Tail Latency in Node.js:

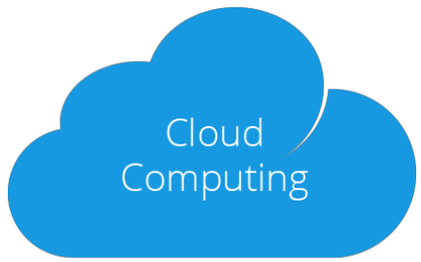
Energy Efficient Turbo Boosting for Long Tail Requests in JavaScript

Wenzhi Cui
Daniel Richins
Yuhao Zhu
Vijay Janapa Reddi

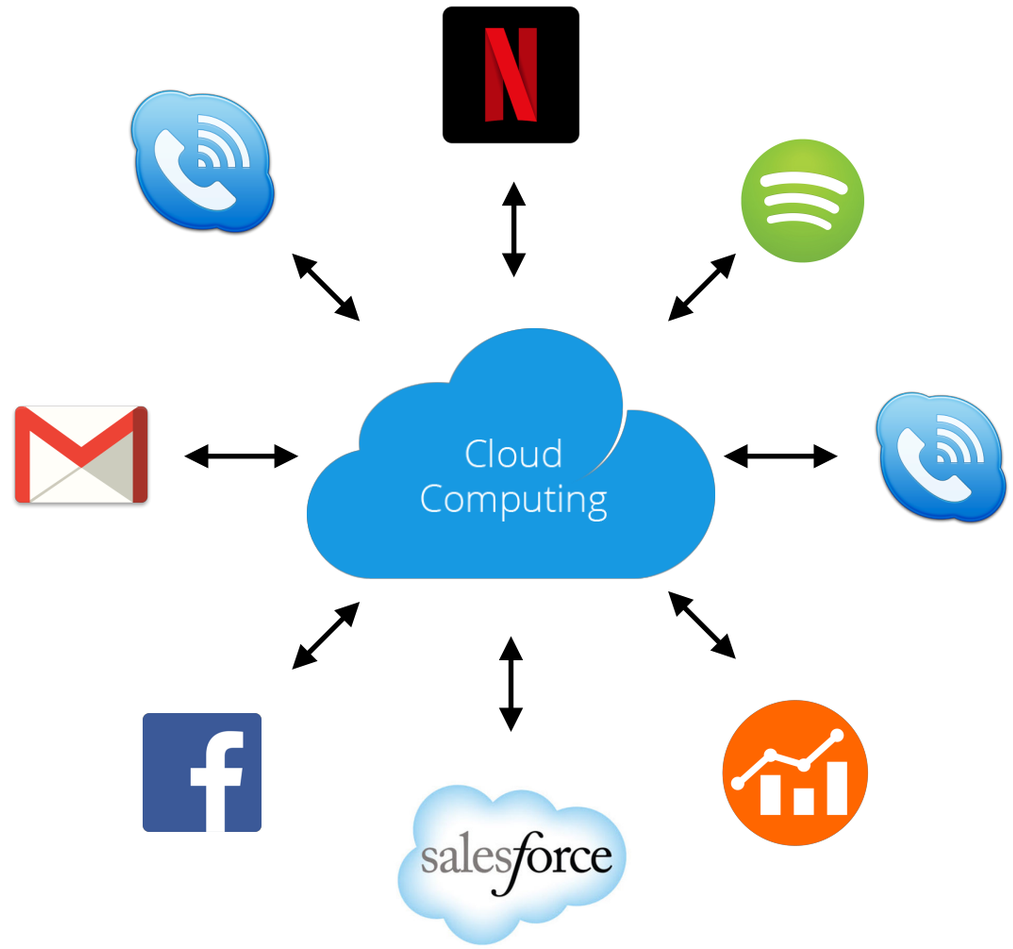
UNIVERSITY of ROCHESTER

Google

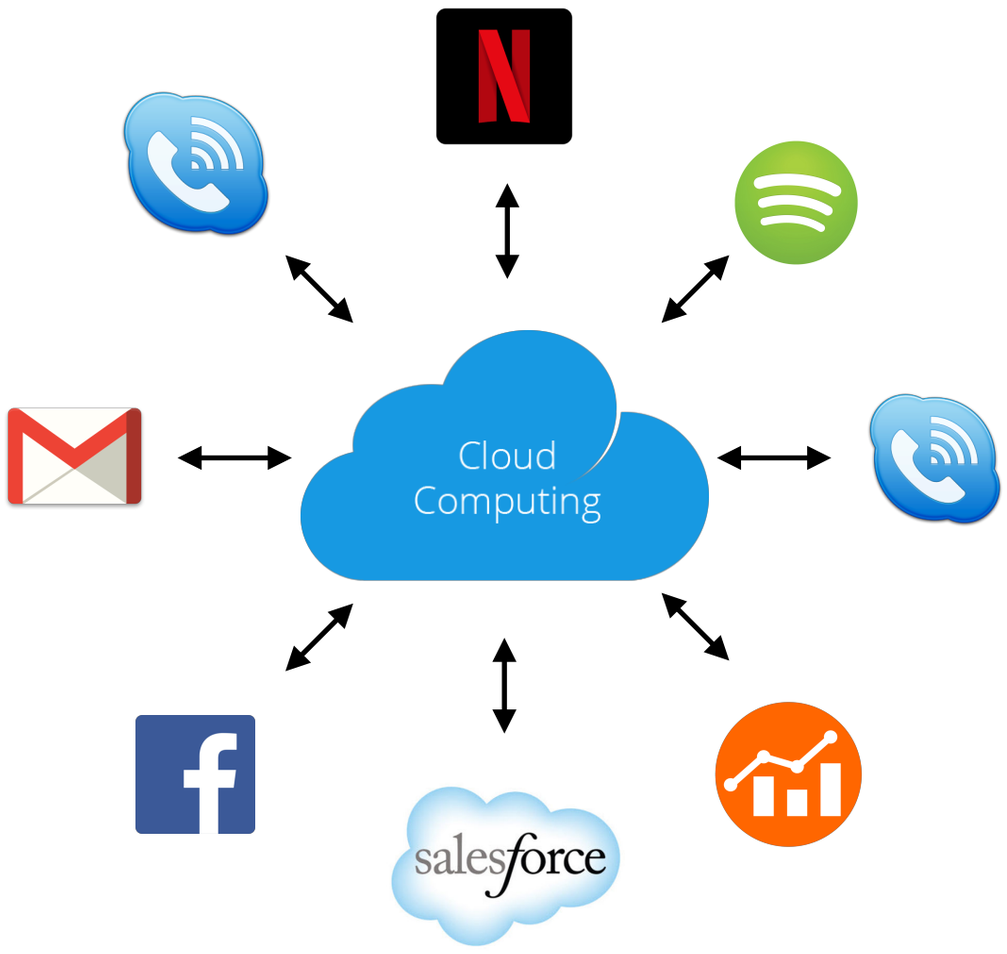
HARVARD UNIVERSITY


Cloud
Computing

Connecting People (2010s)



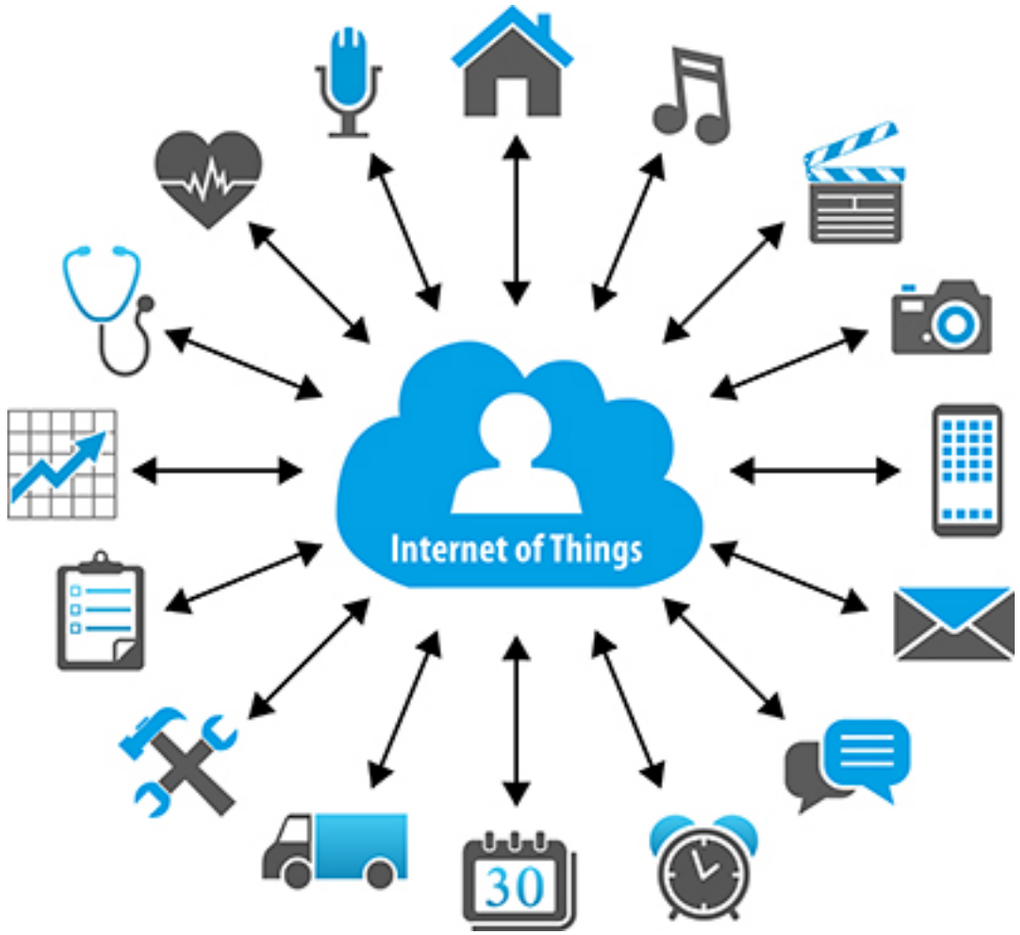
Connecting People (2010s)



1 billion
Gmail users

>1 billion
users

Connecting Things (2020s)



Connecting Things (2020s)

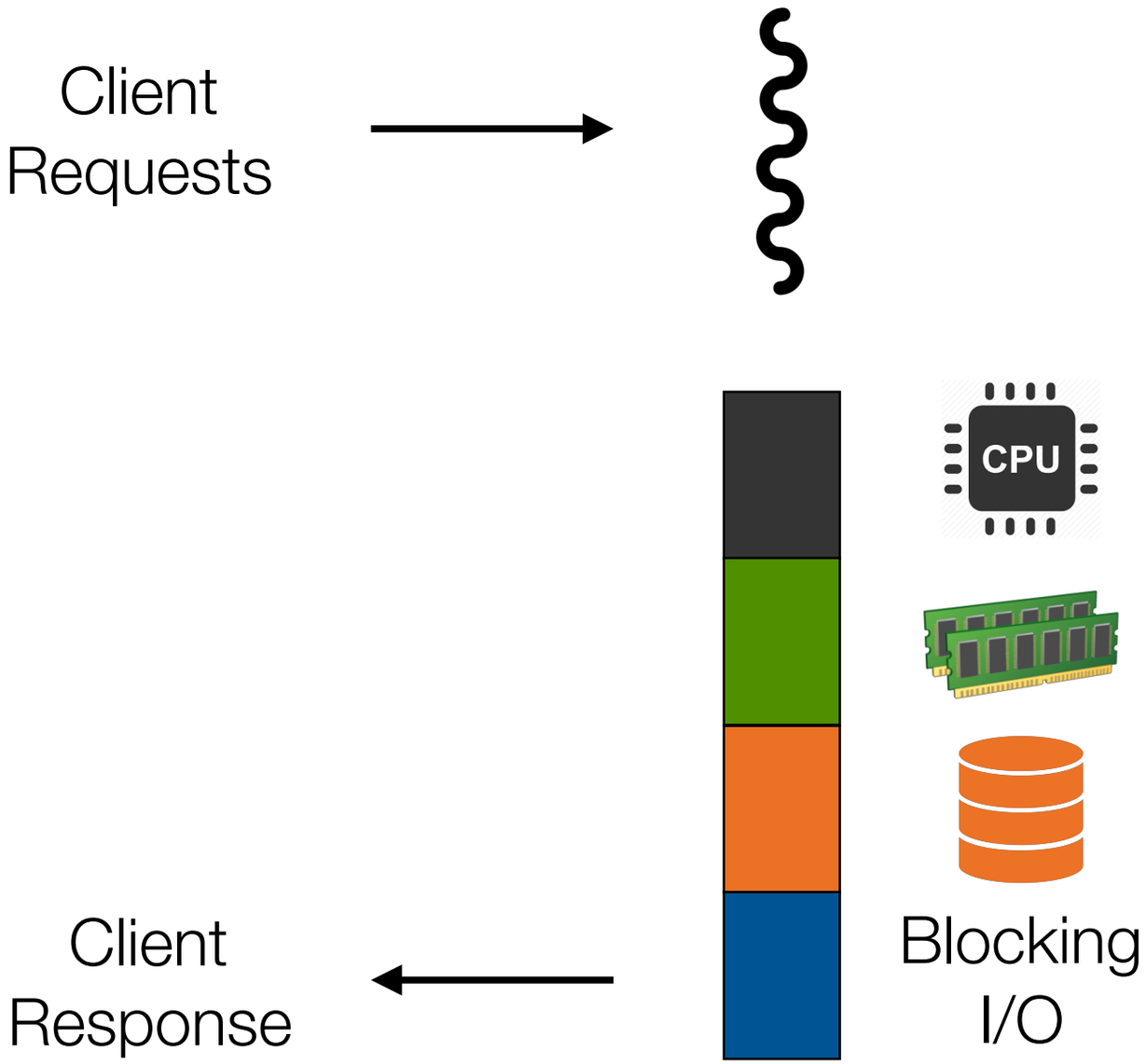
50 Billion Devices

"The Internet of Things" — Cisco
www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

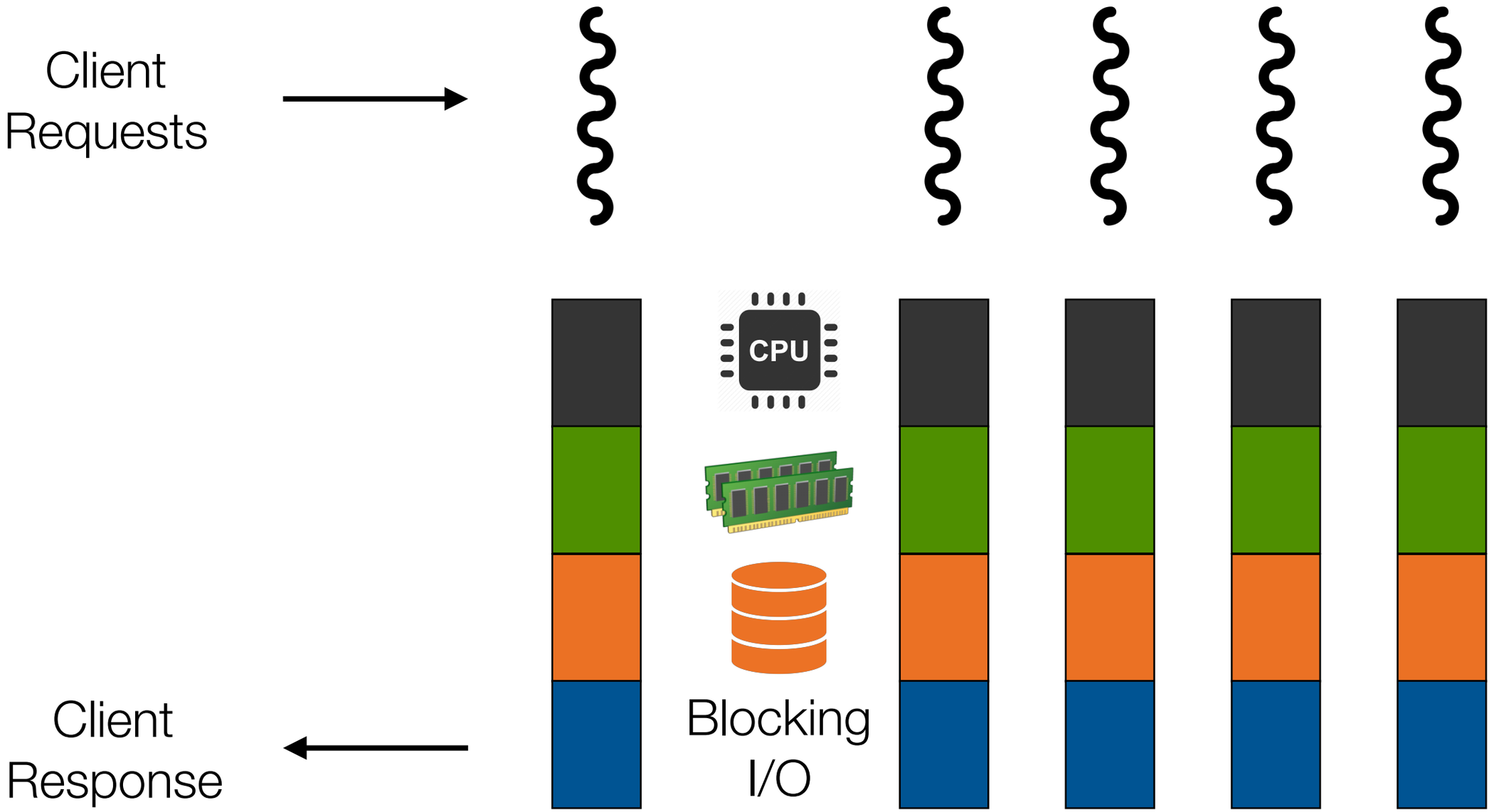
Thread-based Programming: Traditional Approach

Client Requests

Thread-based Programming: Traditional Approach



Thread-based Programming:
Traditional Approach



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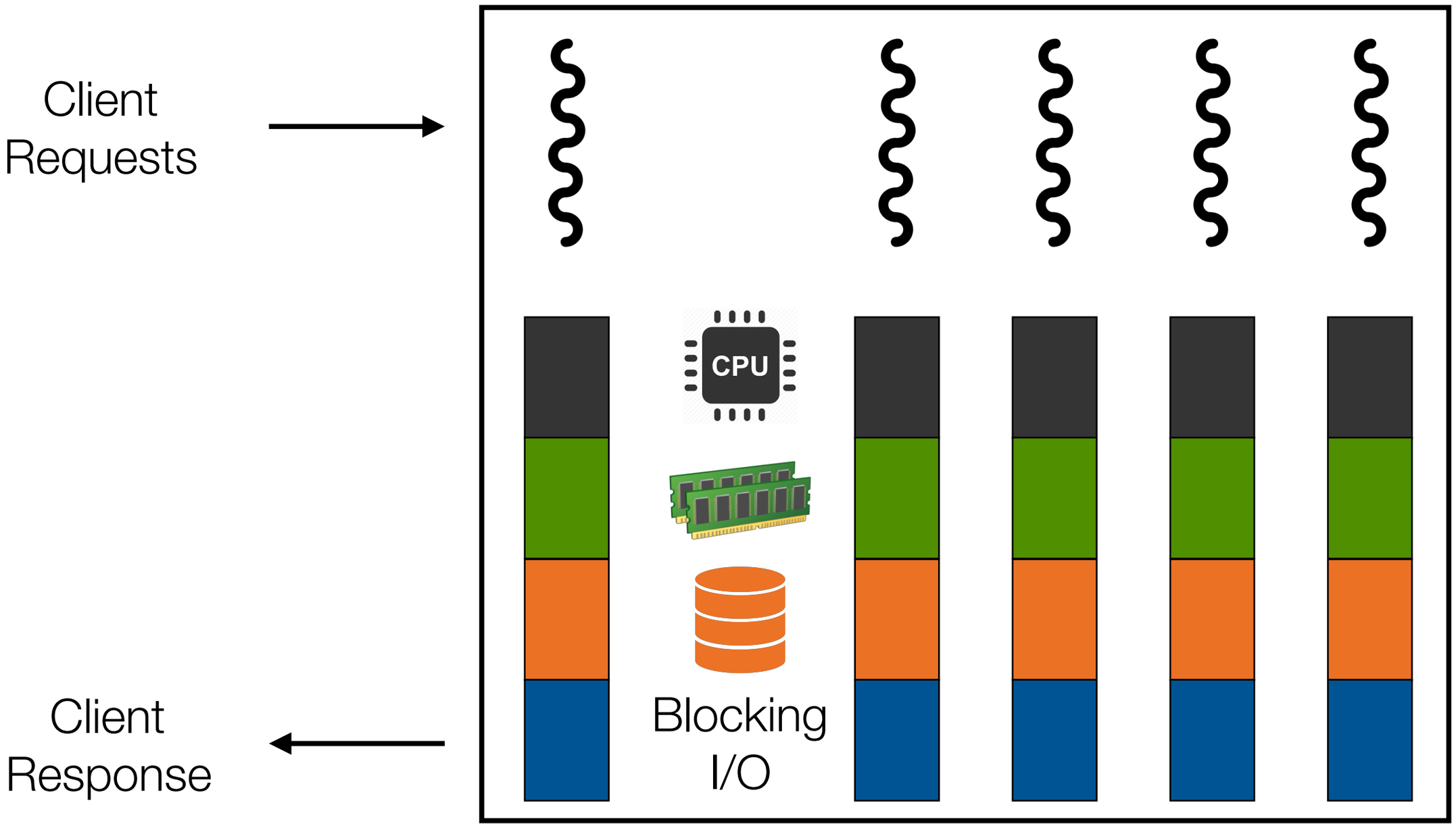
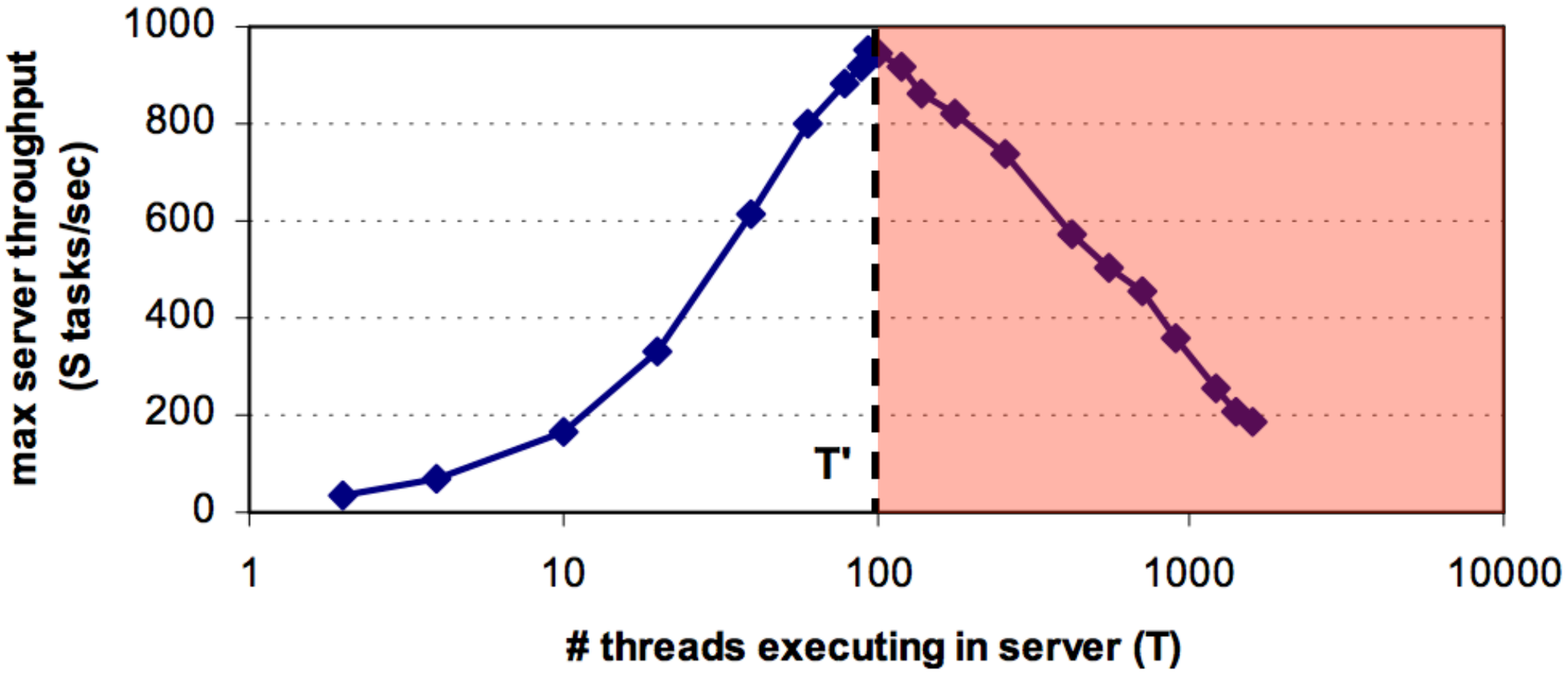


Limited resources & thrashing

Thread-based Programming

[Welsh et al. ’00]



Event-driven Programming: Emerging Approach

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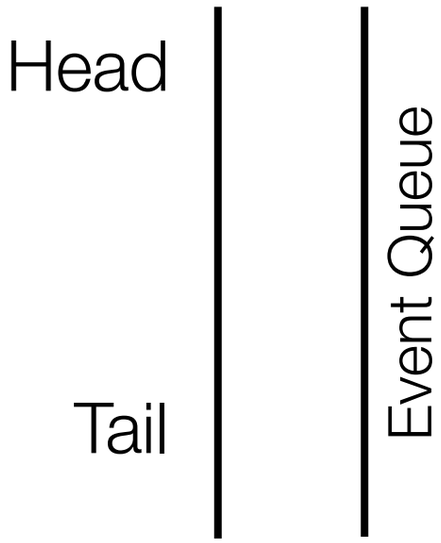

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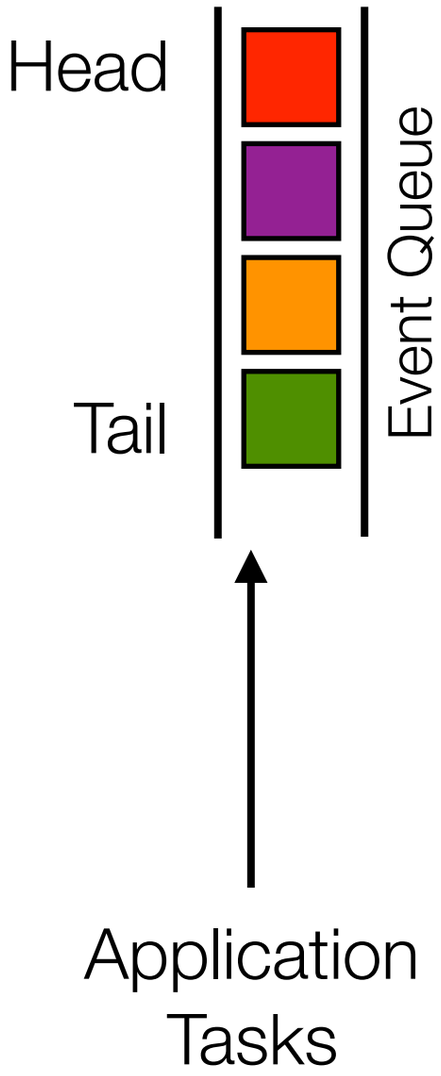
Emerging Approach



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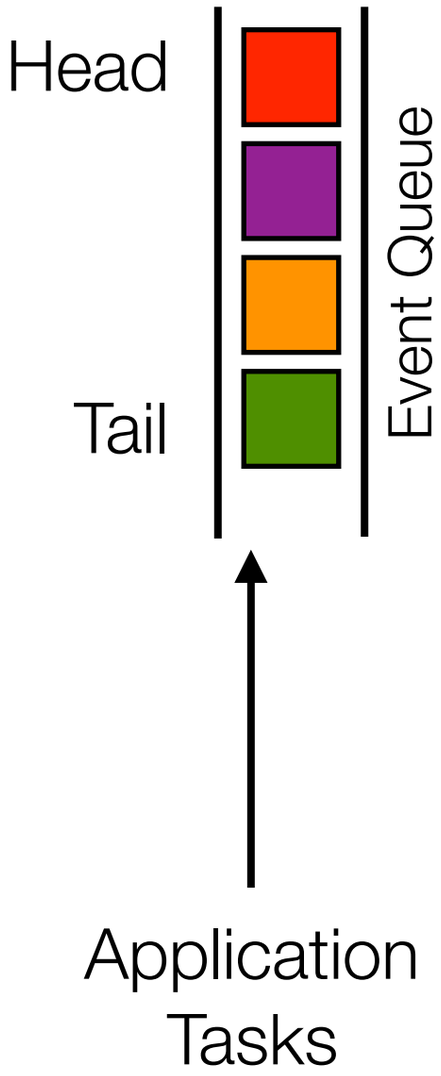
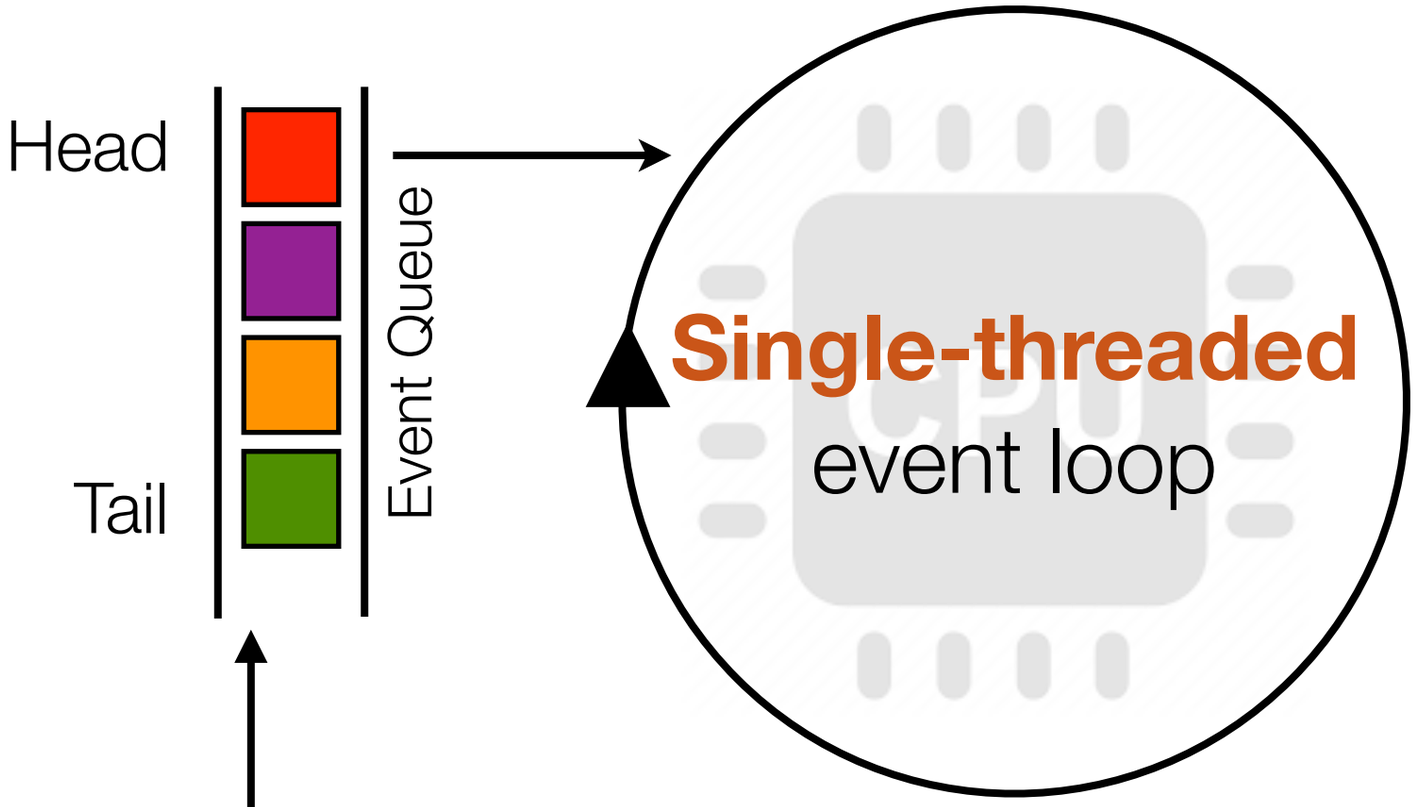



```
fs.readFile('input.txt',
  function (err, data) {
      if (err) return console.error(err);
      console.log(data.toString());
  }
);

console.log("Program continues…");
```

