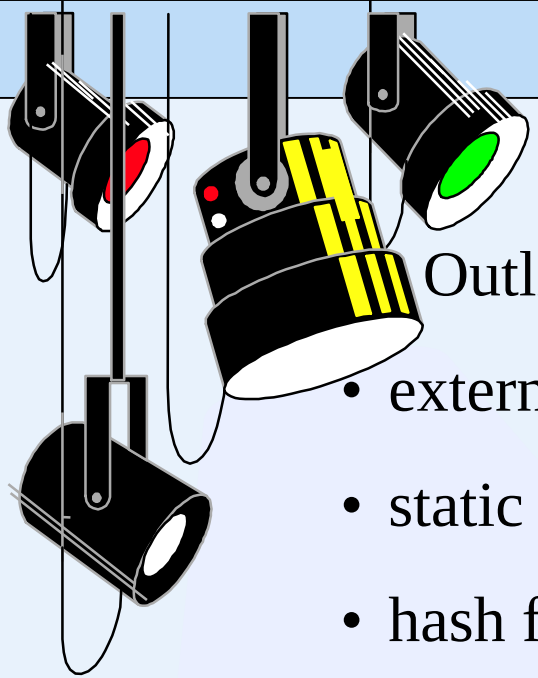
File Organizations



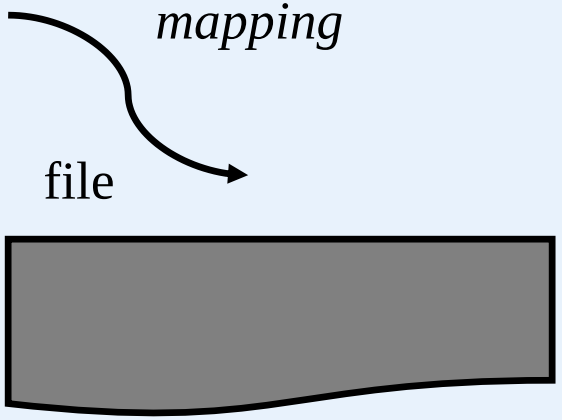
Outline: Hashing (5.9, 5.10, 3rd. ed.; 13.8, 4th, 5th ed.; 17.8, 6th ed.)

- external hashing
- static hashing & dynamic hashing
- hash function
  - mathematical function that maps a key to a bucket address
  - collisions
    - collision resolution scheme
      - open addressing
      - chaining
      - multiple hashing
- linear hashing

Mapping a table into a file

Employee

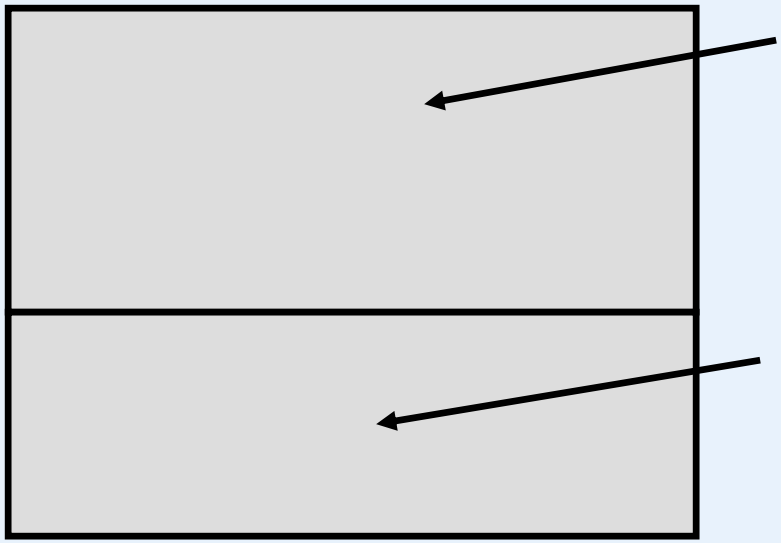
ssn	name	bdate	sex	address	salary
	… …				



- Block (or page)
  - access unit of operating system
  - block size: range from 512 to 4096 bytes
- Bucket
  - access unit of database system
  - A bucket contains one or more blocks.
- A file can be considered as a collection of buckets. Each bucket has an address.

External Hashing

- Consider a file comprising a primary area and an overflow area



- Common implementations are *static* - the number of primary buckets is fixed - and we expect to need to reorganize this type of files on a regular basis.

External Hashing

- Consider a static hash file comprising M primary buckets
- We need a hash function that maps the key onto {0, 1, … M-1}
- If M is prime and Key is numeric then

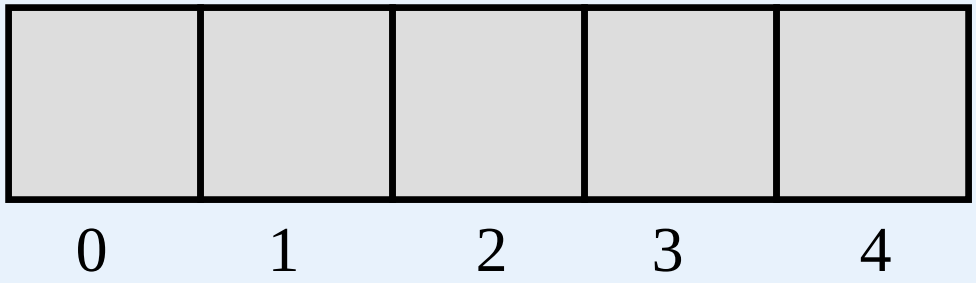
$$Hash(Key) = Key \bmod M$$

  can work well

- A collision may occur when more than one records hash to the same address
- We need a collision resolution scheme for overflow handling because the number of collisions for one primary bucket can exceed the bucket capacity
  - open addressing
  - chaining

Overflow handling

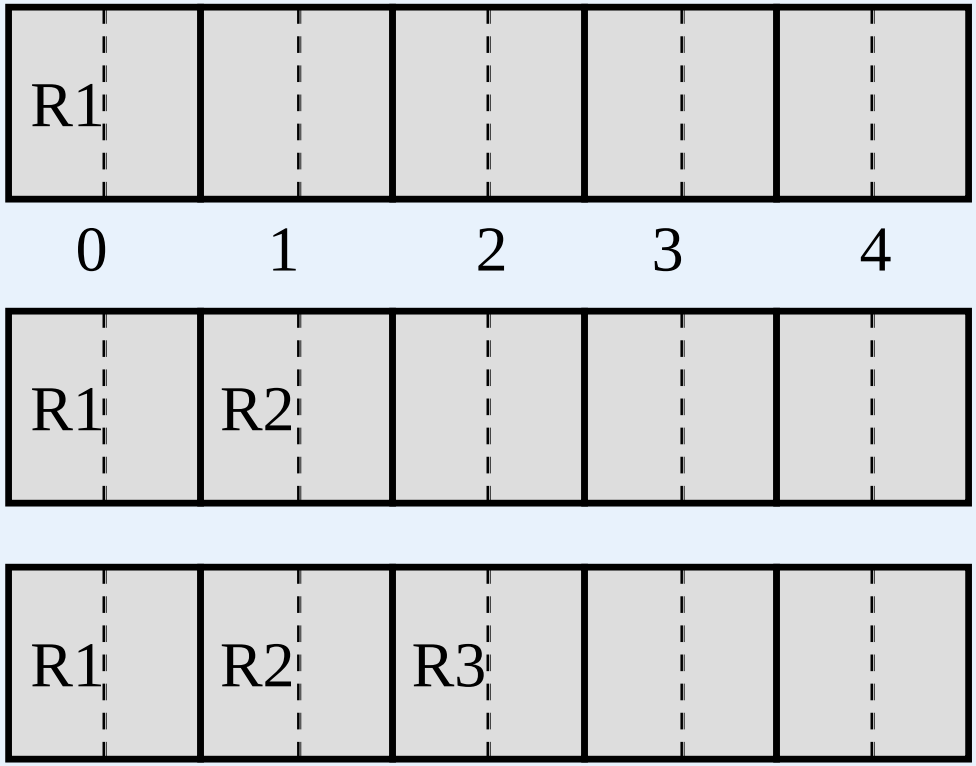
- Open addressing
  - subsequent buckets are examined until an open record position is found
  - no need for an overflow area
  - consider records being inserted R1, R2, R3, R4, R5, R6, R7 with bucket capacity of 2 and hash values 0, 1, 2, 1, 1, 0, 3



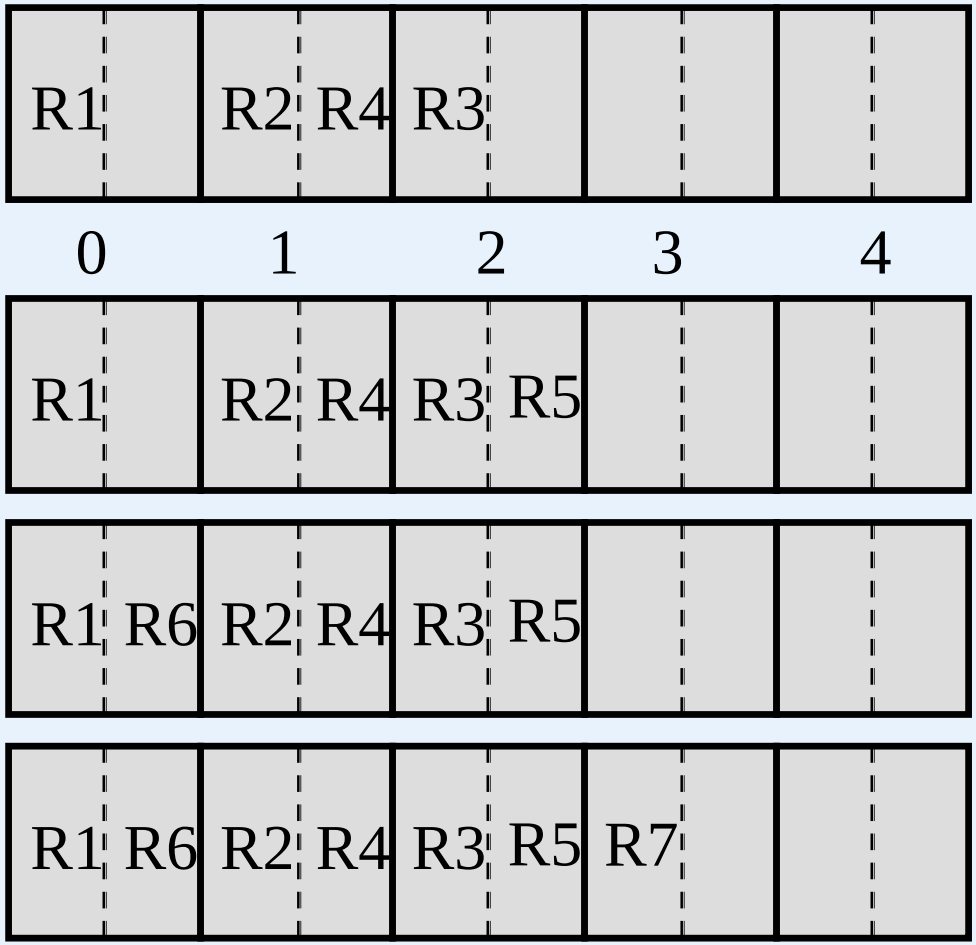
How do we handle retrieval, deletion?

