IMPLEMENTING RIAK IN ERLANG: BENEFITS AND CHALLENGES

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ERLANG

Erlang

- 1980s: Ericsson Computer Science Laboratories (CSL) sought better ways to program telecom switches

- Joe Armstrong created Erlang based on Prolog, with influence from ML, Ada, Smalltalk, other languages

- Open sourced in 1998, available from http://erlang.org

- Ericsson develops and maintains it with community help

- Latest production release: R16B (Feb 2013)

Ericsson Telecom Switch Requirements

- Large number of concurrent activities

- Large software systems distributed across multiple computers

- Continuous operation for years

- Live updates and maintenance

- Tolerance for both hardware and software faults

Today's Data/Web/Cloud/Service Apps

- Large number of concurrent activities

- Large software systems distributed across multiple computers

- Continuous operation for years

- Live updates and maintenance

- Tolerance for both hardware and software faults

CONCURRENCY

They Come For The Concurrency...

- Erlang processes are very lightweight, much lighter than OS threads

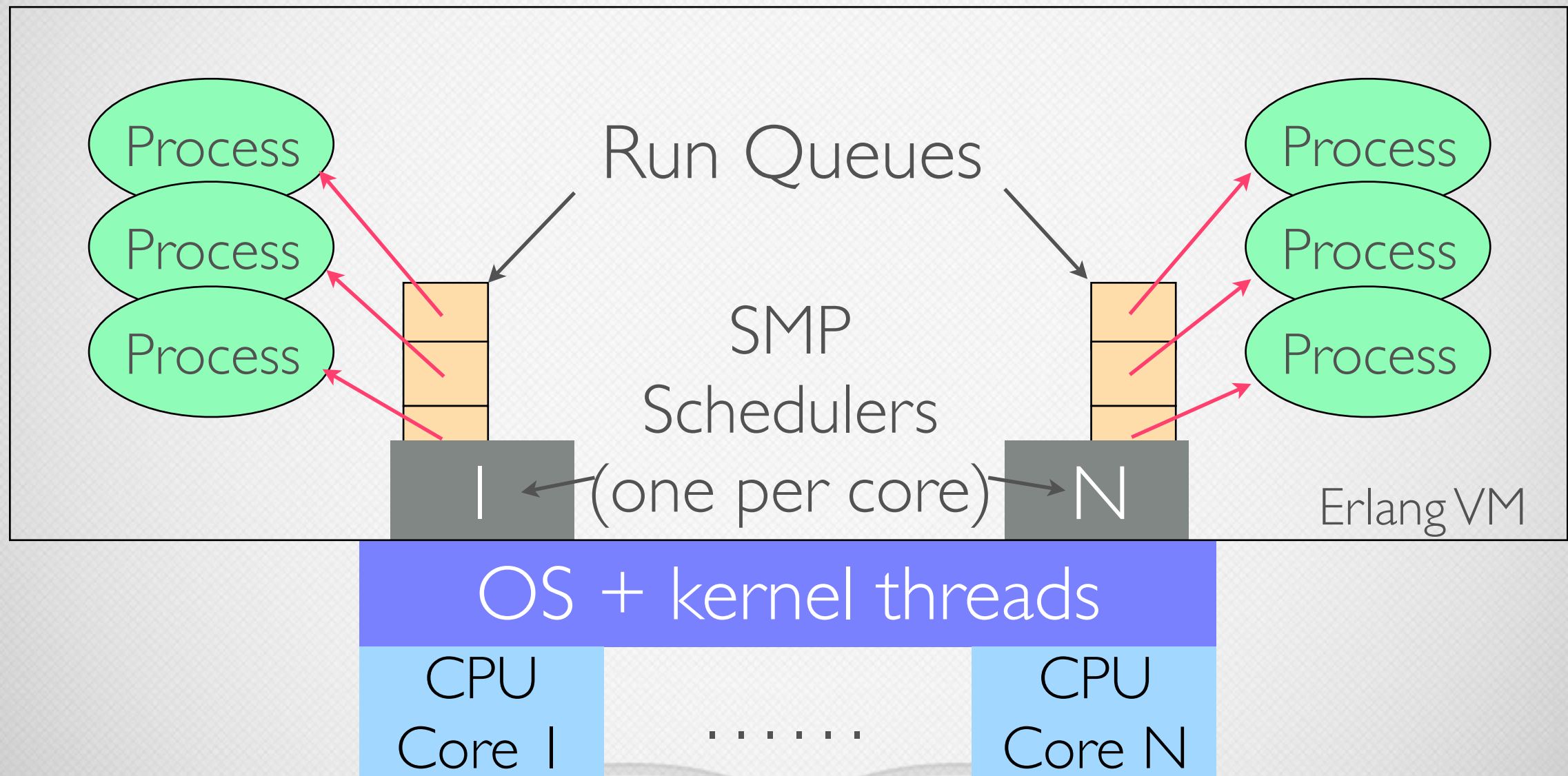- Hundreds of thousands or even millions of processes per Erlang VM instance

...But They Stay For The Reliability

- Isolation: Erlang processes communicate only via message passing

- Distribution: Erlang process model works across nodes

- Linking/supervision/monitoring: allow an Erlang process to take action when another fails

Erlang Process Architecture

Process · Process · Process — Run Queues — Process · Process · Process

SMP
Schedulers
1 ← (one per core) → N

Erlang VM

OS + kernel threads

CPU Core 1 · · · · · · · CPU Core N

A Small Language

- Erlang has just a few elements: numbers, atoms, tuples, lists, records, binaries, functions, modules

- Variables are immutable, no globals

- Flow control via pattern matching, case, if, try-catch, recursion, messages

Concurrency Primitives

- No mutexes, condition variables, or other error-prone concurrency constructs

- All Erlang code runs within some process, always

  - processes are not "extra" like threads in other languages

Concurrency Primitives

- spawn: create a new Erlang process

- ! (exclamation point) or send: send a message to another Erlang process, even on another node

- Messages can be any Erlang term

- Messages from A to B arrive in the order sent

```
Pid1 ! ok,
Pid2 ! [{first, "John"},{last,"Doe"}].
```

Concurrency Primitives

- Each process has a message queue

- receive: receive a message from another Erlang process

- Selective receive allows receiving specific messages from anywhere within the message queue

```
receive
    {ok, Reply} ->
        do_something(Reply);
    {error, Error} ->
        uh_oh(Error)
end.
```

Erlang Immutability

- Erlang assignment is pattern matching, not mutation

- Unbound variables get the value of the right-hand side and then can't be changed

Erlang Immutability

```erlang
foo() ->
    A = 2,    % A is bound to 2
```

Erlang Immutability

```erlang
foo() ->
    A = 2,    % A is bound to 2
    A = 2,    % pattern match A to 2, result is 2
```

Erlang Immutability

```erlang
foo() ->
    A = 2,    % A is bound to 2
    A = 2,    % pattern match A to 2, result is 2
    A = 3.    % pattern match A to 3, throw badmatch
```

Erlang Immutability

```erlang
foo() ->
    A = 2,    % A is bound to 2
    A = 2,    % pattern match A to 2, result is 2
    A = 3.    % pattern match A to 3, throw badmatch
```

Easy To Learn

- Language size means developers become proficient quickly

- Code is typically brief, easy to read, easy to understand

- Erlang's Open Telecom Platform (OTP) frameworks solve recurring problems across multiple domains

RIAK

Riak

- A distributed highly available eventually consistent highly scalable open source key-value database written primarily in Erlang.

Riak

- Modeled after Amazon Dynamo

  - see Andy Gross's "Dynamo, Five Years Later" for details https://speakerdeck.com/argv0/dynamo-five-years-later

- Also provides MapReduce, secondary indexes, and full-text search

- Built for operational ease

Riak Architecture

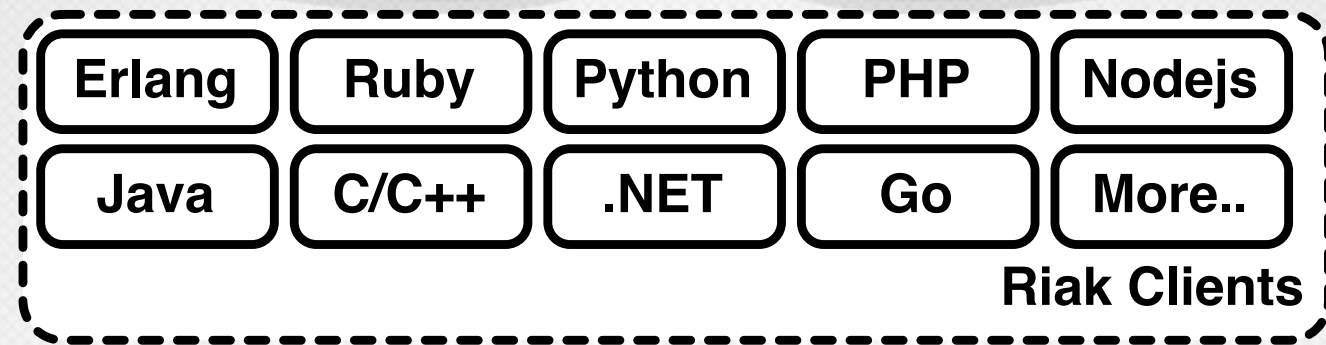Erlang | Ruby | Python | PHP | Nodejs

Java | C/C++ | .NET | Go | More..

