A B-tree library for OCaml

Tom Ridge / OCaml '17 / 2017-09-08

> “ But I also think that the "we write meta-data synchronously, but then the actual data shows up at some random later time" is just crazy talk. That's simply insane. It *guarantees* that there will be huge windows of times where data simply will be lost if something bad happens.
>
> -- Linus Torvalds on filesystems

B-trees

B-trees are datastructures

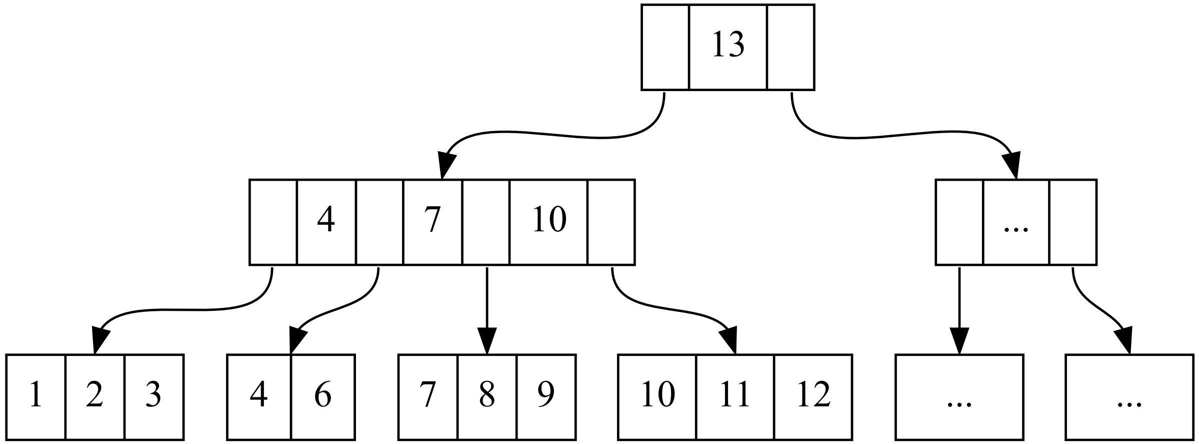
which implement the **map** abstract datatype

(find, insert, delete etc.)

| Search trees

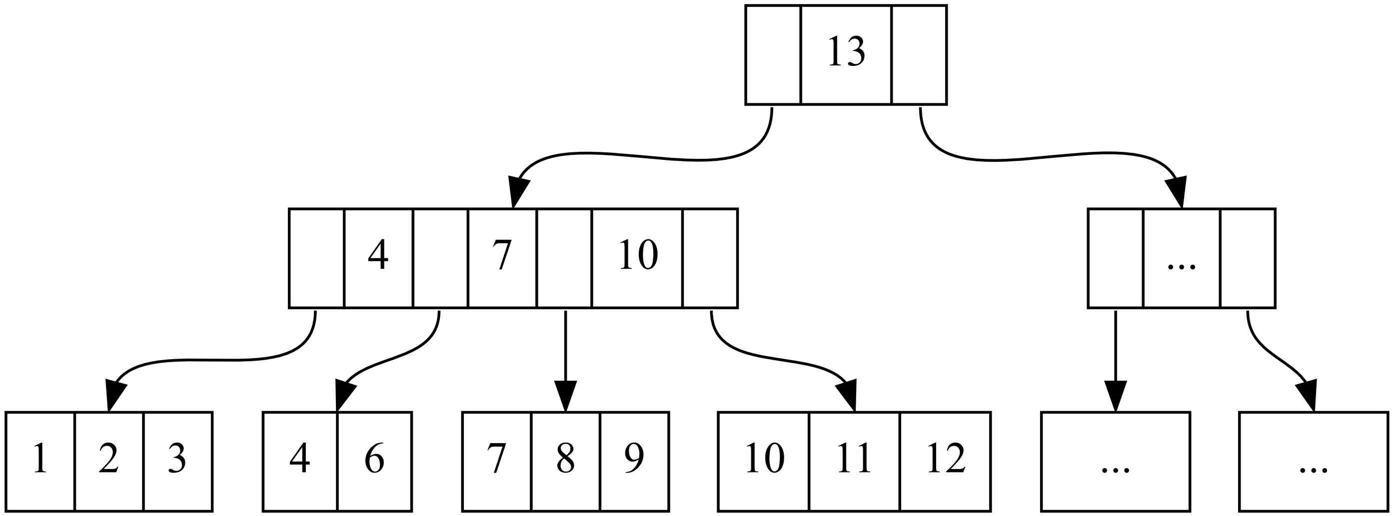
A B-tree is a form of search tree.

A **search tree** is st. the keys
in any subtree are bounded
by [...keys in parent...]



Given a key, you can easily locate a (key,value) in a leaf
by following the appropriate pointers
and this **allows efficient implementation of map ops** such as find

| B-trees, in addition to search trees



A **B-tree** is

a **balanced** search tree

with **min and max size constraints** on nodes

(nodes can be partially full)

| Compared to OCaml's standard maps?