File Organizations

- consider records being inserted R1, R2, R3, R4, R5, R6, R7 with bucket capacity of 2 and hash values 0, 1, 2, 1, 1, 0, 3

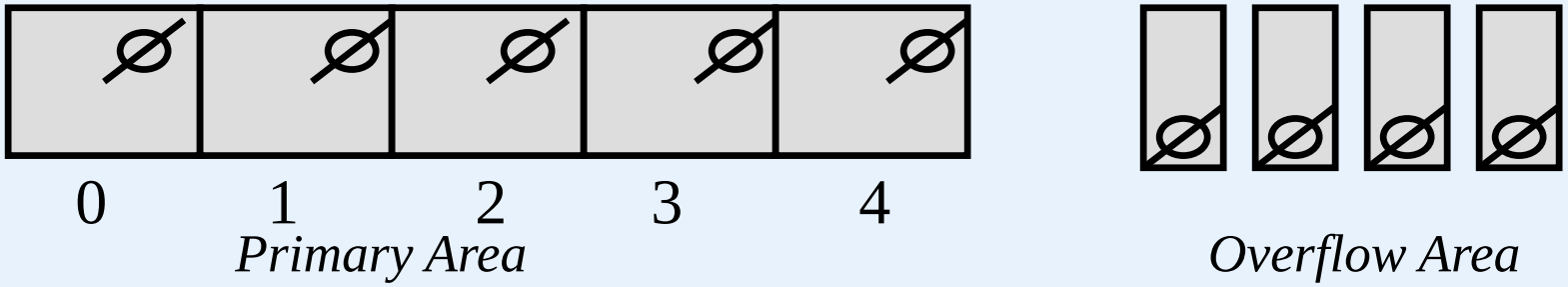


R1, R2, R3, R4, R5, R6, R7
hash values: 0, 1, 2, 1, 1, 0, 3



Overflow handling

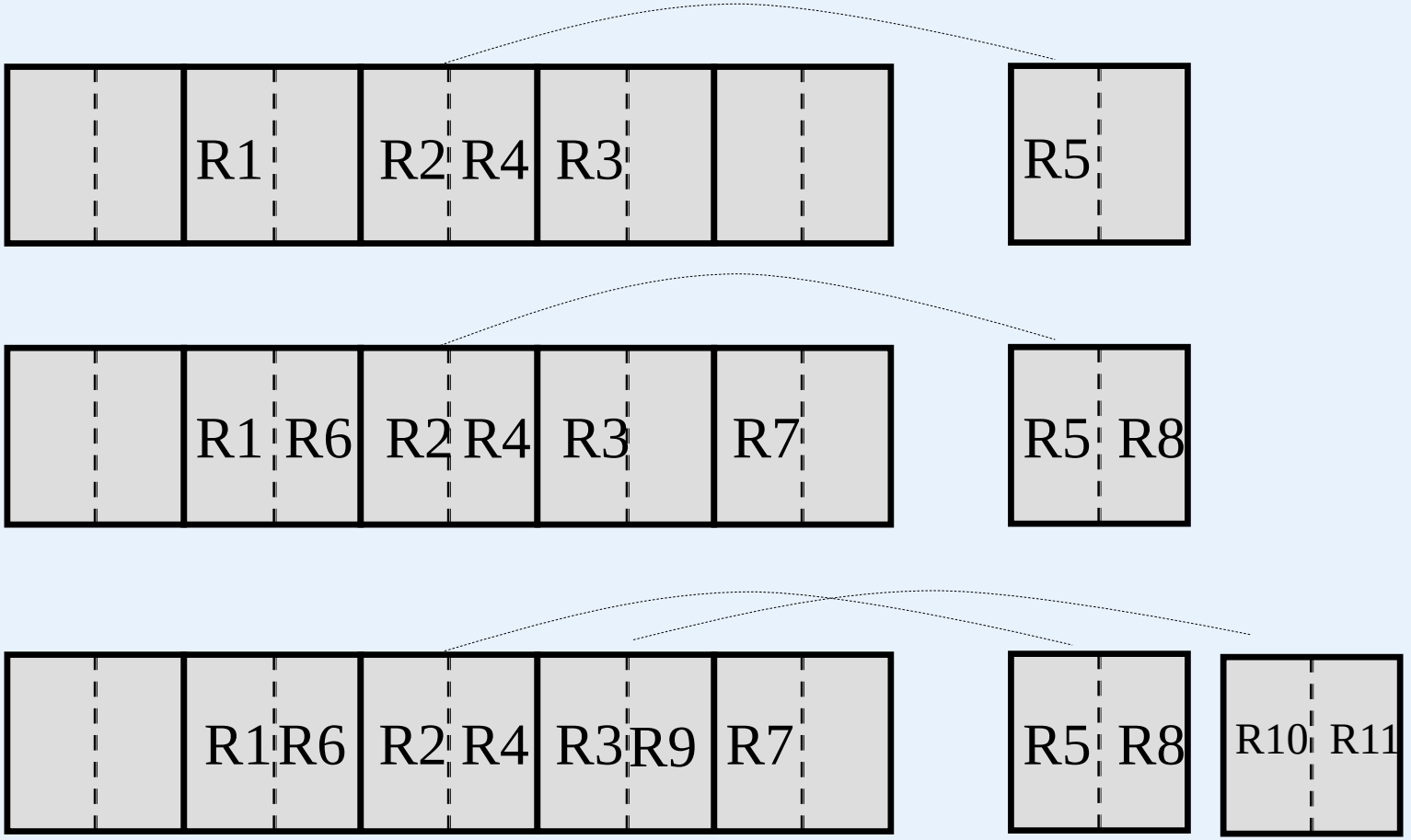
- Chaining
  - a pointer in the primary bucket points to the first overflow record
  - overflow records for one primary bucket are chained together
  - consider records being inserted R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11.
  - with bucket capacity of 2 and hash values 1, 2, 3, 2, 2, 1, 4, 2, 3, 3, 3.
  - deletions?



File Organizations

R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11

1, 2, 3, 2, 2, 1, 4, 2, 3, 3, 3



Overflow handling

- Multiple Hashing
  - when collision occurs a next hash function is tried to find an unfilled bucket
  - eventually we would resort to chaining
  - note that open addressing can suffer from poor performance due to islands of full buckets occurring and having a tendency to get even longer - using a second hash function helps avoid that problem

Linear Hashing

- A dynamic hash file:

  grows and shrinks gracefully

- initially the hash file comprises M primary buckets numbered 0, 1, … M-1
- the hashing process is divided into several phases (phase 0, phase 1, phase 2, …). In phase j, records are hashed according to hash functions h_j(key) and h_{j+1}(key)
- h_j(key) = key mod (2^j*M)

phase 1: h_0(key) = key mod (2^0*M), h_1(key) = key mod (2^1*M)
phase 2: h_1(key) = key mod (2^1*M), h_2(key) = key mod (2^2*M)
phase 3: h_2(key) = key mod (2^2*M), h_3(key) = key mod (2^3*M)
… ...

Linear Hashing

- h_j(key) is used first; to split, use h_{j+1}(key)
- splitting a bucket means to redistribute the records into two buckets: the original one and a new one. In phase j, to determine which ones go into the original while the others go into the new one, we use h_{j+1}(key) = key mod 2^{j+1}*M to calculate their address.
- When to split a bucket?