Riak Clients

image courtesy of Eric Redmond, "A Little Riak Book" https://github.com/coderoshi/little_riak_book/
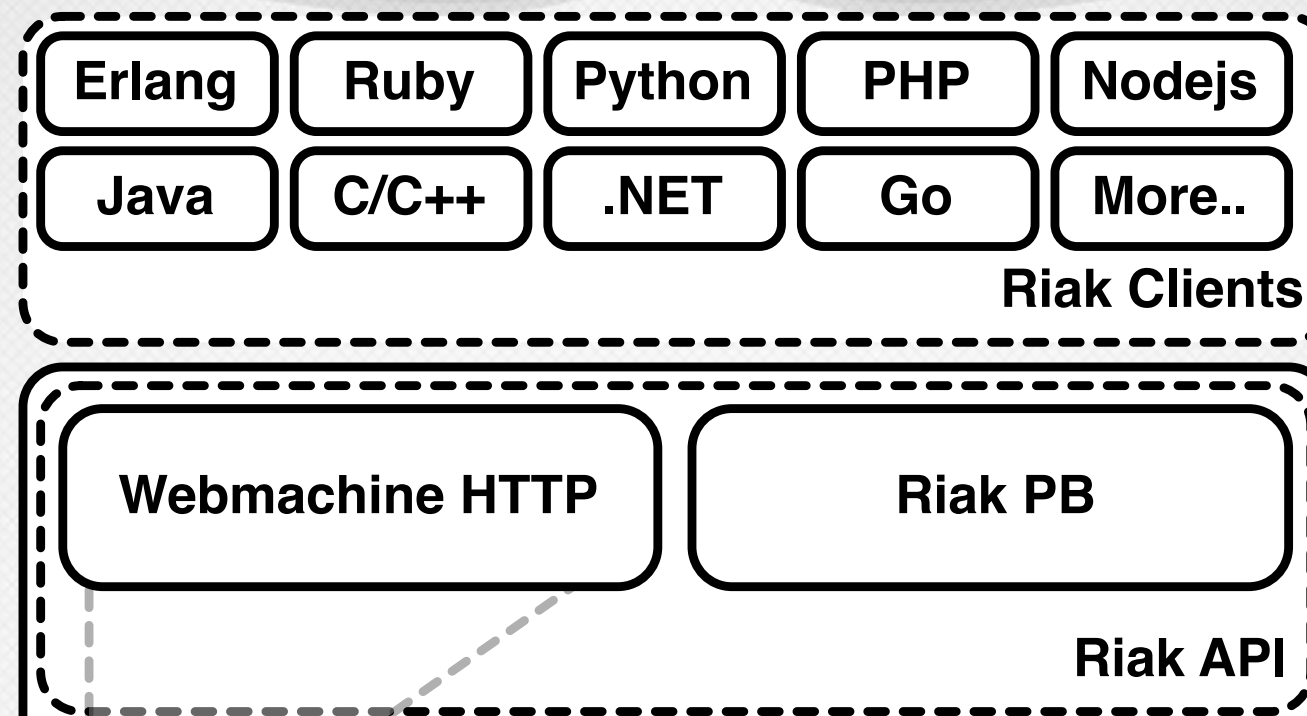
Riak Architecture

Erlang	Ruby	Python	PHP	Nodejs
Java	C/C++	.NET	Go	More..

Riak Clients

Webmachine HTTP	Riak PB

Riak API

image courtesy of Eric Redmond, "A Little Riak Book" https://github.com/coderoshi/little_riak_book/

Riak Architecture

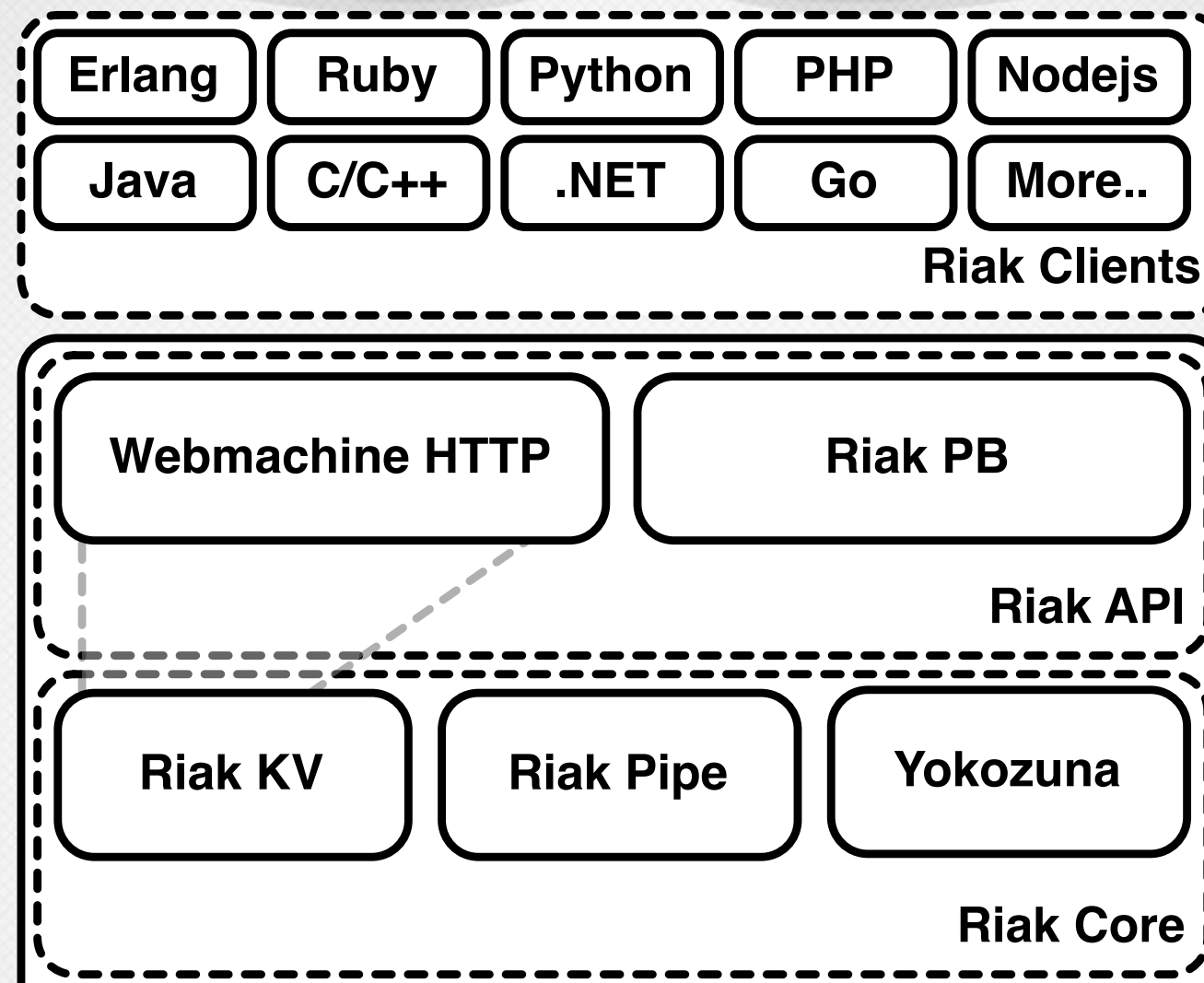**Erlang** **Ruby** **Python** **PHP** **Nodejs**

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Riak Clients

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Riak API

Riak KV **Riak Pipe** **Yokozuna**

Riak Core

image courtesy of Eric Redmond, "A Little Riak Book" https://github.com/coderoshi/little_riak_book/

Riak Architecture

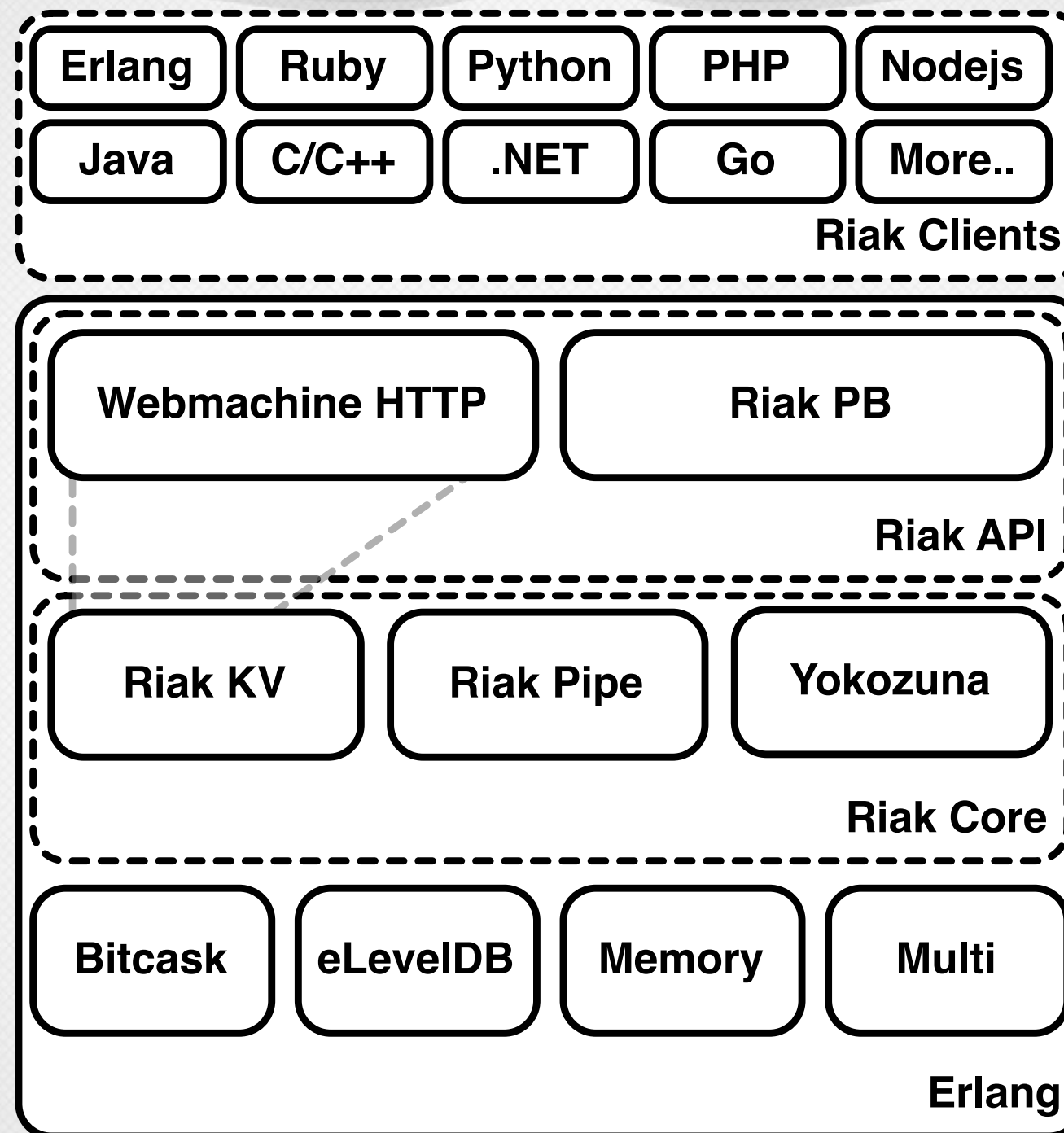**Erlang** **Ruby** **Python** **PHP** **Nodejs**

