Performance Analysis of Virtual Environments

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Introduction

Motivation

Virtual Machines (VMs) becoming pervasive in data centers and academic institutions.

- Honouring SLAs. Promised vs Actual.
- Quantify impact of Virtualization.
- Making sense of performance data.

Introduction

Project Goals

- Empower user to investigate performance problems with as little inertia as possible.

Introduction

Project

- Framework to build tools for performing fine grained analysis of,
  - resource utilization
  - overheads and
  - performance bottlenecks, in virtual setups.

Agenda

- Introduction
- Xen Overview
- Data Collection
- Analysis Framework
- Analysis Algorithms
- Composibility

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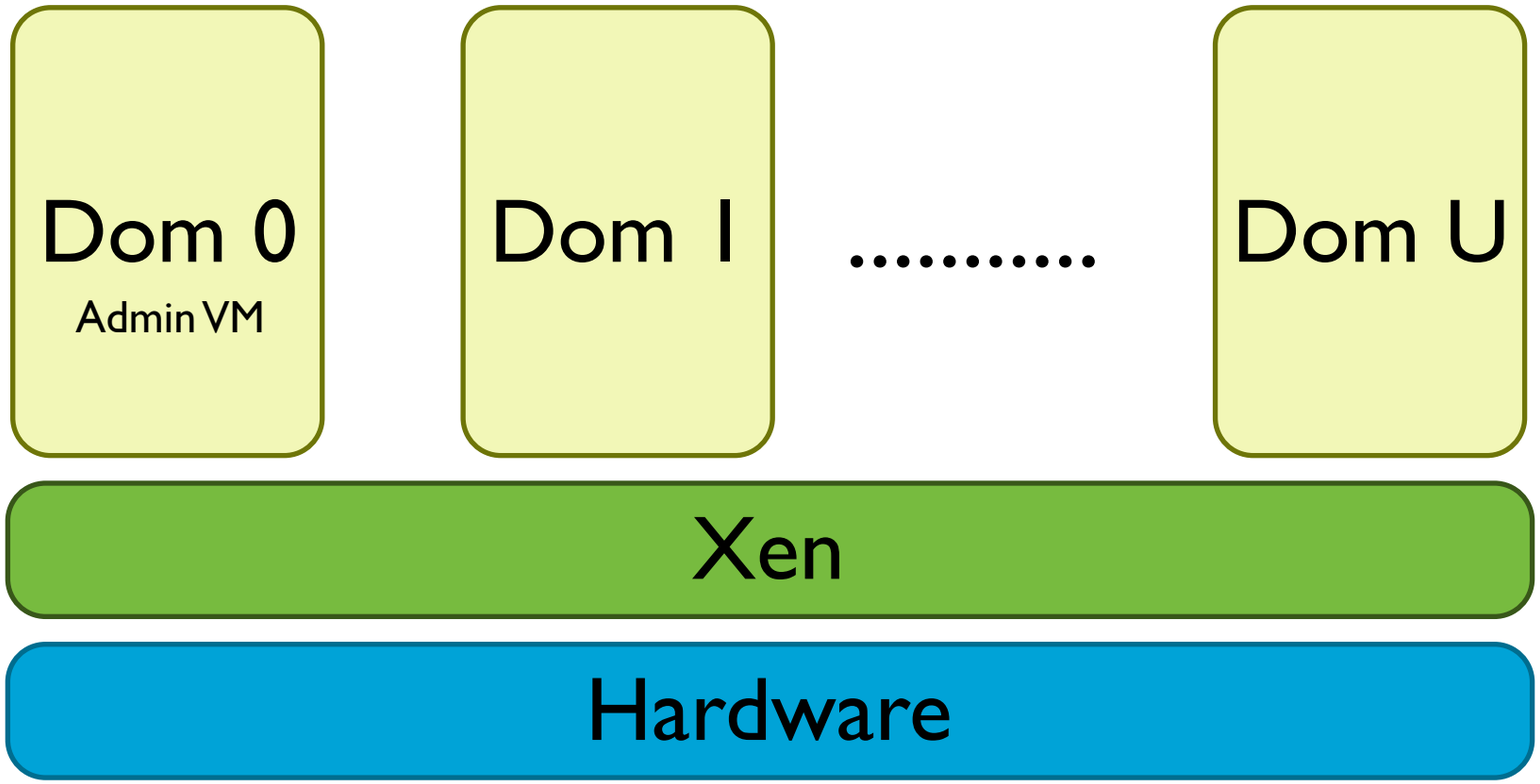
Xen Overview