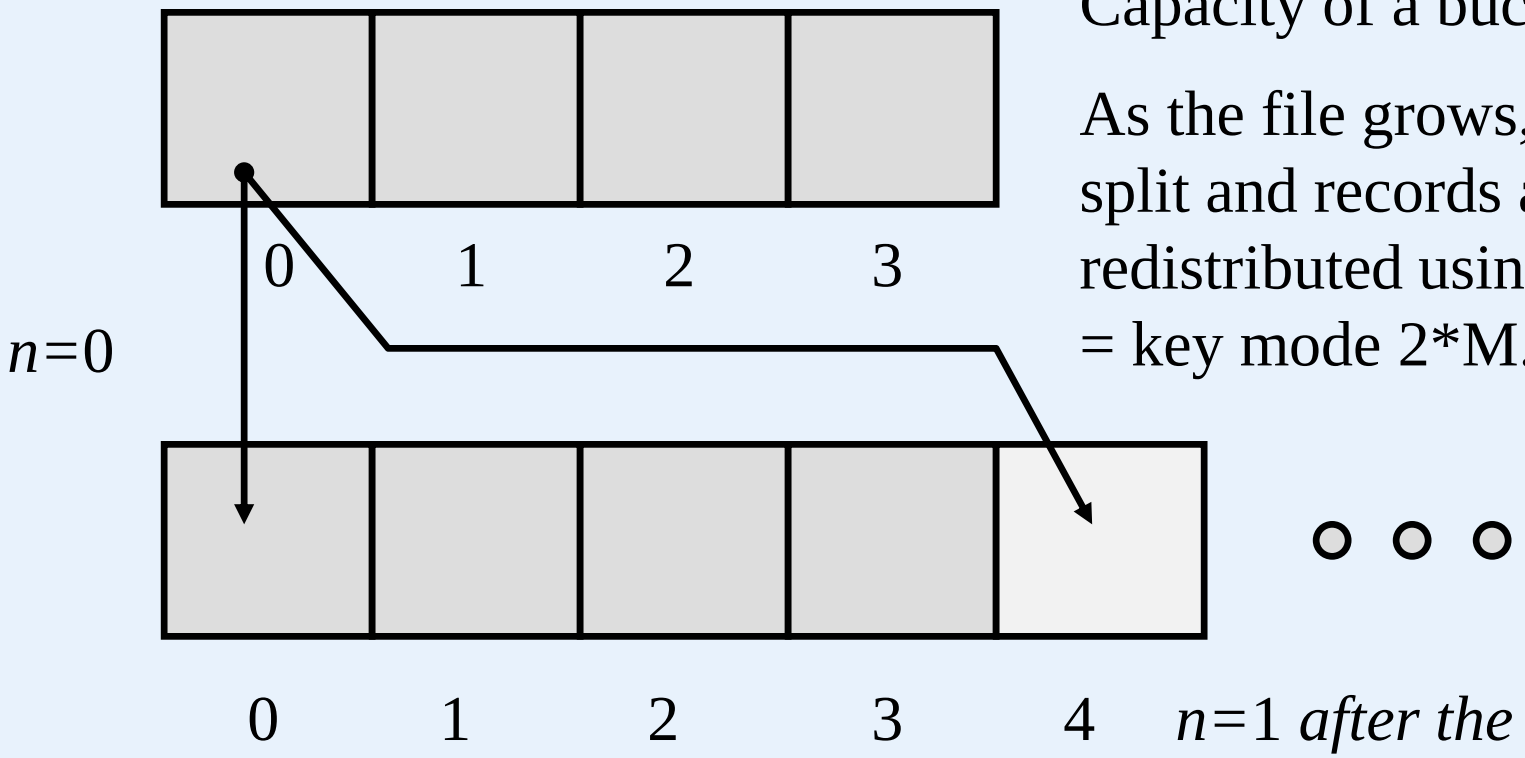
  splitting occurs according to a specific rule such as
  - an overflow occurring, or
  - the load factor reaching a certain value, etc.
- a split pointer keeps track of which bucket to split next
- split pointer goes from 0 to 2^j*M - 1 during the j^{th} phase, j= 0, 1, 2, … ...

Linear Hashing

1. What is a phase?
2. When to split a bucket?
3. How to split a bucket?
4. What bucket will be chosen to split next?
5. How do we find a record inserted into a linear hashing file?

Linear Hashing, example

- initially suppose M=4
- h_0(key) = key mod M; i.e. key mod 4 (rightmost 2 bits)
- h_1(key) = key mod 2*M



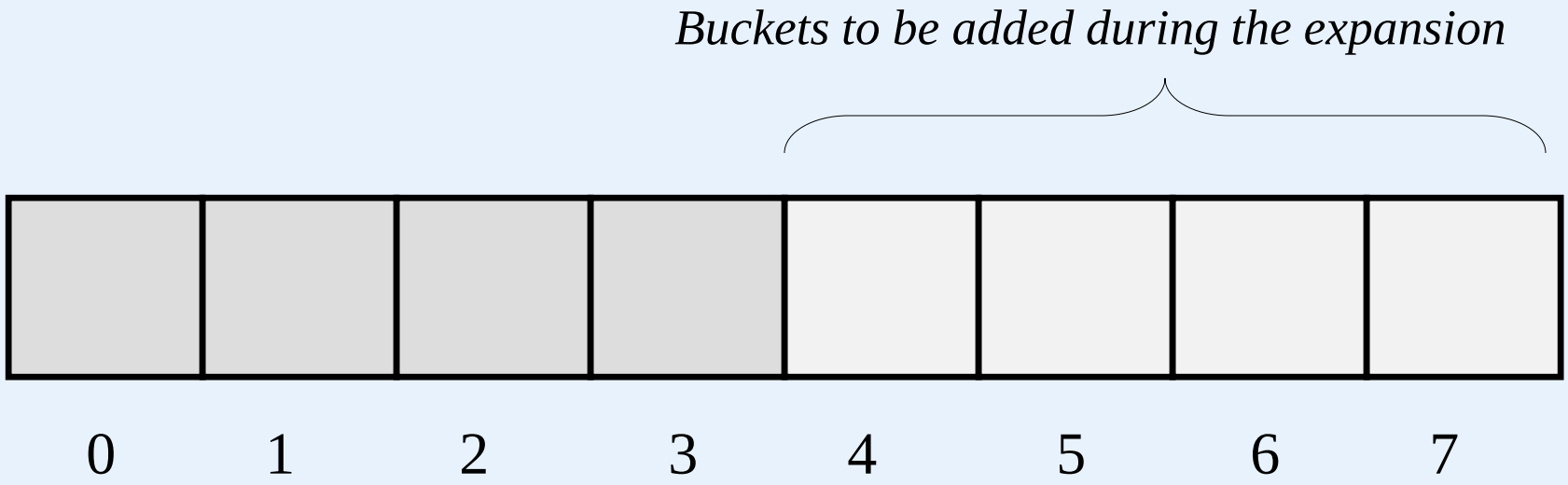
Capacity of a bucket is 2.

As the file grows, buckets split and records are redistributed using h_1(key) = key mode 2*M.

Linear Hashing, example

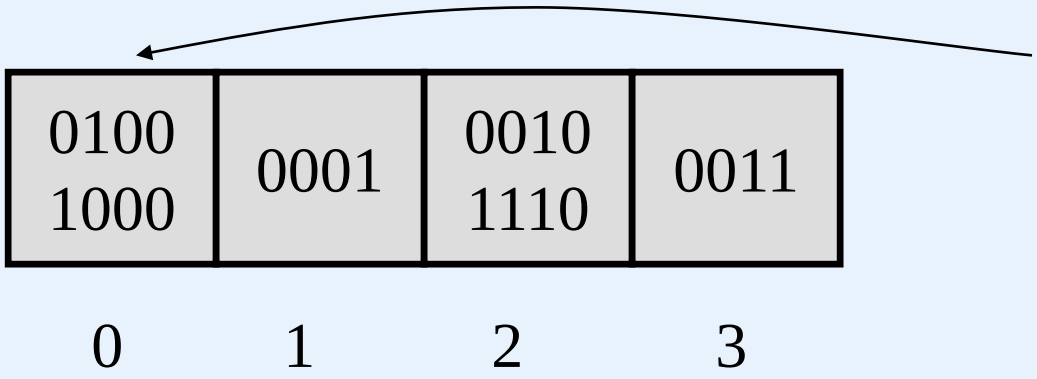
- collision resolution strategy: chaining
- split rule: if load factor > 0.70
- insert the records with key values:

  0011, 0010, 0100, 0001, 1000, 1110, 0101, 1010, 0111, 1100



Linear Hashing, example

- when inserting the sixth record (using h_0 = Key mod M) we would have



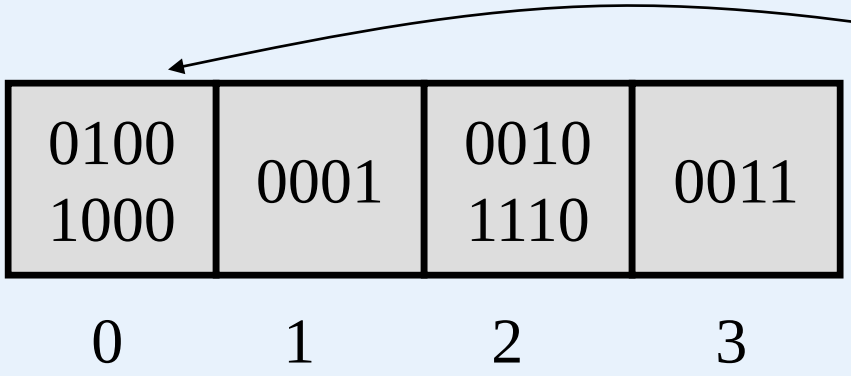
n=0 before the split

(n is the split point, i.e., the point to the bucket to be split.)

0011, 0010, 0100, 0001, 1000, 1110, 0101, 1010, 0111, 1100

Linear Hashing, example

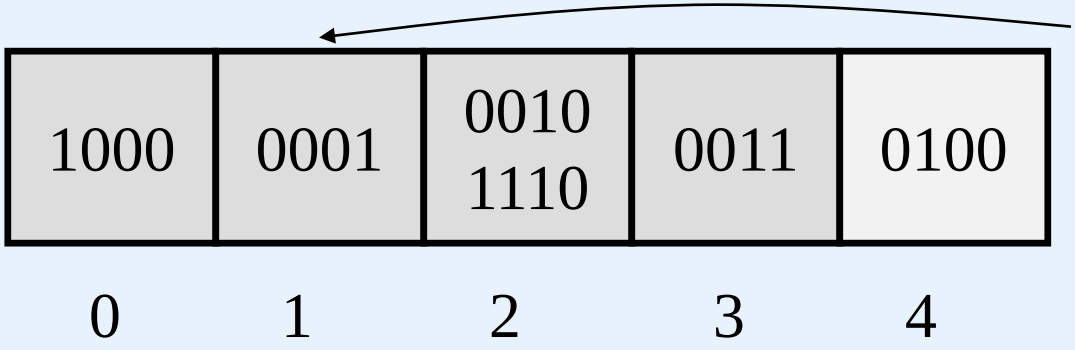
- when inserting the sixth record (using h_0 = Key mod M) we would have



n=0 before the split

(n is the point to the bucket to be split.)

