Immutable Distributed Infrastructure for Unikernels

WG2.8, Greece

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- Background
  - Unikernels
  - Irmin, a large-scale, immutable, branch-consistent storage
- Weakly consistent data structures
  - Mergeable queues
  - Mergeable ropes
- Benchmarking Irmin
- Use Cases

- Modern systems are built in **memory-safe programming languages**.
- We build elaborate libraries and applications to express complex logic.
- ...and watch it all come crashing down when it interfaces with the OS.

Mirage OS is a library operating system that constructs unikernels for secure, high-performance network applications across a variety of cloud computing and mobile platforms.

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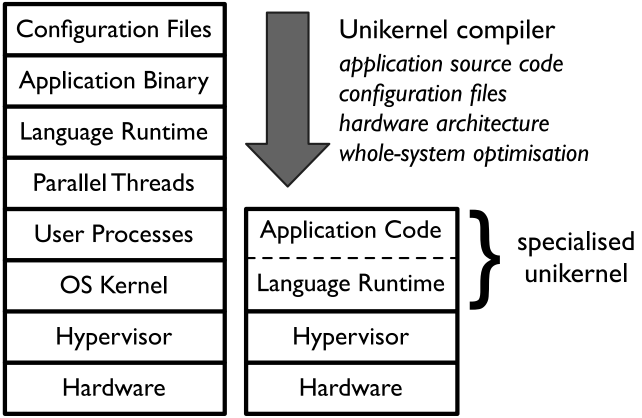
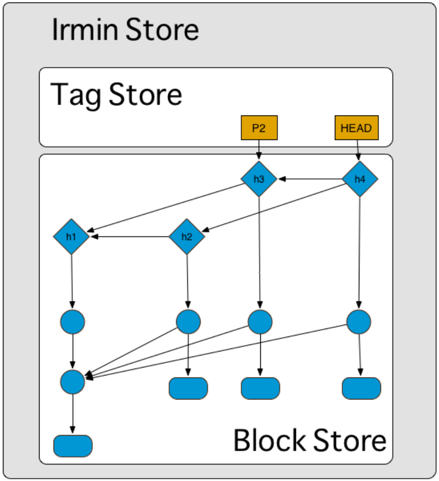

Configuration Files
Application Binary
Language Runtime
Parallel Threads
User Processes
OS Kernel
Hypervisor
Hardware
Unikernel compiler
application source code
configuration files
hardware architecture
whole-system optimisation
Application Code
Language Runtime
Hypervisor
Hardware
specialised unikernel

What should a storage interface to unikernels look like?

- Highly distributed systems
- Frequent failure is an option
- Debugging and tracing must be built into the fabric

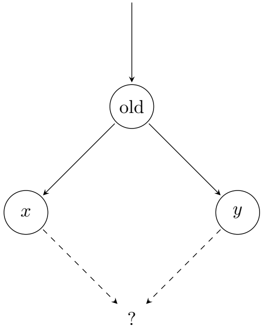
Irmin, large-scale, immutable, branch-consistent storage

- Irmin is a library to **persist** and **synchronize distributed data structures** both on-disk and in-memory
- It enables a style of programming very similar to the **Git workflow**, where distributed **nodes fork, fetch, merge and push** data between each other
- The general idea is that you want every active node to get a **local** (partial) **copy of a global database** and always be very explicit about how and when data is shared and migrated


Irmin Store
Tag Store
P2
HEAD
h3
h4
h1
h2
Block Store

```
type t = ...
(** User-defined contents. *)
type result = [ ‘Ok of t |
   ‘Conflict of string ]

val merge: old:t → t → t →
   result
(** 3-way merge functions. *)
```



