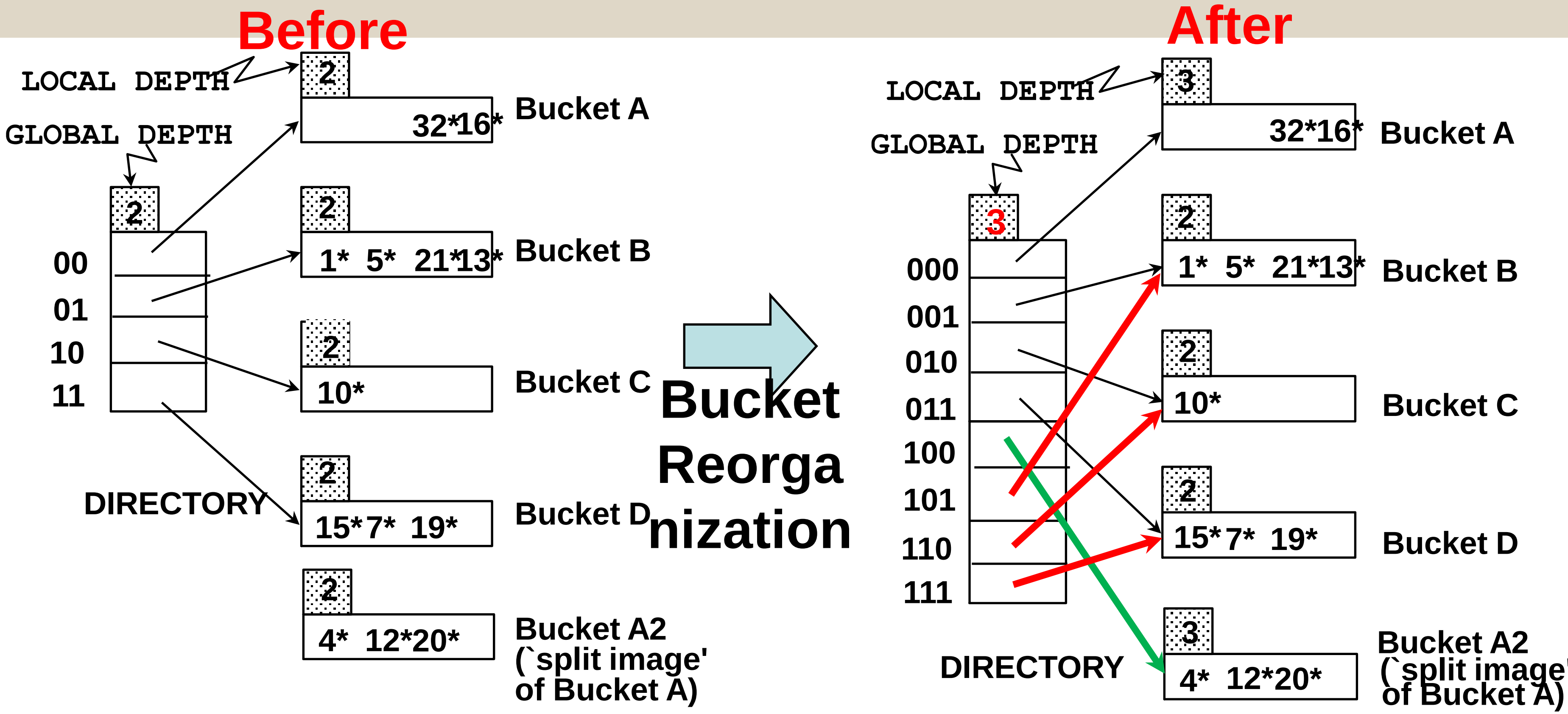




Bucket A2 needs to be pointed from the directory. Thus, we will double the directory (next slide)

Split Image of A (Απεικόνιση Διαίρεσης)

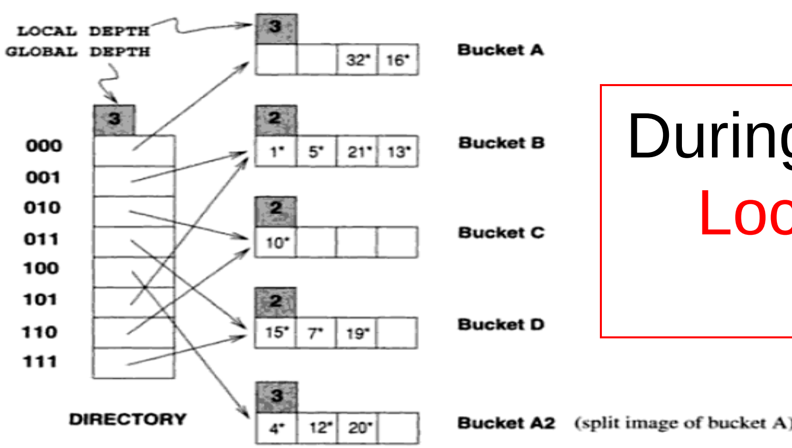
Insert h(r)=20 (Causes Doubling)