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Riak Clients

Webmachine HTTP **Riak PB**

Riak API

Riak KV **Riak Pipe** **Yokozuna**

Riak Core

Bitcask **eLevelDB** **Memory** **Multi**

Erlang

image courtesy of Eric Redmond, "A Little Riak Book" https://github.com/coderoshi/little_riak_book/

Riak Architecture

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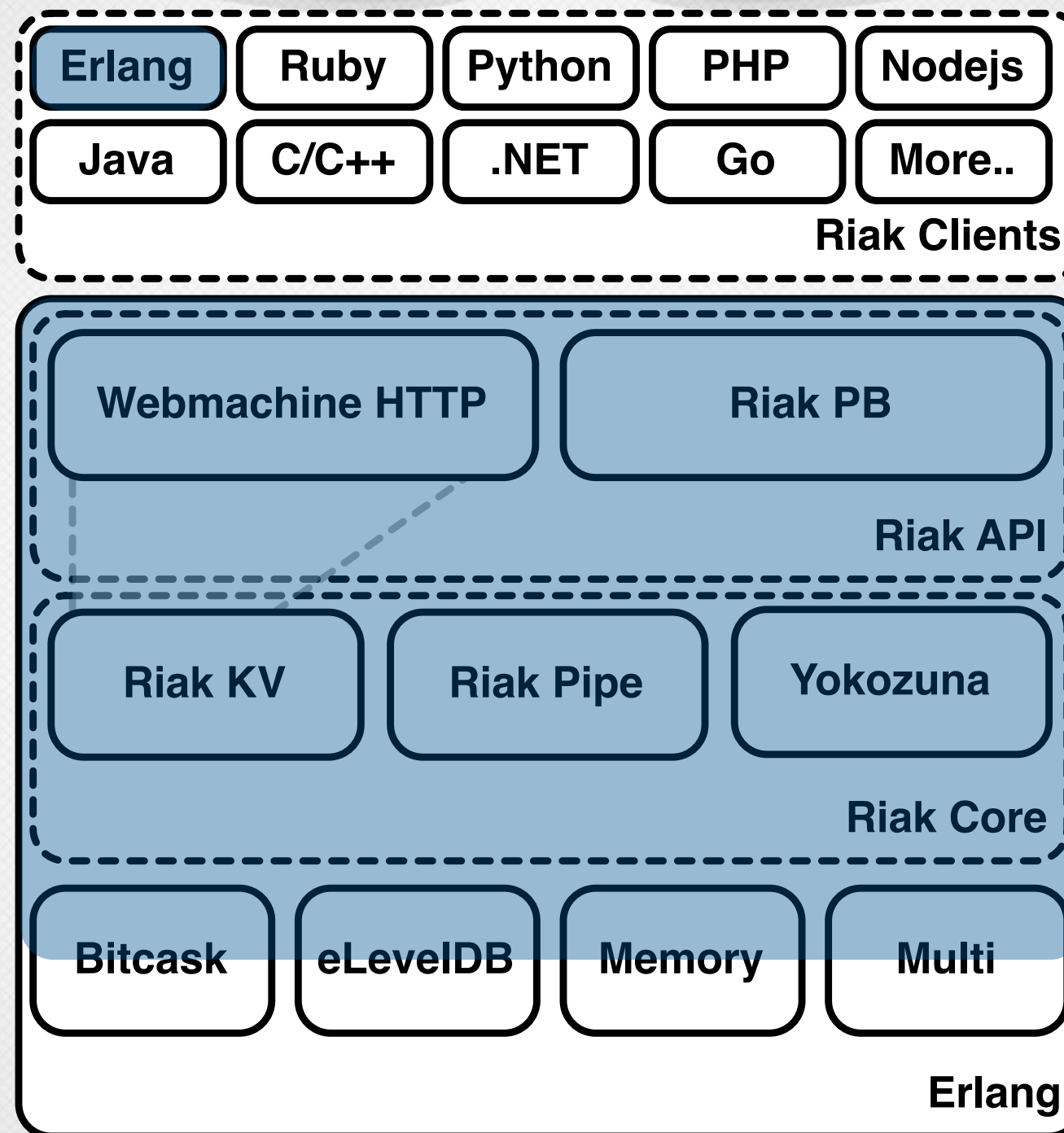
Riak Cluster

node 0

node 3

node 1

node 2

Distributing Data

- Riak uses **consistent hashing** to spread data across the cluster

- Minimizes remapping of keys when number of nodes changes

- Spreads data evenly and minimizes hotspots

node 0

node 1

node 2

node 3

Consistent Hashing

- Riak uses SHA–1 as a hash function

- Treats its 160–bit value space as a ring

- Divides the ring into partitions called "virtual nodes" or vnodes (default 64)

- Each vnode claims a portion of the ring space

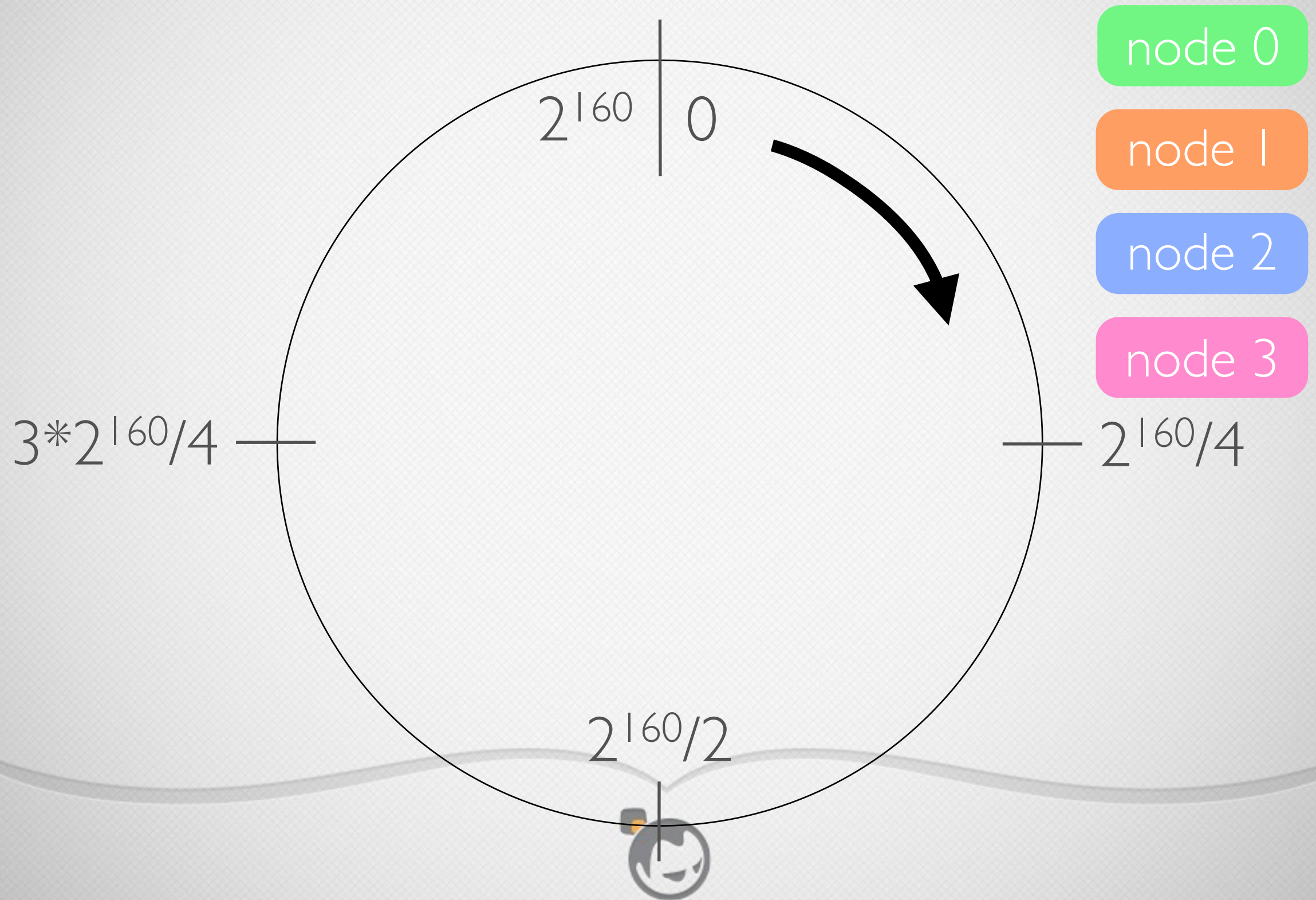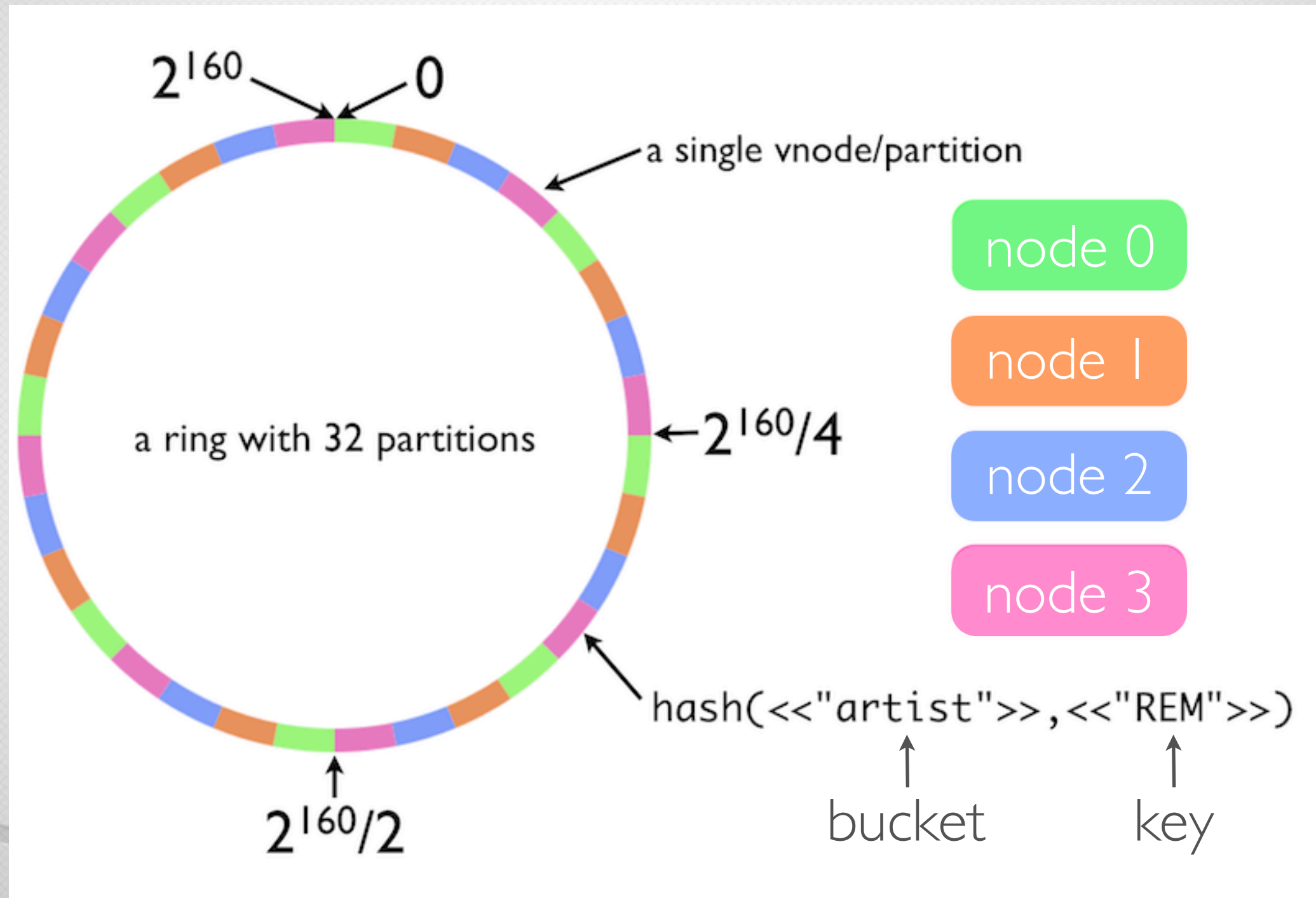- Each physical node in the cluster hosts multiple vnodes