Event-driven Programming:
Emerging Approach

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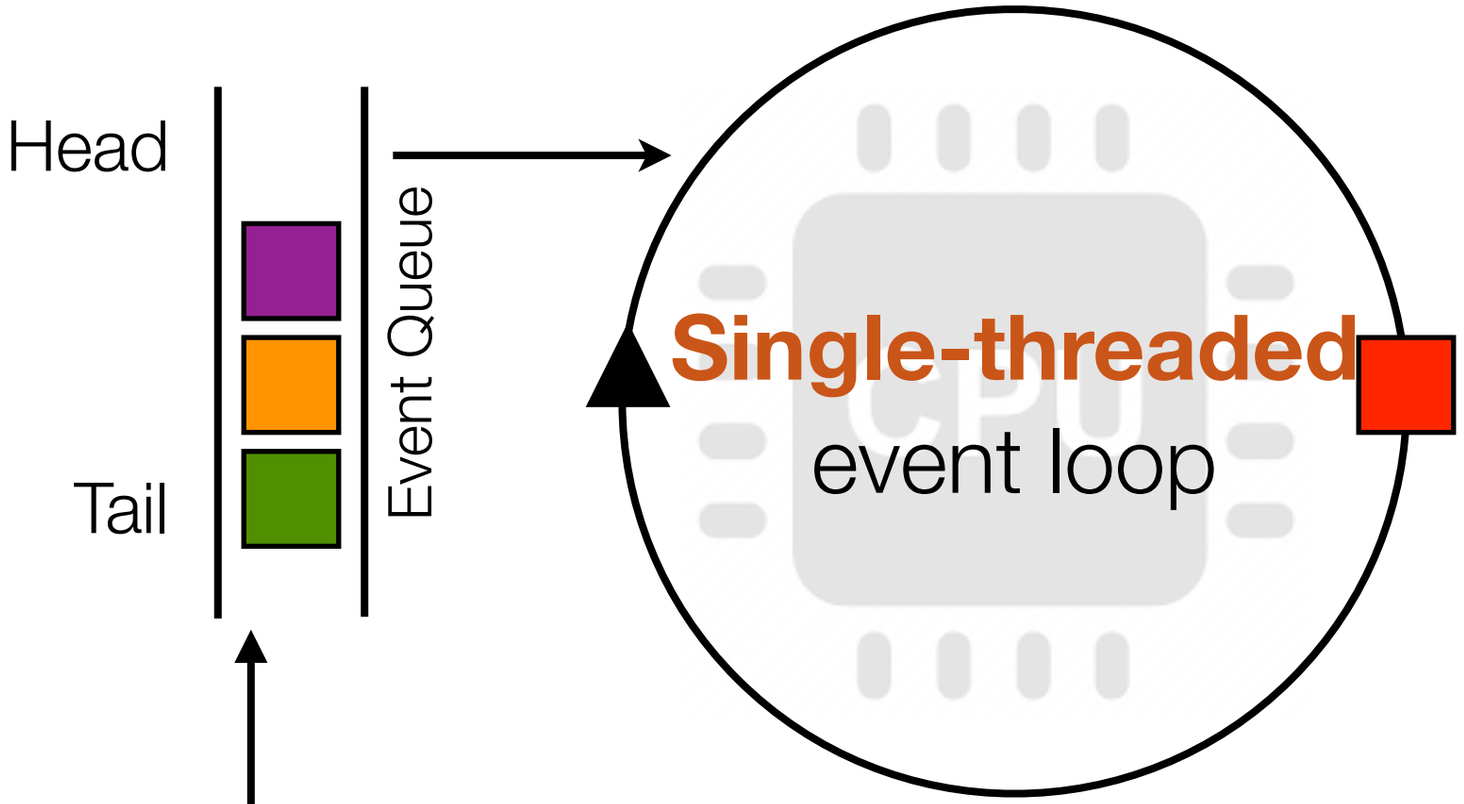


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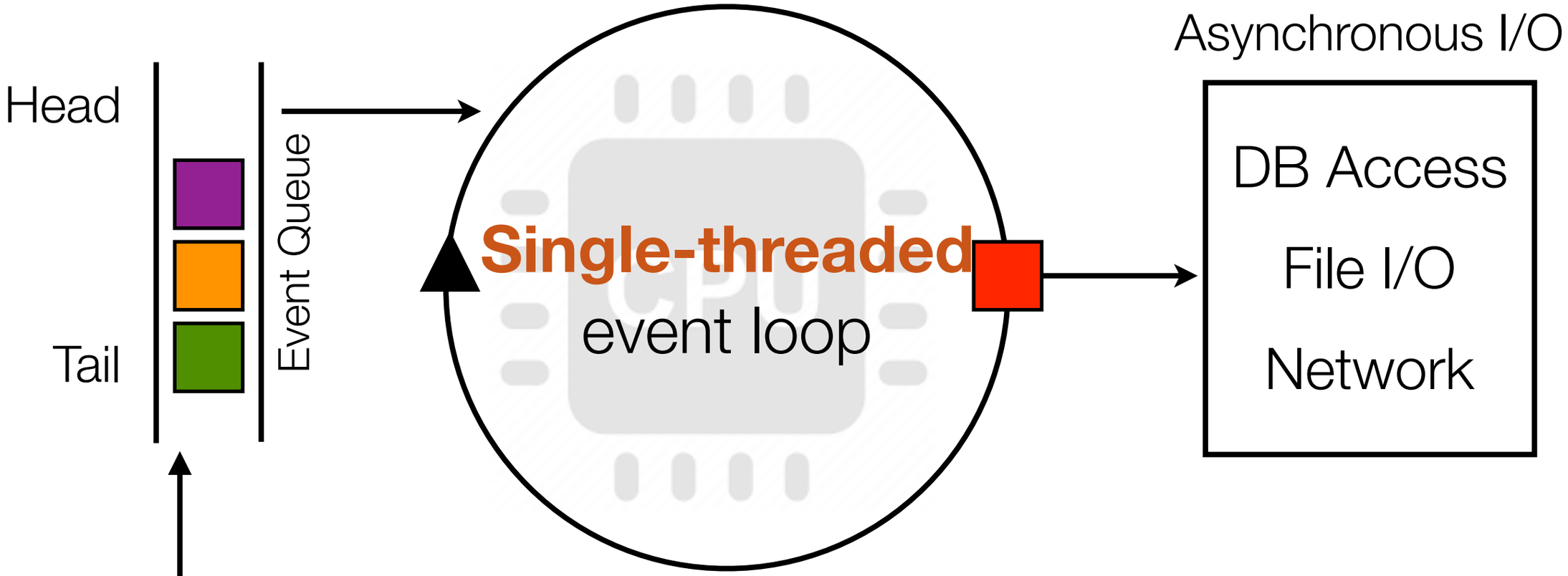


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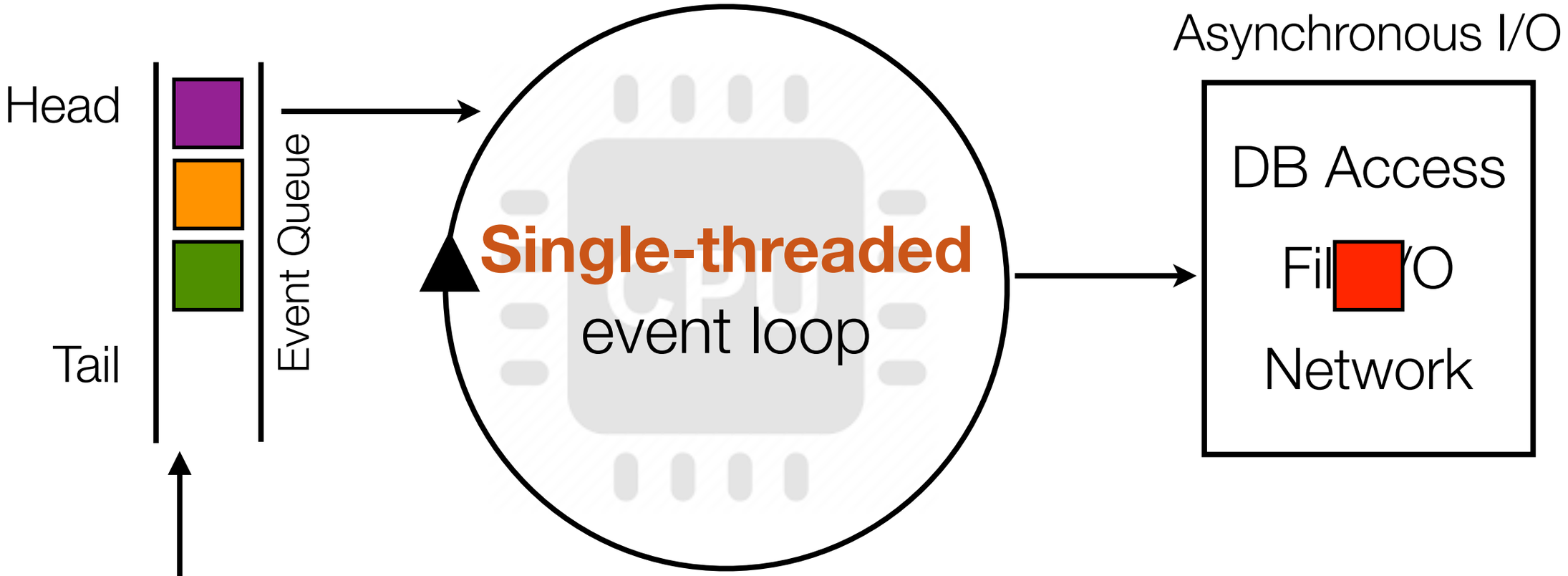


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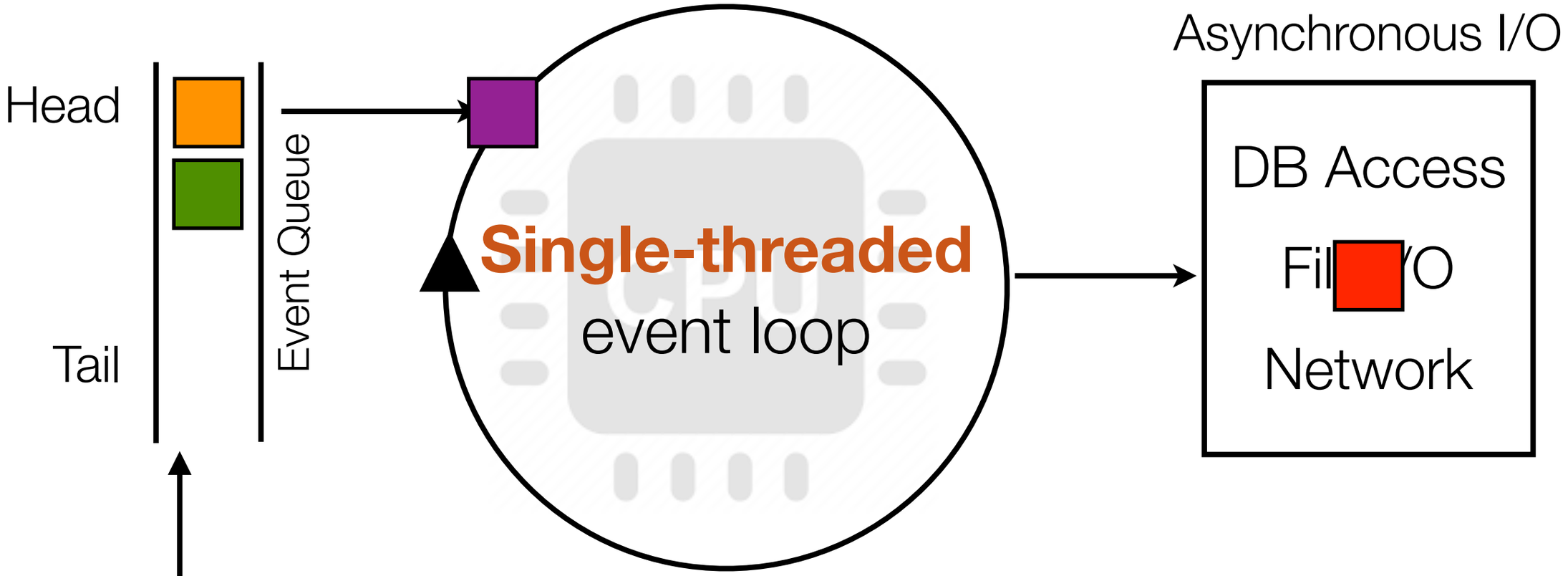


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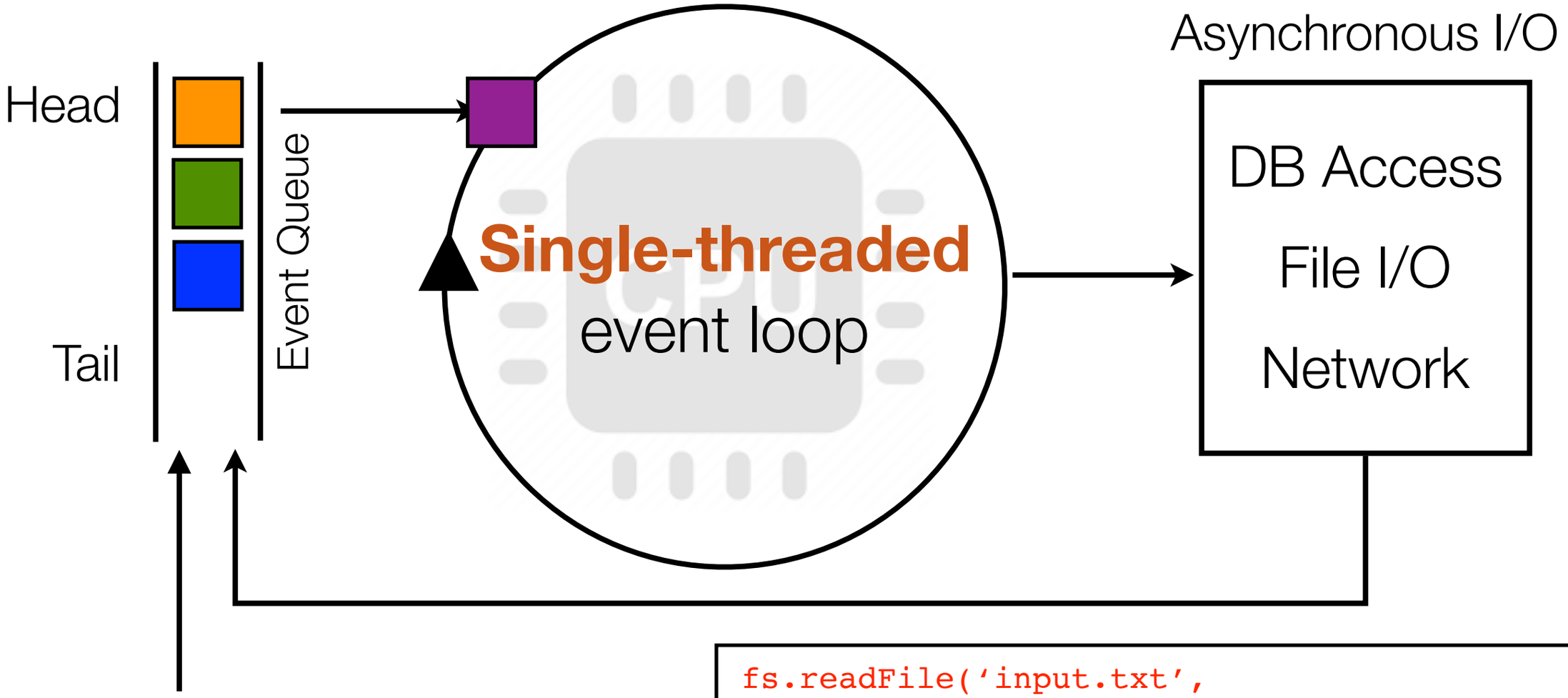


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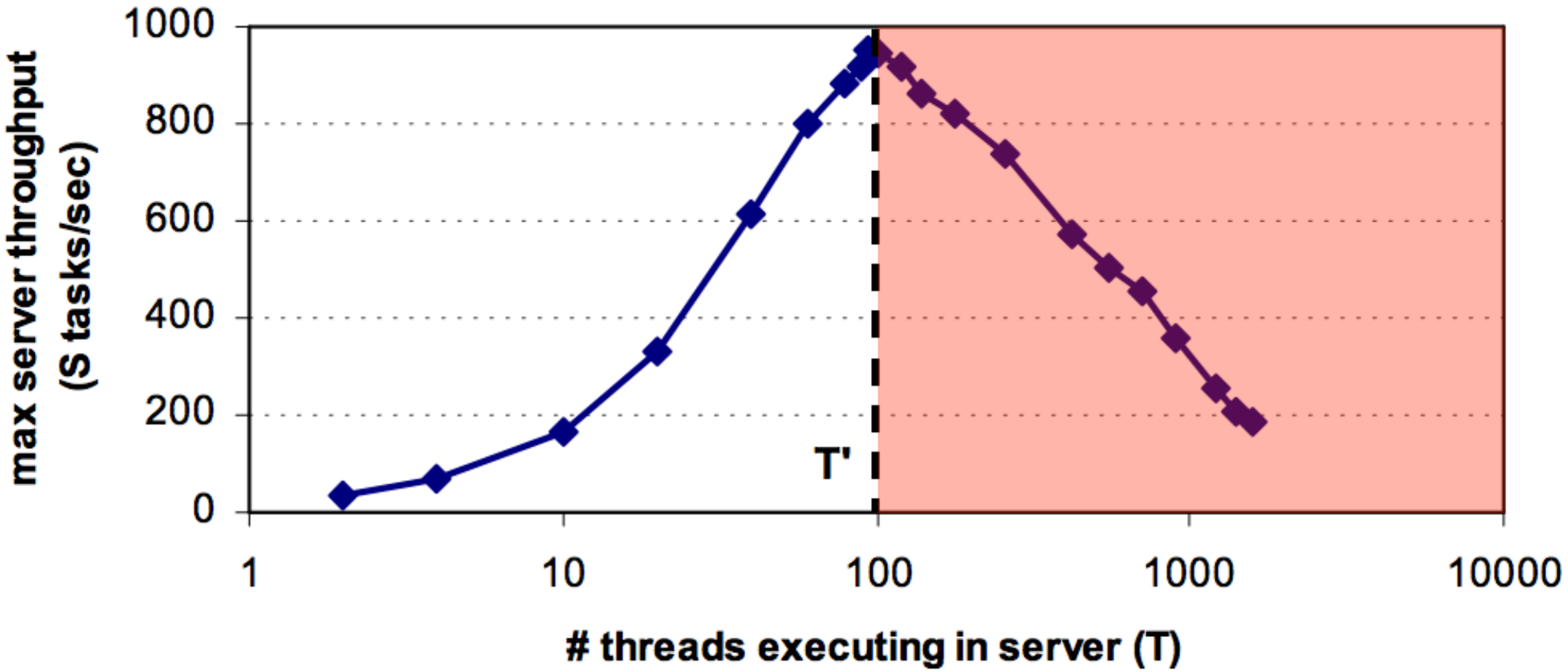
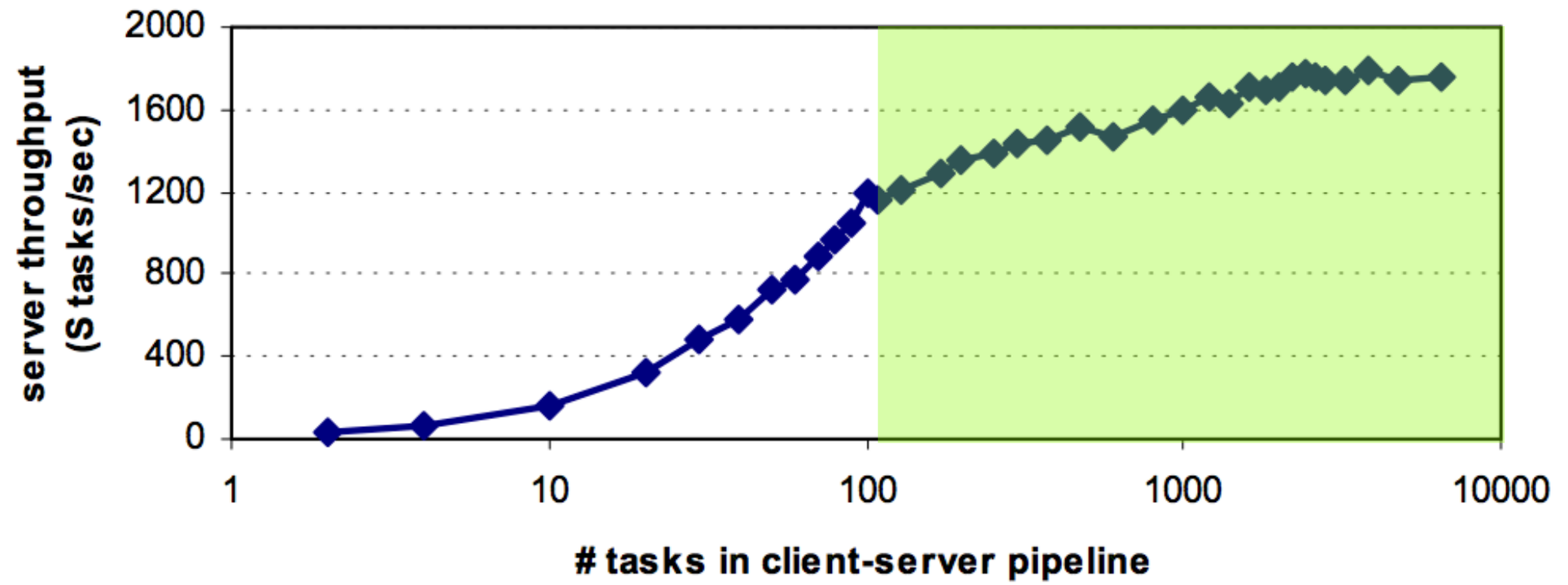
[Welsh et al. ’00]

Thread-based Programming



Event-driven Programming



The Changing Programming Language Landscape

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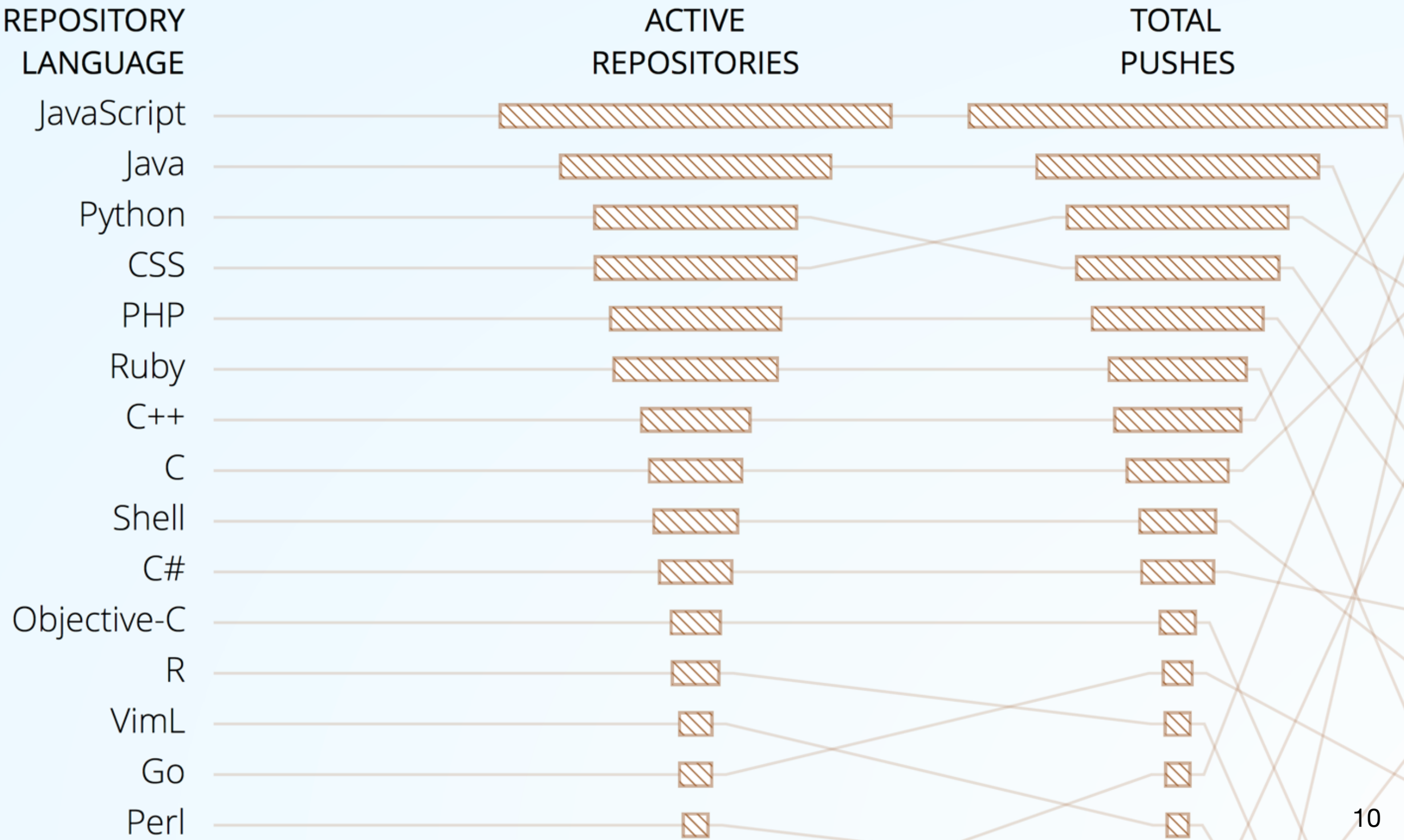