Weakly consistent data structures

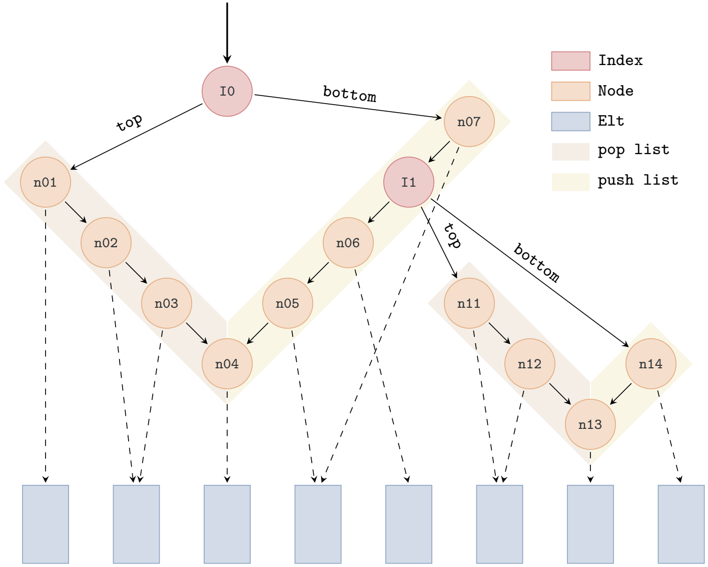
Mergeable queues

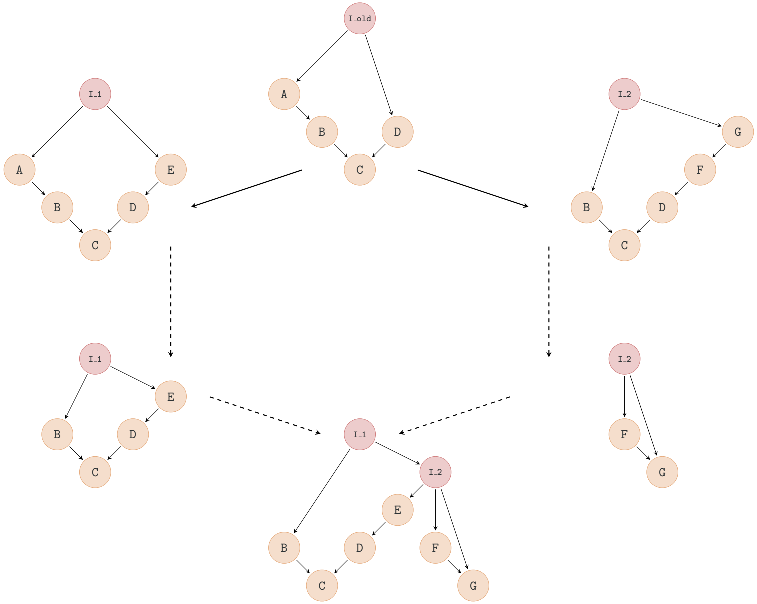
```
module type IrminQueue.S = sig
  type t
  type elt

  val create : unit → t
  val length : t → int
  val is_empty : t → bool

  val push : t → elt → t
  val pop : t → (elt * t)
  val peek : t → (elt * t)

  val merge : IrminMerge.t
end
```


I0
top
bottom
n01
n02
n03
n04
n05
n06
n07
I1
top
bottom
n11
n12
n13
n14
Index
Node
Elt
pop list
push list


I_old
A
B
D
C
I_1
A
E
B
D
C
I_2
G
F
B
D
C
I_1
E
B
D
C
I_2
F
G
I_1
I_2
E
B
D
F
C
G

Current state

Operation	Read	Write	
Push	0	2	$O(1)$
Pop	2 on average	1 on average	$O(1)$
Merge	n	1	$O(n)$

Current state

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Push	0	2	$O(1)$
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Merge	n	1	$O(n)$

With a little more work

Operation	Read	Write	
Push	0	2	$O(1)$
Pop	2 on average	1 on average	$O(1)$
Merge	$\log n$	1	$O(\log n)$

