Hash-based Index

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CS 3200 Lesson 15
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Outline

- Deep dive Hash Index

Hashed-Based Indexing

- Static Hashing: A simple solution; does not support incremental maintenance
- Extendible Hashing: A more advanced **incremental** hash-based index
  - Gracefully supports inserting and deleting data entries
- Linear Hashing: Another incremental hash-based index

Why is Indexing necessary?

- There are lots of data structures like trees, DAGs, and things with many algorithms that operate on them efficiently.
- Why don't these algorithms and data structures translate directly into disk-space structures?
- Pointers work nicely in main memory -- how do you represent pointers in main memory?
- Data structures can be arbitrarily sized, but disk blocks are fixed size (and are larger than many objects).
- Files typically only grow at the end -- they don't support "insert into the middle."

Introduction

- *As for any index, 3 alternatives for data entries* **k***:
  - Data record with key value **k**
  - <**k**, rid of data record with search key value **k**>
  - <**k**, list of rids of data records with search key **k**>
  - Choice orthogonal to the *indexing technique*
- *Hash-based* indexes are best for *equality selections*. ***Cannot*** support range searches.
- Static and dynamic hashing techniques exist; trade-offs similar to ISAM vs. B+ trees.

Hashing mechanism

- Your index is a collection of *buckets* (bucket = page)
- Define a hash function, *h*, that maps a key to a bucket.
- Store the corresponding data in that bucket.
- Collisions
  - Multiple keys hash to the same bucket.
  - Store multiple keys in the same bucket.
- What do you do when buckets fill?
  - Chaining: link new pages(overflow pages) off the bucket.

Hashing to search key

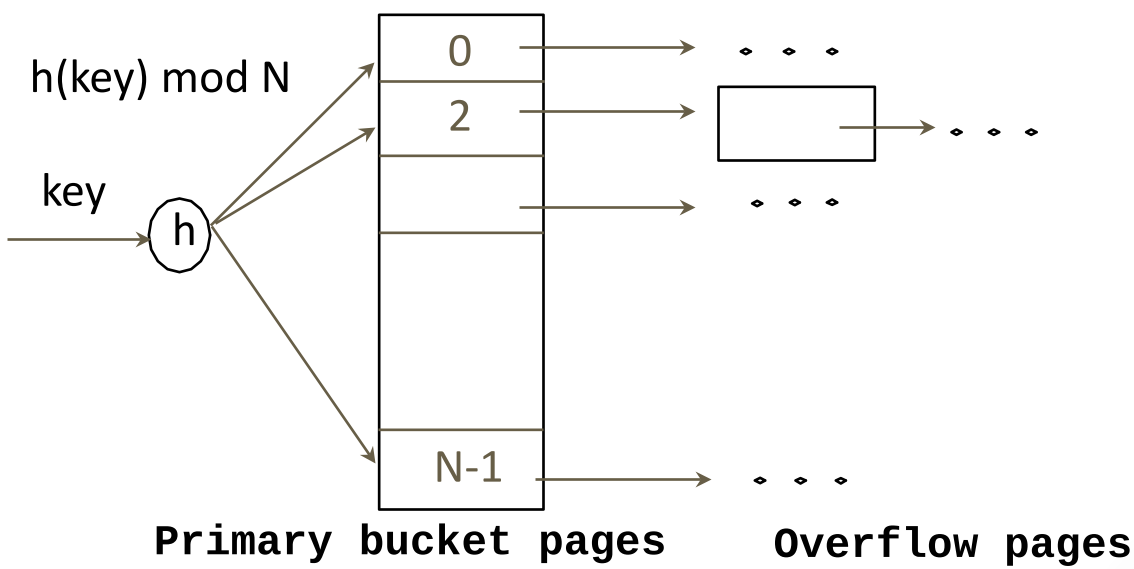
- Buckets contain *data entries*.
- Hash fn works on *search key* field of record *r.* Must distribute values over range 0 ... M-1.
  - **h**(*key*) = (a * *key* + b) usually works well.
  - a and b are constants; lots known about how to tune **h**.
- Long overflow chains can develop and degrade performance.
  - *Extendible* and *Linear Hashing*: Dynamic techniques to fix this problem.

