IMPLEMENTING RIAK IN ERLANG: BENEFITS AND CHALLENGES

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ERLANG

Ericsson Telecom Switch Requirements

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- Large number of concurrent activities

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Today's Data/Web/Cloud/ Service Apps

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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

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- 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

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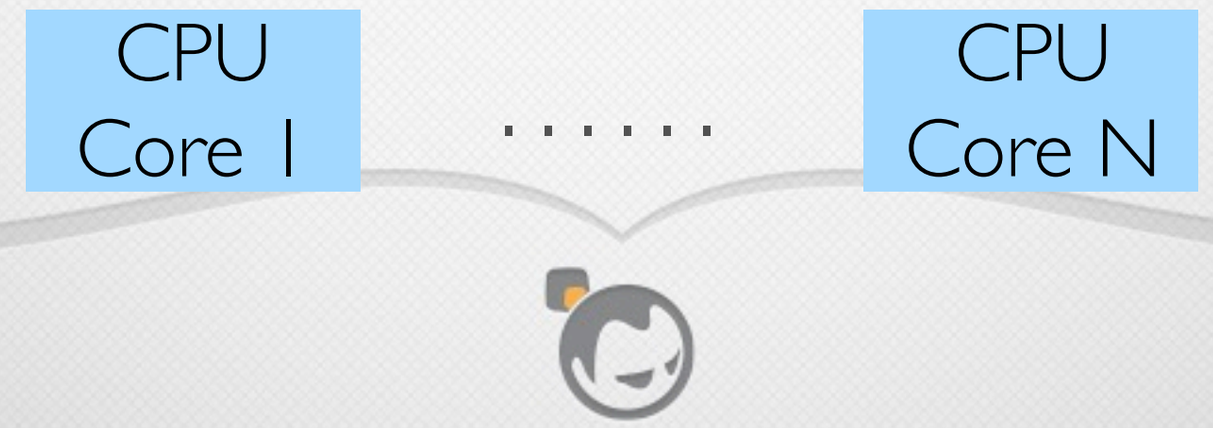

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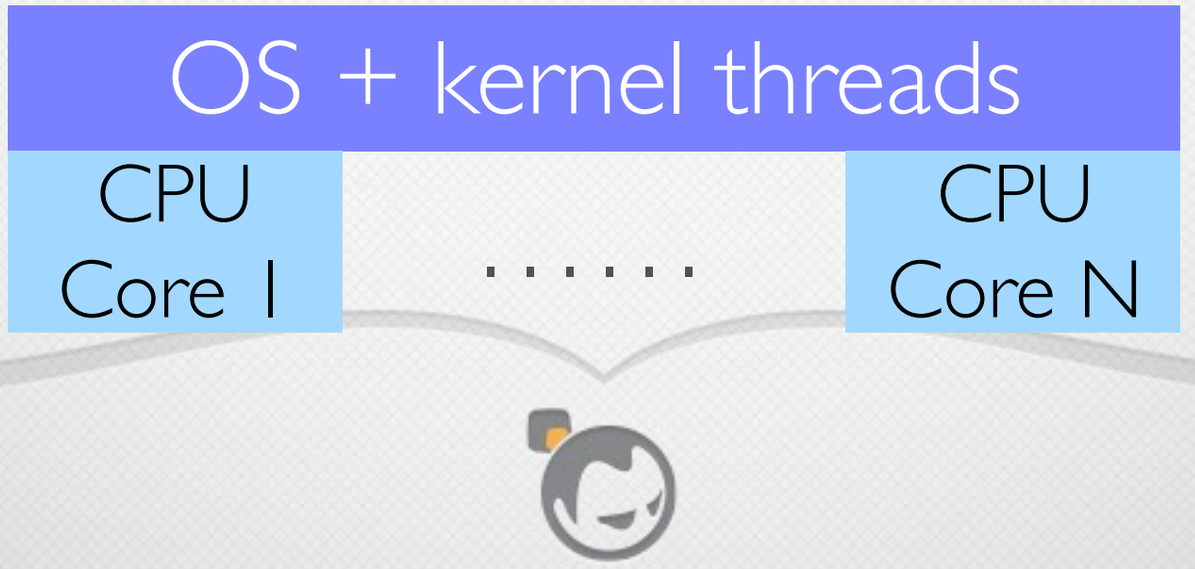

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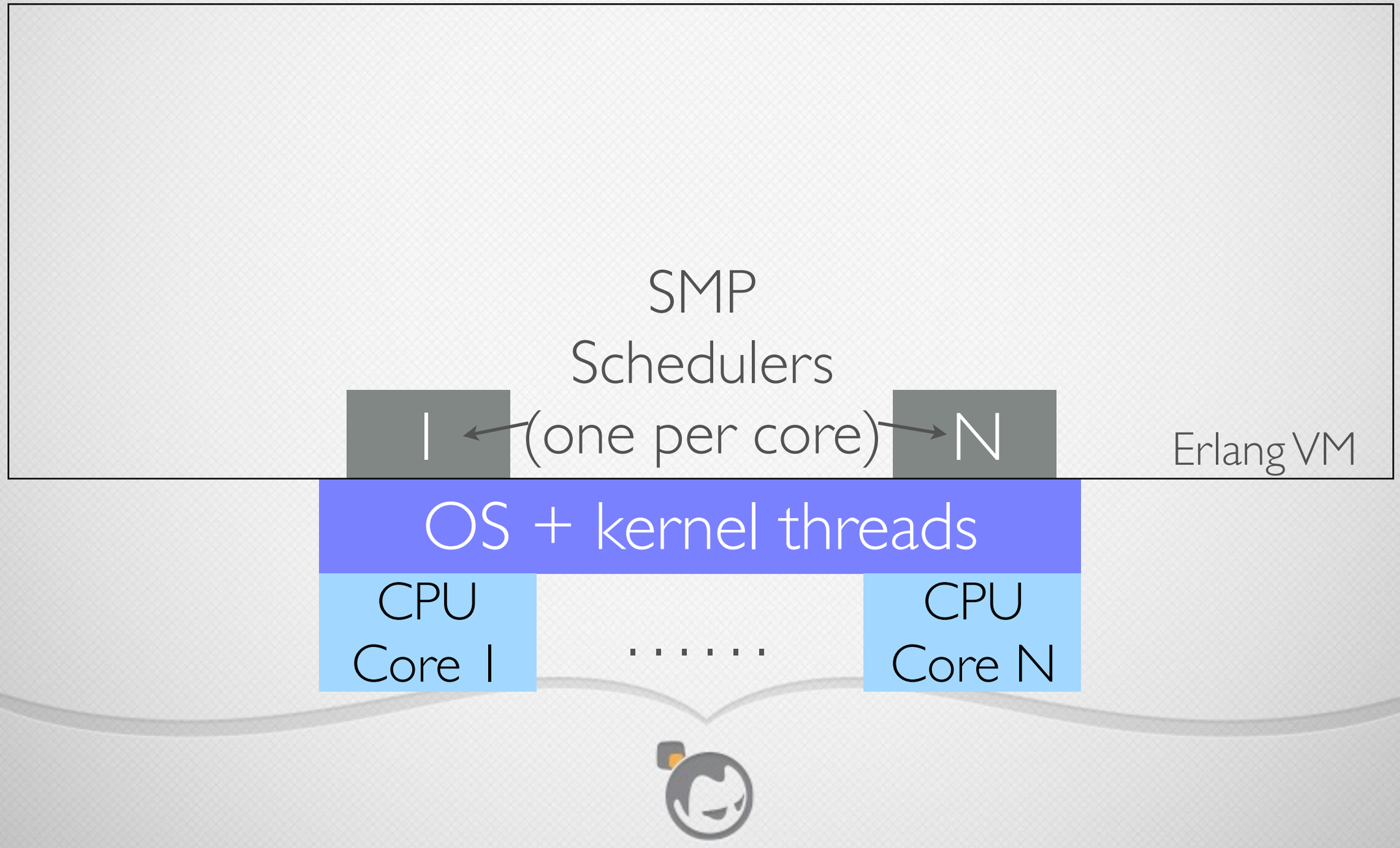

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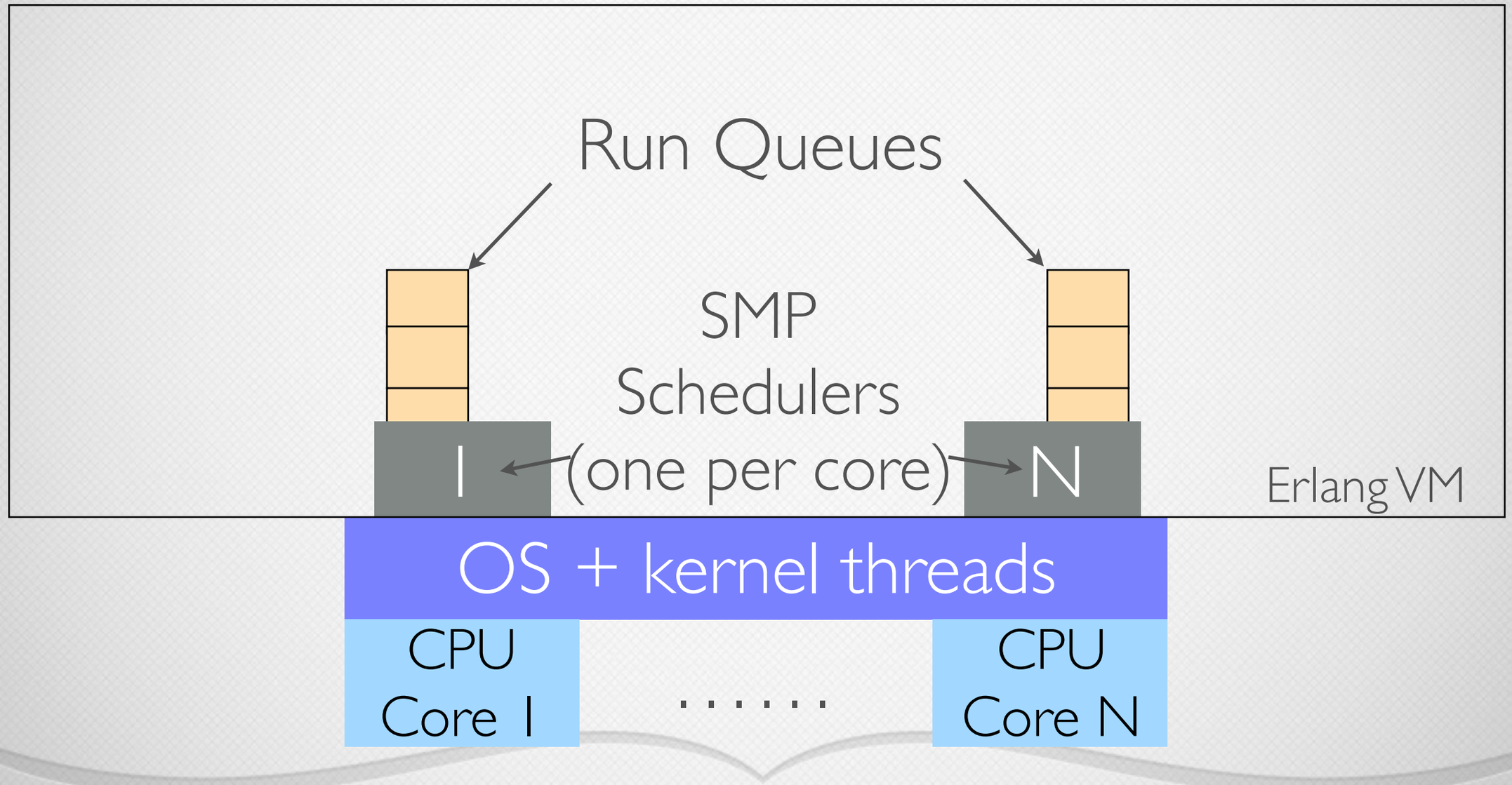