- but the load factor 6/8= 0.75 > 0.70 and so bucket 0 must be split (using h_1 = Key mod 2M):

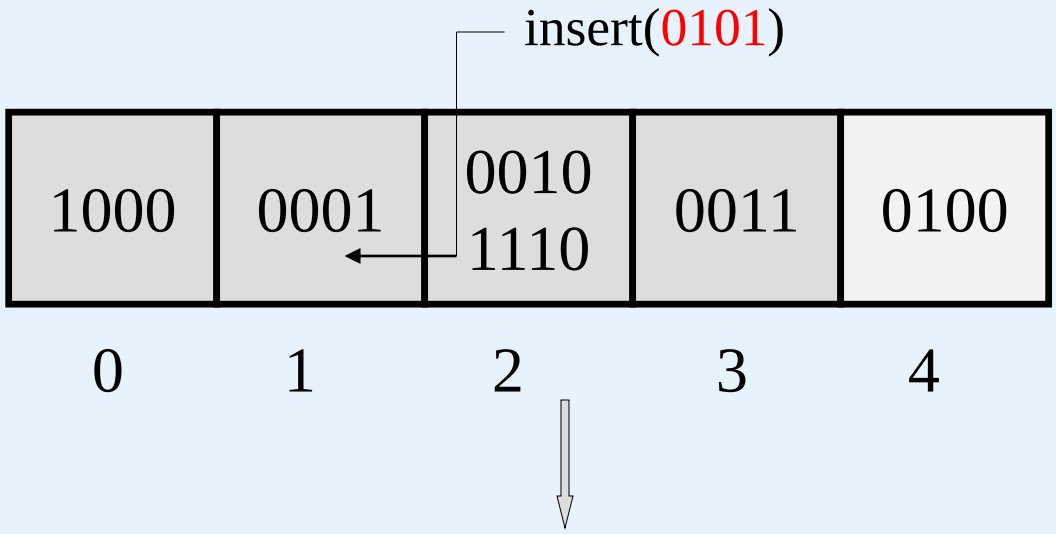


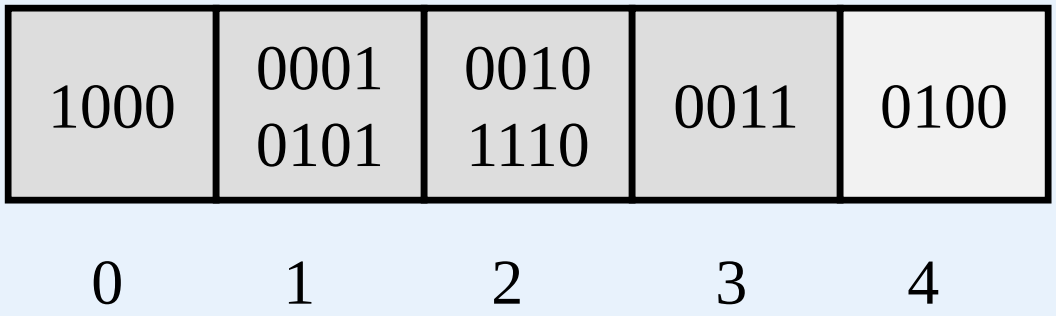
n=1 after the split

load factor: 6/10=0.6

no split

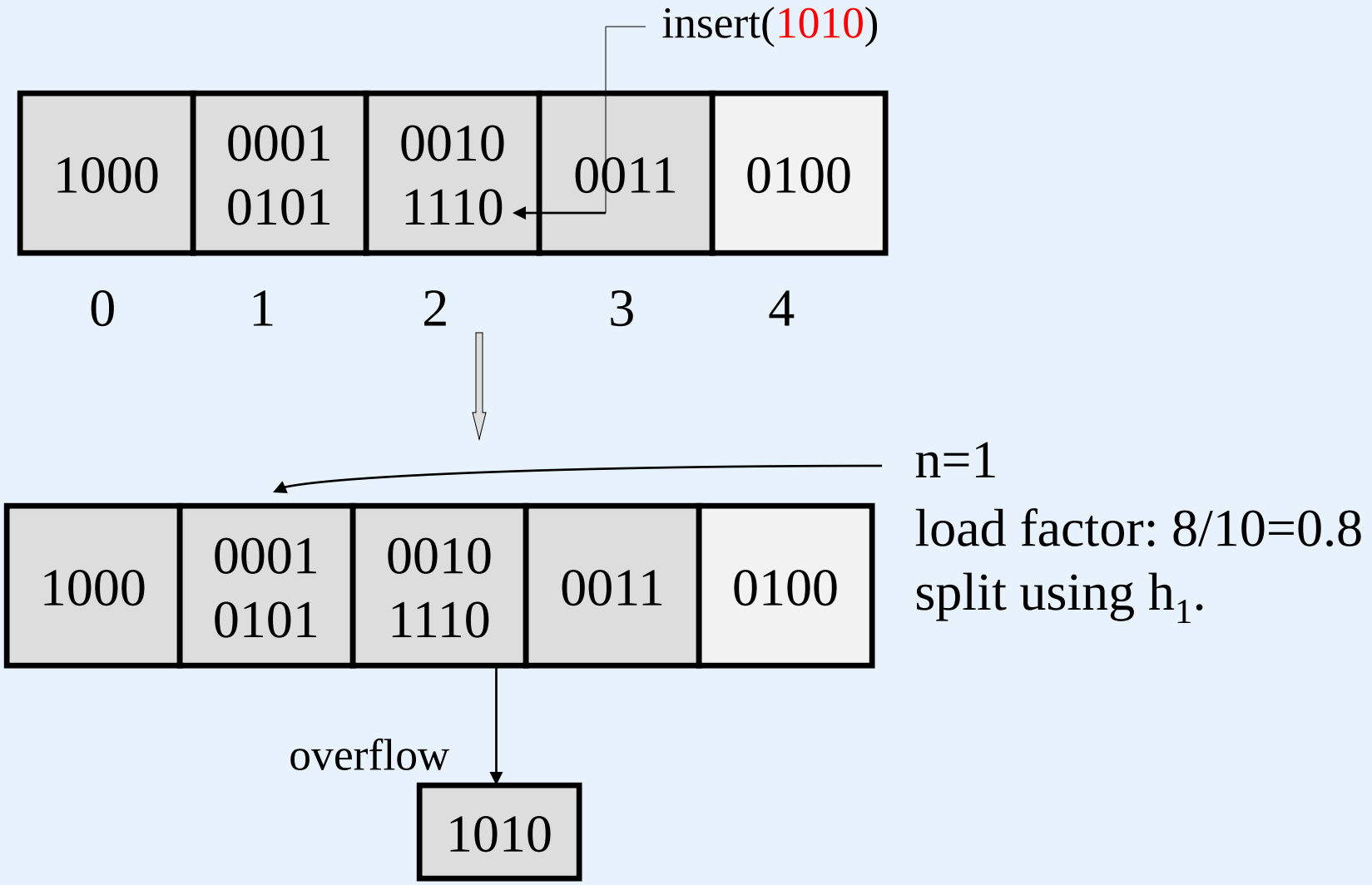
Linear Hashing, example



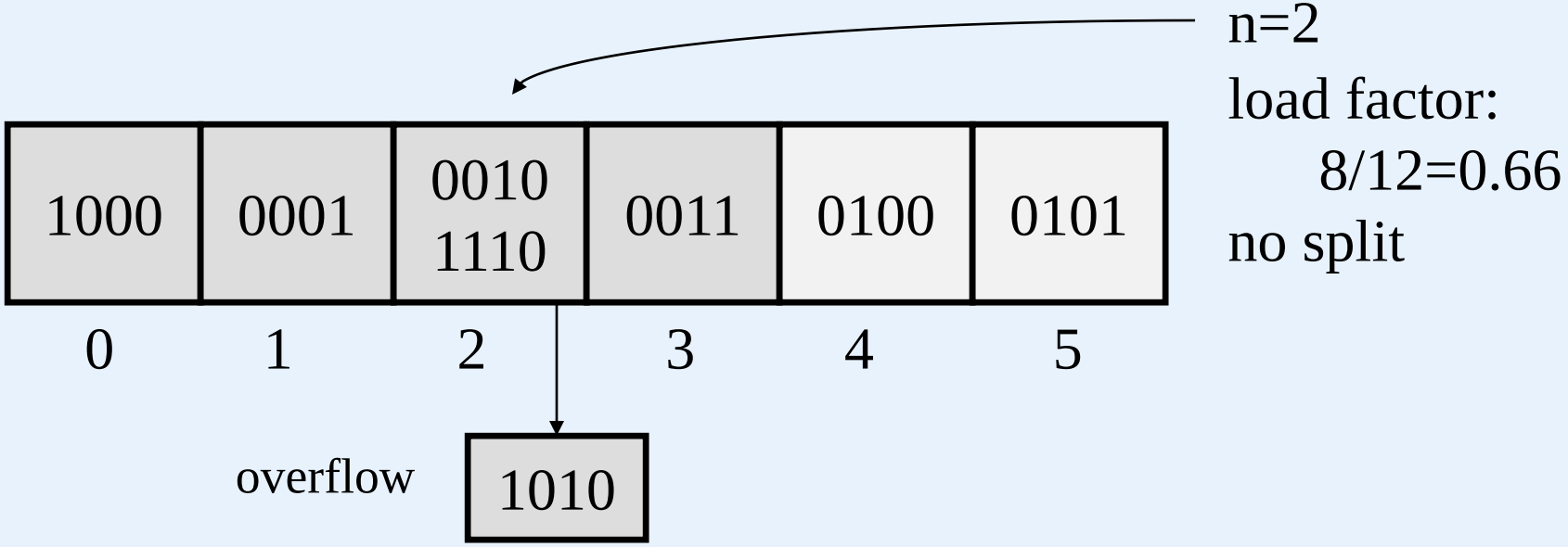


n=1
load factor: 7/10=0.7
no split

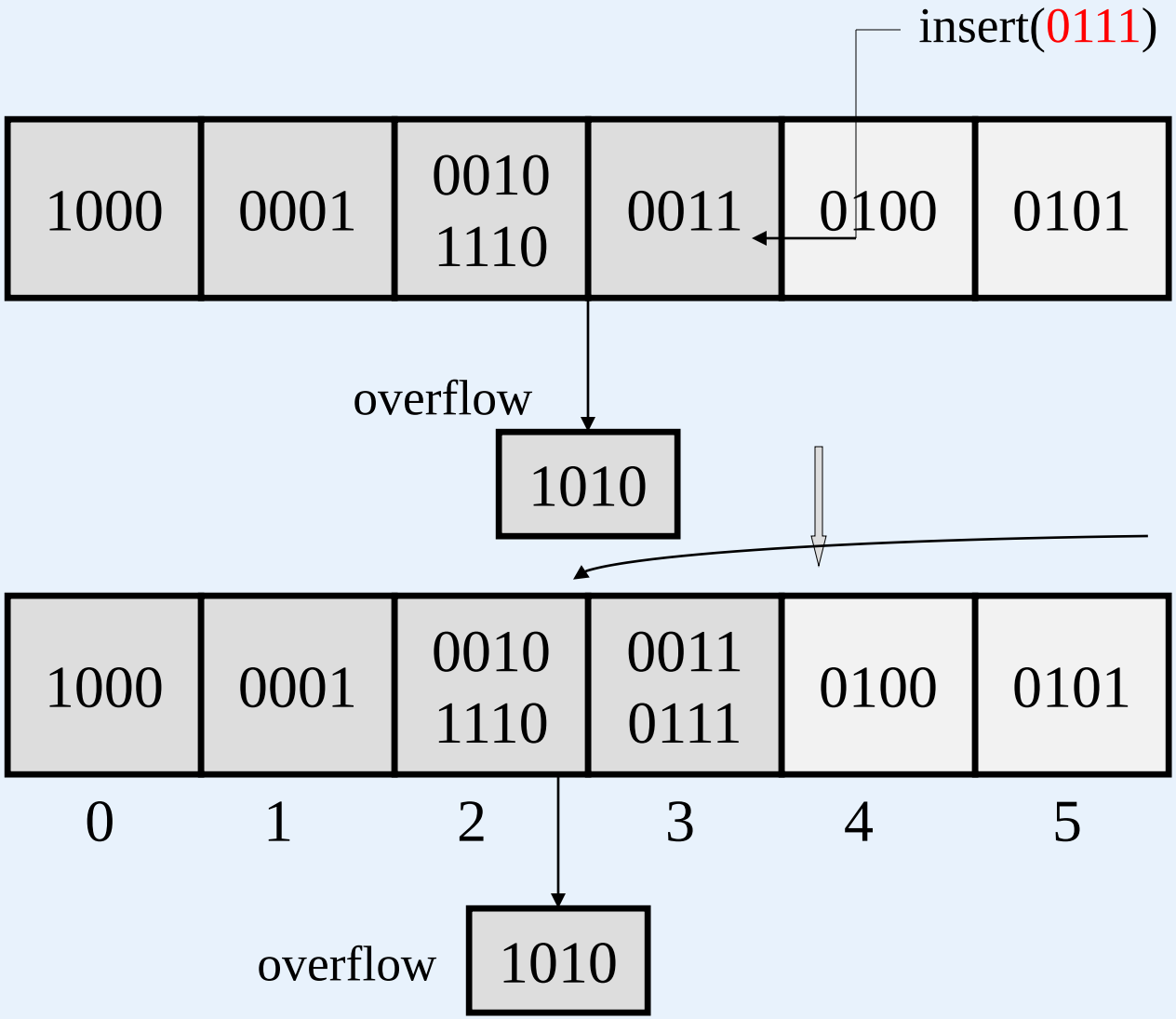
Linear Hashing, example



