# Indexing

Introduction to Databases

CompSci 316 Fall 2018

DUKE
COMPUTER SCIENCE

# Announcements (Thu., Nov. 8)

- Project milestone #2 due today
- Homework #3 sample solution to be posted on Sakai by this weekend
- Homework #4 to be assigned later today

# What are indexes for?

- Given a value, locate the record(s) with this value

```
SELECT * FROM R WHERE A = value;
SELECT * FROM R, S WHERE R.A = S.B;
```

- Find data by other search criteria, e.g.
  - Range search

```
SELECT * FROM R WHERE A > value;
```

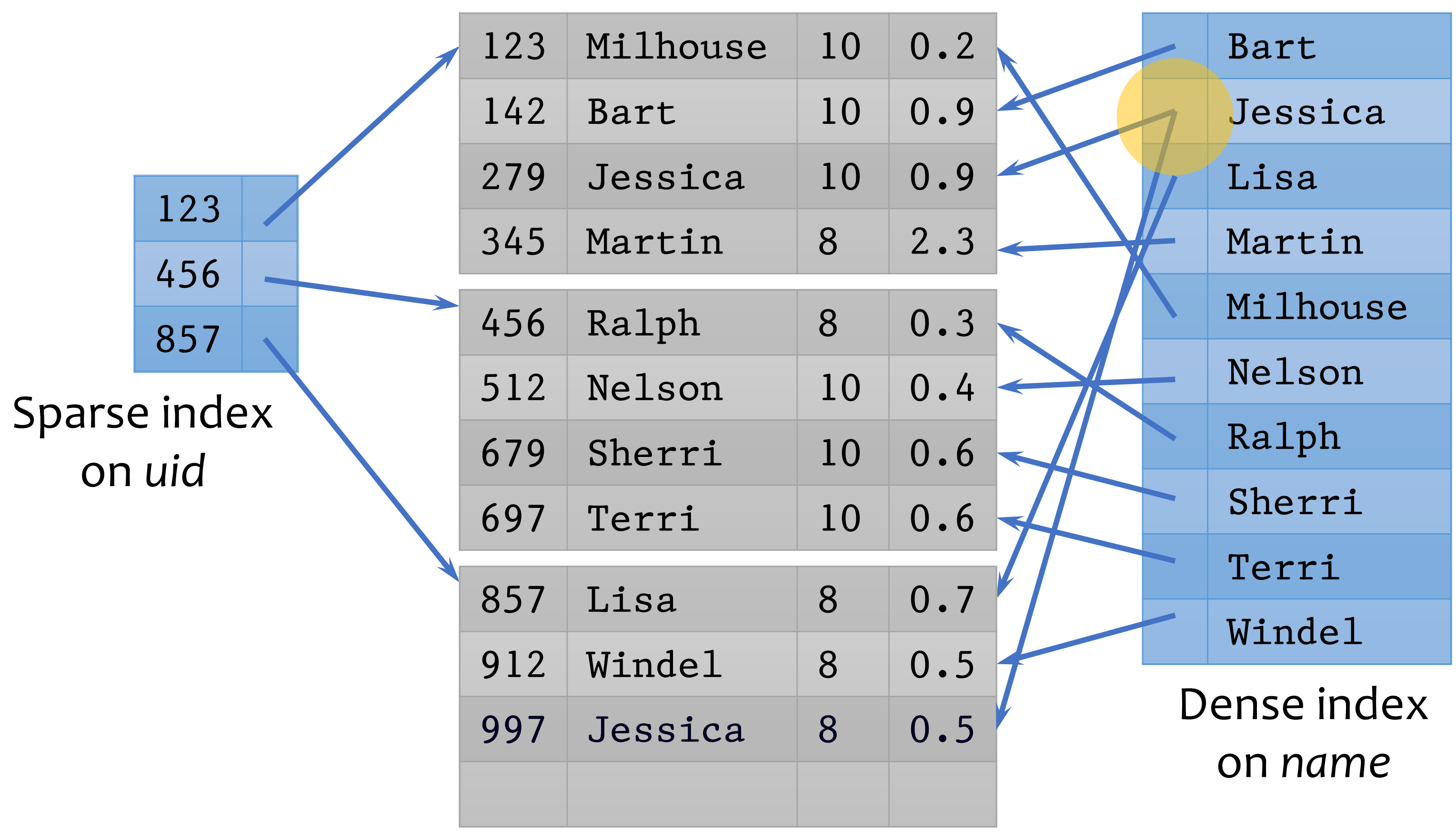
  - Keyword search

database indexing | Search

Focus of this lecture

# Dense and sparse indexes

- Dense: one index entry for each search key value
  - One entry may "point" to multiple records (e.g., two users named Jessica)
- Sparse: one index entry for each block
  - Records must be clustered according to the search key



# Dense versus sparse indexes

- Index size
  - Sparse index is smaller
- Requirement on records
  - Records must be clustered for sparse index
- Lookup
  - Sparse index is smaller and may fit in memory
  - Dense index can directly tell if a record exists
- Update
  - Easier for sparse index

# Primary and secondary indexes

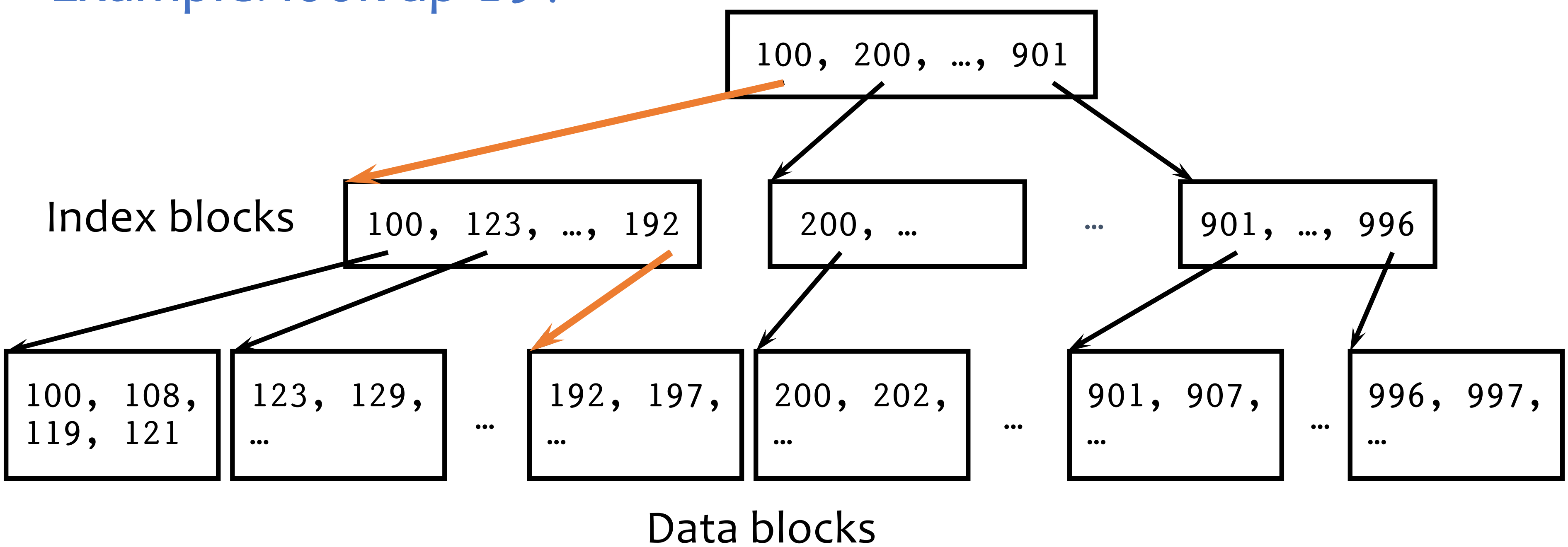
- Primary index
  - Created for the primary key of a table
  - Records are usually clustered by the primary key
  - Can be sparse
- Secondary index
  - Usually dense
- SQL
  - `PRIMARY KEY` declaration automatically creates a primary index, `UNIQUE` key automatically creates a secondary index
  - Additional secondary index can be created on non-key attribute(s):

```
CREATE INDEX UserPopIndex ON User(pop);
```