- Open source.
- Widely used. Ex Amazon EC2

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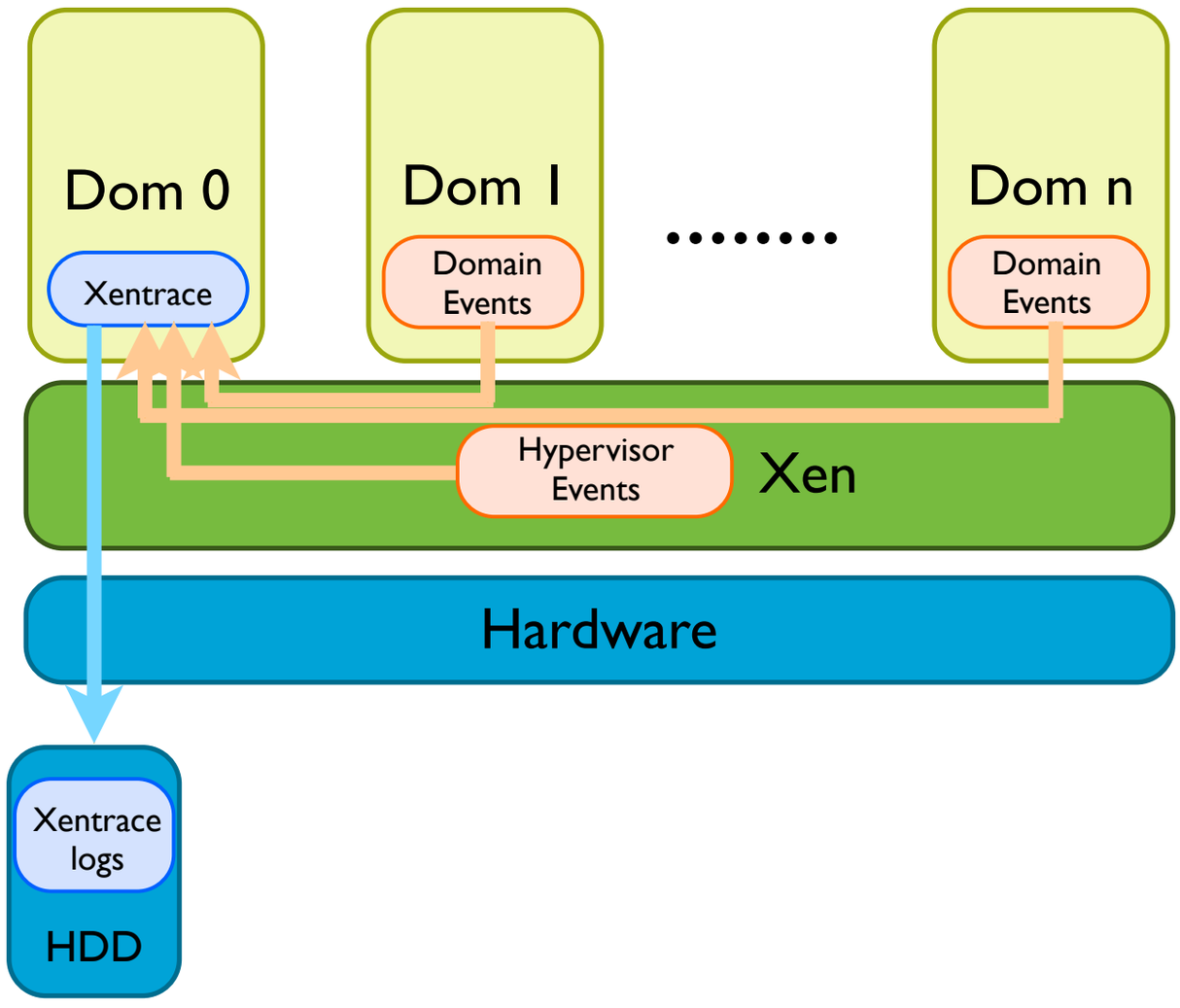
Data Collection

Xentrace - Overview

Xentrace is a lightweight tracing utility that collects hypervisor and domain level events. Ships with Xen.



Data Collection

Xentrace - Advantages

- Widely available since it ships with Xen.
- Easily extensible.

Data Collection

Xentrace - Data

- Not originally intended for performance.
- Xentrace collects enormous amounts of raw information.
  - E.x: data collected during a disk intensive load for 1 minute exceeds 700 MB
- Hence, chose as the source of performance data.