Linear Hashing, example



Linear Hashing, example

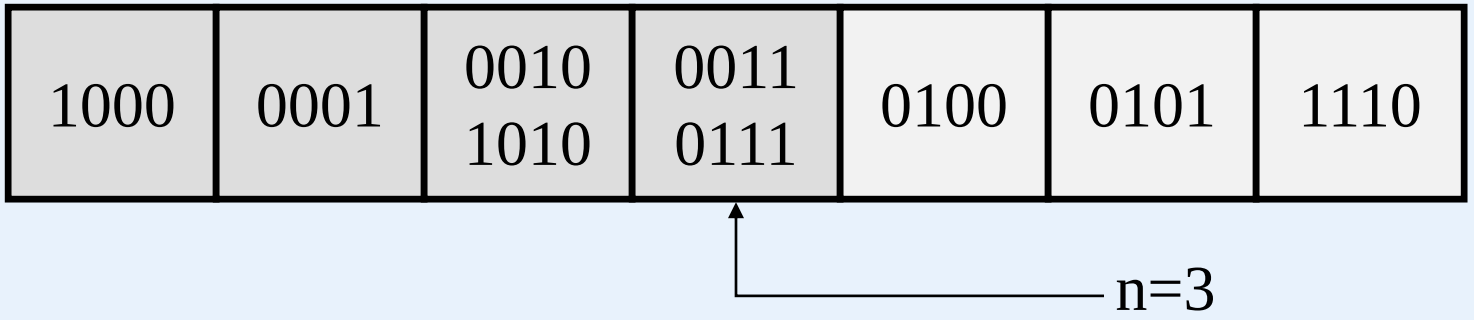


n=2

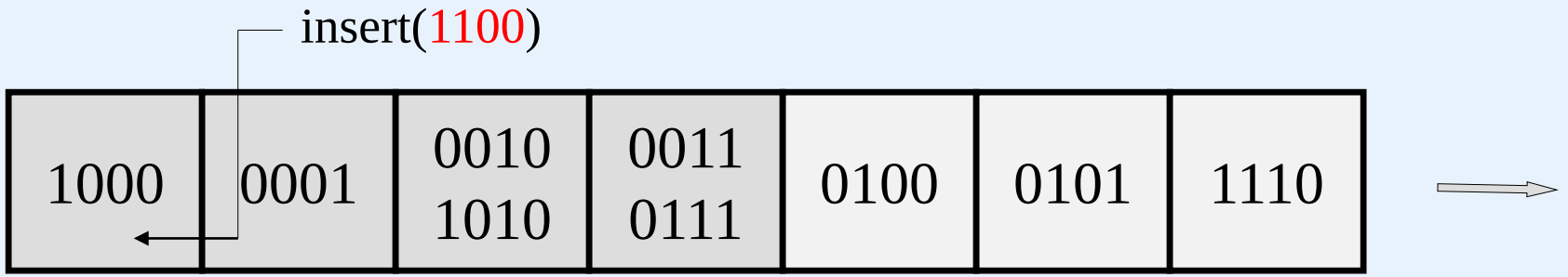
load factor:
9/12=0.75

split using h_1.

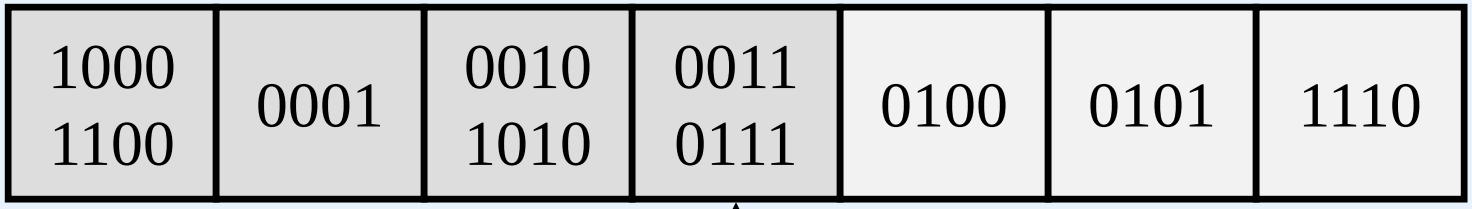
Linear Hashing, example



load factor: 9/14=0.642
no split.



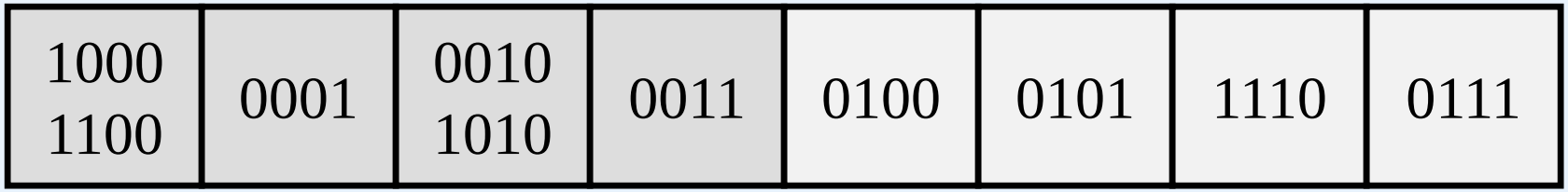
Linear Hashing, example



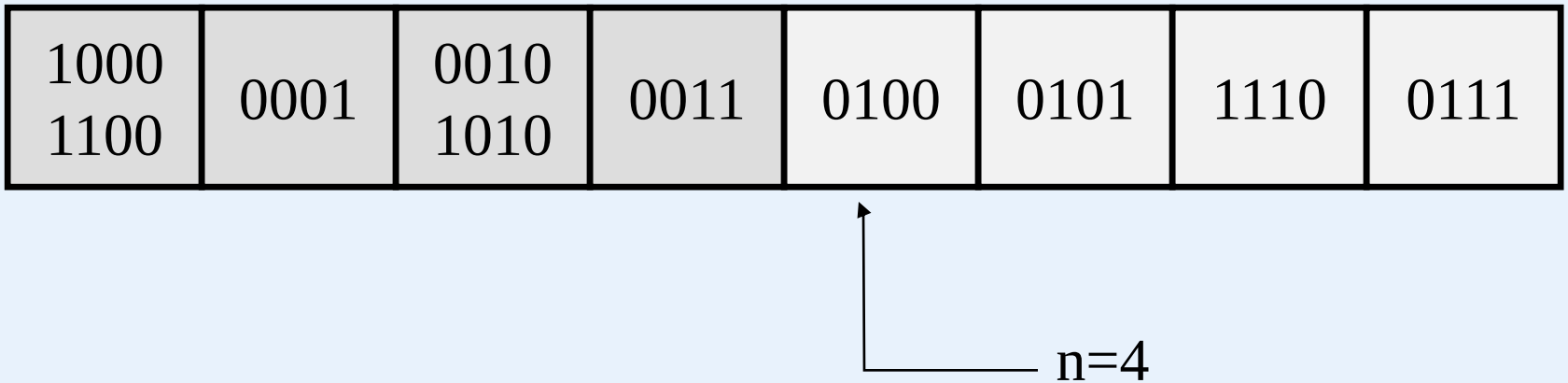
n=3

load factor: 10/14=0.71

split using h_1.