# ISAM

- What if an index is still too big?
  - Put a another (sparse) index on top of that!
  - ☞ISAM (Index Sequential Access Method), more or less

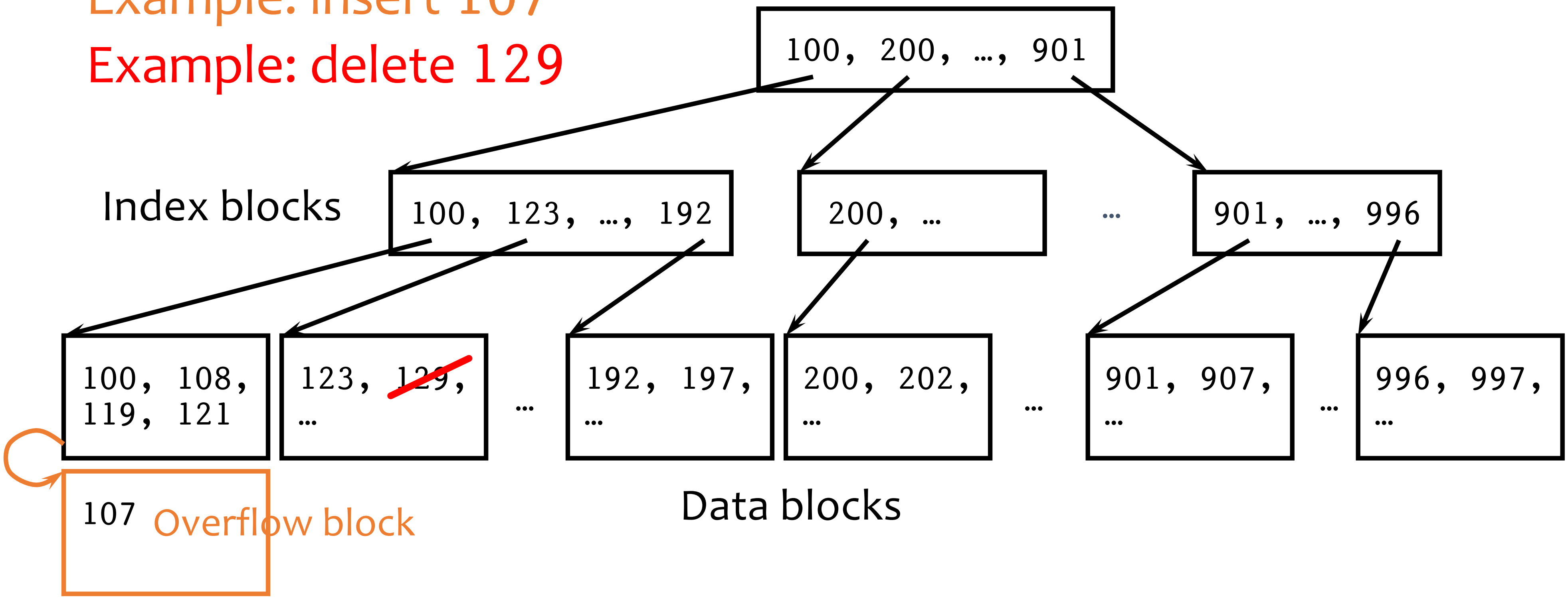
Example: look up 197



# Updates with ISAM

Example: insert 107

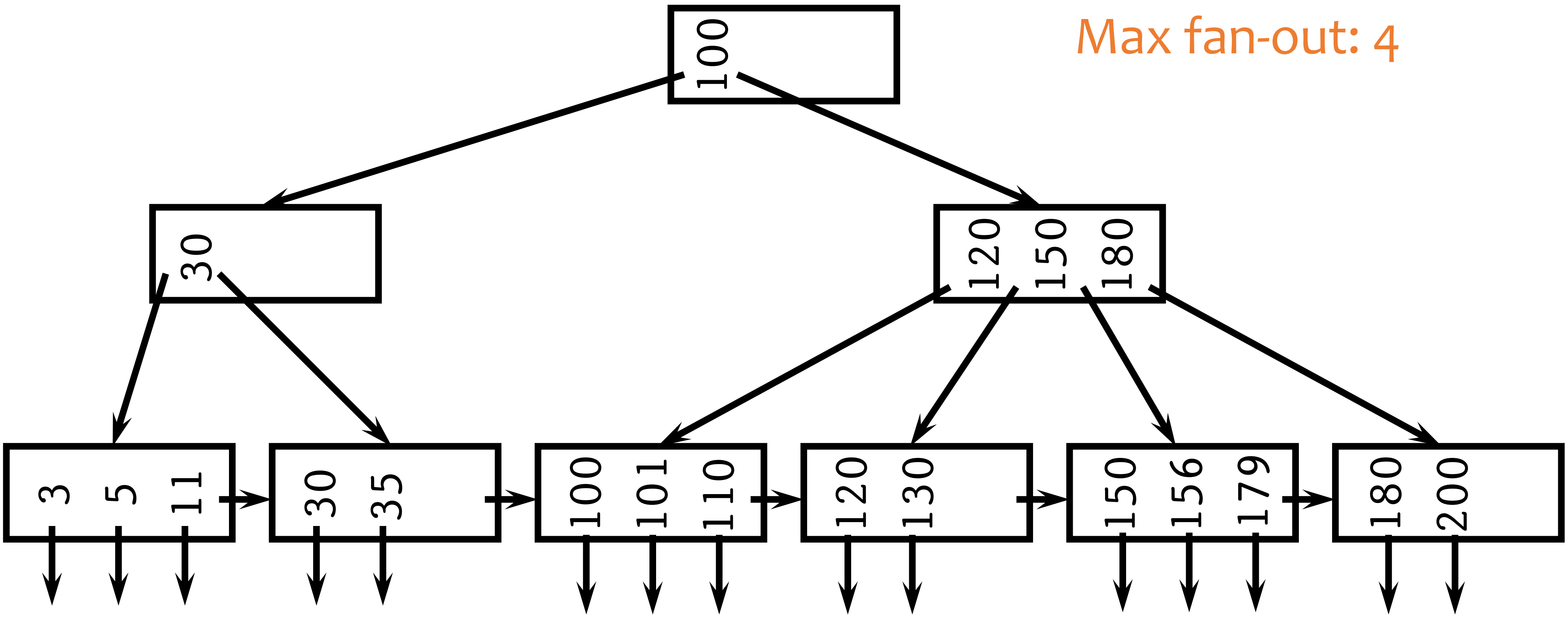
Example: delete 129



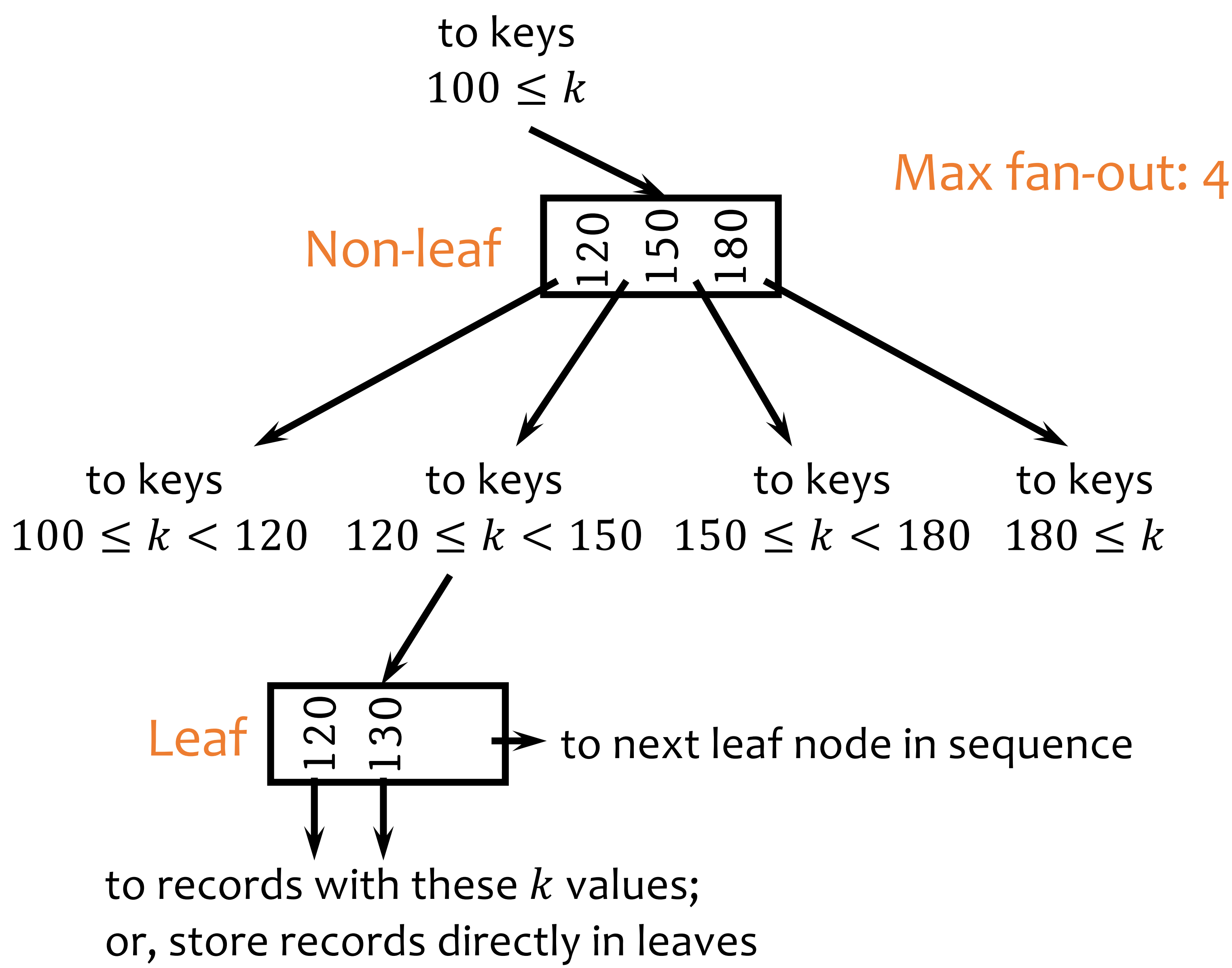

- Overflow chains and empty data blocks degrade performance
  - Worst case: most records go into one long chain, so lookups require scanning all data!

# $B^+$-tree

- A hierarchy of nodes with intervals
