Designing an Index for ZooDB

Jonas Nick & Bogdan Vancea

June 2, 2014

Outline

1 Introduction

2 Goals & Challenges

3 The new Index Implementation

4 Benchmarks

ZooDB
The JDO Database

- an open source object database written in Java
- JDO standard compliant
- 4 times faster than competitor db4o
- zoodb.org

Database Index

Key-Value data structure

1. **fast** retrieval
2. **ordered** iteration
3. stored in a **file**

Database Index

Key-Value data structure

1. **fast** retrieval
2. **ordered** iteration
3. stored in a **file**

```
ZooJdoHelper.createIndex(pm, Person.class, "name",
false);
```

Database Index

Key-Value data structure

1. **fast** retrieval
2. **ordered** iteration
3. stored in a **file**

```
ZooJdoHelper.createIndex(pm, Person.class, "name",
false);
```

Attribute Index
Value → Object-ID

Database Index

Key-Value data structure

1. **fast** retrieval
2. **ordered** iteration
3. stored in a **file**

```
ZooJdoHelper.createIndex(pm, Person.class, "name", false);
```

Attribute Index
Value → Object-ID

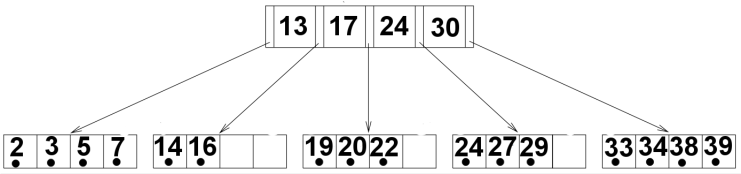
ObjectID Index
OID → Diskpos

Free Space Index
Page-ID → TxID

B+ Tree

Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

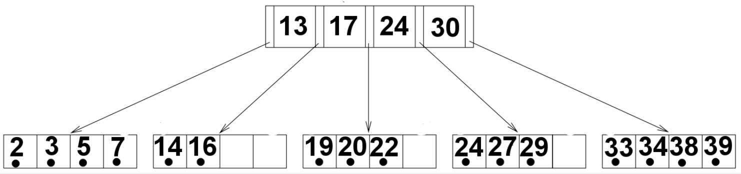
B+ Tree



- Inner node contains keys and children pointer, leaf contains keys and values.

Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

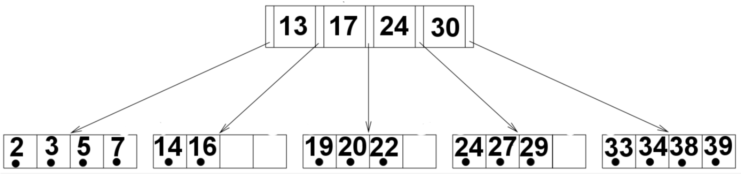
B+ Tree



- Inner node contains keys and children pointer, leaf contains keys and values.
- **Node fills one disk page.**

Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

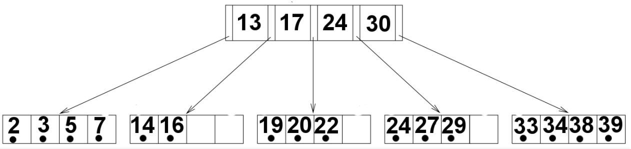
B+ Tree



- Inner node contains keys and children pointer, leaf contains keys and values.
- **Node fills one disk page.**
- Node has maximum and minimum number of entries.

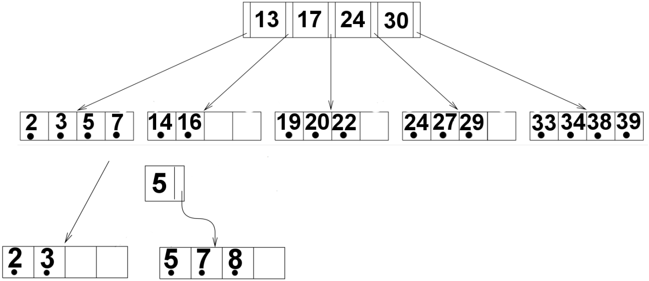
Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

Example: insert $(8, v)$



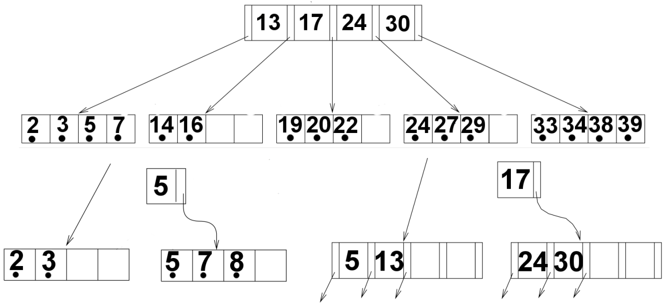
Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