Linear Hashing, example



load factor: 10/16=0.625
no split.

- At this point, all the 4 (M) buckets are split. The size of the primary area becomes 2M. n should be set to 0. It begins a second phase.
- In the second phase, we will use h_1 to insert records and h_2 to split a bucket.
  - note that $h_1(K) = K \bmod 2M$ and $h_2(K) = K \bmod 4M$.

Linear Hashing including two Phases:

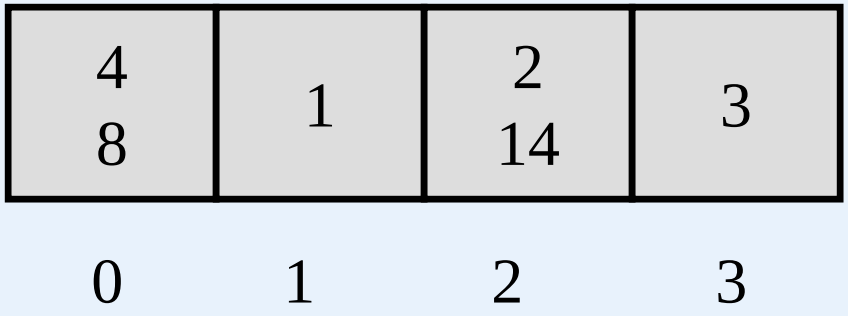
- collision resolution strategy: chaining
- split rule: load factor > 0.7
- initially M = 4 (M: size of the primary area)
- hash functions: $h_i(key) = key \bmod 2^i \times M$ (i = 0, 1, 2, …)
- bucket capacity = 2

Trace the insertion process of the following keys into a linear hashing file:

3, 2, 4, 1, 8, 14, 5, 10, 7, 24, 17, 13, 15.

The first phase – phase$_0$

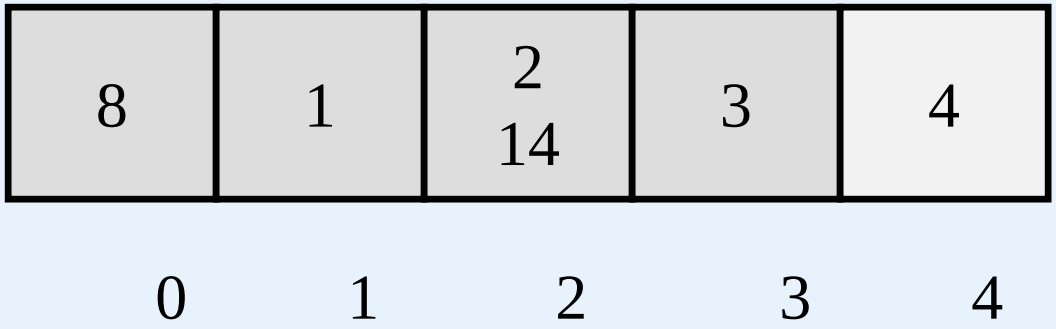
- when inserting the sixth record we would have



n=0 before the split

(n is the point to the bucket to be split.)

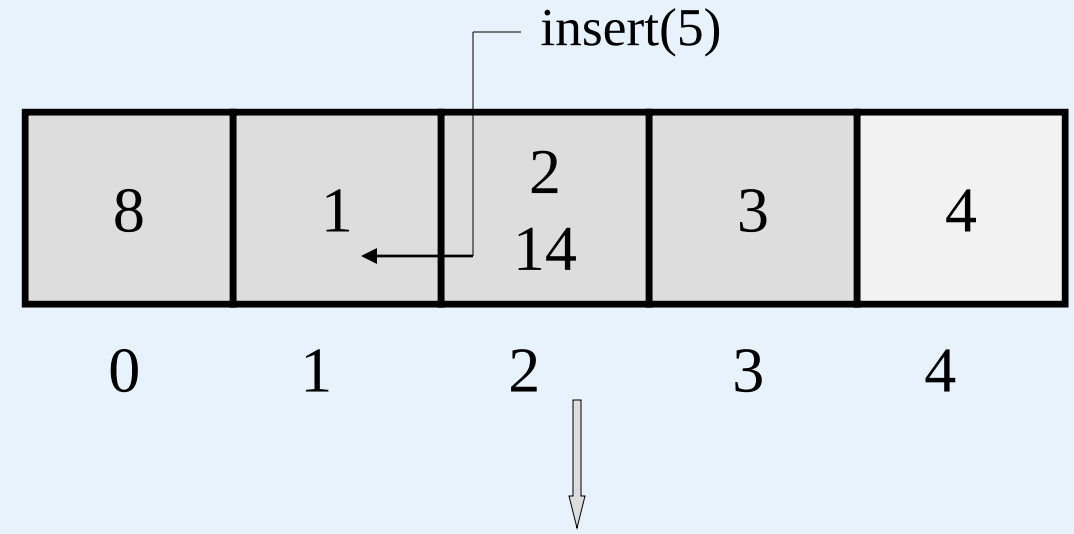
- but the load factor 6/8= 0.75 > 0.70 and so bucket 0 must be split (using h_1 = Key mod 2M):

