

CMU SCS

Carnegie Mellon Univ.
 Dept. of Computer Science
 15-415/615 – DB Applications

Faloutsos & Pavlo
 Lecture#11 (R&G ch. 11)
Hashing

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Outline

- ➔ • (static) hashing
- extendible hashing
- linear hashing
- Hashing vs B-trees

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(Static) Hashing

Review

Problem: “*find EMP record with ssn=123*”
 What if disk space was free, and time was at premium?

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Hashing

Review

A: Brilliant idea: key-to-address transformation:

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CMU SCS **Review**

Hashing

Since space is NOT free:

- use M , instead of 999,999,999 slots
- hash function: $h(key) = slot-id$

#0 page
#123 page
#999,999,999

123; Smith; Main str

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CMU SCS **Review**

Hashing

Typically: each hash bucket is a page, holding many records:

#0 page
#h(123)
 M

123; Smith; Main str

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Hashing

Notice: could have **clustering**, or non-clustering versions:

#0 page
#h(123)
 M

123; Smith; Main str.

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Hashing


Notice: could have clustering, or **non-clustering** versions:

#0 page
#h(123)
 M

EMP file

...
234; Johnson; Forbes ave
123; Smith; Main str.
...
345; Tompson; Fifth ave
...

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Indexing- overview

- hashing
 - ➔ – hashing functions
 - size of hash table
 - collision resolution
- extendible hashing
- Hashing vs B-trees

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Design decisions

Review

- 1) formula $h()$ for hashing function
- 2) size of hash table M
- 3) collision resolution method

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Design decisions - functions

Review

- Goal: uniform spread of keys over hash buckets
- Popular choices:
 - Division hashing
 - Multiplication hashing

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Division hashing

Review

$$h(x) = (a*x+b) \bmod M$$

- eg., $h(\text{ssn}) = (\text{ssn}) \bmod 1,000$
 - gives the last three digits of ssn
- M : size of hash table - choose a prime number, defensively (why?)

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Division hashing

Review

- eg., $M=2$; hash on driver-license number (dln), where last digit is 'gender' (0/1 = M/F)
- in an army unit with predominantly male soldiers
- Thus: avoid cases where M and keys have common divisors - prime M guards against that!

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Multiplication hashing

Review

$$h(x) = \lfloor \text{fractional-part-of}(x * \phi) \rfloor * M$$

- ϕ : golden ratio ($0.618\dots = (\text{sqrt}(5)-1)/2$)
- in general, we need an irrational number
- advantage: M need not be a prime number
- but ϕ must be irrational

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Other hashing functions

Review

- quadratic hashing (bad)
- ...

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Other hashing functions

Review

- quadratic hashing (bad)
- ...
- conclusion: use division hashing

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Design decisions

Review

- 1) formula $h()$ for hashing function
- ➡ 2) size of hash table M
- 3) collision resolution method

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Size of hash table

Review

- eg., 50,000 employees, 10 employee-records / page
- Q: $M=??$ pages/buckets/slots

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Size of hash table

Review

- eg., 50,000 employees, 10 employees/page
- Q: $M=??$ pages/buckets/slots
- A: utilization $\sim 90\%$ and
 - M : prime number

Eg., in our case: $M = \text{closest prime to } 50,000/10 / 0.9 = 5,555$

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Design decisions

Review

- 1) formula $h()$ for hashing function
- 2) size of hash table M
- ➡ 3) collision resolution method

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Collision resolution

Review

- Q: what is a 'collision' ?
- A: ??

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Collision resolution

Review

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Collision resolution

Review

- Q: what is a 'collision' ?
- A: ??
- Q: why worry about collisions/overflows?
(recall that buckets are ~90% full)
- A: 'birthday paradox'

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Collision resolution

Review

- open addressing
 - linear probing (ie., put to next slot/bucket)
 - re-hashing
- separate chaining (ie., put links to overflow pages)

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CMU SCS **Review**

Collision resolution

linear probing:

123; Smith; Main str.