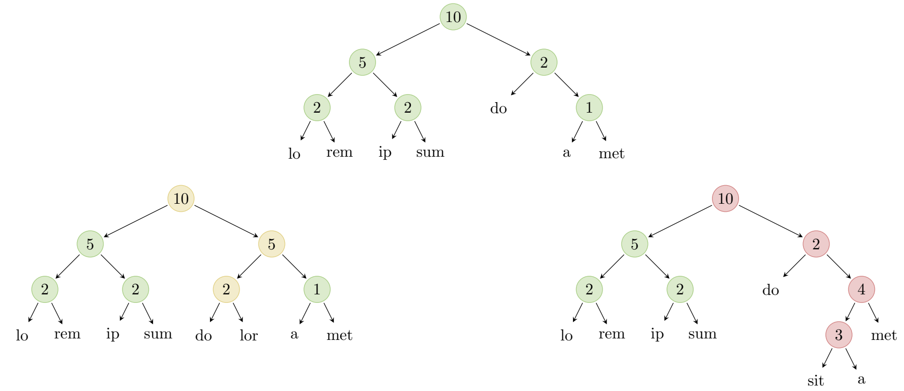
Mergeable ropes

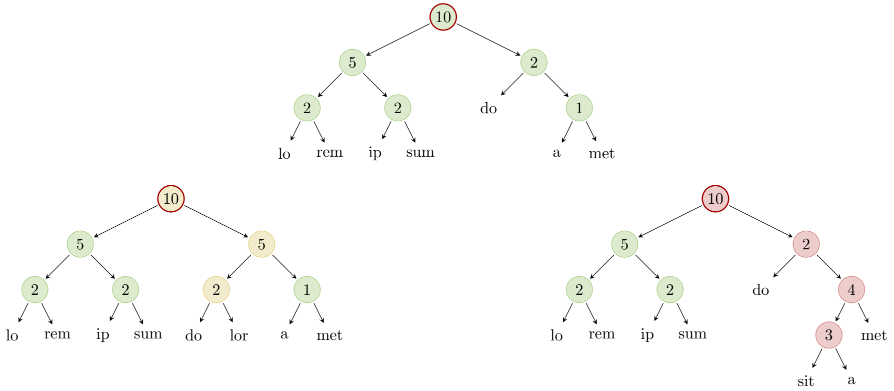
```
module type IrminRope.S = sig
  type t
  type value (* e.g char *)
  type cont  (* e.g string *)

  val create : unit → t
  val make : cont → t
  ...
  val set : t → int → value → t
  val get : t → int → value
  val insert : t → int → cont → t
  val delete : t → int → int → t
  val append : t → t → t
  val split : t → int → (t * t)

  val merge : IrminMerge.t
end
```

Operation	Rope	String
Set/Get	$O(\log n)$	$O(1)$
Split	$O(\log n)$	$O(1)$
Concatenate	$O(\log n)$	$O(n)$
Insert	$O(\log n)$	$O(n)$
Delete	$O(\log n)$	$O(n)$
Merge	$\log(f(n))$	$f(n)$


10
5
2
2
2
do
1
lo
rem
ip
sum
a
met
10
5
5
2
2
2
1
lo
rem
ip
sum
do
lor
a
met
10
5
2
2
2
do
4
lo
rem
ip
sum
3
met
sit
a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rem
ip
sum
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met
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lo
rem
ip
sum
do
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met
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do
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rem
ip
sum
3
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sit
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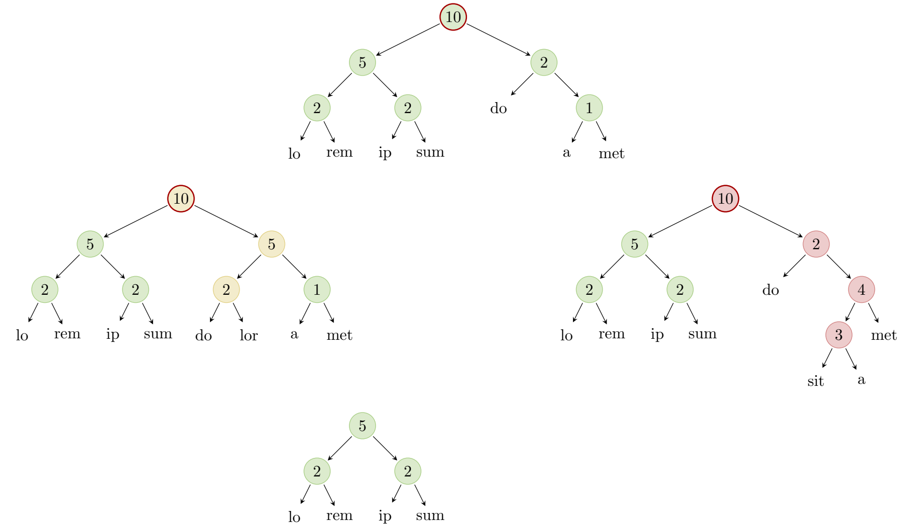
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rem
ip
sum
do
lor
a
met
10
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do
lo
rem
ip
sum
met
sit
a
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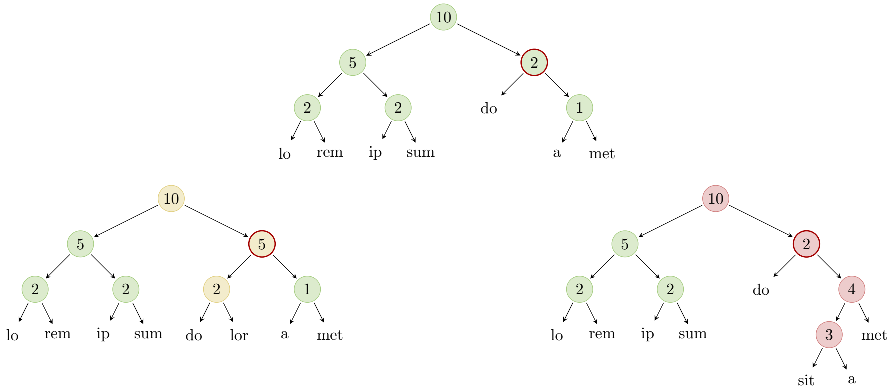
lo
rem
ip
sum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sum
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do
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rem
ip
sum
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do
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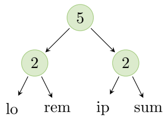
sit
a
met