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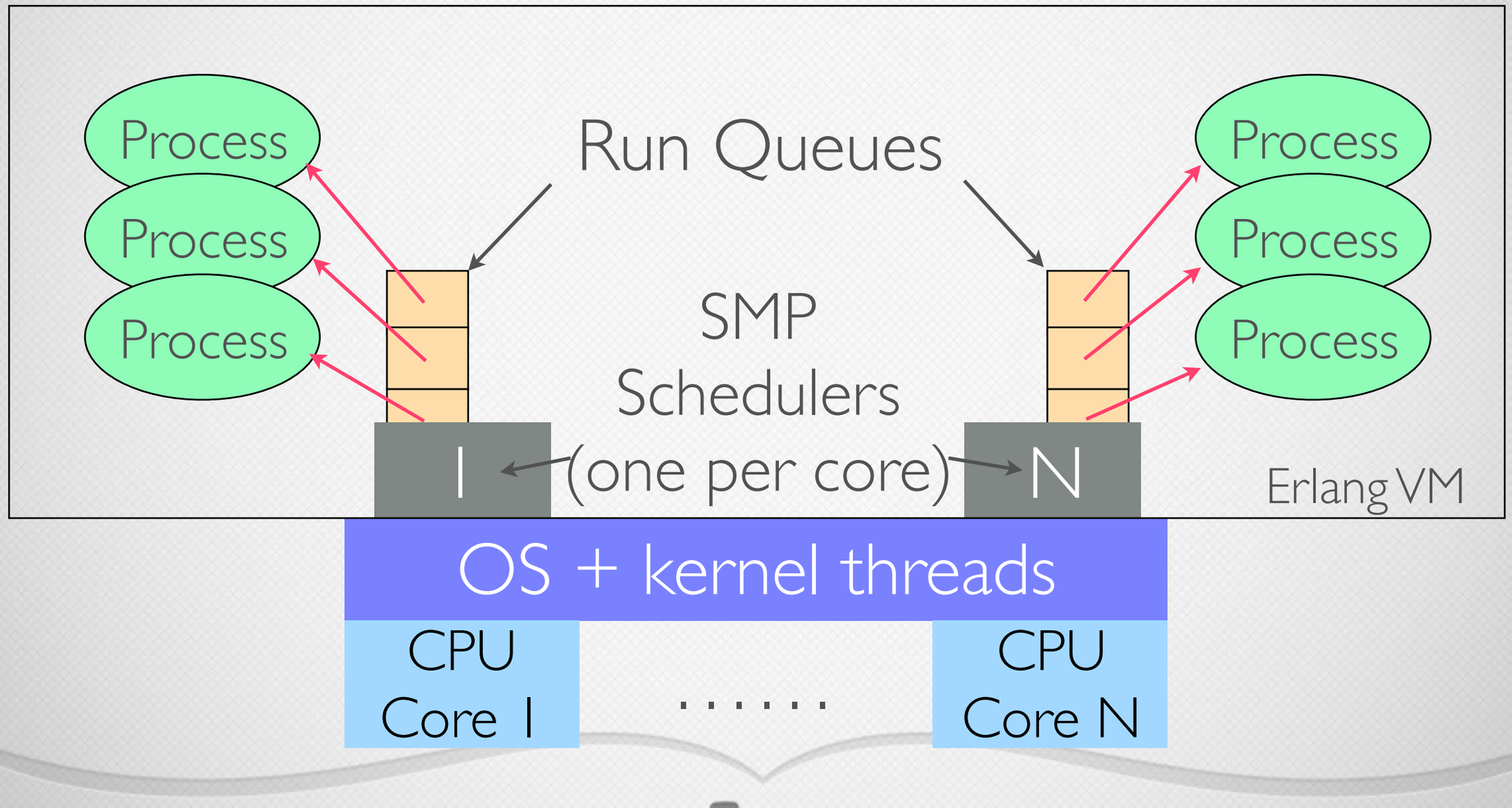

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- Variables are immutable, no globals
- Flow control via pattern matching, case, if, try-catch, recursion, messages