- Balanced (more or less): good performance guarantee
- Disk-based: one node per block; large fan-out



# Sample B⁺-tree nodes



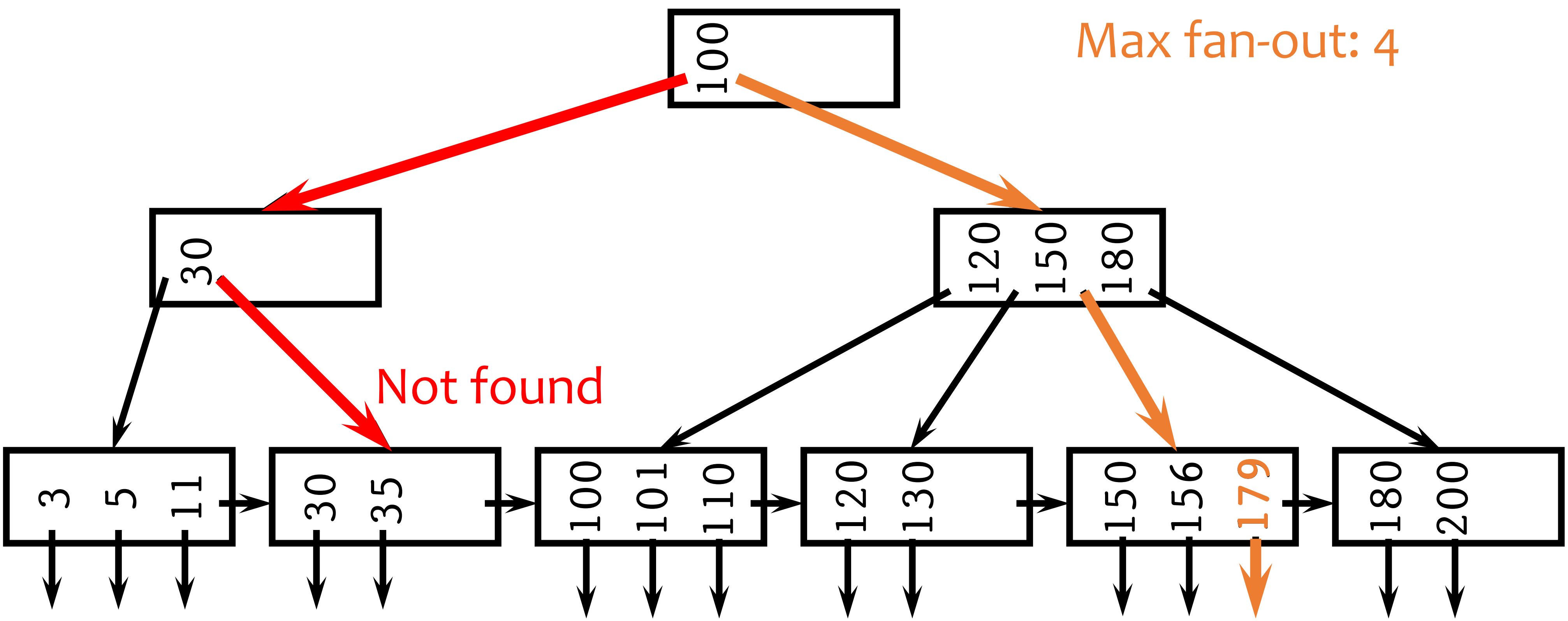
# B+-tree balancing properties

- Height constraint: all leaves at the same lowest level
- Fan-out constraint: all nodes at least half full (except root)

| | Max # pointers | Max # keys | Min # active pointers | Min # keys |
|---|---|---|---|---|
| Non-leaf | $f$ | $f-1$ | $\lceil f/2 \rceil$ | $\lceil f/2 \rceil - 1$ |
| Root | $f$ | $f-1$ | 2 | 1 |
| Leaf | $f$ | $f-1$ | $\lfloor f/2 \rfloor$ | $\lfloor f/2 \rfloor$ |

