Runtime Model of Ruby, JavaScript, Erlang,

and other popular languages

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Why Runtime Model?

Simulating Fireworks

Why not use Erlang processes for simulating particles?

Key Behaviors: CPU-bound and IO-bound

CPU-bound: How fast can we calculate something?

IO-bound: How many "simultaneous" interactions with the outer world can we handle?

Main Questions to Runtime Model

- How efficient are CPU-bound tasks?
  - does runtime support parallelism?
- How efficient are IO-bound tasks?
  - what is concurrency model?
- How efficient is Memory management?
  - does runtime use GC and what kind of GC?

CPU-bound

CPU-bound tasks

CPU-bound - time to complete a task is determined by the speed of the CPU

Examples:

- compiling assets
- building Ruby during installation
- resizing images
- creating ActiveRecord objects after obtaining response from database

CPU-bound: key efficiency factors

1. Bare performance
2. Parallelism
3. GC or non-GC

CPU-bound tasks: Bare Performance

The closer to bare metal - the faster

The champions: statically typed languages compiled to native code

- C/C++
- Rust
- Swift
- Go

CPU-bound tasks: Bare Performance

The runner-ups: statically typed languages with JIT

- Java, Scala
- C#, F#

CPU-bound tasks: Bare Performance

Not that bad: dynamic languages with JIT

Raw estimation: best is about 50% of statically typed languages performance

- Clojure
- JavaScript V8
- JRuby Truffle

CPU-bound tasks: Bare Performance

The also-runs: dynamic languages without JIT

- Erlang / Elixir
- Python
- Ruby MRI

CPU-bound tasks: Parallelism

Parallelism - simultaneous execution of computations

Boils down to using all available cores of CPU

CPU-bound tasks: Parallelism

Parallel:

- C/C++
- Rust
- Go
- JVM (Java, Scala, Clojure, JRuby)
- .NET (C#, F#)
- Haskell
- Erlang / Elixir

Non-Parallel (GIL):

- Ruby MRI
- Python

Non-Parallel (Event Loop):

- JavaScript (Node.JS)
- Ruby (EventMachine)
- Python (Twisted)

CPU-bound tasks: non-GC vs GC

Raw estimation: ~10% performance penalty when using GC

Non-GC:

- C/C++
- Rust
- Swift

GC:

- Go
- Java / Scala
- C# / F#
- JavaScript
- Ruby
- Erlang / Elixir
- Python

CPU-bound tasks

Best combo:

- Statically-typed, compiled to native code
- Non-GC
- Parallel

Garbage Collector

Garbage Collector

Main contributions to Runtime Model:

1. Expect about ~10% of performance penalty
2. Leads to GC "pauses" in execution
3. There is a maximum heap size, which can be handled efficiently

Garbage Collector Types

Reference-Counting:

- Python
- Perl 5

Tracing:

- JVM
- .NET
- Go
- Ruby
- JavaScript/Node.JS
- Haskell
- Erlang / Elixir
- …

Garbage Collector: Tracing

Generational GC dominates

Generational GC:

- JVM
- .NET
- Ruby
- JavaScript/Node.JS
- Erlang / Elixir
- Haskell

Concurrent, Tri-color, mark-sweep:

- Go

GC at a different angle

1. GC in a shared-heap runtime
2. GC in a multi-heap runtime

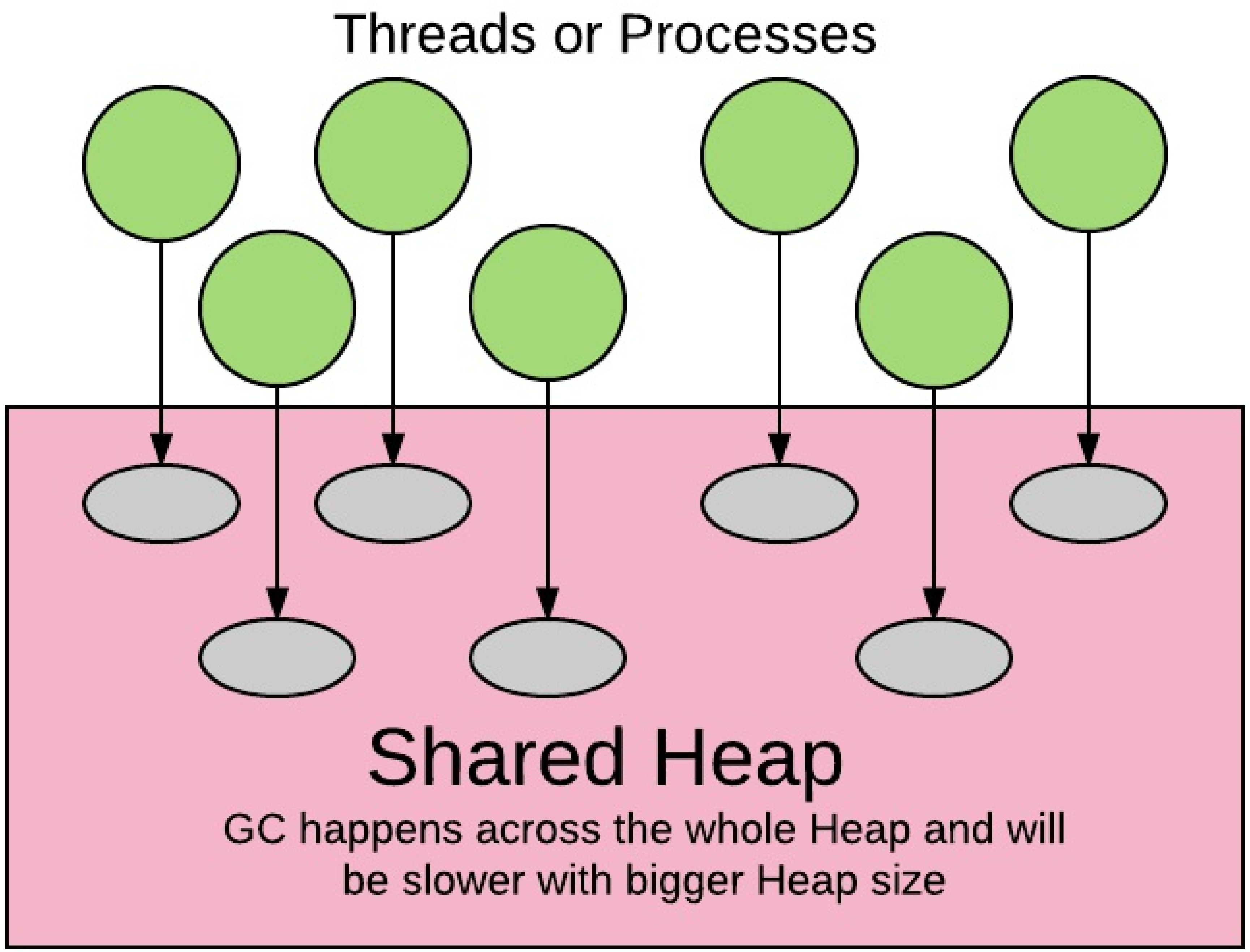
GC in a shared-heap runtime

Mostly all popular runtimes use shared heap

Examples:

- JVM
- .NET
- Go
- Ruby
- JavaScript/Node.JS
- Python
- Haskell
- ...

GC in a shared-heap runtime



GC in a shared-heap runtime

Main issue: GC should be done across one chunk of memory and complexity of GC grows linearly (or worse) with a heap size

Outcomes:

- Performance degradation on big heap size
- Increased delays in runtime execution due to GC