Example: insert $(8, v)$



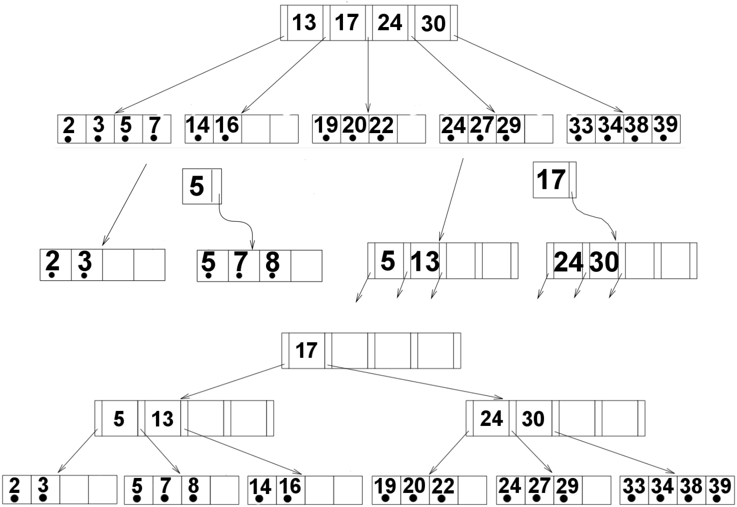
Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

Example: insert $(8, v)$



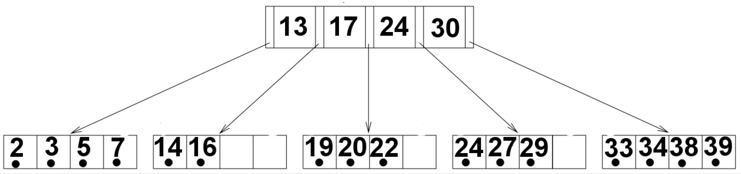
Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

Example: insert $(8, v)$



Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

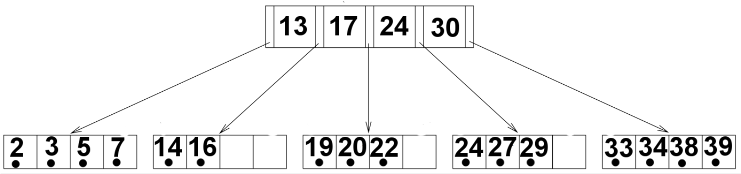
B+ Tree



- Inner node contains keys and children pointer, leaf contain keys and values.
- **Node fills one disk page.**
- Node has maximum and minimum number of entries.

Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

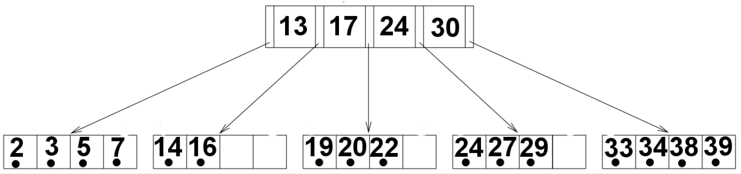
B+ Tree



- Inner node contains keys and children pointer, leaf contain keys and values.
- **Node fills one disk page.**
- Node has maximum and minimum number of entries.
- Rebalancing
  - on insert: split
  - on delete: redistribute or merge

Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

B+ Tree



- Inner node contains keys and children pointer, leaf contain keys and values.
- **Node fills one disk page.**
- Node has maximum and minimum number of entries.
- Rebalancing
    - on insert: split
    - on delete: redistribute or merge
- Insert, remove, search are logarithmic.

Images adapted from Database Management Systems by Ramakrishnan and Gehrke.

Goals

- faster B+ tree index

Goals

- faster B+ tree index
- key unique and key-value unique
    - Ex. insert (1,1), (1,2)

Goals

- faster B+ tree index
- key unique and key-value unique
    - Ex. insert (1,1), (1,2)
- range query iterators

Goals

- faster B+ tree index
- key unique and key-value unique
    - Ex. insert (1,1), (1,2)
- range query iterators
- buffer manager to allow caching
    - fetches pages

Goals

- faster B+ tree index
- key unique and key-value unique
    - Ex. insert (1,1), (1,2)
- range query iterators
- buffer manager to allow caching
    - fetches pages
- prefix sharing