# Lookups

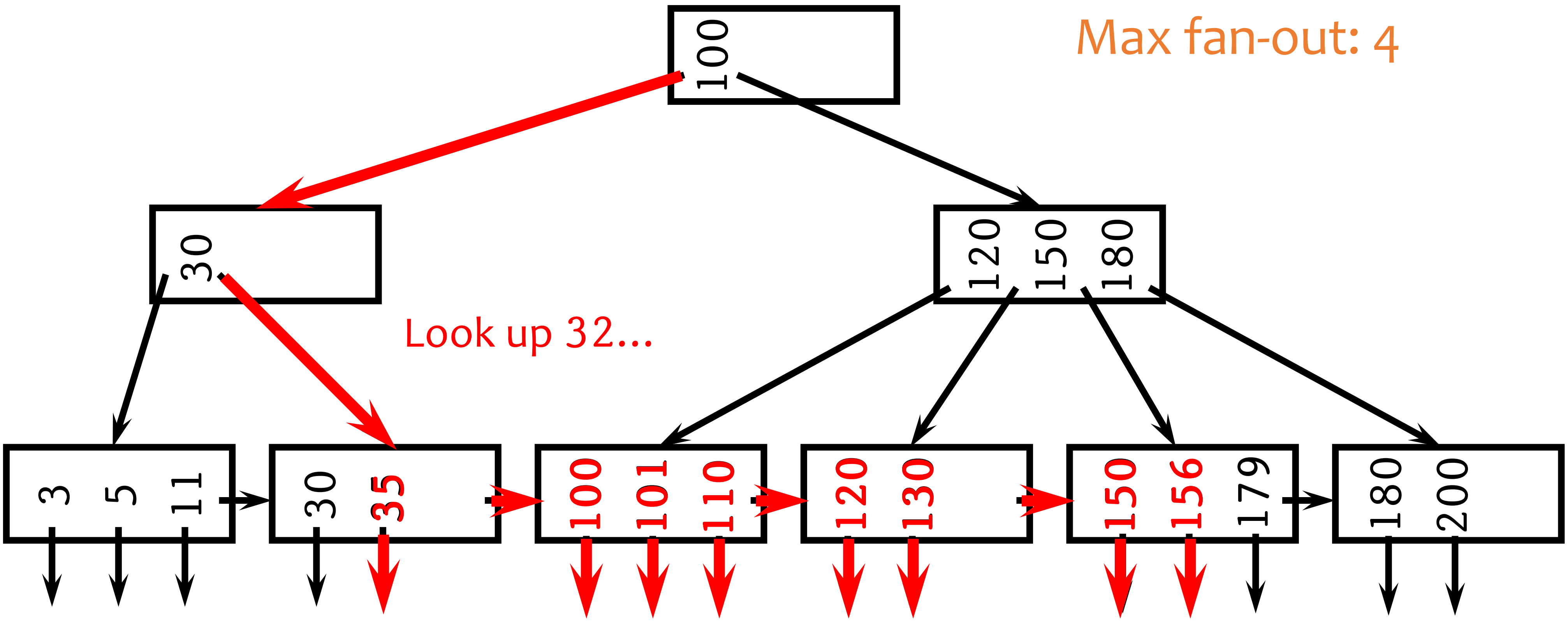
- `SELECT * FROM R WHERE k = 179;`
- `SELECT * FROM R WHERE k = 32;`