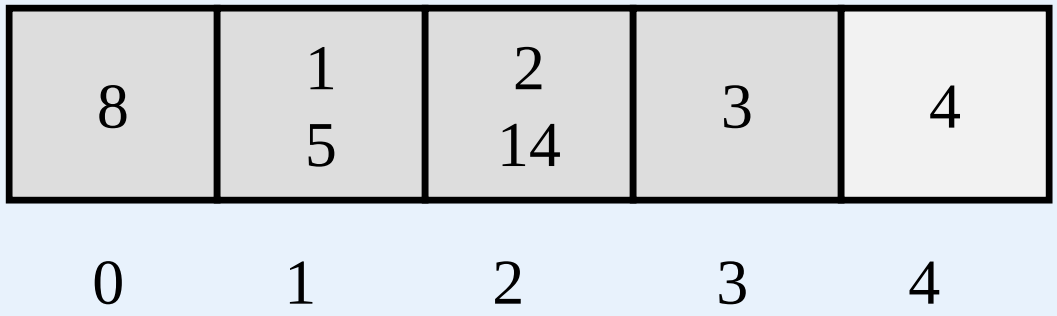


n=1 after the split

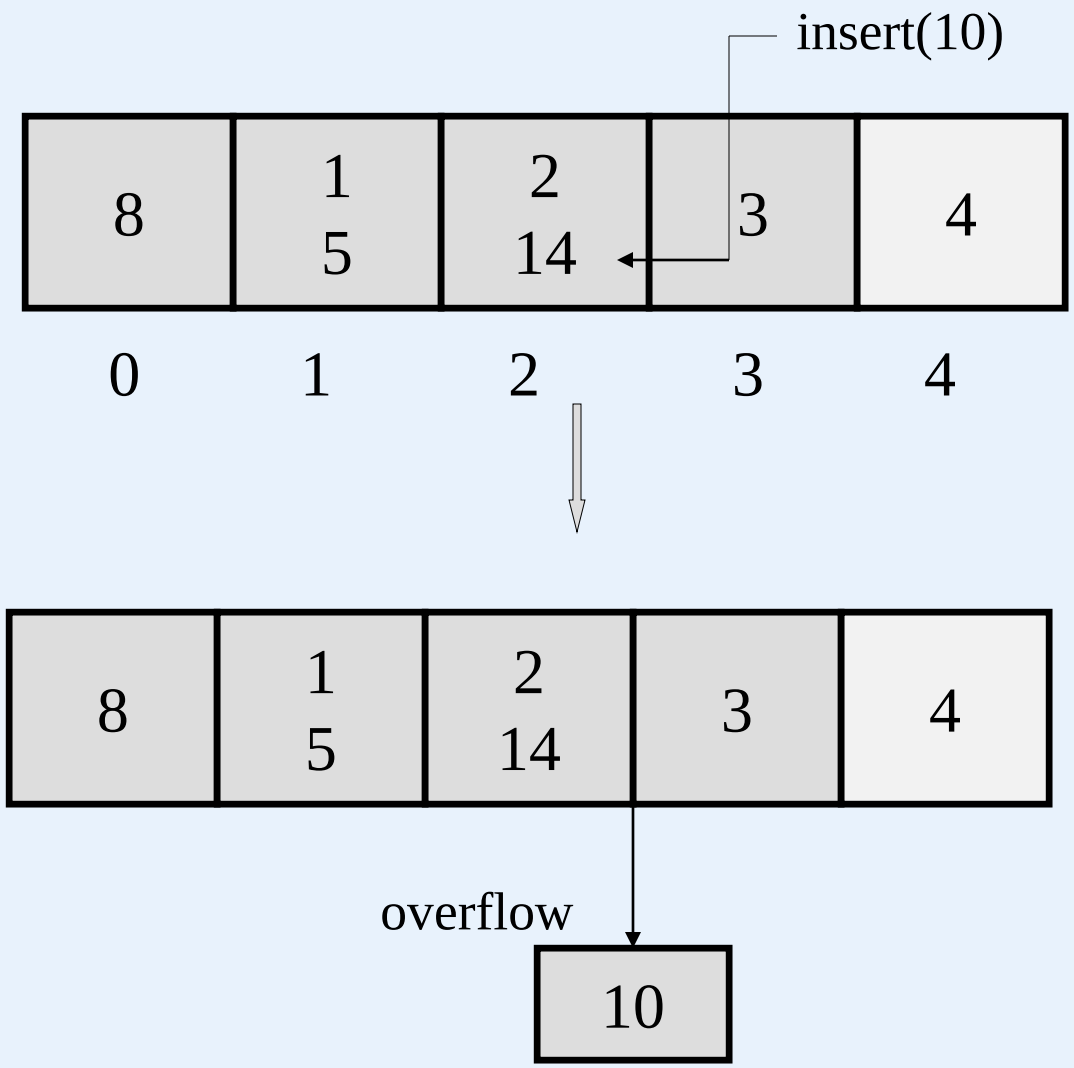
load factor: 6/10=0.6

no split





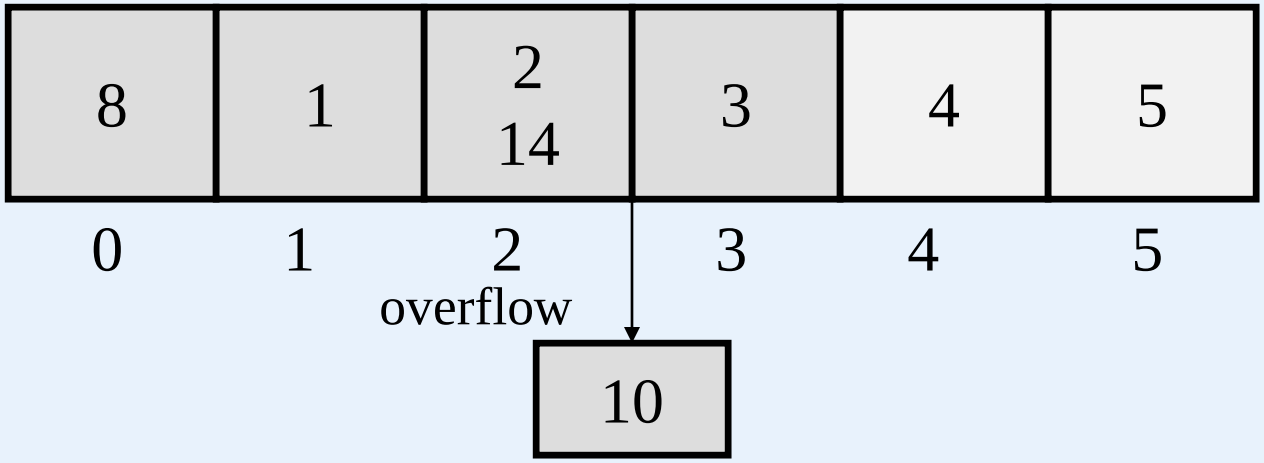
n=1
load factor: 7/10=0.7
no split



n=1

load factor: 8/10=0.8

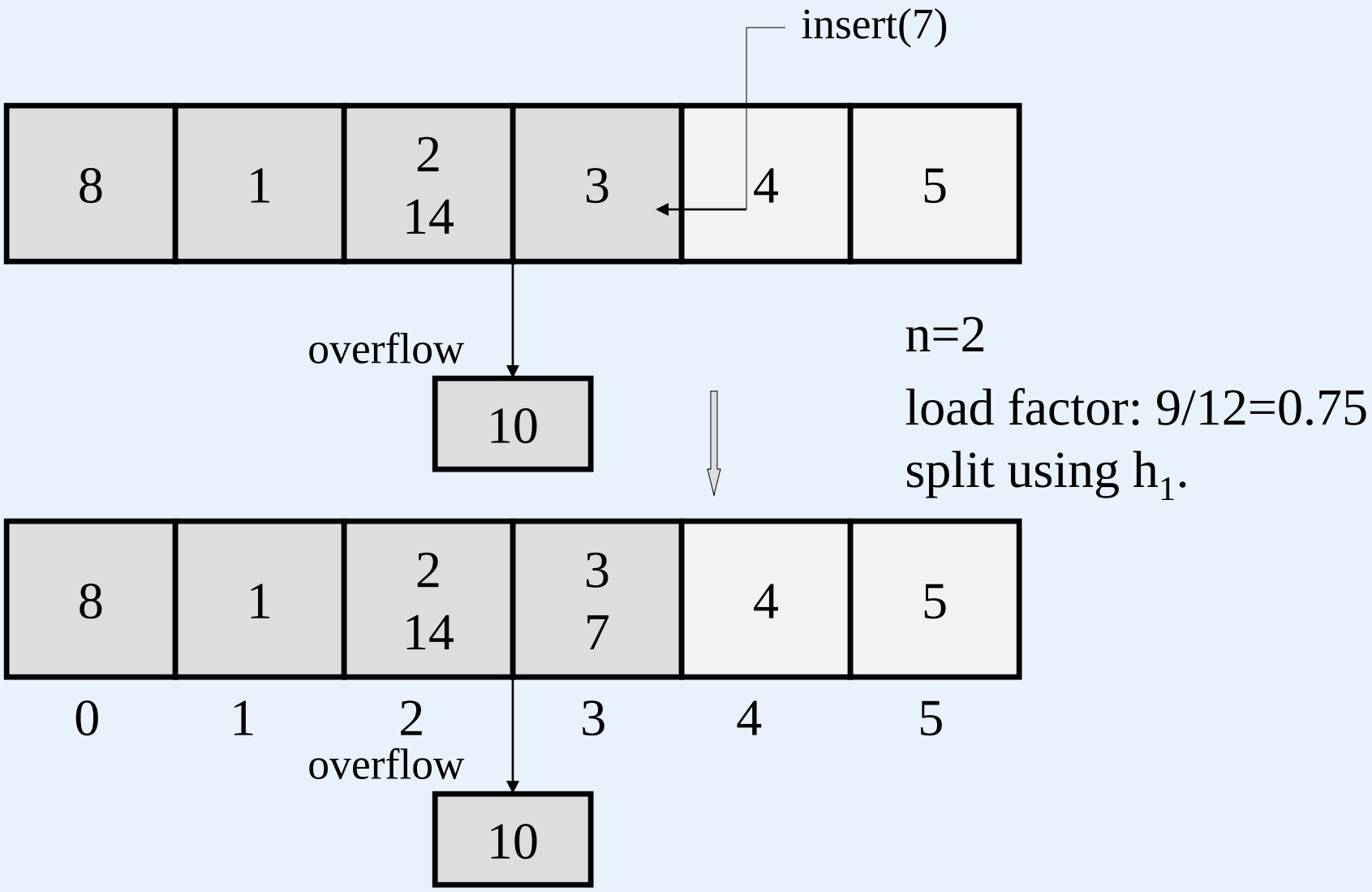
split using h_1.

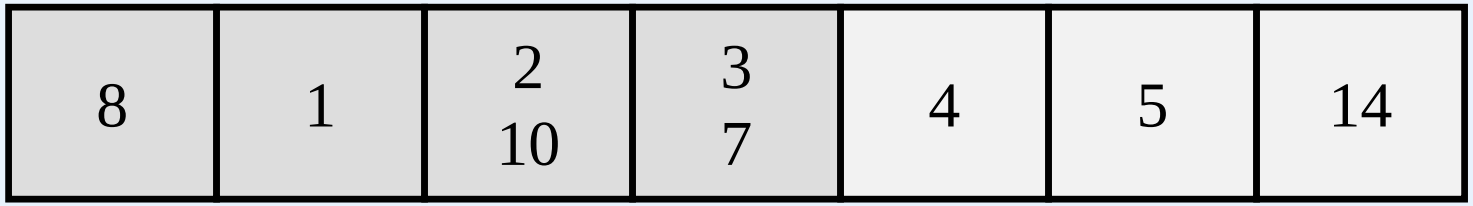


n=2

load factor: 8/12=0.66

no split

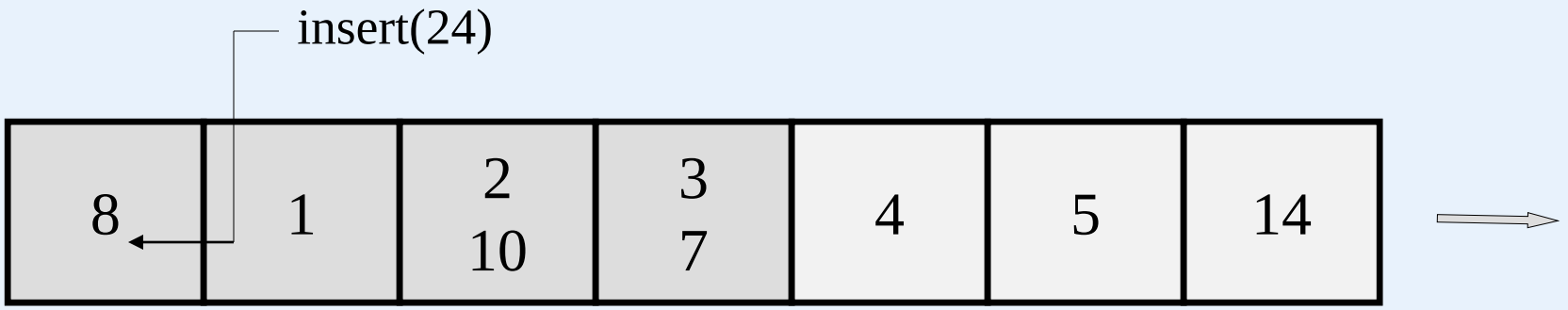

insert(7)
8
1
2
14
3
4
5
overflow
10
n=2
load factor: 9/12=0.75
split using h_1.
8
1
2
14
3
7
4
5
0
1
2
3
4
5
overflow
10

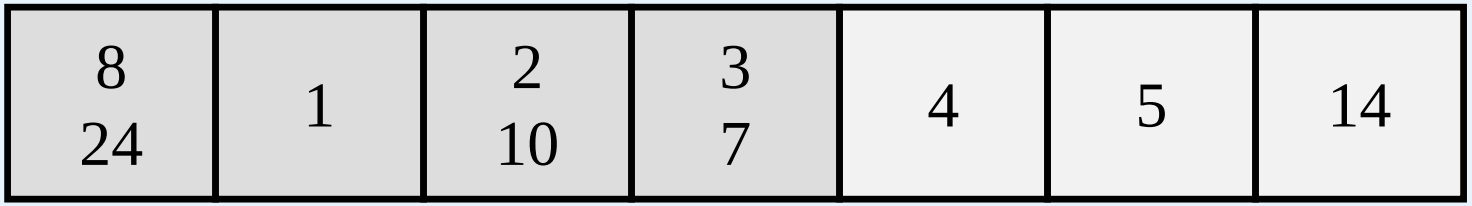


n=3

load factor: 9/14=0.642

no split.