node 0

node 1

node 2

node 3

Hash Ring

2^{160} 0

$3 * 2^{160}/4$

$2^{160}/4$

$2^{160}/2$

node 0

node 1

node 2

node 3

Hash Ring

2^{160} ← → 0

a single vnode/partition

node 0

node 1

node 2

node 3

a ring with 32 partitions

← $2^{160}/4$

$2^{160}/2$
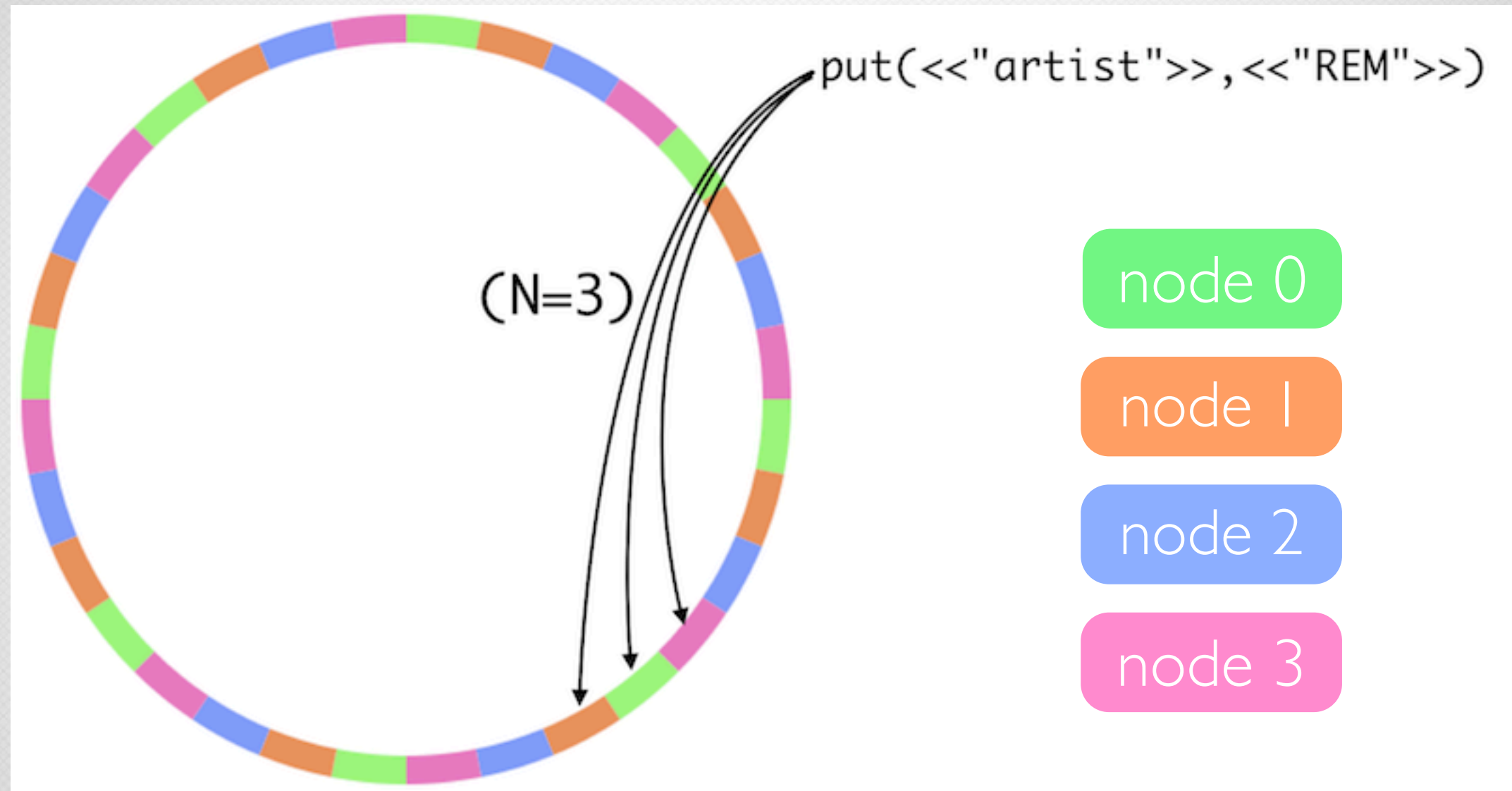
hash(<<"artist">>,<<"REM">>)

bucket   key

N/R/W Values

- N = number of replicas to store (default 3, can be set per bucket)

- R = read quorum = number of replica responses needed for a successful read (can be specified per-request)

- W = write quorum = number of replica responses needed for a successful write (can be specified per-request)
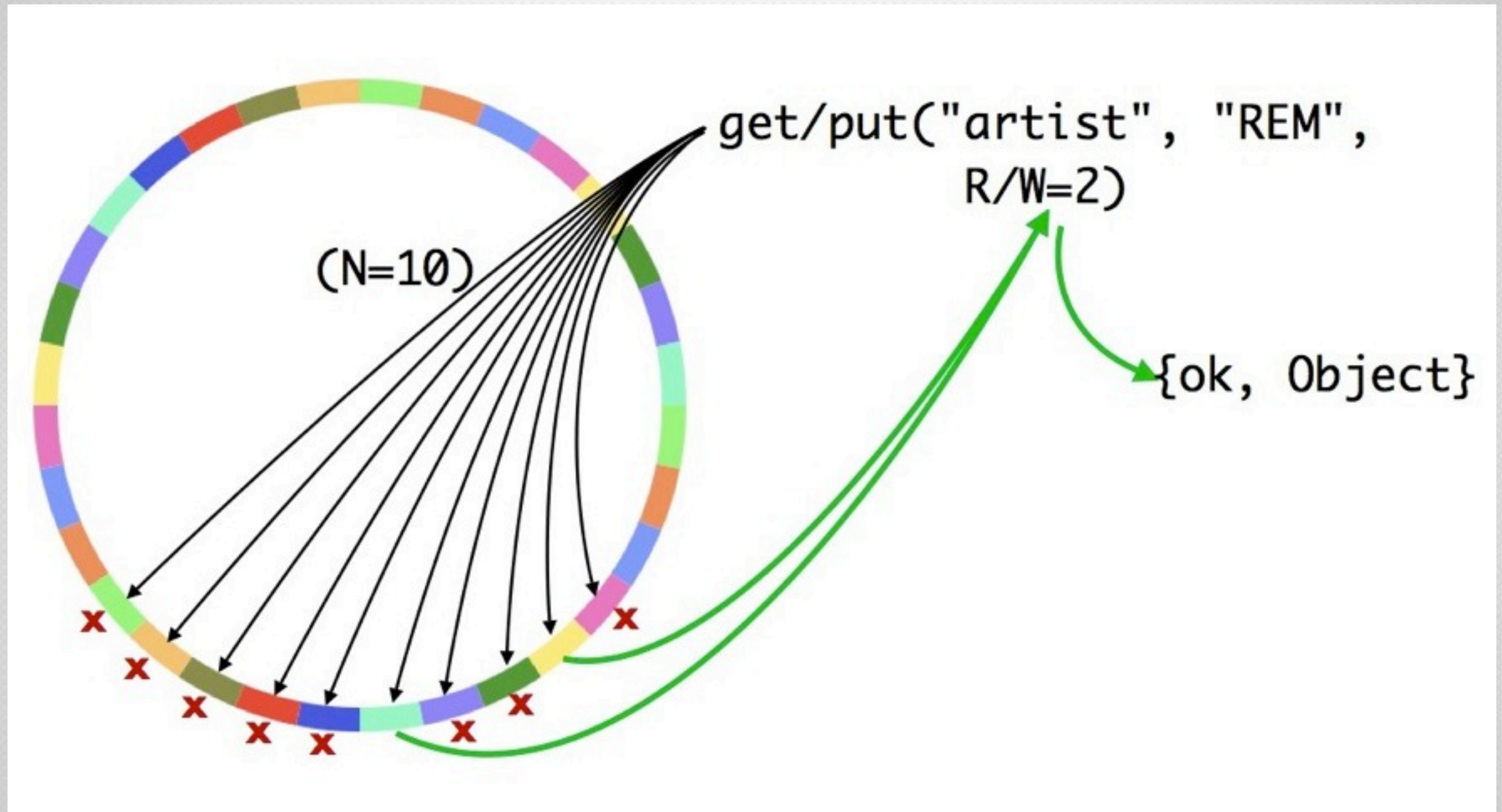
N/R/W Values

put(<<"artist">>,<<"REM">>)

(N=3)

node 0
node 1
node 2
node 3

for details see http://docs.basho.com/riak/1.3.1/tutorials/fast-track/Tunable-CAP-Controls-in-Riak/

N/R/W Values

get/put("artist", "REM", R/W=2)

