CPS216: Data-intensive Computing Systems

Operators for Data Access

Shivnath Babu

Problem

- Relation: Employee (ID, Name, Dept, …)
- 10 M tuples
- (Filter) Query:

```
SELECT   *
FROM     Employee
WHERE    Name = "Bob"
```

Solution #1: Full Table Scan

- Storage:
  - Employee relation stored in contiguous blocks
- Query plan:
  - Scan the entire relation, output tuples with Name = "Bob"
- Cost:
  - Size of each record = 100 bytes
  - Size of relation = 10 M x 100 = 1 GB
  - Time @ 20 MB/s ≈ 1 Minute

Solution #2

- Storage:
  - Employee relation sorted on Name attribute
- Query plan:
  - Binary search

Solution #2

- Cost:
  - Size of a block: 1024 bytes
  - Number of records per block: 1024 / 100 = 10
  - Total number of blocks: 10 M / 10 = 1 M
  - Blocks accessed by binary search: 20
  - Total time: 20 ms x 20 = 400 ms

Solution #2: Issues

- Filters on different attributes:

```
SELECT  *
FROM    Employee
WHERE   Dept = “Sales”
```

- Inserts and Deletes

Indexes

- Data structures that efficiently evaluate a class of filter predicates over a relation
- Class of filter predicates:
  - Single or multi-attributes (index-key attributes)
  - Range and/or equality predicates
- (Usually) independent of physical storage of relation:
  - Multiple indexes per relation

Indexes

- Disk resident
  - Large to fit in memory
  - Persistent
- Updated when indexed relation updated
  - Relation updates costlier
  - Query cheaper

Problem

- Relation: Employee (ID, Name, Dept, …)
- (Filter) Query:

```
SELECT   *
FROM     Employee
WHERE    Name = "Bob"
```

Single-Attribute Index on Name that supports equality predicates

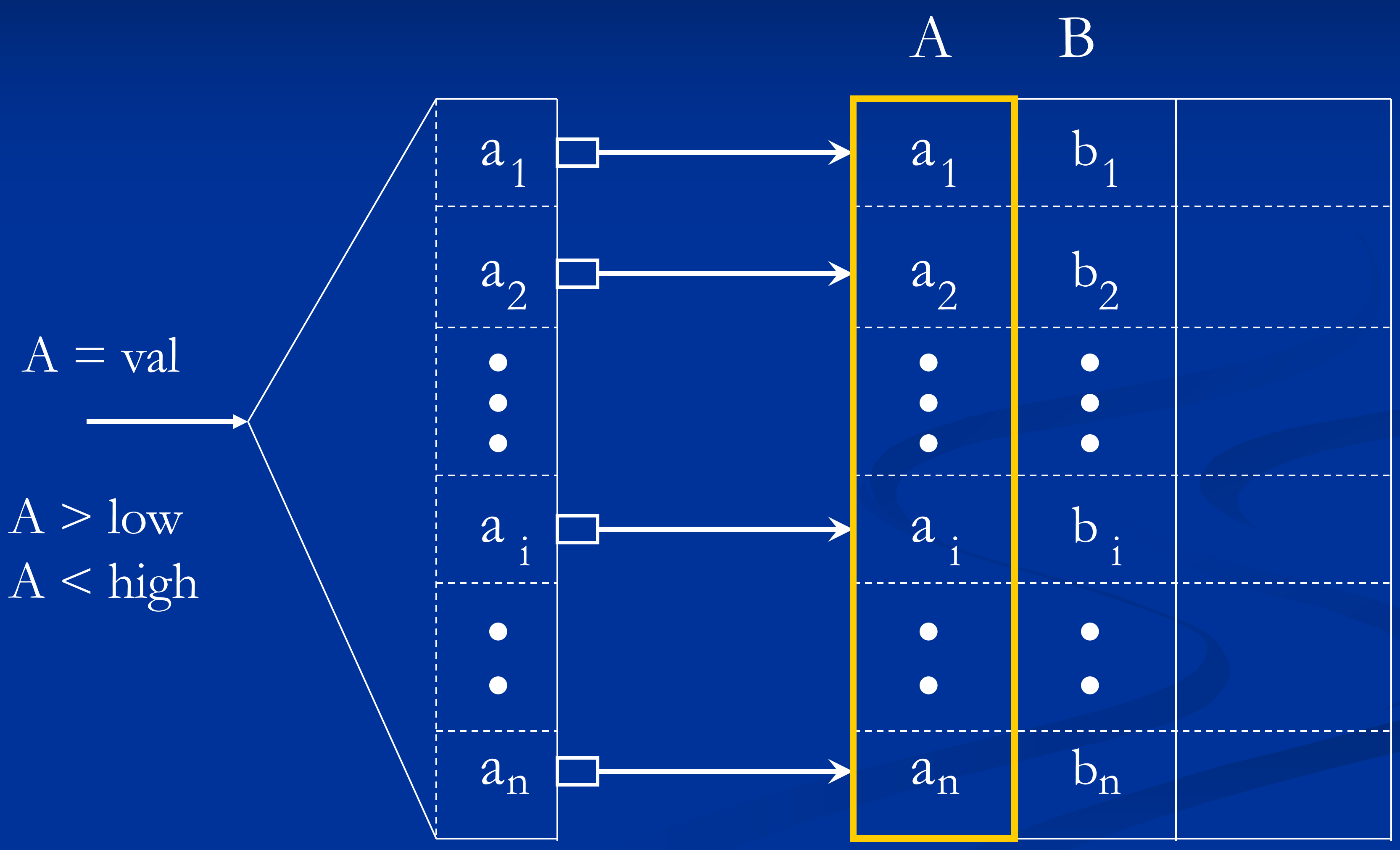
Roadmap

- Motivation
- Single-Attribute Indexes: Overview
- Order-based Indexes
  - B-Trees
- Hash-based Indexes (May cover in future)
  - Extensible Hashing
  - Linear Hashing
- Multi-Attribute Indexes (Chapter 14 GMUW, May cover in future)

Single Attribute Index: General Construction

A	B	
a_1	b_1	
a_2	b_2	
• • •	• • •	
a_i	b_i	
• •	• •	
a_n	b_n	

Single Attribute Index: General Construction

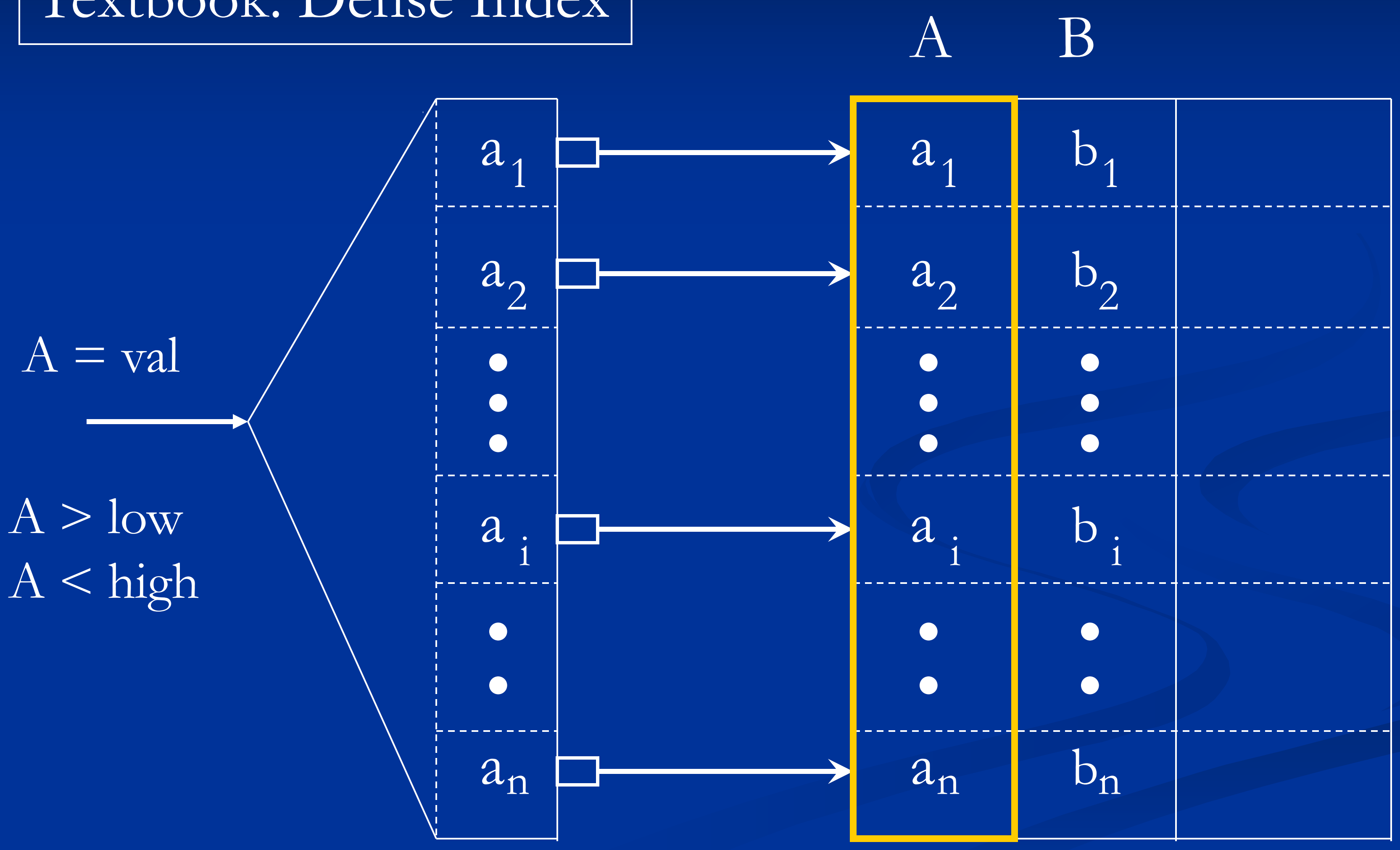


Exceptions

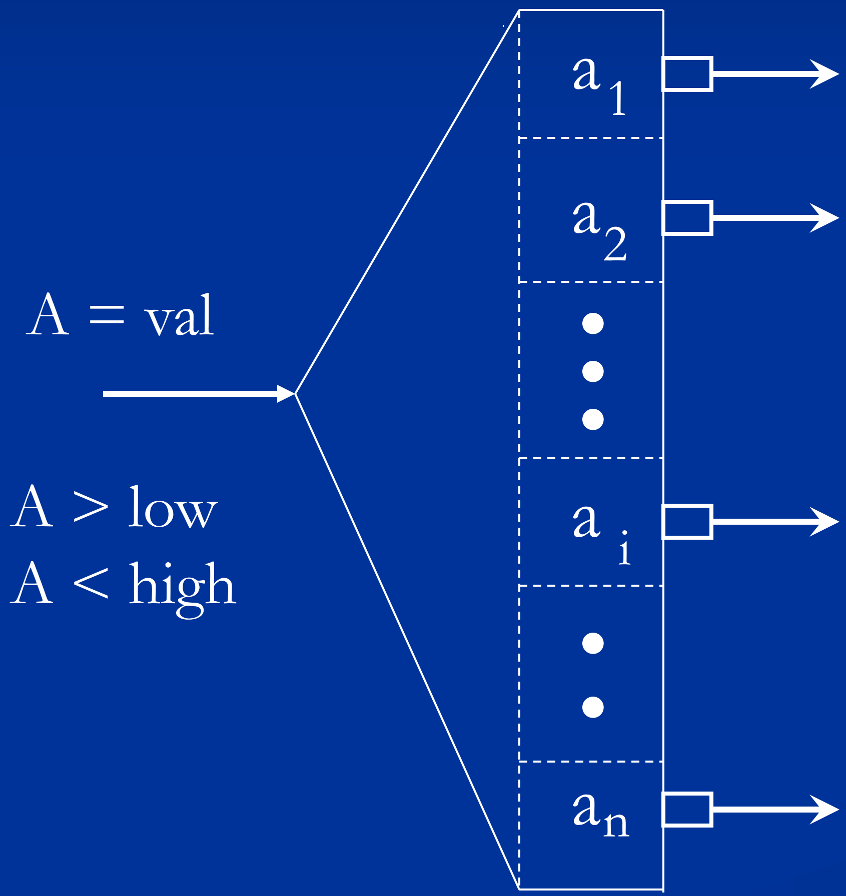
- Sparse Indexes
  - Require specific physical layout of relation
  - Example: Relation sorted on indexed attribute
  - More efficient

Single Attribute Index: General Construction

Textbook: Dense Index



Single Attribute Index: General Construction



How do we organize (attribute, pointer) pairs?

Idea: Use dictionary data structures

Issue: Disk resident?