#0 page

#h(123)

M

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CMU SCS **Review**

Collision resolution

re-hashing

123; Smith; Main str.

#0 page

#h(123)

M

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CMU SCS **Review**

Collision resolution

separate chaining

123; Smith; Main str.

#0 page

#h(123)

M

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CMU SCS **Review**

Design decisions - conclusions

- function: division hashing
 - $h(x) = (a*x+b) \text{ mod } M$
- size M : ~90% util.; prime number.
- collision resolution: separate chaining
 - easier to implement (deletions!);
 - no danger of becoming full

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Outline

- (static) hashing
- ➔ • extendible hashing
- linear hashing
- Hashing vs B-trees

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Problem with static hashing

- problem: overflow?
- problem: underflow? (underutilization)

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Solution: Dynamic/extendible hashing

- idea: shrink / expand hash table on demand..
- ..dynamic hashing

Details: how to grow gracefully, on overflow?

Many solutions - One of them: 'extendible hashing' [Fagin et al]

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Extendible hashing

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Extendible hashing

solution: don't overflow – instead:
SPLIT the bucket in two

123; Smith; Main str.

#0 page
#h(123)
M

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Extendible hashing

in detail:

- keep a directory, with ptrs to hash-buckets
- Q: how to divide contents of bucket in two?
- A: hash each key into a very long bit string; keep only as many bits as needed

Eventually:

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Extendible hashing

directory

00...
01...
10...
11...

0001...
0111...

10101...
10011...
10110...

1101...

101001...

(Book, and HW4 use suffix)

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Extendible hashing

directory

00...
01...
10...
11...