Static vs. Dynamic Hashing

- Static: number of buckets predefined; never changes.
  - Either, overflow chains grow very long, OR
  - A lot of wasted space in unused buckets.
- Dynamic: number of buckets changes over time.
  - Hash function must adapt.
  - Usually, start revealing more bits of the hash value as the hash table grows.

Static Hashing

- # primary pages fixed, allocated sequentially, never de-allocated; overflow pages if needed.
- **h**(*k*) mod M = bucket to which data entry with key *k* belongs. (M = # of buckets)



Static Hashing (Contd.)

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Extendible Hashing

- Situation: Bucket (primary page) becomes full. Why not re-organize file by *doubling* # of buckets?
  - Reading and writing all pages is expensive!
  - *Idea*: Use *directory of pointers to buckets,* double # of buckets by *doubling the directory,* splitting just the bucket that overflowed!
  - Directory much smaller than file, so doubling it is much cheaper. Only one page of data entries is split. *No overflow page*!
  - Trick lies in how hash function is adjusted!

Static Hash-based Index

- Number of buckets (N) is fixed ahead of time, when the index is created
- What happens if we insert a lot of data entries?
  - Long overflow chains of pages, slower search
- Might consider periodically doubling N and“rehashing” the file
  - Entire file has to be read and written (expensive)
  - Index unavailable while reorganizing
  - Extendible hashing is a dynamic hash index, which helps fix this problem

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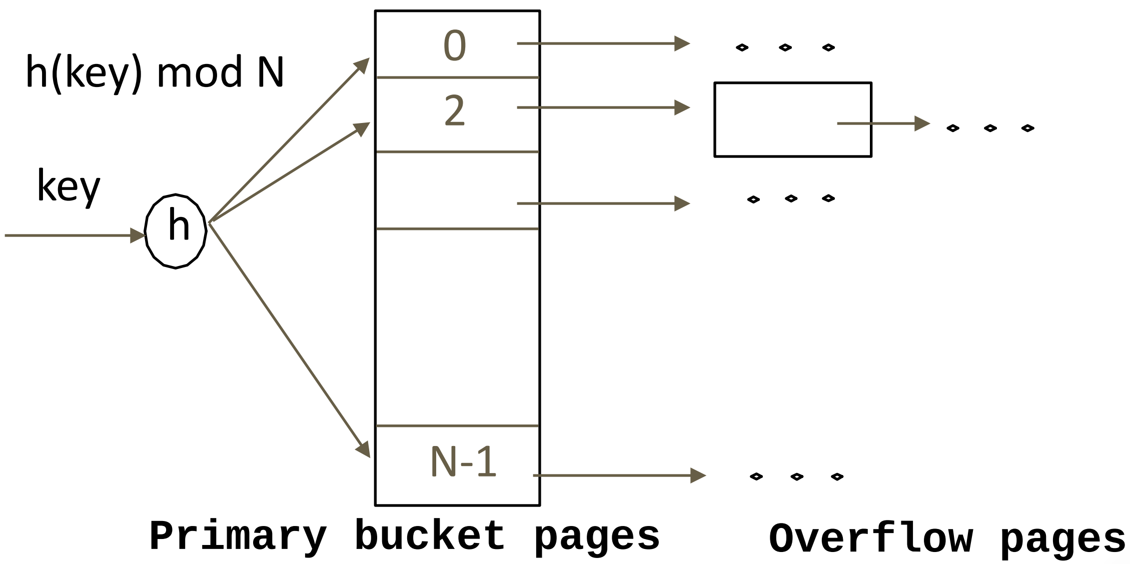

Static hashing

- Buckets map to pages.
  - Must be able to directly translate from a bucket number to a page number.
  - Where do you store overflow pages?
  - If number of buckets is fixed (static hashing), store overflow buckets after regular buckets.
  - Use free list to manage overflow buckets.
- Static hashing isn't very practical for databases.
- Databases change in size fairly substantially.
- If you have to pre-allocate, often waste space