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

```
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    A = 2,    % A is bound to 2
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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

Riak

- A distributed

Riak

- A distributed highly available

Riak

- A distributed highly available eventually consistent

Riak

- A distributed highly available eventually consistent highly scalable

Riak

- A distributed highly available eventually consistent highly scalable open source

Riak

- A distributed highly available eventually consistent highly scalable open source key-value database

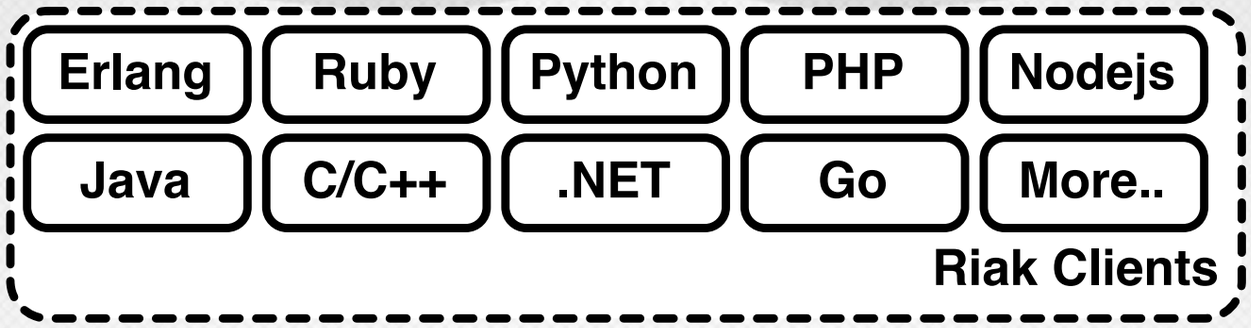
Riak

- 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



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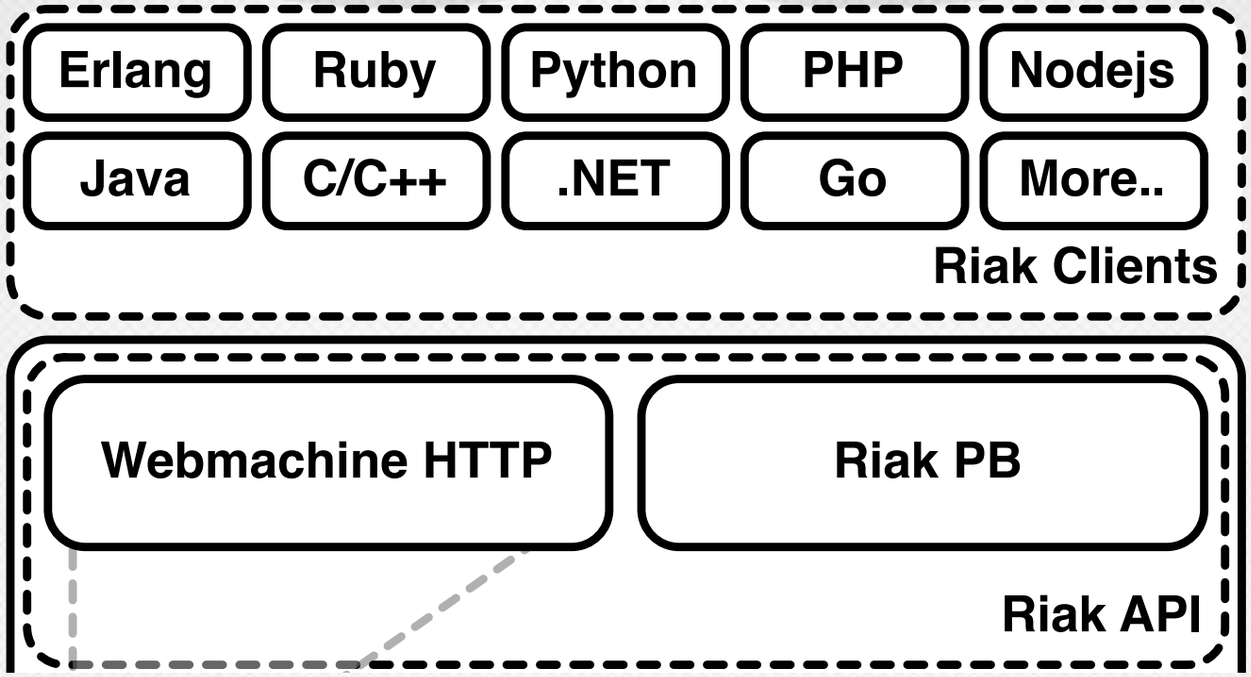

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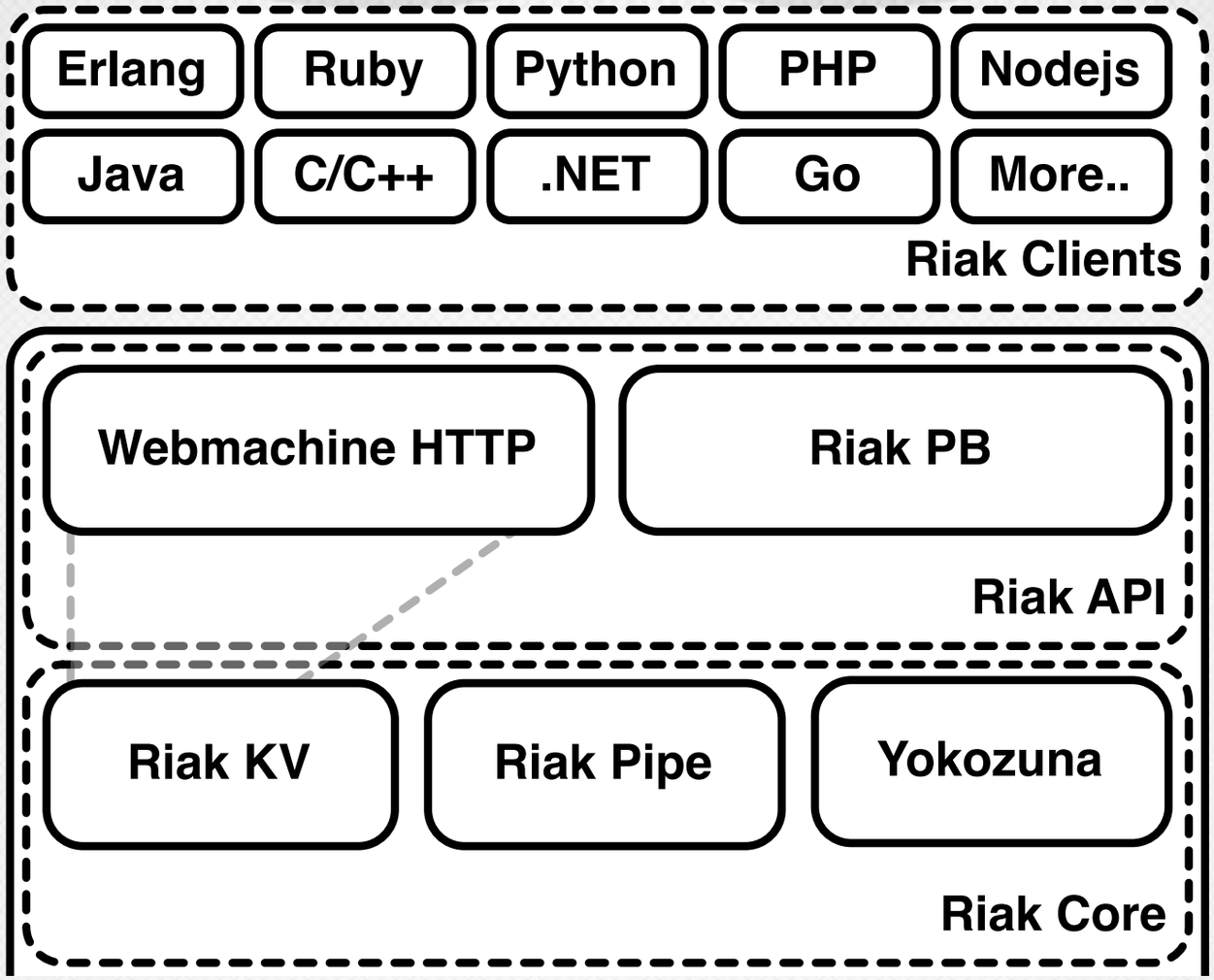

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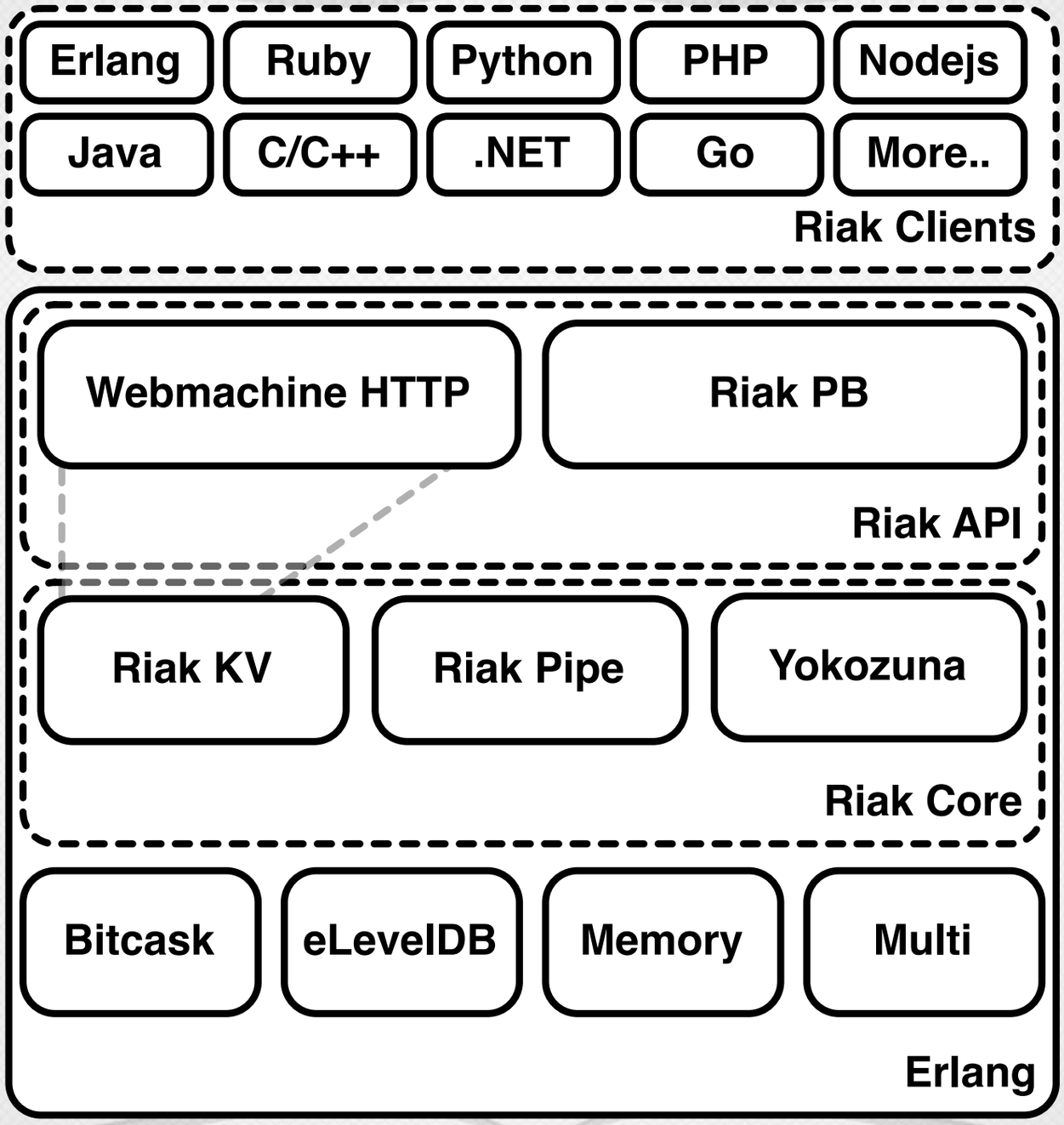

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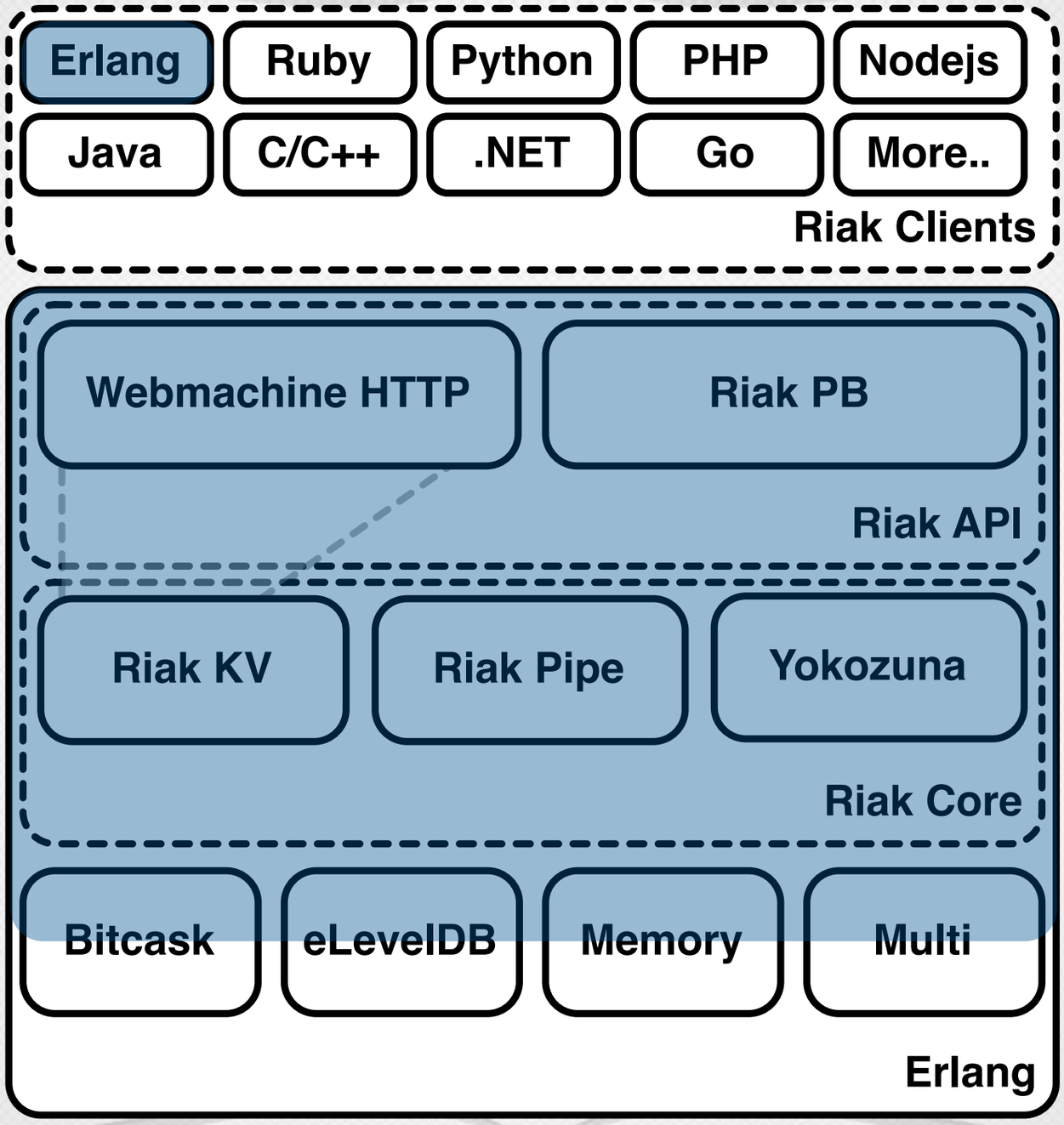

- Erlang parts

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Riak Cluster

node 0

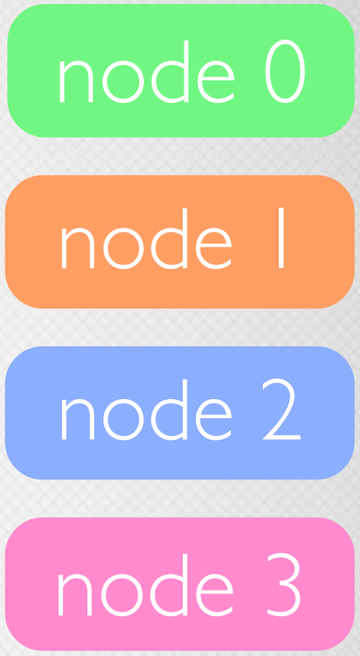