- **When does bucket split cause directory doubling?**
  - *When target bucket is full AND Local Depth == Global Depth*
    - *Otherwise, a red pointer is available (i.e., vacant page is already avail.).*
- *Notice that after doubling some pointers (red) are redundant (those will be utilized in subsequent inserts)*

Comments on Extendible Hashing (Σχόλια για τον Επεκτατό Κατακερματισμό)

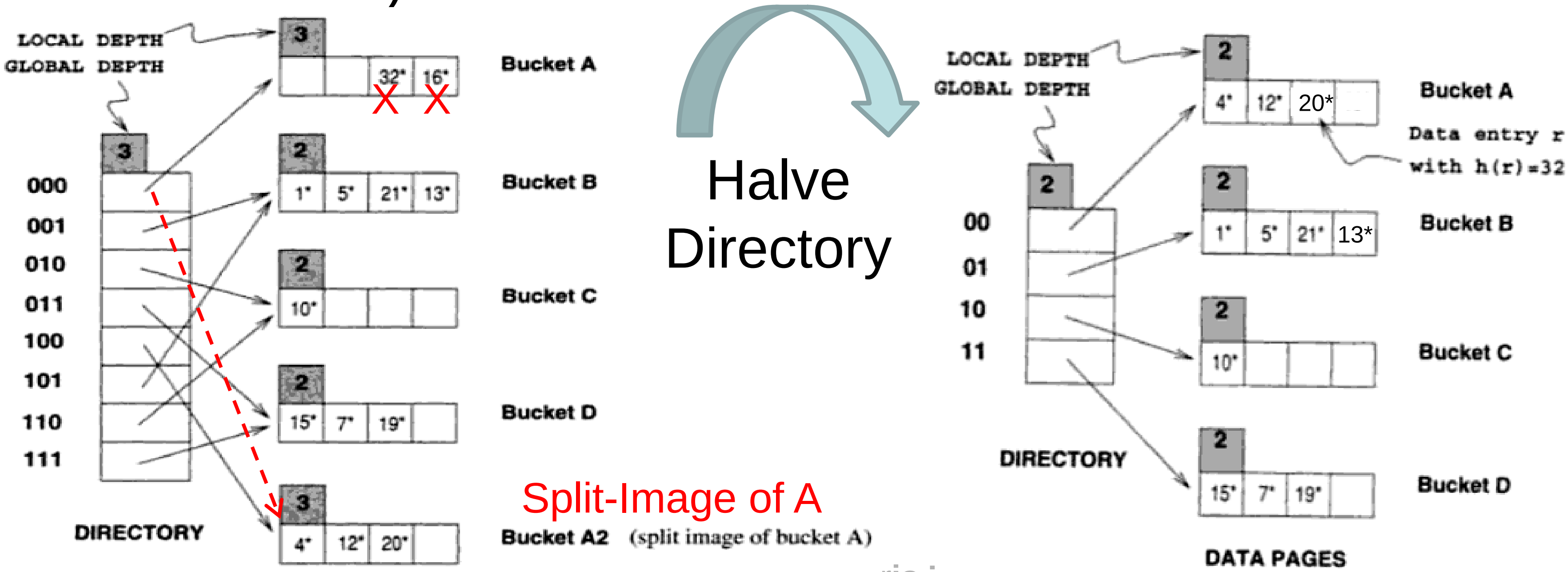
- *Global depth of directory*: Tells us how many least significant bits to utilize during **the selection of the target bucket**.
  - Initially equal to $\log_2$(#Buckets), e.g., $\log_2 8=3$
  - **Directory Doubles => Increment Global Depth**
- *Local depth of a bucket*: Tells as how many **least significant bits** to utilize to determine if an **entry belongs to a given bucket.**
  - **Bucket is Split => Increment Local Depth**
- **(GlobalDepth – LocalDepth)** can be larger than 1 (e.g., if corresponding buckets are continuously splitted leaving in that way the local depth of other nodes small while global depth increases)



During an Insertion to full bucket if
Local Depth == Global Depth
then we need to split!