Extendible Hashing

- **Main Idea:** Use a directory of (logical) pointers to bucket pages
- On overflow, double the directory (not # number of buckets)
  - Why does this help?
  - Directory much smaller than entire index
  - Only one page of data entries is split at a time
  - No overflow pages

Extendible Hashing

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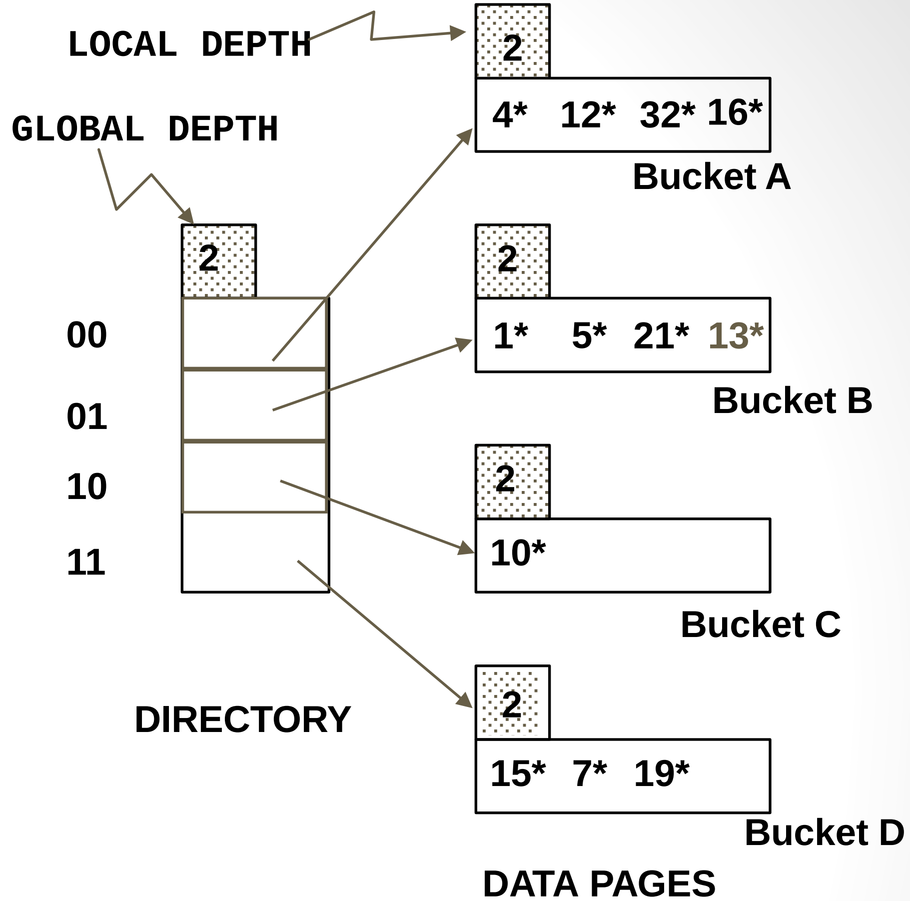
Example