# Range query

- `SELECT * FROM R WHERE k > 32 AND k < 179;`

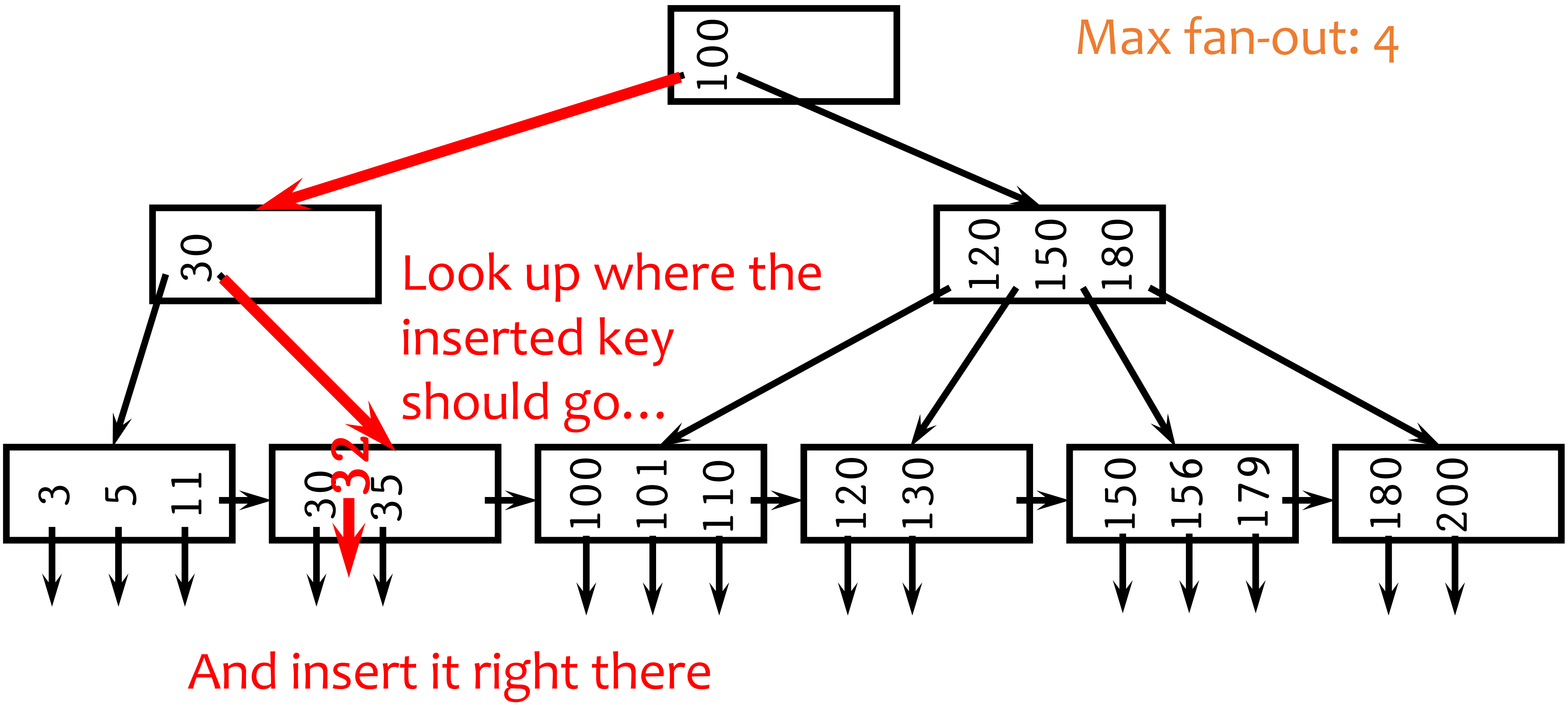
Max fan-out: 4




And follow next-leaf pointers until you hit upper bound

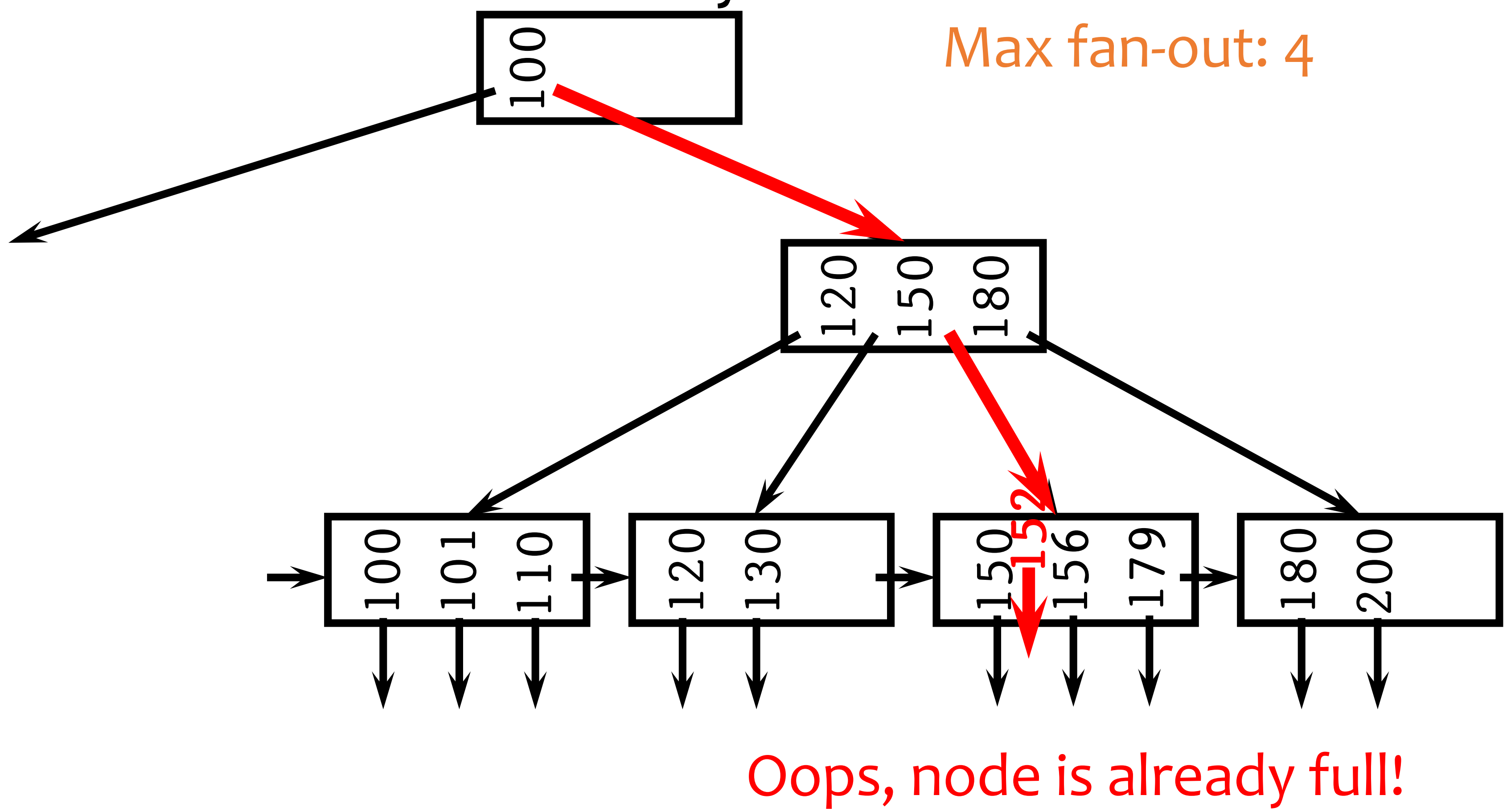
# Insertion

- Insert a record with search key value 32

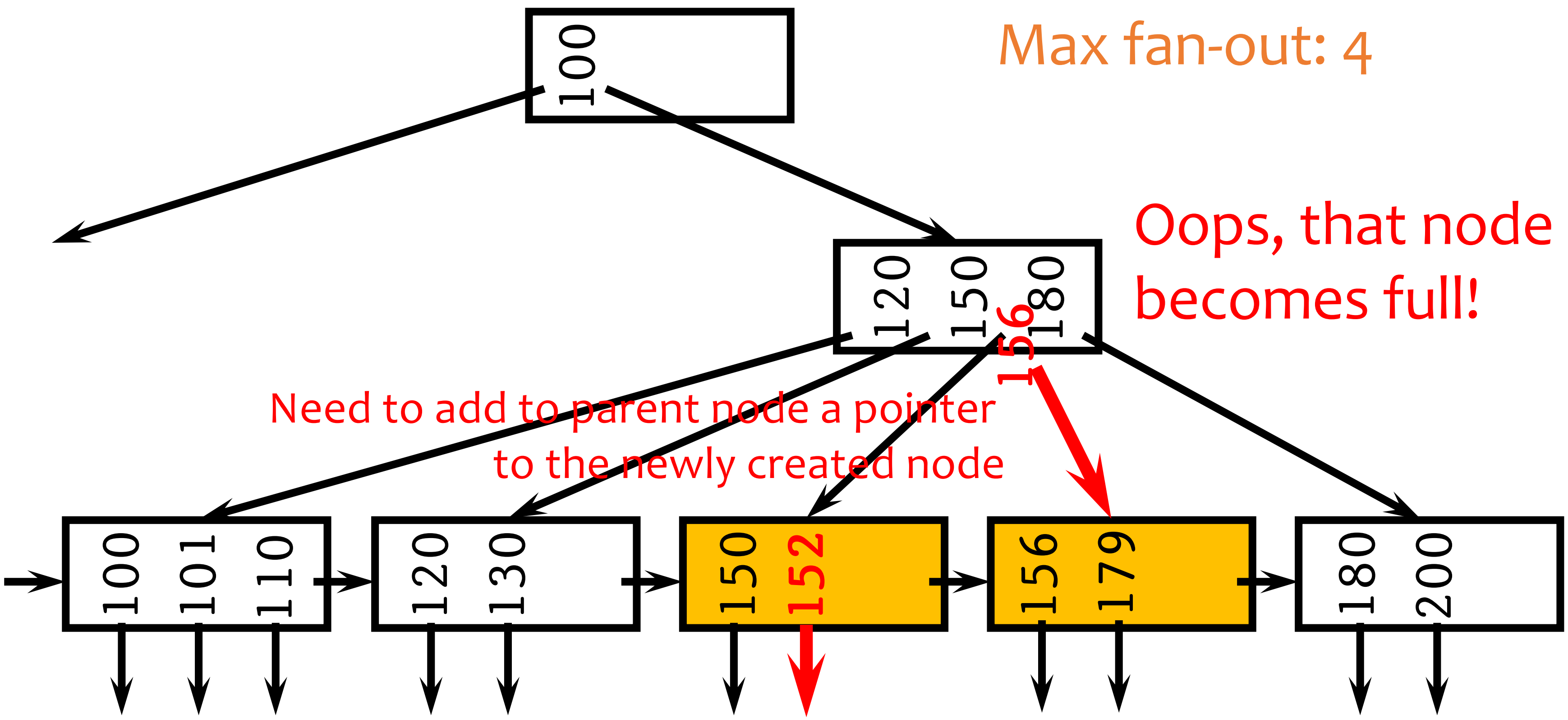


# Another insertion example

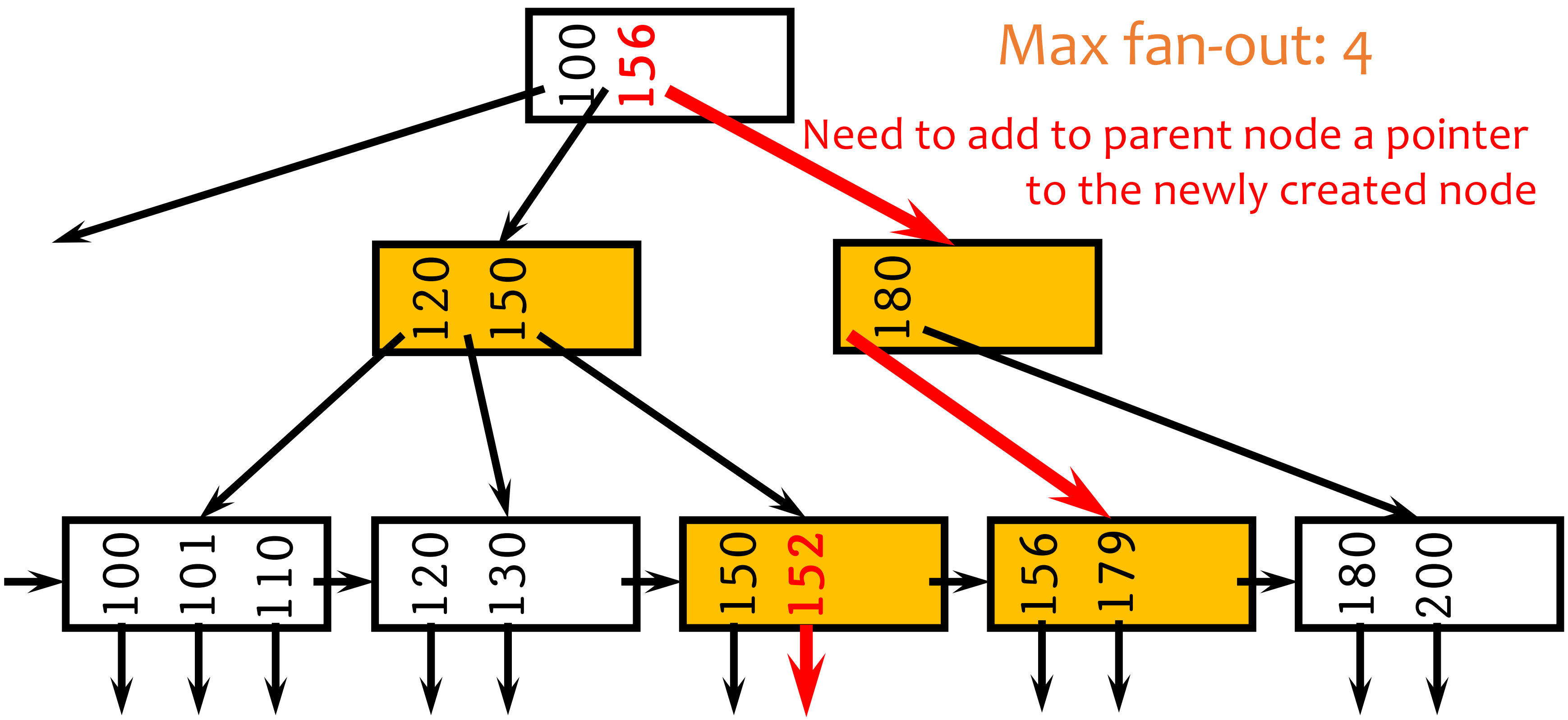