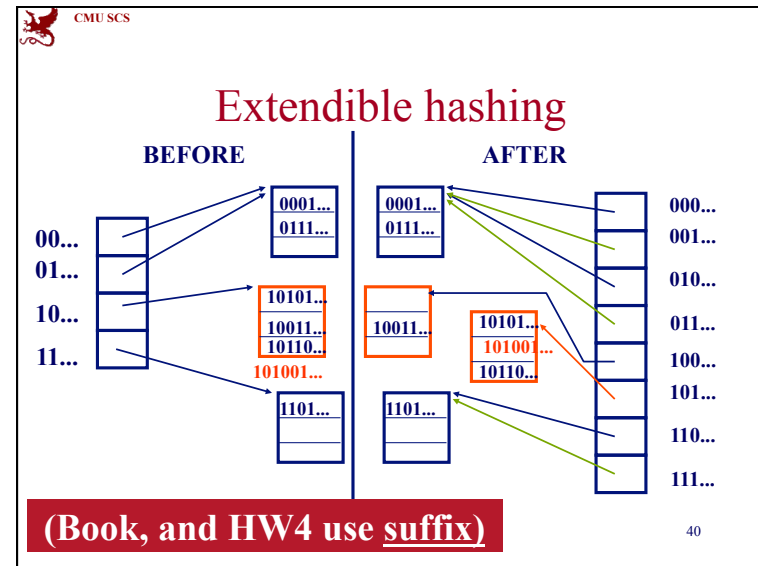
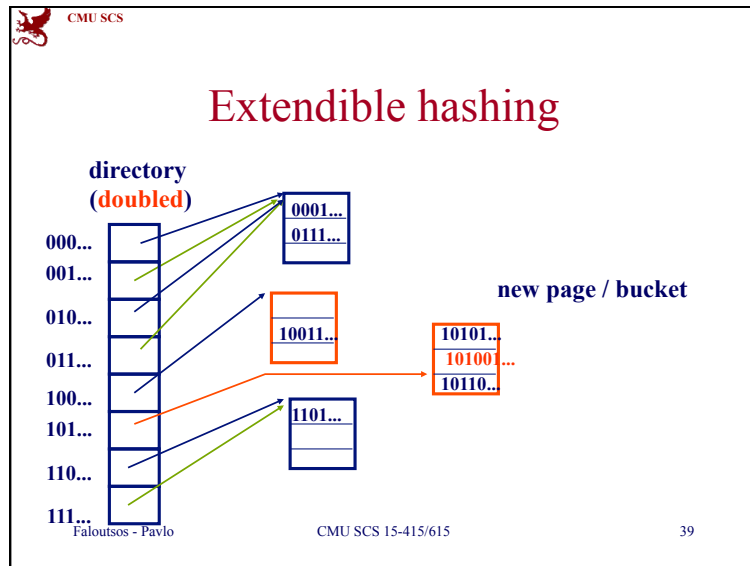
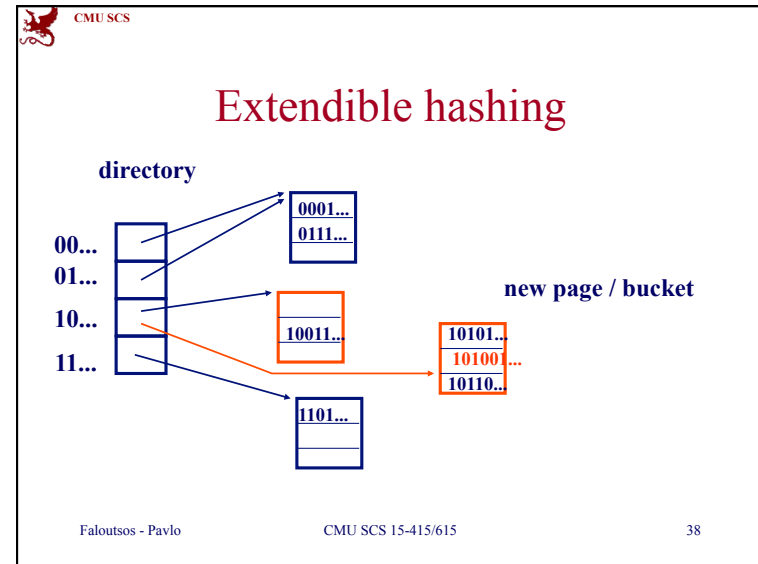
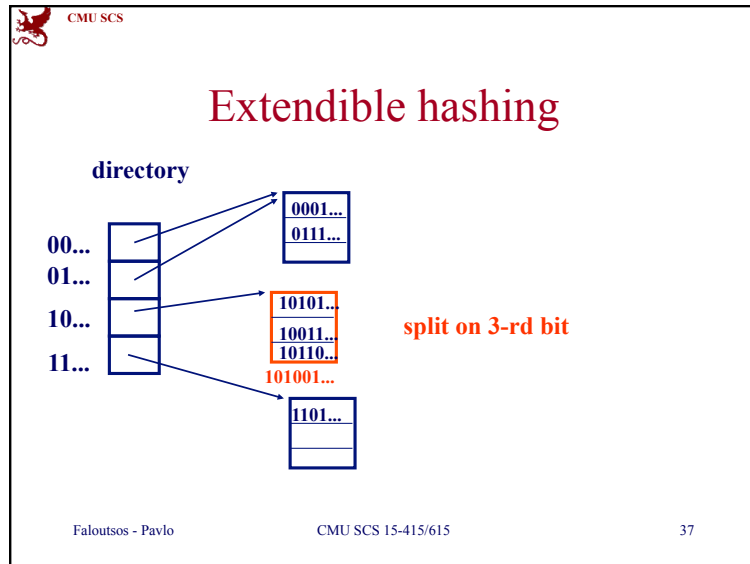
0001...
0111...