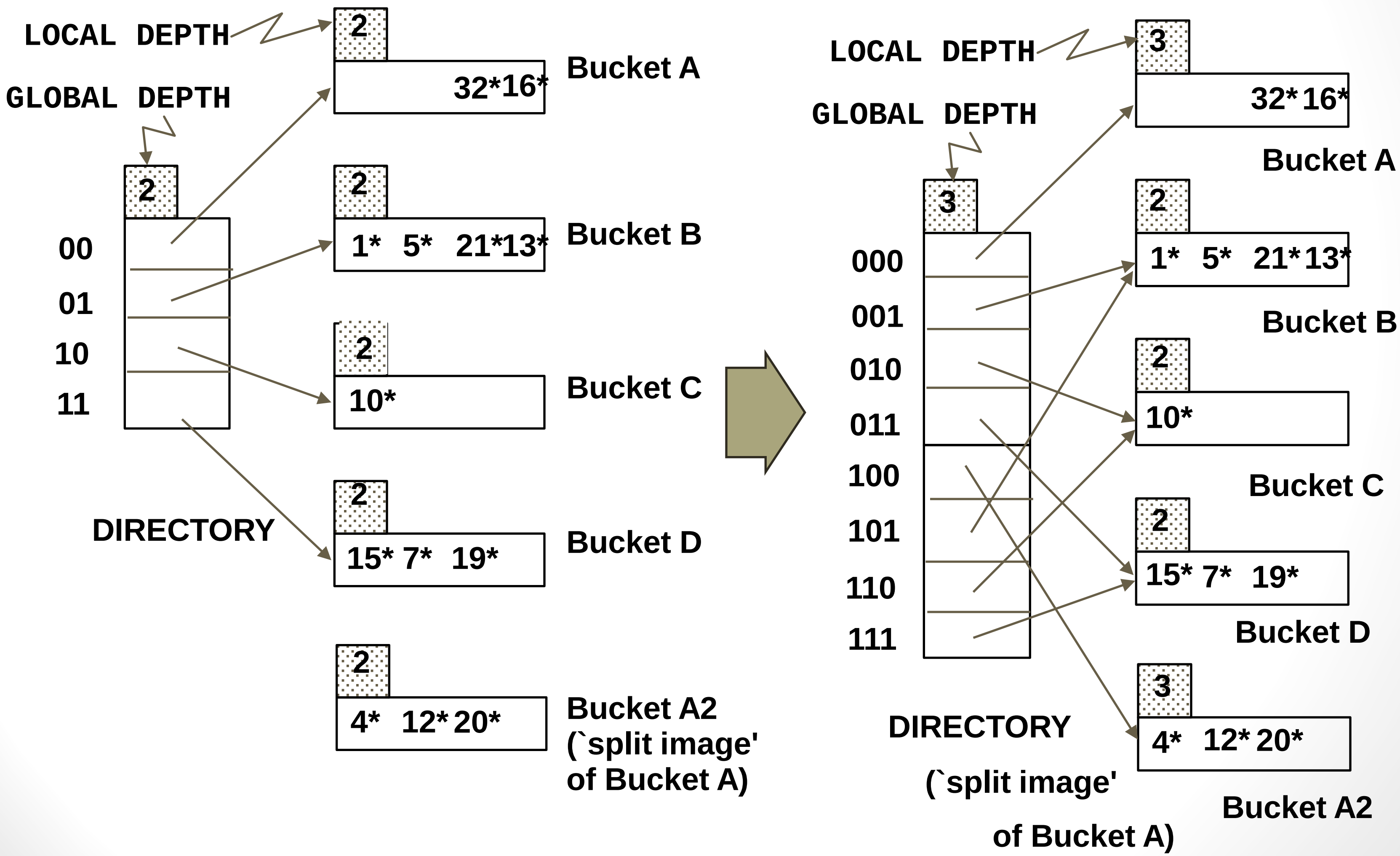
- Directory is array of size 4.
- To find bucket for *r*, take last `*global depth*' # bits of **h**(*r*); we denote *r* by **h**(*r*).
  - If **h**(*r*) = 5 = binary 101, it is in bucket pointed to by 01.



❖ **<u>Insert</u>**: If bucket is full, *<u>split</u>* it (*allocate new page, re-distribute*).

❖ *If necessary*, double the directory. (As we will see, splitting a bucket does not always require doubling; we can tell by comparing *global depth* with *local depth* for the split bucket.)

Insert h(r)=20 (Causes Doubling)