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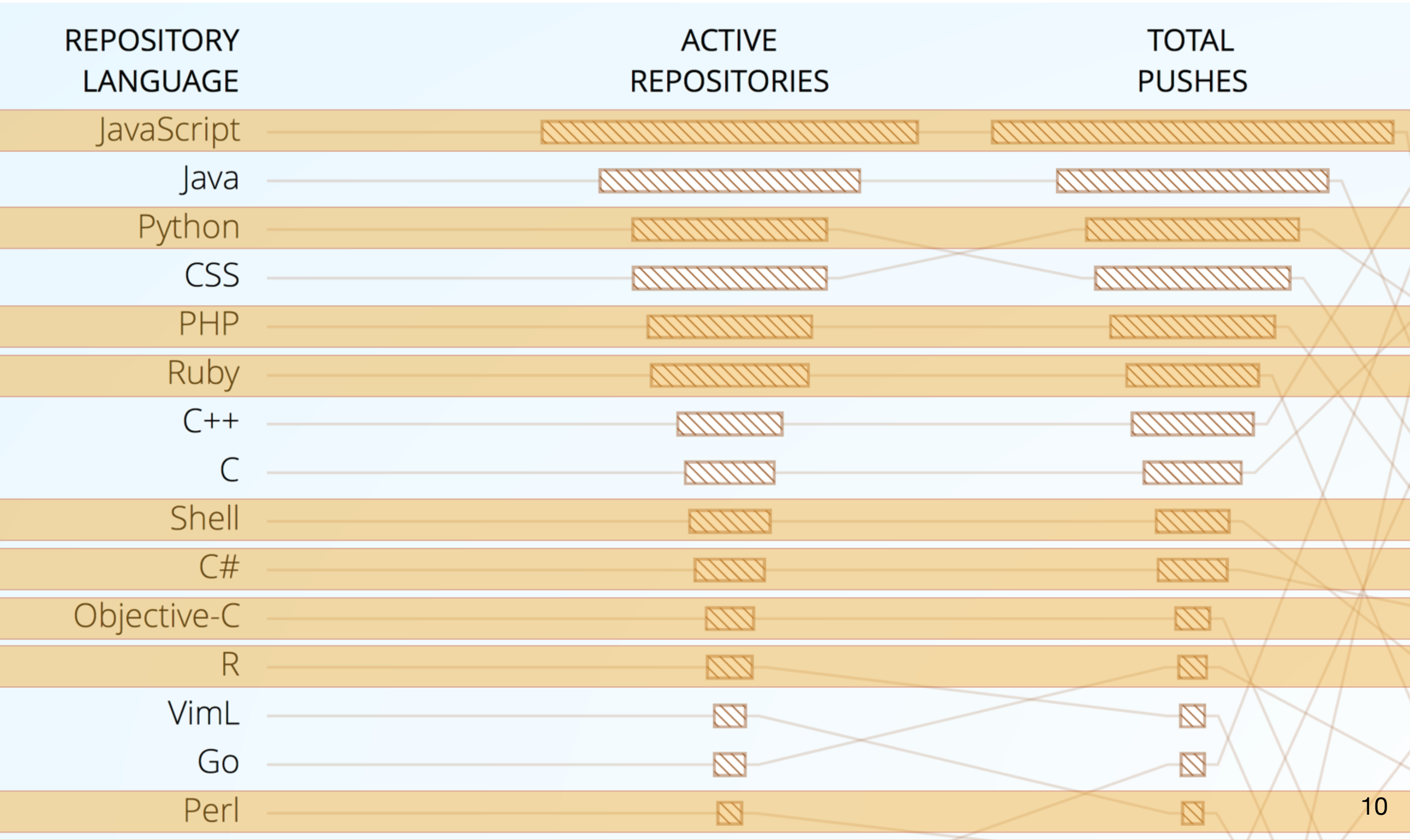
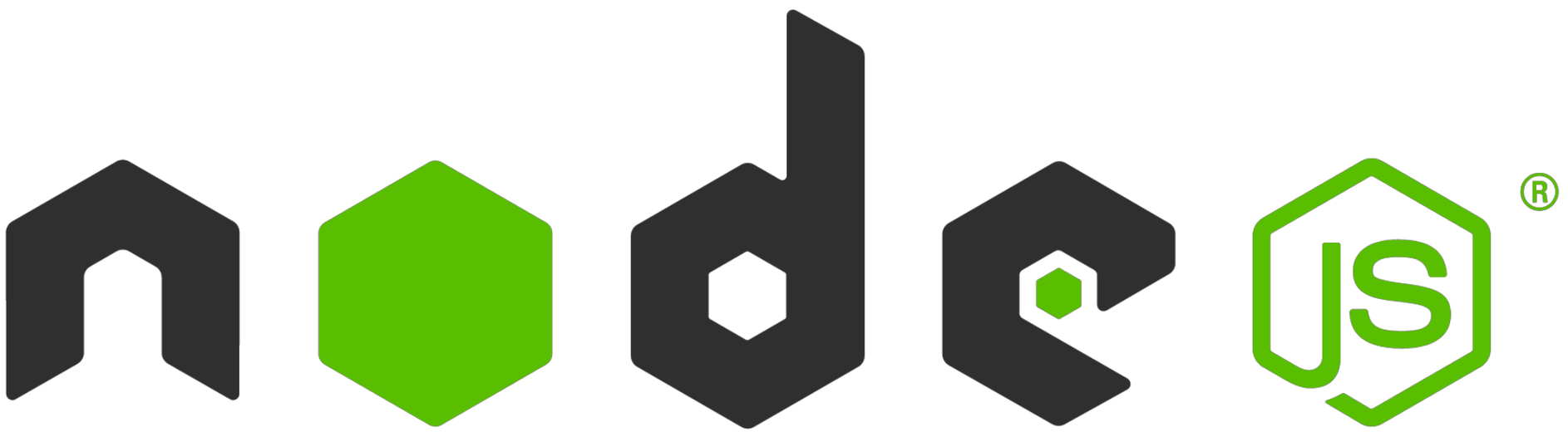
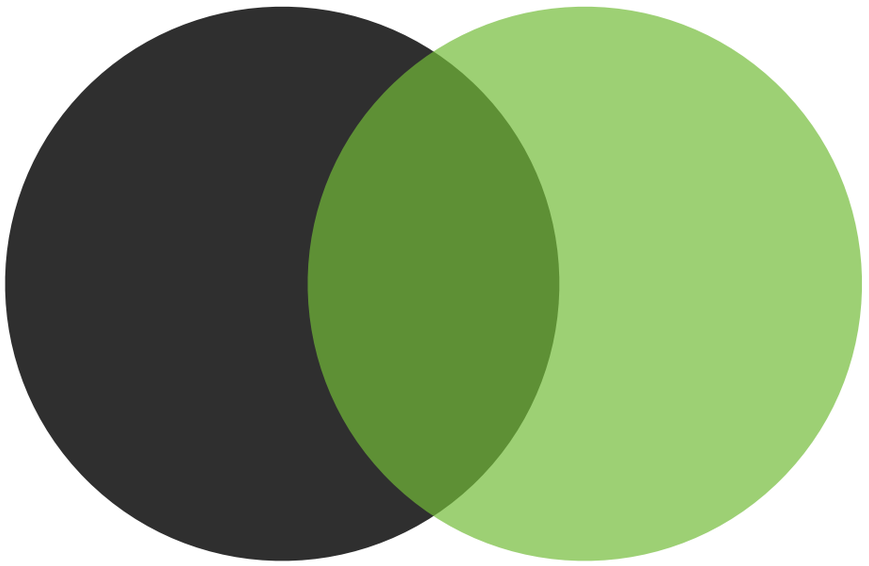




Event-driven Execution Model



Managed Language


PayPal

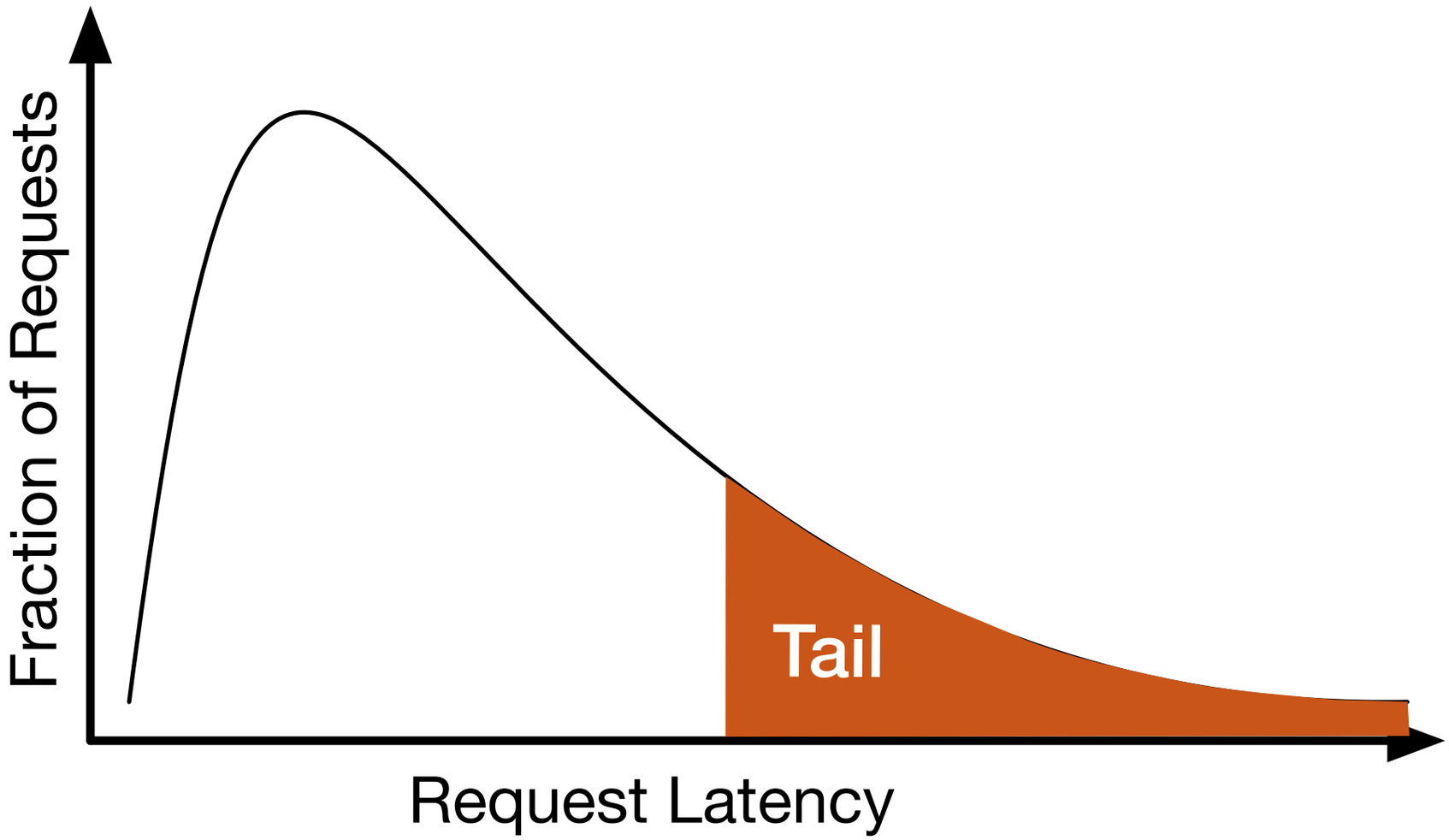

ebay


Linked in

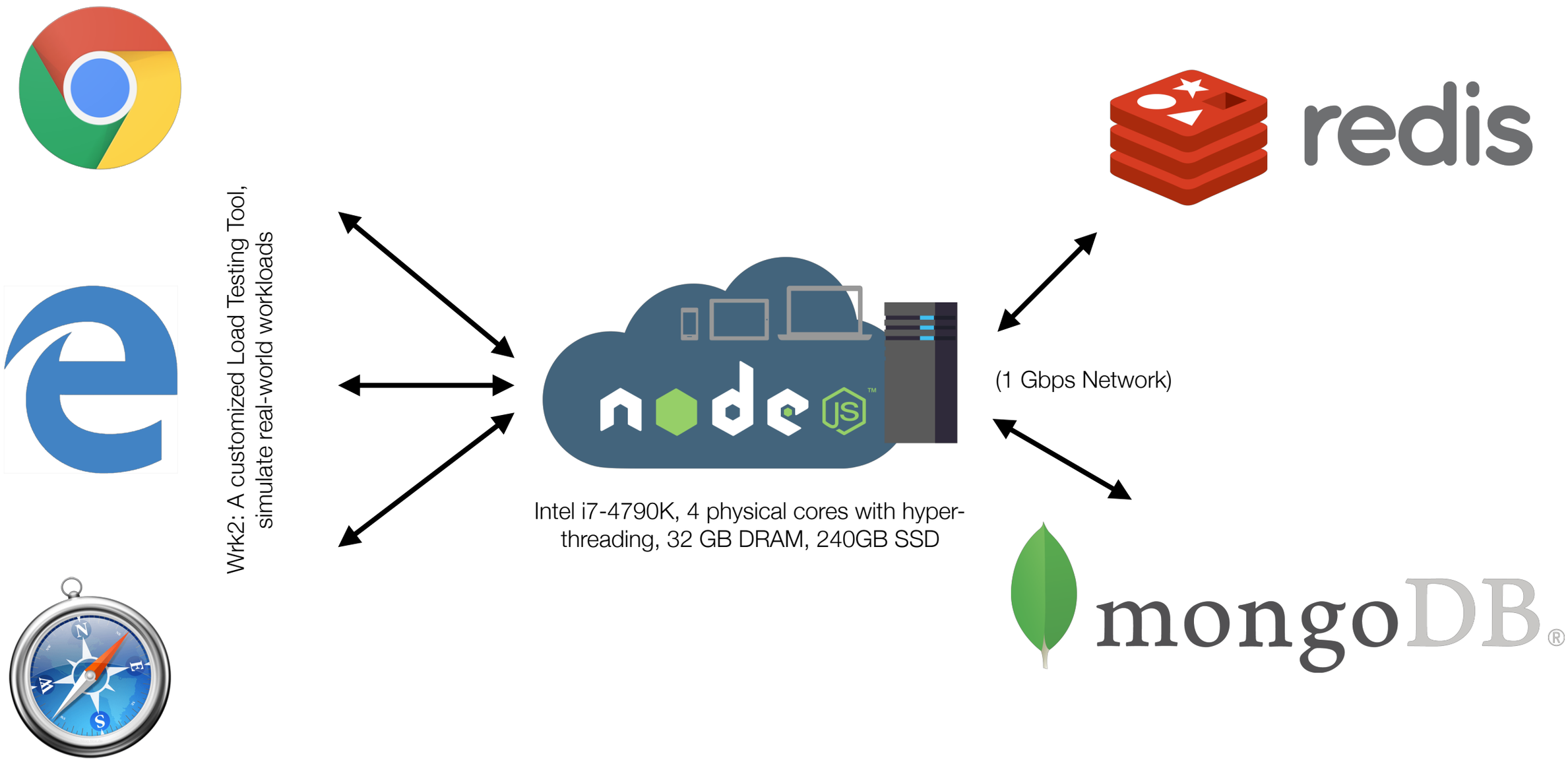

UBER


NETFLIX

Taming Tail Latencies in Event-Driven Web Services



Experimental Setup

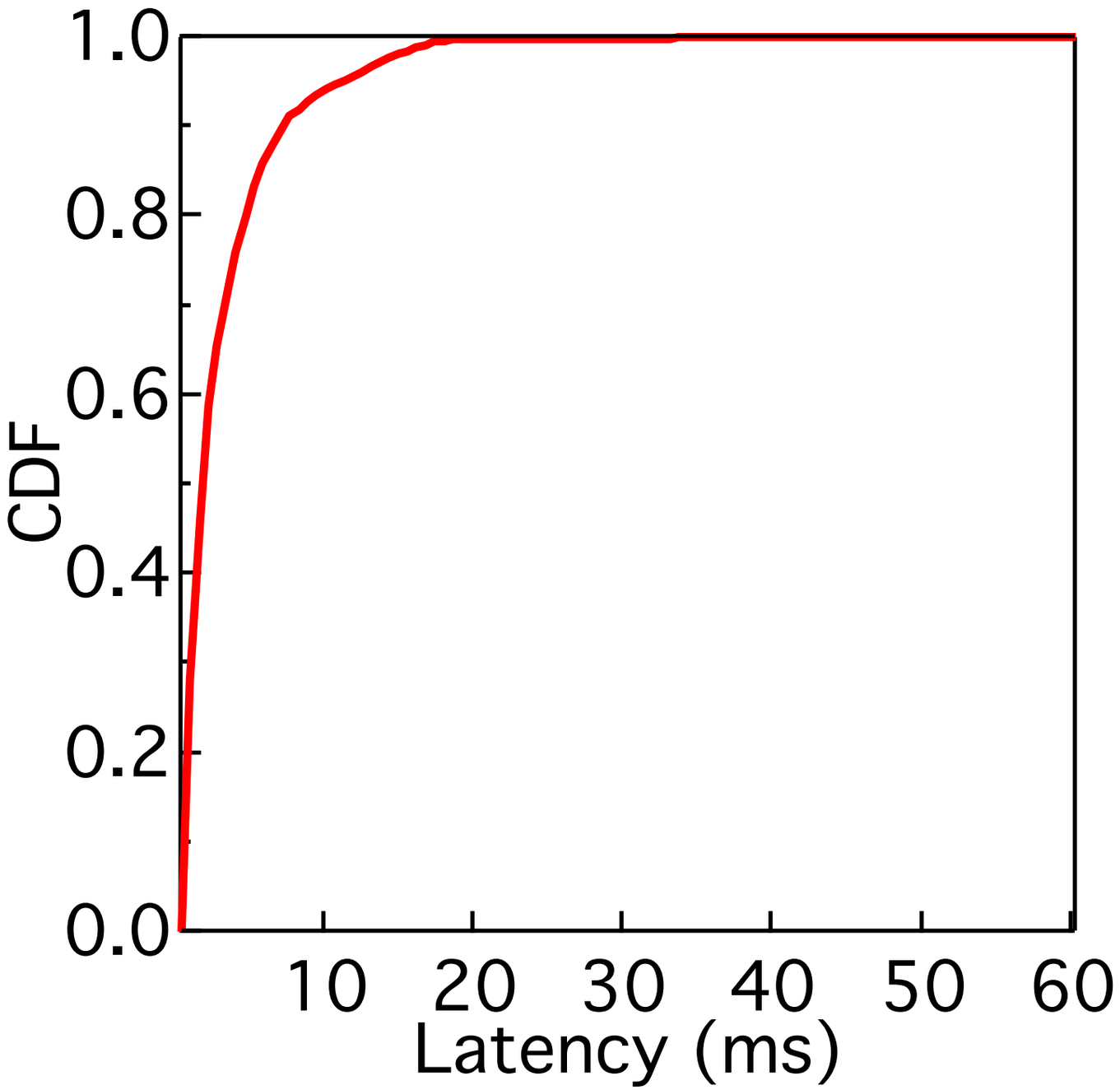


Applications

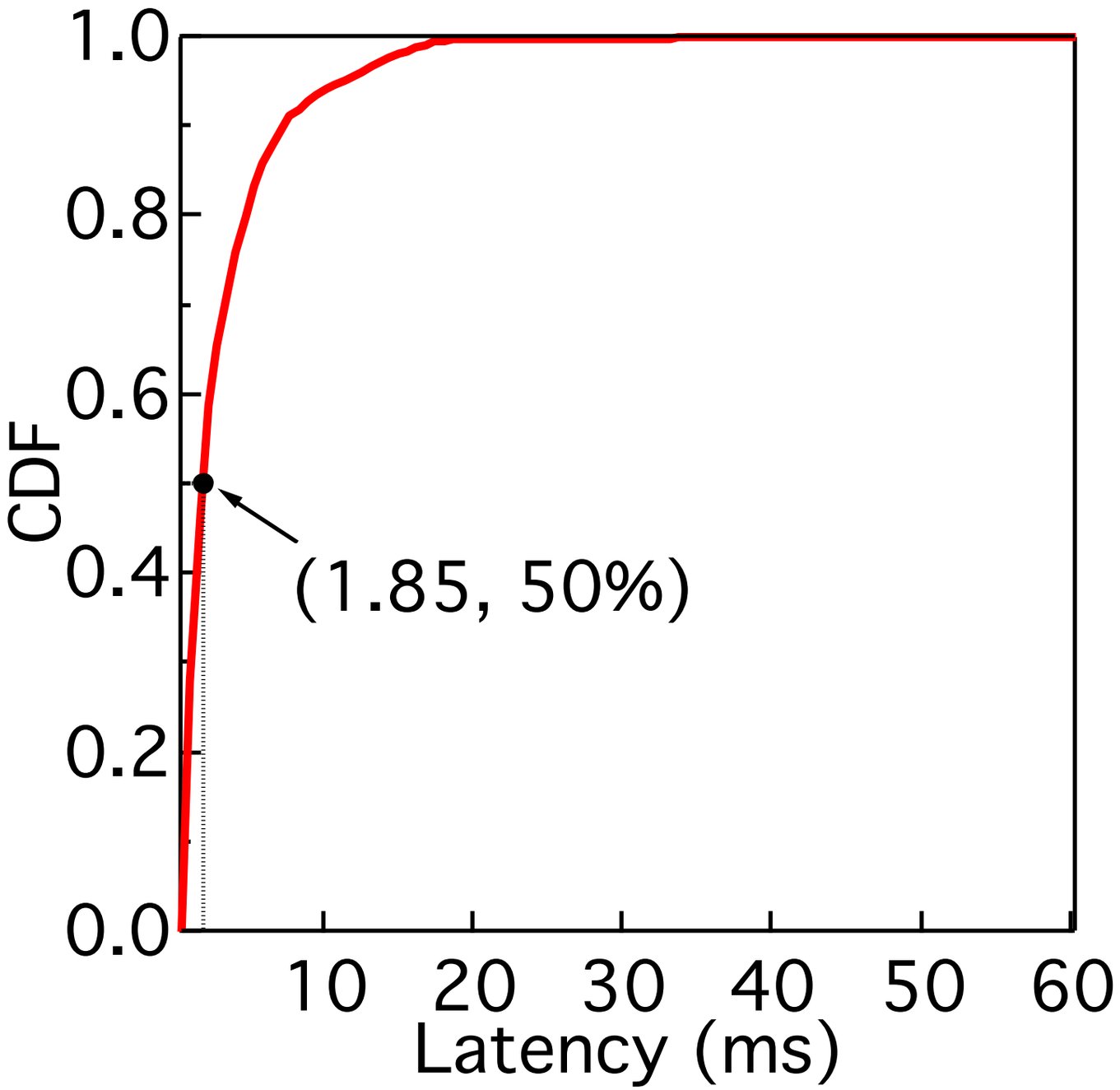
Benchmarks	I/O Type	#Requests	Description
Etherpad lite	N/A	20K	Real time word processor.
Todo	Redis	40K	Online Task Manager.
Lighter	Disk	40K	Blogging Engine.
Let’s Chat	MongoDB	10K	Web-based Chat Application.
Client Manager	MongoDB	40K	Online Address book.