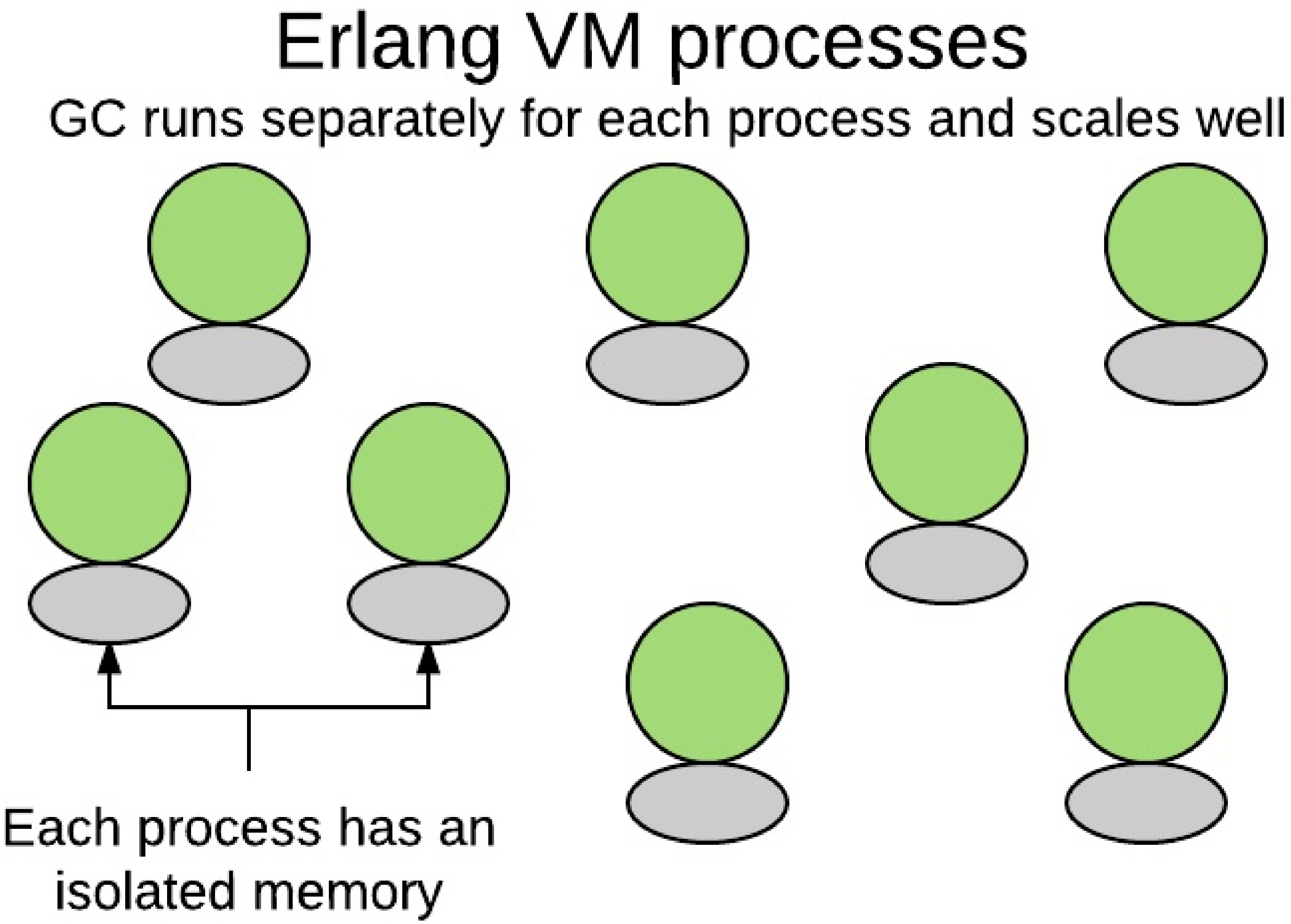
GC in a multi-heap runtime

Example:

- Erlang VM

Main trick: each process has its own isolated heap, which shares nothing with others

GC in a multi-heap runtime



GC in a multi-heap runtime

Main outcomes of Erlang VM memory layout:

1. GC can be done on a much smaller area and scales well
2. GC can be totally avoided by finishing process before GC kicks in (web-request is finished)
3. Erlang VM can use 128Gb and support 2 million active connections

IO-bound

IO-bound

IO-bound: how many "simultaneous" interactions with the outer world can we handle?