Extendible Hashing: **Delete**
(Επεκτατός Κατακερματισμός: **Διαγραφή**)

- **Delete:** Essentially the **reverse** operation of **insertion**
- If removal of data entry makes **bucket empty** then **merge** with **`split image’** (e.g., delete 32,16, then merge with A2)
- If **every bucket is** pointed by two directory elements we should halve the directory (although not necessary for correctness)



Comments on Extendible Hashing (Σχόλια για τον Επεκτατό Κατακερματισμό)

- **Equality Search Cost:** If directory fits in memory then answered with **1** disk access; else **2.**
  - **Static Hashing** on the other hand performs eq**uality searches** with **1 I/O** (assuming no collisions).
- Yet, the Extendible Hashing Directory can usually easily fit in main memory, thus same cost.

Other issues:

- Directory can grow large if the distribution *of hash values* is **skewed (ασύμμετρη κατανομή)** (e.g., some buckets are utilized by many keys, while others remain empty).
- Multiple entries with same hash value (**collisions**) cause problems … as splitting will not redistribute equally the keys

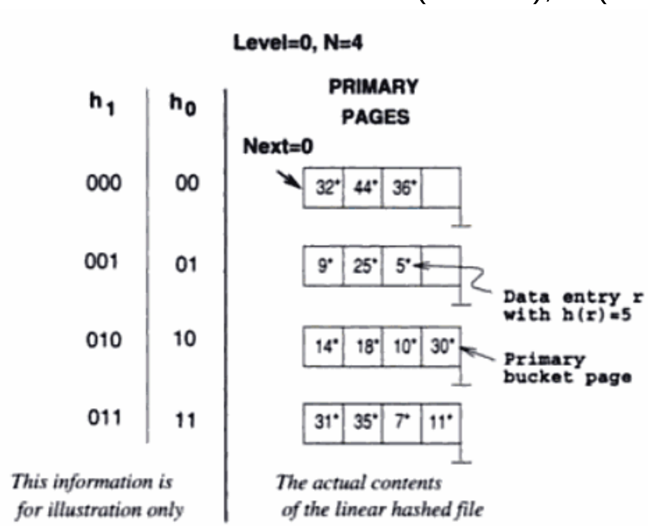
Linear Hashing (LH)
(Γραμμικός Κατακερματισμός - ΓΚ)

- Another **dynamic hashing** scheme (like EH).
- LH handles the problem of long overflow chains (presented in Static Hashing) **without using a directory** (what EH does)
- ***Idea***: Use a family of hash functions $\mathbf{h}_0$, $\mathbf{h}_1$, $\mathbf{h}_2$, ... where each hash function maps the elements to twice the range of its predecessor, i.e.,
  - if $\mathbf{h_i(r)}$ maps a data entry **r** into **M** buckets, then $\mathbf{h_{i+1}(r)}$ maps a data entry into one of **2M** buckets. Hash functions are like below:
    - $\mathbf{h}_i(key) = \mathbf{h}(key) \bmod (2^i N)$, i=0,1,2… and N="initial-#-of-buckets"
  - We proceed in **rounds** of splits: During round ***Level*** only $\mathbf{h}_{Level}(r)$ and $\mathbf{h}_{Level+1}(r)$ are in use.
  - The buckets in the file are **split** (every time we have an overflow), **one-by-one** from the **first** to the **last** bucket, thereby **doubling the number of buckets**.

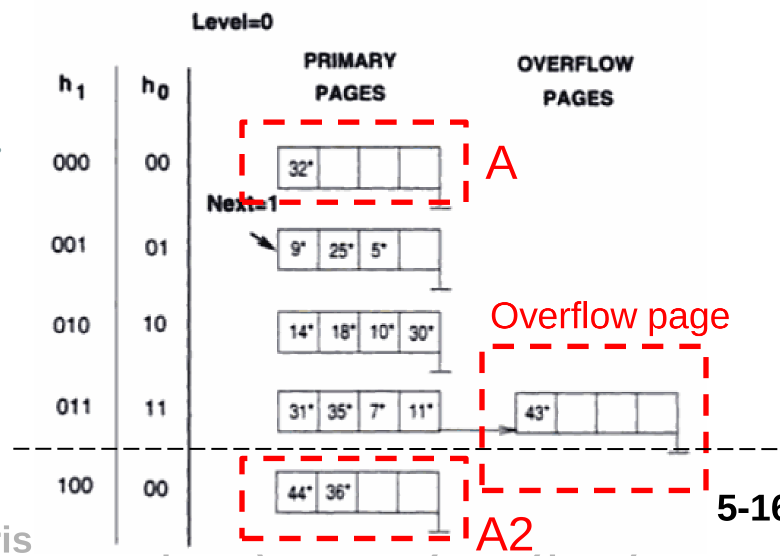
Linear Hashing: **Insertion**
(Γραμμικός Κατακερματισμός: **Εισαγωγή**)