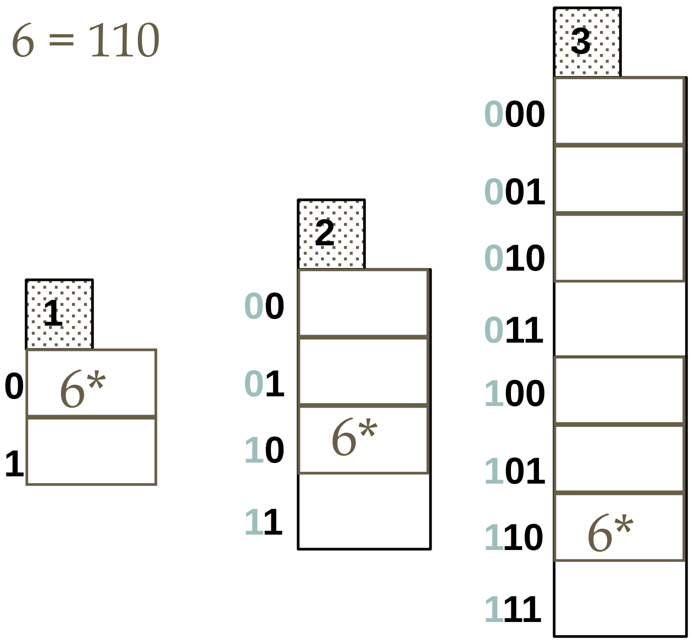


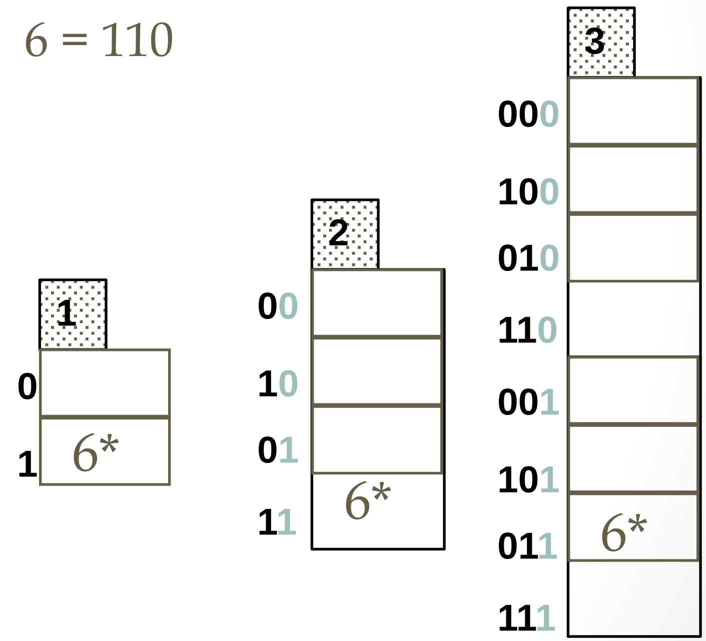
Points to Note

- 20 = binary 10100. Last **2** bits (00) tell us *r* belongs in A or A2. Last **<u>3</u>** bits needed to tell which.
  - *Global depth of directory*: Max # of bits needed to tell which bucket an entry belongs to.
  - *Local depth of a bucket*: # of bits used to determine if an entry belongs to this bucket.
- When does bucket split cause directory doubling?
  - Before insert, *local depth* of bucket = *global depth*. Insert causes *local depth* to become > *global depth*; directory is doubled by *copying it over* and `fixing' pointer to split image page. (Use of least significant bits enables efficient doubling via copying of directory!\)

Directory Doubling

Why use least significant bits in directory?
⇔ Allows for doubling via copying!





Least Significant vs. Most Significant

Comments on Extendible Hashing

- If directory fits in memory, equality search answered with one disk access; else two.
  - 100MB file, 100 bytes/rec, 4K pages contains 1,000,000 records (as data entries) and 25,000 directory elements; chances are high that directory will fit in memory.
  - Directory grows in spurts, and, if the distribution *of hash values* is skewed, directory can grow large.
  - Multiple entries with same hash value cause problems!
- **Delete**: If removal of data entry makes bucket empty, can be merged with `split image'. If each directory element points to same bucket as its split image, can halve directory.

Linear Hashing

- This is another dynamic hashing scheme, an alternative to Extendible Hashing.
- LH handles the problem of long overflow chains without using a directory, and handles duplicates.
- *Idea*: Use a family of hash functions $\mathbf{h}_0$, $\mathbf{h}_1$, $\mathbf{h}_2$, ...
  - $\mathbf{h}_i(key) = \mathbf{h}(key) \bmod (2^i N)$; N = initial # buckets
  - **h** is some hash function (range is *not* 0 to N-1)
  - If $N = 2^{d0}$, for some *d0*, $\mathbf{h}_i$ consists of applying **h** and looking at the last *di* bits, where $di = d0 + i$.
  - $\mathbf{h}_{i+1}$ doubles the range of $\mathbf{h}_i$ (similar to directory doubling)

Linear Hashing (Contd.)