5
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lo
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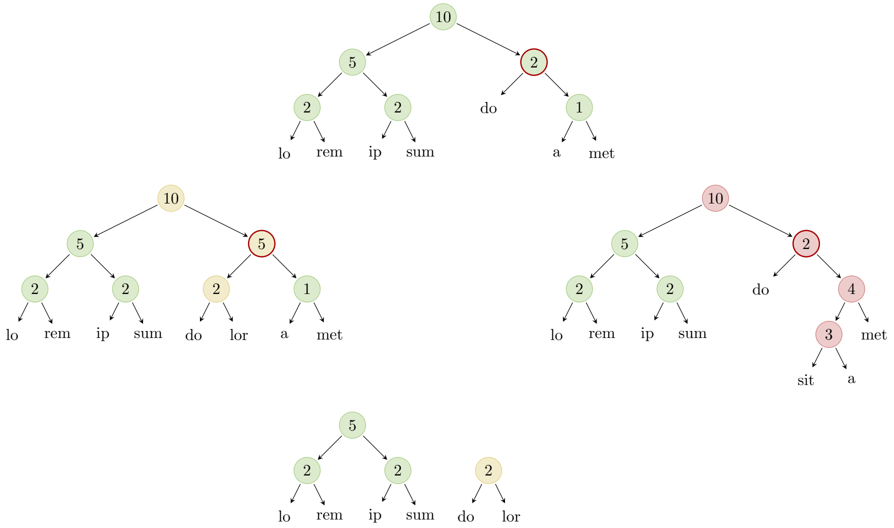
sum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sum
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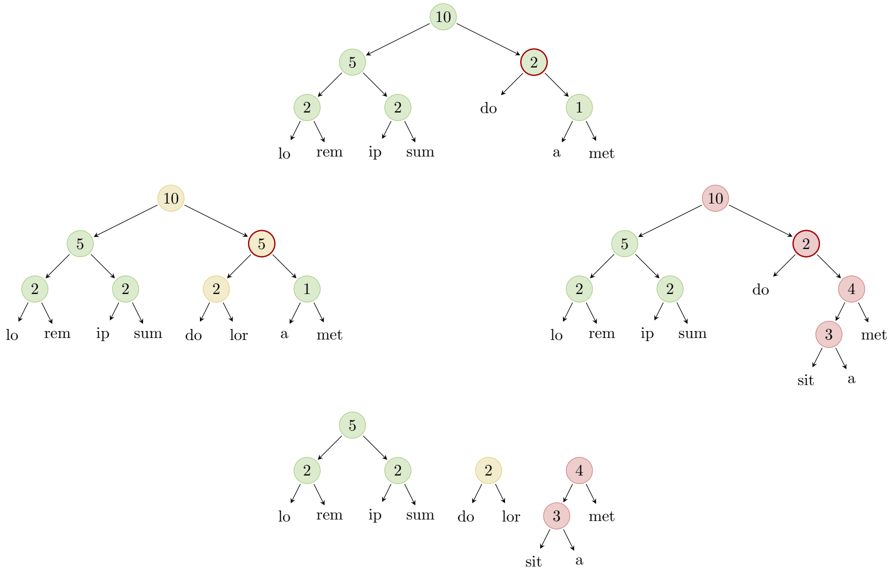
do
lor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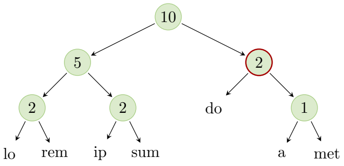
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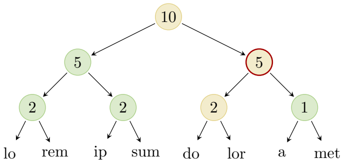
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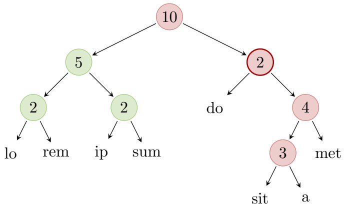
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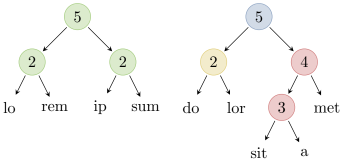
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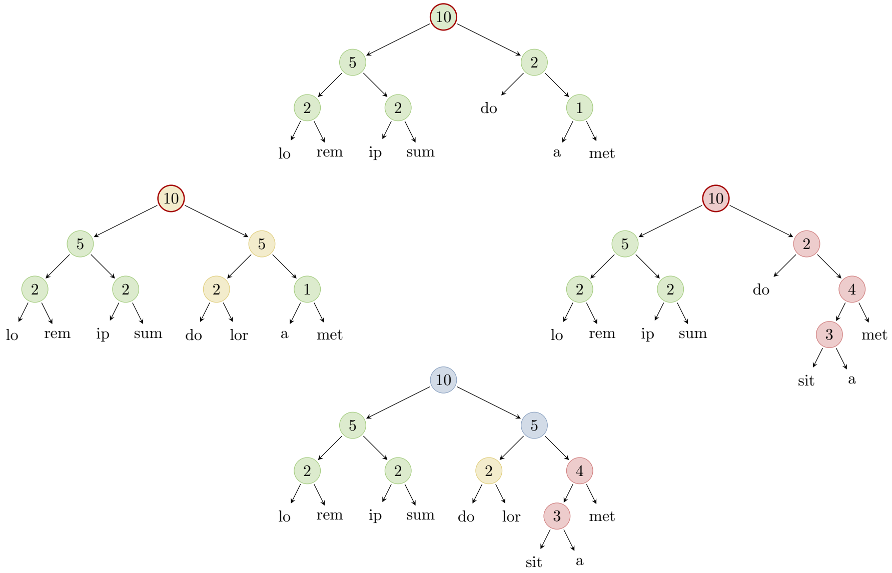