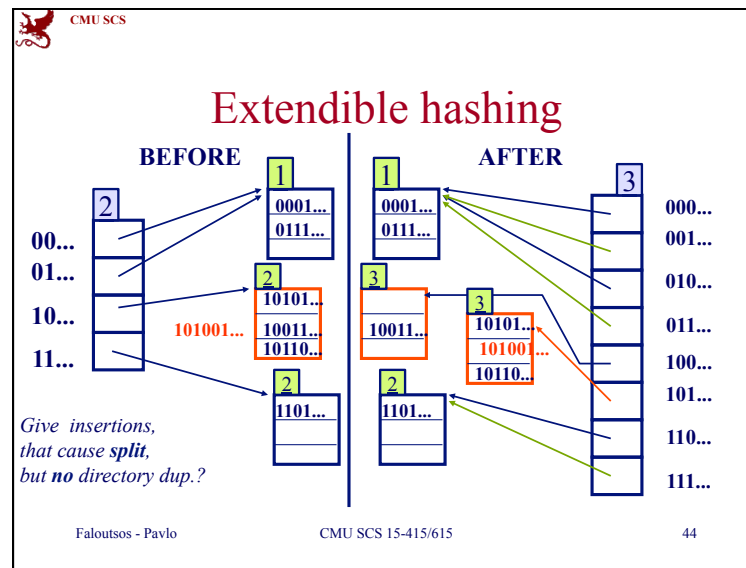
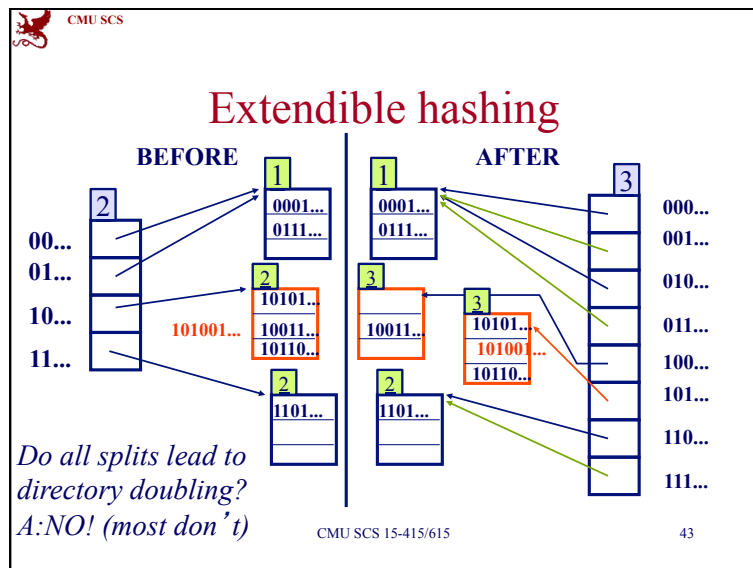
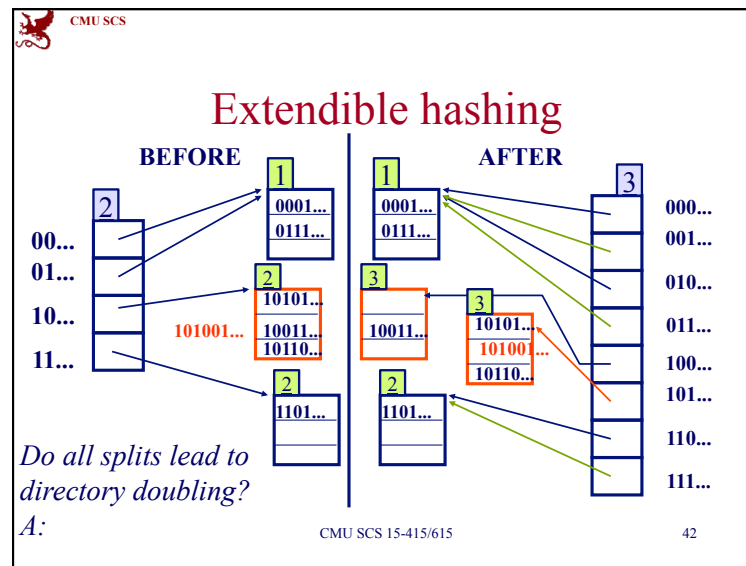
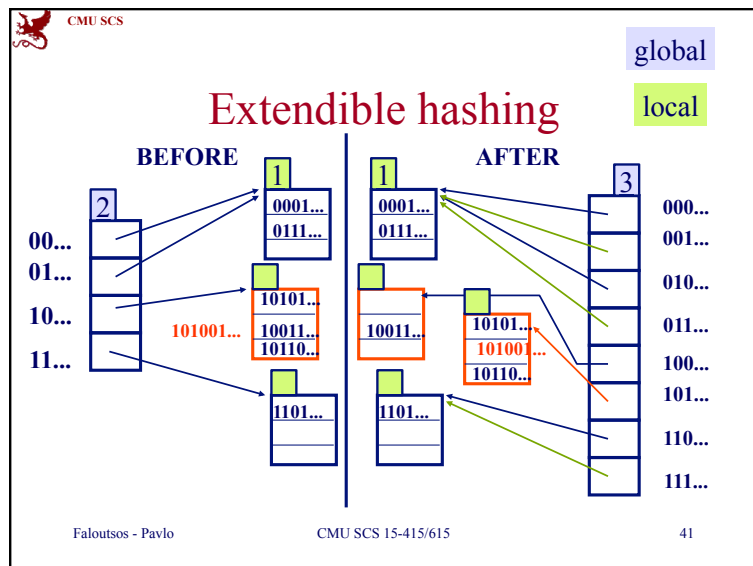
10101...
10011...
10110...