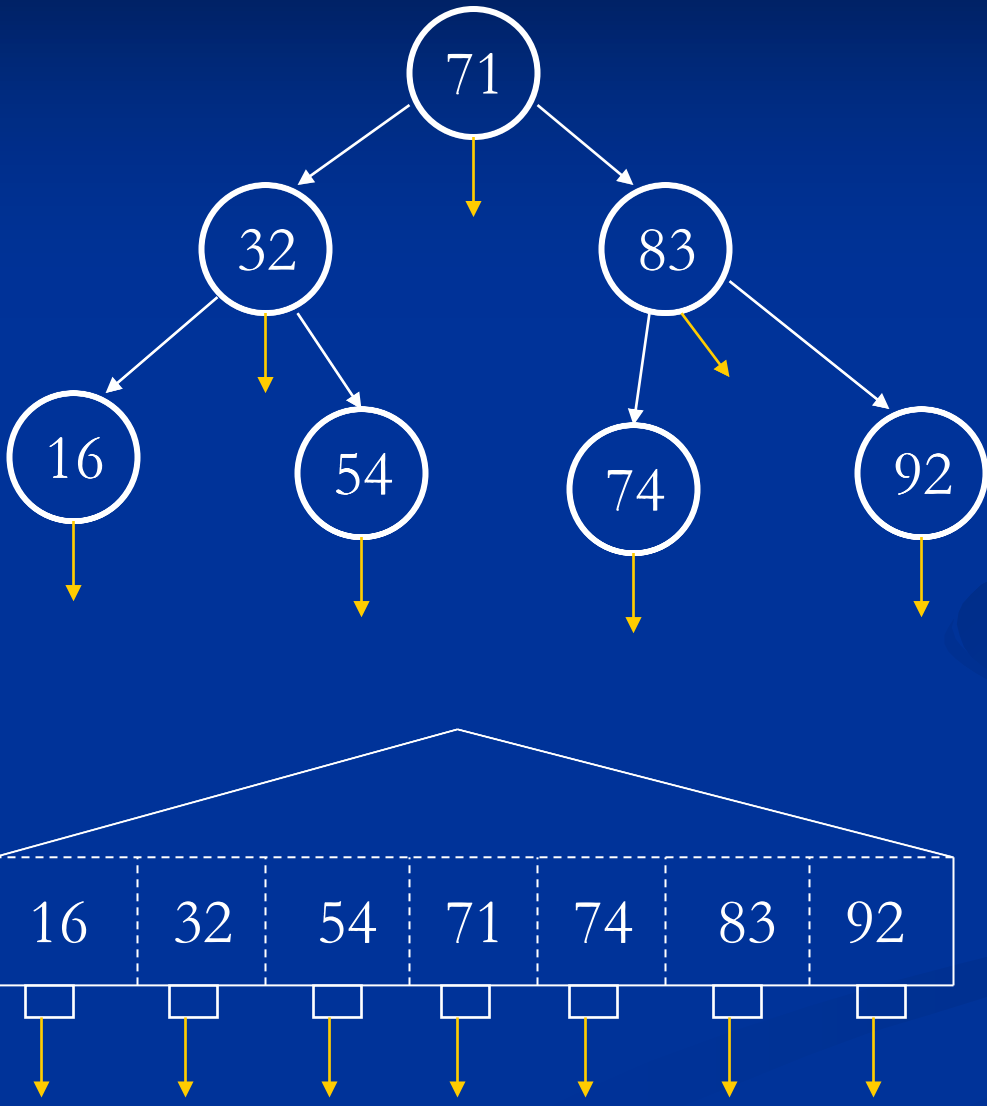
Roadmap

- Motivation
- Single-Attribute Indexes: Overview
- Order-based Indexes
  - B-Trees
- Hash-based Indexes
  - Extensible Hashing
  - Linear Hashing
- Multi-Attribute Indexes

B-Trees

- Adaptation of search tree data structure
  - 2-3 trees
- Supports range predicates (and equality)

Use Binary Search Tree Directly?



Use Binary Search Tree Directly?

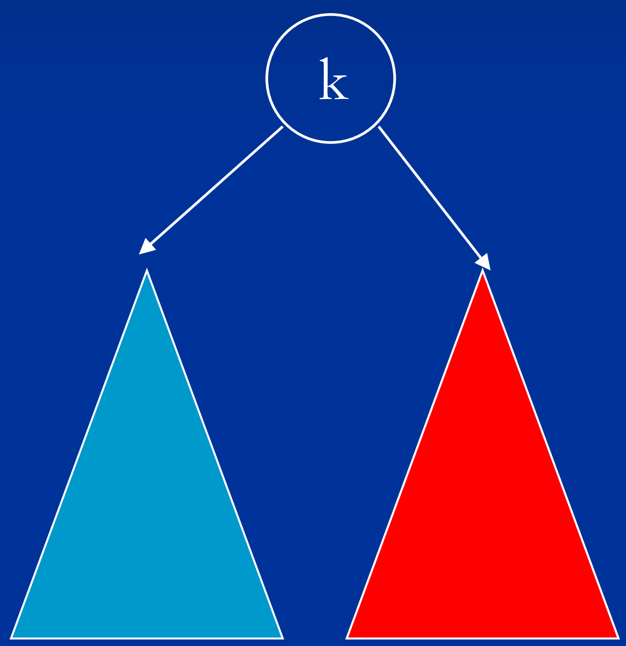
- Store records of type
  <key, left-ptr, right-ptr, data-ptr>
- Remember position of root
- Question: will this work?
  - Yes
  - But we can do better!

Use Binary Search Tree Directly?

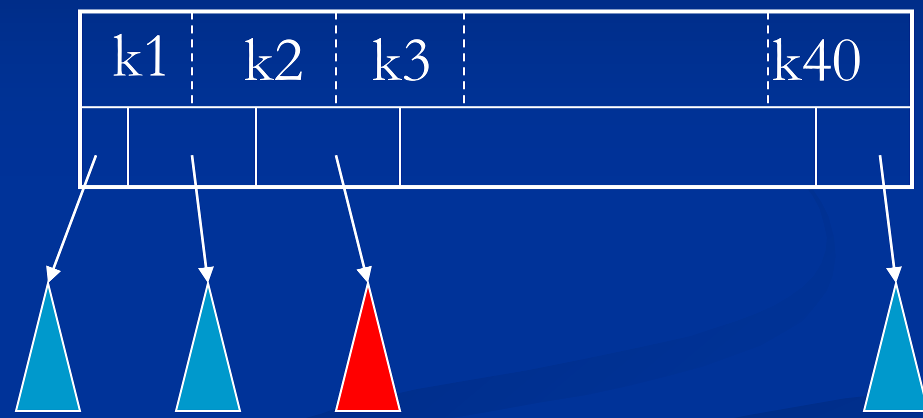
- Number of keys: 1 M
- Number of levels: log (2^20) = 20
- Total cost index lookup: 20 random disk I/O
  - 20 x 20 ms = 400 ms