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do
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sum
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3
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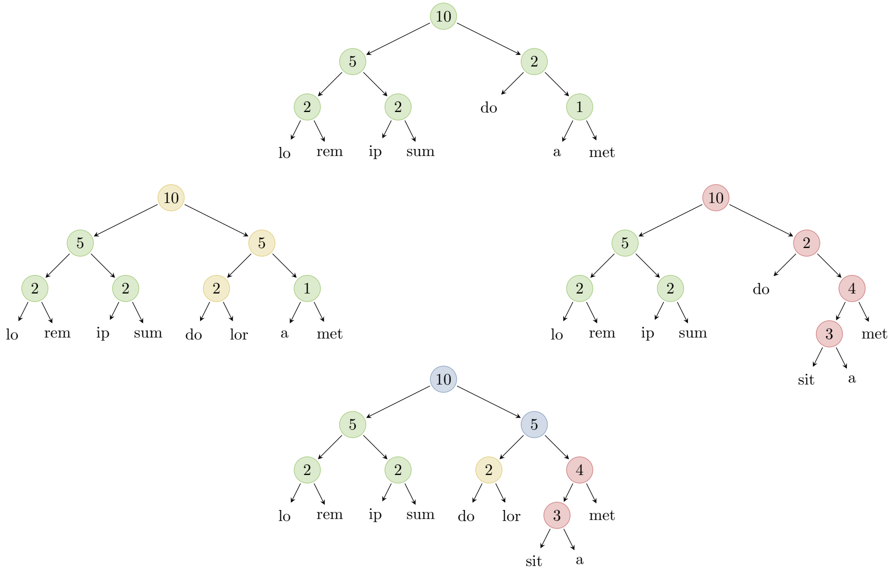
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1
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do
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2
2
do
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ip
sum
3
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sit
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4
lo
rem
ip
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do
lor
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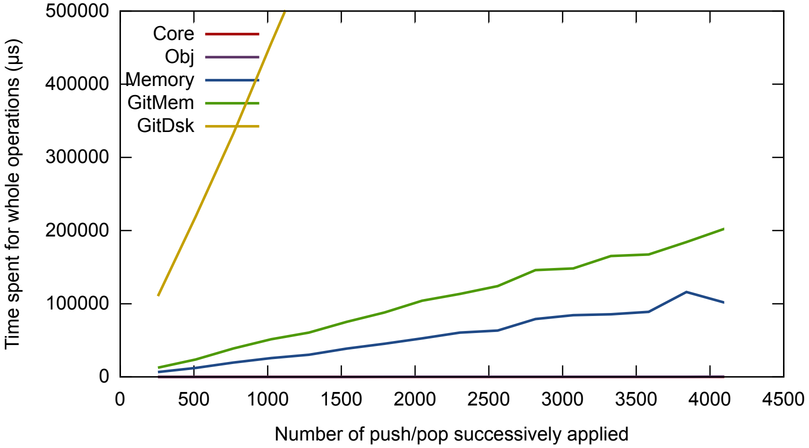
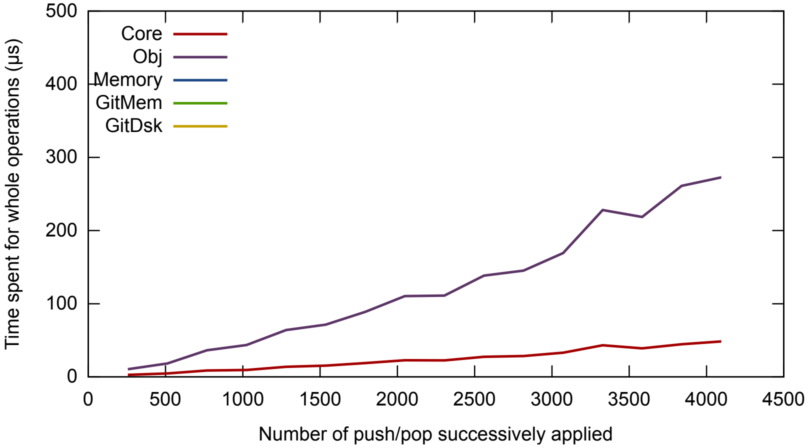
sit
a