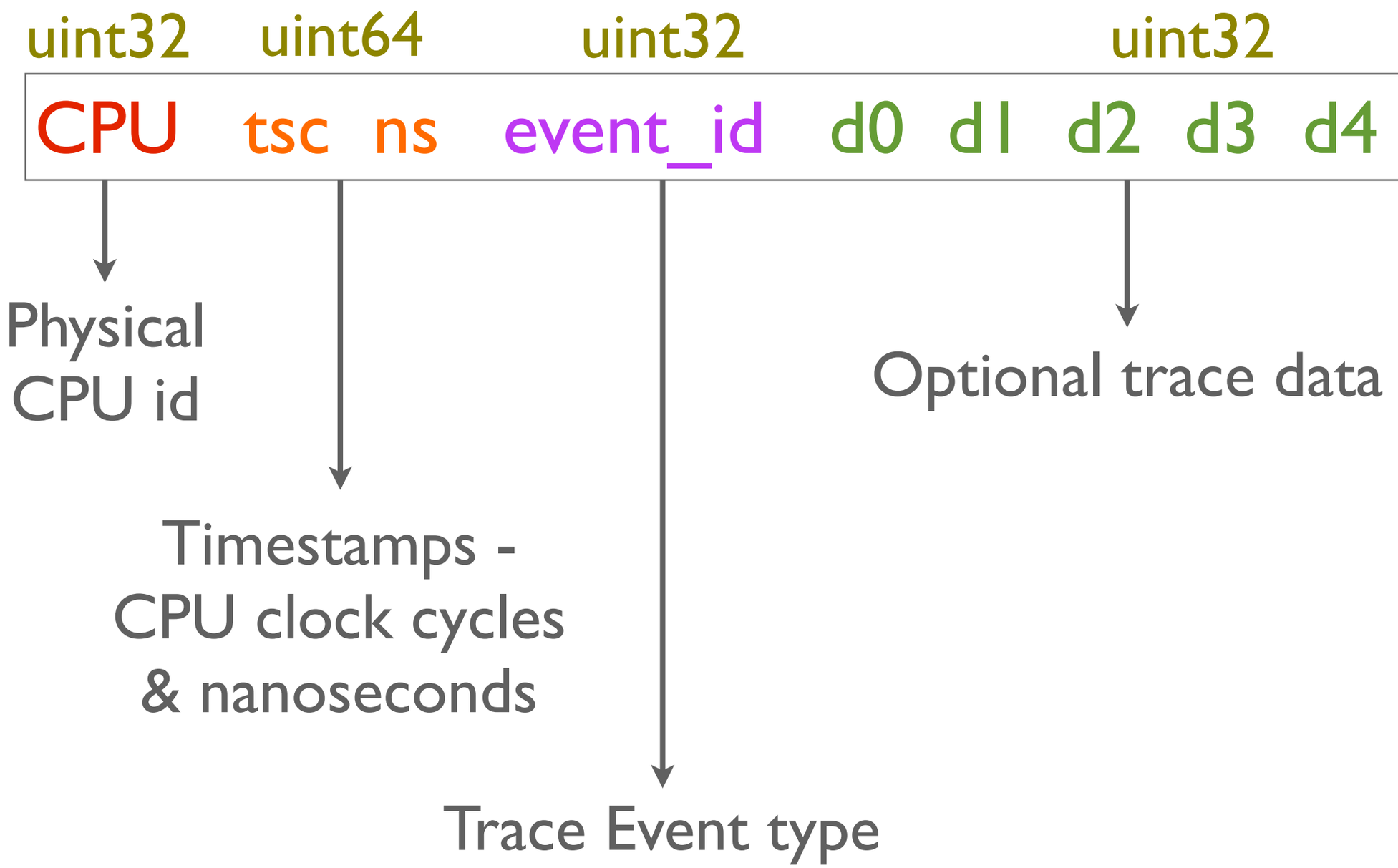
Data Collection

Xentrace - Details

- Event masks to selectively capture event data.
- Log data is in binary format.
- Additional events not provided by Xentrace, can be manually added and collected by inserting trace macros in Xen or domain source.

Data Collection

Xentrace - Event Format



Data Collection

Xentrace - Limitations

- xentrace_format : binary to text.
  - E.x: 700 MB log has 20+ million lines of text

- Very difficult to manually peruse and,
  - identify performance problems.
  - gain high level overview of performance.