(N=10)

{ok, Object}

Implementing Consistent Hashing

- Erlang's crypto module integration with OpenSSL provides the SHA-1 function

- Hash values are 160 bits

- But that's OK, Erlang's integers are infinite precision

- And Erlang binaries store these large values efficiently

Implementing Consistent Hashing

```erlang
1> HashBin = crypto:sha("my object key").
```

Implementing Consistent Hashing

```
1> HashBin = crypto:sha("my object key").
<<189,73,125,145,132,154,3,75,50,12,195,156,7,170,128,52,
157,242,158,159>>
```

Implementing Consistent Hashing

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1> HashBin = crypto:sha("my object key").
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157,242,158,159>>
2> byte_size(HashBin).
20
```

Implementing Consistent Hashing

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2> byte_size(HashBin).
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3> <<HashInt:160/integer>> = HashBin.
<<189,73,125,145,132,154,3,75,50,12,195,156,7,170,128,52,
157,242,158,159>>
```

Implementing Consistent Hashing

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4> HashInt.
1080638148638140855100958270058021626367330918047
```

Implementing Consistent Hashing

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```

Riak's Ring

```
5> rp(riak_core_ring_manager:get_my_ring()).
```

Riak's Ring

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5> rp(riak_core_ring_manager:get_my_ring()).
{ok,{chstate_v2,'dev1@127.0.0.1',
```

Riak's Ring

```
5> rp(riak_core_ring_manager:get_my_ring()).
{ok,{chstate_v2,'dev1@127.0.0.1',
                [{'dev1@127.0.0.1',{211,63521635595}},
                 {'dev2@127.0.0.1',{3,63521635521}},
                 {'dev3@127.0.0.1',{3,63521635544}}],
```

Riak's Ring

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5> rp(riak_core_ring_manager:get_my_ring()).
{ok,{chstate_v2,'dev1@127.0.0.1',
                [{'dev1@127.0.0.1',{211,63521635595}},
                 {'dev2@127.0.0.1',{3,63521635521}},
                 {'dev3@127.0.0.1',{3,63521635544}}],
            {64,
             [{0,'dev1@127.0.0.1'},
              {22835963083295358096932575511191922182
123945984,

               'dev2@127.0.0.1'},
              {45671926166590716193865151022383844364
247891968,

              ...
```

Riak's Ring

```
5> rp(riak_core_ring_manager:get_my_ring()).
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123945984,
                   'dev2@127.0.0.1'},
                  {45671926166590716193865151022383844364
247891968,
                  ...
```

Ring State

- All nodes in a Riak cluster are peers, no masters or slaves

- Nodes exchange their understanding of ring state via a gossip protocol

Distributed Erlang

- Erlang has distribution built in — it's required for supporting multiple nodes for reliability

- By default Erlang nodes form a mesh, every node knows about every other node

- Riak uses this for intra-cluster communication

Distributed Erlang

- Riak lets you simulate a multi-node installment on a single machine, nice for development

- "make devrel" or "make stagedevrel" in a riak repository clone (git://github.com/basho/riak.git)

- Let's assume we have nodes dev1, dev2, and dev3 running in a cluster, nothing on the 4th node yet

- Instead of starting riak, let's start the 4th node as just a plain distributed erlang node

node 0

node 1

node 2

node 3

Distributed Erlang

```
$ erl -name dev4@127.0.0.1 -setcookie riak
Erlang R15B01 (erts-5.9.1) [source] [64-bit] [smp:8:8]
 [async-threads:0] [kernel-poll:false]

Eshell V5.9.1  (abort with ^G)
(dev4@127.0.0.1)1>
```

Distributed Erlang

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$ erl -name dev4@127.0.0.1 -setcookie riak
Erlang R15B01 (erts-5.9.1) [source] [64-bit] [smp:8:8]
 [async-threads:0] [kernel-poll:false]

Eshell V5.9.1  (abort with ^G)
(dev4@127.0.0.1)1> nodes().
[]
```

Distributed Erlang

```
$ erl -name dev4@127.0.0.1 -setcookie riak
Erlang R15B01 (erts-5.9.1) [source] [64-bit] [smp:8:8]
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Eshell V5.9.1  (abort with ^G)
(dev4@127.0.0.1)1> nodes().
[]
(dev4@127.0.0.1)2> net_adm:ping('dev1@127.0.0.1').
pong
```

Distributed Erlang

```
$ erl -name dev4@127.0.0.1 -setcookie riak
Erlang R15B01 (erts-5.9.1) [source] [64-bit] [smp:8:8]
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[]
(dev4@127.0.0.1)2> net_adm:ping('dev1@127.0.0.1').
pong
(dev4@127.0.0.1)3> nodes().
['dev1@127.0.0.1','dev3@127.0.0.1','dev2@127.0.0.1']
```

Distributed Erlang

```
$ erl -name dev4@127.0.0.1 -setcookie riak
Erlang R15B01 (erts-5.9.1) [source] [64-bit] [smp:8:8]
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pong
(dev4@127.0.0.1)3> nodes().
['dev1@127.0.0.1','dev3@127.0.0.1','dev2@127.0.0.1']
```

Distributed Erlang Mesh

- Nodes talk to each other occasionally to check liveness

- Mesh approach makes it easy to set up a cluster

- But communication overhead means it doesn't scale to large clusters > 150 nodes (yet)

node 0

node 3

node 1

node 2
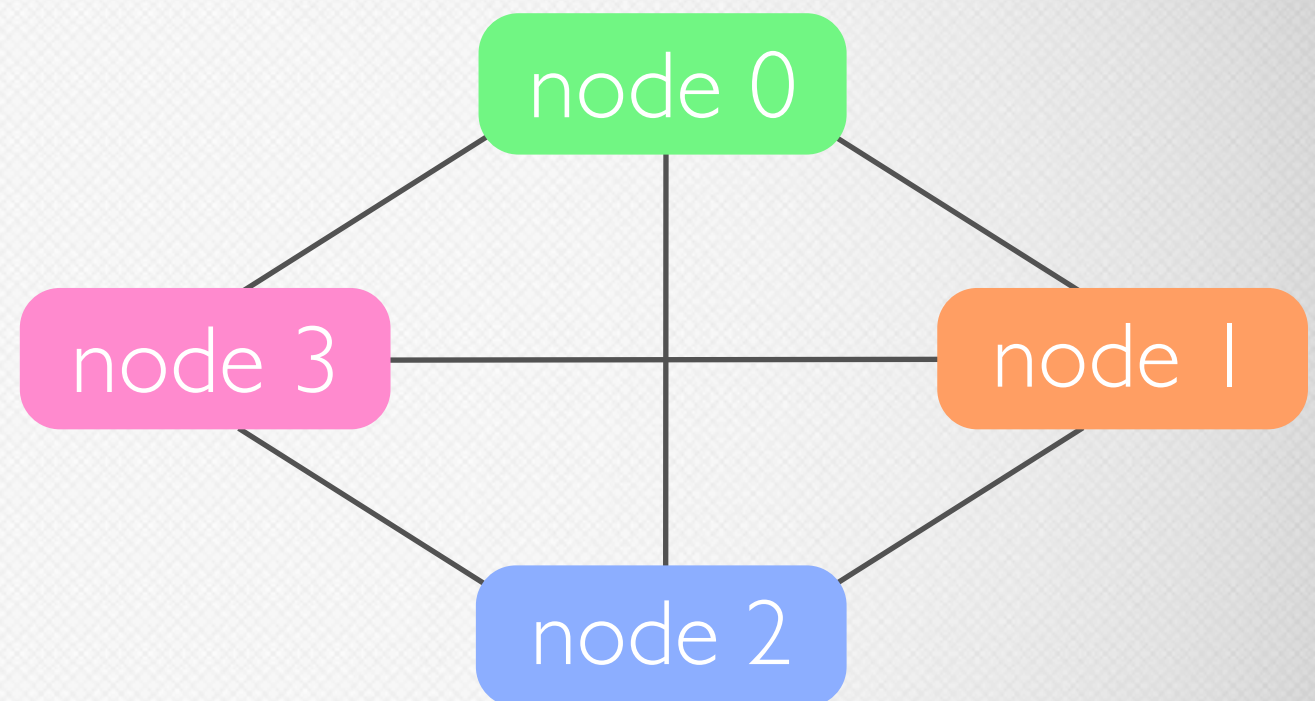
Gossip

- Riak nodes are peers, there's no master

- But the ring has state, such as what vnodes each node has claimed

- Nodes periodically send their understanding of the ring state to other randomly chosen nodes

- Riak gossip module also provides an API for sending ring state to specific nodes