B-Tree: less than 3 random disk I/O

B-Tree vs. Binary Search Tree

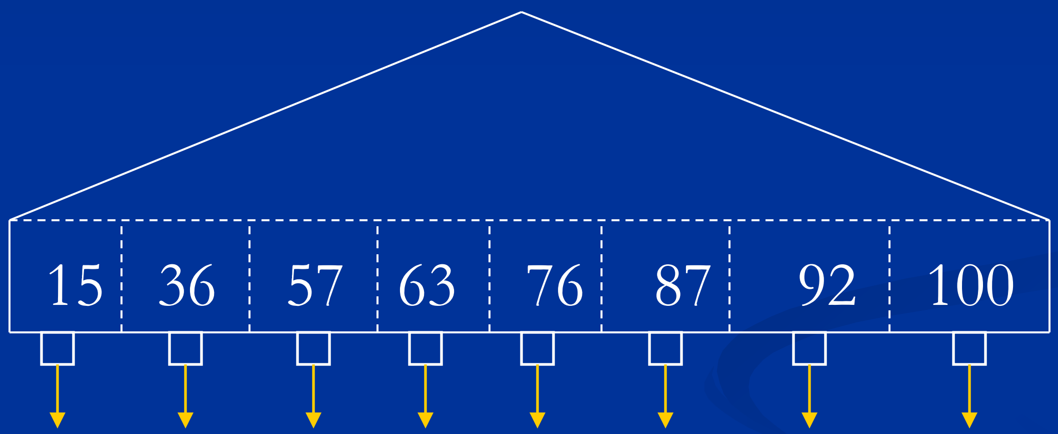


1 Random I/O prunes tree by half

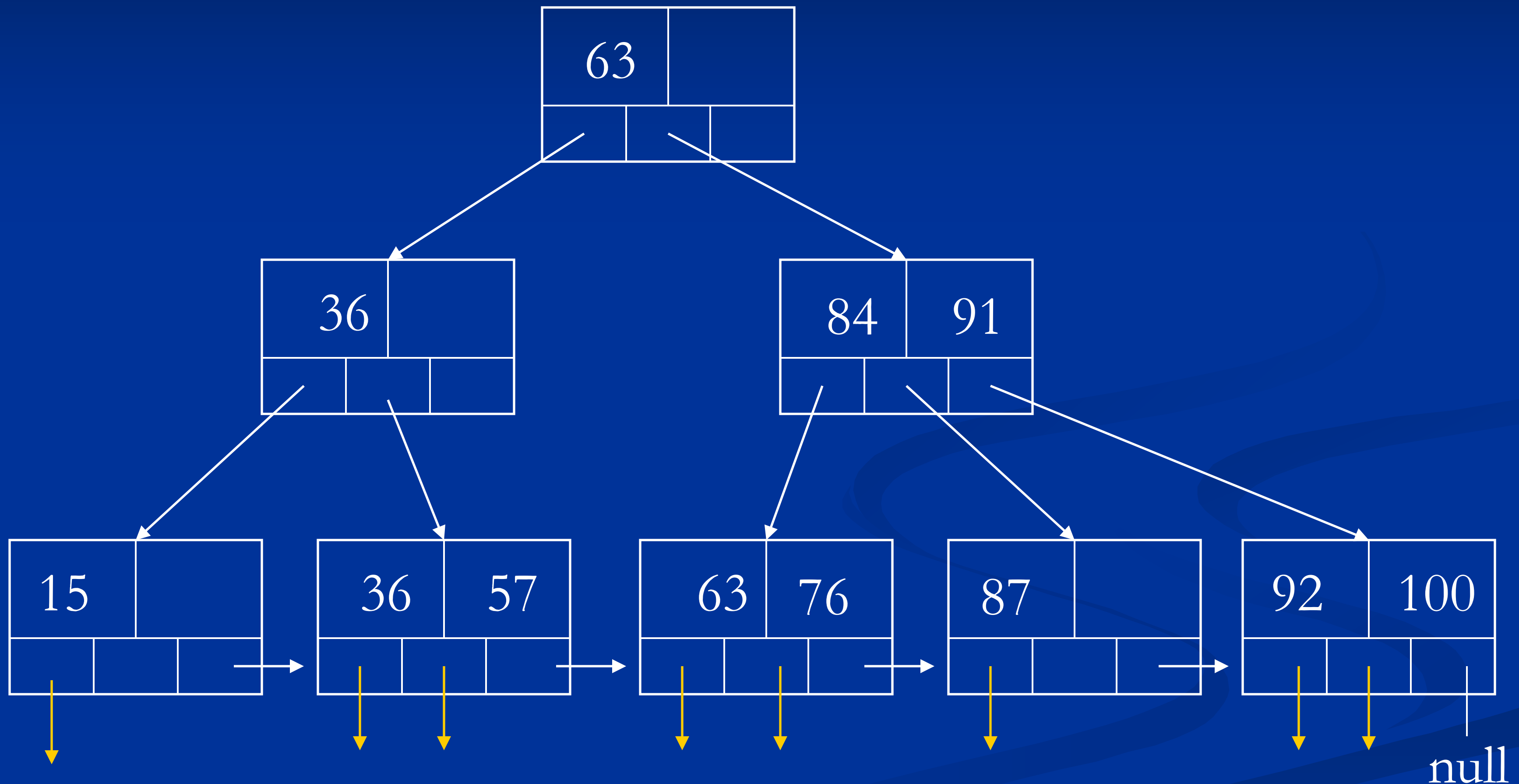


1 Random I/O prunes tree by 40

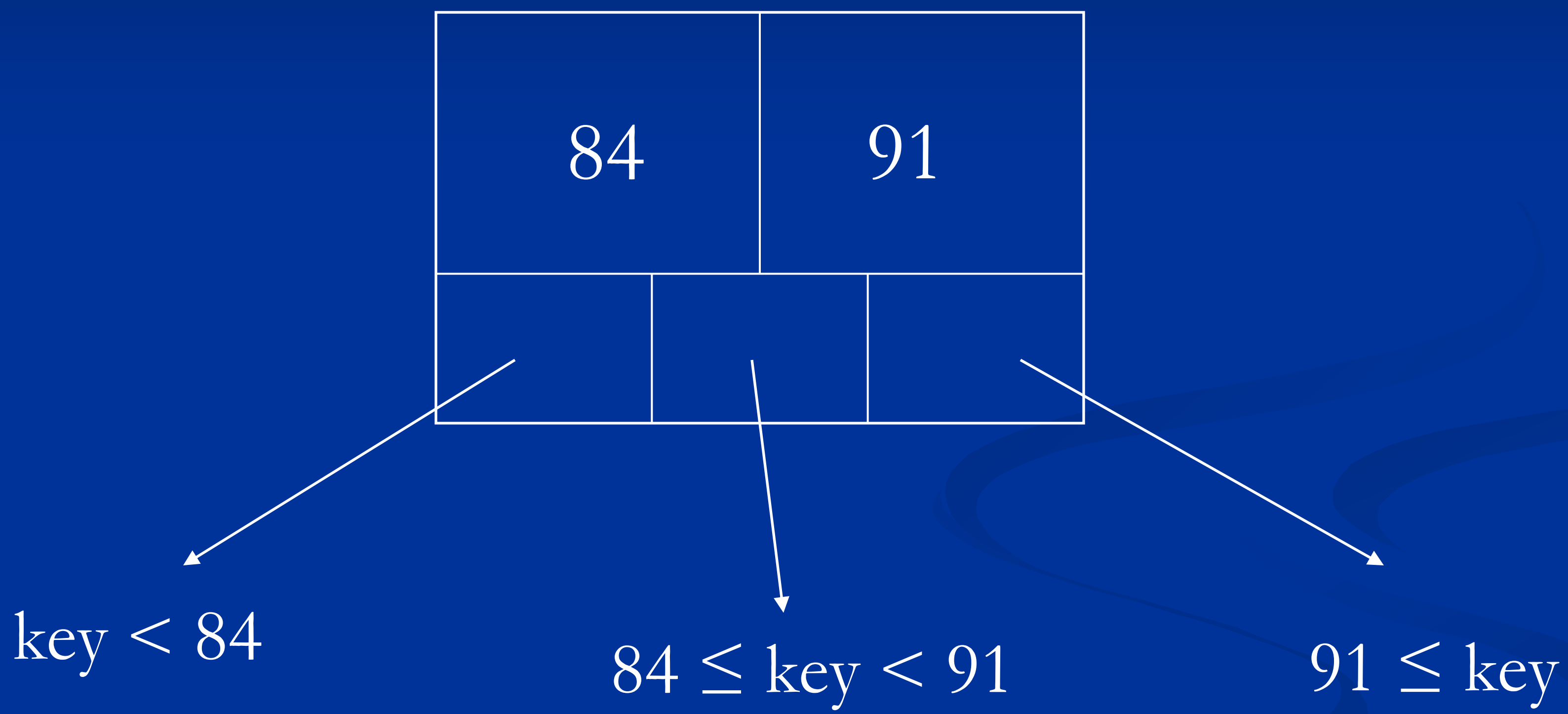
B-Tree Example



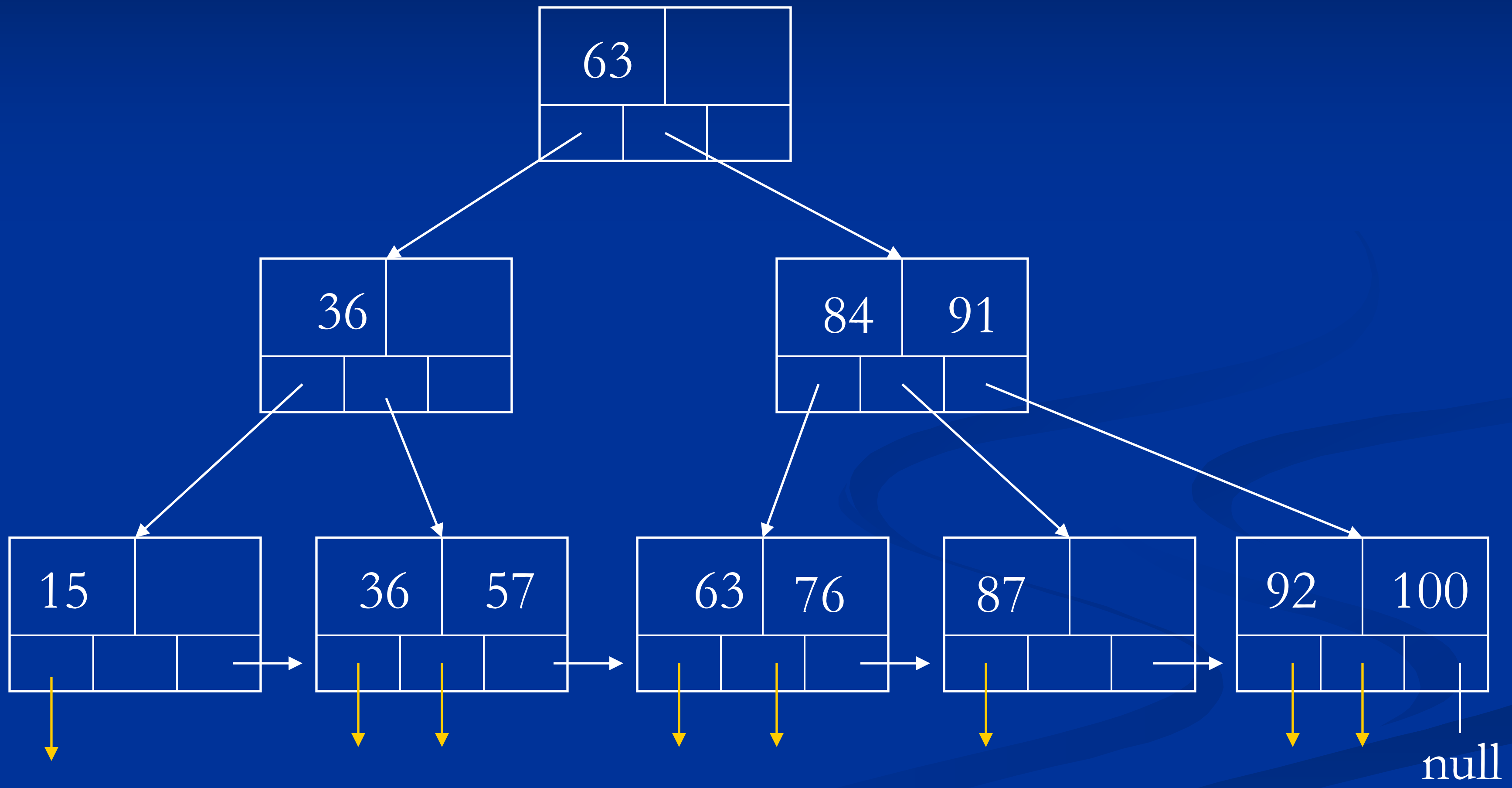
B-Tree Example



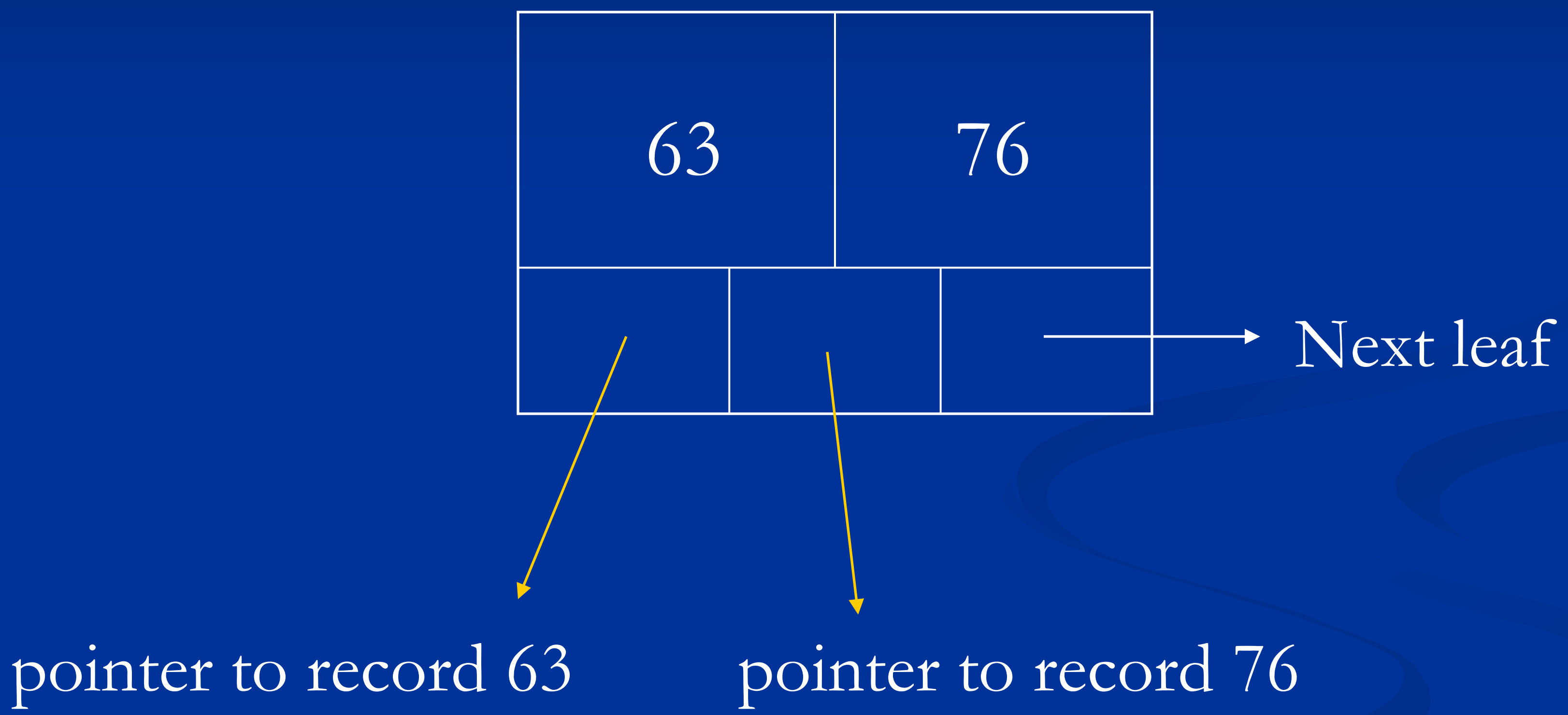