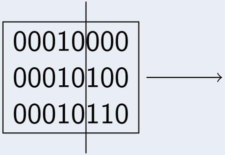
Prefix Sharing

Exploit common prefix

00010000
00010100
00010110

Prefix Sharing

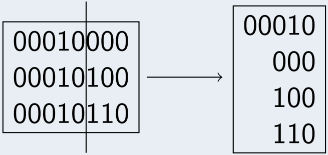
Exploit common prefix



00010000
00010100
00010110

Prefix Sharing

Exploit common prefix

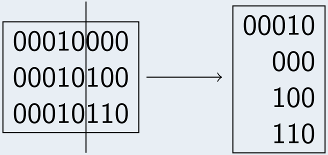


00010000
00010100
00010110

00010
000
100
110

Prefix Sharing

Exploit common prefix



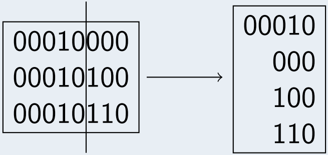
00010000
00010100
00010110

00010
000
100
110

- variable number of key-value entries per node

Prefix Sharing

Exploit common prefix



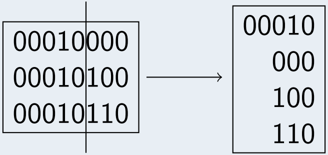
00010000
00010100
00010110

00010
000
100
110

- variable number of key-value entries per node
- prefix determines
    - if can be split without underflow

Prefix Sharing

Exploit common prefix



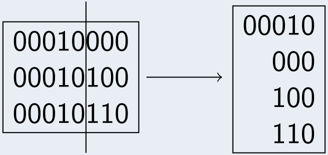
00010000
00010100
00010110

00010
000
100
110

- variable number of key-value entries per node
- prefix determines
    - if can be split without underflow
    - if can be merged without overflow

Prefix Sharing

Exploit common prefix



- variable number of key-value entries per node
- prefix determines
  - if can be split without underflow
  - if can be merged without overflow
  - the number redistributions

Challenges

- runtime dominated by disk access

Challenges

- runtime dominated by disk access
  - prefer fewer nodes

Challenges

- runtime dominated by disk access
    - prefer fewer nodes
    - rarely modify nodes

Challenges

- runtime dominated by disk access
    - prefer fewer nodes
    - rarely modify nodes
- New features are costly.

Challenges

- runtime dominated by disk access
    - prefer fewer nodes
    - rarely modify nodes
- New features are costly.
- Textbook algorithms need to be adapted.

Challenges

- runtime dominated by disk access
    - prefer fewer nodes
    - rarely modify nodes
- New features are costly.
- Textbook algorithms need to be adapted.
    1. not optimized for practical scenarios

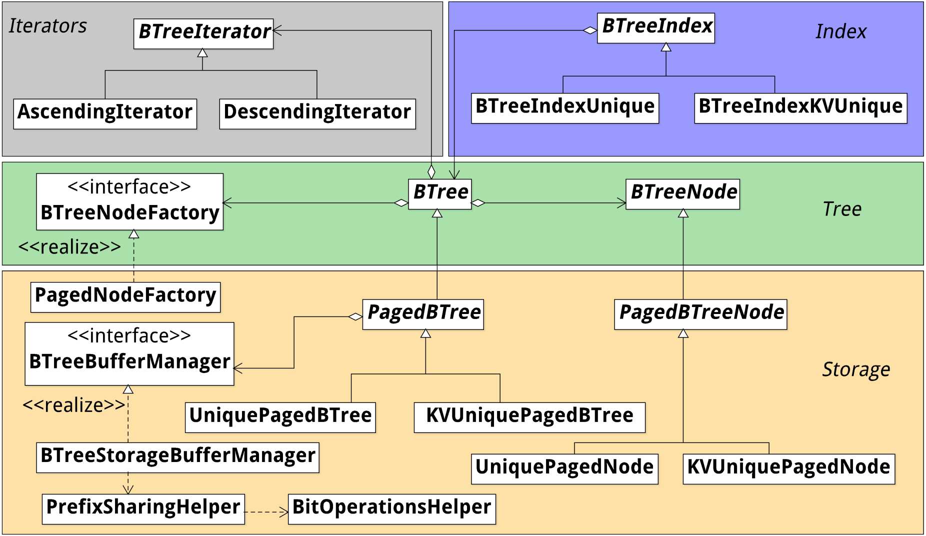
Challenges

- runtime dominated by disk access
  - prefer fewer nodes
  - rarely modify nodes
- New features are costly.
- Textbook algorithms need to be adapted.
  1. not optimized for practical scenarios
  2. do not cover duplicates nor prefix sharing

Challenges

- runtime dominated by disk access
    - prefer fewer nodes
    - rarely modify nodes
- New features are costly.
- Textbook algorithms need to be adapted.
    1. not optimized for practical scenarios
    2. do not cover duplicates nor prefix sharing
- low-level implementation optimizations