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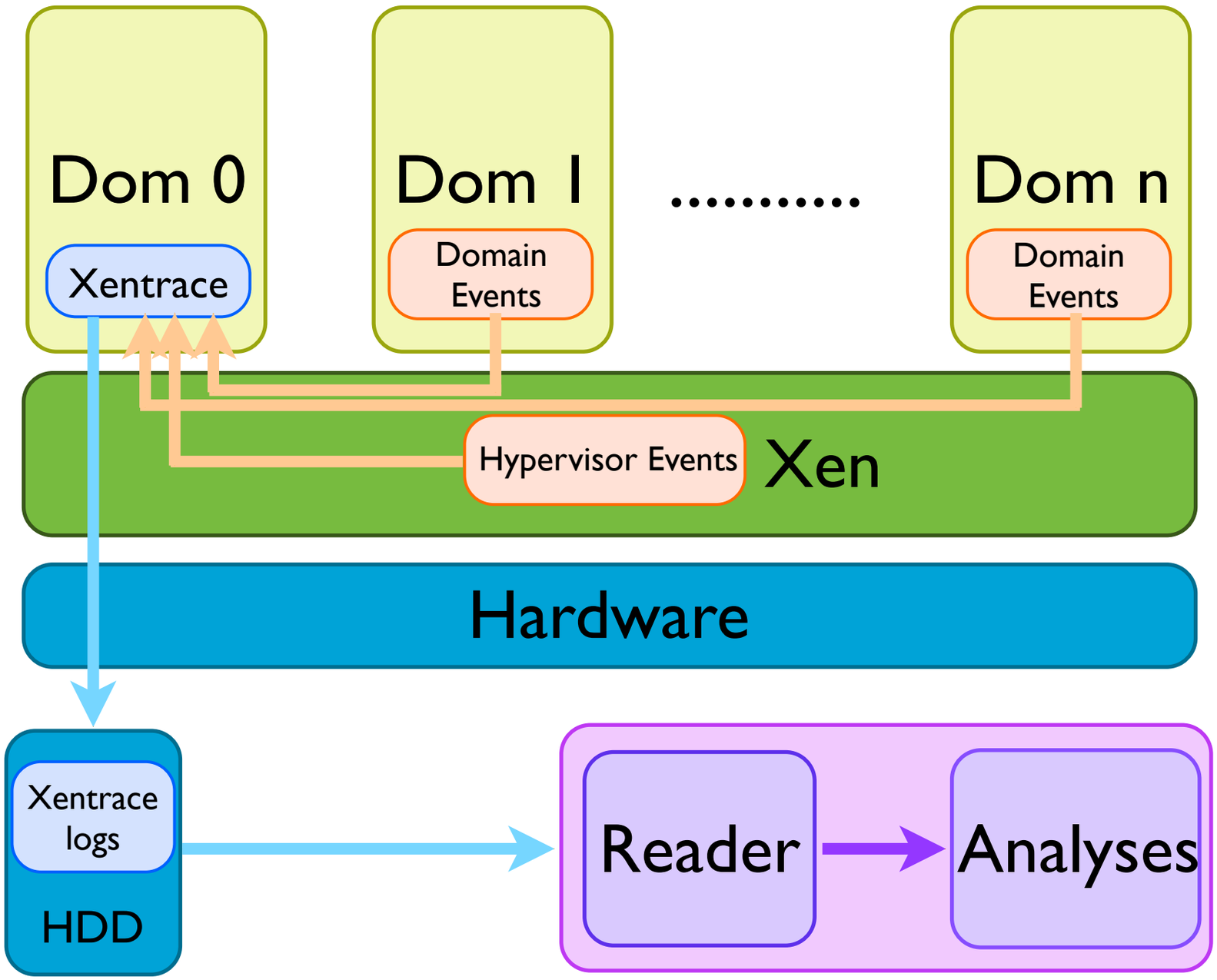
Analysis Framework

Architecture



Analysis Framework

Overview

- Implementation split in two components.
  - Reader: Parses binary log data offline and passes C - style structs to Analyses component.
  - Analyses: Algorithms consisting a group of handlers for different event types. Generate high level performance metrics like CPU utilization, disk i/o performance etc.

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  - Reader
  - Analyses
- Analysis Algorithms
- Composibility

Analysis Framework

Reader - Caveats

- Two caveats make parsing non-trivial.
  - Events collected in logs not completely ordered.