Meaning of Internal Node



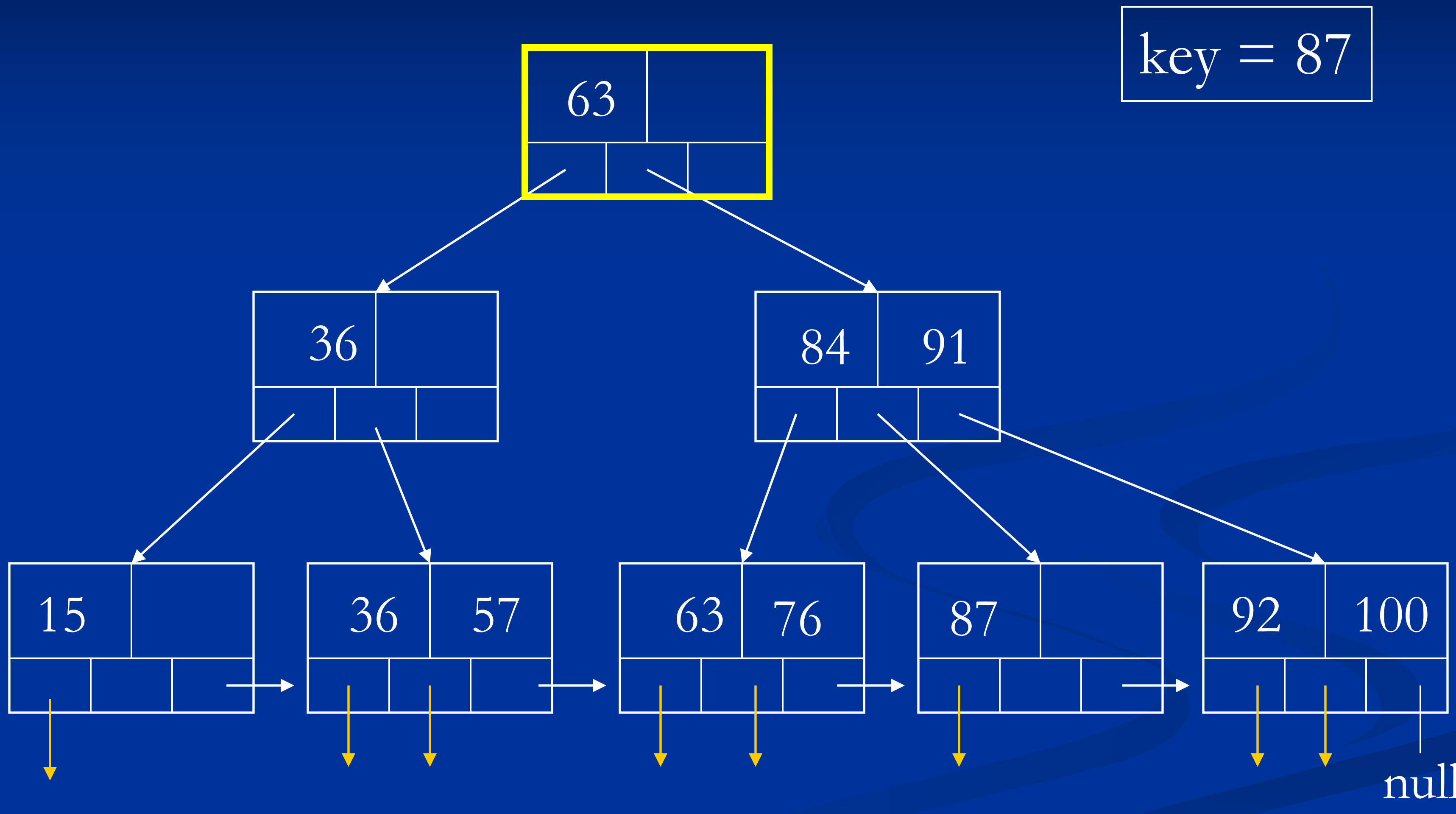
B-Tree Example



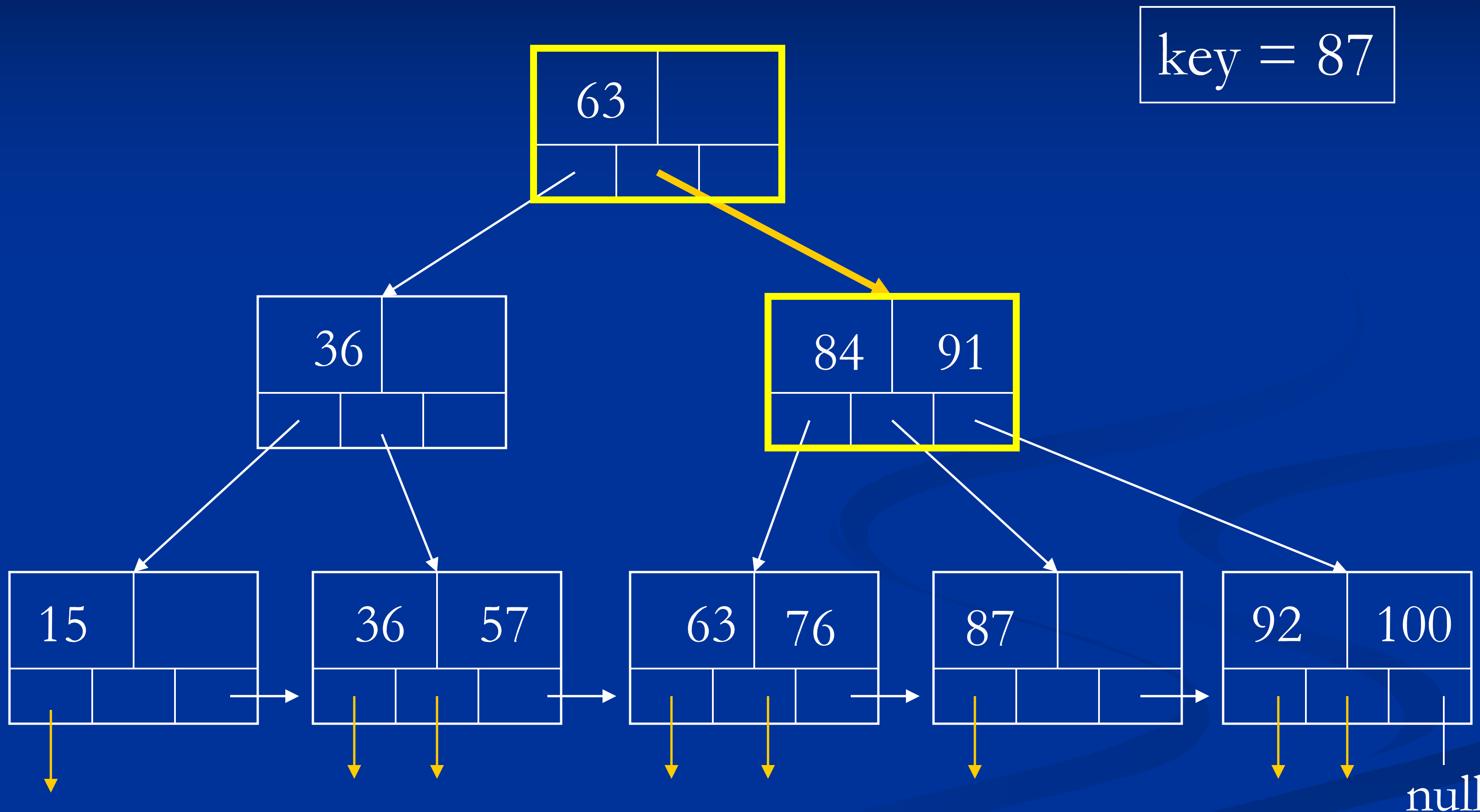
Meaning of Leaf Nodes



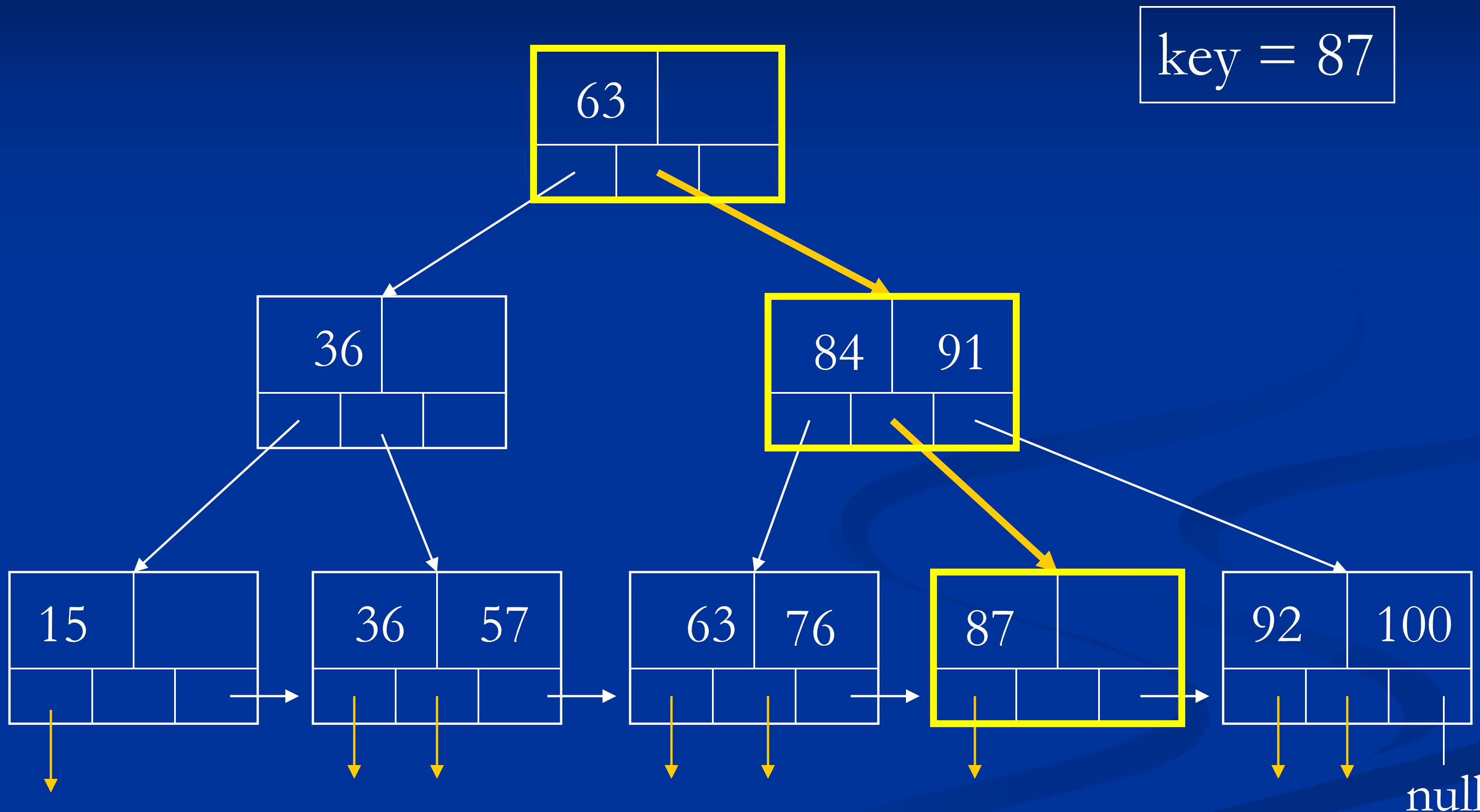
Equality Predicates



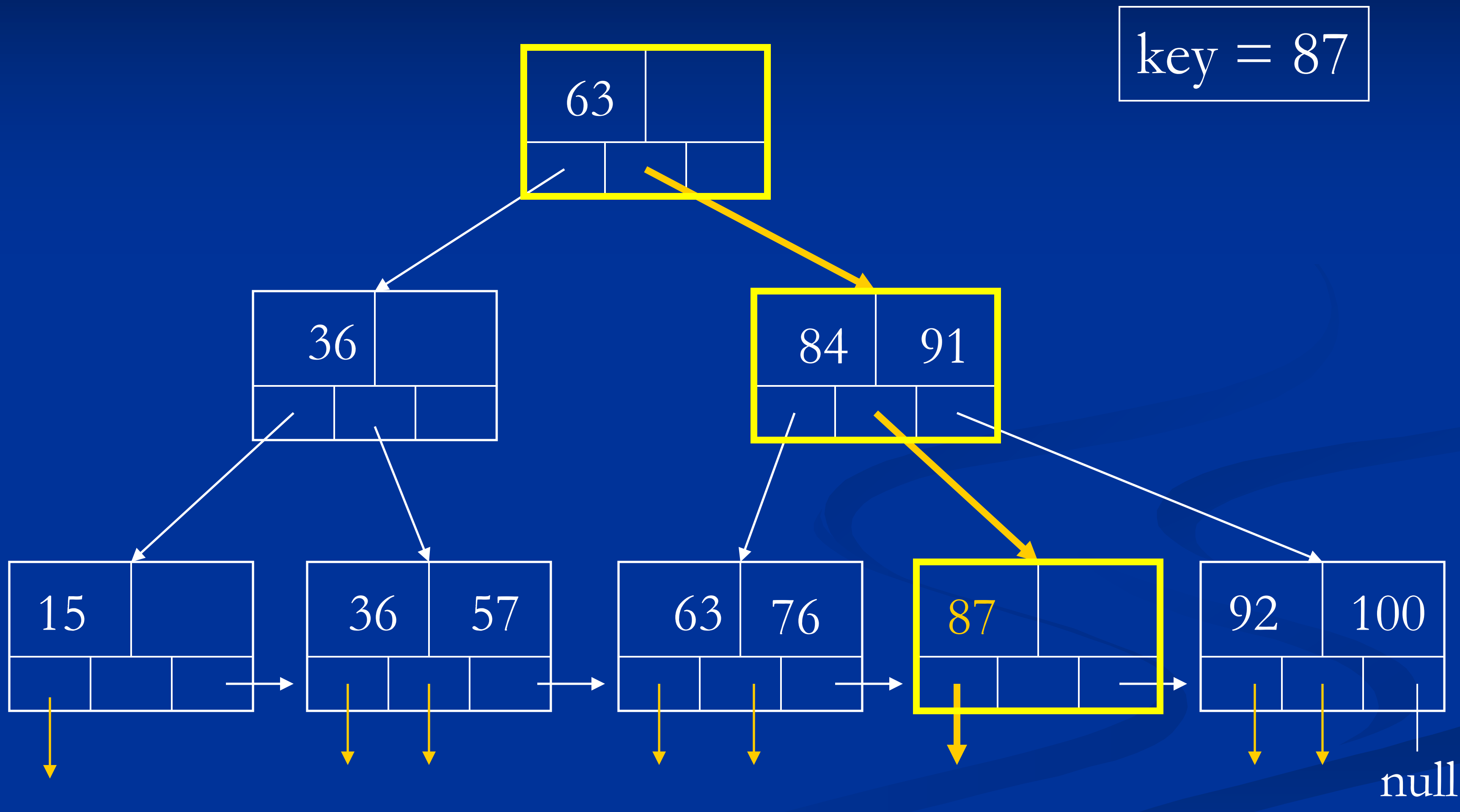
Equality Predicates



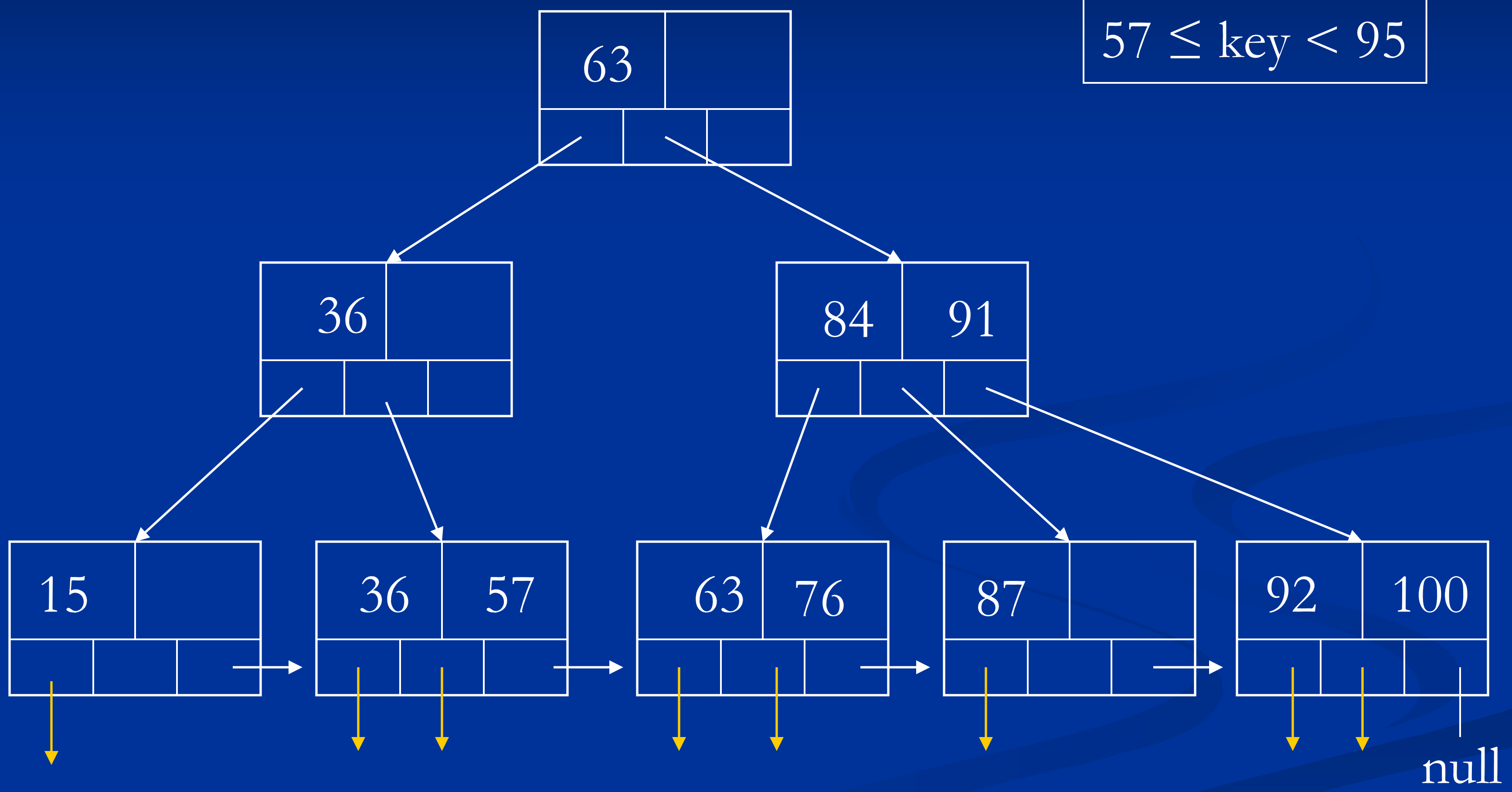
Equality Predicates