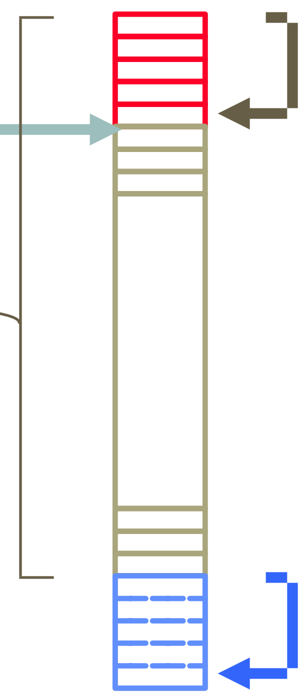
- Directory avoided in LH by using overflow pages, and choosing bucket to split round-robin.
  - Splitting proceeds in `rounds'. Round ends when all N_R initial (for round *R*) buckets are split. Buckets 0 to *Next-1* have been split; *Next* to N_R yet to be split.
  - Current round number is *Level*.
  - **Search:** To find bucket for data entry *r*, find $\mathbf{h}_{Level}(r)$:
    - If $\mathbf{h}_{Level}(r)$ in range `*Next* to N_R' , *r* belongs here.
    - Else, r could belong to bucket $\mathbf{h}_{Level}(r)$ or bucket $\mathbf{h}_{Level}(r) + N_R$; must apply $\mathbf{h}_{Level+1}(r)$ to find out.

Dynamic Hashing vs. Linear Hashing

- Dynamic hash implementation.
  - Periodically double the size of the database.
  - Rehash every key into new table.
- Dynamic Linear Hashing (Litwin)
  - Grow table one bucket at a time.
  - Split buckets sequentially; rehash just the splitting bucket.
  - Maintain overflow buckets as necessary.
  - Keep track of max bucket to identify the correct number of bits to consider in the hash value

Overview of LH File

- In the middle of a round.



Bucket to be split
Next

Buckets that existed at the beginning of this round: this is the range of h_{Level}

Buckets split in this round: If h_{Level} (search key value) is in this range, must use $h_{Level+1}$ (search key value) to decide if entry is in `split image' bucket.