Insert Algorithm Outline:

- Find target buffer (similarly to search with **$h_{Level}(r)$ and $h_{Level+1}(r)$**)
- If target bucket is **NOT full**, insert and finish (e.g., insert h(r)=9, which is binary 10**01**, can be inserted to bucket B).
- If target bucket is full:
  - Add **overflow page** and **insert data entry**. (e.g., by inserting **h(r)=43** (1010**11**) causes the split of bucket A and redistribution between **A** and **A2**
  - **Split *Next*** bucket and **increment *Next*** (can be performed in batch mode)
    - Note that 32(100**000**), 44(101**100**), 36(100**100**)



Add 43 (1010**11**$_2$)



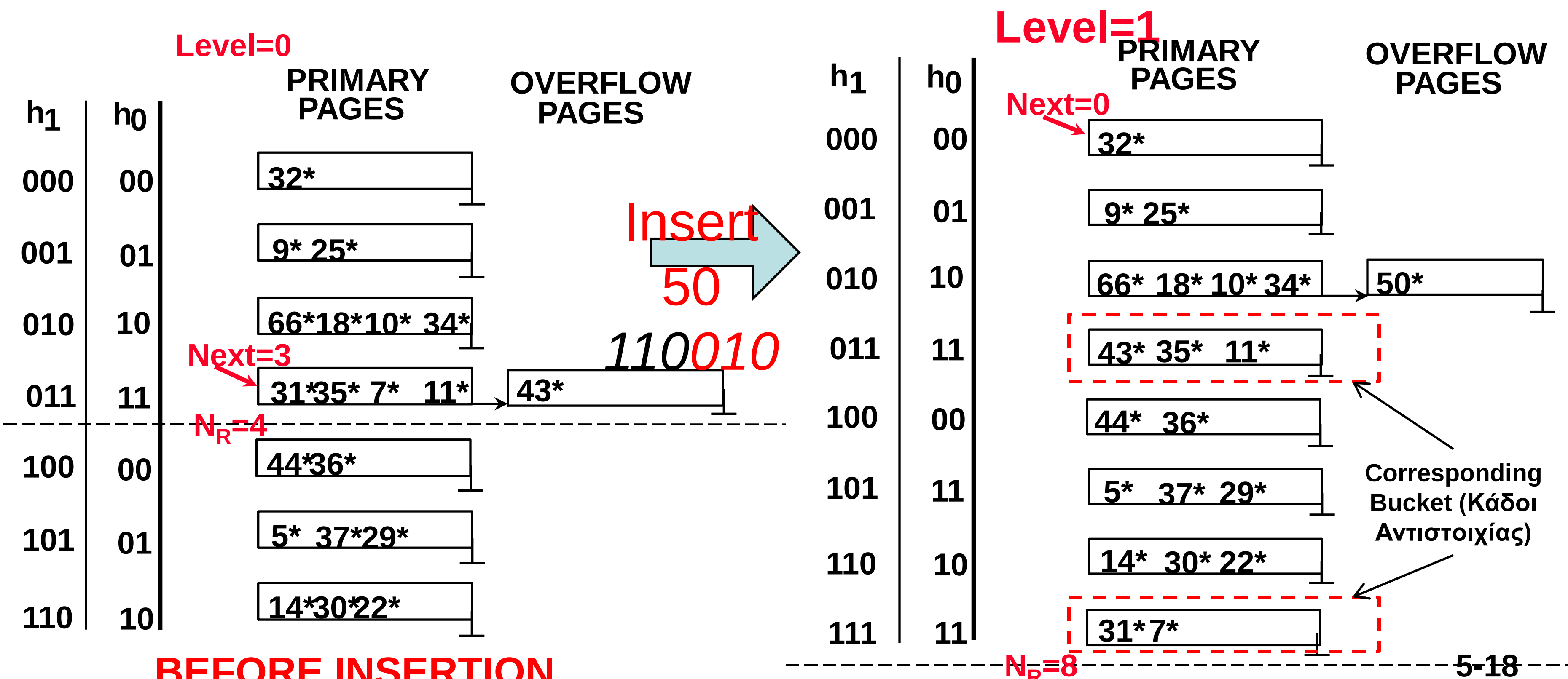
Linear Hashing: **Insertion Remarks**
(Γραμμικός Κατακερματισμός: **Επισημάνσεις Εισαγωγής**)