Equality Predicates

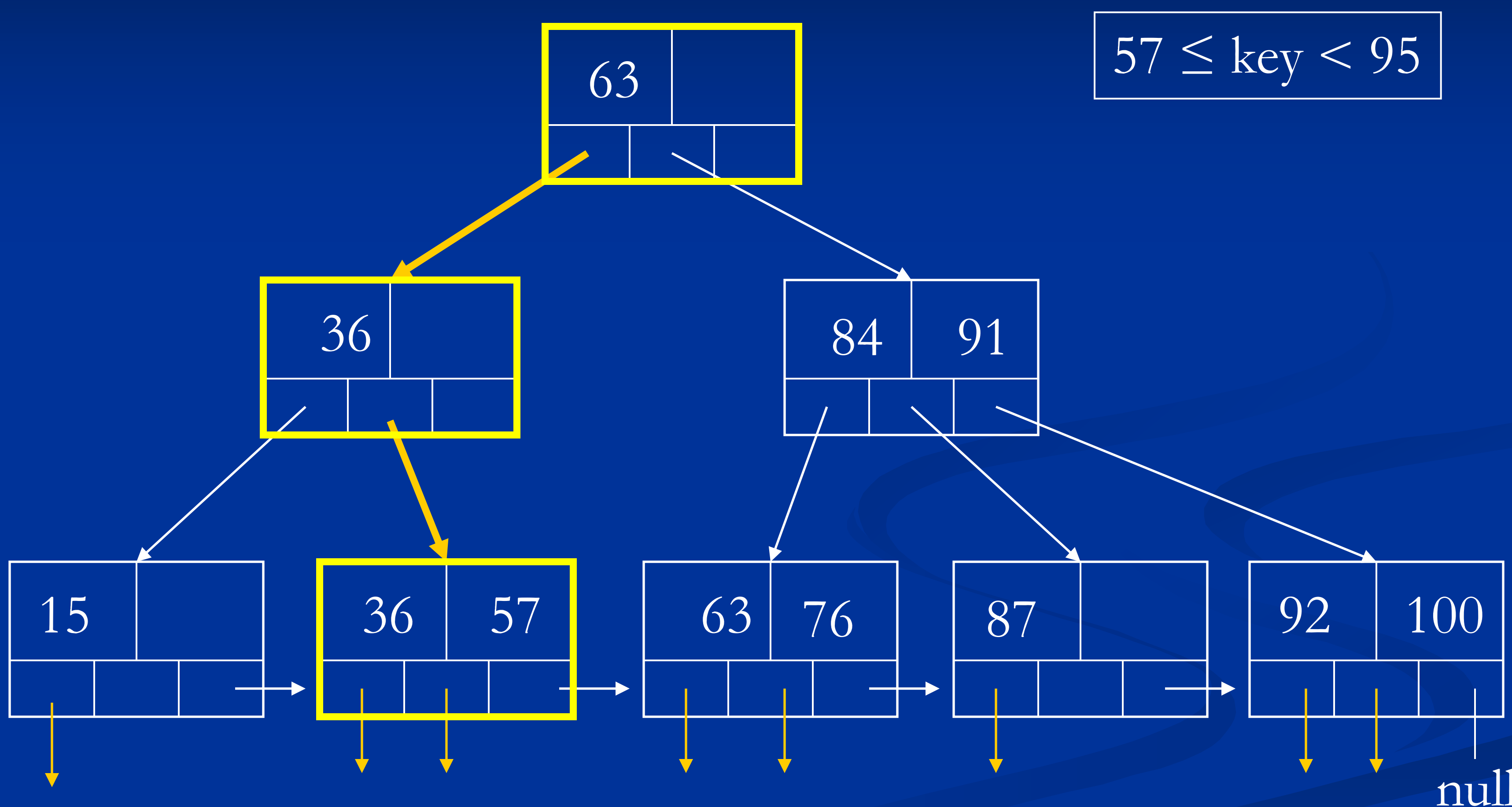


Range Predicates

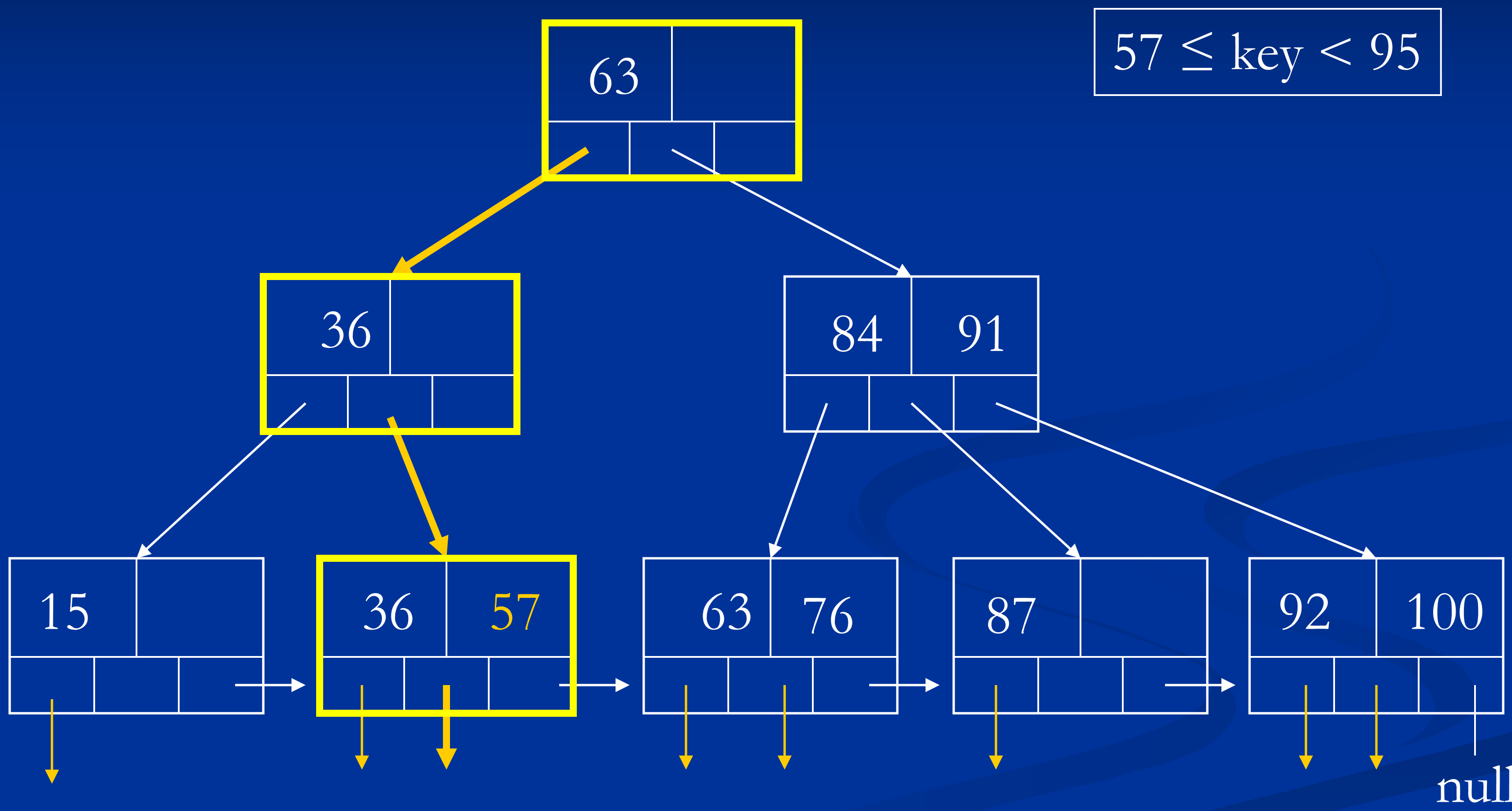


$57 \leq \text{key} < 95$

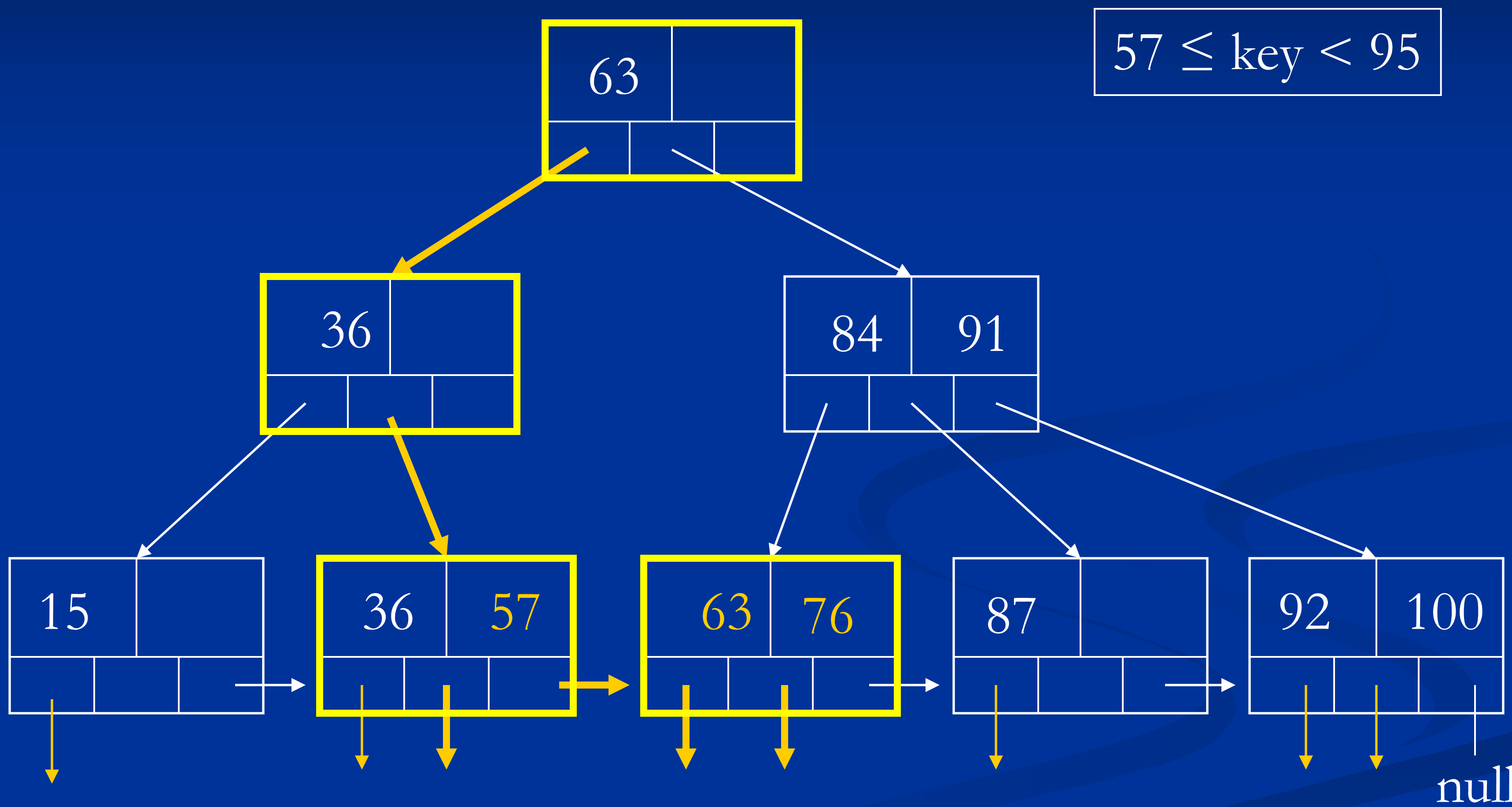
Range Predicates



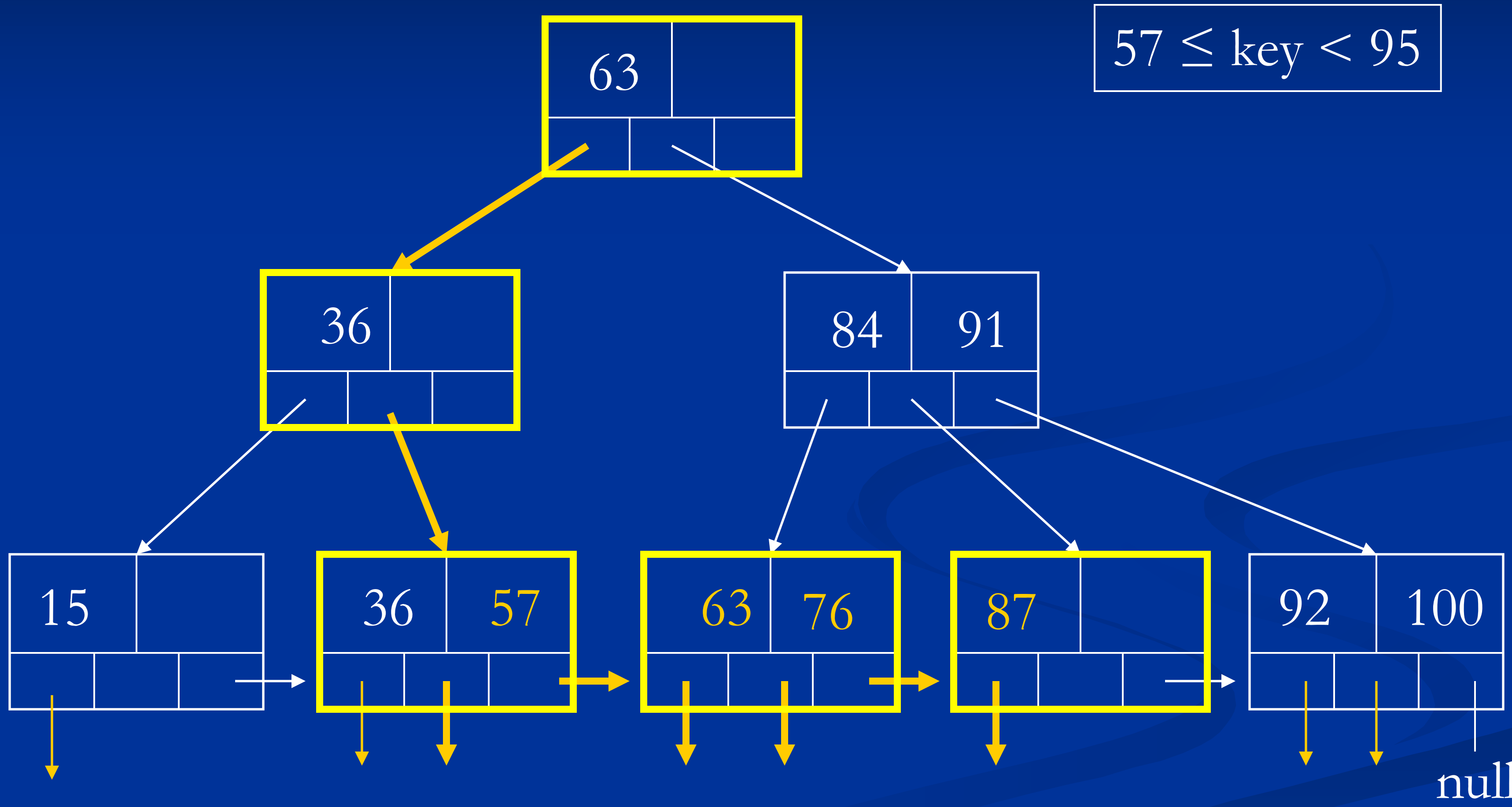
Range Predicates



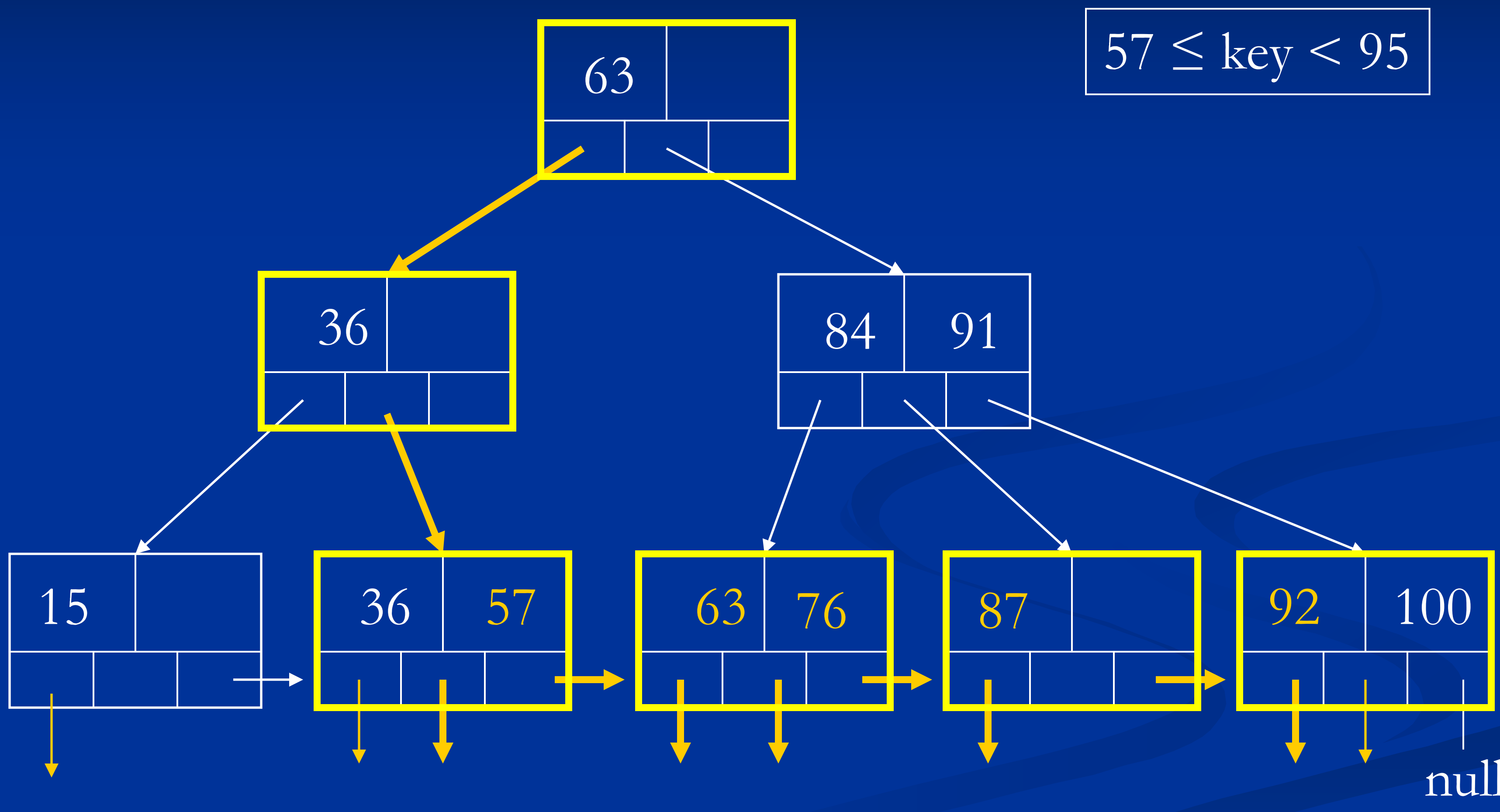
Range Predicates



Range Predicates