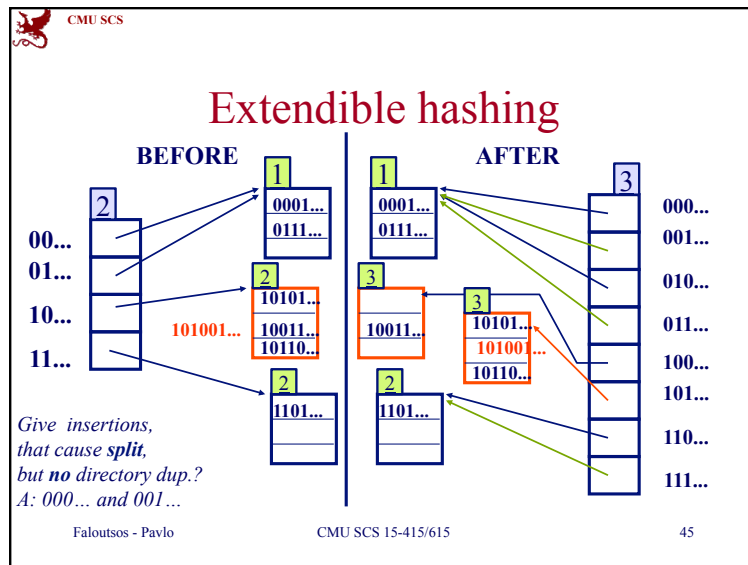
1101...

101001...

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(Note)

- The **textbook** uses the signature bits from **right to left**
- For HW4, use the **textbook's** approach.

foils →

3

000...
001...
010...
011...
100...
101...
110...
111...

← textbook

(Book, and HW4 use suffix)

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Extensible hashing


- Summary: directory doubles on demand
- or halves, on shrinking files
- needs 'local' and 'global' depth

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Outline

- (static) hashing
- extensible hashing
- ➡ linear hashing
- Hashing vs B-trees

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Linear hashing - overview

- Motivation
- main idea
- search algo
- insertion/split algo
- deletion

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Linear hashing

Motivation: ext. hashing needs directory etc etc; which doubles (ouch!)

Q: can we do something simpler, with smoother growth?

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Linear hashing

Motivation: ext. hashing needs directory etc etc; which doubles (ouch!)