- *The buckets in the file **are split** (every time we have an overflow), **one-by-one** from the **first** to the **last** bucket* $\mathbf{N_R}$ *(using **Next** index), thereby **doubling** the number of **buckets**.*
- Since buckets are split round-robin, **long overflow chains presumably don't develop** (like static hashing) as eventually every bucket has a good probability of a split!
- LH can choose any **criterion** to **`trigger' (προκαλέσει) split :**
  - e.g., Split whenever an **overflow page** is added.
  - e.g., Split whenever the **index is e.g., 75% full.**
  - Many other **heuristics** could be utilized.

Linear Hashing: **Increasing Level after Insert**

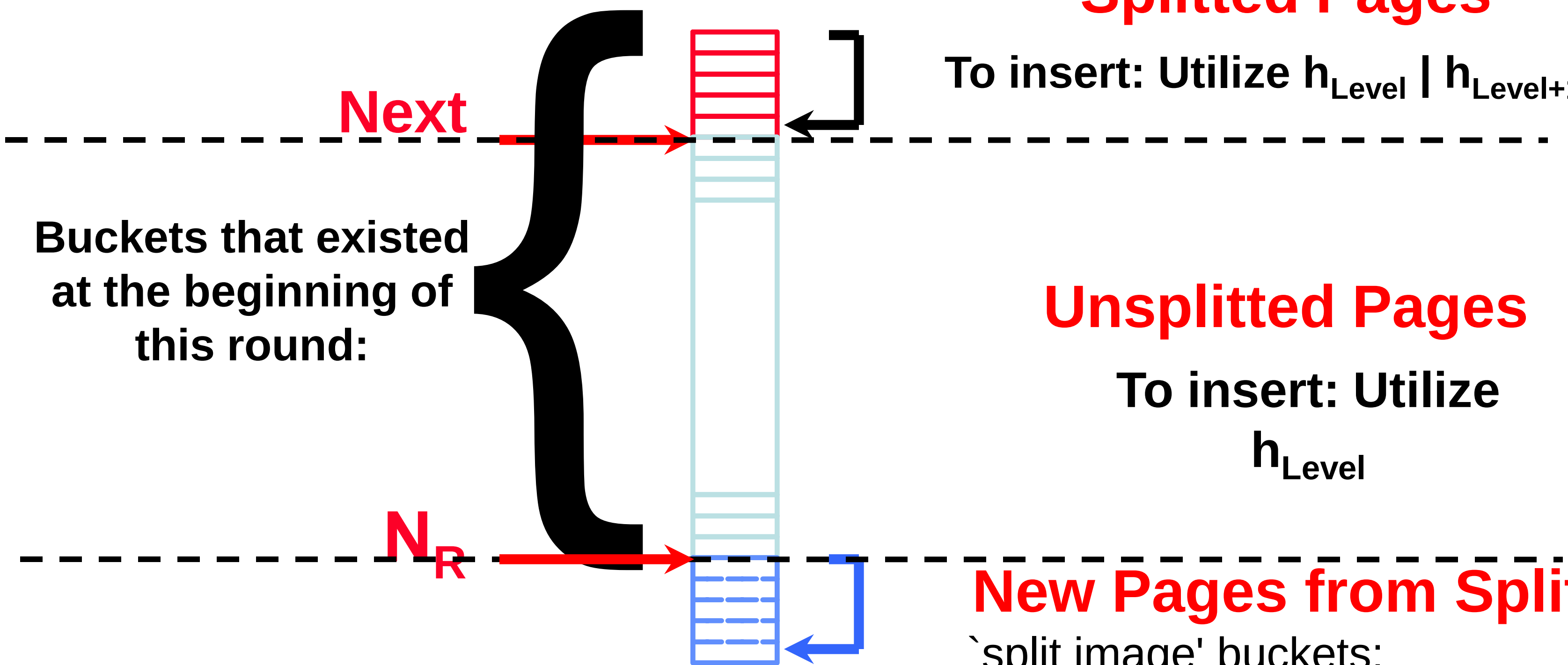
If **Next = N_R** (after overflow) then level is increased by 1 (thus h2, h1 will be utilized) and Next becomes 0