Control Vs. Data

- Distributed Erlang: good for control plane, not so good for data plane

- Sending large data can cause busy distribution ports and head-of-line blocking

- Use TCP, UDP, etc. directly for data plane traffic

- Don't mix control plane and data plane traffic

  - unfortunately Riak currently still does this in a few places
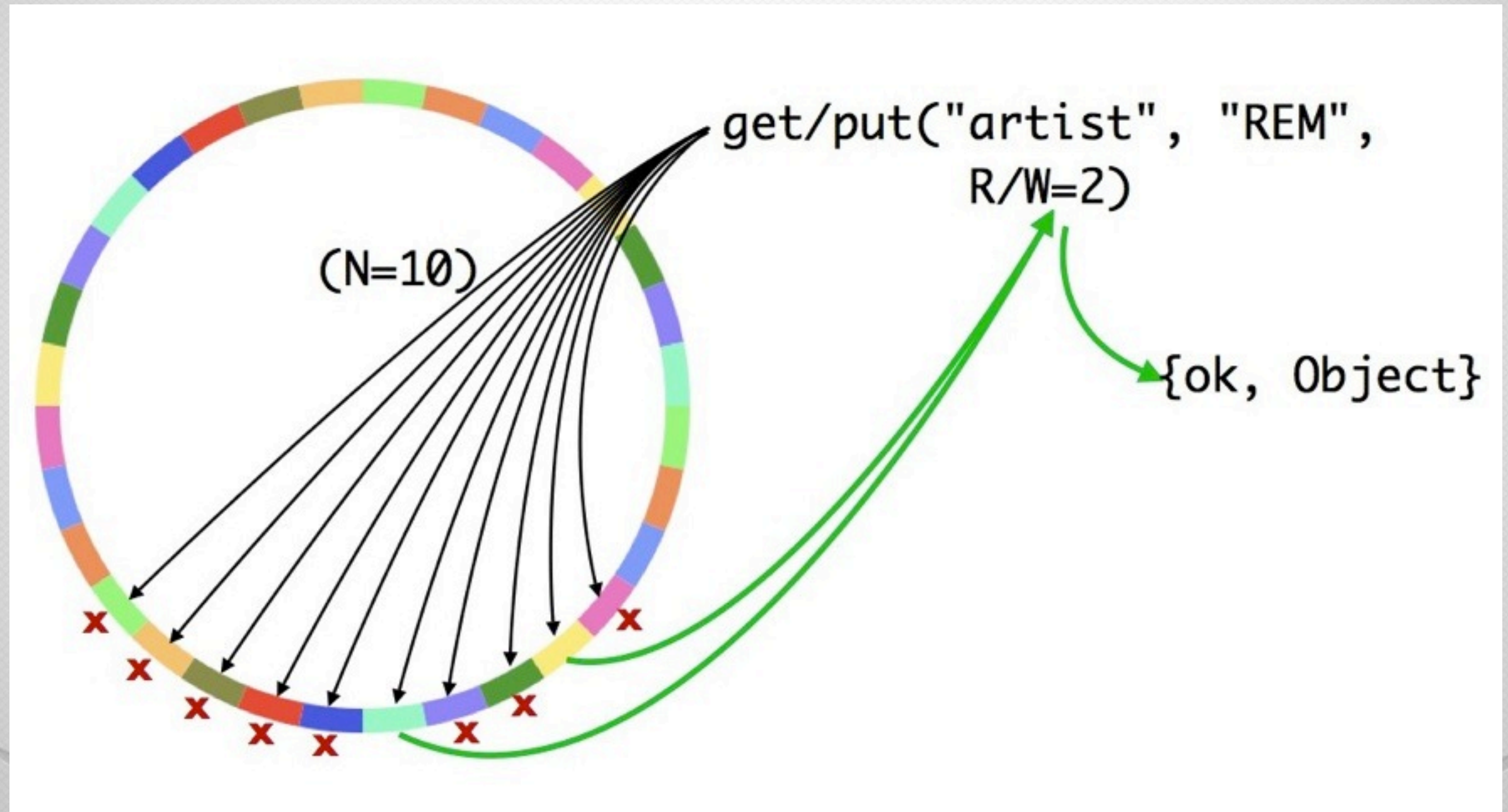
Riak Core

Riak Clients

Riak API

- consistent hashing
- vector clocks
- sloppy quorums

Riak Core
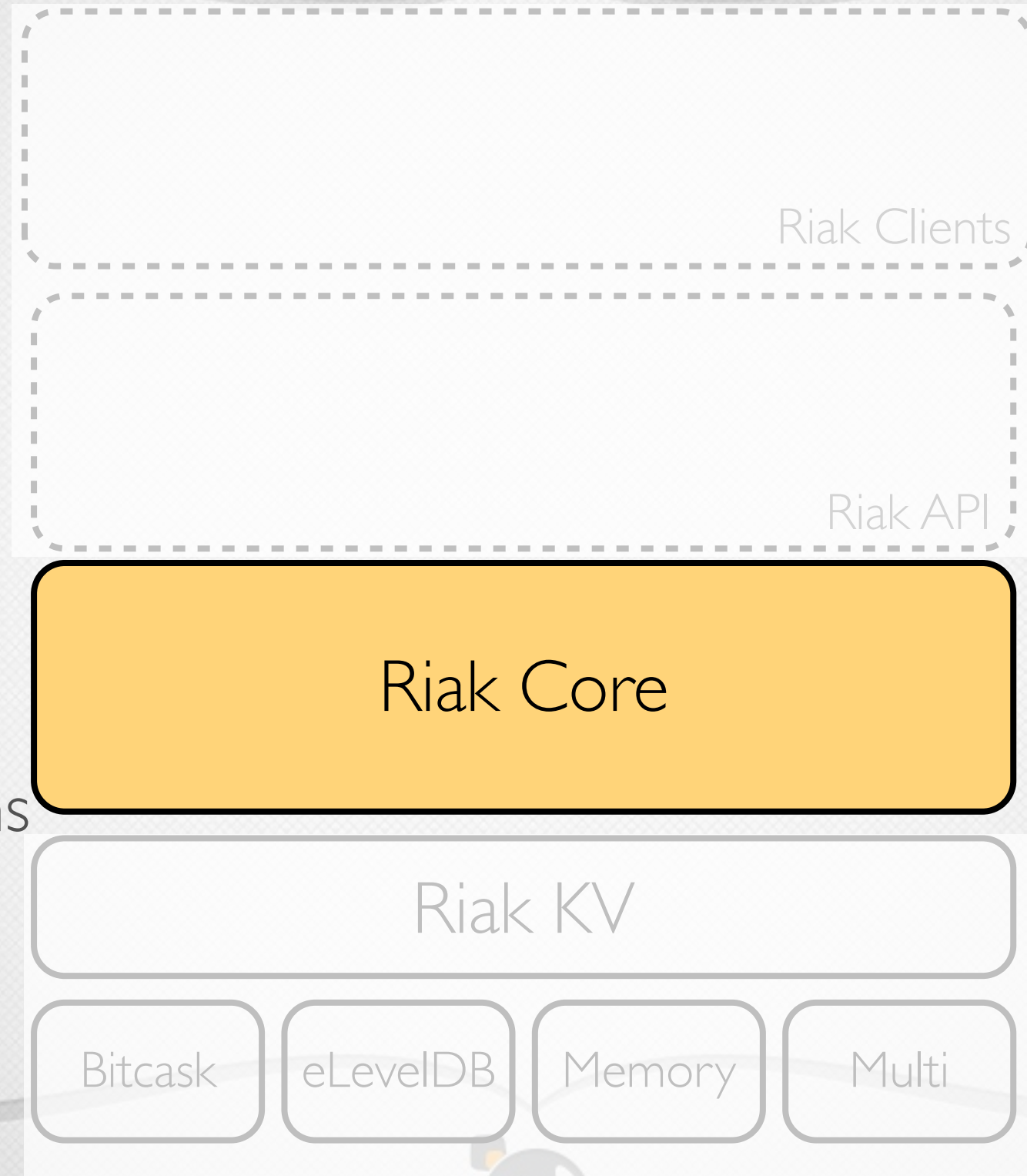
- gossip protocols
- virtual nodes (vnodes)
- hinted handoff

Riak KV

Bitcask   eLevelDB   Memory   Multi

N/R/W Values

Hinted Handoff

- Fallback vnode holds data for unavailable primary vnode

- Fallback vnode keeps checking for availability of primary vnode

- Once primary vnode becomes available, fallback hands off data to it

- Fallback vnodes are started as needed, thanks to Erlang lightweight processes

Read Repair

- If a read detects a vnode with stale data, it is repaired via asynchronous update

- Helps implement eventual consistency

- Riak supports active anti-entropy (AAE) to actively repair stale values

Core Protocols

- Gossip, handoff, read repair, etc. all require intra-cluster protocols

- Erlang distribution and other features help significantly with protocol implementations

- Erlang monitors allow processes and nodes to watch each other while interacting

  - A monitoring process/node is notified if a monitored process/node dies, great for aborting failed interactions

Binary Handling

- Erlang's binaries make working with network packets easy

- For example, deconstructing a TCP message (from Cesarini & Thompson "Erlang Programming")

TCP Header

Offsets Octet		0								1								2								3							
Octet	Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	Source port															Destination port															
4	32	Sequence number																														
8	64	Acknowledgment number (if ACK set)																														
12	96	Data offset				Reserved 0 0 0			N S	C W R	E C E	U R G	A C K	P S H	R S T	S Y N	F I N	Window Size															
16	128	Checksum															Urgent pointer (if URG set)															

source: http://en.wikipedia.org/wiki/Transmission_Control_Protocol

Binary Handling

`TcpBuf.`

Binary Handling

TCP header fields

```
<<SourcePort:16, DestinationPort:16,
SequenceNumber:32, AckNumber:32,
DataOffset:4, _Rsrvd:4, Flags:8,
WindowSize:16, Checksum:16, UrgentPtr:16,
                = TcpBuf.
```

Binary Handling

```
<<SourcePort:16, DestinationPort:16,
  SequenceNumber:32, AckNumber:32,
  DataOffset:4, _Rsrvd:4, Flags:8,
  WindowSize:16, Checksum:16, UrgentPtr:16,
  Data/binary>> = TcpBuf.
```

TCP data payload

Binary Handling

```
<<SourcePort:16, DestinationPort:16,
  SequenceNumber:32, AckNumber:32,
  DataOffset:4, _Rsrvd:4, Flags:8,
  WindowSize:16, Checksum:16, UrgentPtr:16,
  Data/binary>> = TcpBuf.
```

Protocols With OTP

- OTP provides libraries of standard modules

- And also **behaviors**: implementations of common patterns for concurrent, distributed, fault-tolerant Erlang apps

OTP Behavior Modules

- A behavior is similar to an abstract base class in OO terms, providing:

  - a message handling tail-call optimized loop

  - integration with underlying OTP system for code upgrade, tracing, process management, etc.