- Insert a record with search key value 152



# Node splitting



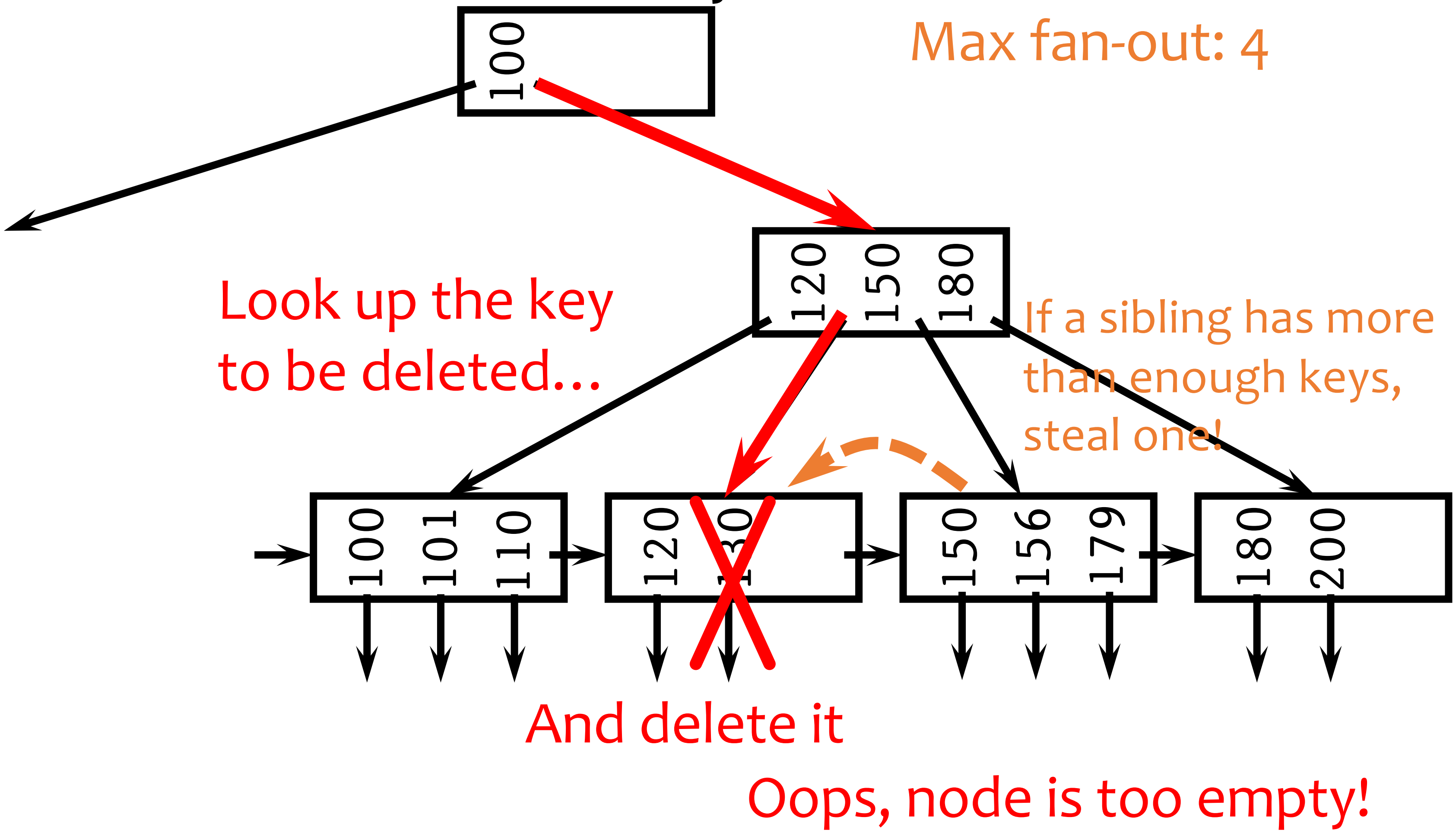
# More node splitting




- In the worst case, node splitting can "propagate" all the way up to the root of the tree (not illustrated here)
  - Splitting the root introduces a new root of fan-out 2 and causes the tree to grow "up" by one level