Github Repo: https://github.com/nodebenchmark/benchmarks

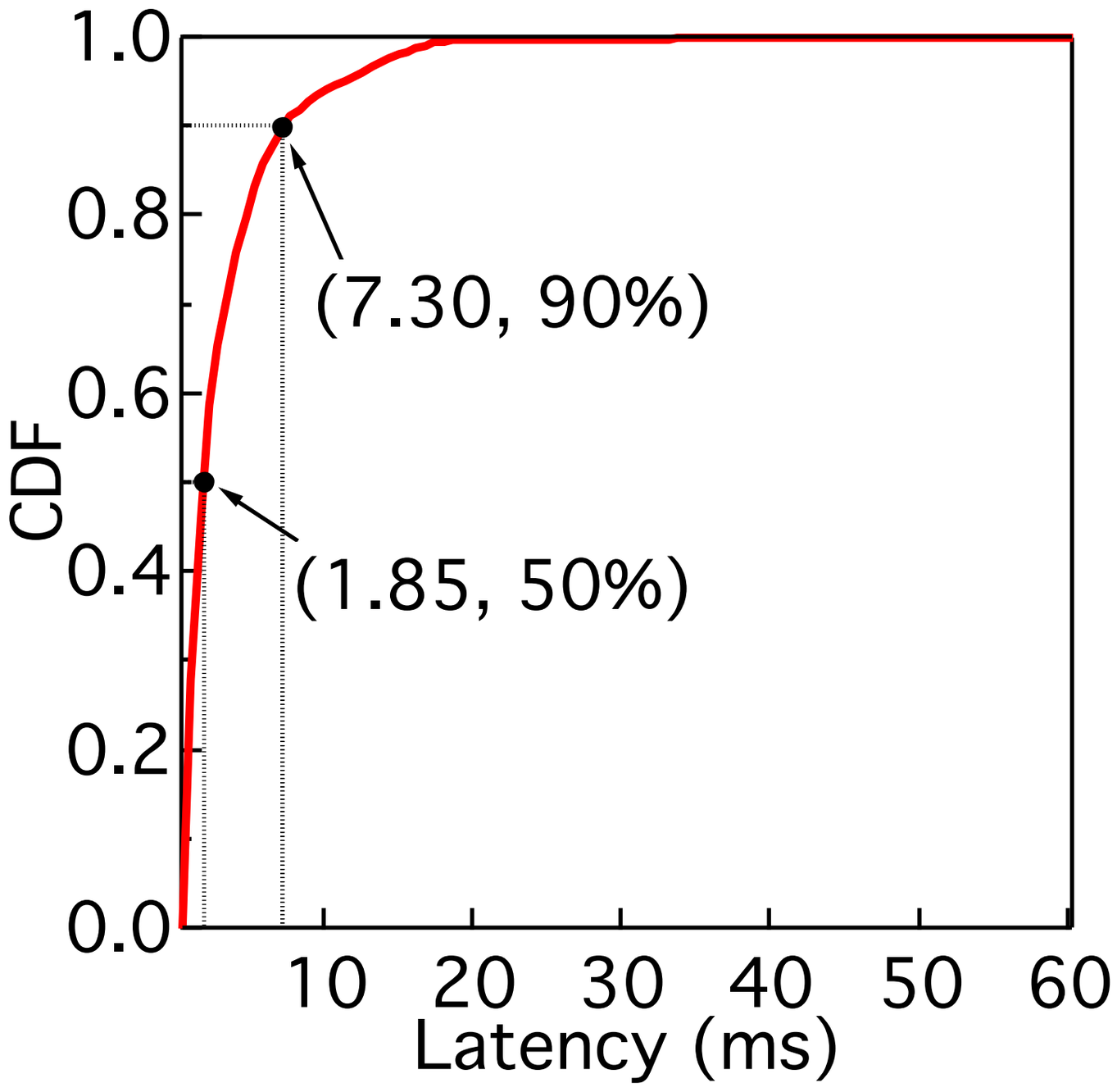
Etherpad: An Example



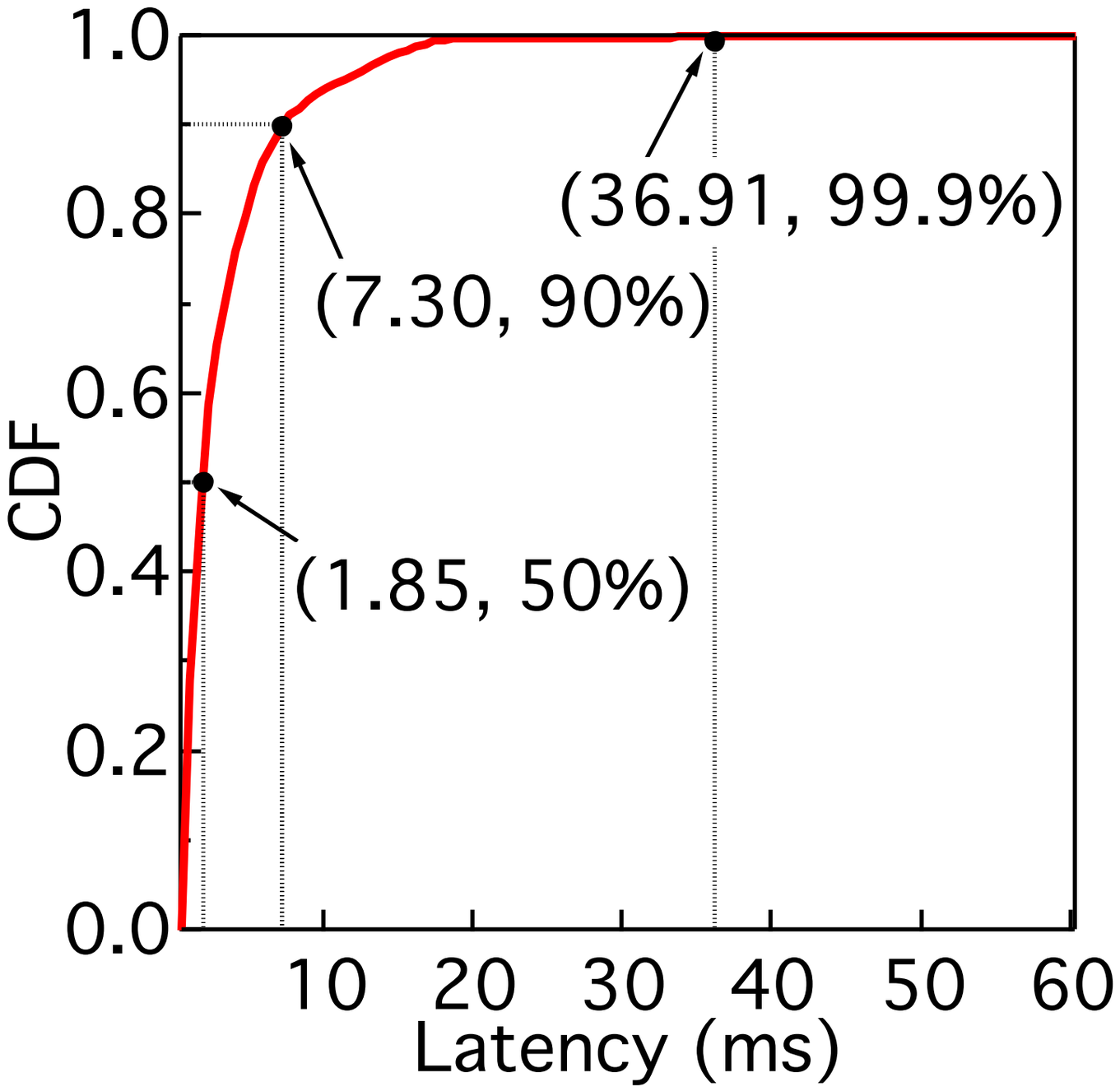
Etherpad: An Example



Etherpad: An Example



Etherpad: An Example



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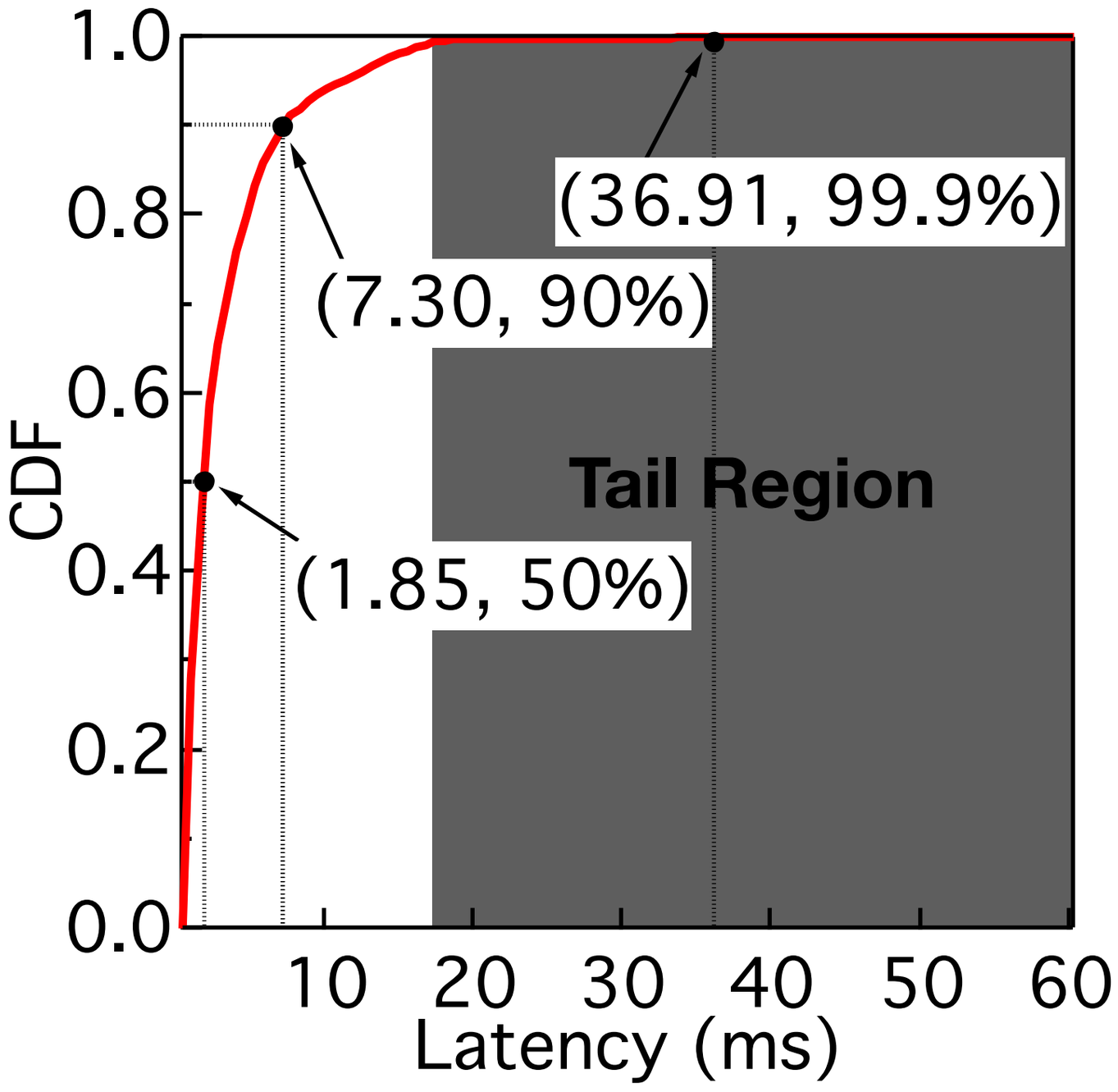
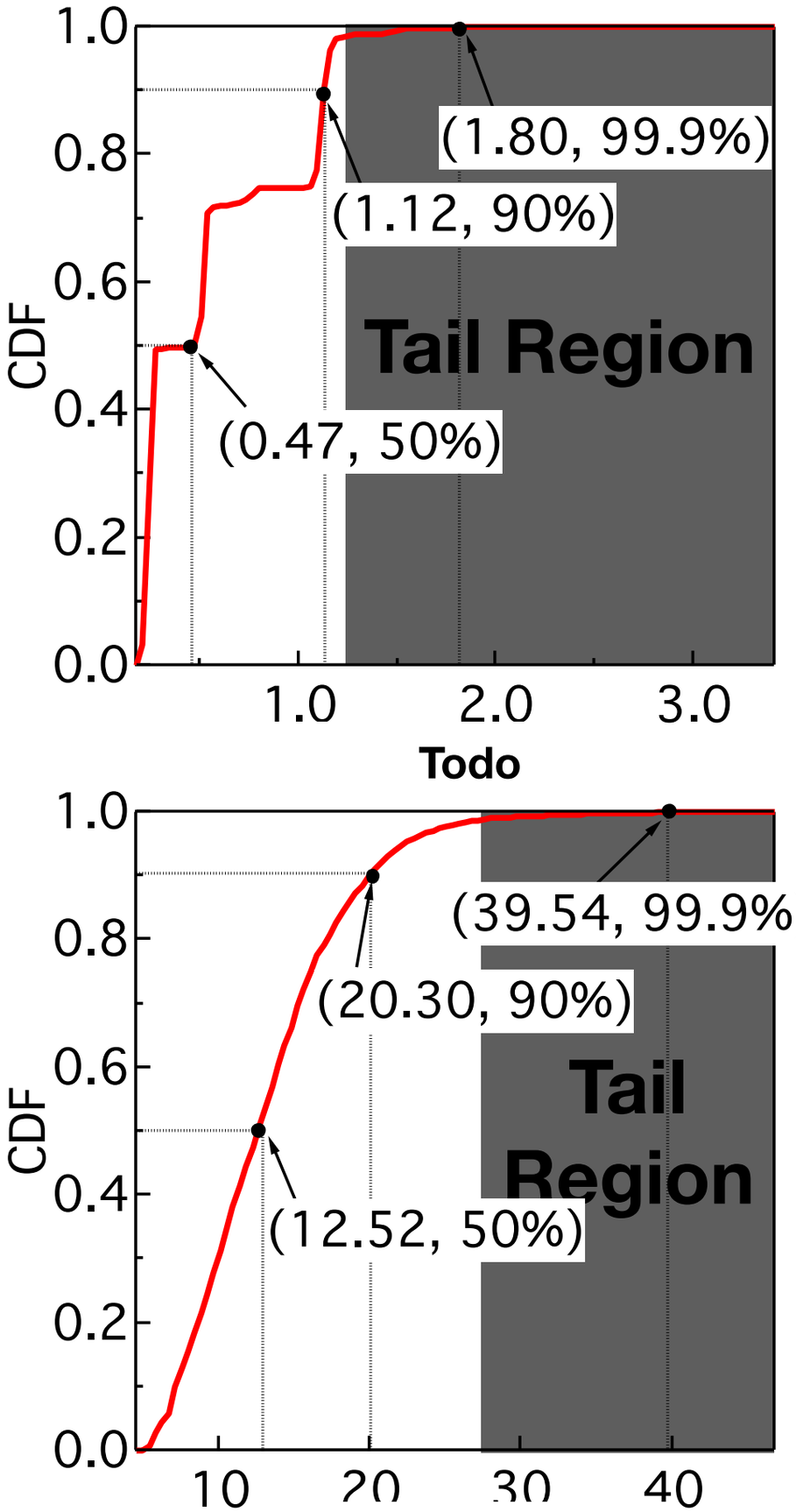
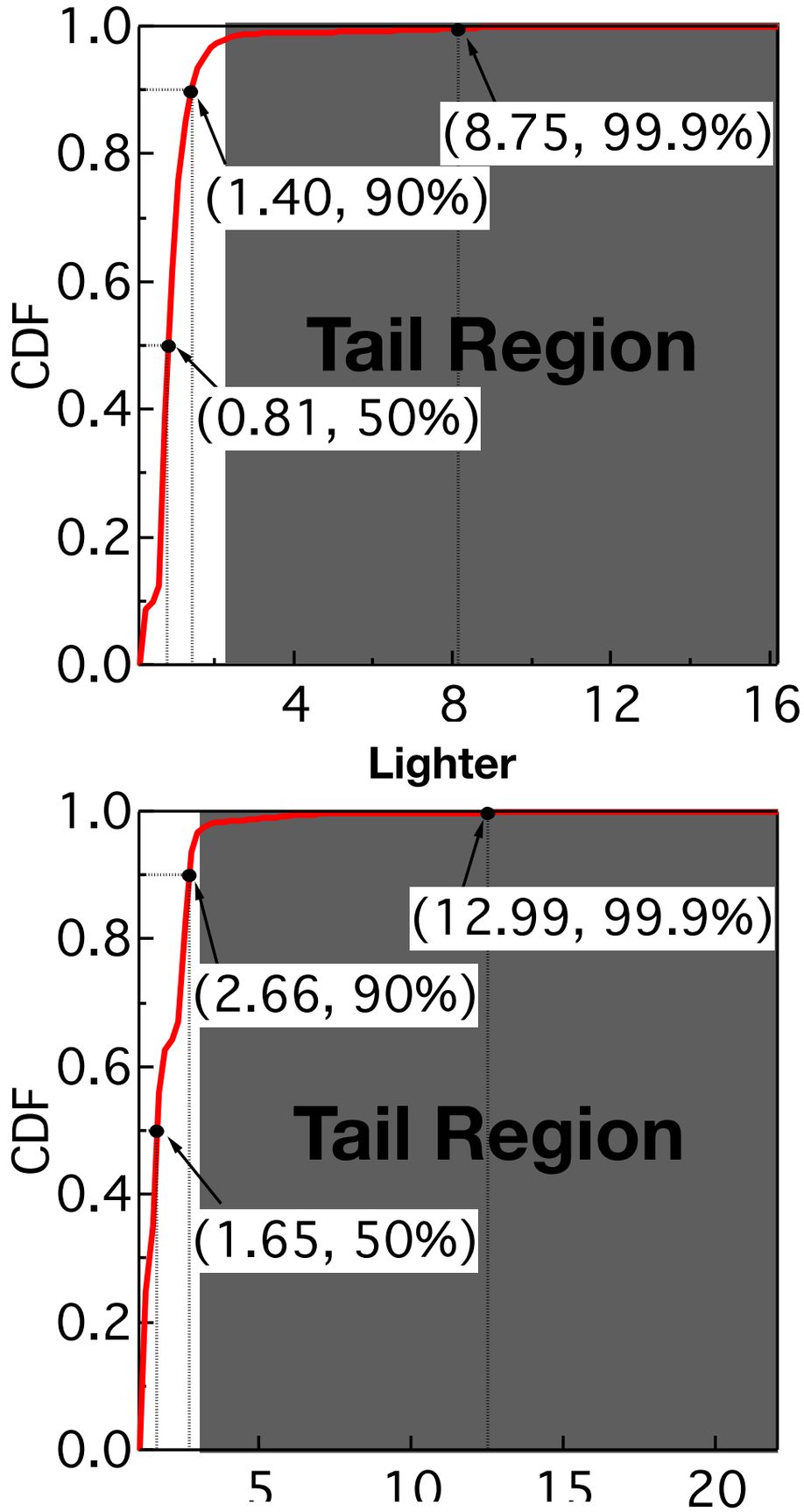
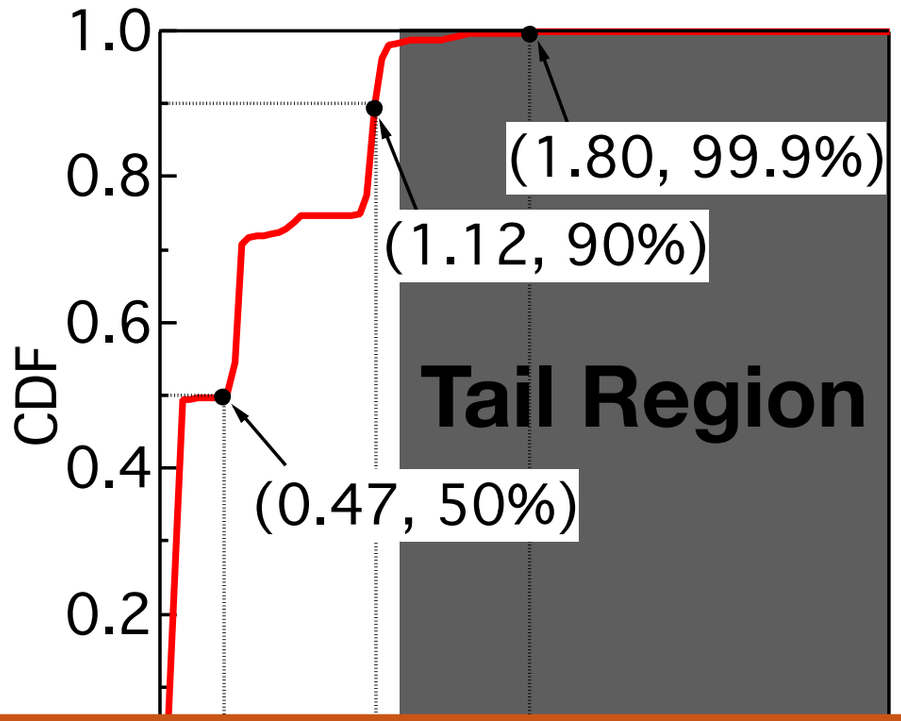


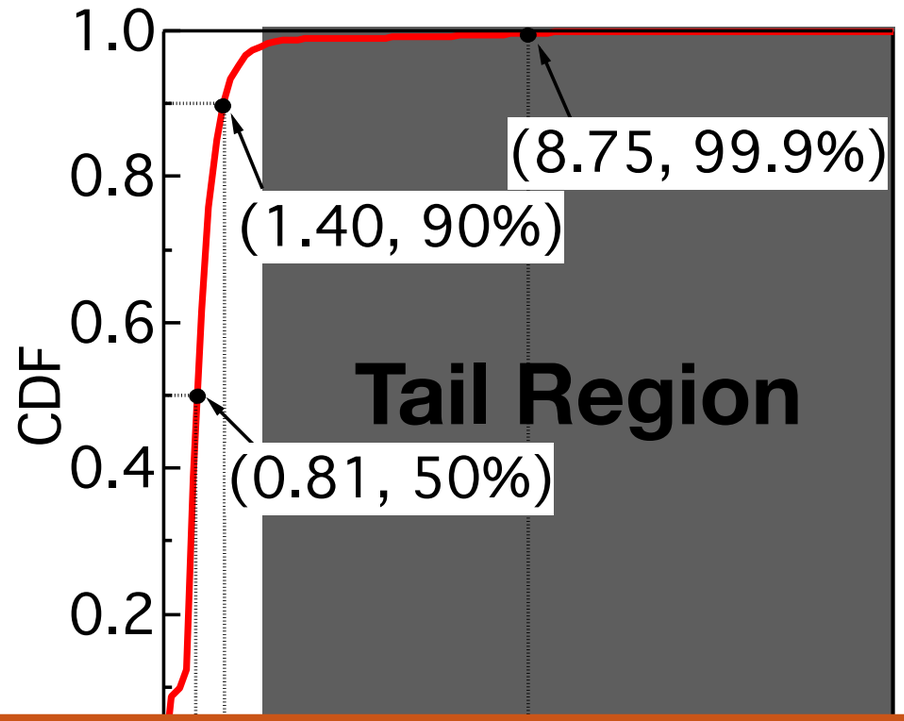

1.0
0.8
0.6
0.4
0.2
0.0
CDF
1.0
2.0
3.0
Todo
(1.80, 99.9%)
(1.12, 90%)
(0.47, 50%)
Tail Region


1.0
0.8
0.6
0.4
0.2
0.0
CDF
4
8
12
16
Lighter
(8.75, 99.9%)
(1.40, 90%)
(0.81, 50%)
Tail Region

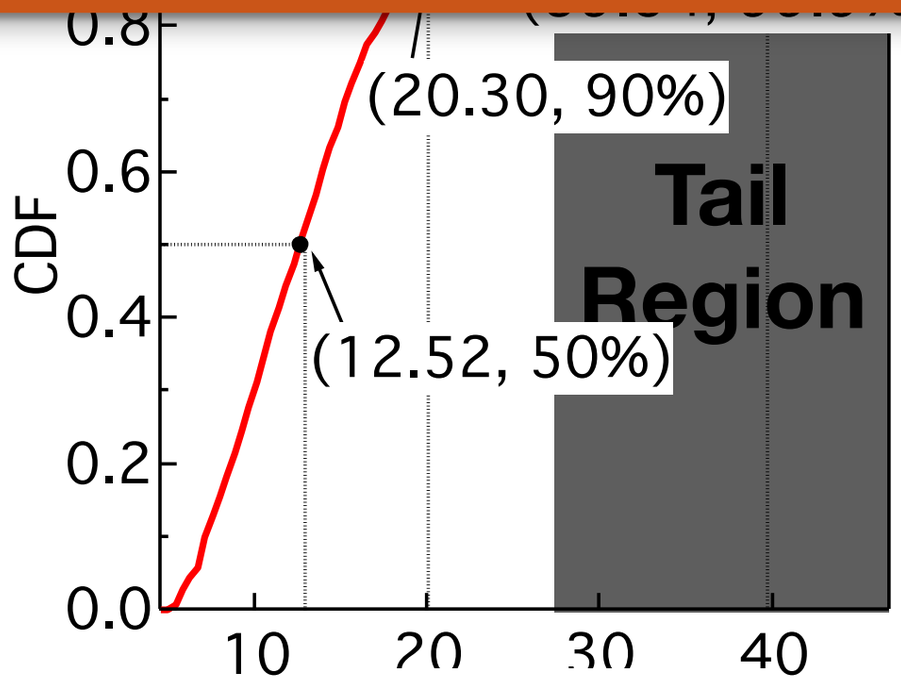
1.0
0.8
0.6
0.4
0.2
0.0
CDF
10
20
30
40
Let's Chat
(39.54, 99.9%)
(20.30, 90%)
(12.52, 50%)
Tail Region

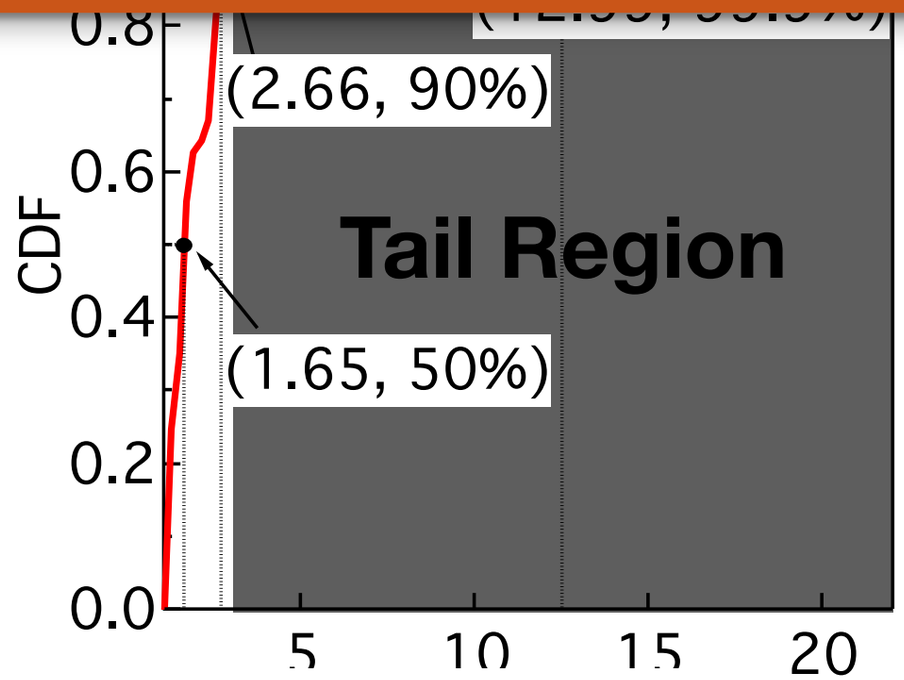
1.0
0.8
0.6
0.4
0.2
0.0
CDF
5
10
15
20
Client Manager
(12.99, 99.9%)
(2.66, 90%)
(1.65, 50%)
Tail Region





Tail latency (99.9%) is 9.1x longer than median request latency





System Overview

Step 1 **Step 2** **Step 3**

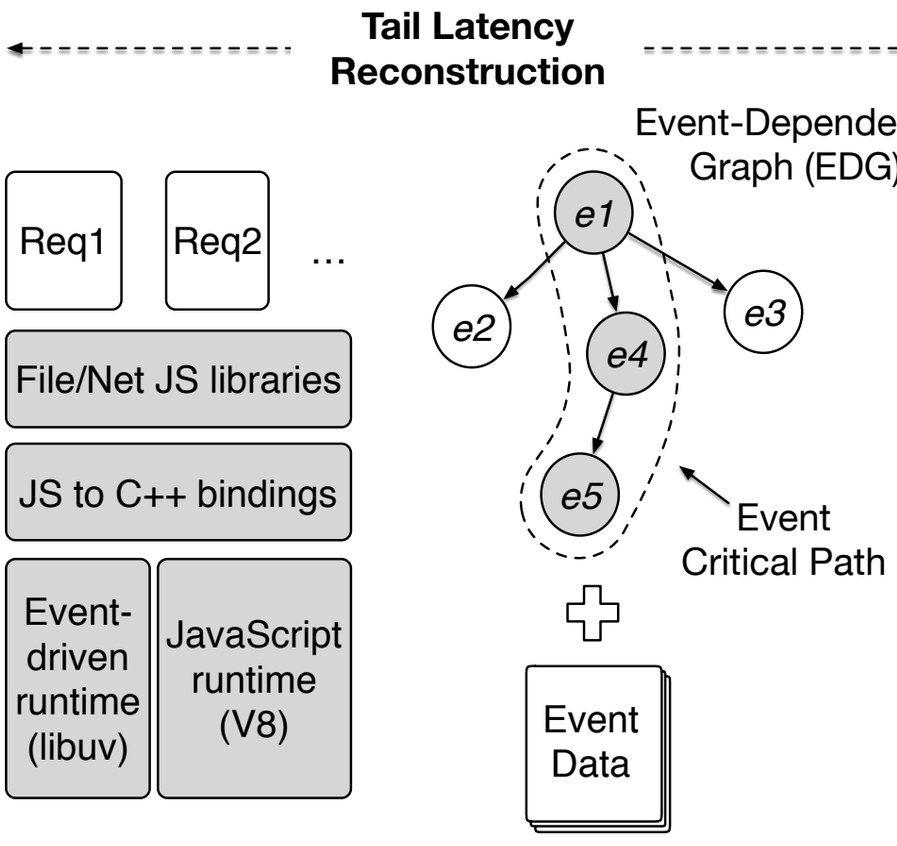
System Overview

Step 1 **Step 2** **Step 3**

Tools to Root-cause Tail in Node.js

System Overview

Step 1 **Step 2** **Step 3**

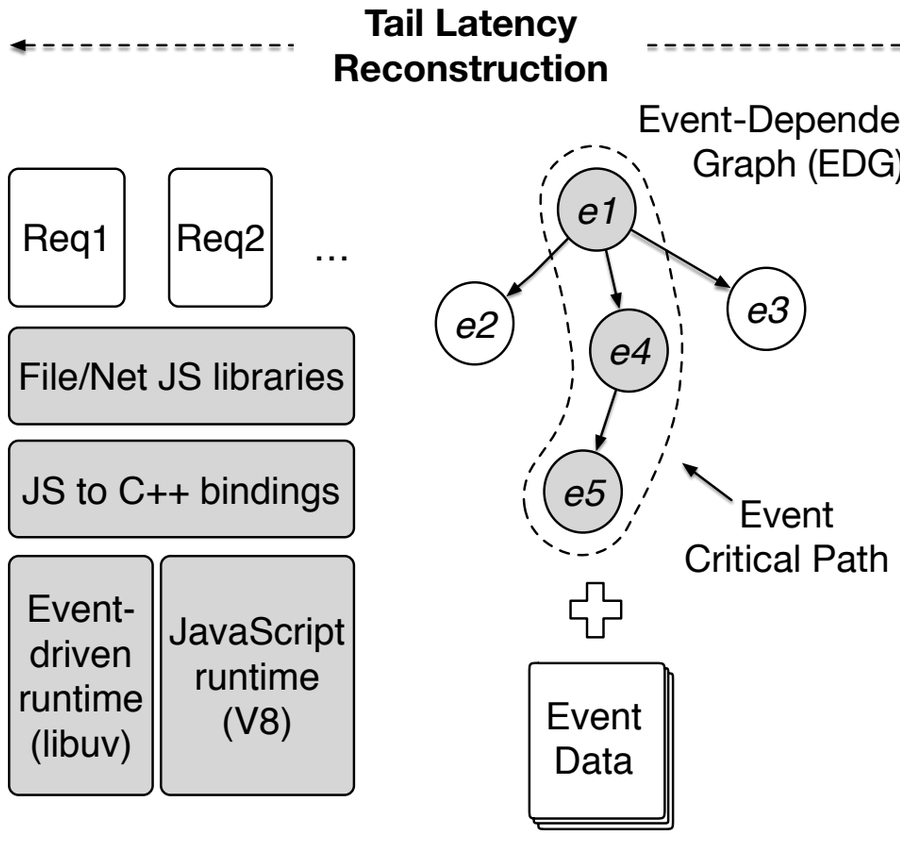


System Overview

Step 1

Step 2

Step 3



Root-causing Tail in Node.js

System Overview

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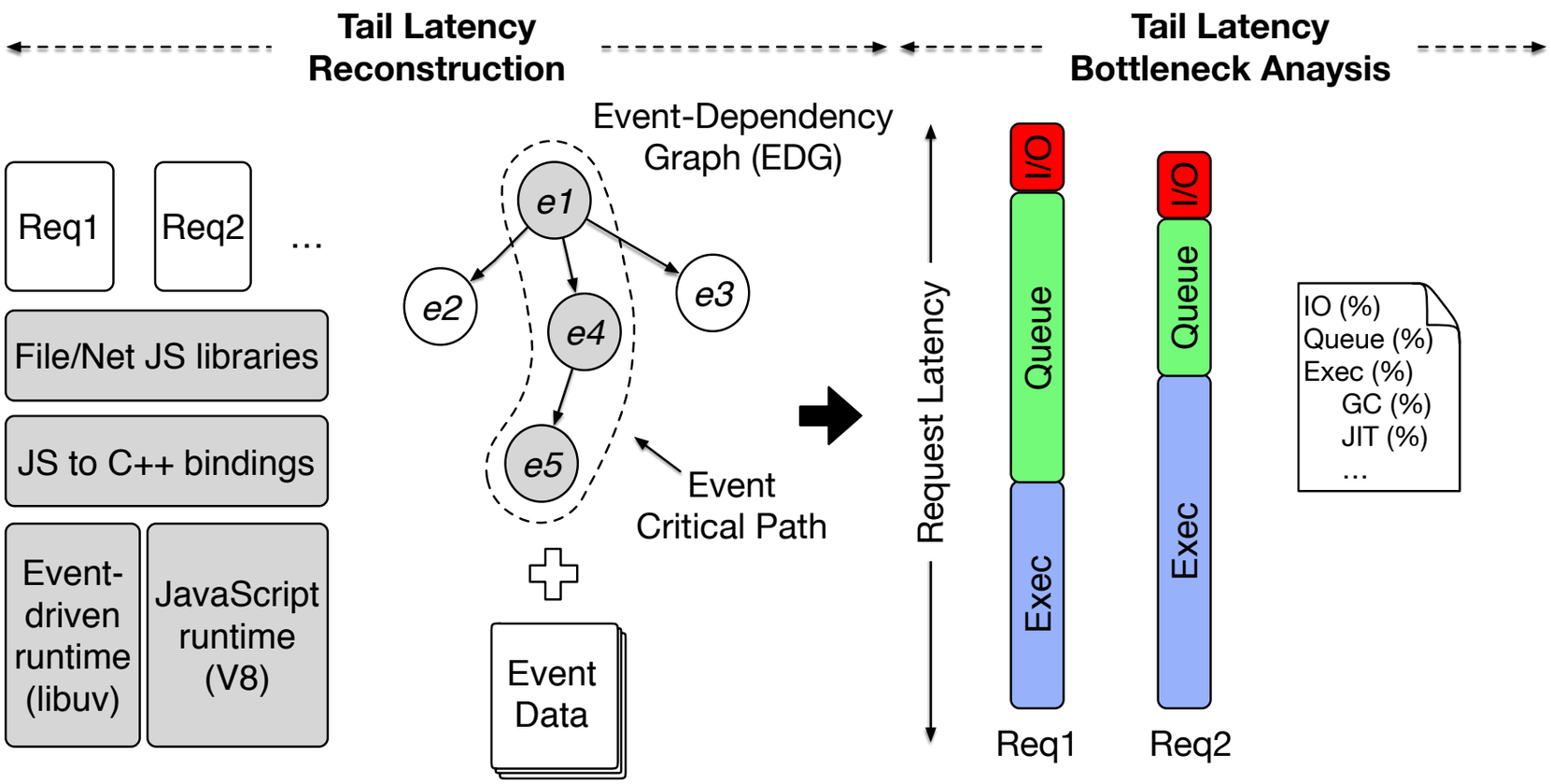
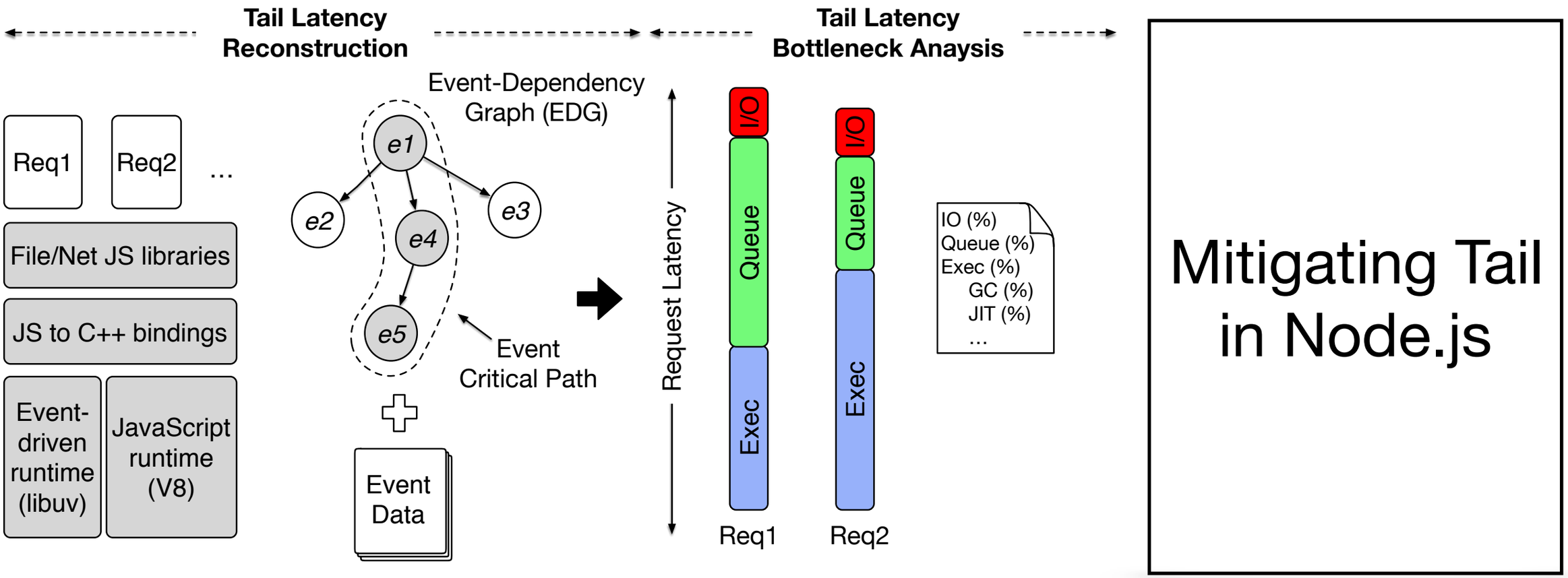