node 3

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



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Consistent Hashing

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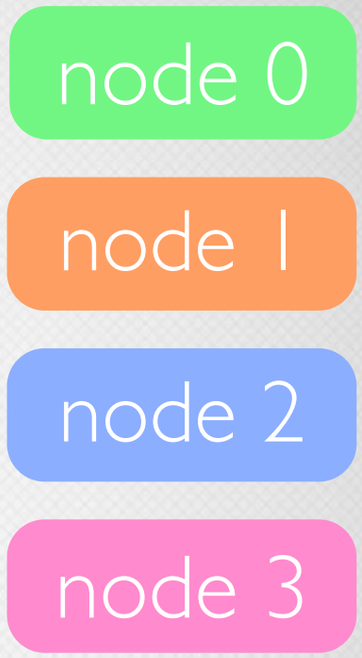

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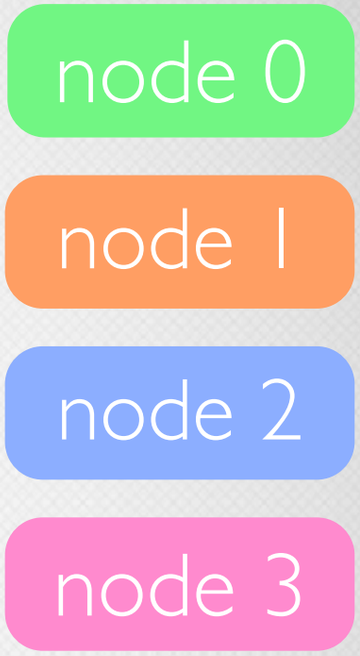

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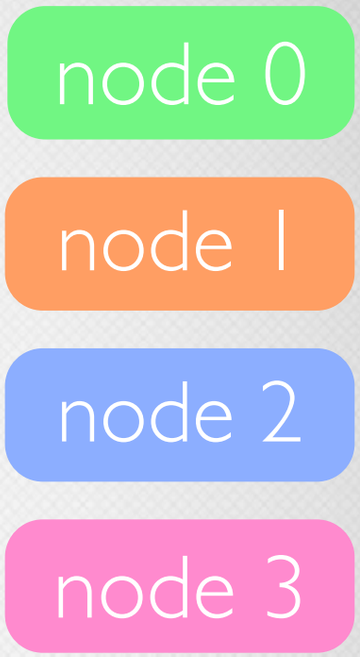

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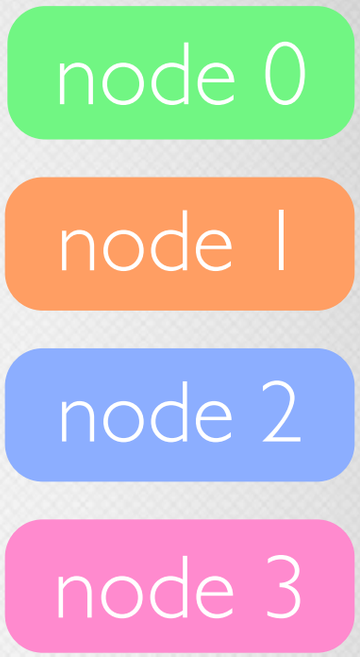

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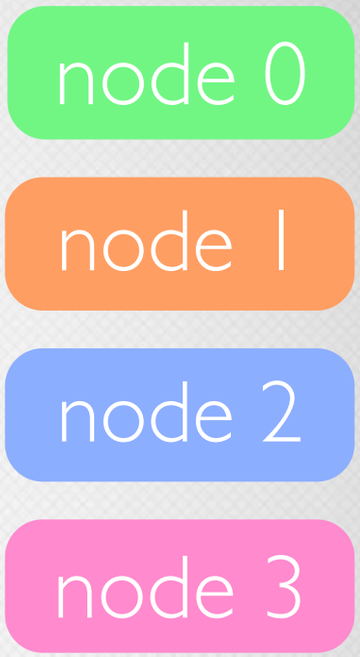
- Each physical node in the cluster hosts multiple vnodes



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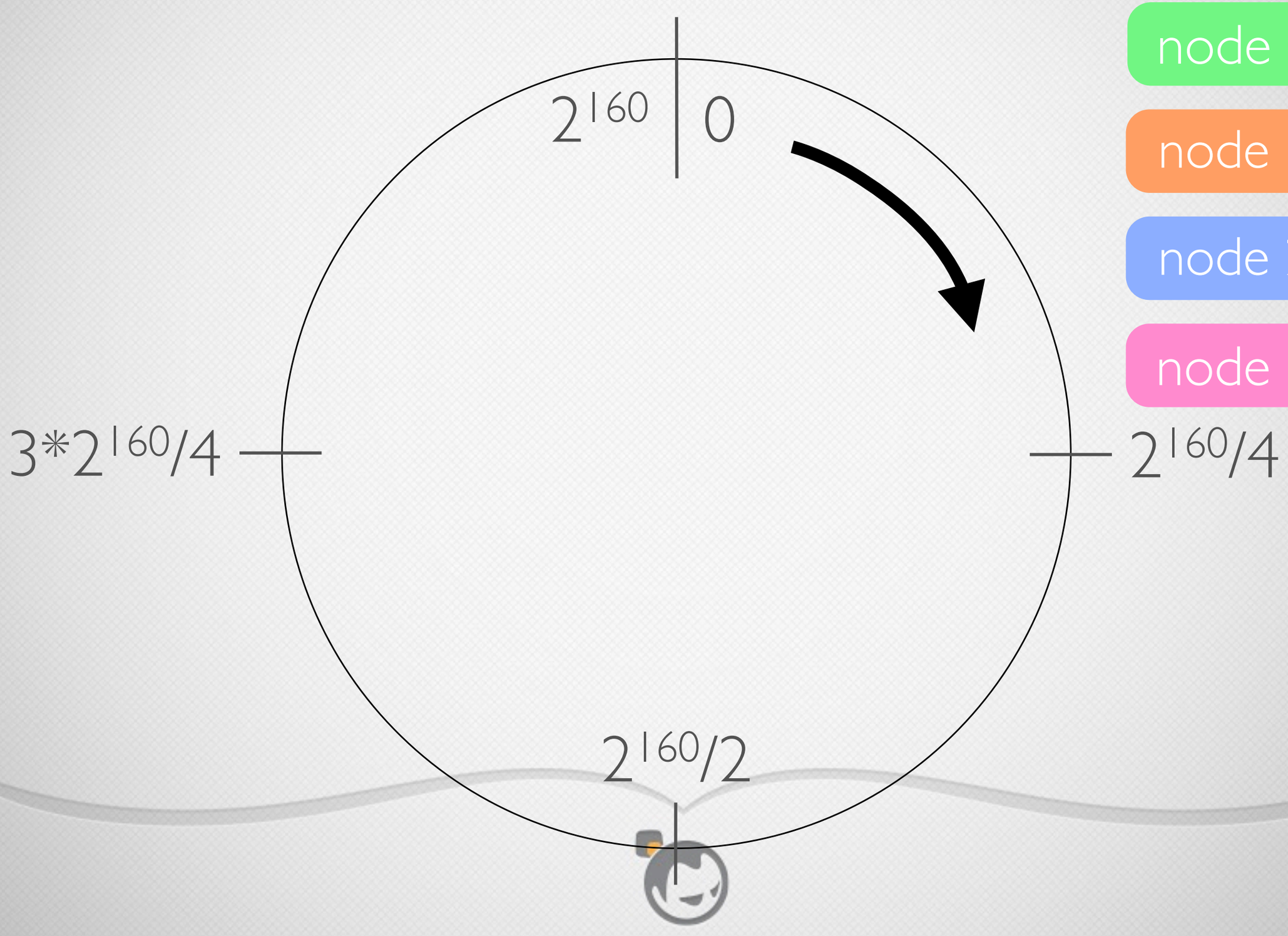

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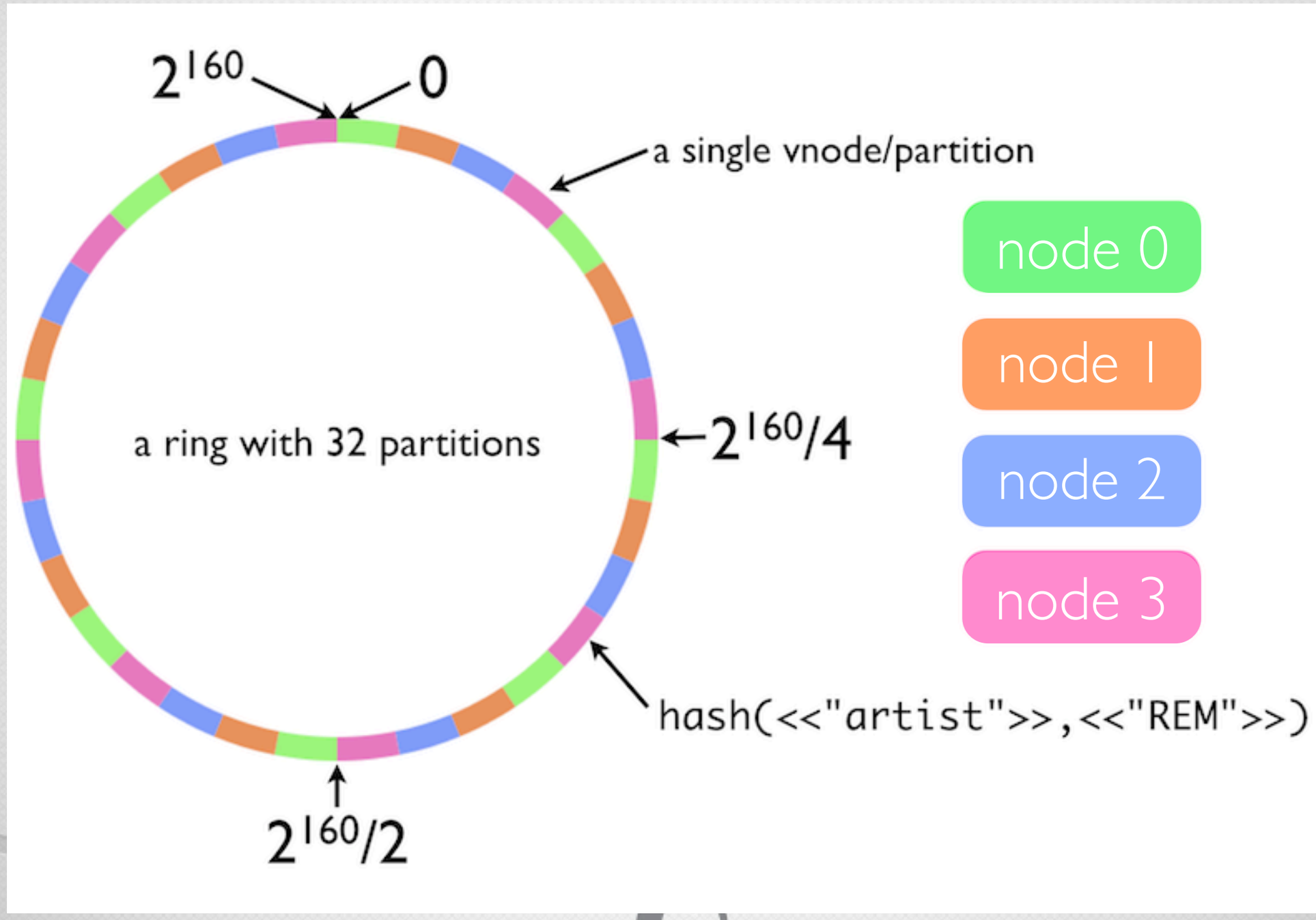
2^160
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a single vnode/partition
a ring with 32 partitions
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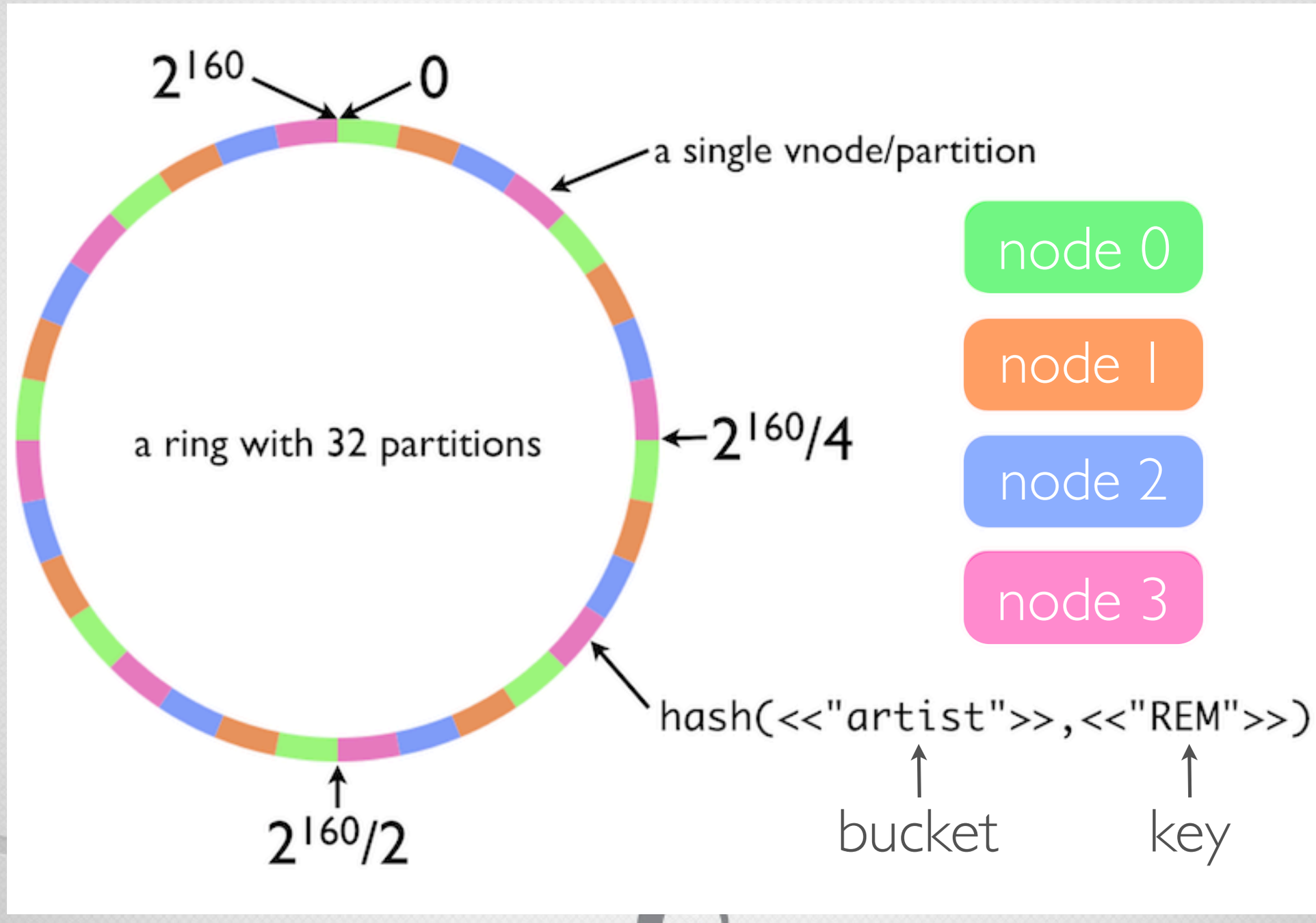
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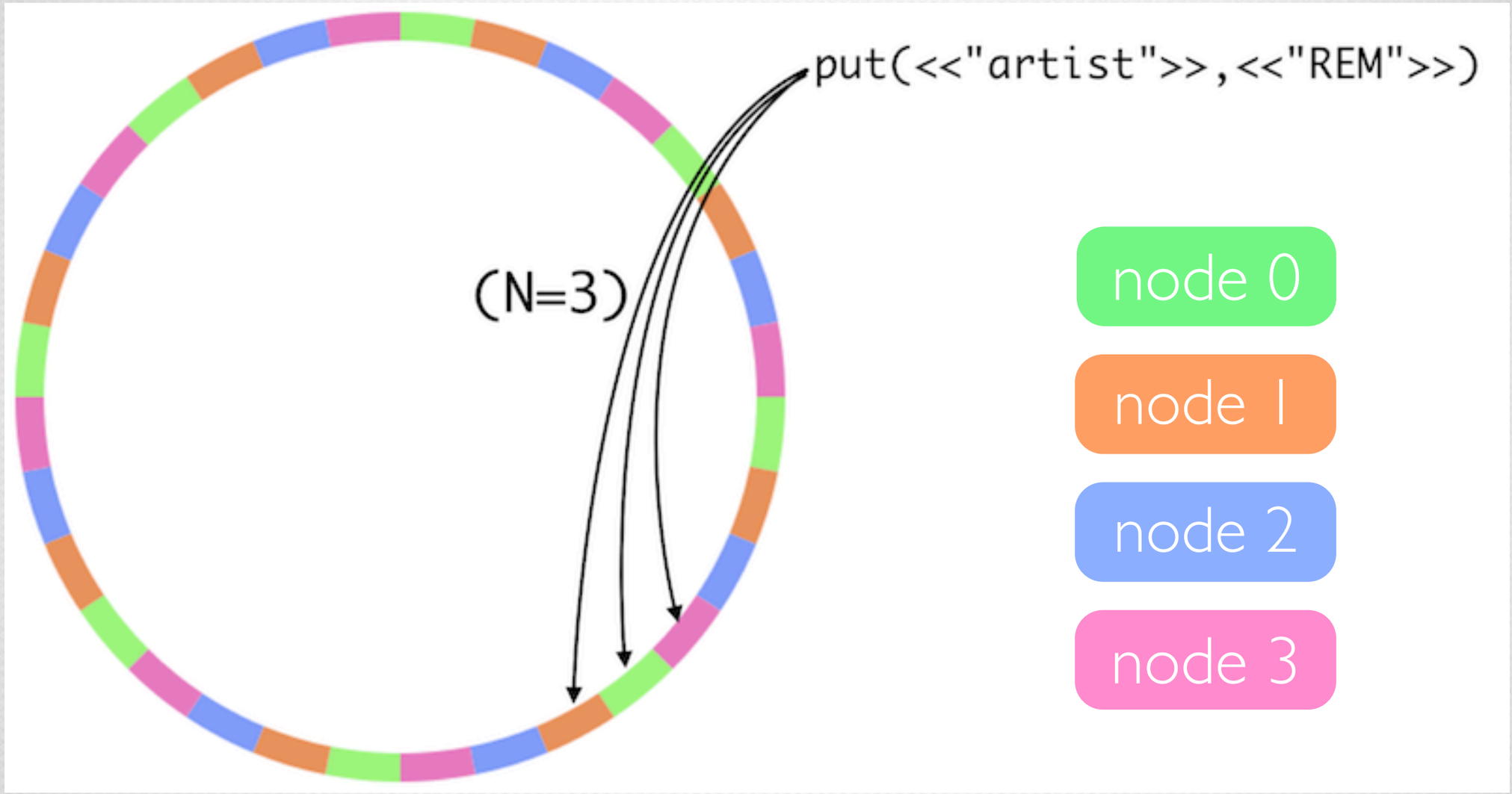

for details see http://docs.basho.com/riak/1.3.1/tutorials/fast-track/Tunable-CAP-Controls-in-Riak/