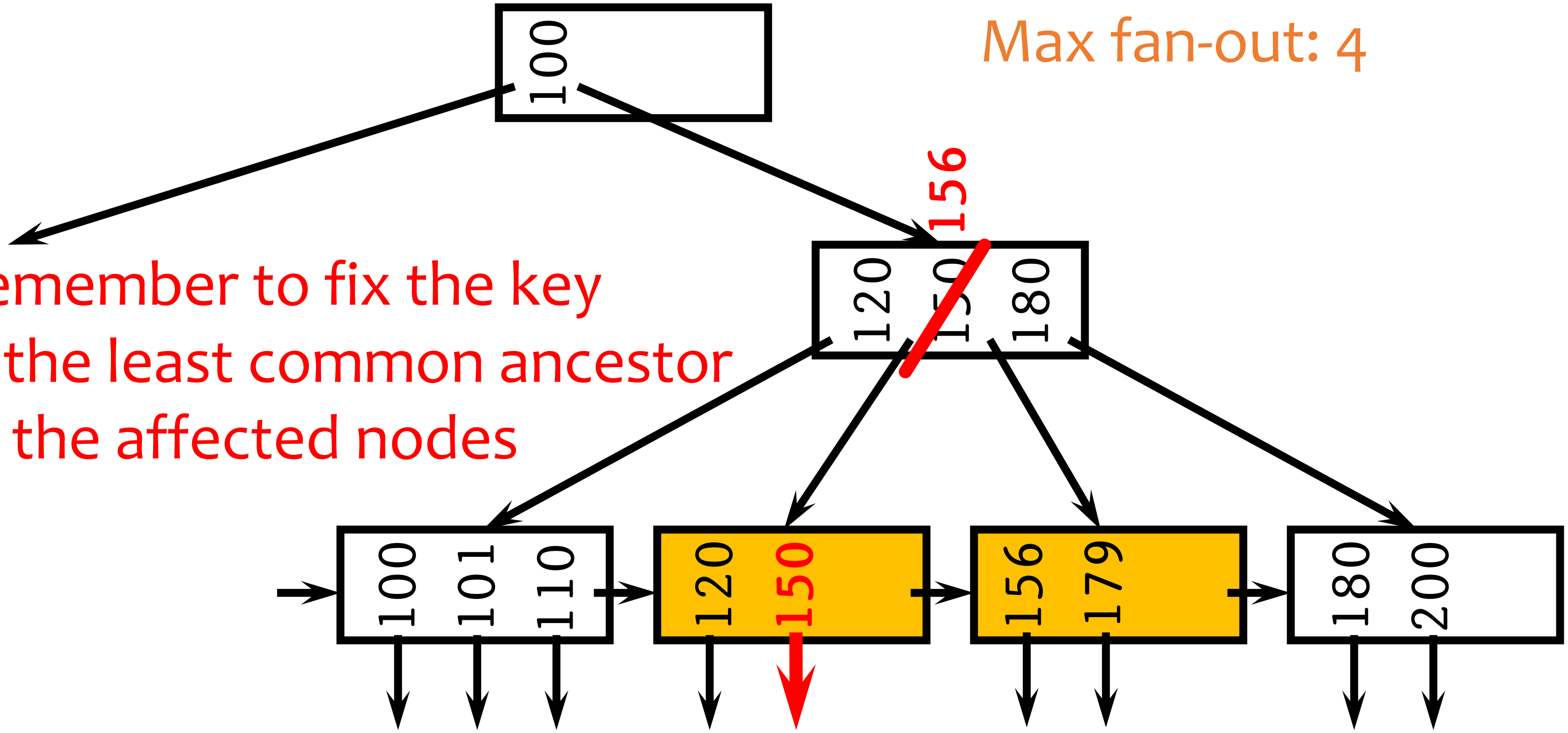
# Deletion

- Delete a record with search key value 130



# Stealing from a sibling

Max fan-out: 4

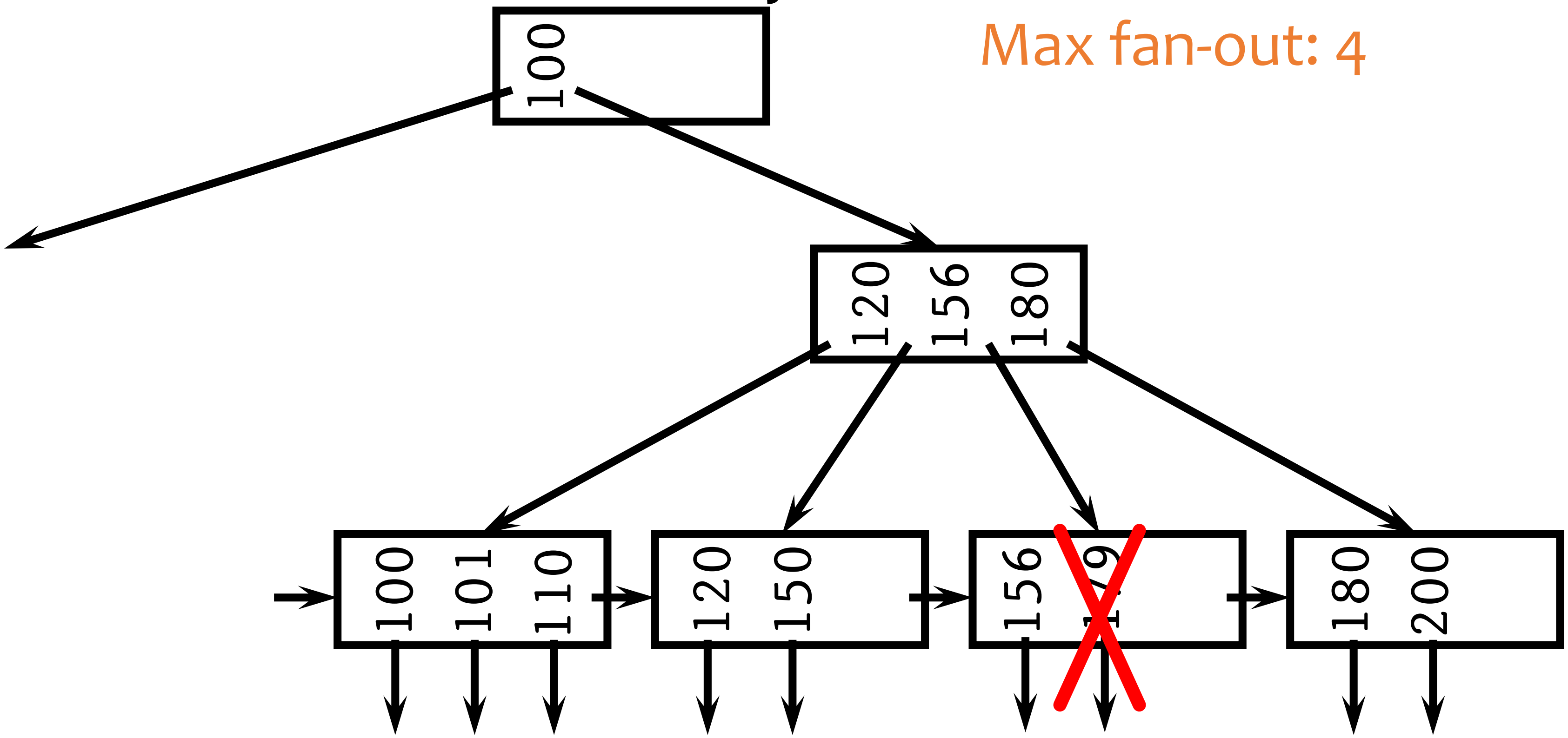



Remember to fix the key
in the least common ancestor
of the affected nodes

# Another deletion example

- Delete a record with search key value 179

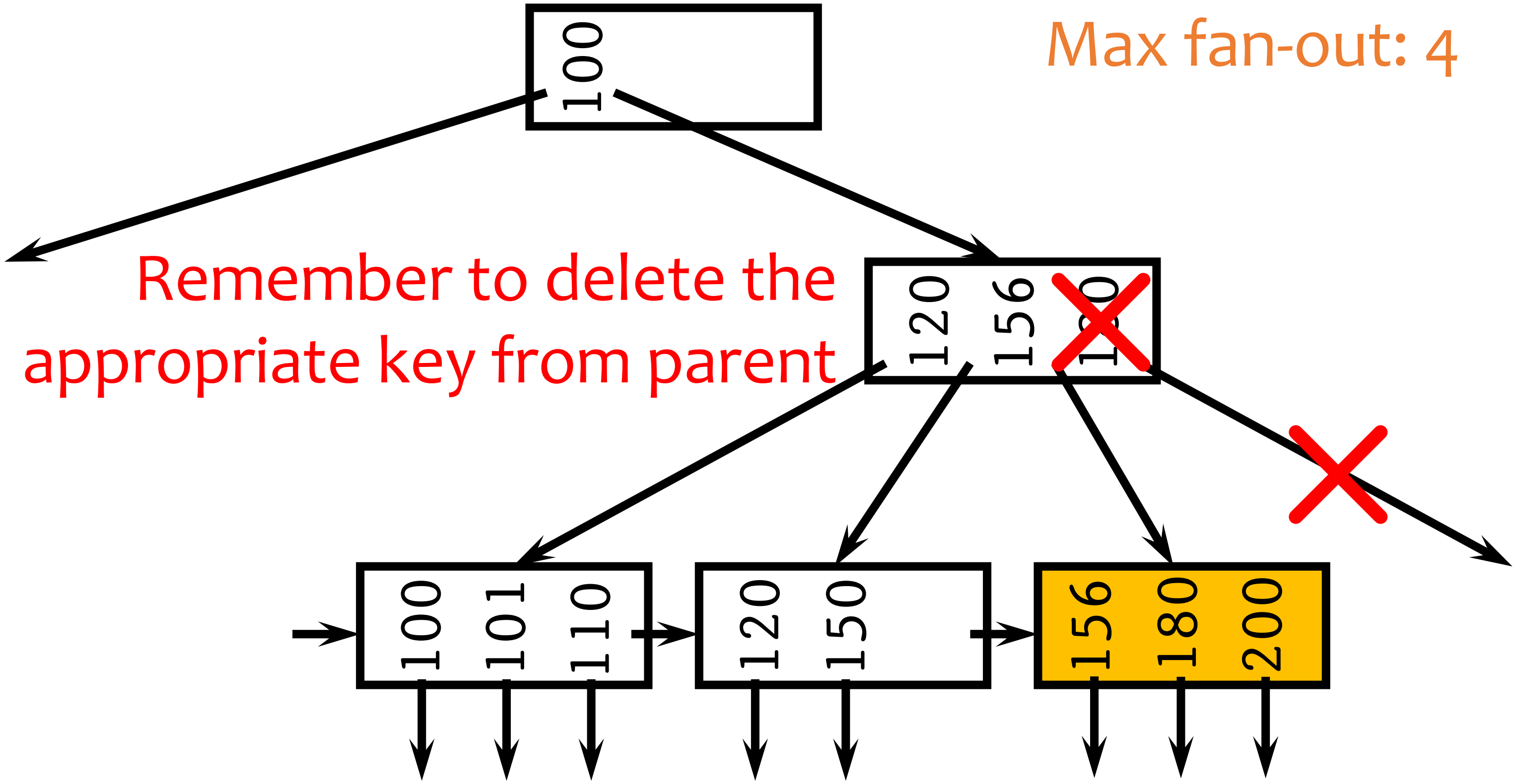
Max fan-out: 4




Cannot steal from siblings

Then coalesce (merge) with a sibling!

# Coalescing




- Deletion can "propagate" all the way up to the root of the tree (not illustrated here)
  - When the root becomes empty, the tree "shrinks" by one level

# Performance analysis

- How many I/O's are required for each operation?
  - $h$, the height of the tree (more or less)
  - Plus one or two to manipulate actual records
  - Plus $O(h)$ for reorganization (rare if $f$ is large)
  - Minus one if we cache the root in memory
- How big is $h$?
  - Roughly $\log_{\text{fanout}} N$, where $N$ is the number of records
  - B$^+$-tree properties guarantee that fan-out is least $f/2$ for all non-root nodes
  - Fan-out is typically large (in hundreds)—many keys and pointers can fit into one block
  - A 4-level B$^+$-tree is enough for "typical" tables

# $B^+$-tree in practice

- Complex reorganization for deletion often is not implemented (e.g., Oracle)