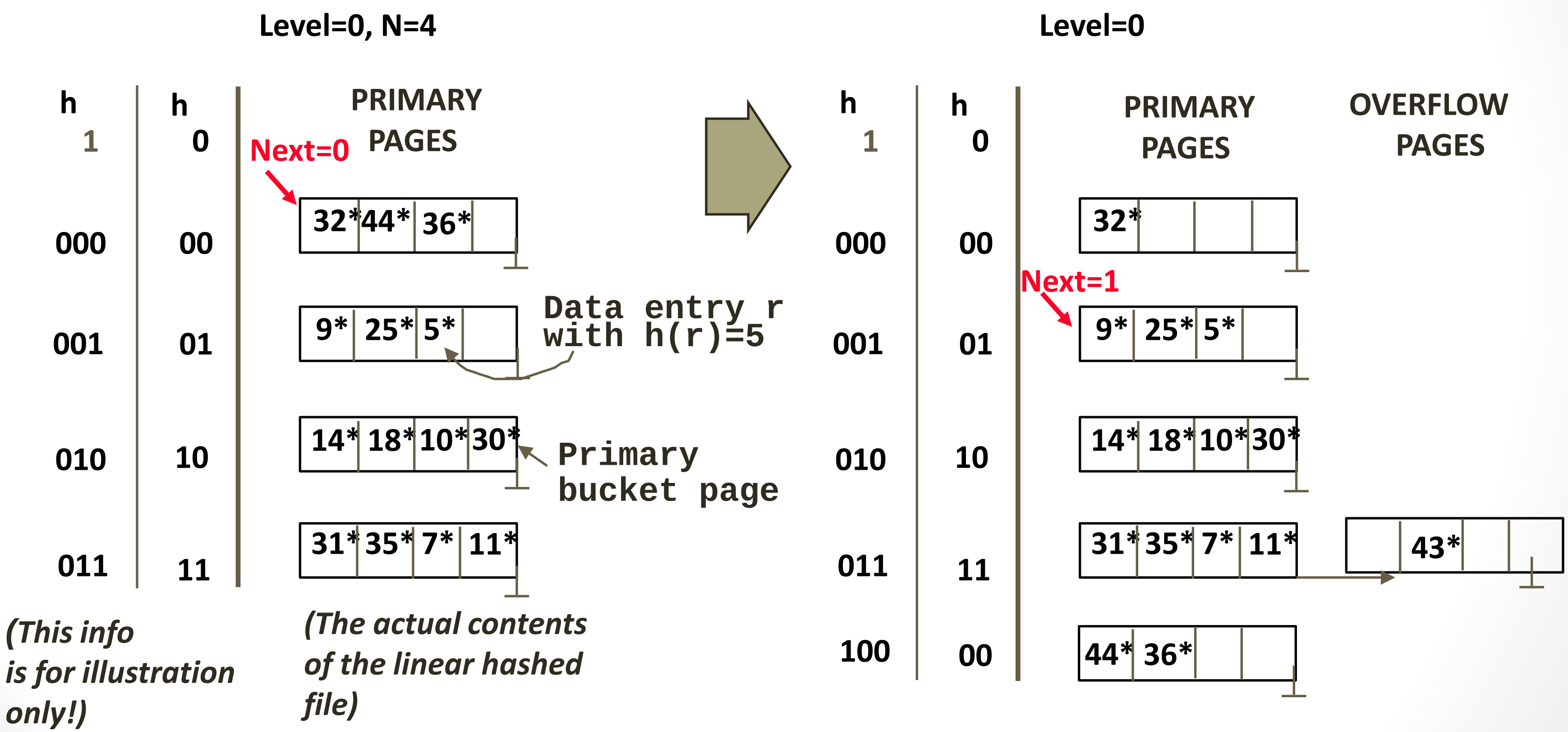
`split image' buckets: created (through splitting of other buckets) in this round

Linear Hashing (Contd.)