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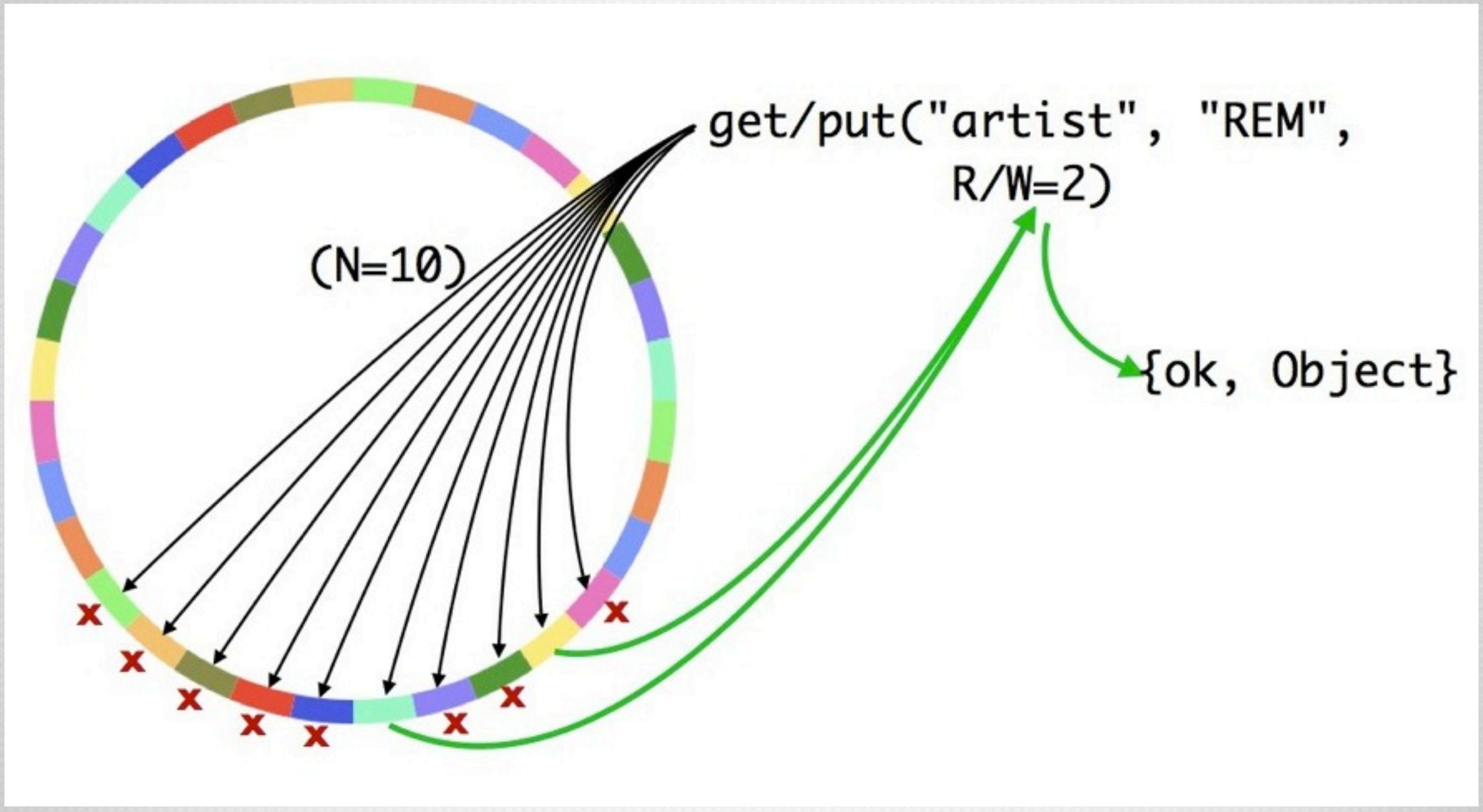

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- But that's OK, Erlang's integers are infinite precision
- And Erlang binaries store these large values efficiently

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Ring State

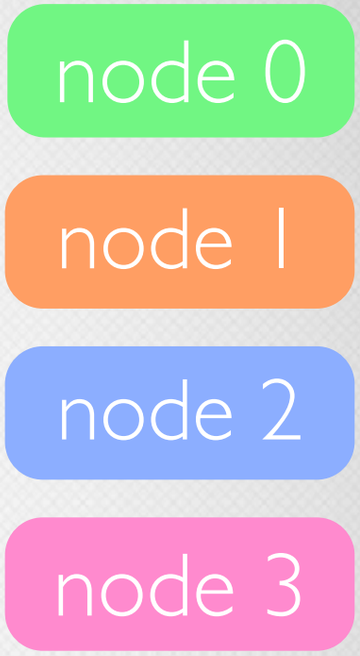
- All nodes in a Riak cluster are peers, no masters or slaves
- Nodes exchange their understanding of ring state via a gossip protocol

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



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Distributed Erlang Mesh

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node 3

node 1

node 2

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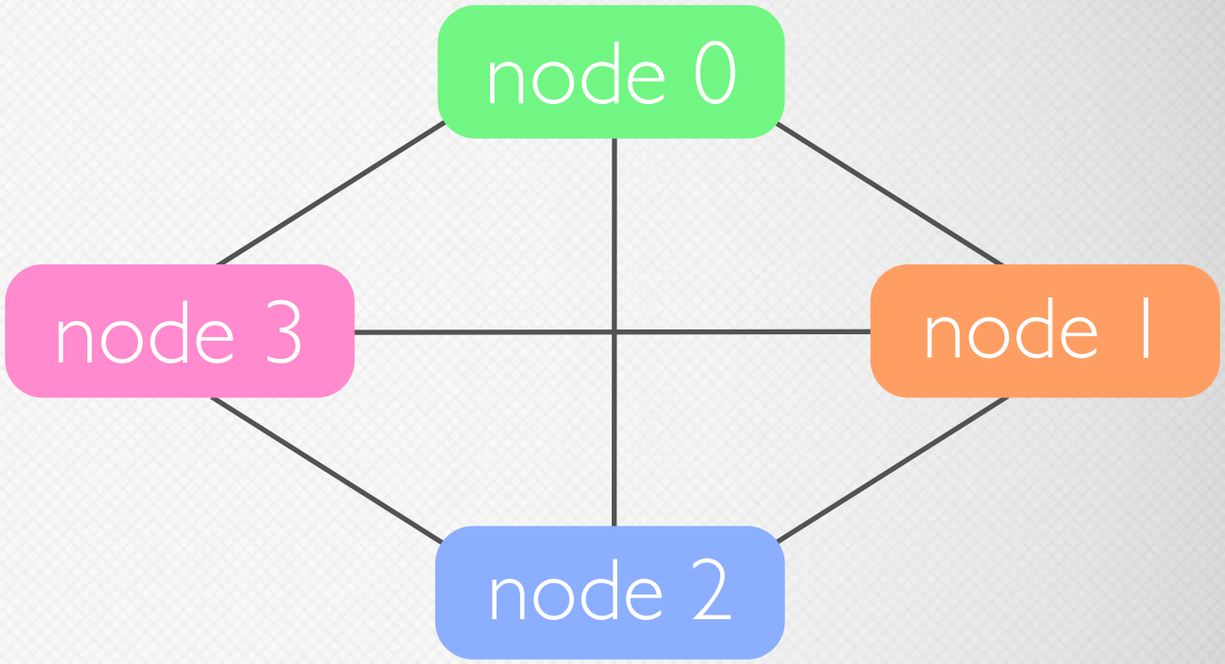

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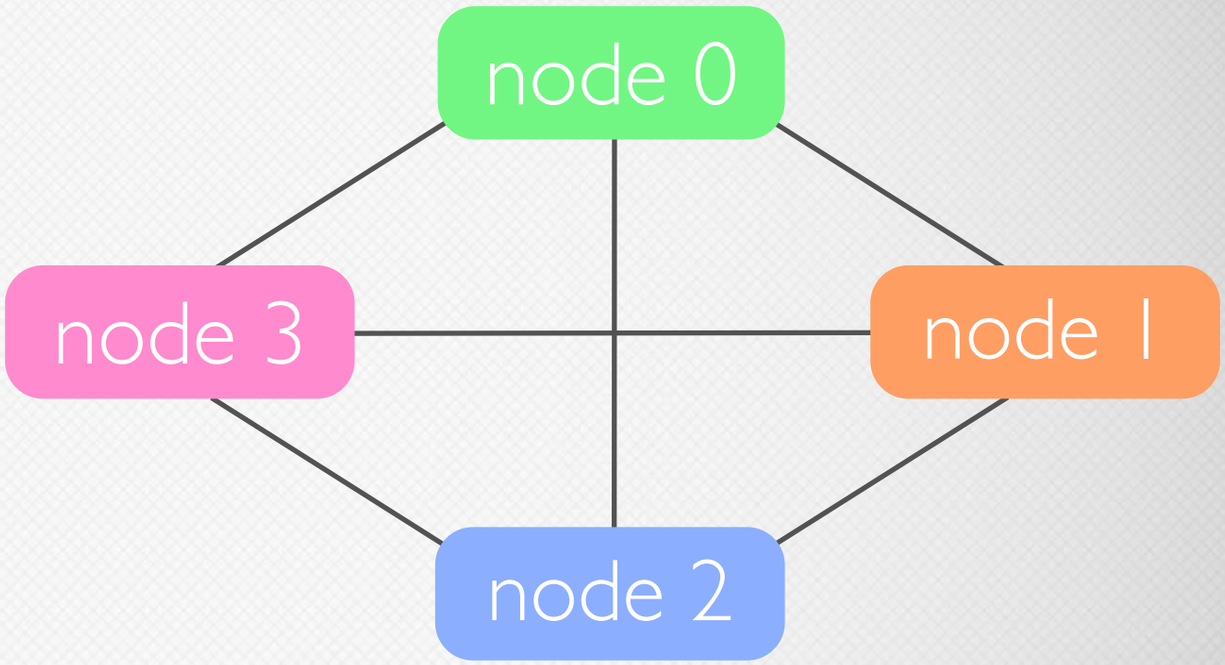

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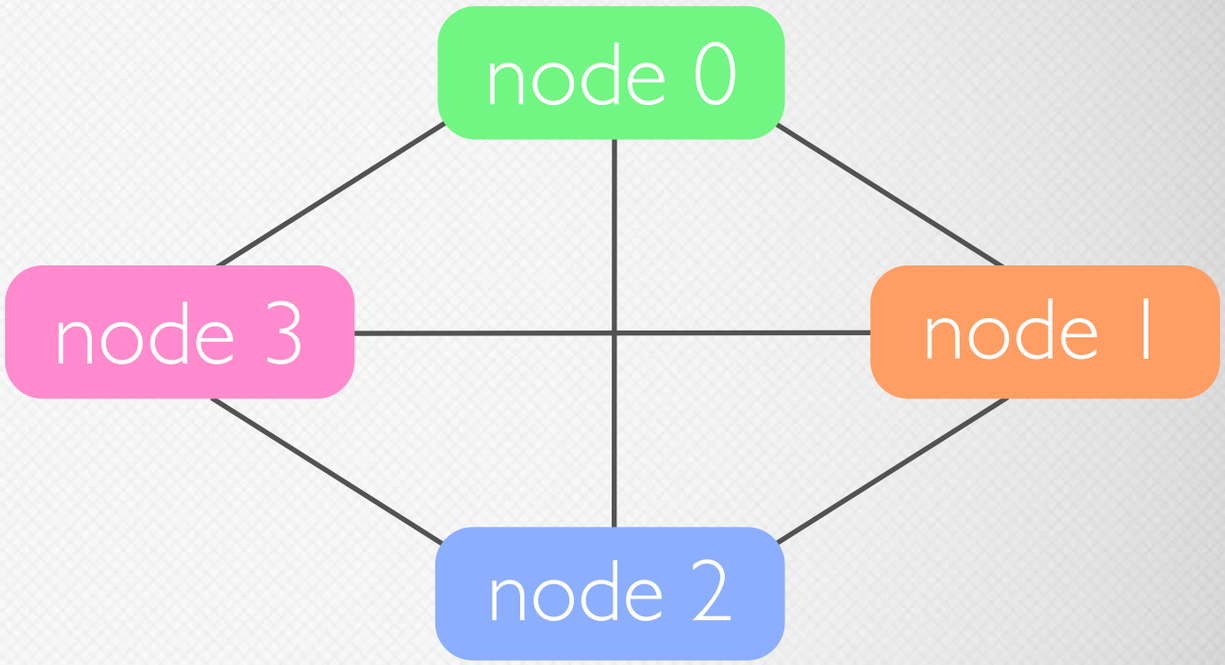
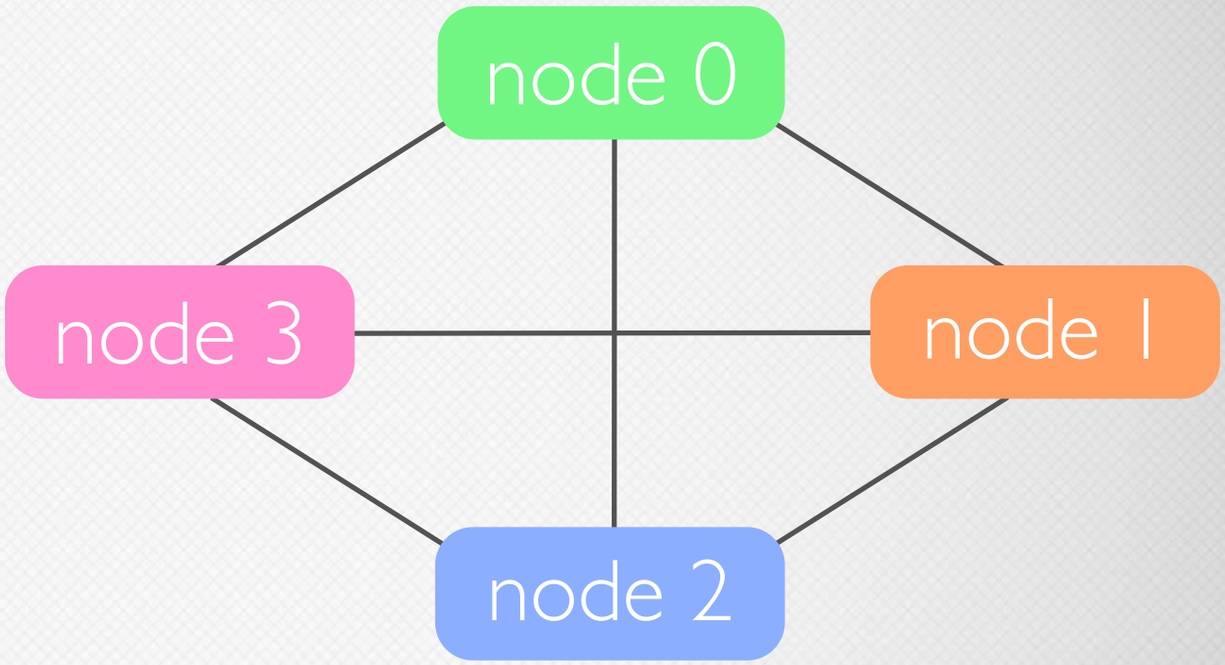
- Mesh approach makes it easy to set up a cluster



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)



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

Control Vs. Data