Benchmarking Irmin

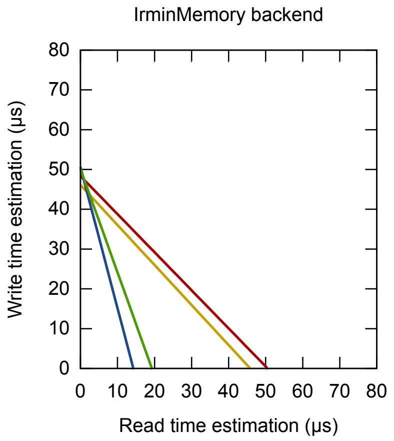


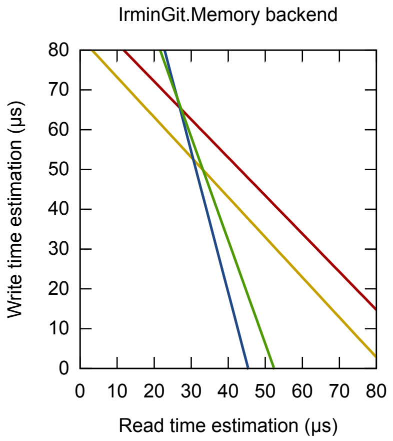
Time spent for whole operations (µs)
500000
400000
300000
200000
100000
0
Core
Obj
Memory
GitMem
GitDsk
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Number of push/pop successively applied

```
module ObjBackend ...  = struct
  type t = unit
  type key = K.t
  type value = V.t

  let create () = return ()
  let clear () = return ()

  let add t value =
    return (Obj.magic (Obj.repr value))

  let read t key =
    return (Obj.obj (Obj.magic key))

  let mem t key = return true
  ...
end
```