- *Below the addition of 50* (110010)causes Next to become equal to 4, thus the Level is increased by one.*



Overview of LH File (Ανασκόπηση Αρχείου ΓΚ)

- *Assume that we are in the **middle** of an **execution**.*
- *Then the Linear Hash file has the **following structure***



Splitted Pages

To insert: Utilize h_{Level} | $h_{Level+1}$

Buckets that existed at the beginning of this round:

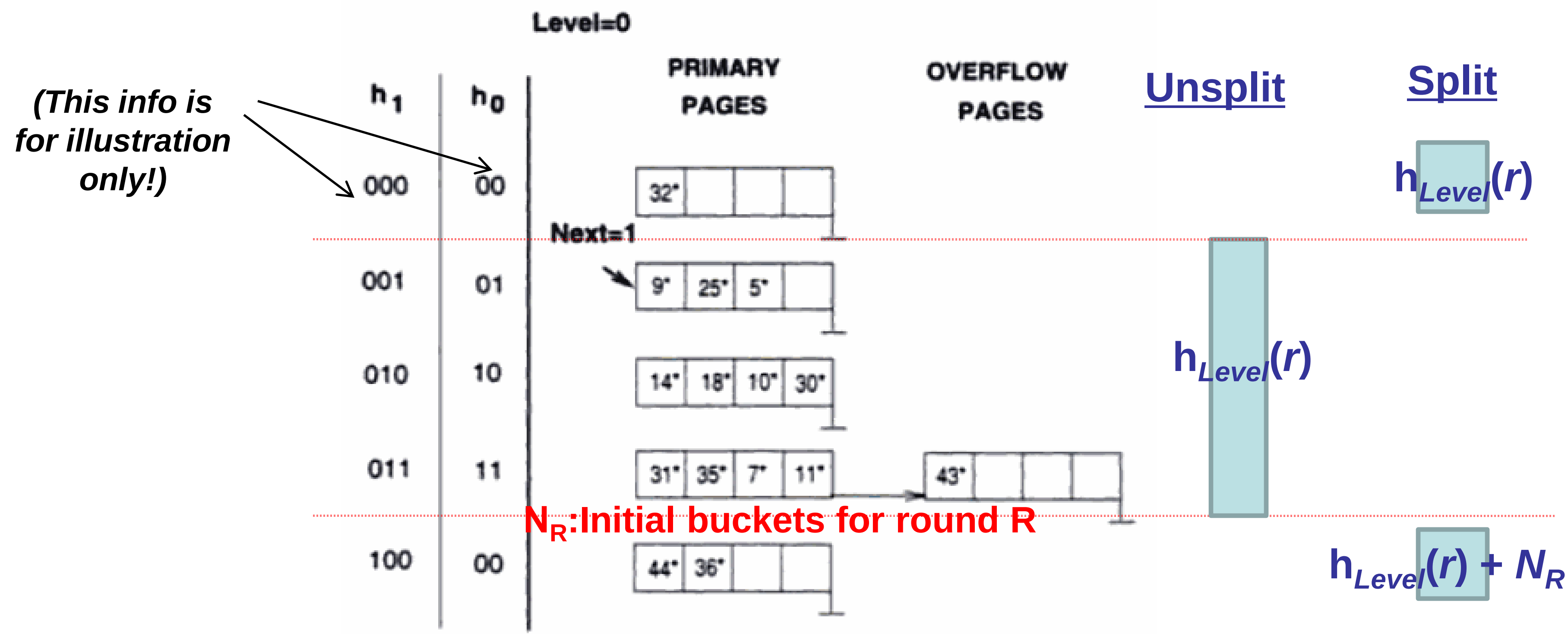
Unsplitted Pages

To insert: Utilize h_{Level}

New Pages from Split

\`split image' buckets: created (through splitting of other buckets) in this round

Linear Hashing: **Search**
(Γραμμικός Κατακερματισμός : **Αναζήτηση**)



Search: To find bucket for data entry *r*, find **h_{Level}**(*r*)*:*

Unsplit Bucket: If **h**$_{Level}$(*r*) in range **[*Next..N*$_R$)** then *r* belongs here (e.g., 9)

Split Bucket: If **h**$_{Level}$(*r*) maps to bucket smaller than N*ext (i.e., a bucket that was split previously, then* **r** could belong to bucket **h$_{Level}$(*r*)** or bucket **h$_{Level}$(*r*) + *N*$_R$**; **must apply h$_{Level+1}$(*r*) to find out (e.g., 44_{10}=101100$_2$)**