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

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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

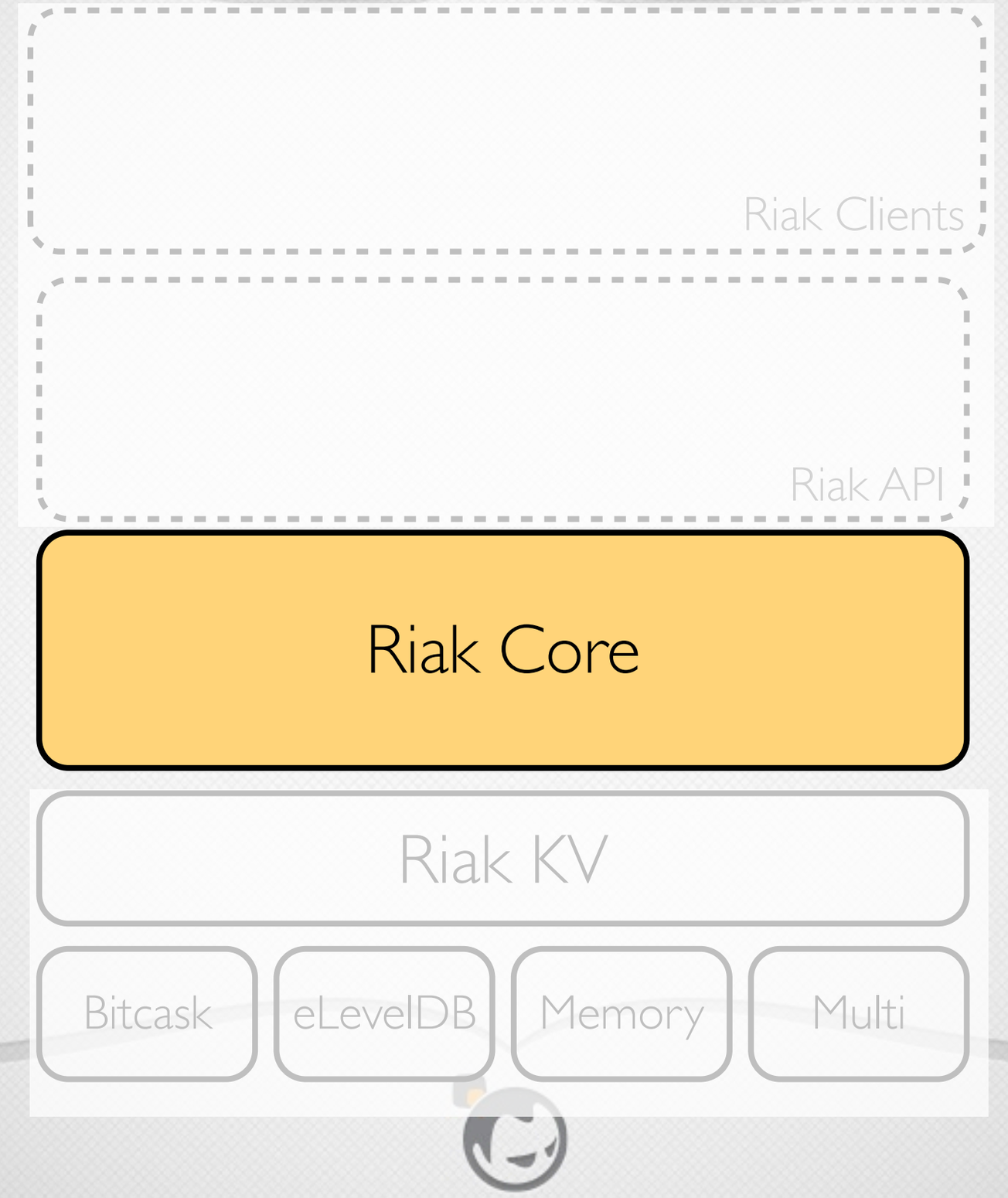
Riak Clients

Riak API

Riak KV

Bitcask | eLevelDB | Memory | Multi

Riak Core


Riak Clients
Riak API
Riak Core
Riak KV
Bitcask
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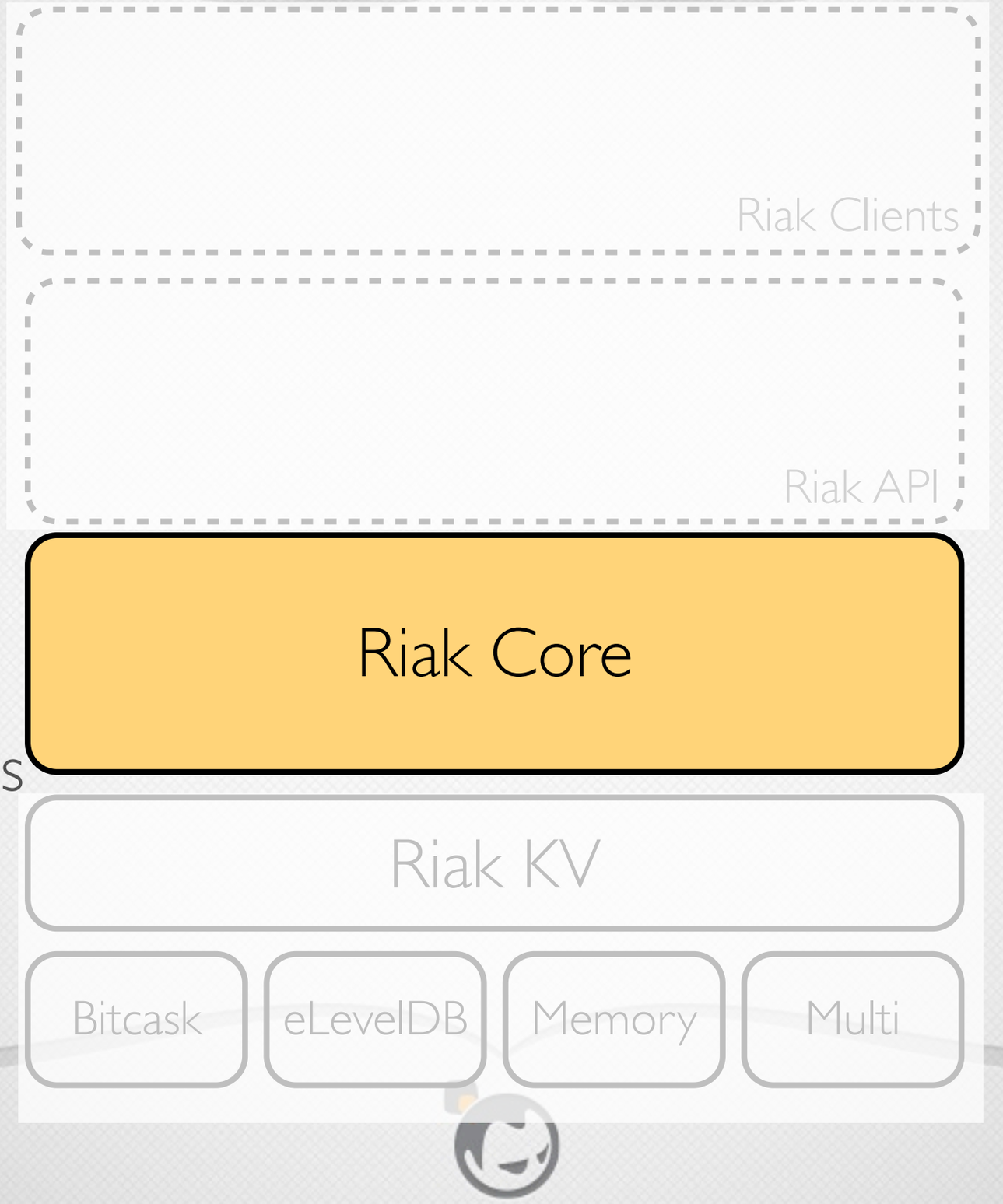
Multi

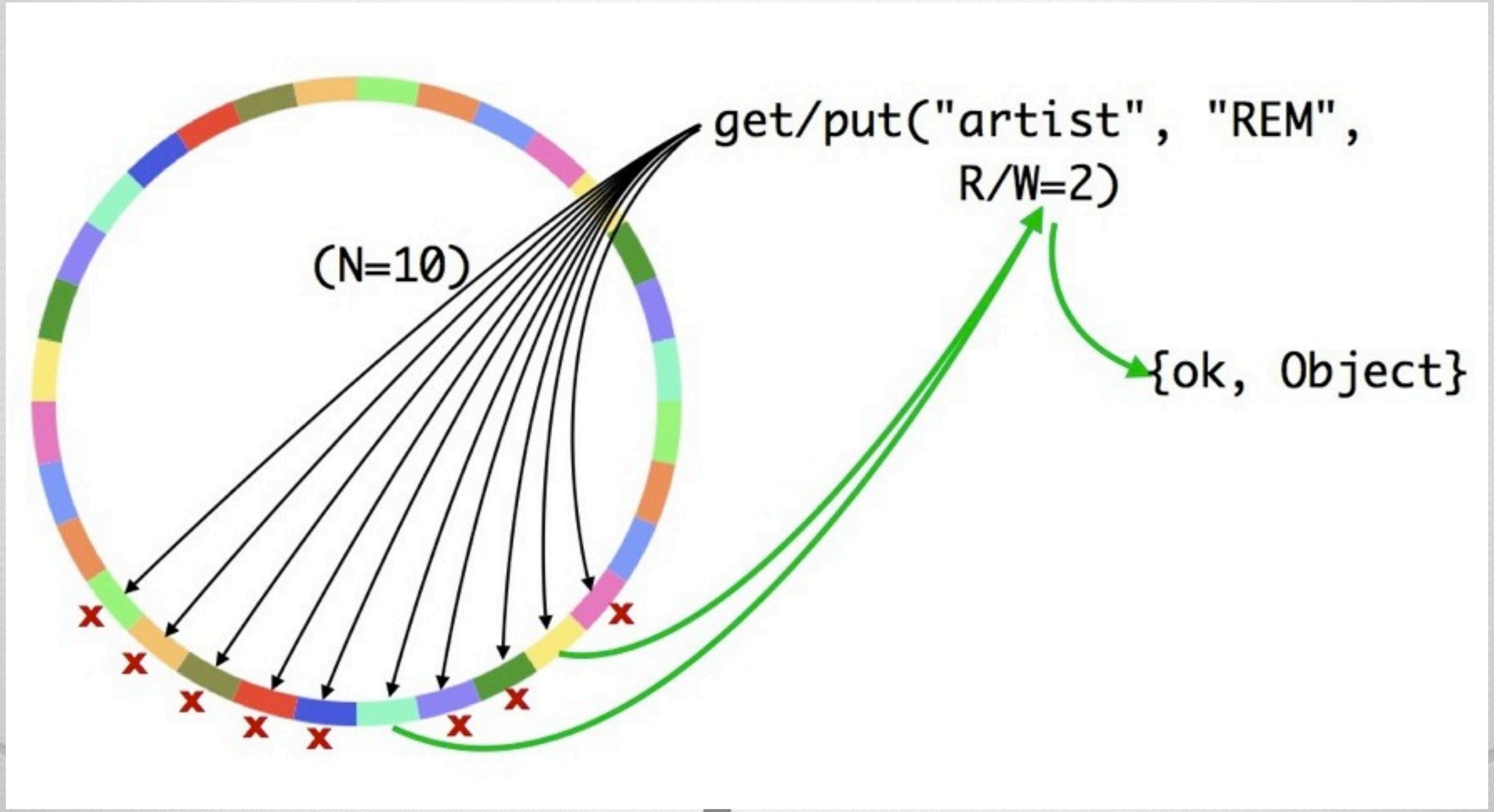
Riak Core

- consistent hashing
- vector clocks
- sloppy quorums



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

N/R/W Values



Hinted Handoff

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- Fallback vnode holds data for unavailable primary vnode

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- 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
- Starting at version 1.3, 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				NS	CWR	ECE	URG	ACK	PSH	RST	SYN	FIN	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

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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_*

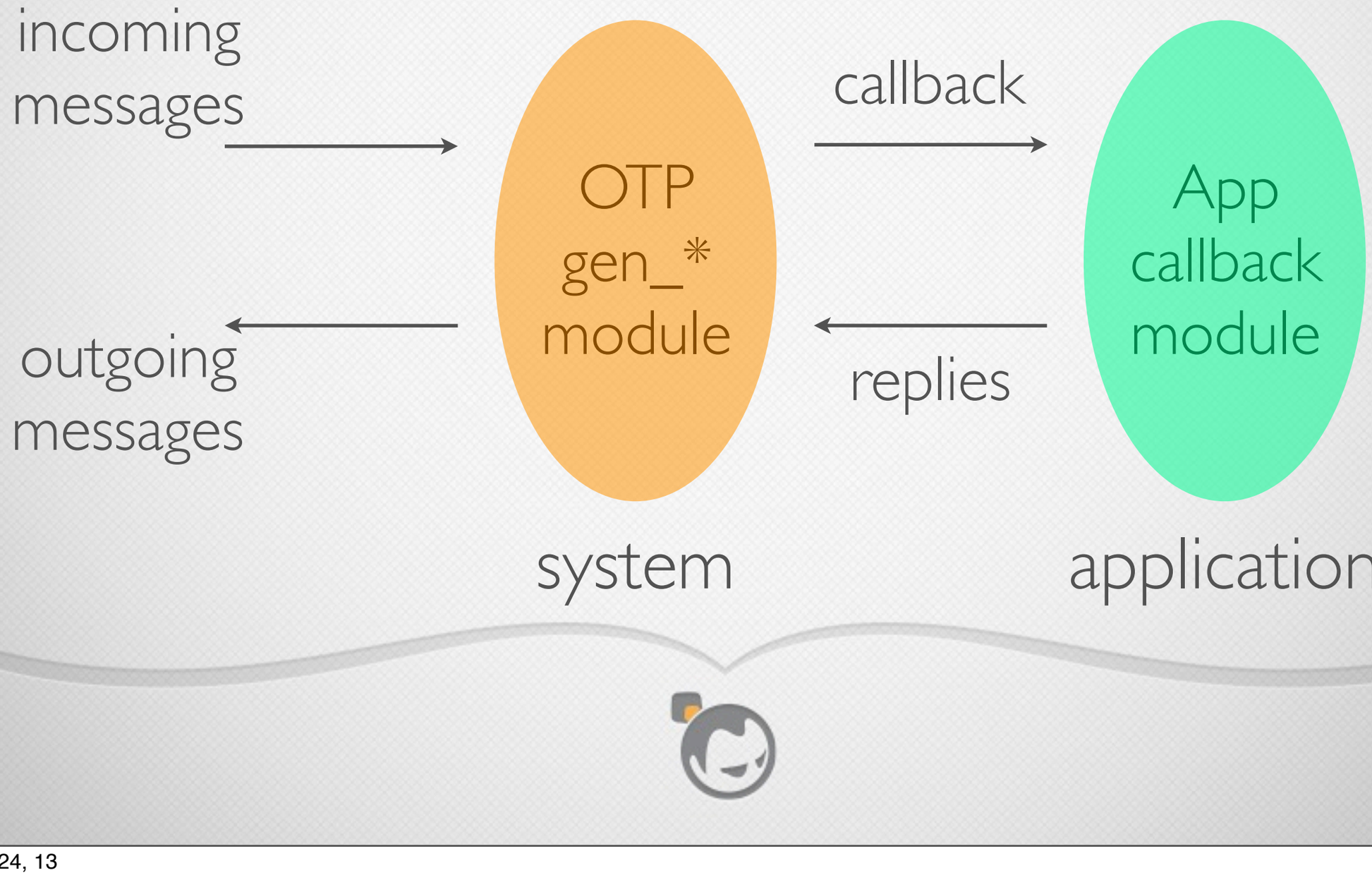
- Riak makes heavy use of these behaviors, e.g.:
  - FSMs for get and put operations