Examples:

- IRB/Pry input/output
- Reading file content
- Handling web request
- Handling websocket connection
- Performing database query
- Calling remote service
- Reading data from Redis
- Sending Email

IO-bound: Blocking vs Non-Blocking IO

Synchronous or Blocking: waits for the other side to be ready for IO-interaction

Asynchronous or Non-Blocking: handles other IO-interactions until the other side is ready to interact

IO-bound: Synchronous or Blocking

Pros:

- Easy to develop - sequential code

Cons:

- Working thread is dedicated to only one IO-interaction

IO-bound: Asynchronous or Non-Blocking

Pros:

- High performance - ability to handle large number of connections

Cons:

- Harder to write code
- Callback / Promise hell

IO-bound: Main Concurrency Models

1. Blocking IO + OS Threads
2. Event Loop or Reactor pattern
3. Green Threads

IO-bound: Blocking IO + Threads

In such combination runtime blocks on any IO operation, and OS handles switch to another thread.

Pros:

- Easy to write logic per thread - everything is sequential
- Quite performant - max limit ~ 5000 concurrent threads
- Memory efficient - everything is shared

Cons:

- Shared state is a big issue for mutable languages
- Requires usage of different thread synchronization primitives
- High requirements to quality of third-party libraries

IO-bound: Blocking IO + Threads

Managed Runtimes:

- JVM
- .NET
- Ruby MRI (despite having GIL)
- Python (despite having GIL)

IO-bound: Blocking IO + Processes

- Unicorn - Ruby web-server
- Postgres for handling client connections
- Apache (one of the modes)

Pros:

- Isolated memory - no risks of simultaneous writes to the same memory
- Sequential, "blocking" code

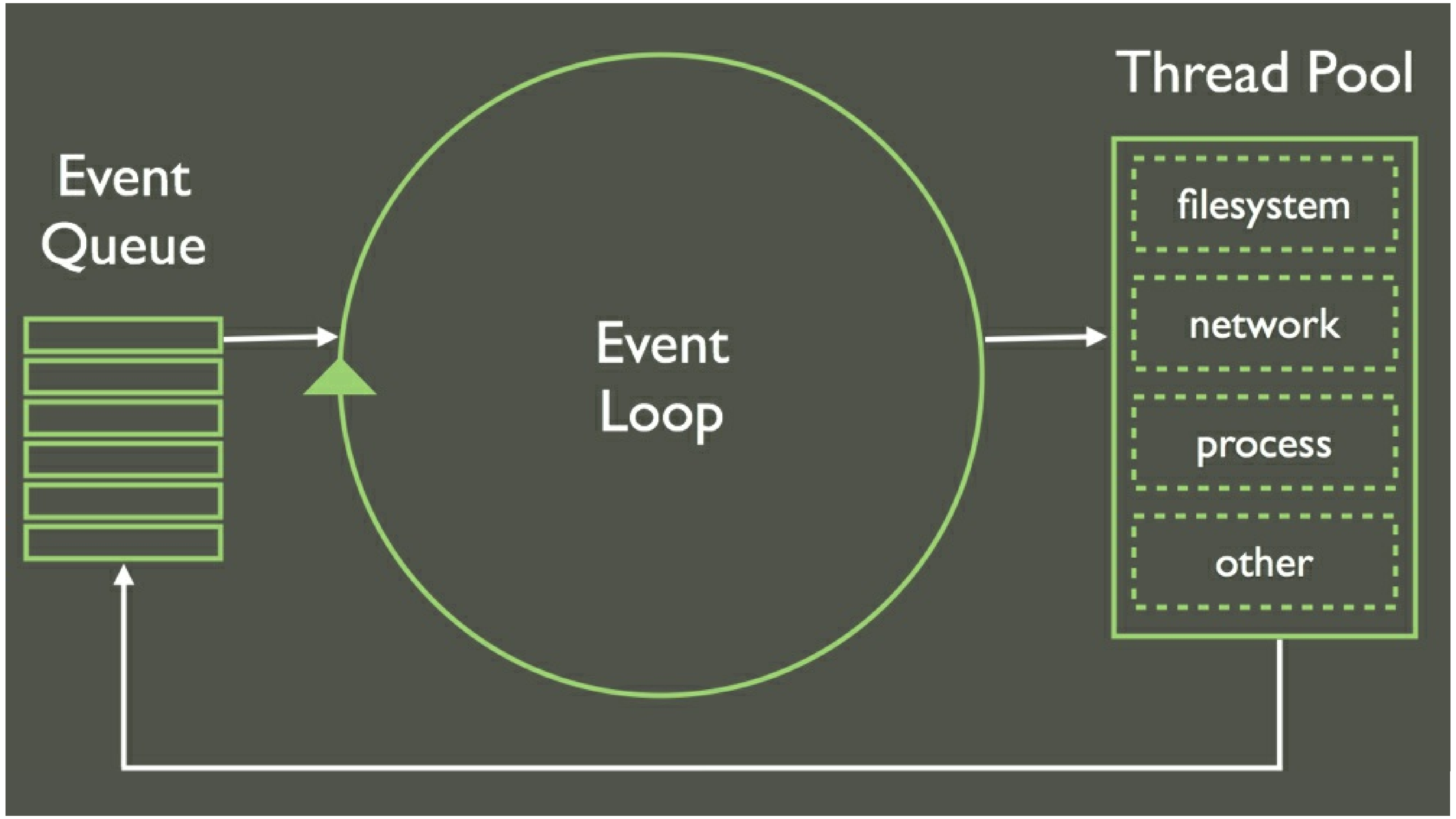
Cons:

- Higher memory consumption compared to threads
- Lower performance compared to asynchronous mode

IO-bound: Asynchronous: Event Loop or Reactor pattern

- Node.JS
- Ruby + EventMachine
- Python + Twisted

IO-bound: Asynchronous: Event Loop



IO-bound: Asynchronous: Event Loop or Reactor pattern

Pros:

- Memory-efficient - shared memory
- Memory-safe - no race conditions, because only one "callback" is performed till it finishes
- High-performant - potentially can handle millions of connections

Cons:

- Single-threaded - only one CPU core is used
- Callback / Promise hell, but can be avoided with coroutines or async/await

IO-bound: Synchronous Asynchronity: Green Threads

Instead of using OS threads, runtime has its own scheduler and manages threads without OS.

- API looks like synchronous
- But under the hood everything runs asynchronously

Green Threads Benefits compared to OS Threads:

- Smaller memory usage per thread
- Cheaper context-switch

IO-bound: Green Threads: Failure Stories

- Java 1.1
- Ruby 1.8

Main issues:

- Using mutexes as a main concurrency primitive
- Not efficient implementation

Both switched to OS Threads

IO-bound: Green Threads: Success Stories

- Erlang VM
- Golang VM
- GHC Haskell

Main difference - simpler set of primitives for handling concurrency without mutexes and synchronization:

- Actors and message-passing in Erlang
- Gorotines and channels in Go
- MVar and STM in Haskell

IO-bound: Green Threads of Go

Pros:

- Sequential "blocking" code
- Memory-efficient - one virtual machine
- Non-copying memory exchange between goroutines through channels
- Great IO-performance

Cons:

- Go still has a possibility to mutate a global state

IO-bound: Green Threads of Erlang

Pros:

- Sequential "blocking" code
- Memory-efficient - one virtual machine
- Great IO-performance: can handle about ~2_000_000 connections

Cons:

- Copies data when exchanging messages between processes

Ruby MRI Runtime

Ruby MRI Runtime: CPU-bound

CPU-bound:

- dynamic
- no JIT
- non-parallel

CPU-bound performance is poor

MRI-team is going to add JIT, still not clear when it will happen

Ruby MRI Runtime: GC

GC:

- one big heap - delays in GC
- generational mark&sweep - good

Current GC is quite good

MRI-team does not have any further plans to improve GC speed

Ruby MRI Runtime: IO-bound

IO-bound:

- blocking
- single-threaded
- multi-process (Unicorn)