500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Core
Obj
Memory
GitMem
GitDsk
Time spent for whole operations (µs)
Number of push/pop successively applied

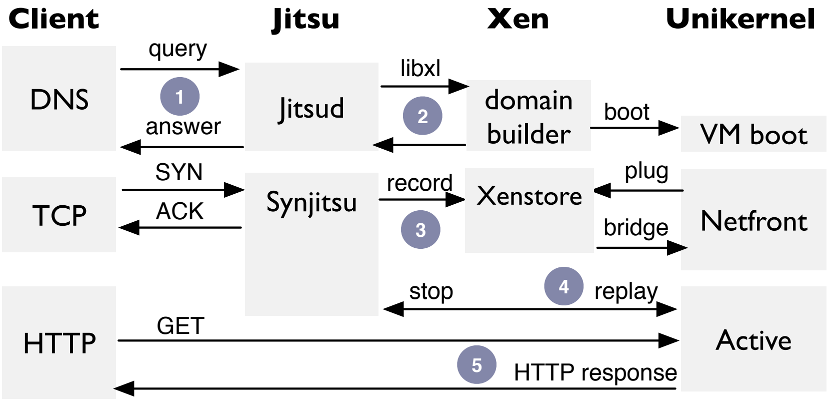

IrminMemory backend
Write time estimation (µs)
Read time estimation (µs)
0
10
20
30
40
50
60
70
80

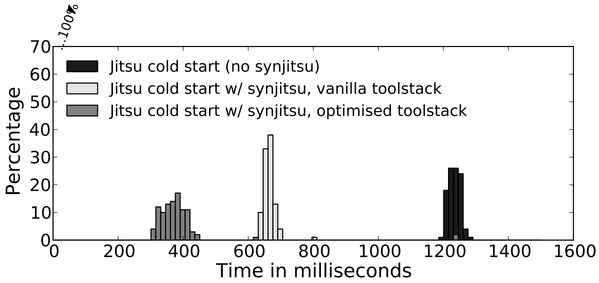

IrminGit.Memory backend
Write time estimation (µs)
Read time estimation (µs)
0
10
20
30
40
50
60
70
80

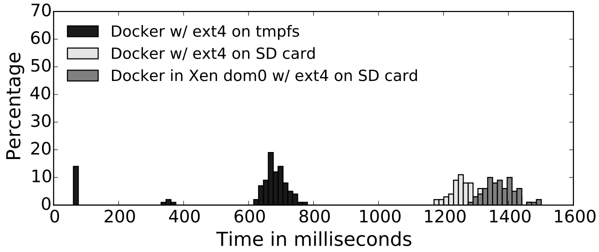
Status

- HTTP REST APIs for remote clients.
- JavaScript compilation for pure browser operation.
- Bidirectional lenses (Git commits map to Irmin commits from any direction)
- Open source at `https://github.com/mirage/irmin`
- JFLA 2015 paper got great feedback. Now building more data structures, evaluating block scheduling.

- **Jitsu: Just-In-Time Summoning of Unikernels**
  `https://www.youtube.com/watch?v=DSzvFwIVm5s`
- Ported complex Xen toolstack to use Irmin.
- Jitsu becomes the `inetd` of Xen:
  - Launch VMs in response to network requests in real-time.
  - Irmin coordinates toolstack RPCs with low latency.
  - Connection setup is proxied to eliminate packet loss.


Client
Jitsu
Xen
Unikernel
DNS
query
1
answer
Jitsud
libxl
2
domain builder
boot
VM boot
TCP
SYN
ACK
Synjitsu
record
3
Xenstore
plug
bridge
Netfront
stop
4
replay
HTTP
GET
Active
5
HTTP response


...100%
Jitsu cold start (no synjitsu)
Jitsu cold start w/ synjitsu, vanilla toolstack
Jitsu cold start w/ synjitsu, optimised toolstack
Percentage
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
1400
1600
Time in milliseconds


Docker w/ ext4 on tmpfs
Docker w/ ext4 on SD card
Docker in Xen dom0 w/ ext4 on SD card
Percentage
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
1400
1600
Time in milliseconds