Functor Map.Make

```
module Make:
  functor (Ord : OrderedType) -> S  with type key = Ord.t
```

Functor building an implementation of the map structure given a totally ordered type.

Uses balanced, binary search trees.

✘ B-trees are n-ary trees, and the **code is more complicated**
they also have **greater space overhead**

✔ Tree balancing ops (rotating, splitting etc) can be costly
B-trees try to **minimize this work**
eg insert into non-full nodes without doing any rebalancing

✔ B-trees are also **tuned to block devices**:
choose max node size st. **every node fits into a single on-disk block**

| B-tree usage

B-trees are widely used in **databases**

such as Oracle, SQLServer, PostgreSQL… all of them?

to provide fast access to large indexed (or key/value) data

B-trees are also used in modern **filesystems**

such as HFS, HFS+, NTFS, jfs2, ext4, reiser4 and btrfs

to support features like snapshots etc

Quick calculation for an `int -> int` map:

assuming: 64 bit (8 byte) ints, blk size 4096 bytes

have **>16M (k,v) bindings**, >256 MB of data, in a tree of height 3

If we **cache the top two layers** (root and children, 1MB)

at most 1 block read to locate any (k,v) binding

| Implementation in OCaml

Core code developed in Isabelle/HOL to allow formal verification

Interesting aspects:

- novel design
  - to allow certain features (see later), and for correctness
- small step, framestack-based operational semantics
  - (for concurrency and atomicity modelling)
- state-passing style, monad for state and error

Code then extracted to OCaml and wrapped in an OCaml-friendly API

| OCaml, (int->int) map example usage

```
(* create and init store, write some values, and close *)
let do_write () = (
  Printf.printf "Executing %d writes...\n" max;
  print_endline "Writing...";
  (* create and initialize *)
  let s = ref (from_file ~fn ~create:true ~init:true) in
  (* get map operations *)
  let map_ops = imperative_map_ops s in
  (* write values *)
  for x=1 to max do
    map_ops.insert (k x) (v x);
  done;
  close !s;
  ())
```

| Open existing store and delete some entries

```
(* open store, delete some values, and close *)
let do_delete () = (
  print_endline "Deleting...";
  let s = ref (from_file ~fn ~create:false ~init:false) in
  let map_ops = imperative_map_ops s in
  for x=100 to 200 do
    map_ops.delete (k x);
  done;
  close !s;
  ())
```

Check entries have been deleted

```
let do_full_check () = (
  print_endline "Full check...";
  let s = ref (from_file ~fn ~create:false ~init:false) in
  let map_ops = imperative_map_ops s in
  for x = 1 to max do
    if (100 <= x && x <= 200) then
      assert(map_ops.find (k x) = None)
    else
      assert(map_ops.find (k x) = Some(v x))
  done;
  close !s)
```

Quick demo

| Quick demo

```
$ src $ time ./ii_example.native
Executing 10000 writes...
Writing...
Deleting...
Checking...
Full check...

real    0m0.941s
user    0m0.756s
sys     0m0.168s
```

Is this good? Nothing really to compare against, and see next slide.

Quick demo

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real	0m0.941s
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# expected size 16B * 10k = 160kB (+tree overhead)? why 79MB?
$ src $ ls -alh btree.store
-rw-r----- 1 tr61 tr61 79M Sep  1 19:26 btree.store
```

| Persistent datastructures

Don't confuse **persistent datastructures** with **persistent storage**!

A **persistent datastructure** (eg OCaml's maps)
allows access to previous versions when modified

This library provides a B-tree **persistent datastructure**
backed by **persistent storage** (this scheme is similar to "copy-on-write")

Expected store size? `160kB * 10k = 1600 MB = 1.6 GB`
so why only 76MB?

In real use, **caching** would reduce the number of on-disk states
an explicit API **sync** op would force cache flush and write a state to disk
and **atomicity** via on-disk pointer swinging

| Take away point

A **fast** (maybe), **correct** (hopefully) **CoW B-tree library** in OCaml suitable for storing and accessing large, indexed data

| The bigger picture: "Future filesystems"

Project funded by EPSRC and Microsoft Research (PhD student)

"Formal methods applied to filesystems"
(specification and implementation)

Main goal: to be able to write **correct** programs
that use the filesystem or other persistent storage eg block dev

Filesystem specification: see the paper on **SibylFS, SOSP'15**

Filesystem implementation: currently writing **ImpFS**
the B-tree library is a key component

Questions?

| Extra slide: components

- block device (eg raw, or backed by a file, or a network connection etc)
- store (above blk dev; keeps track of free blocks)
- btree API, including "bindings" and "insert many"
- marshalling/on-disk layout, currently courtesy of Jane Street's binprot
- LRU caching (eg above blk dev, store, btree etc)

Other interesting points

- components are flexible: assemble your own stack with shared caches, or disjoint caches etc
- testing via wf assertion checking and exhaustive state space exploration

End