Q: can we do something simpler, with smoother growth?

A: split buckets from left to right, **regardless** of which one overflowed (‘crazy’, but it works well!) - Eg.:

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Linear hashing

Initially: $h(x) = x \bmod N$ (N=4 here)

Assume capacity: 3 records / bucket

Insert key ‘17’

bucket- id 0 1 2 3

4	8	5	9	6	7	11
		13				

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Linear hashing

Initially: $h(x) = x \bmod N$ (N=4 here)

17 overflow of bucket#1

bucket- id 0 1 2 3

4	8	5	9	6	7	11
		13				

↓

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Linear hashing

Initially: $h(x) = x \bmod N$ (N=4 here)

17 overflow of bucket#1

Split #0, anyway!!!

bucket- id 0 1 2 3

4	8	5	9	6	7	11
		13				

↓

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CMU SCS

Linear hashing

Initially: $h(x) = x \bmod N$ (N=4 here)

Split #0, anyway!!!

17

Q: But, how?

bucket- id 0 1 2 3

4	8	5	9	6	7	11
		13				

↓

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Linear hashing

A: use two h.f.: $h_0(x) = x \bmod N$

$h_1(x) = x \bmod (2*N)$

17

bucket- id 0 1 2 3

4	8	5	9	6	7	11
		13				

↓

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Linear hashing - after split:

A: use two h.f.: $h0(x) = x \text{ mod } N$
 $h1(x) = x \text{ mod } (2*N)$

bucket- id 0 1 2 3 4

8	5 9 13	6	7 11	4
---	-----------	---	------	---

17

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Linear hashing - after split:

A: use two h.f.: $h0(x) = x \text{ mod } N$
 $h1(x) = x \text{ mod } (2*N)$

bucket- id 0 1 2 3 4

8	5 9 13	6	7 11	4
---	-----------	---	------	---

17 overflow

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Linear hashing - after split:

A: use two h.f.: $h0(x) = x \text{ mod } N$
 $h1(x) = x \text{ mod } (2*N)$

split ptr

bucket- id 0 1 2 3 4

8	5 9 13	6	7 11	4
---	-----------	---	------	---

17 overflow

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Linear hashing - overview

- Motivation
- main idea
- ➡ • search algo
- insertion/split algo
- deletion

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Linear hashing - searching?

- $h_0(x) = x \bmod N$ (for the un-split buckets)
- $h_1(x) = x \bmod (2*N)$ (for the splitted ones)

bucket- id 0 1 2 3 4

8 5 9 6 7 11 4

13

17 overflow

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Linear hashing - searching?

Q1: find key '6'? Q2: find key '4'?

Q3: key '8'?

bucket- id 0 1 2 3 4

8 5 9 6 7 11 4

13

17 overflow

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Linear hashing - searching?

Algo to find key 'k':

```

compute b = h0(k);    // original slot
if b < split_ptr    // has been split
    compute b = h1(k)
search bucket b
  
```

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Linear hashing - overview

- Motivation
- main idea
- search algo
- ➡ insertion/split algo
- deletion

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Linear hashing - insertion?

Algo: insert key ' k '

- compute appropriate bucket ' b '
- if the **overflow criterion** is true
 - split the bucket of 'split-ptr'
 - split-ptr ++ (*)

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Linear hashing - insertion?

notice: overflow criterion is up to us!!

Q: suggestions?

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Linear hashing - insertion?

notice: overflow criterion is up to us!!

Q: suggestions?

A1: space utilization \geq u-max

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Linear hashing - insertion?

notice: overflow criterion is up to us!!

Q: suggestions?

A1: space utilization \geq u-max

A2: avg length of ovf chains $>$ max-len

A3: whenever an overflow page is created  **HW4**

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Linear hashing - insertion?

notice: overflow criterion is up to us!!

Q: suggestions?

A1: space utilization \geq u-max

A2: avg length of ovf chains $>$ max-len

A3: whenever an overflow page is created

A4: ...