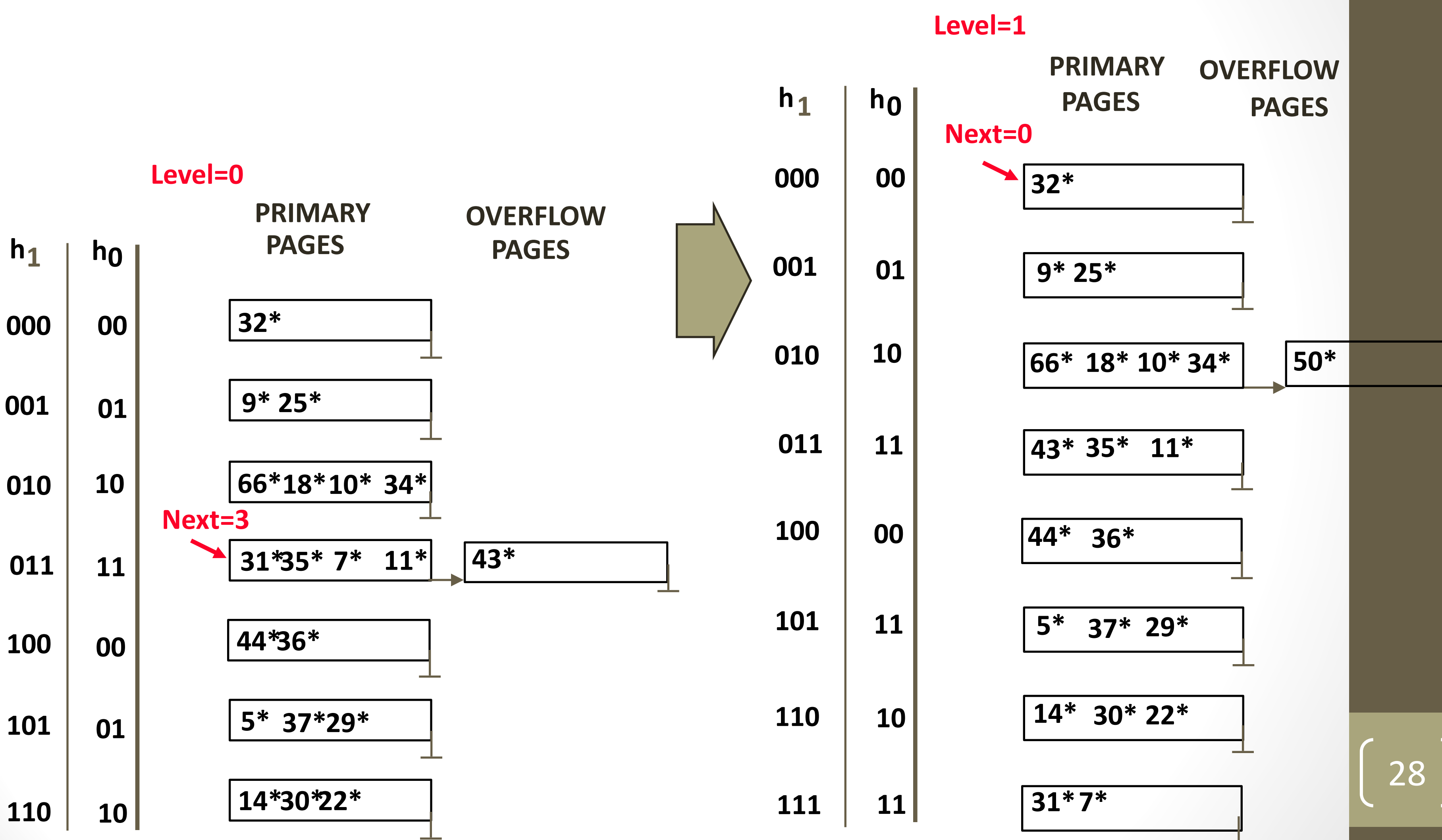
- Insert: Find bucket by applying $\mathbf{h}_{Level}$ / $\mathbf{h}_{Level+1}$:
  - If bucket to insert into is full:
    - Add overflow page and insert data entry.
    - (*Maybe*) Split *Next* bucket and increment *Next*.
- Can choose any criterion to `trigger' split.
- Since buckets are split round-robin, long overflow chains don't develop!
- Doubling of directory in Extendible Hashing is similar; switching of hash functions is *implicit* in how the # of bits examined is increased.

Example of Linear Hashing

- On split, $h_{Level+1}$ is used to redistribute entries.



Example: End of a Round



LH Described as a Variant of EH

- The two schemes are actually quite similar:
  - Begin with an EH index where directory has *N* elements.
  - Use overflow pages, split buckets round-robin.
  - First split is at bucket 0. (Imagine directory being doubled at this point.) But elements <1,*N*+1>, <2,*N*+2>, ... are the same. So, need only create directory element *N*, which differs from 0, now.
    - When bucket 1 splits, create directory element *N*+1, etc.
- So, **directory can double gradually**. Also, primary bucket pages are created in order. If they are *allocated* in sequence too (so that finding i'th is easy), we actually don't need a directory! Voila, LH.

Hash index record

- *As for any index, 3 alternatives for data entries* **k***:
  - Data record with key value **k**
  - <**k**, rid of data record with search key value **k**>
  - <**k**, list of rids of data records with search key **k**>

Summary: Hash-Based Indexes

- Hash-based indexes: best for equality searches, cannot support range searches.
- Static Hashing can lead to long overflow chains.
- Extendible Hashing avoids overflow pages by splitting a full bucket when a new data entry is to be added to it. (*Duplicates may require overflow pages.*)
  - Directory to keep track of buckets, doubles periodically.
  - Can get large with skewed data; additional I/O if this does not fit in main memory.

Summary: Linear hashing

- Linear Hashing avoids directory by splitting buckets round-robin, and using overflow pages.
  - Overflow pages not likely to be long.
  - Duplicates handled easily.
  - Space utilization could be lower than Extendible Hashing, since splits not concentrated on `dense' data areas.
    - Can tune criterion for triggering splits to trade-off slightly longer chains for better space utilization.
- For hash-based indexes, a *skewed* data distribution is one in which the *hash values* of data entries are not uniformly distributed!