  - Vnode FSM
  - Gossip module is a gen_server

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



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

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Application

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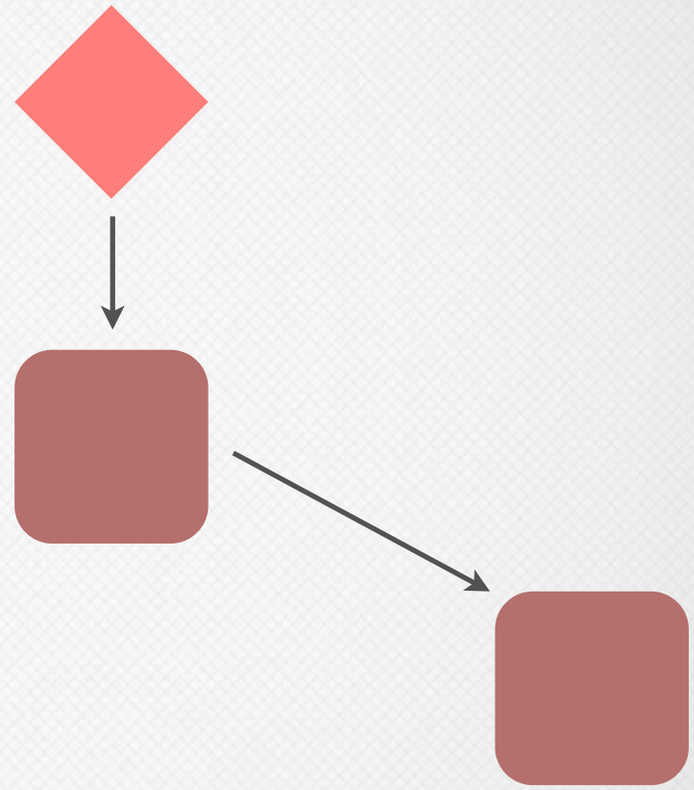
Application

Supervisors

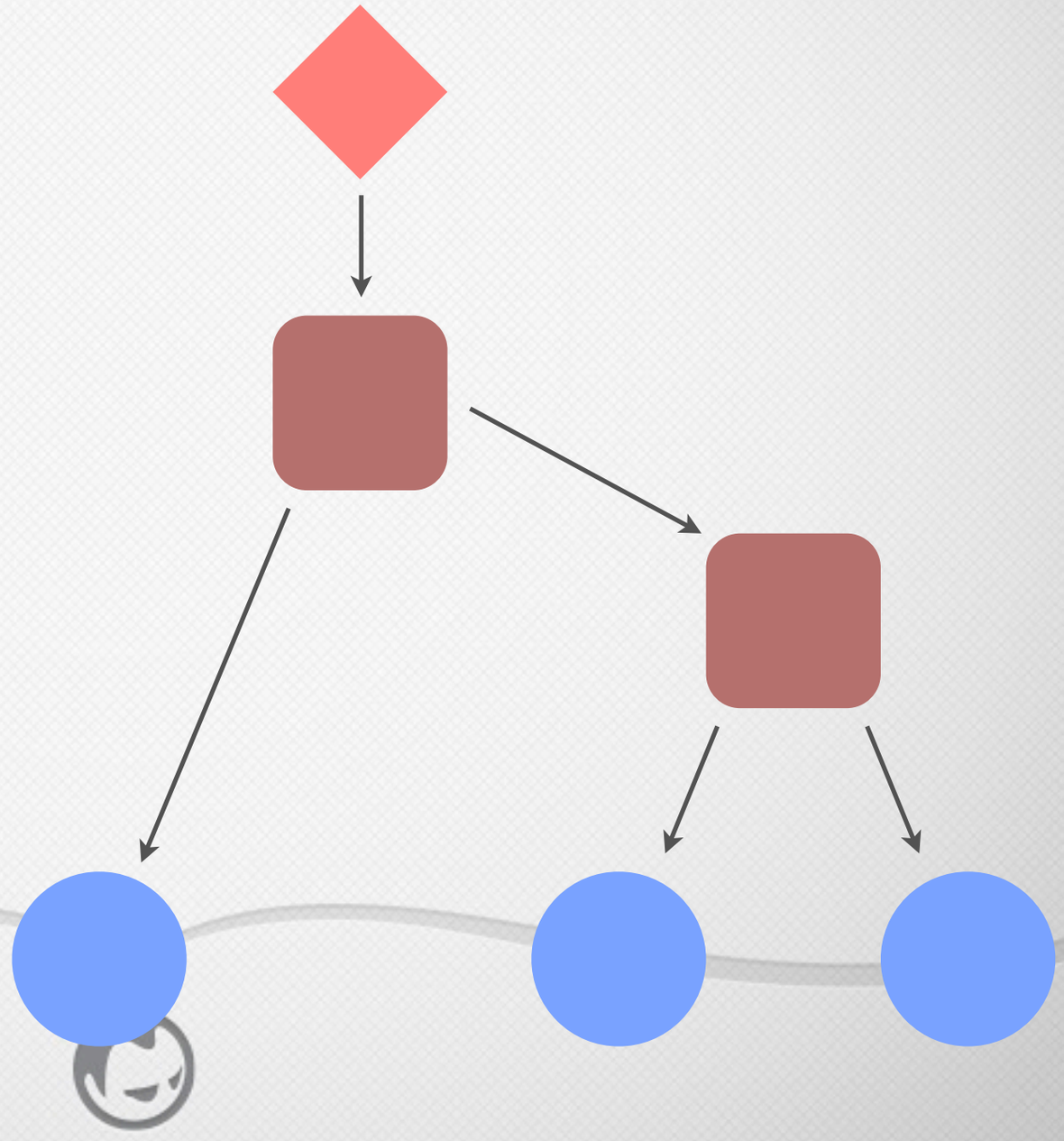


Application, Supervisors, Workers

Application

Supervisors

Workers



Application, Supervisors, Workers

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Supervisors

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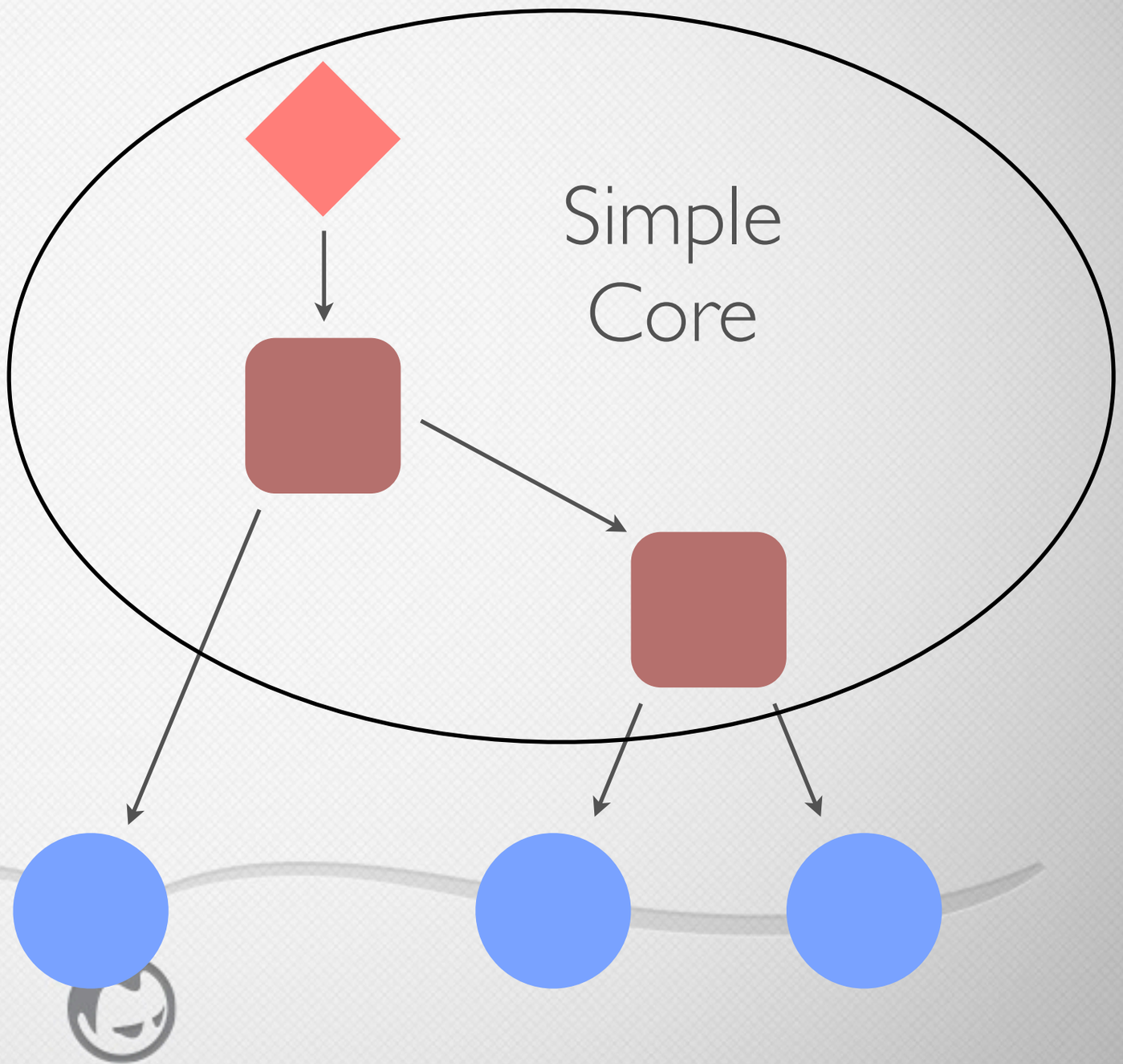


Erlang/OTP System Facilities

- Get status of an OTP process
- Get process info for any process
- Trace function calls, messages
- Releases
- Live upgrades

INTEGRATION

Riak Architecture

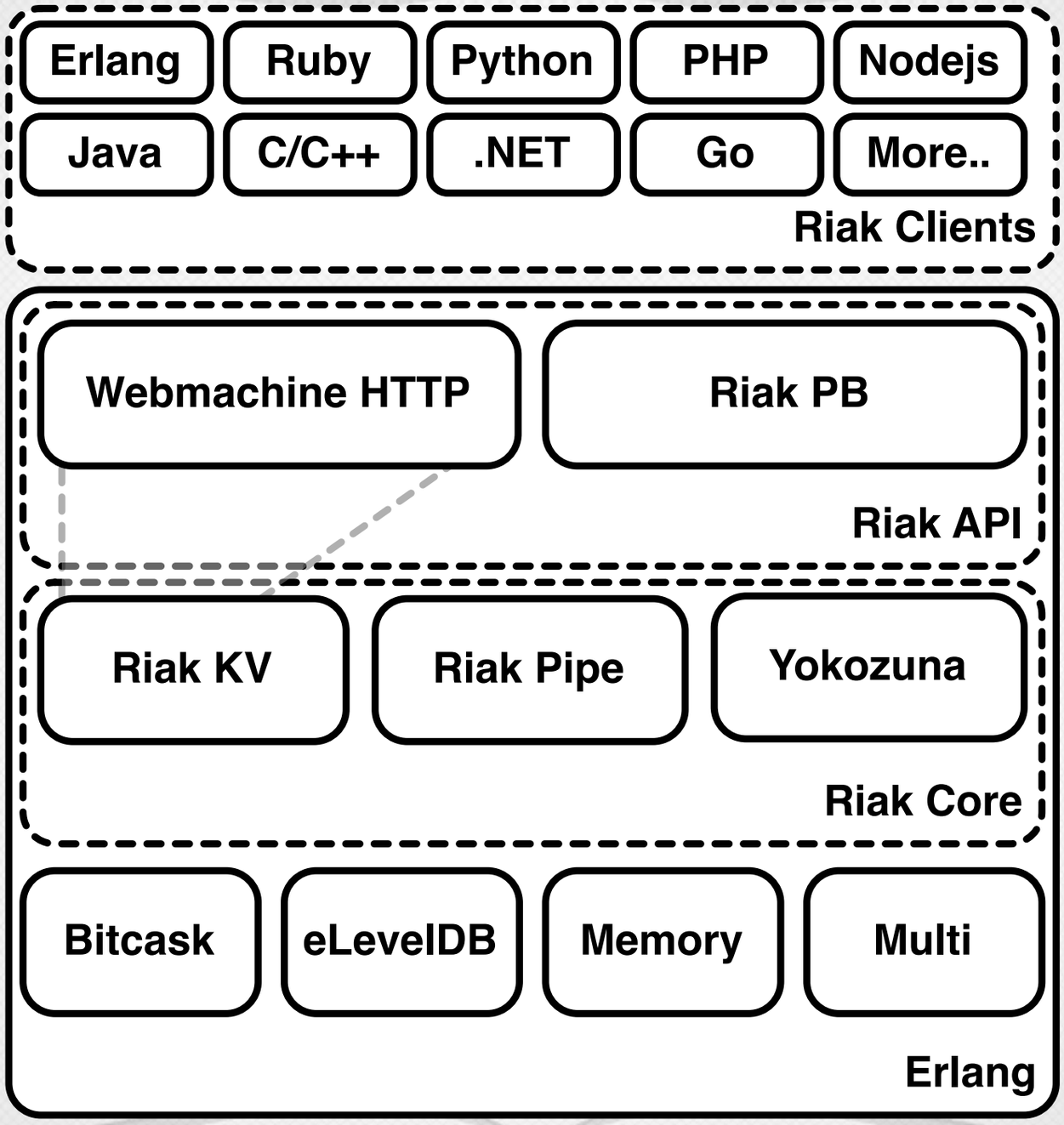
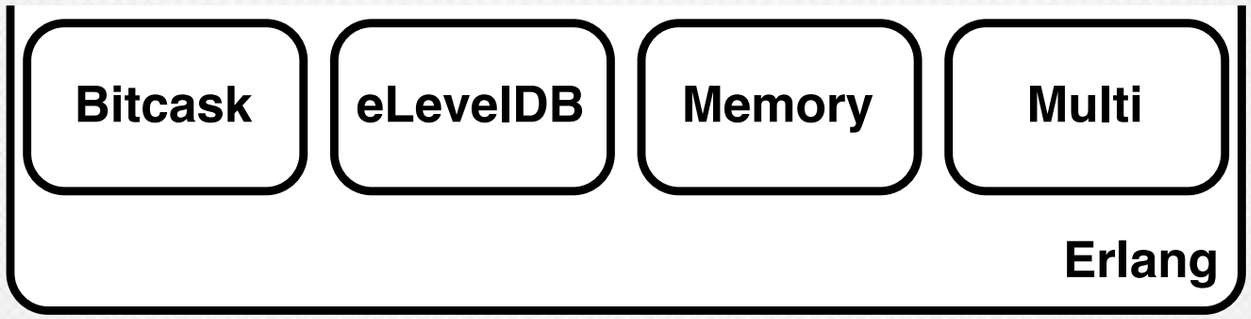


image courtesy of Eric Redmond, "A Little Riak Book" https://github.com/coderoshi/little_riak_book/

Riak Architecture



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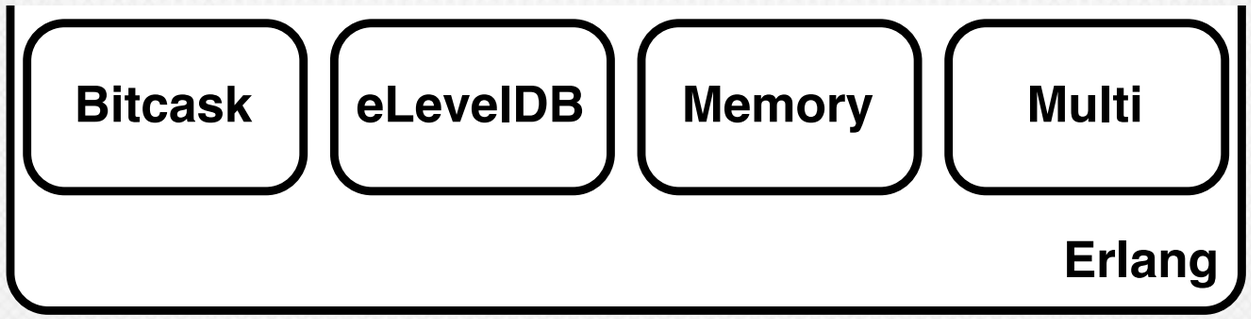
Riak Architecture

Erlang on top



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

Example: Eleveldb