System Overview

Step 1

Step 2

Step 3



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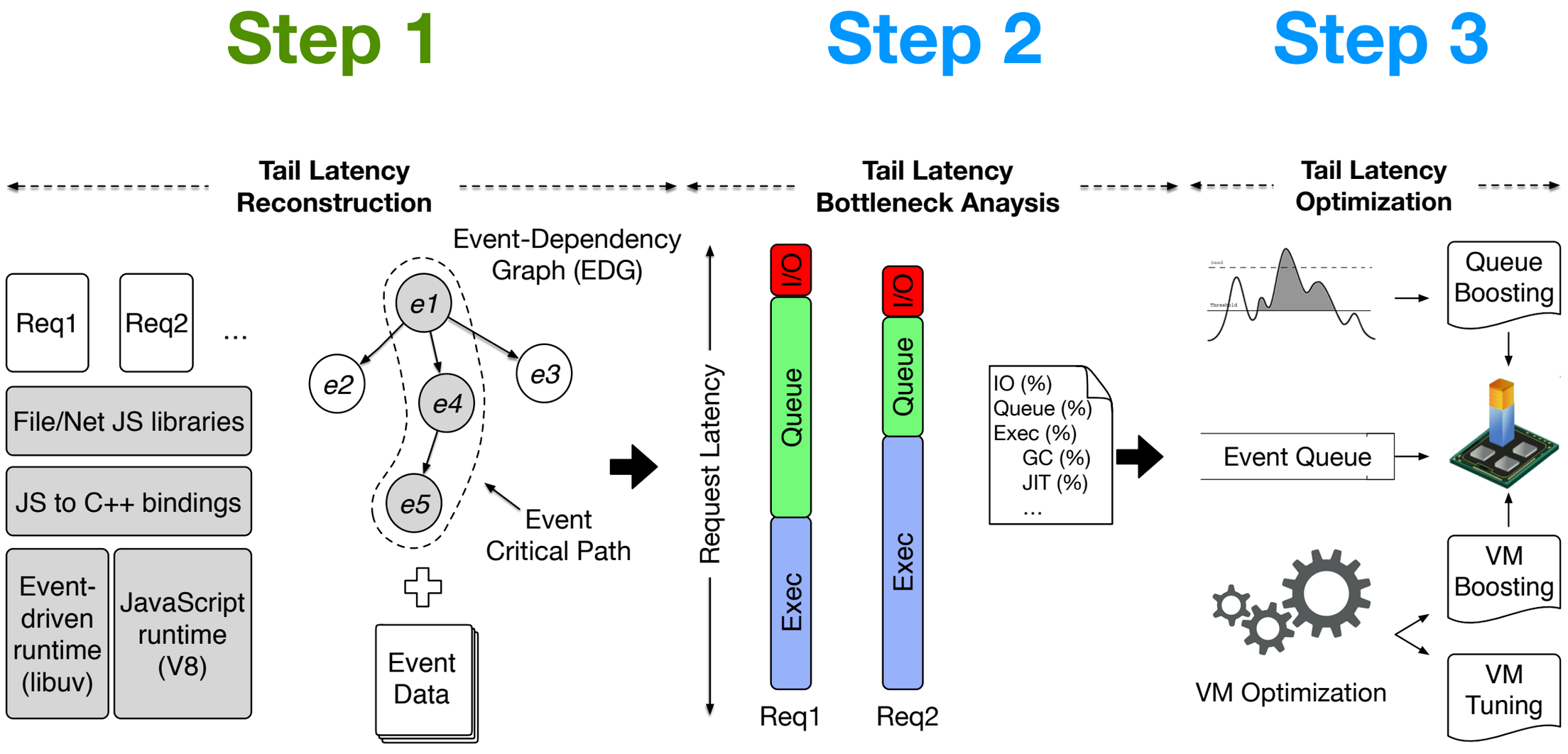

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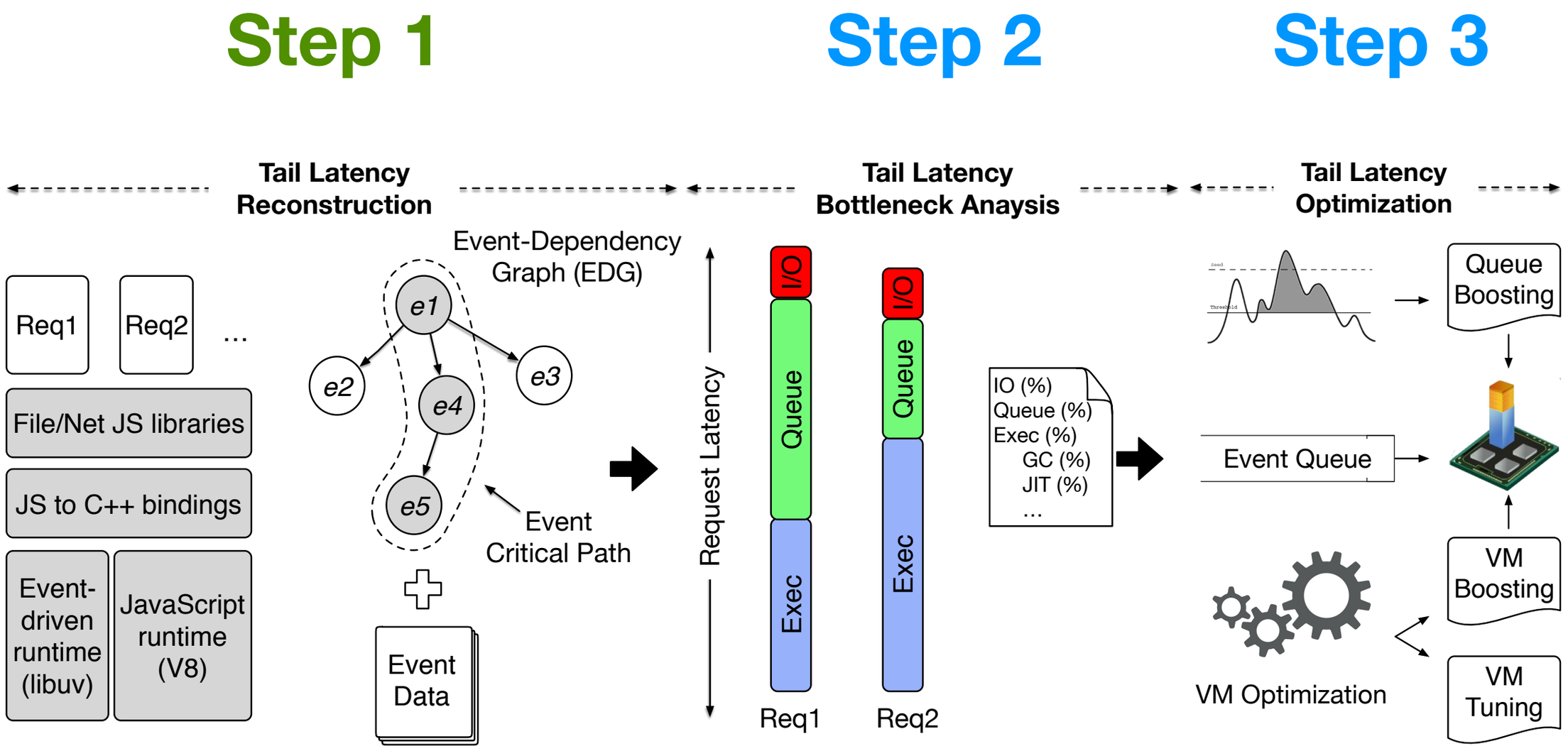
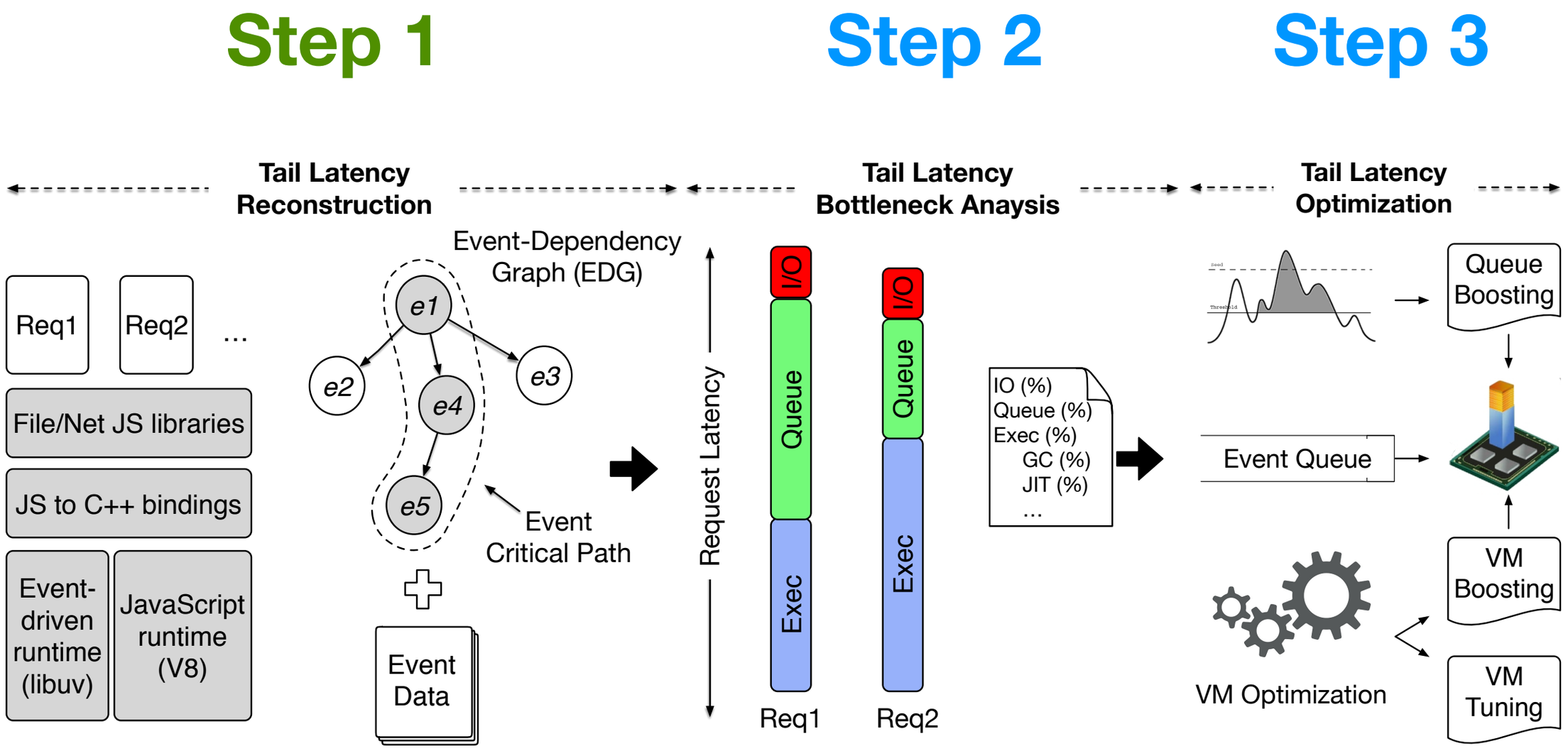


Static Instrumentation

System Overview



Static Instrumentation

Dynamic Analysis & Optimization

Step 1: Latency Reconstruction

```
var count = N;
fs.readdir("/data", function dir(err, files) {
});
```

Step 1: Latency Reconstruction

```
var count = N;
fs.readdir("/data", function dir(err, files) {
  files.foreach(function file(f, index) {
  });
});
```

Step 1: Latency Reconstruction

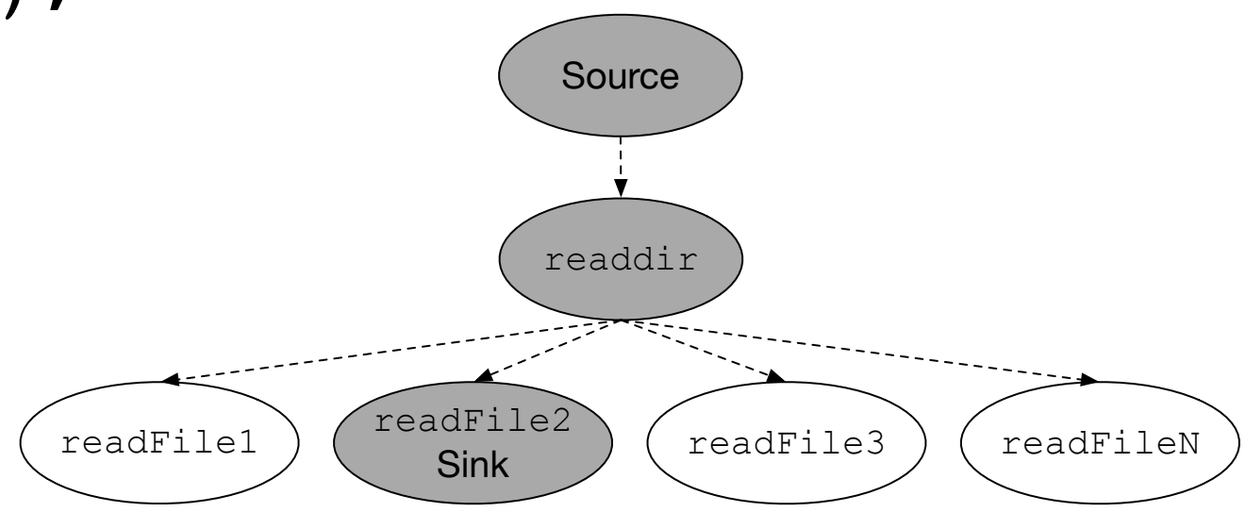
```
var count = N;
fs.readdir("/data", function dir(err, files) {
  files.foreach(function file(f, index) {
    var fname = …;
    fs.readFile(fname, function read(err, data) {
    });
  });
});
```

Step 1: Latency Reconstruction

```
var count = N;
fs.readdir("/data", function dir(err, files) {
  files.foreach(function file(f, index) {
    var fname = …;
    fs.readFile(fname, function read(err, data) {
      count -= 1;
      if (count == 0)
        sendResponse();
    });
  });
});
```

Step 1: Latency Reconstruction

```
var count = N;
fs.readdir("/data", function dir(err, files) {
  files.foreach(function file(f, index) {
    var fname = …;
    fs.readFile(fname, function read(err, data) {
      count -= 1;
      if (count == 0)
        sendResponse();
    });
  });
});
```



Event Dependency Graph (EDG)

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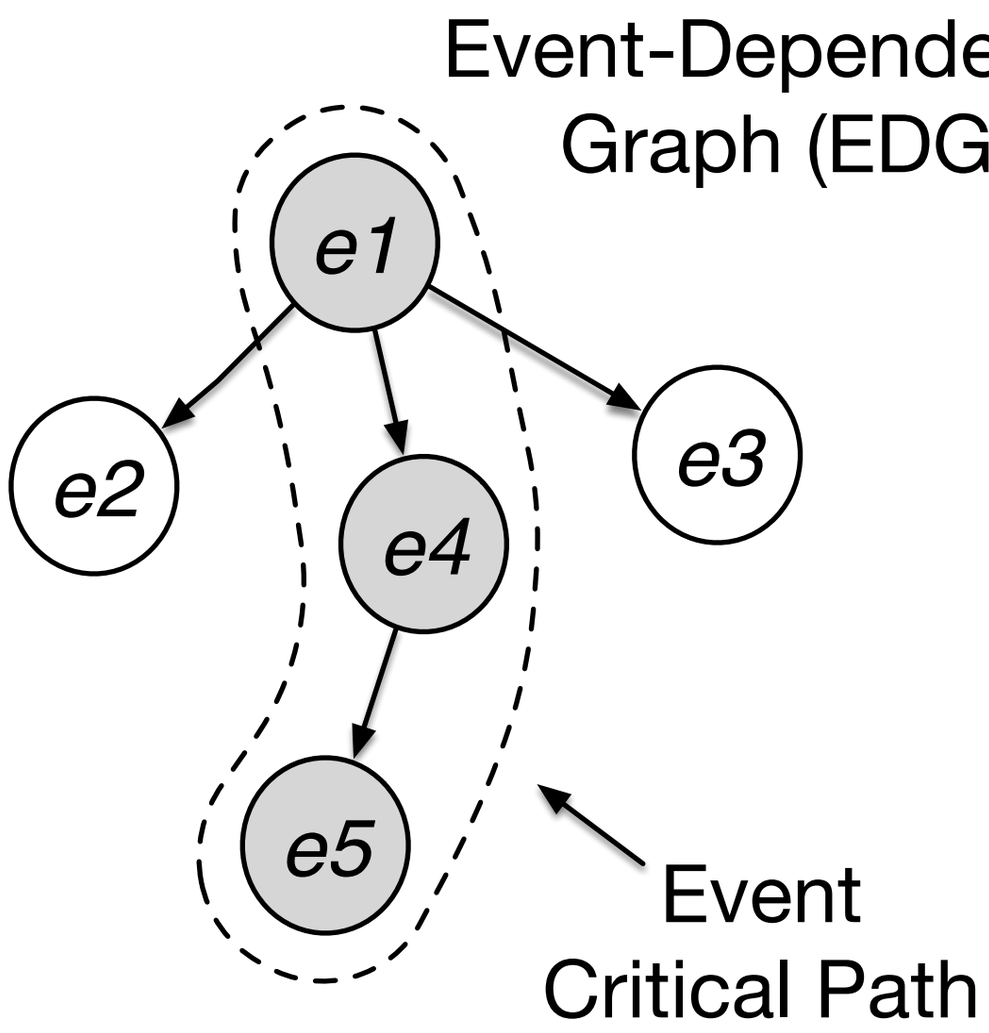

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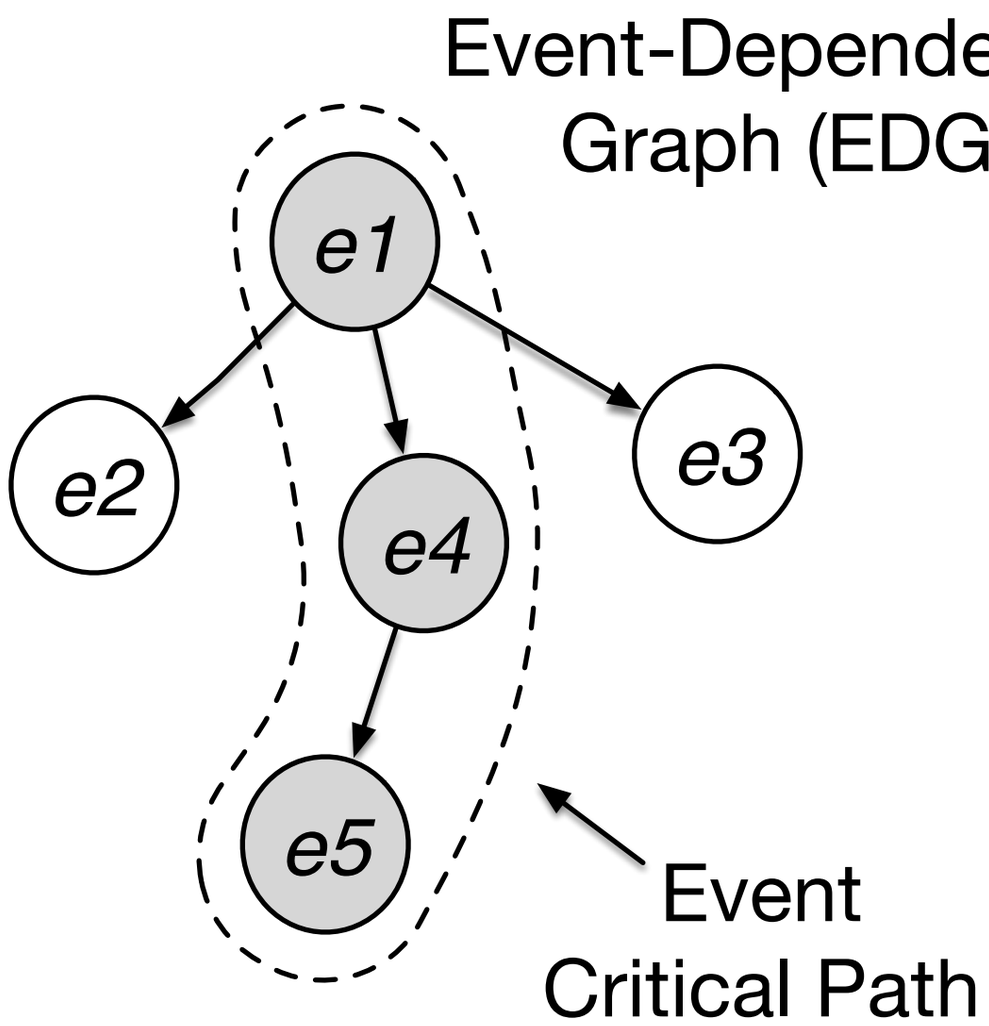

$$Latency(R) = \sum_{i=1}^{N-1} T(e_i), e_i \in ECP(R)$$

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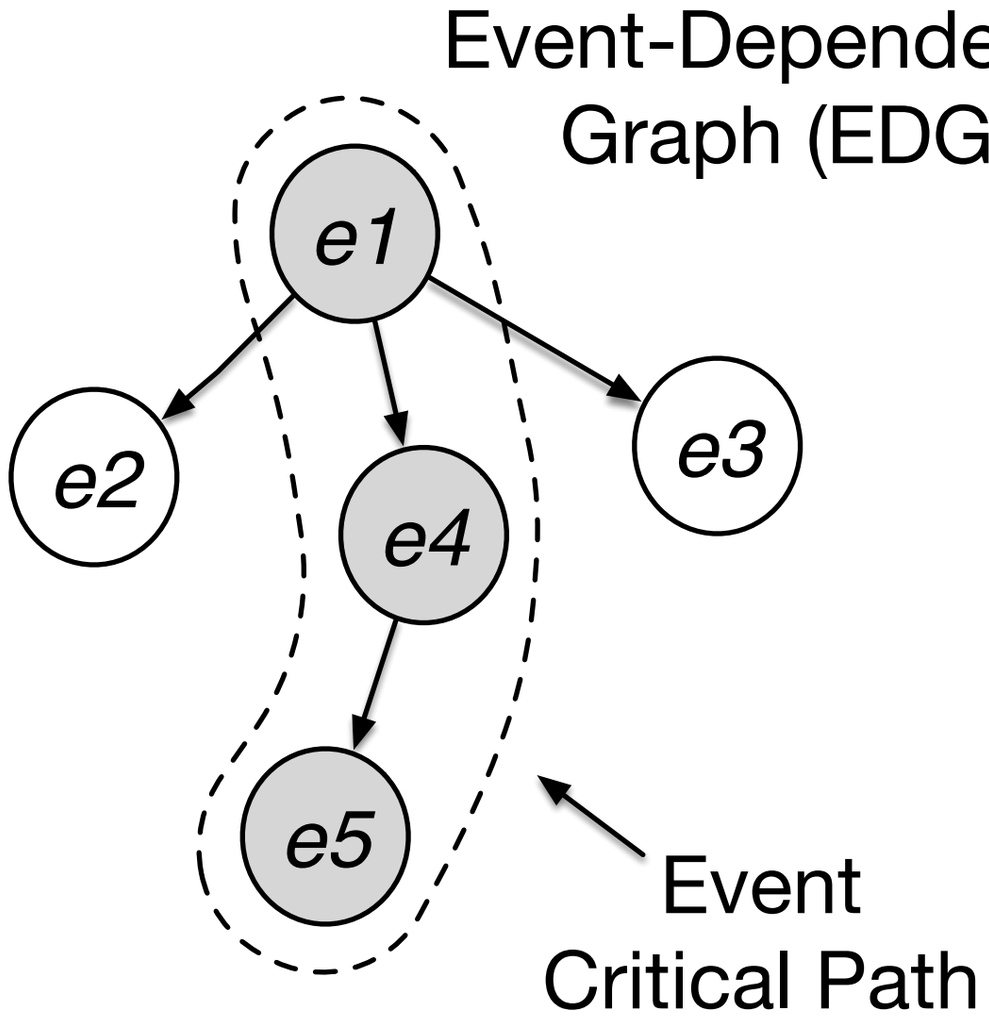


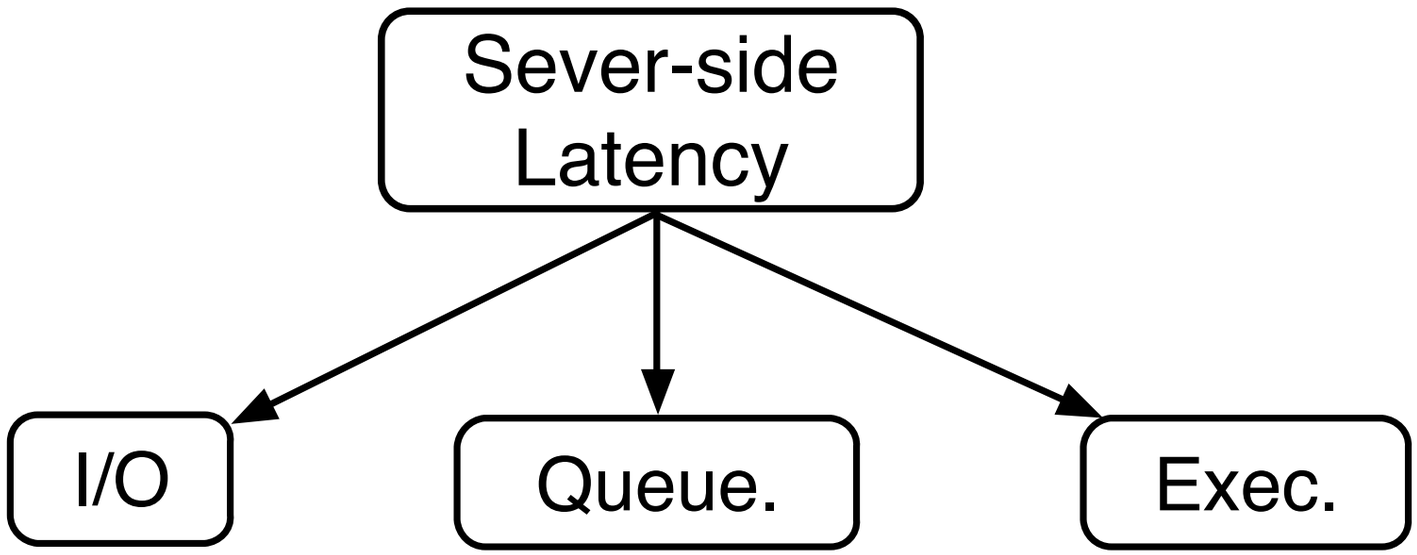
$$Latency(R) = \sum_{i=1}^{N-1} T(e_i), e_i \in ECP(R)$$

How do we obtain the latency of each event?

Deconstructing Event Latency

Sever-side Latency

Deconstructing Event Latency



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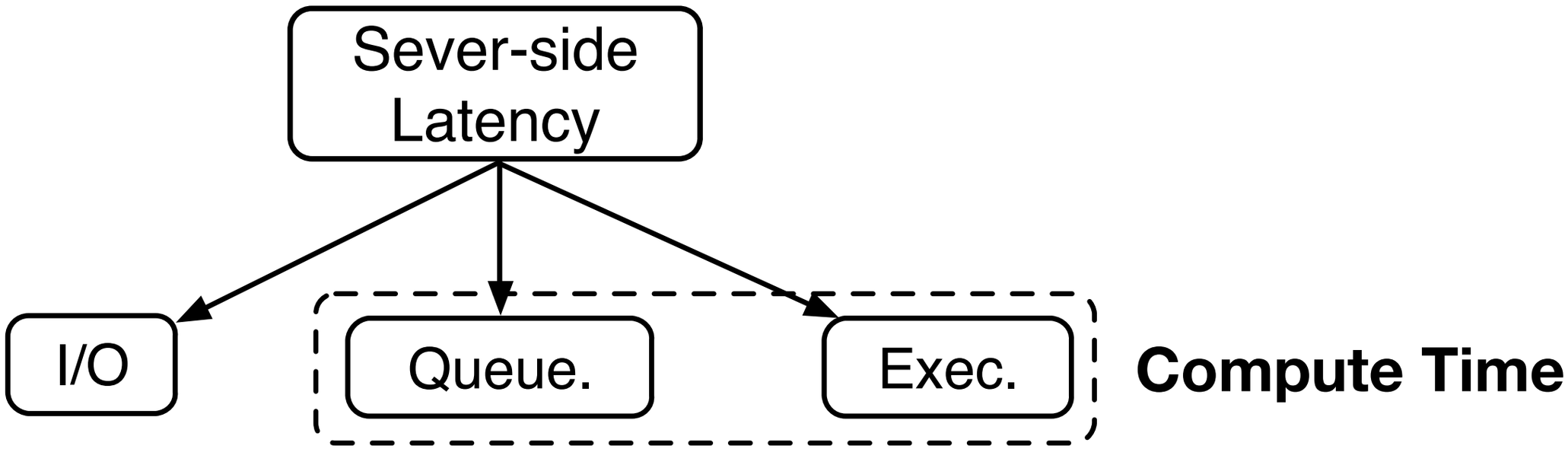

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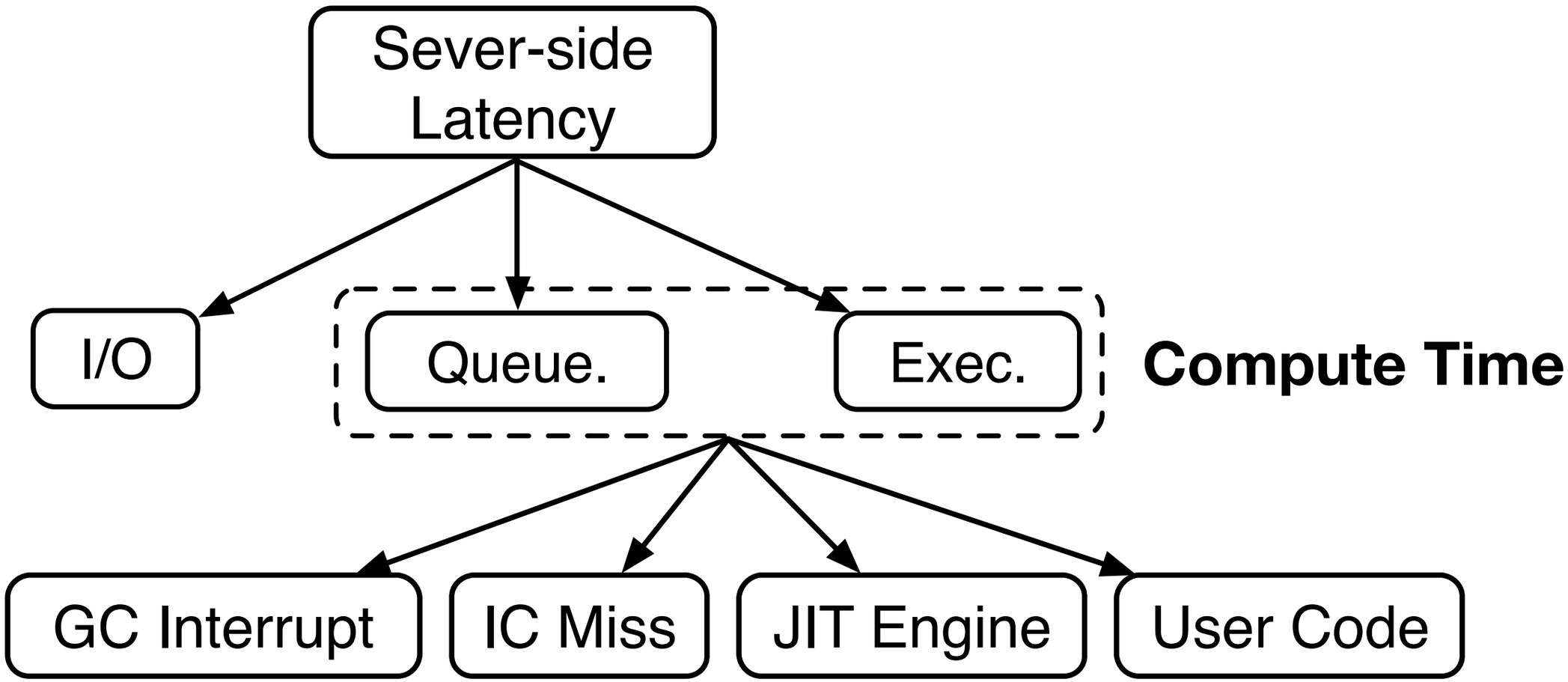
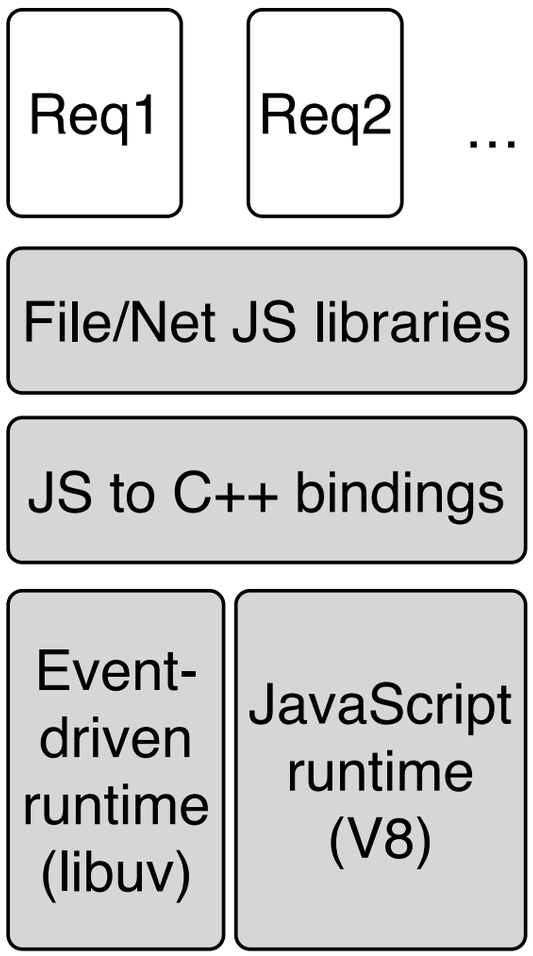


Offline Instrumentation + Online Analysis

Instrument the Node.js runtime so that at runtime we could easily obtain: EDG & event latency info.