OTP Behaviors

- application: plugs into Erlang application controller

- supervisor: manages and monitors worker processes

- gen_server: server process framework

- gen_fsm: finite state machine framework

- gen_event: event handling framework

Gen_server

- Generic server behavior for handling messages

- Supports server-like components, distributed or not

- "Business logic" lives in app-specific callback module

- Maintains state in a tail-call optimized receive loop

Gen_fsm

- Behavior supporting finite state machines (FSMs)

- Tail-call loop for maintaining state, like gen_server

- States and events handled by app-specific callback module

- Allows events to be sent into an FSM either sync or async

Riak And Gen_*

- Riak makes heavy use of these behaviors, e.g.:

  - FSMs for get and put operations

 - Vnode FSM

  - Gossip module is a gen_server

Behavior Benefits

- Standardized frameworks providing common patterns, common vocabulary

- Used by pretty much all non-trivial Erlang systems

- Erlang developers understand them, know how to read them

Behavior Benefits

- Separate a lot of messaging, debugging, tracing support, system concerns from business logic

incoming
messages

callback

OTP
gen_*
module

App
callback
module

outgoing
messages

replies

system
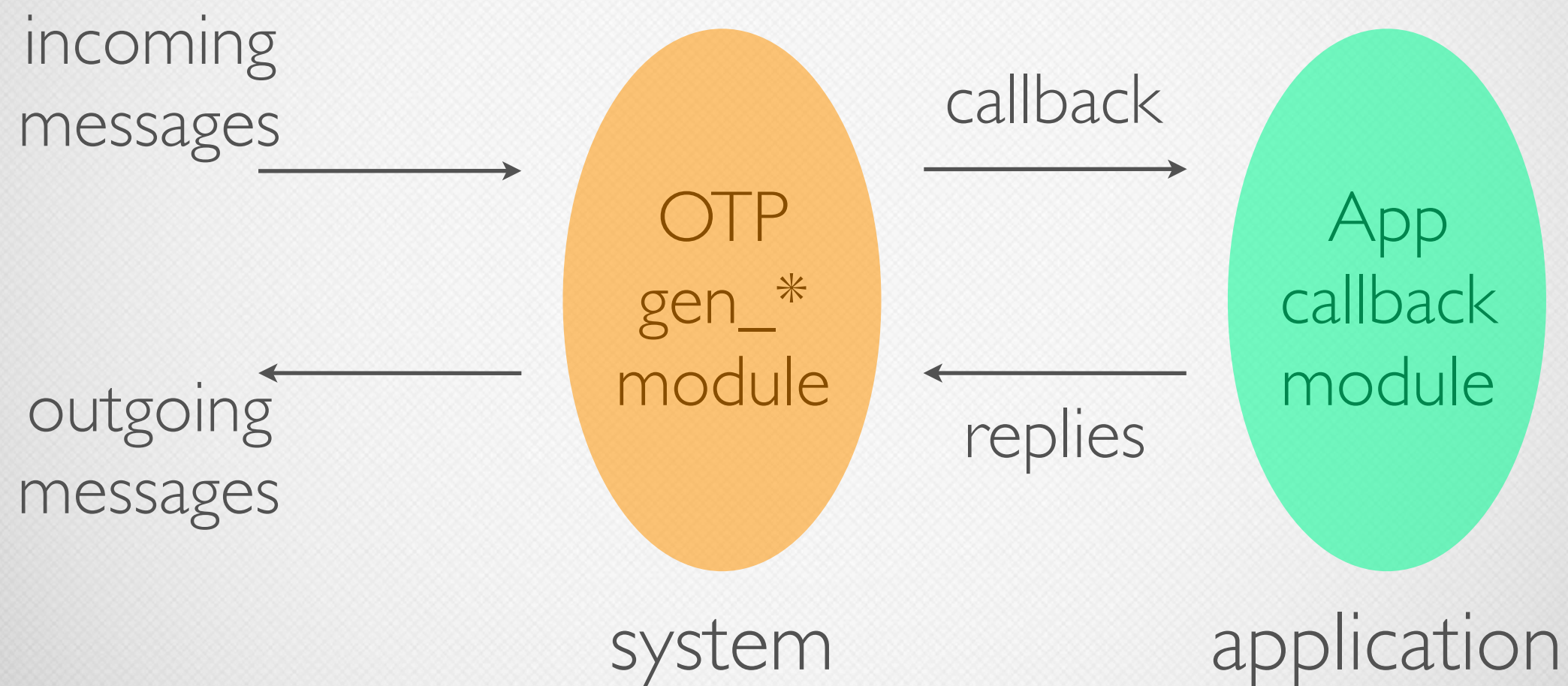
application

Application Behavior

- Provides an entry point for an OTP-compliant app

- Allows multiple Erlang components to be combined into a system

- Erlang apps can declare their dependencies on other apps

- Erlang runtime starts apps in reverse dependency order

- A running Riak system comprises about 30 different applications

App Startup Sequence

- Hierarchical sequence

- Erlang system application controller starts the app

- App starts supervisor(s)

- Each supervisor starts workers

- Workers are typically instances of OTP behaviors

Workers & Supervisors

- Workers implement application logic

- Supervisors:

  - start child workers and sub-supervisors

  - link to the children and trap child process exits

  - take action when a child dies, typically restarting one or more children

Let It Crash

- In his doctoral thesis, Joe Armstrong, creator of Erlang, wrote:

  - *Let some other process do the error recovery.*

  - *If you can't do what you want to do, die.*

  - *Let it crash.*

  - *Do not program defensively.*

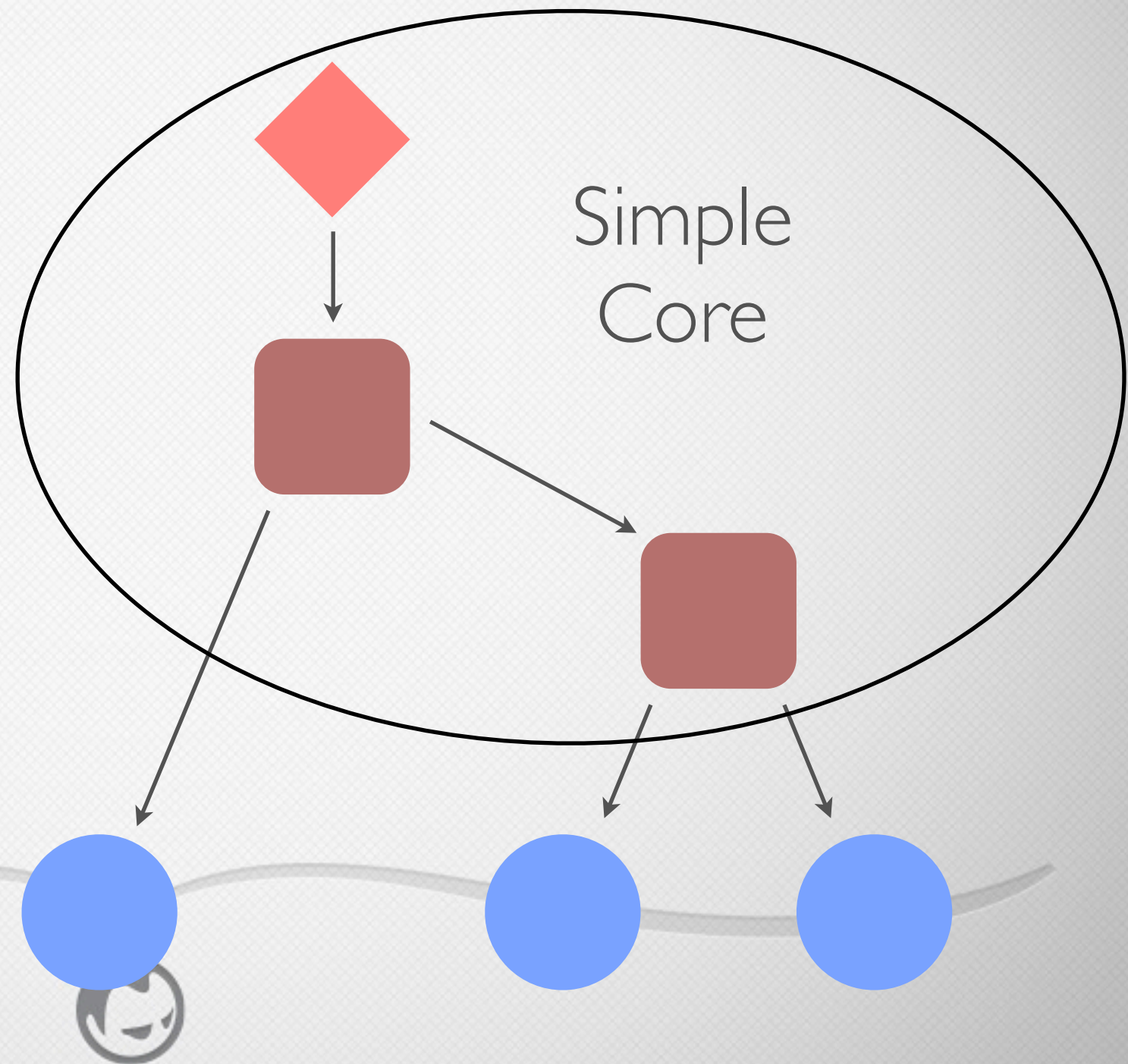   see http://www.erlang.org/download/armstrong_thesis_2003.pdf