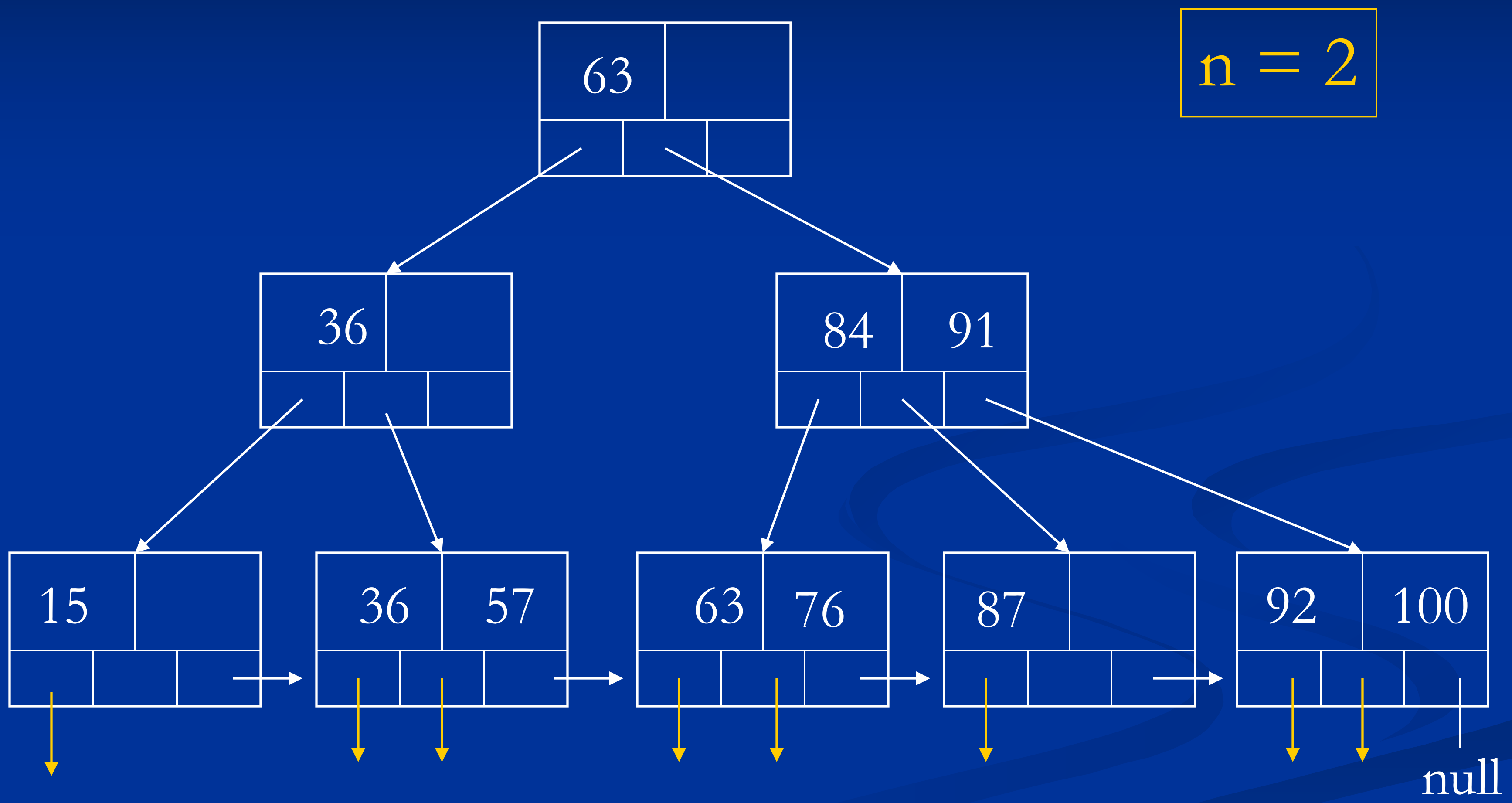
Range Predicates



General B-Trees

- Fixed parameter: n
- Number of keys: n
- Number of pointers: n + 1

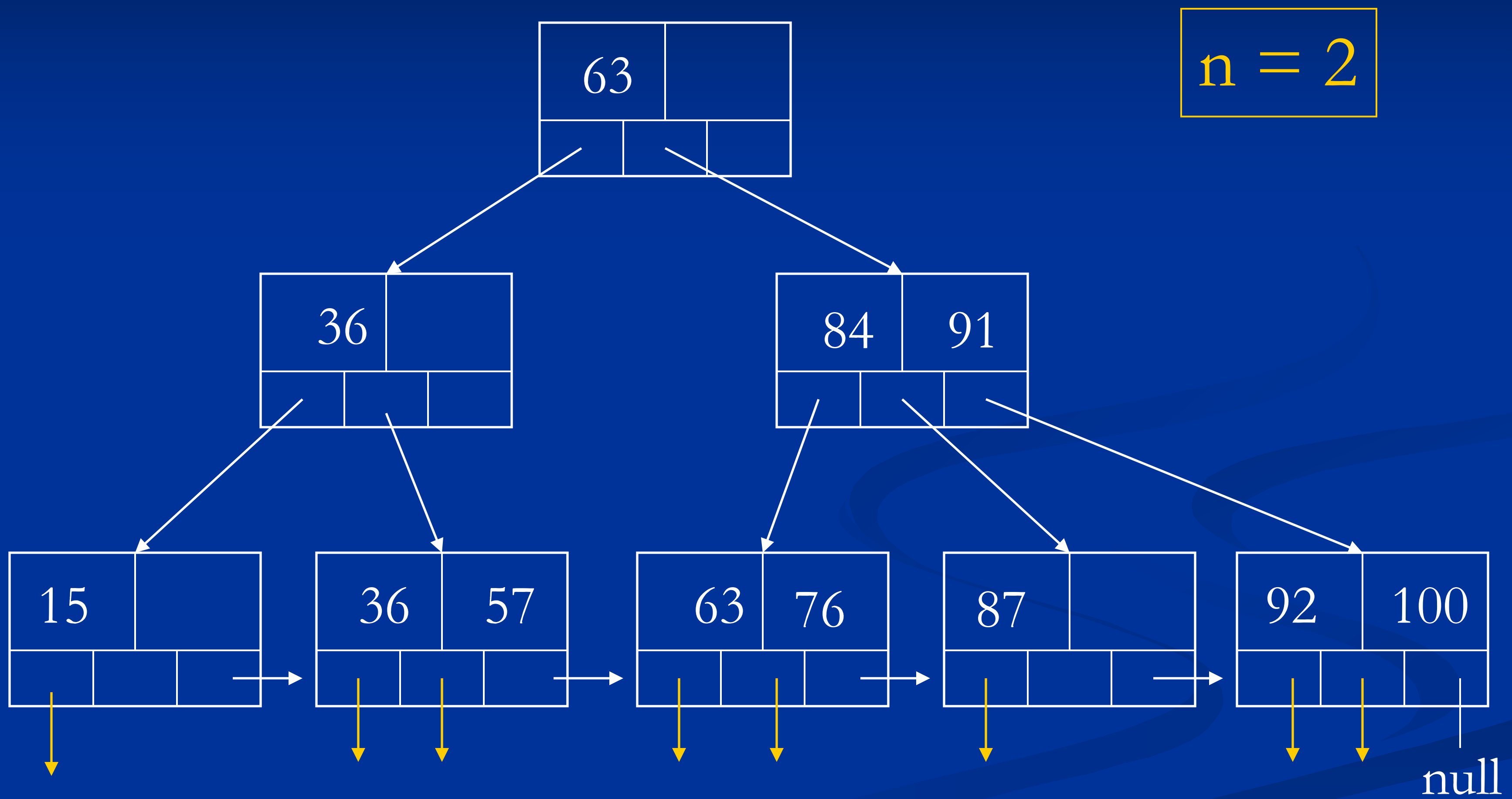
B-Tree Example



General B-Trees

- Fixed parameter: n
- Number of keys: n
- Number of pointers: n + 1
- All leaves at same depth
- All (key, record pointer) in leaves