```erlang
%% Erlang
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```

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

Example: Eleveldb

```
// 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

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- If the NIF blocks, the scheduler thread blocks
- THIS IS VERY BAD
- NIFs should block for no more than 1 millisecond

NIF Caveats

- Last fall 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 calls that were taking multiple seconds in some cases
- Lesson: put long-running activities in their own threads

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

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

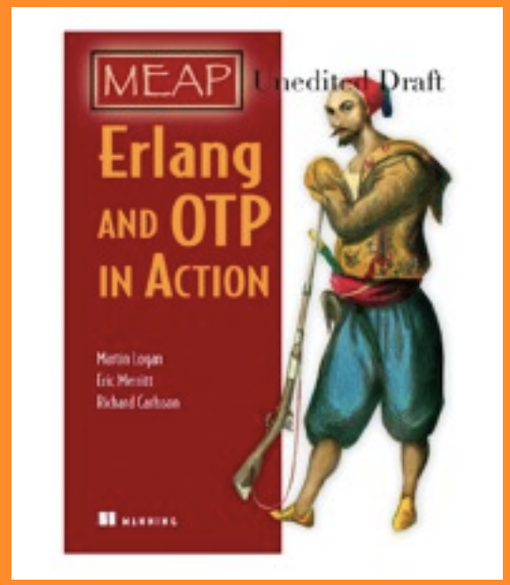
- Erlang is easy to learn
- Not really a problem to hire Erlang programmers
- Basho hires great developers, those who need to learn Erlang just do it
- BTW we're hiring, see http://bashojobs.theresumator.com

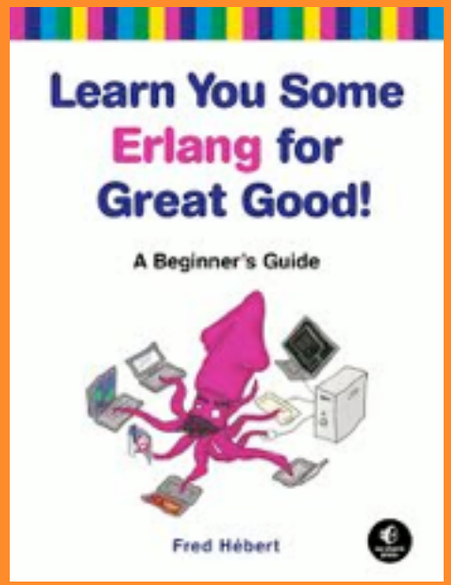
SUMMARY

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
  https://github.com/coderoshi/little_riak_book/

- 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

http://basho.com
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