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Linear hashing - insertion?

Algo: insert key 'k'

- compute appropriate bucket 'b'
- if the **overflow criterion** is true
 - split the bucket of 'split-ptr'
 - split-ptr ++ (*)

what if we reach the right edge??

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Linear hashing - split now?

$h0(x) = x \bmod N$ (for the un-split buckets)

$h1(x) = x \bmod (2*N)$ for the splitted ones

split ptr

↓

0	1	2	3	4	5	6

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Linear hashing - split now?

$h0(x) = x \bmod N$ (for the un-split buckets)

$h1(x) = x \bmod (2*N)$ for the splitted ones

split ptr

↓

0	1	2	3	4	5	6	7

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Linear hashing - split now?

~~$h0(x) = x \text{ mod } N$ (for the un-split buckets)~~
 ~~$h1(x) = x \text{ mod } (2*N)$ (for the splitted ones)~~

split ptr

0 1 2 3 4 5 6 7

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Linear hashing - split now?

~~$h0(x) = x \text{ mod } N$ (for the un-split buckets)~~
 ~~$h1(x) = x \text{ mod } (2*N)$ (for the splitted ones)~~

split ptr

0 1 2 3 4 5 6 7

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Linear hashing - split now?

this state is called 'full expansion'

split ptr

0 1 2 3 4 5 6 7

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Linear hashing - observations

In general, at any point of time, we have at **most two** h.f. active, of the form:

- $h_n(x) = x \text{ mod } (N * 2^n)$
- $h_{n+1}(x) = x \text{ mod } (N * 2^{n+1})$

(after a full expansion, we have only one h.f.)

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Linear hashing - overview

- Motivation
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- search algo
- insertion/split algo
- ➔ • deletion

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Linear hashing - deletion?

- reverse of insertion:

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Linear hashing - deletion?

- reverse of insertion:
- if the underflow criterion is met
 - contract!

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Linear hashing - how to contract?

$h0(x) = \text{mod } N$ (for the un-split buckets)
 $h1(x) = \text{mod } (2*N)$ (for the splitted ones)

split ptr

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Linear hashing - how to contract?

$h_0(x) = \text{mod } N$ (for the un-split buckets)
 $h_1(x) = \text{mod } (2*N)$ (for the splitted ones)

split ptr

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Linear hashing - how to contract?

$h_0(x) = \text{mod } N$ (for the un-split buckets)
 $h_1(x) = \text{mod } (2*N)$ (for the splitted ones)

split ptr

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Linear hashing - how to contract?

$h_0(x) = \text{mod } N$ (for the un-split buckets)
 $h_1(x) = \text{mod } (2*N)$ (for the splitted ones)

split ptr

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Linear hashing - how to contract?

$h_0(x) = \text{mod } N$ (for the un-split buckets)
 $h_1(x) = \text{mod } (2*N)$ (for the splitted ones)

split ptr

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Outline

- (static) hashing
- extendible hashing
- linear hashing
- ➔ • Hashing vs B-trees


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Hashing - pros?

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Hashing - pros?

- Speed,
 - on exact match queries
 - on the average


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B(+)-trees - pros?

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B(+)-trees - pros?

- Speed on search:
 - exact match queries, worst case
 - range queries
 - nearest-neighbor queries
- Speed on insertion + deletion
- smooth growing and shrinking (no re-org)

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B(+)-trees vs Hashing

<ul style="list-style-type: none"> • Speed on search: <ul style="list-style-type: none"> – exact match queries, worst case – range queries – nearest-neighbor queries • Speed on insertion + deletion • smooth growing and shrinking (no re-org) 	<ul style="list-style-type: none"> • Speed, <ul style="list-style-type: none"> – on exact match queries – on the average
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Conclusions

- B-trees and variants: in all DBMSs
- hash indices: in some
 - (but hashing is useful for joins - later...)

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