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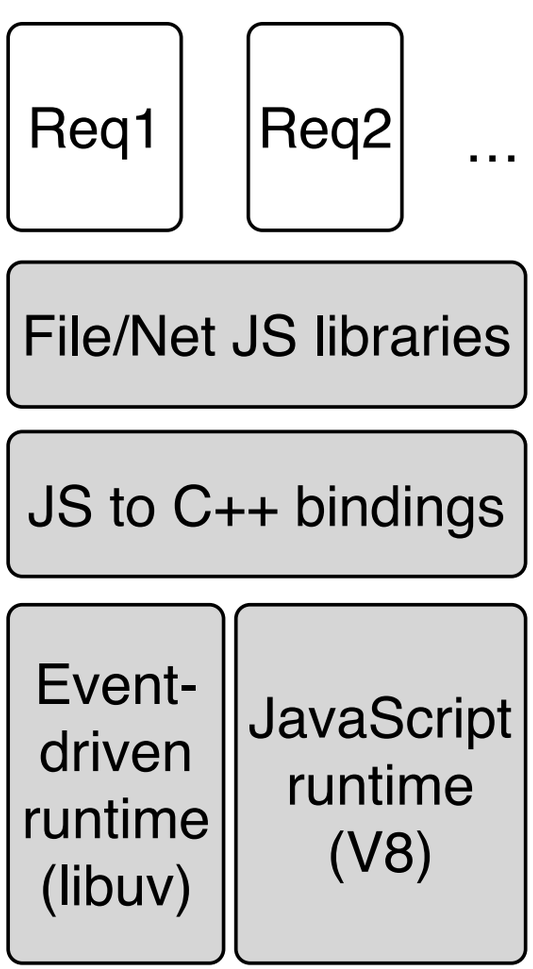
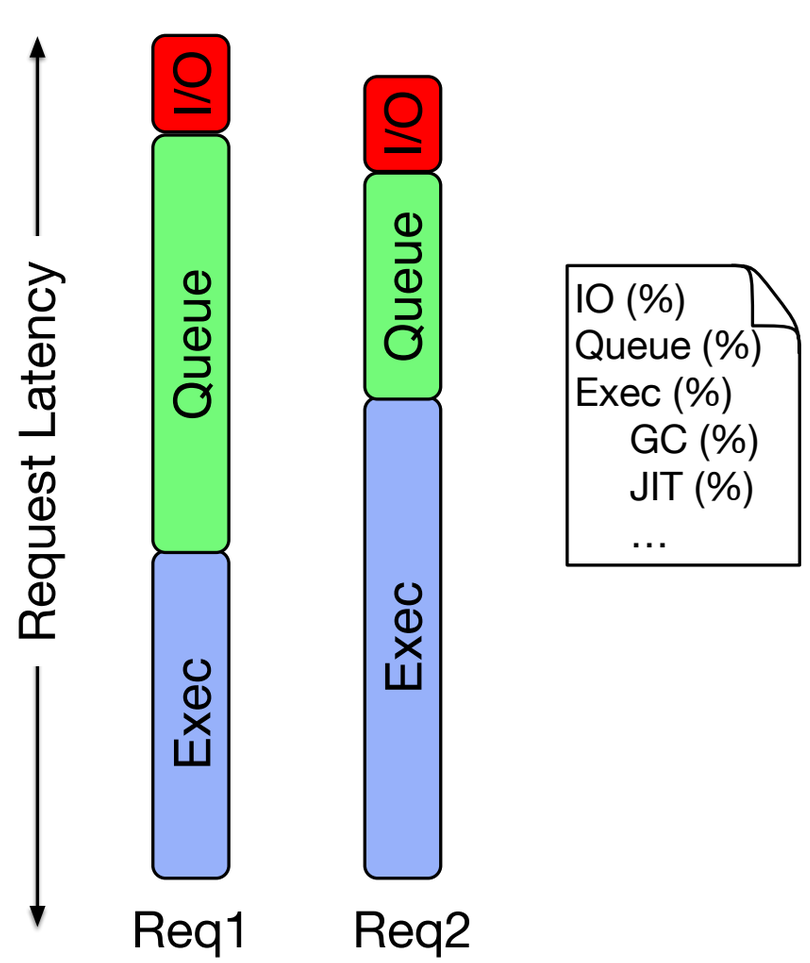
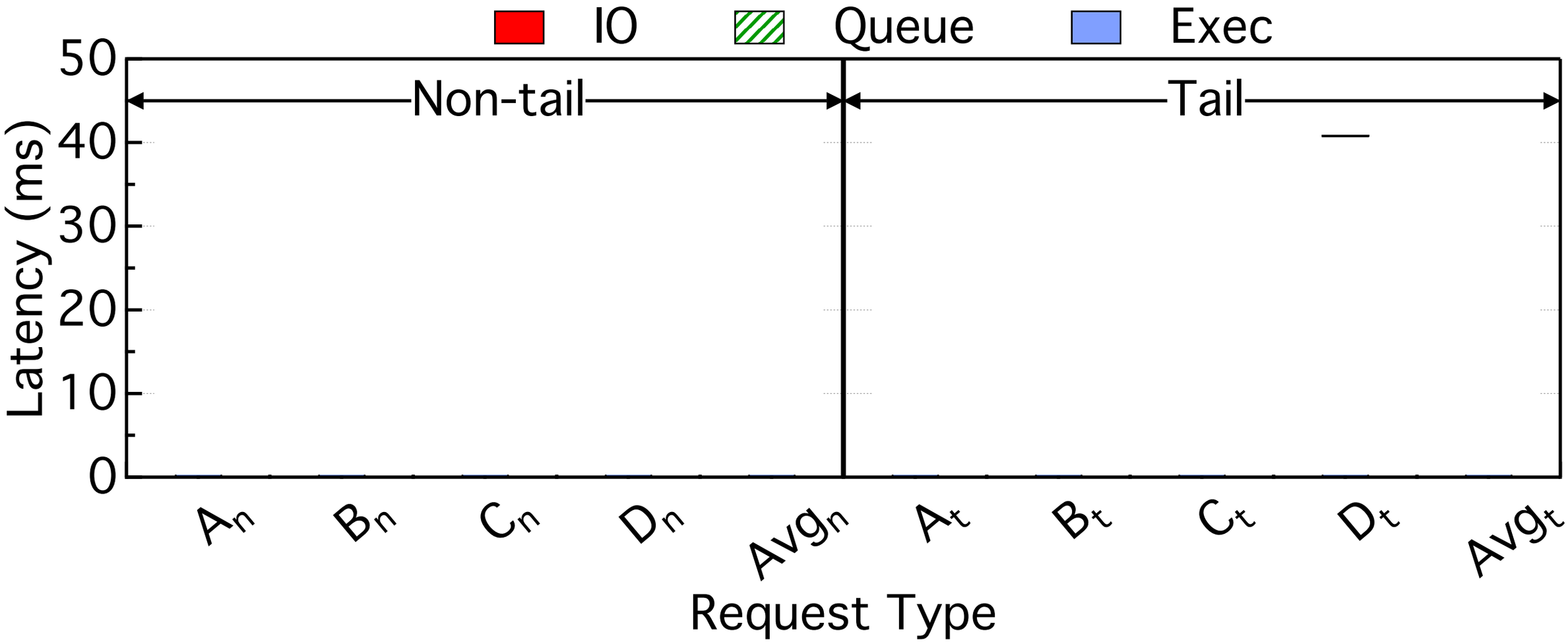


Identify root-causes of long tails at runtime.



Step 2: EDG-based Bottleneck Analysis



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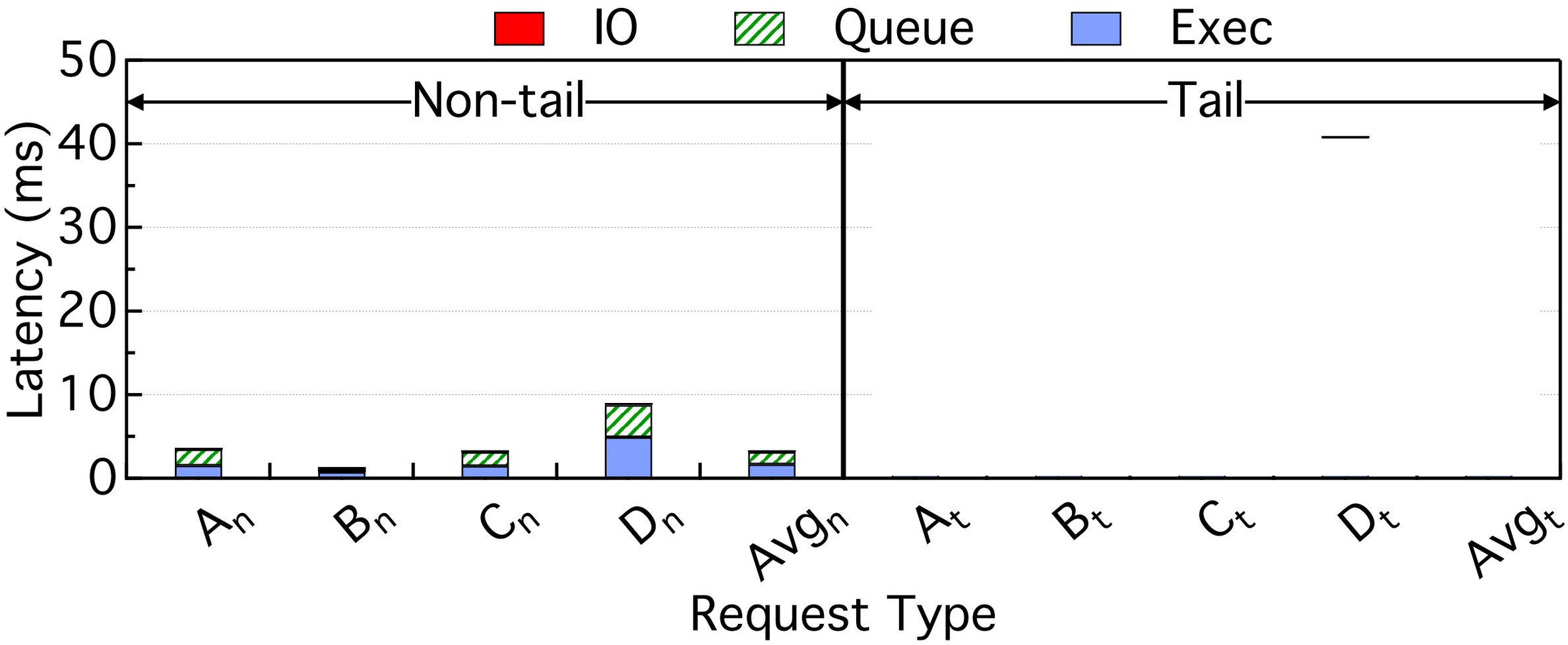

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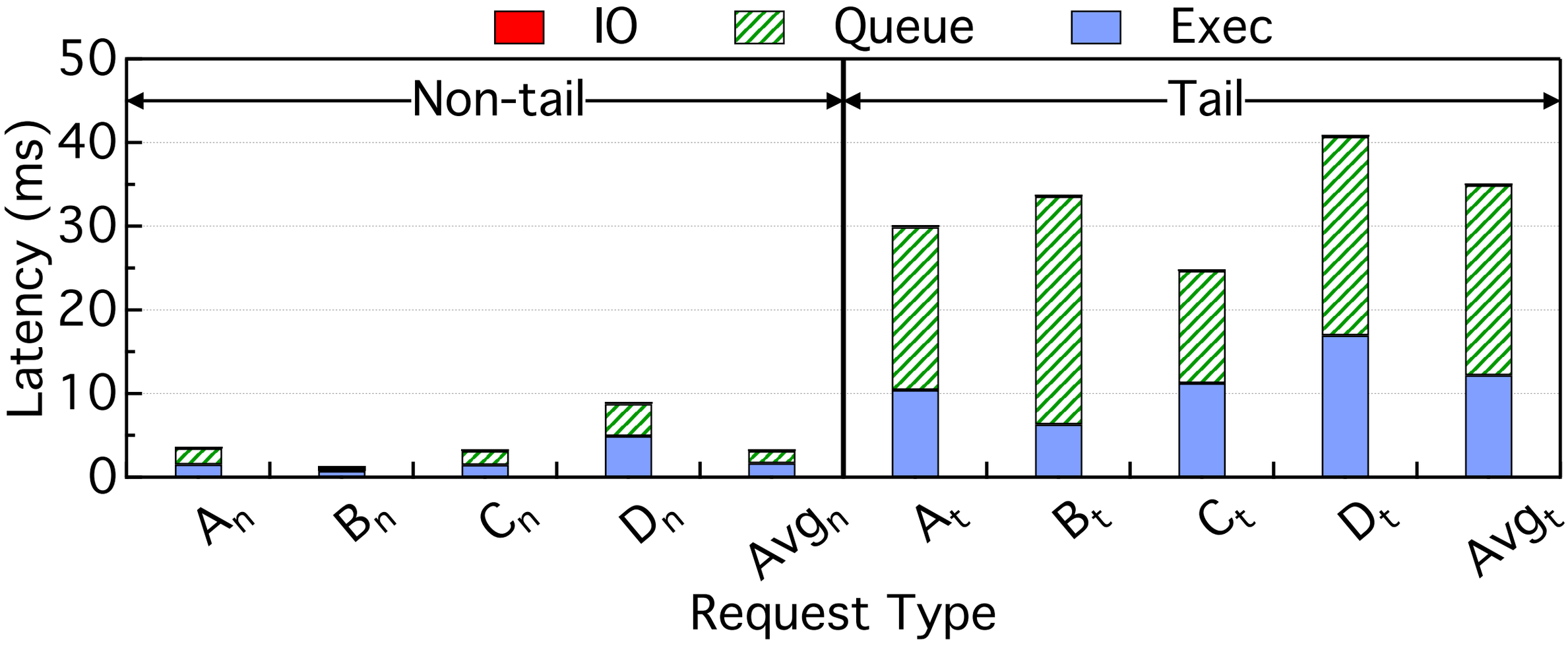

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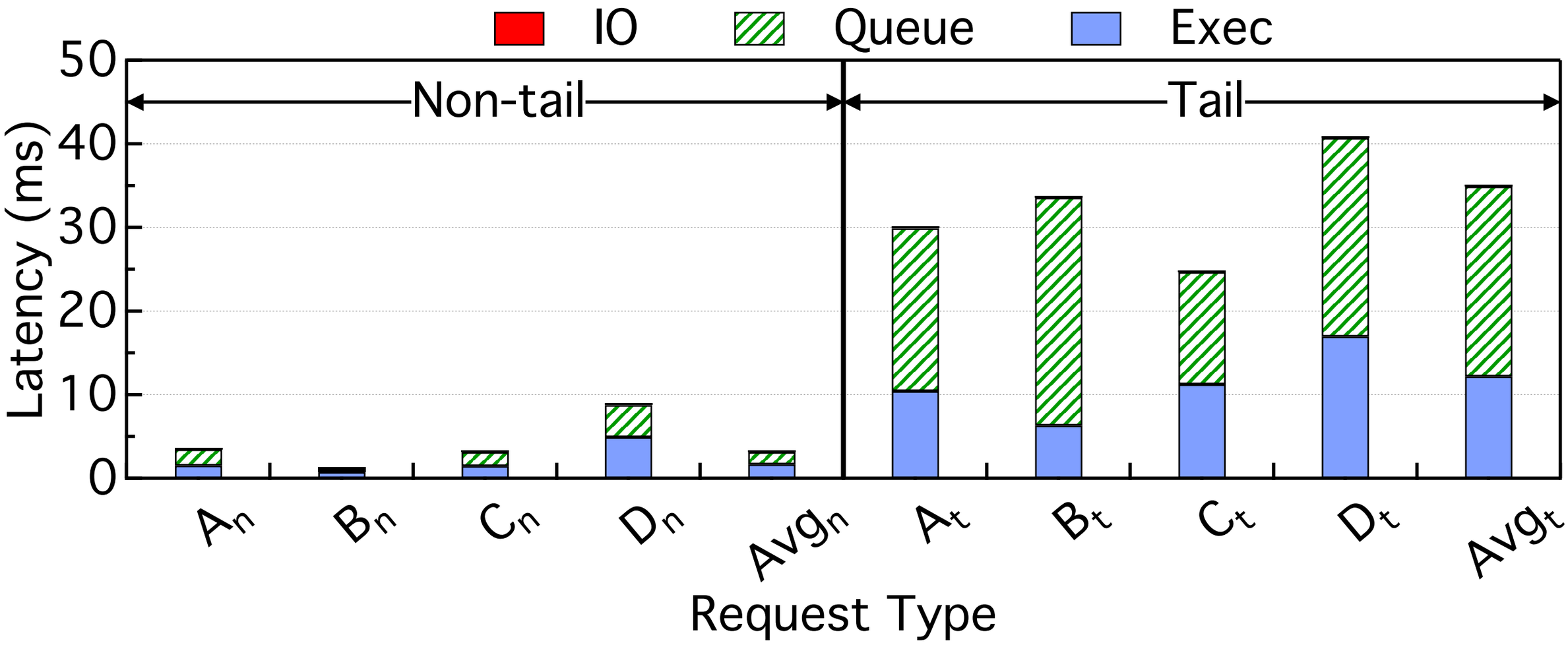
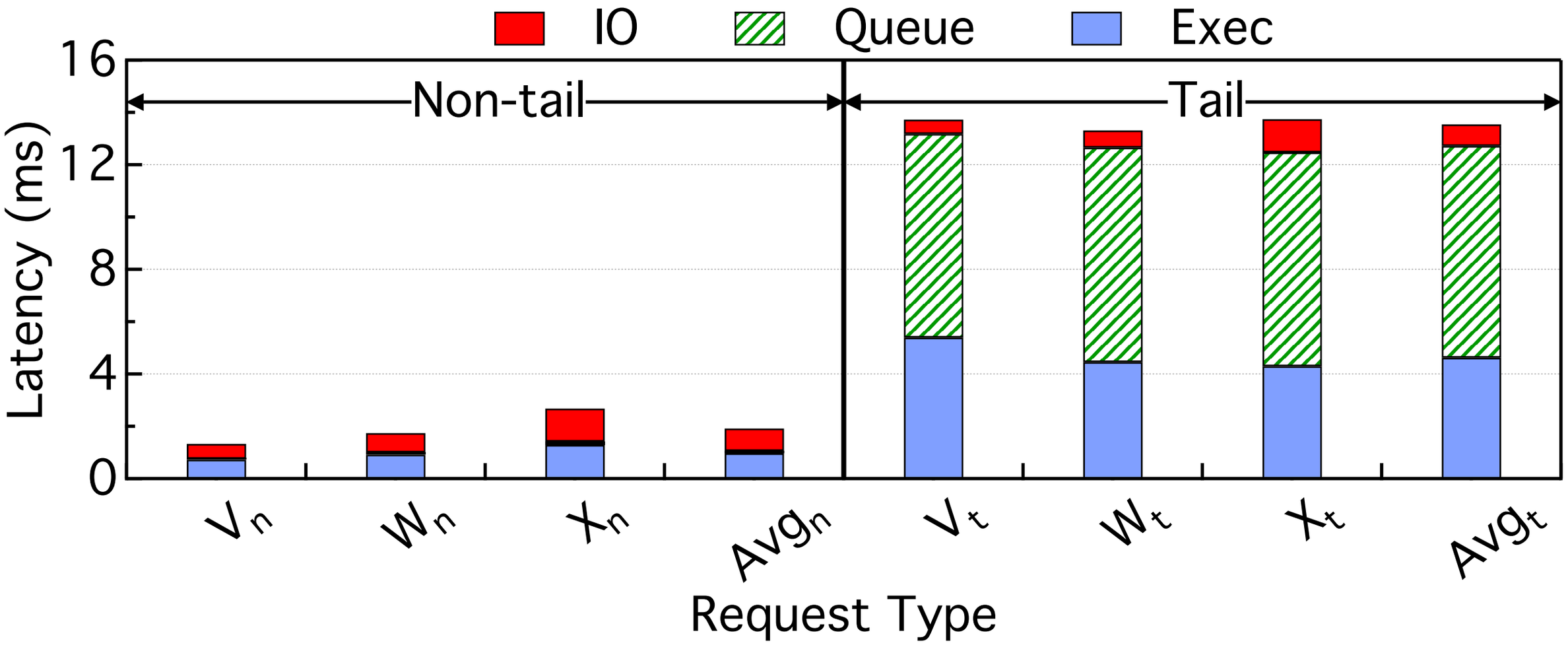


Etherpad: *Queue and Exec. latency increases in tails, and I/O latency is not dominant for this particular application.*

EDG-based Bottleneck Analysis



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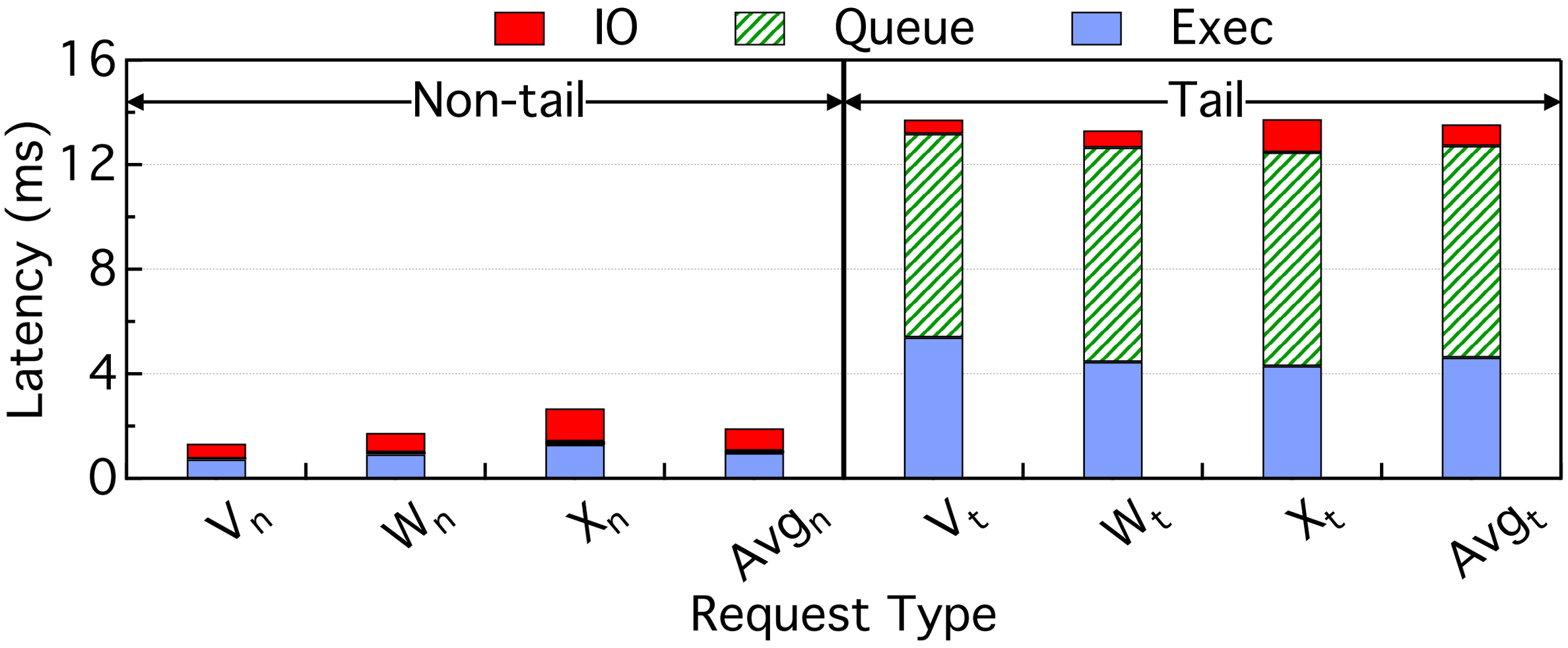

Client Manager: *Queue and Exec. latency dominate in tails, but unlike Etherpad I/O plays a notable role in the requests.*

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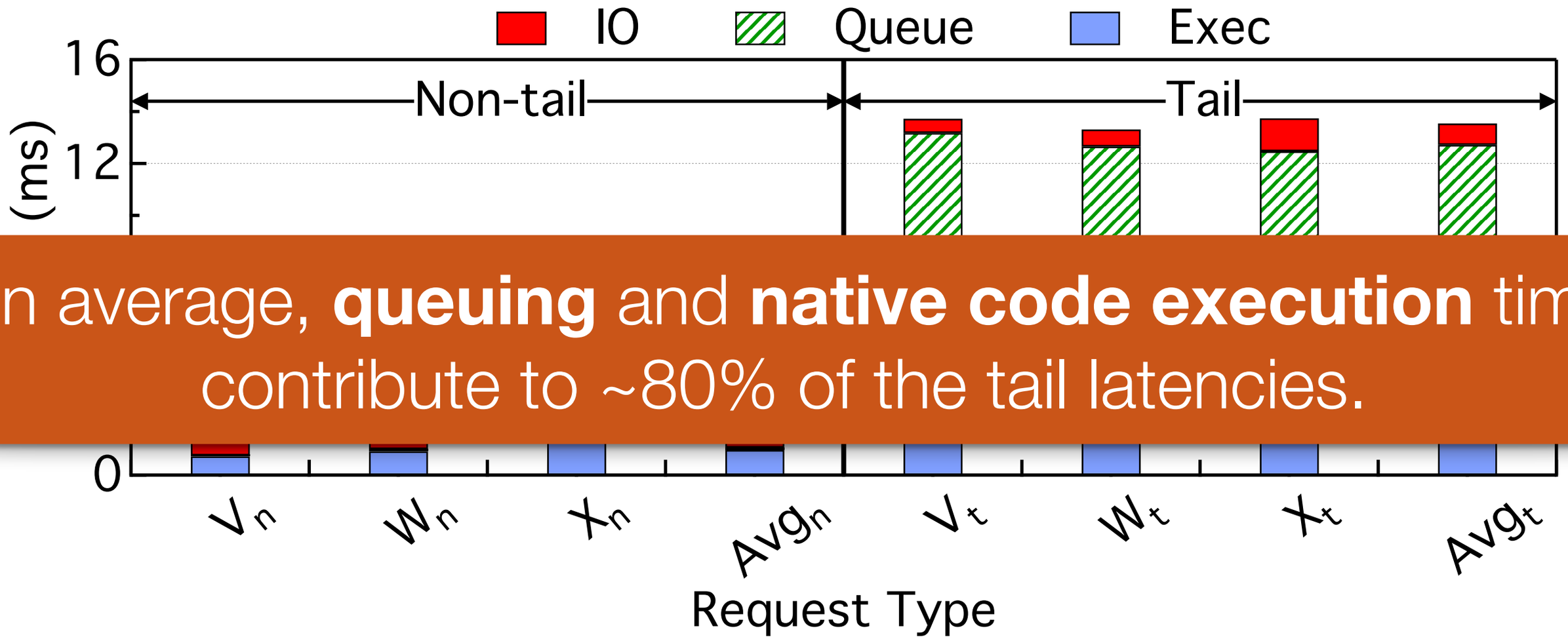
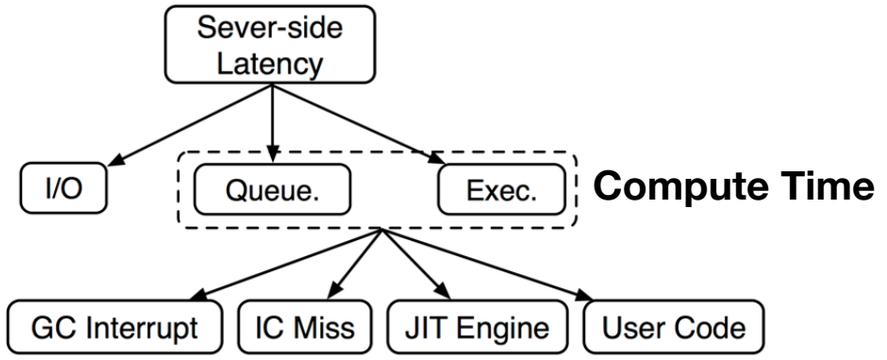


On average, **queuing** and **native code execution** time contribute to ~80% of the tail latencies.