Index Implementation



Operations

Operations

- Search - similar to normal B+ Tree

Operations

- Search - similar to normal B+ Tree
- Insert overflow
  1. redistribute left ?
  2. split

Operations

- Search - similar to normal B+ Tree
- Insert overflow
  1. redistribute left ?
  2. split
- Delete underflow
  1. merge with left/right ?
  2. split between left and right ?
  3. redistribute left/right

Operations

- Search - similar to normal B+ Tree
- Insert overflow
  1. redistribute left ?
  2. split
- Delete underflow
  1. merge with left/right ?
  2. split between left and right ?
  3. redistribute left/right
- Write
  - only write dirty nodes
  - prefix encoding

Operations

- Search - similar to normal B+ Tree
- Insert overflow
  1. redistribute left ?
  2. split
- Delete underflow
  1. merge with left/right ?
  2. split between left and right ?
  3. redistribute left/right
- Write
  - only write dirty nodes
  - prefix encoding
- insert/delete more costly, exactly how much?

Microbenchmarks

- full in-memory, index only tests

Microbenchmarks

- full in-memory, index only tests

Duration - Old index is the baseline

Operation	No Prefix sharing	Prefix sharing
Search	1	0.9 - 1.1
Insert	1	1.6 - 2.8
Delete	1	1.45 - 2.9

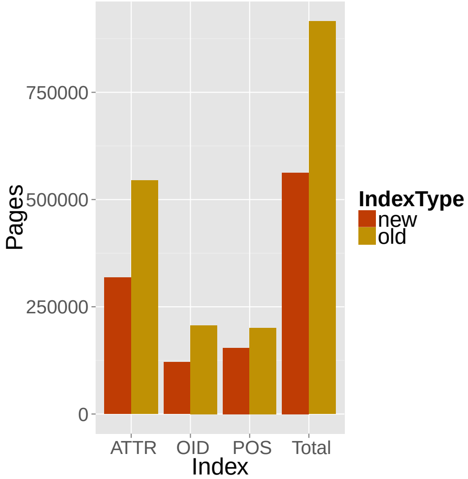
Size of B+ tree - Old index is the baseline

Operation	No Prefix sharing	Prefix sharing
Insert	1	0.5 - 1.1
Delete	1	0.5 - 0.75

StackOverflow Data Import

- real-world workload
- StackOverflow data
  - 1.3 million users
  - 10.3 million posts
  - 13 million comments
  - 25 million votes
- 3 key unique attribute indexes
- 9 key-value unique attribute indexes

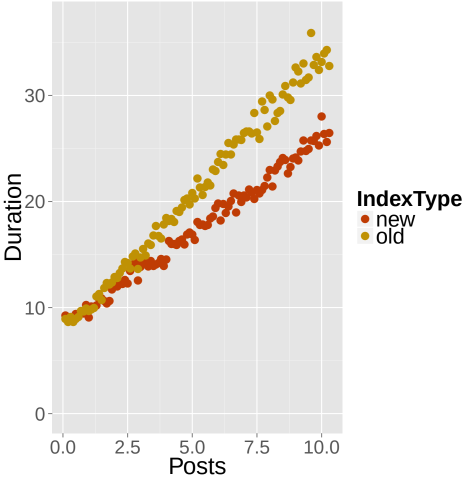
StackOverflow Import - Index Sizes



- page size: 4KB
- database size: 31 GB

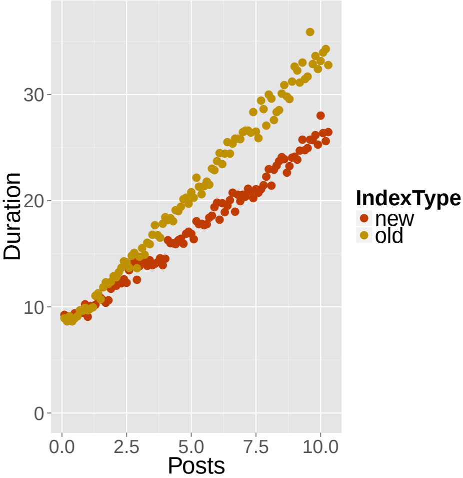
Index	Space saving (%)
Atrribute	41.6
OID	41.5
POS	23.1
Total	38.5

StackOverflow Import - Commit times



- import with new index 25% faster
- why?

StackOverflow Import - Commit times



- import with new index 25% faster
- why?
- more entries in a node → fewer dirty nodes
- data locality

Summary

- prefix sharing: trade-off between speed and space
- works well in practice
- microbenchmarks
- implementation complexity.

Q&A

- Thank you for your attention!
- Questions ?