B-Tree Example



General B-Trees: Space related constraints

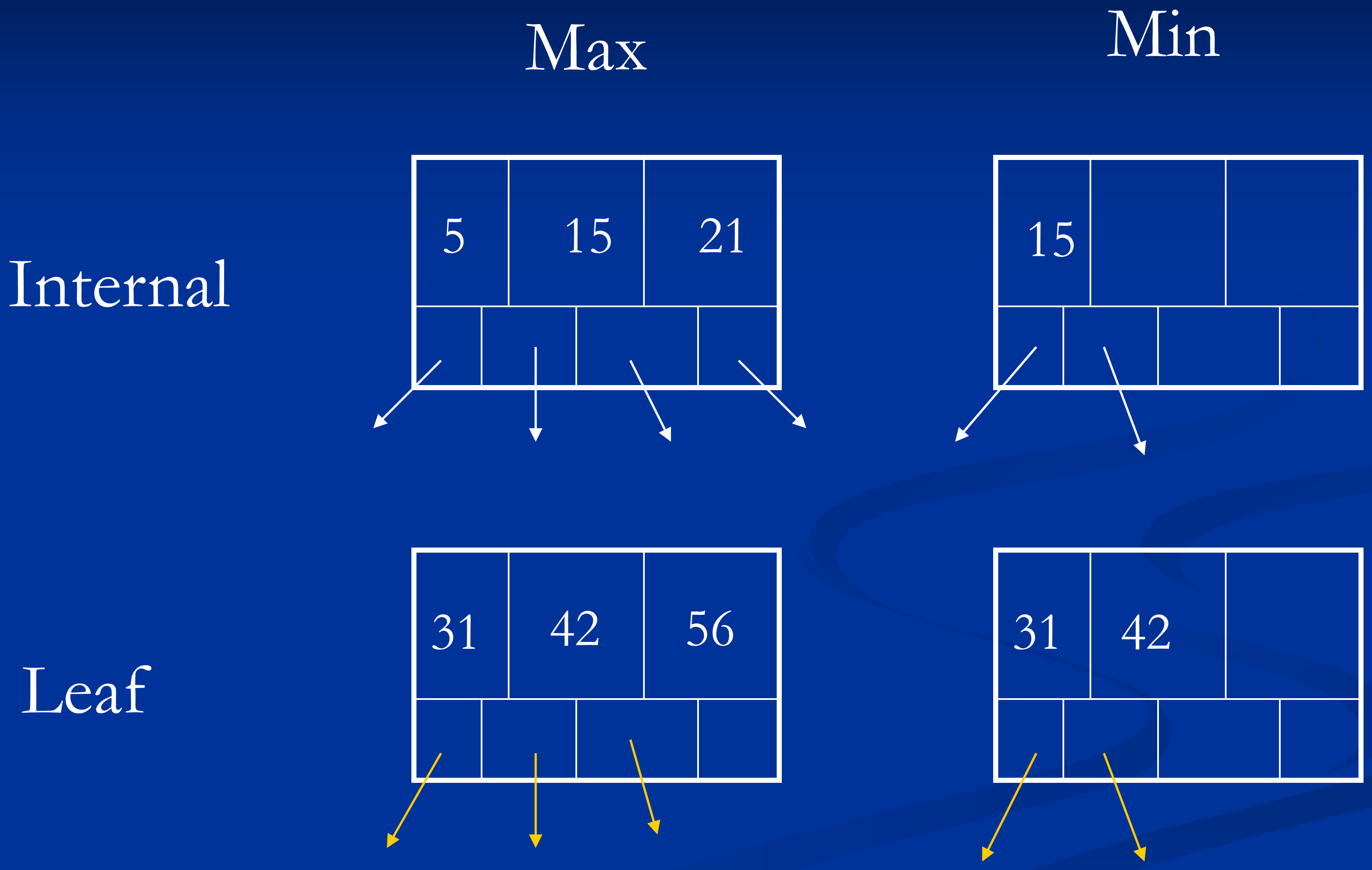
- Use at least

Root: 2 pointers

Internal: $\lceil (n+1)/2 \rceil$ pointers

Leaf: $\lfloor (n+1)/2 \rfloor$ pointers to data

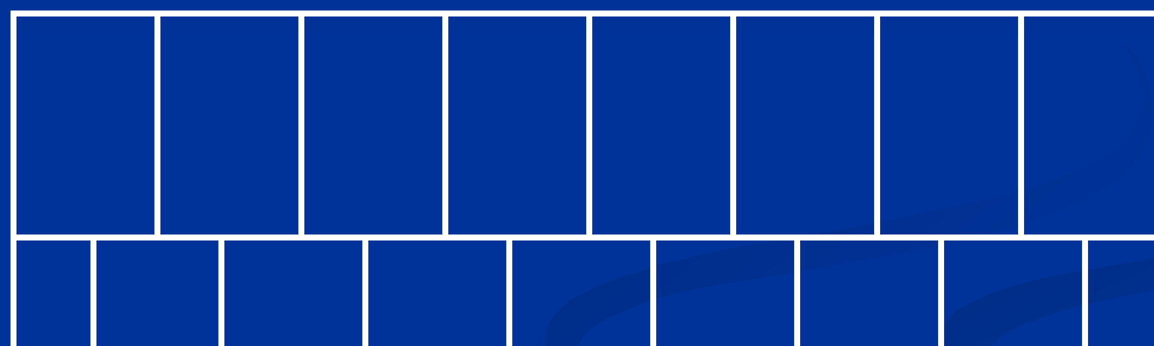
n=3



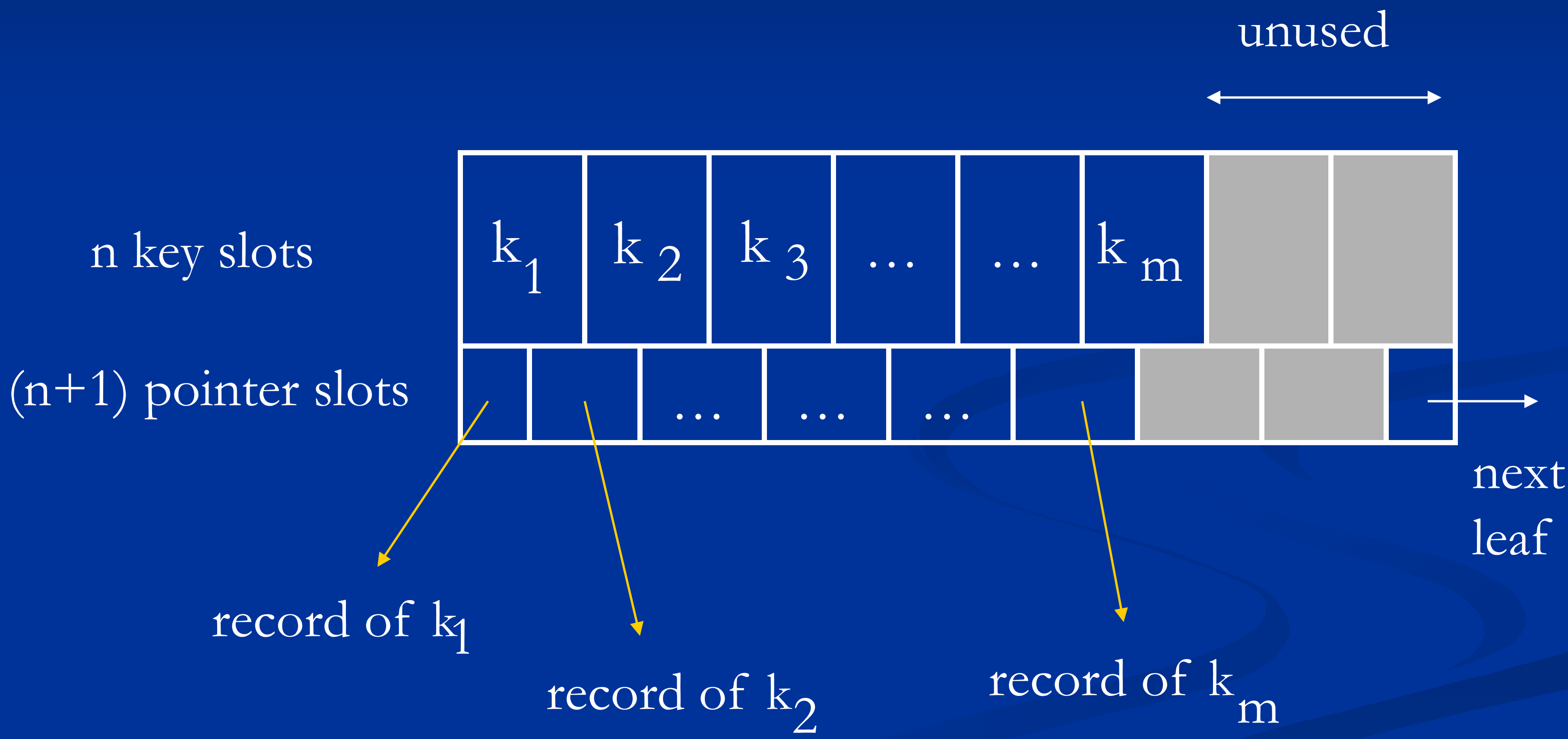
Leaf Nodes

n key slots

(n+1) pointer slots

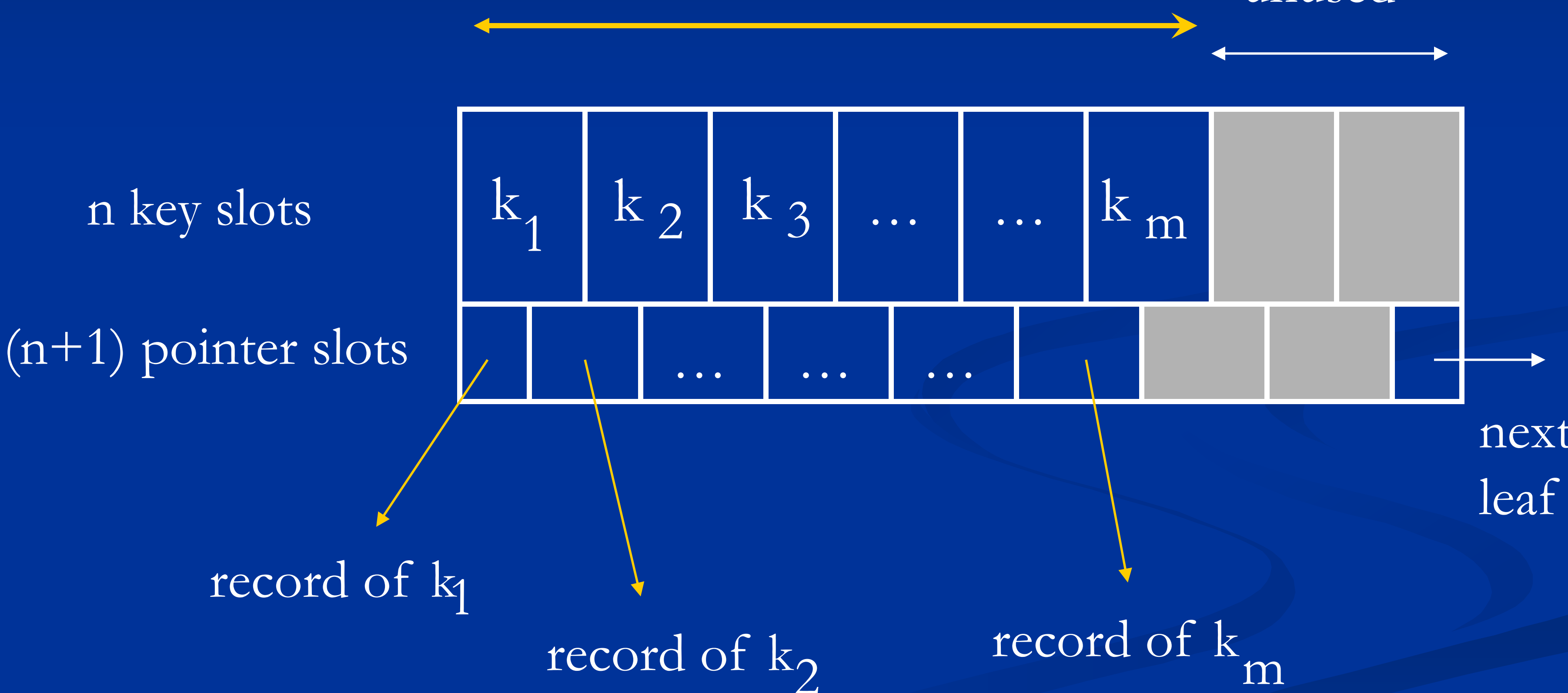


Leaf Nodes


unused
n key slots
(n+1) pointer slots
k 1
k 2
k 3
…
…
k m
…
…
…
next
leaf
record of k1
record of k2
record of k m