Client Manager: *Queue and Exec. latency dominate in tails, but unlike Etherpad I/O plays a notable role in the requests.*

Breakdown Within Compute



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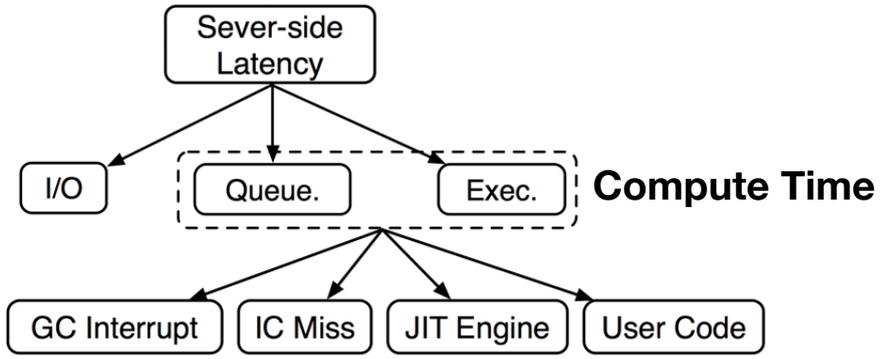
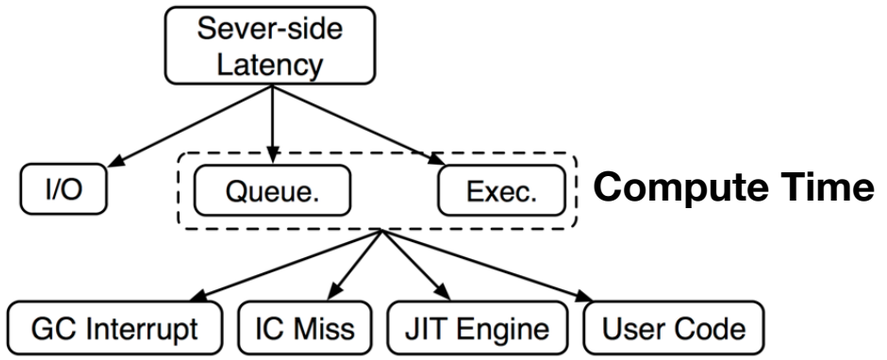


	Non-tail			
Application	**IC**	**GC**	**JIT**	**Native**
Etherpad Lite	0.3%	1.9%	0%	97.8%
Todo	1.8%	0.5%	0%	97.7%
Lighter	4.9%	4.7%	0%	90.4%
Let's Chat	2.7%	3.9%	0%	93.4%
Client Manager	3.2%	3.1%	0%	93.7%

Breakdown Within Compute



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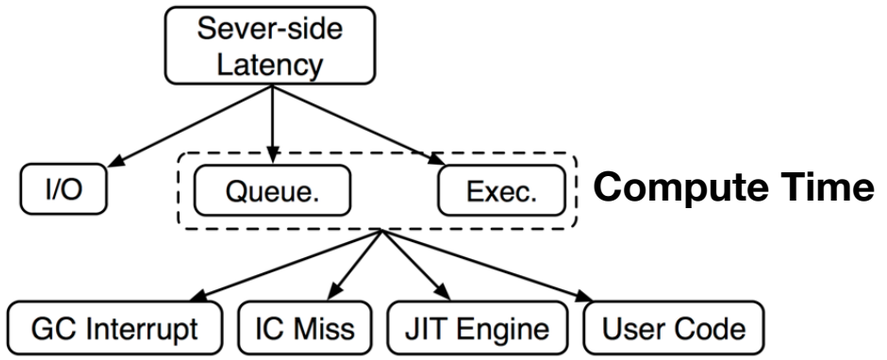

	Non-tail				Tail			
Application	**IC**	**GC**	**JIT**	**Native**	**IC**	**GC**	**JIT**	**Native**
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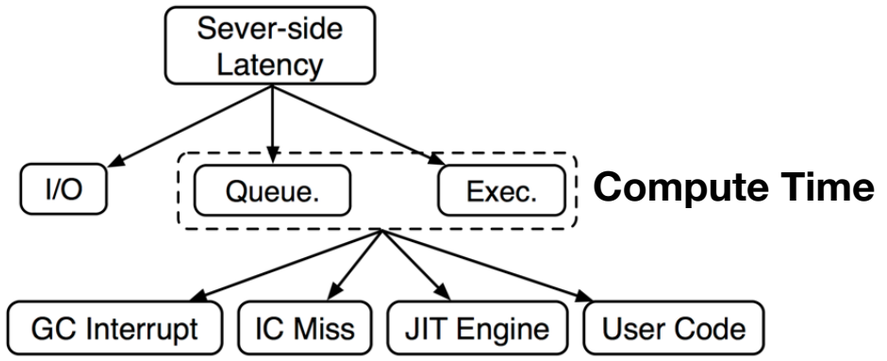
Todo	1.8%	0.5%	0%	97.7%	0.6%	31.0%	0%	68.4%
Lighter	4.9%	4.7%	0%	90.4%	4.4%	45.3%	0%	50.3%
Let's Chat	2.7%	3.9%	0%	93.4%	3.6%	48.4%	0%	48.0%
Client Manager	3.2%	3.1%	0%	93.7%	3.9%	70.3%	0%	25.8%

Breakdown Within Compute



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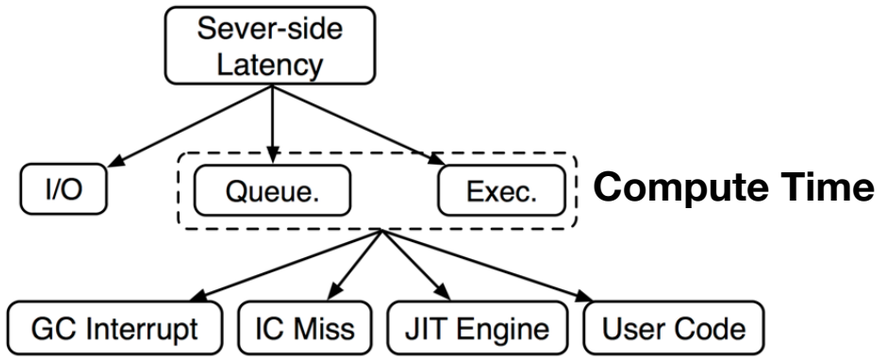

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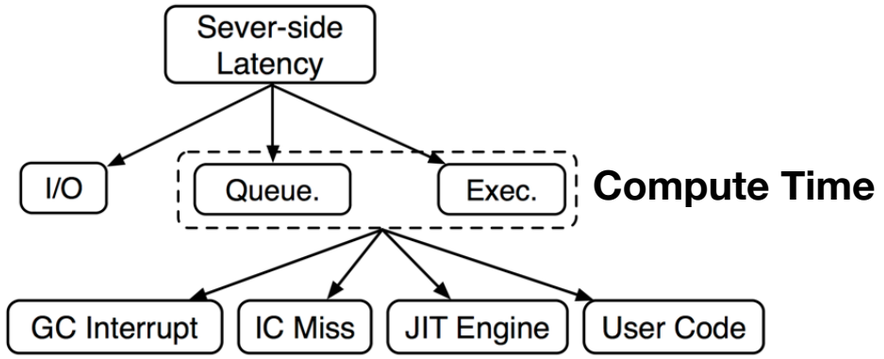

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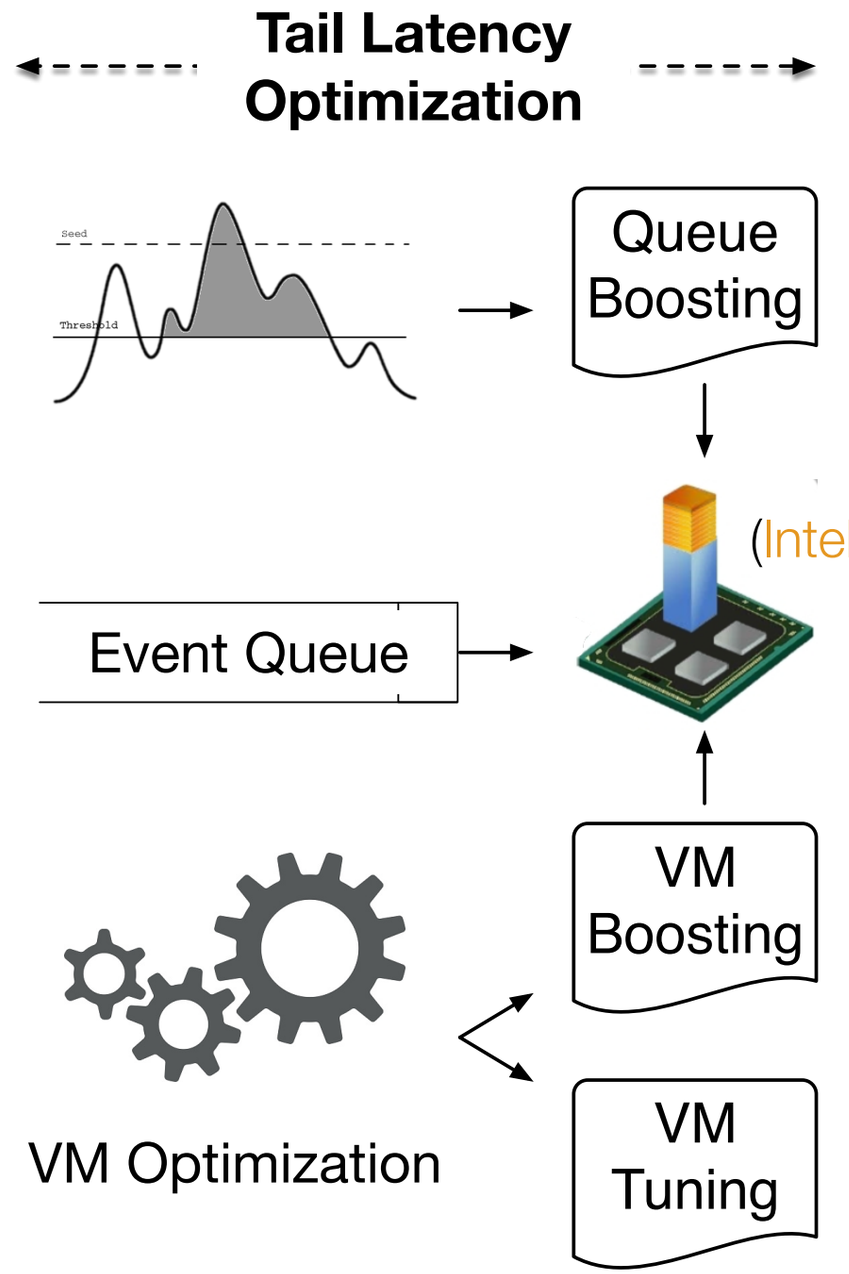
We should focus optimization efforts on **Garbage Collection** and **Generated Native Code**

Step 3: Tail Latency Optimization

- Leveraging the **turbo boosting** capability of modern CPUs
- Key: wisely choose what to boost
- GC Boosting
  - Boost GC
- Queue Boosting
  - Boost when the system is “busy”
  - Use event queue stats as “hints”



Optimization 1: VM Optimization (GC Boost)

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- **Observations:**
  - GCs are infrequent, little overall energy overhead
  - IPC during GC is relatively high: ~1.3

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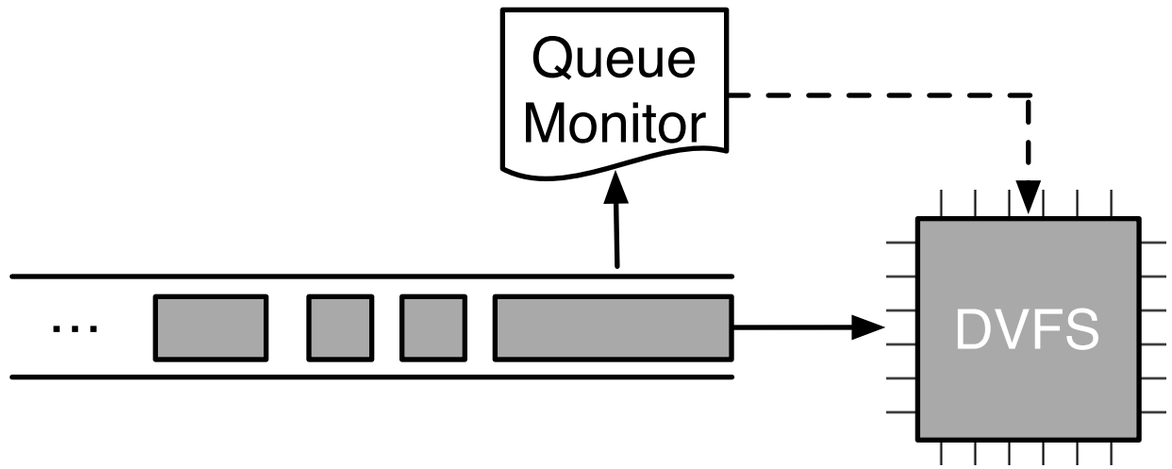
Client Manager	3.2%	3.1%	0%	93.7%	3.9%	70.3%	0%	25.8%

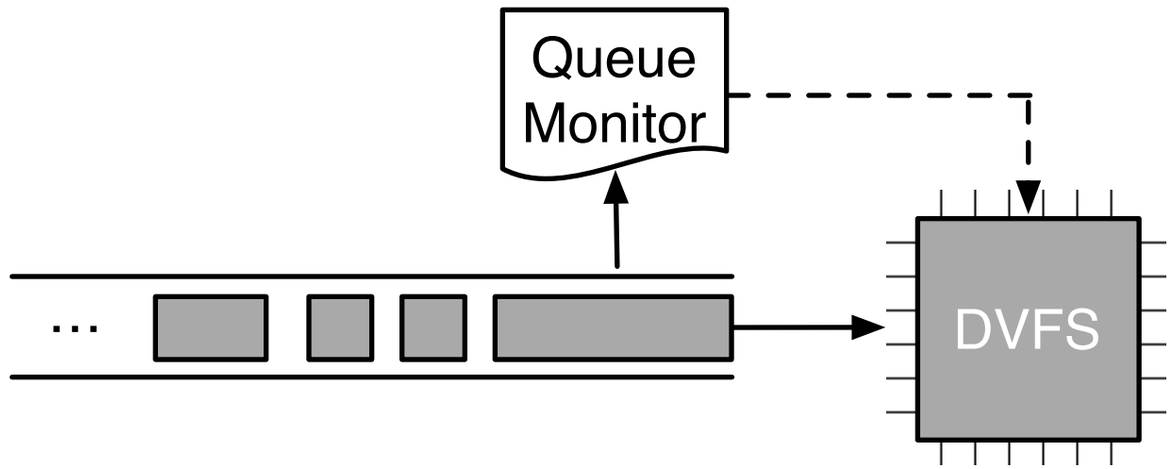
- **Implementation**
  - User-space DVFS embedded in Google V8: enter boosting at GC **prologues** and exit boosting at GC **epilogues**
  - More benefits if we have access to fine-grained per-core DVFS mechanism

Optimization 2: Queue Boost



Optimization 2: Queue Boost

- More general compute acceleration: Boost when the system is “busy”



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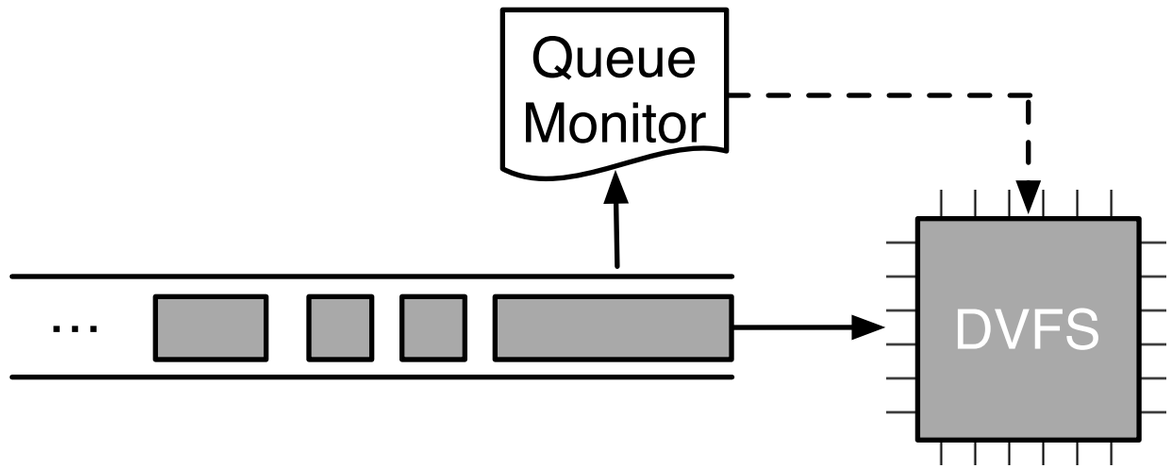
- More general compute acceleration: Boost when the system is “busy”
- How do you detect that?



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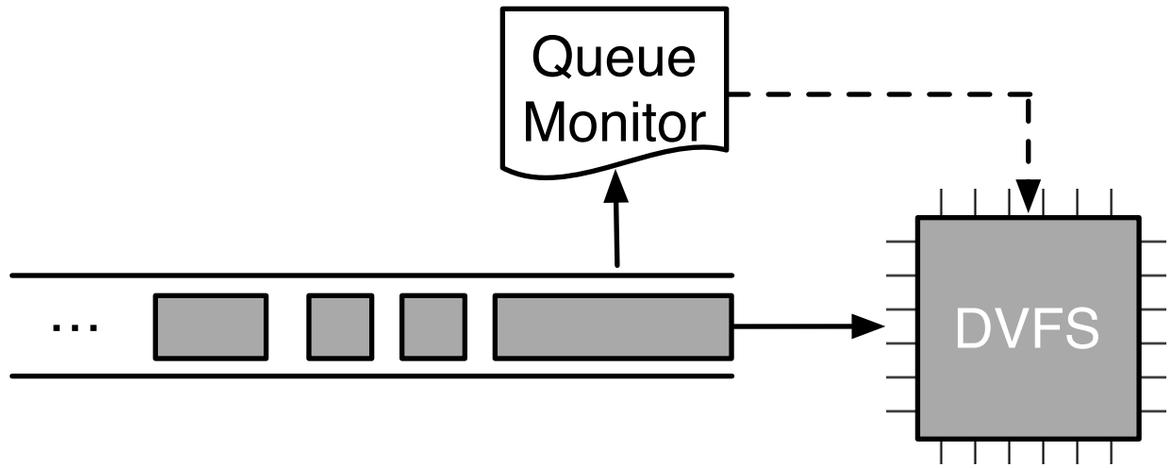

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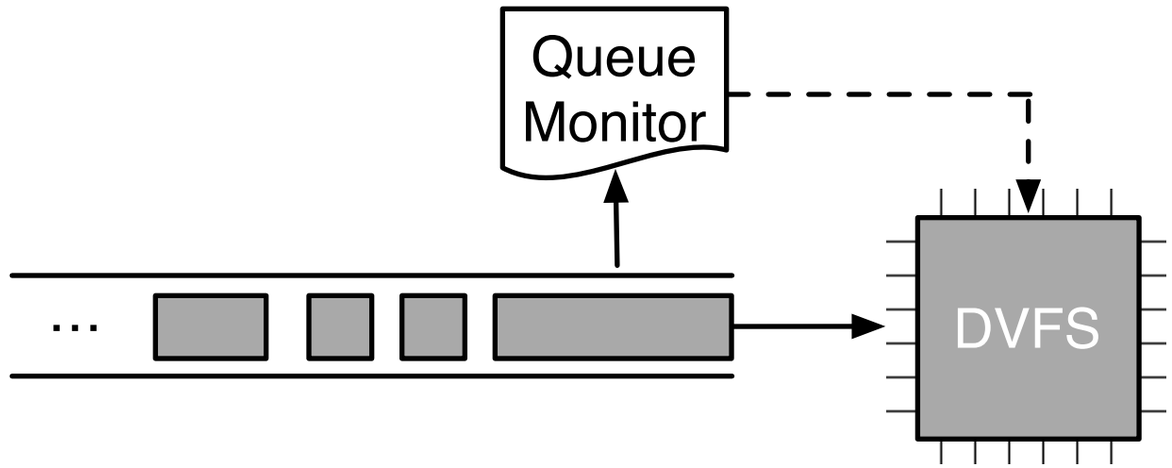

- Implementation:
  - Periodic **Sampling:** Every 1 ms
  - Dynamic **Thresholding**
    - Sample the average value of event number and per event processing time
    - Amplify the average value to decide a dynamic threshold by 2-3x

Evaluation

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  - **Adrenaline** [HPCA 2015]

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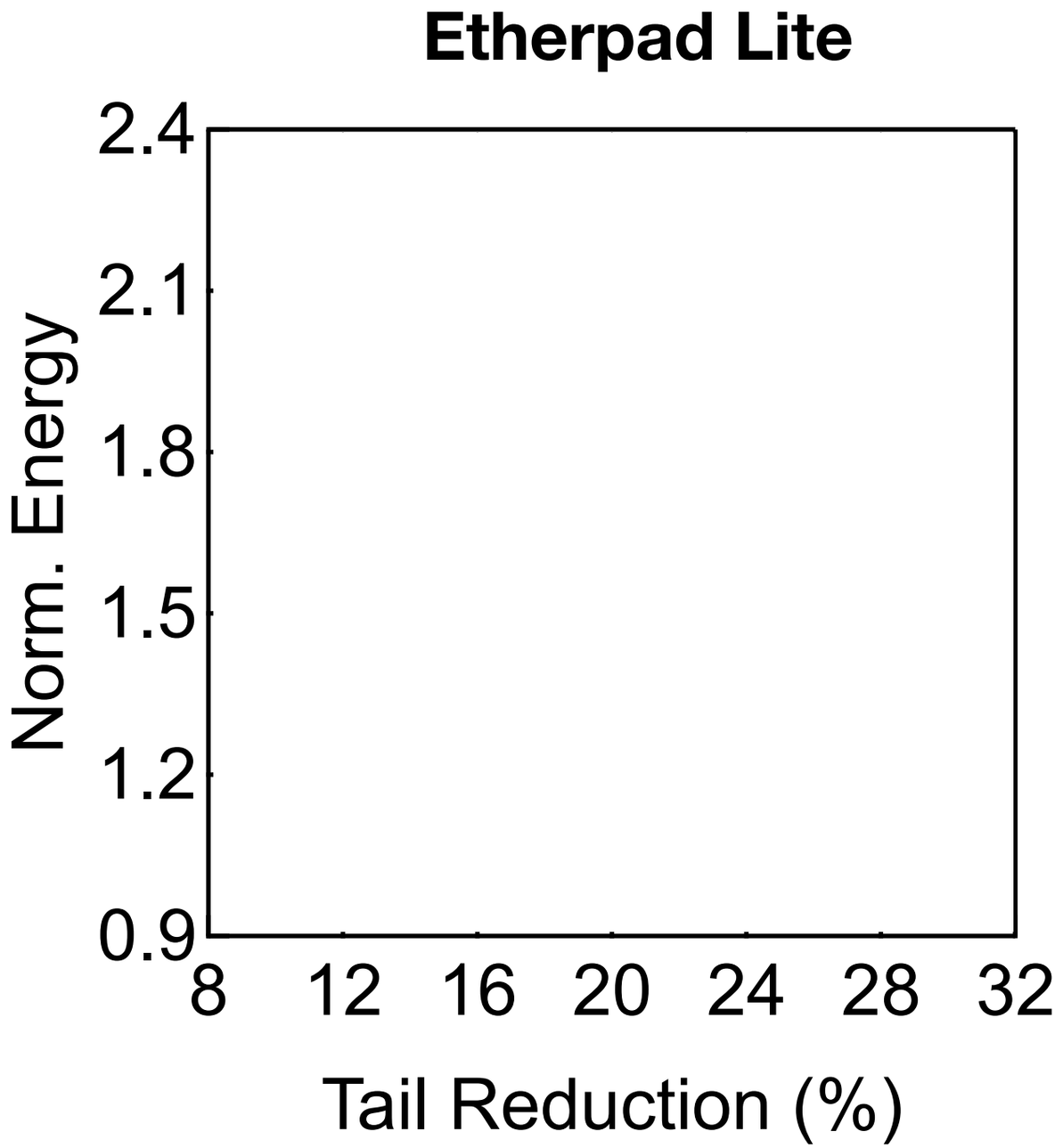

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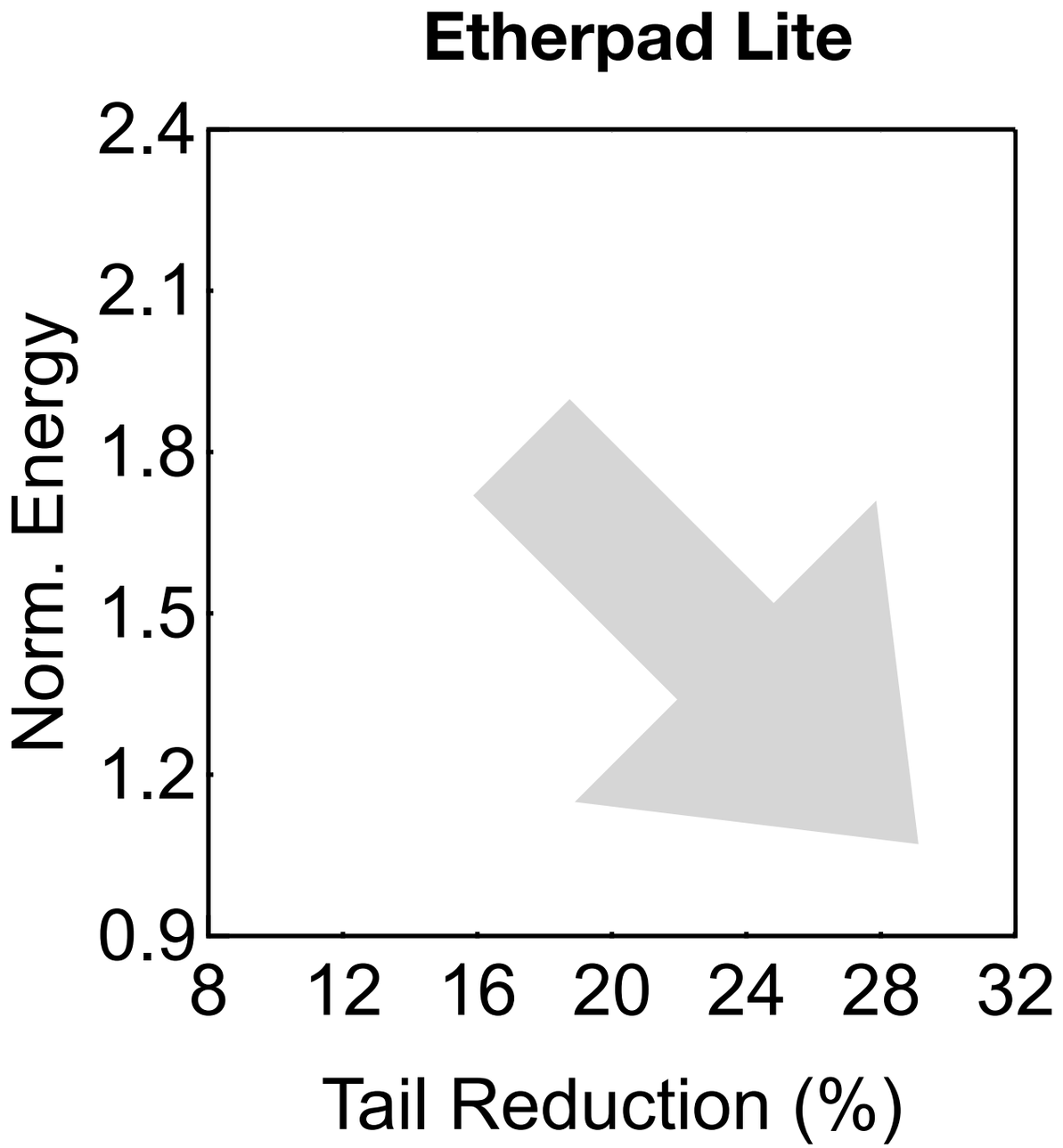

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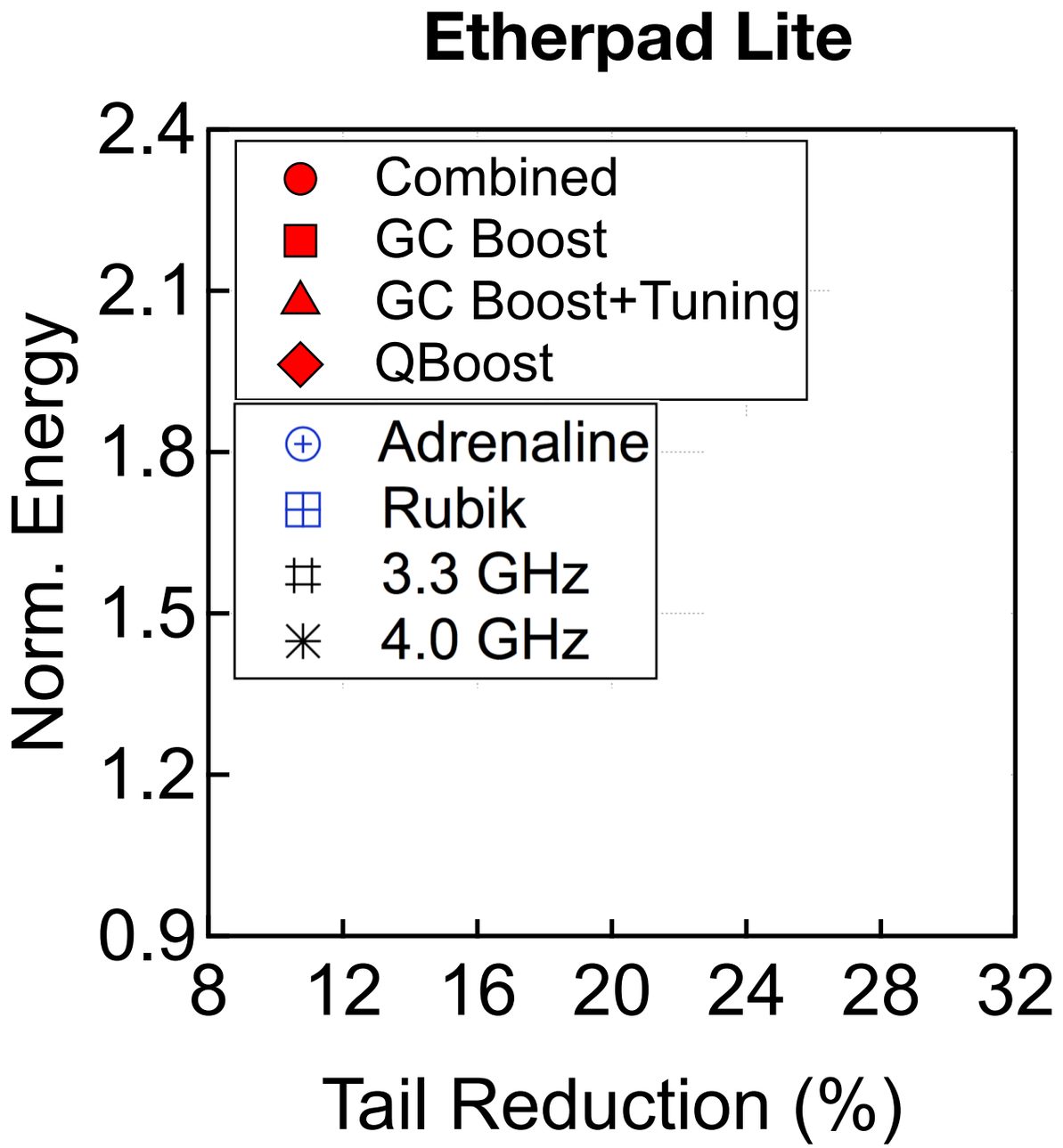