  - Leave nodes less than half full and periodically reorganize
- Most commercial DBMS use $B^+$-tree instead of hashing-based indexes because $B^+$-tree handles range queries

# The Halloween Problem

- Story from the early days of System R…

```
UPDATE Payroll
SET salary = salary * 1.1
WHERE salary >= 100000;
```

  - There is a $B^+$-tree index on *Payroll*(*salary*)
  - The update never stopped (why?)
- Solutions?
  - Scan index in reverse, or
  - Before update, scan index to create a "to-do" list, or
  - During update, maintain a "done" list, or
  - Tag every row with transaction/statement id

# $B^+$-tree versus ISAM

- ISAM is more static; $B^+$-tree is more dynamic
- ISAM can be more compact (at least initially)
  - Fewer levels and I/O's than $B^+$-tree
- Overtime, ISAM may not be balanced
  - Cannot provide guaranteed performance as $B^+$-tree does

# $B^+$-tree versus B-tree

- B-tree: why not store records (or record pointers) in non-leaf nodes?
  - These records can be accessed with fewer I/O’s
- Problems?

# Beyond ISAM, B-, and B$^{+}$-trees

- Other tree-based indexes: R-trees and variants, GiST, etc.
  - How about binary tree?

vs.

- Hashing-based indexes: extensible hashing, linear hashing, etc.
- Text indexes: inverted-list index, suffix arrays, etc.
- Other tricks: bitmap index, bit-sliced index, etc.