Application, Supervisors, Workers

Application

Supervisors

Workers

Simple Core

Erlang/OTP System Facilities

- Get status of an OTP process

- Get process info for any process

- Trace function calls, messages

- Releases
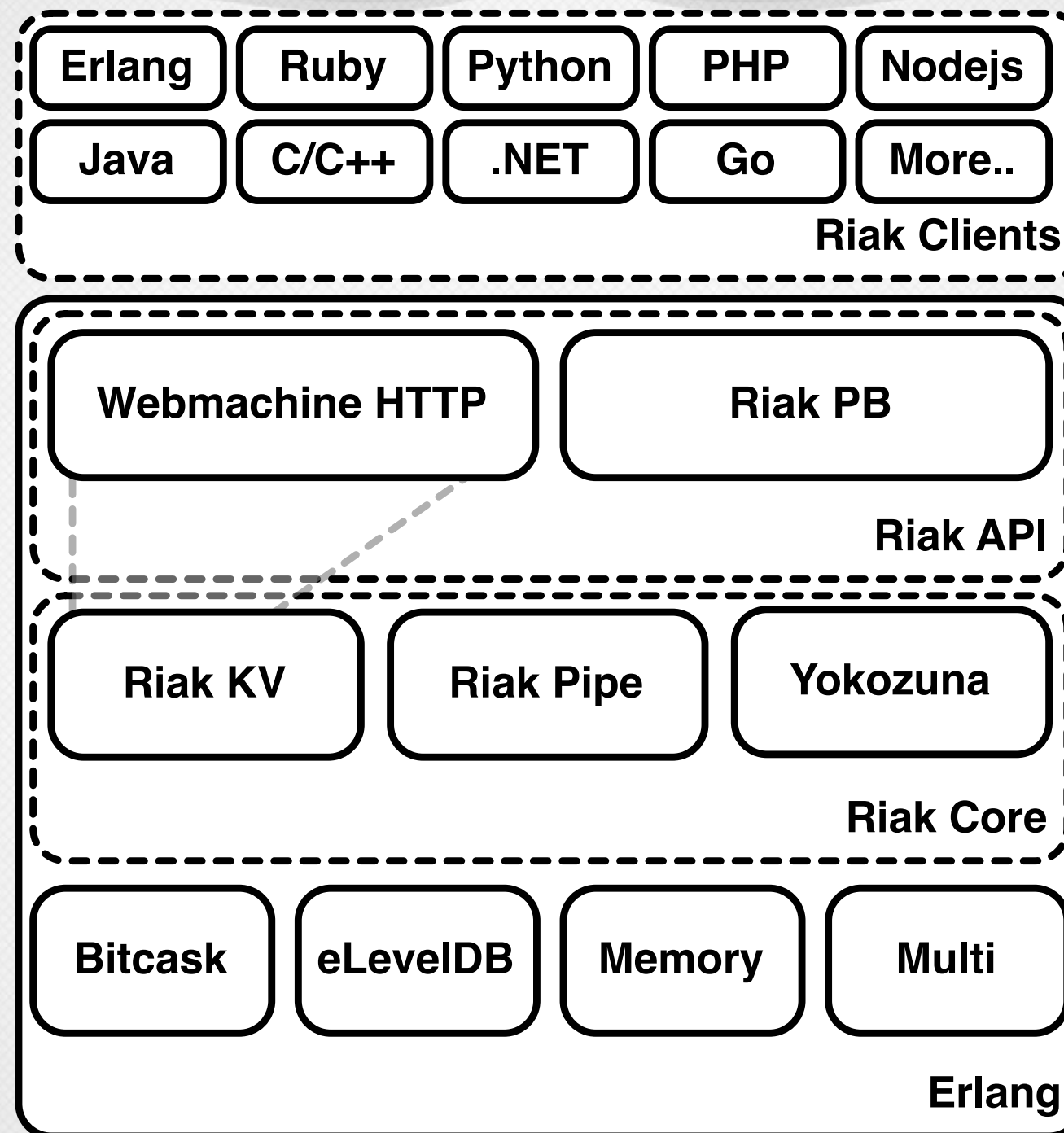
- Live upgrades
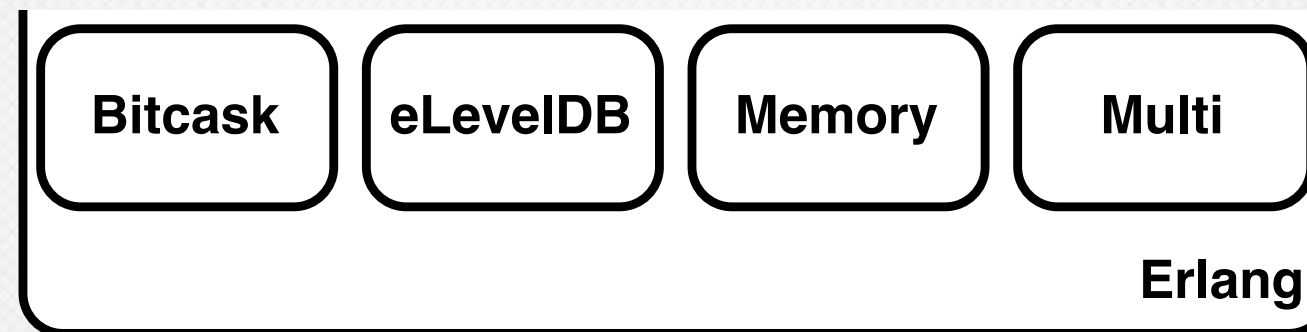
INTEGRATION

Riak Architecture

Erlang | Ruby | Python | PHP | Nodejs

Java | C/C++ | .NET | Go | More..

Riak Clients

Webmachine HTTP | Riak PB

Riak API

Riak KV | Riak Pipe | Yokozuna

Riak Core

Bitcask | eLevelDB | Memory | Multi

Erlang

image courtesy of Eric Redmond, "A Little Riak Book" https://github.com/coderoshi/little_riak_book/

Riak Architecture

Erlang on top

Bitcask	eLevelDB	Memory	Multi

Erlang

C/C++ on the bottom

image courtesy of Eric Redmond, "A Little Riak Book" https://github.com/coderoshi/little_riak_book/

Linking With C/C++

- Erlang provides the ability to dynamically link C/C++ libraries into the VM

- One way is through the driver interface

  - for example the VM supplies network and file system facilities via drivers

- Another way is through Native Implemented Functions (NIFs)

Native Implemented Functions (NIFs)

- Lets C/C++ functions operate as Erlang functions

- Erlang module serves as entry point

- When module loads it dynamically loads its NIF shared library, overlaying its Erlang functions with C/C++ replacements

Example: Eleveldb

- NIF wrapper around Google's LevelDB C++ database

- Erlang interface plugs in underneath Riak KV

Example: Eleveldb

```erlang
%% Erlang
open(Name, Opts) ->
    erlang:nif_error({error, not_loaded}).
```

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%% Erlang
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```

```cpp
// C++
ERL_NIF_TERM
eleveldb_open(ErlNifEnv* env, int argc,
              const ERL_NIF_TERM argv[])
{
```

Example: Eleveldb

```cpp
// C++
ERL_NIF_TERM
eleveldb_open(ErlNifEnv* env, int argc,
              const ERL_NIF_TERM argv[])
{
    char name[4096];
    if (enif_get_string(env,argv[0],name,
                        sizeof name,ERL_NIF_LATIN1) &&
        enif_is_list(env, argv[1]))
    {
        ...
```

NIF Features

- Easy to convert arguments and return values between C/C++ and Erlang

- Ref count binaries to avoid data copying where needed

- Portable interface to OS multithreading capabilities (threads, mutexes, cond vars, etc.)

NIF Caveats

- Crashes in your linked-in C/C++ kill the whole VM

- Lesson: use NIFs and drivers only when needed, and don't write crappy code

NIF Caveats

- NIF calls execute within a VM scheduler thread

- If the NIF blocks, the scheduler thread blocks

- THIS IS VERY BAD

- NIFs should block for no more than 1 millisecond

NIF Caveats

- In 2012 Basho found "scheduler anomalies" where

  - the VM would put most of its schedulers to sleep, by design, under low load

  - but would fail to wake them up as load increased

- Caused by NIF and BIF calls that were taking multiple seconds in some cases

- Lesson: put long-running activities in their own threads or break up long calls into multiple calls

- Or wait for "dirty" schedulers, targeted for Erlang R17

TESTING

Eunit

- Erlang's unit testing facility

- Support for asserting test results, grouping tests, setup and teardown, etc.

- Used heavily in Riak

QuickCheck

- Property-based testing product from Quviq, invented by John Hughes (a co-inventor of Haskell)

- Create a model of the software under test

- QuickCheck runs randomly-generated tests against it

- When it finds a failure, QuickCheck automatically shrinks the testcase to a minimum for easier debugging

- Used heavily in Riak, especially to test various protocols and interactions

BUILD AND RELEASE

Application Directories

- Erlang applications tend to use a standard directory layout

- Certain tools expect to find this layout

```
$ ls
Makefile        c_src           priv            rebar.config
test            ebin            rebar           src
```

Rebar

- A tool created by Dave "Dizzy" Smith (formerly of Basho) to manage Erlang apps

- Manages dependencies, builds, runs tests, generates releases

- Now the de facto standard Erlang build and release tool

MISCELLANEOUS

Miscellaneous

- Memory

- Erlang shell

- Hot code loading

- VM knowledge

- Finding Erlang developers

Memory

- Process message queues have no limits, can cause out-of-memory conditions if a process can't keep up

- By design, VM dies if it runs out of memory

- Apps like Riak run Erlang memory monitors that help log and notify about looming out-of-memory conditions

Interactive Erlang Shell

- Hard to imagine working without it

- Huge help during development and debug

Hot Code Loading

- It really works

- Use it all the time during development

- We've also used it to load repaired code into live production systems for customers (with their permission of course)

VM Knowledge

- Running high-scale high-load systems like Riak requires knowledge of Erlang VM internals

- No different than working with the JVM or other language runtimes

Finding Erlang Devs

- Erlang is easy to learn

- Not really a problem to hire Erlang programmers

- Basho hires great developers, those who need to learn Erlang just do it

- BTW we're hiring, see
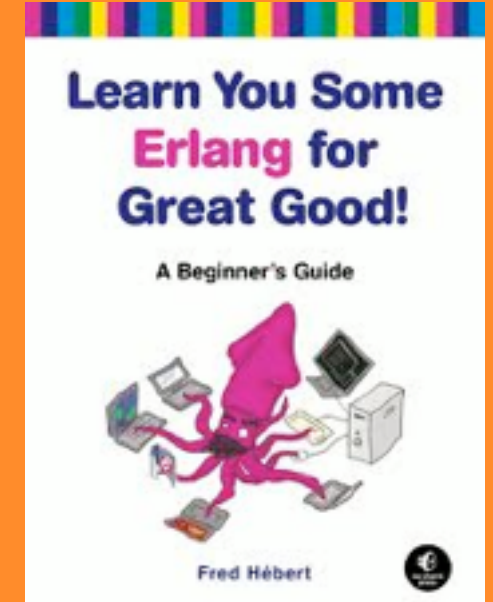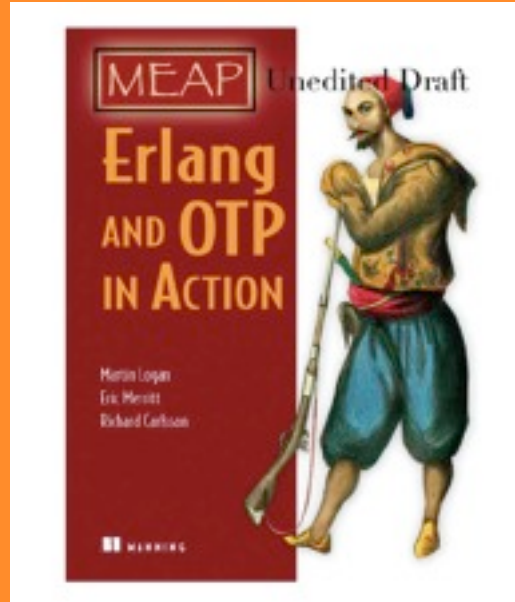 http://bashojobs.theresumator.com

SUMMARY

Summary: Why Erlang For Riak?

- Distributed systems features

  - sort of a "distributed systems DSL"

- Concurrency features

- Reliability features

- Runtime introspection capabilities

- Individual developer and team productivity

For More Erlang Info

For More Riak Info

- "A Little Riak Book" by Basho's Eric Redmond
  http://littleriakbook.com

- Mathias Meyer's "Riak Handbook"
  http://riakhandbook.com

- Eric Redmond's "Seven Databases in Seven Weeks"
  http://pragprog.com/book/rwdata/seven-databases-in-seven-weeks

For More Riak Info

- Basho documentation
  http://docs.basho.com

- Basho blog
  http://basho.com/blog/

- Basho's github repositories
  https://github.com/basho
  https://github.com/basho-labs

THANKS

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