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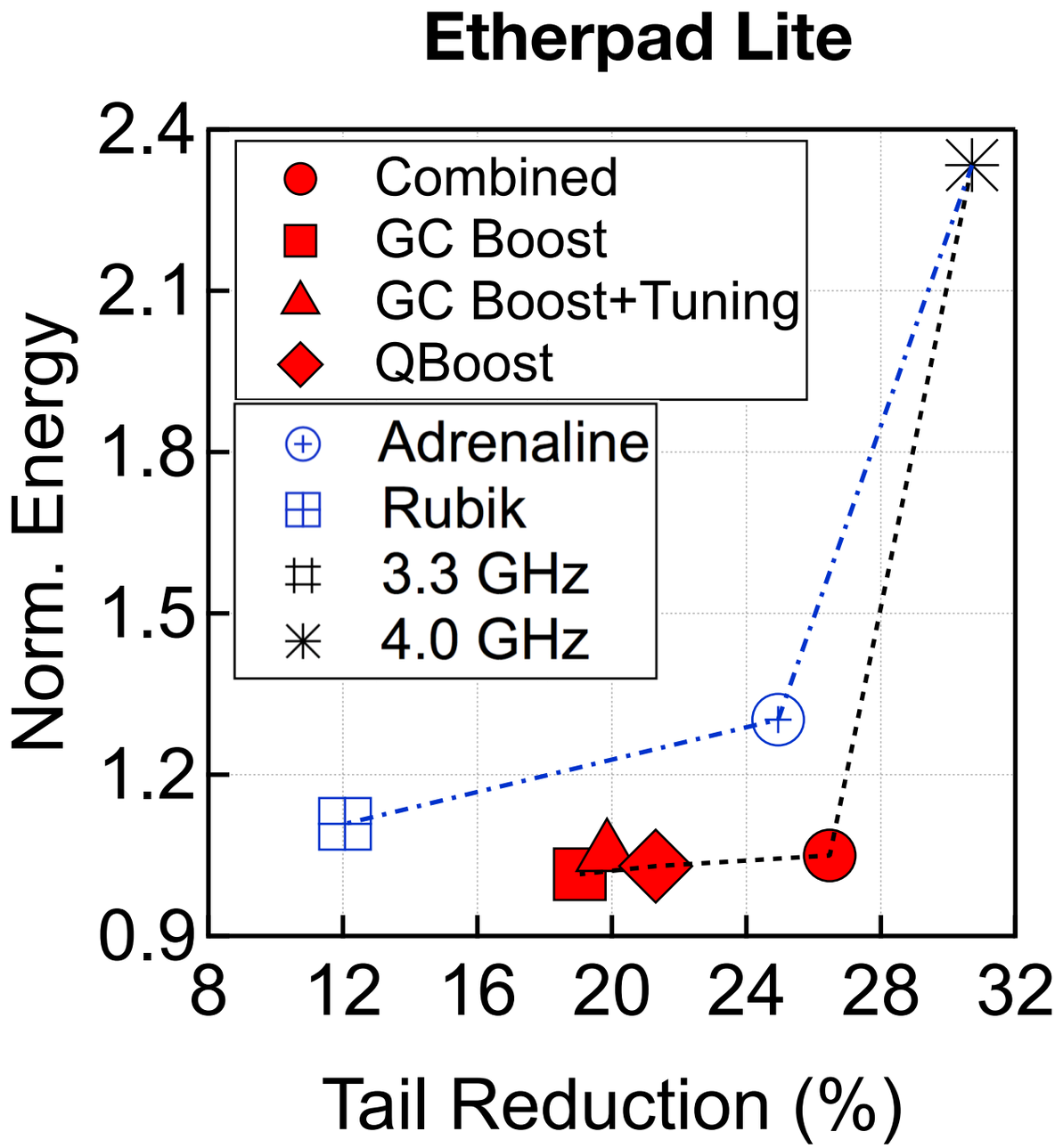

Combined
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GC Boost+Tuning
QBoost

Adrenaline
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3.3 GHz
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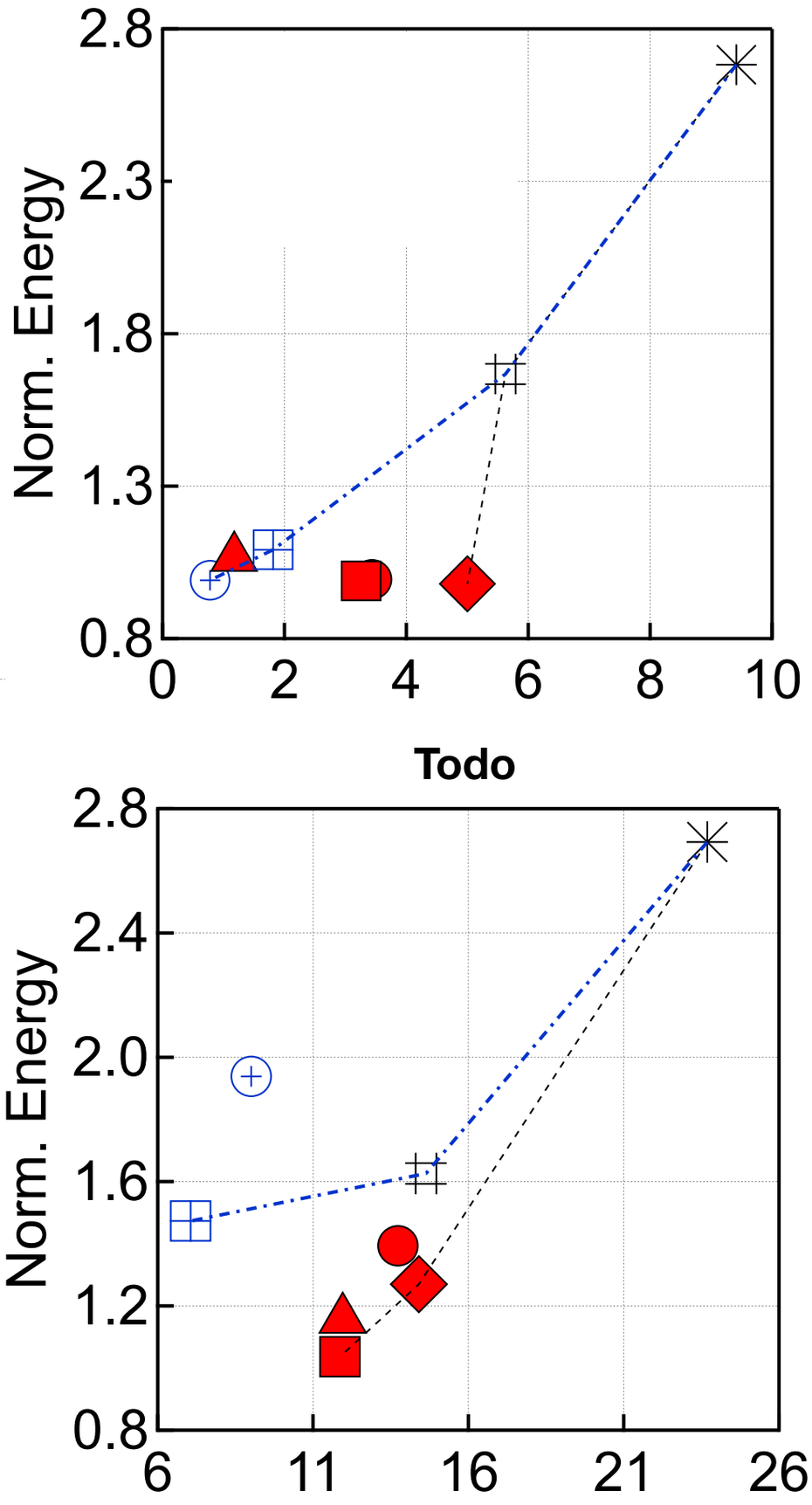

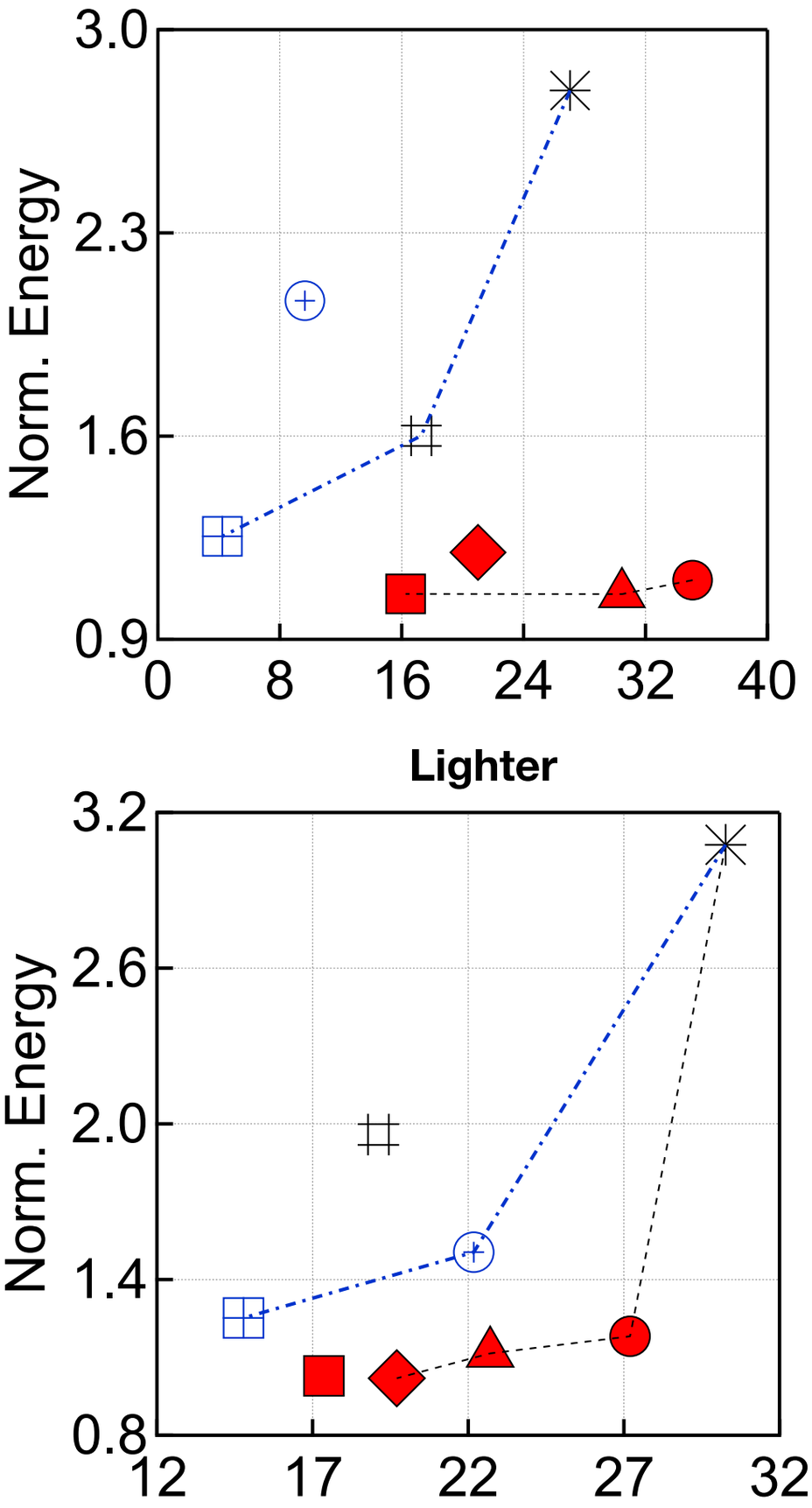

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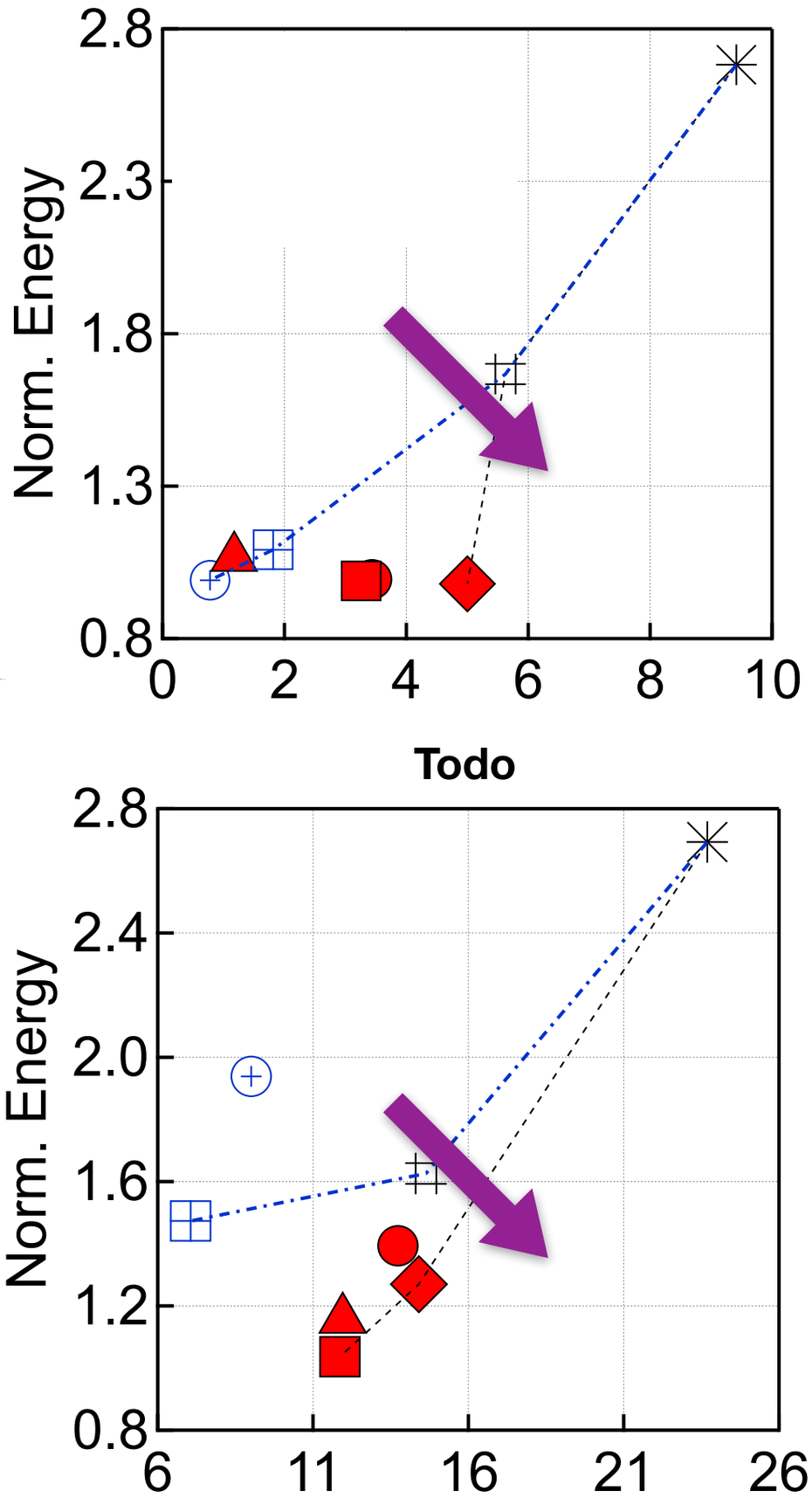
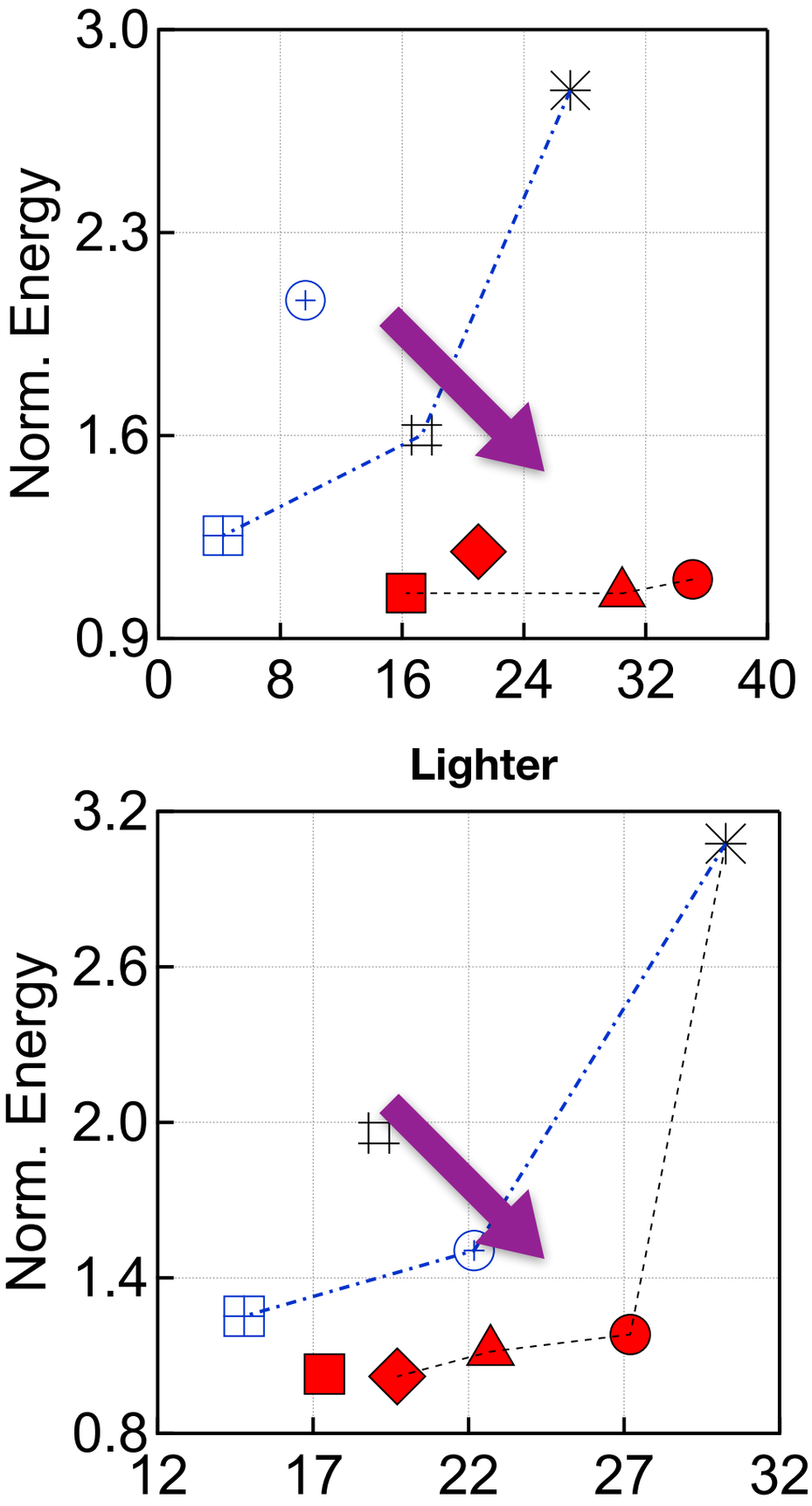
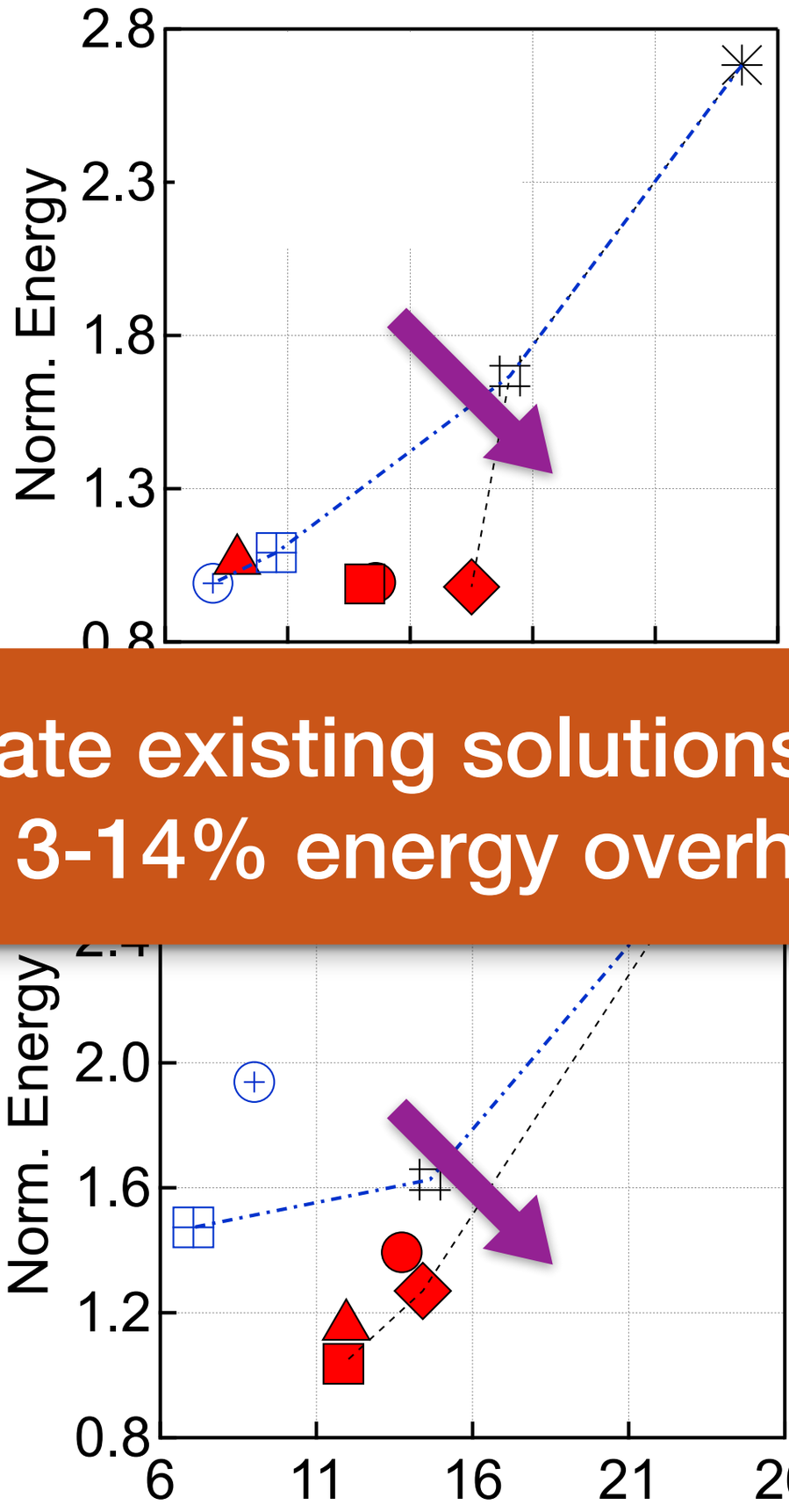
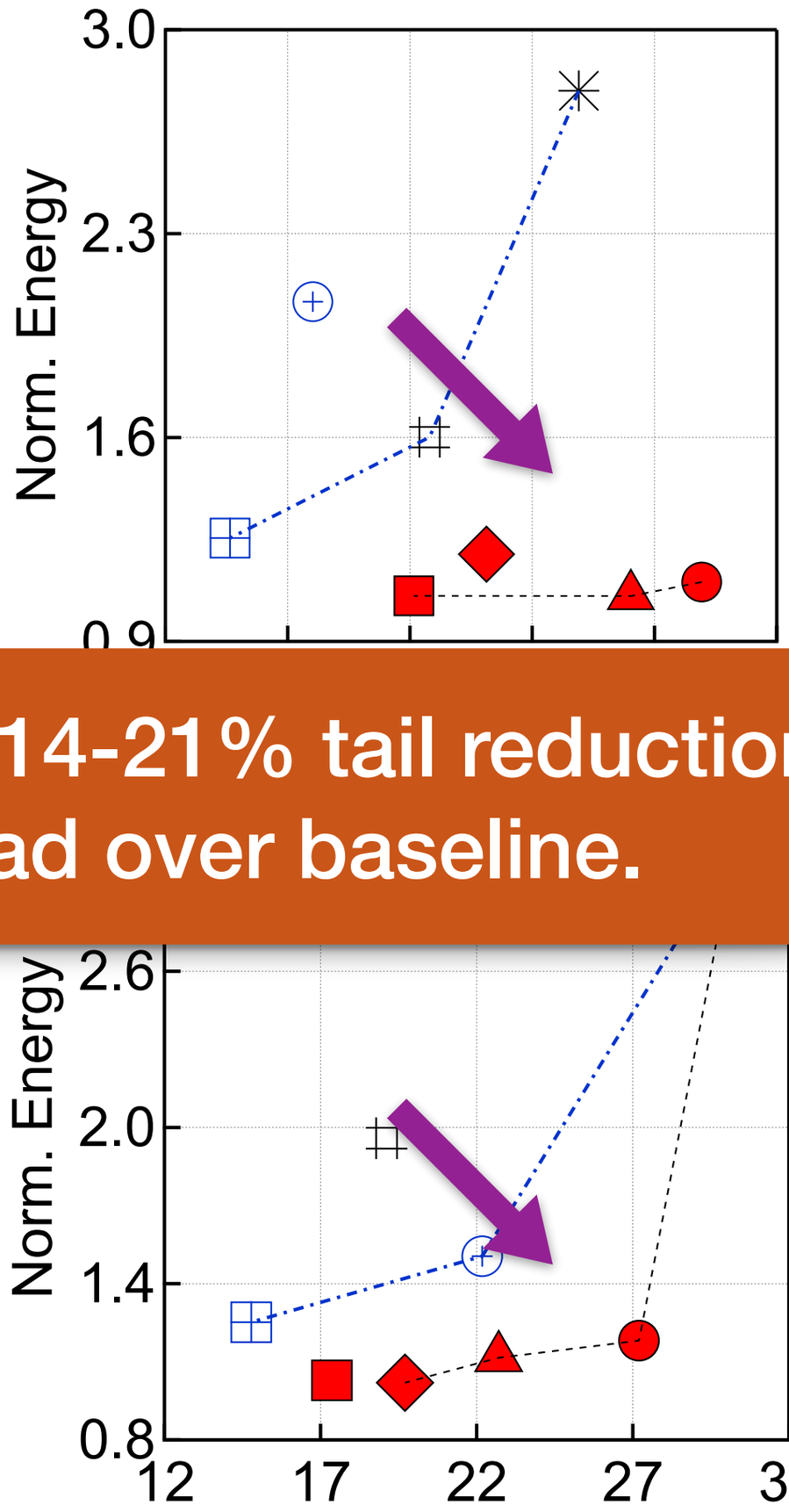


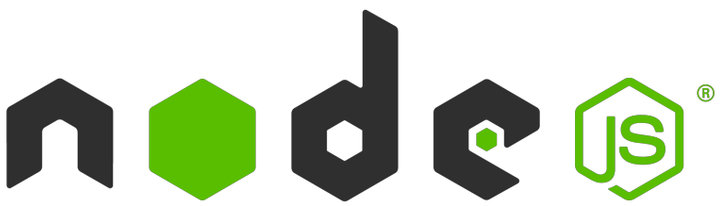






Pareto-dominate existing solutions; 14-21% tail reduction with only 3-14% energy overhead over baseline.

Conclusions



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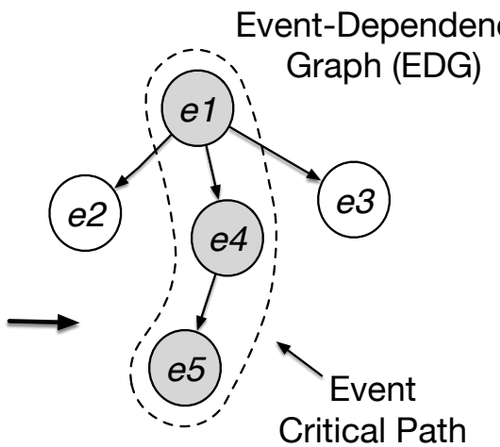

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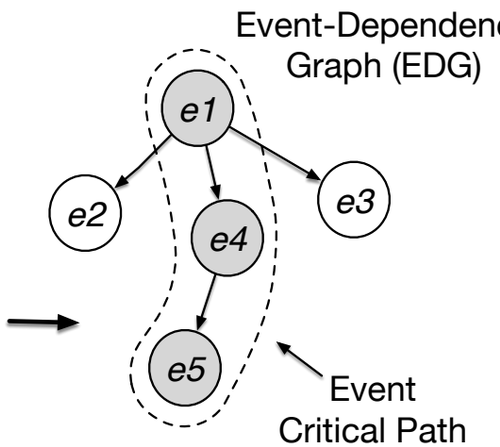

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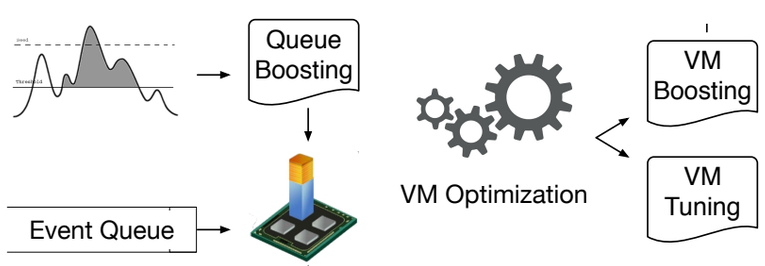

Intelligently leverage existing hardware features, turbo boosting in particular, to reduce latency with little to none energy overhead.