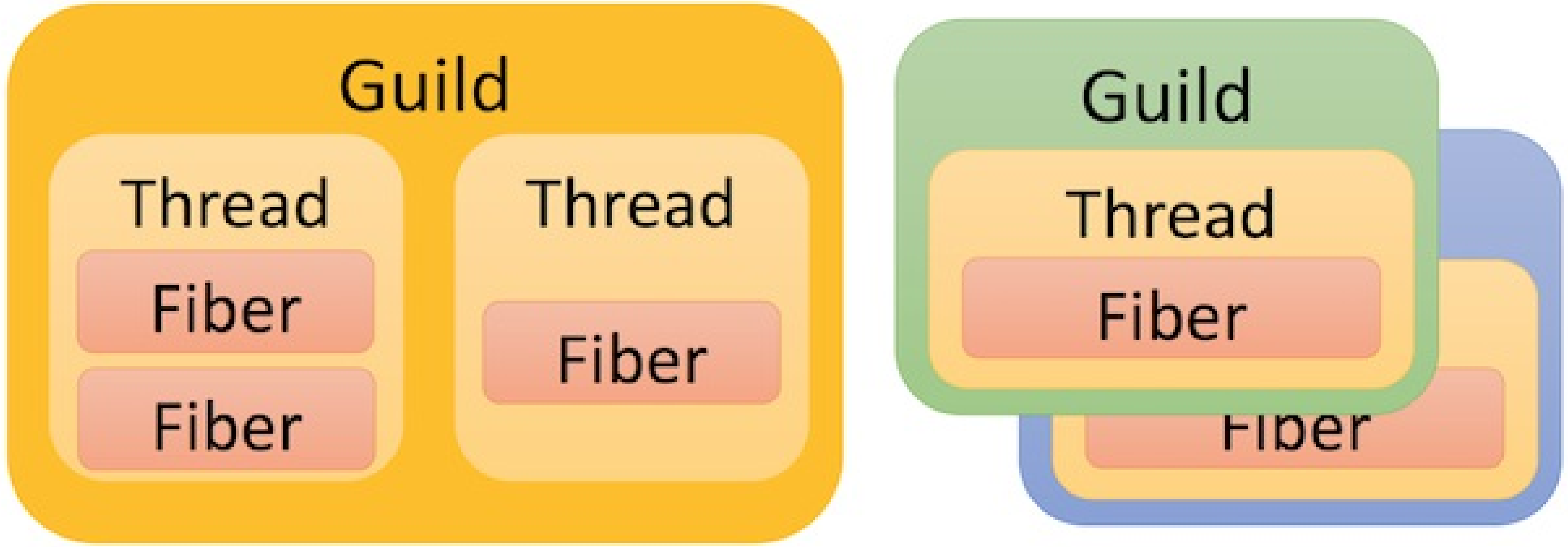
IO-bound stuff is not efficient compared to Node.JS or Erlang - slower 5-10x

Why Ruby doesn't use Threads and Java does?

- Java was built and promoted from the start as a concurrency-focused language
- Every library was meant to work in multi-threaded environment
- Ruby was never built with multi-threading in mind
- Main risk is to run into library which unsafely changes global state

Ruby MRI Runtime: New Hope - Guilds

Guild is a set of Threads and Fibers which can't directly access memory of another Guild



Ruby MRI Runtime: New Hope - Guilds

Pros:

- Memory-efficient - non-mutable stuff is shared (code, freezed objects)
- Memory-safe - different Guilds can't simultaneously mutate same object
- Good enough performance for web-requests
- Parallel - Guilds don't have GIL

Ruby MRI Runtime: New Hope - Guilds

Cons:

- Still can't handle big amount of connections - Guilds are more expensive than Green Threads or Event Loop
- Compared to Event Loop or Green Treads:
    - Memory usage is higher
    - Context switch is slower

Ruby MRI Runtime: New Hope - Guilds

MRI team is keen to implement them, but there are a lot of small issues with memory sharing, which should be addressed

Estimated performance gain: ~3-5x

Other factors contributing to Runtime Model

- Data Structures: mutable or immutable, O(?)
- GC implementation details
- Heap and Stack usage
- Memory Model
- CPU Architecture
- Underlying OS system calls(pthreads, select, epoll/kqueue, etc)
- ...

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