Leaf Nodes

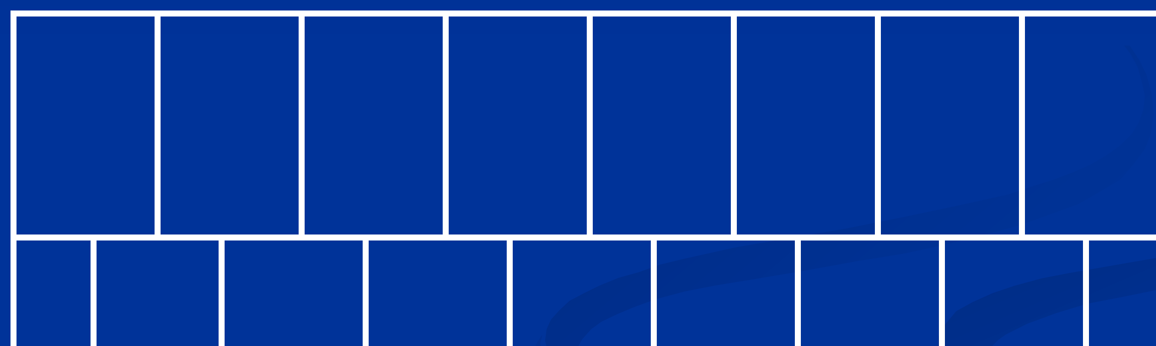
$$m \geq \left\lfloor \frac{(n+1)}{2} \right\rfloor$$



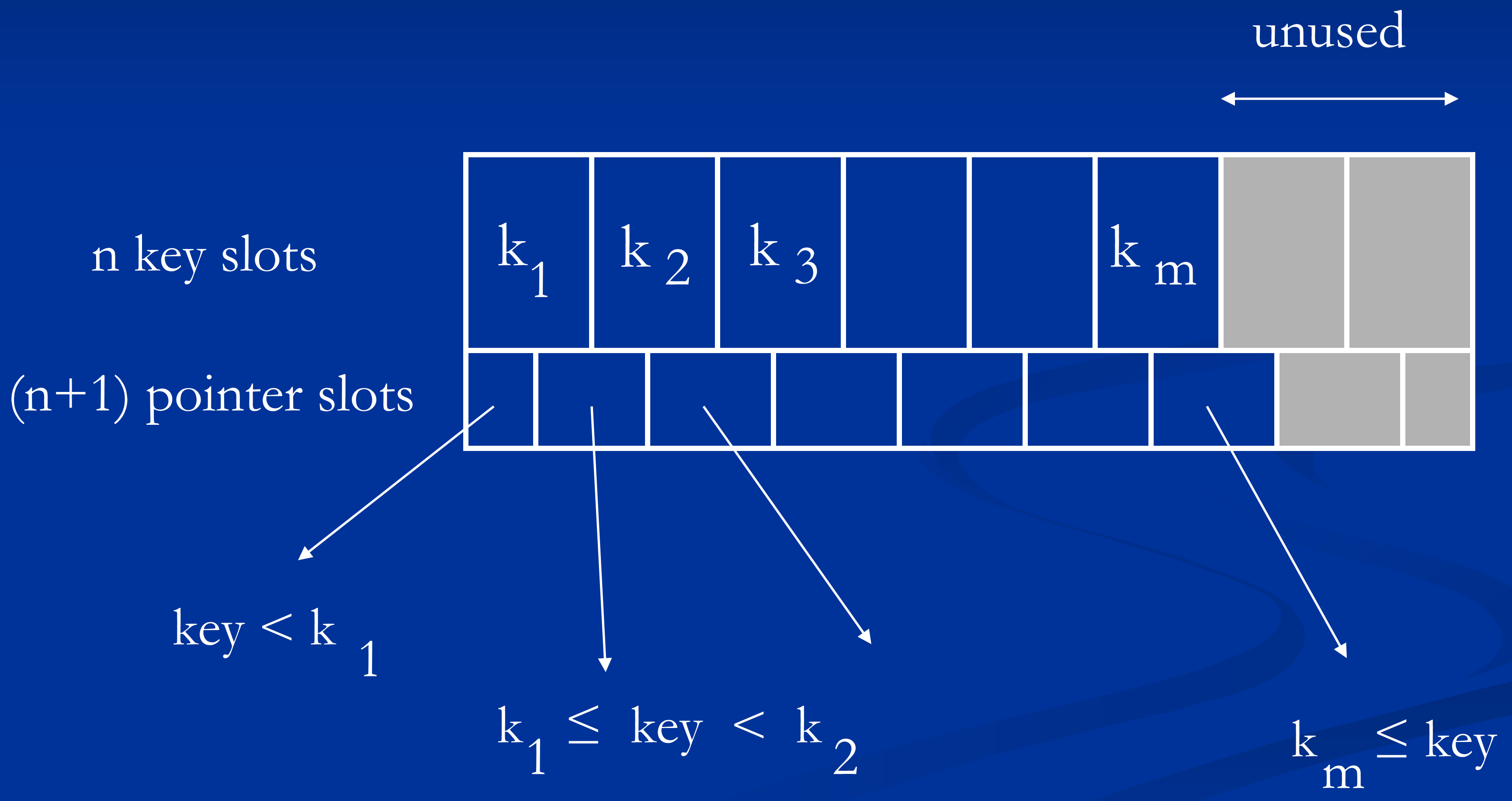
Internal Nodes

n key slots

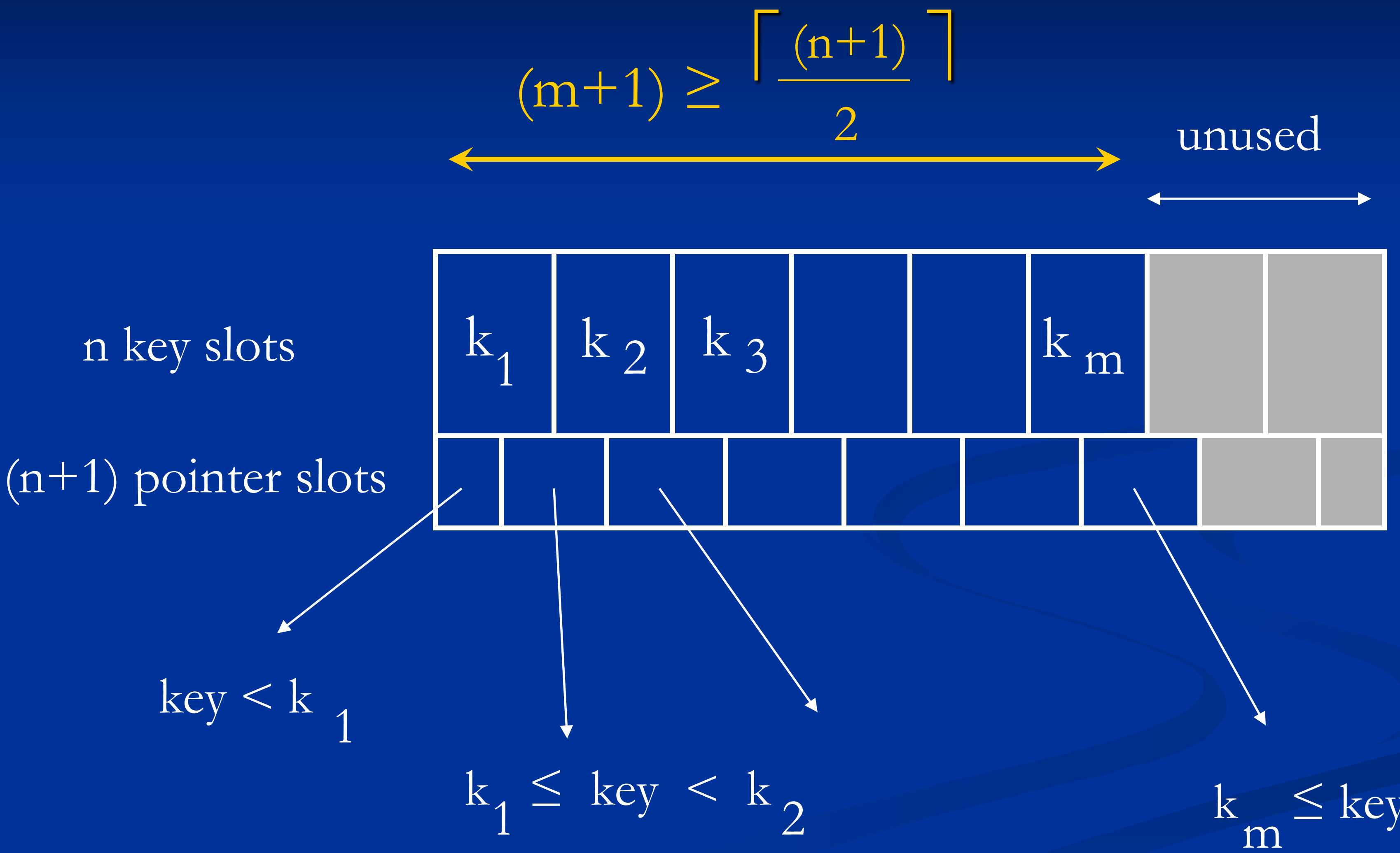
(n+1) pointer slots



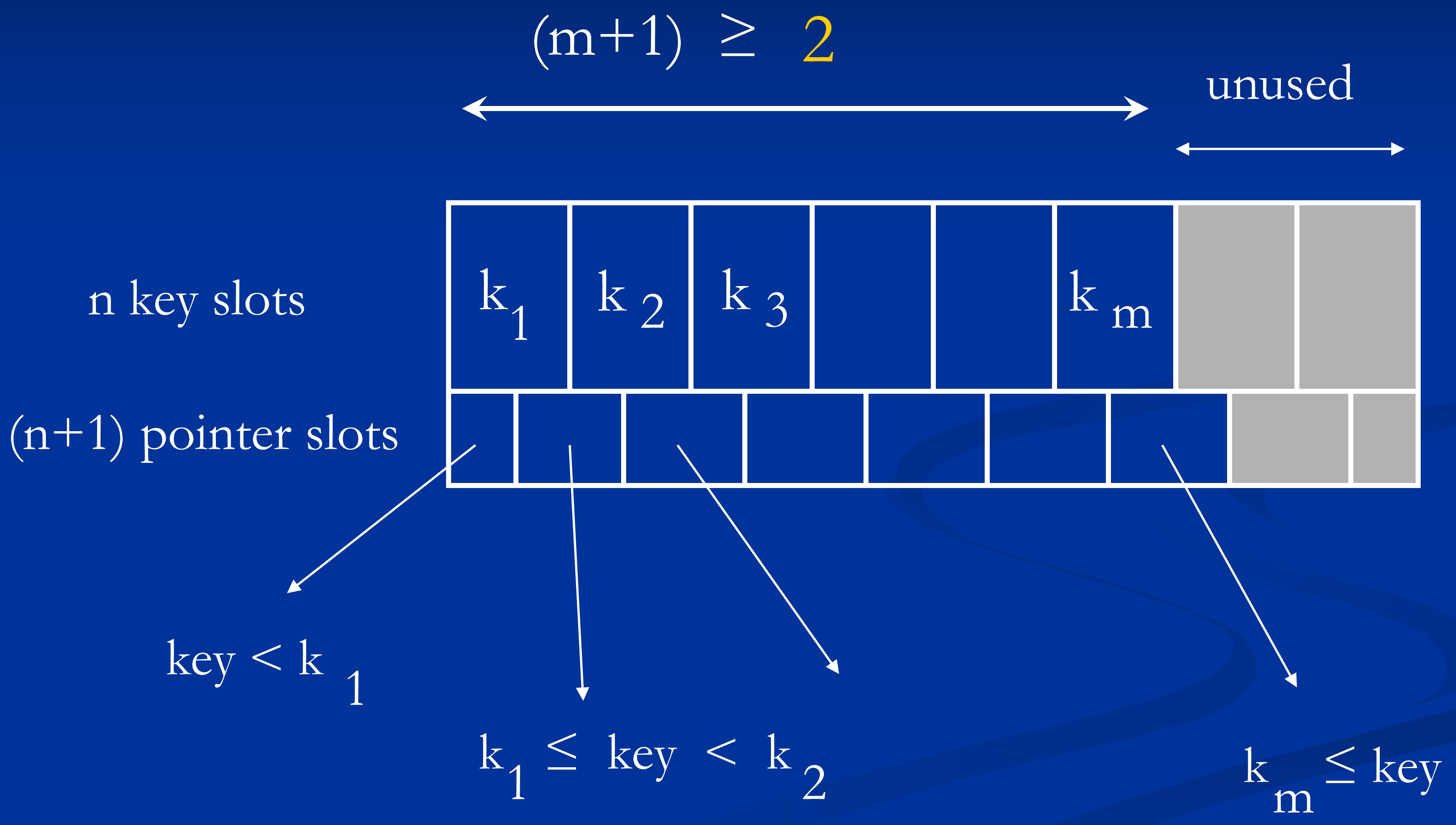
Internal Nodes



Internal Nodes



Root Node



$(m+1) \geq 2$
unused
n key slots
(n+1) pointer slots
k_1 k_2 k_3 k_m
$key < k_1$
$k_1 \leq key < k_2$
$k_m \leq key$

Limits

- Why the specific limits $\lceil (n+1)/2 \rceil$ and $\lfloor (n+1)/2 \rfloor$?
- Why different limits for leaf and internal nodes?
- Can we reduce each limit?
- Can we increase each limit?
- What are the implications?