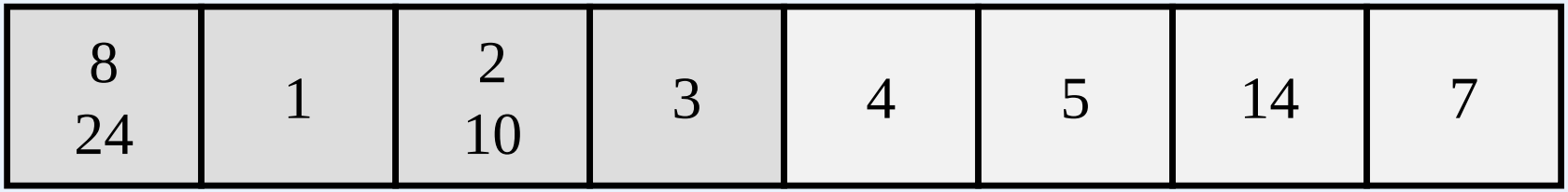


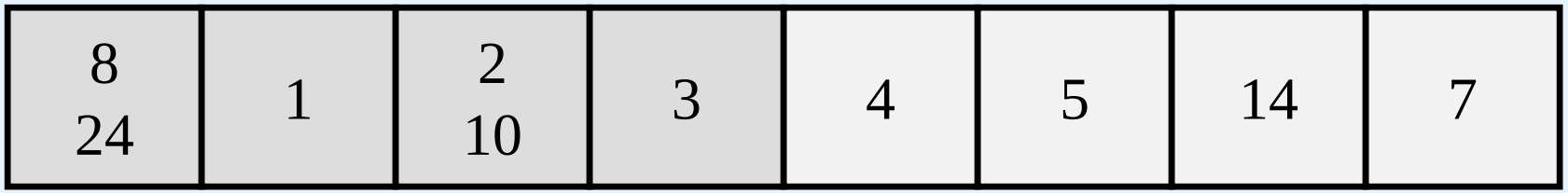


n=3

load factor: 10/14=0.71

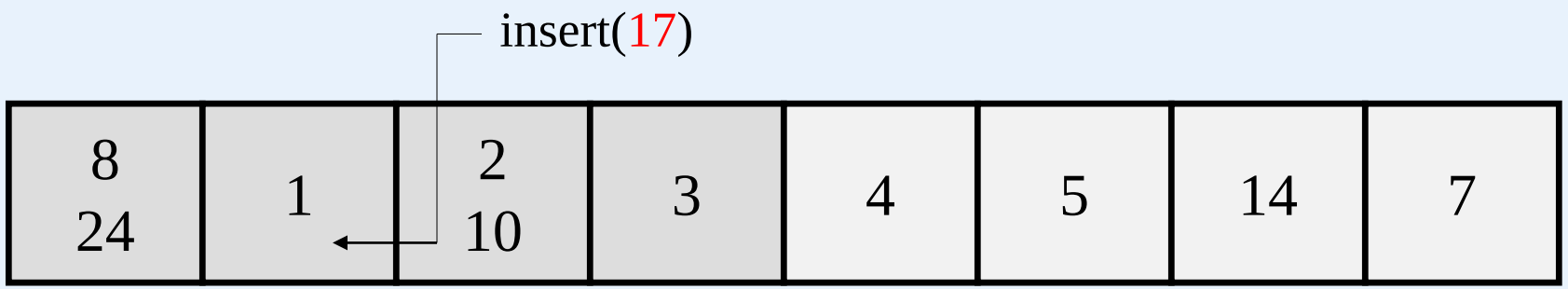
split using h_1.





The second phase – phase$_1$

n = 0; using h_1 = Key mod 2M to insert and
h_2 = Key mod 4M to split.

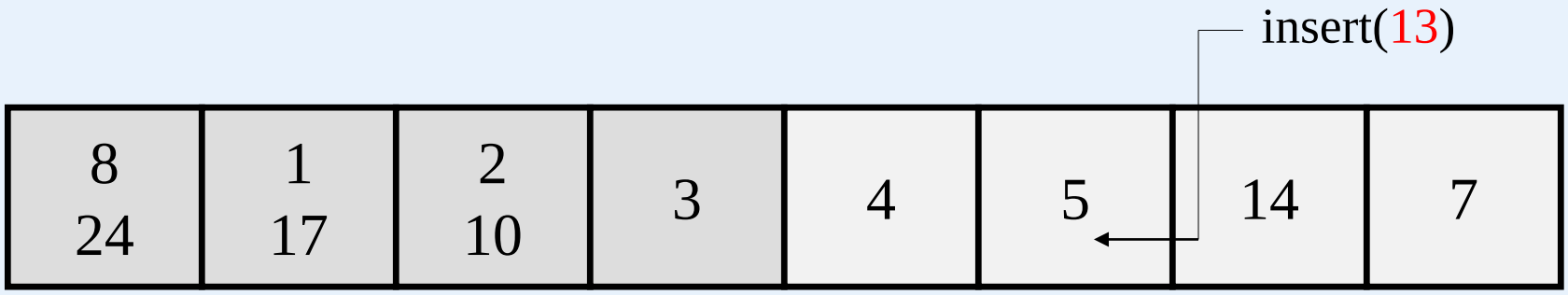


8 24	1 17	2 10	3	4	5	14	7

n=0

load factor: 11/16=0.687

no split.



8 24	1 17	2 10	3	4	5 13	14	7

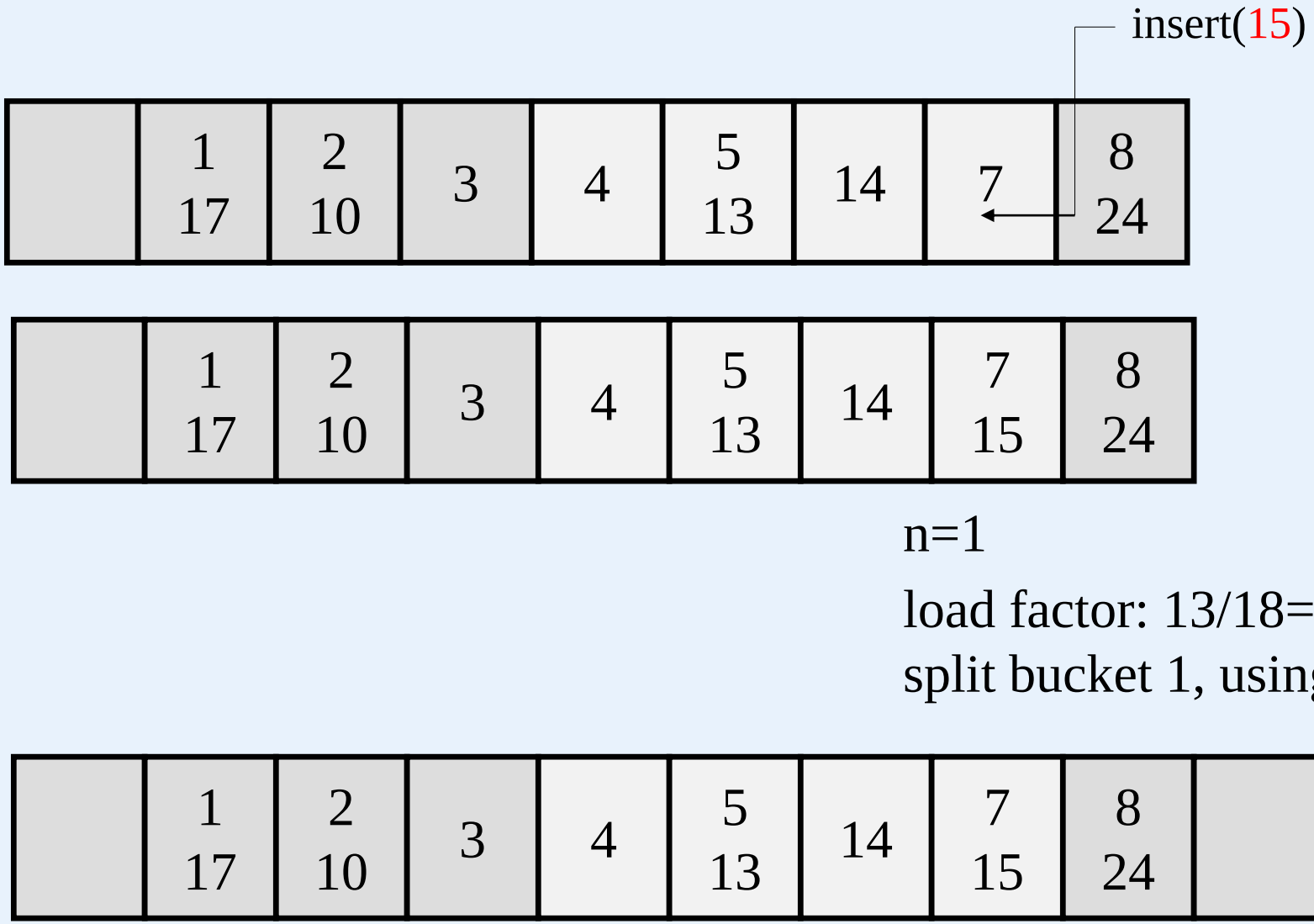
n=0

load factor: 12/16=0.75

split bucket 0, using h_2:

h_2 = Key mod 4M

	1 17	2 10	3	4	5 13	14	7	8 24


insert(15)
1
17
2
10
3
4
5
13
14
7
8
24
1
17
2
10
3
4
5
13
14
7
15
8
24
n=1
load factor: 13/18=0.722
split bucket 1, using h_2.
1
17
2
10
3
4
5
13
14
7
15
8
24

How to find a KEY in a linear hash file?

M – the size of the initial primary area
j – the last phase
n – the next bucket to be split

Algorithm find(KEY, M, *j*, *n*)

if $j = 0$ **then** return $h_0(\text{KEY}) = \text{KEY} \bmod M$;
else

BUCKET_LOC := $h_{j-1}(\text{KEY}) = \text{KEY} \bmod 2^{j-1}M$;
if BUCKET_LOC < *n* **then** return $h_j(\text{KEY})$
else return BUCKET_LOC;