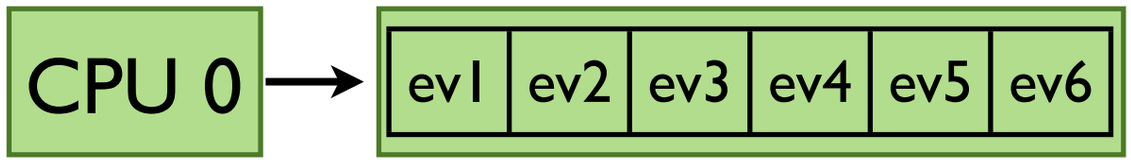
Analysis Framework

Reader - Unordered logs

CPU 0

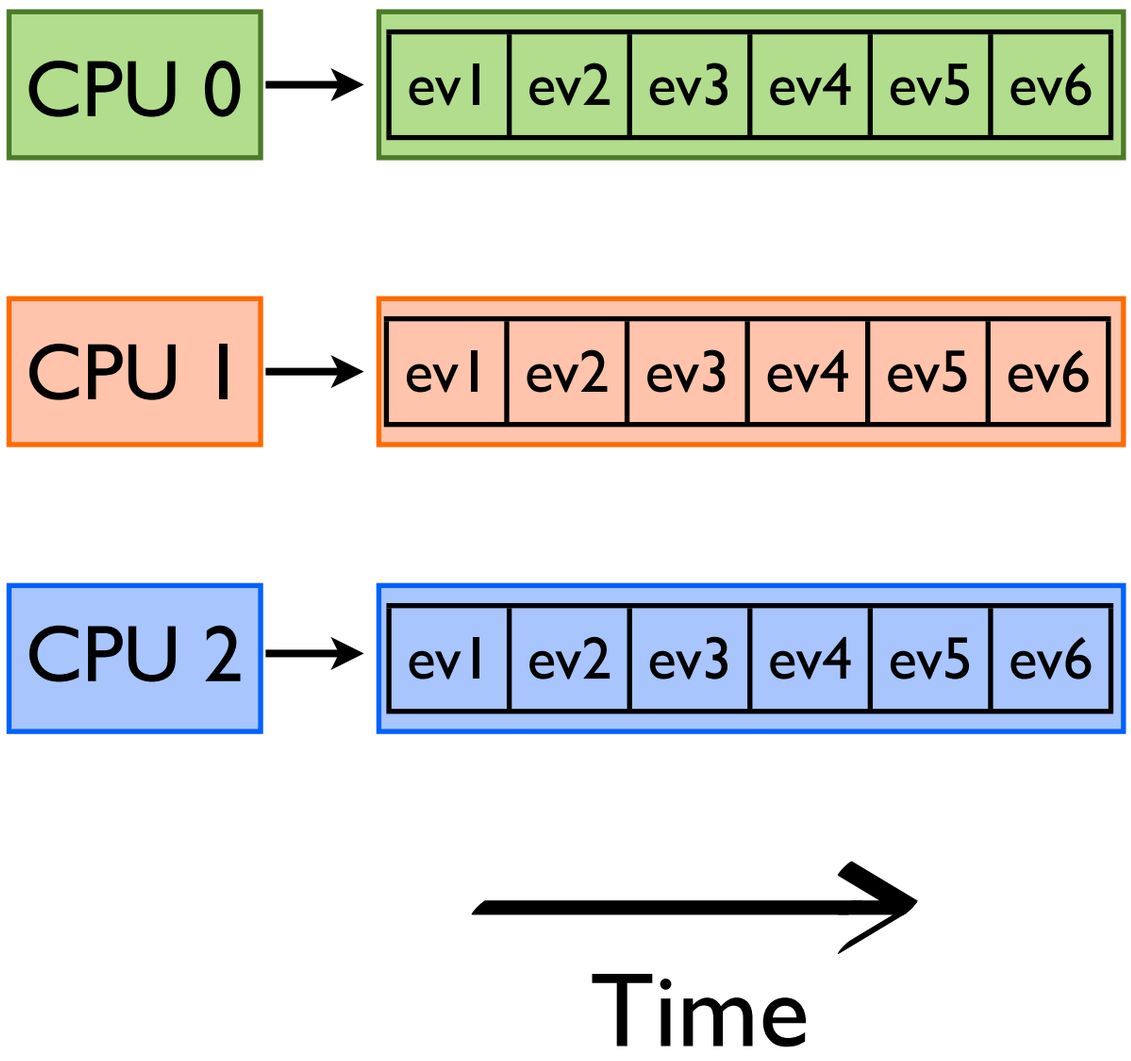
Analysis Framework

Reader - Unordered logs



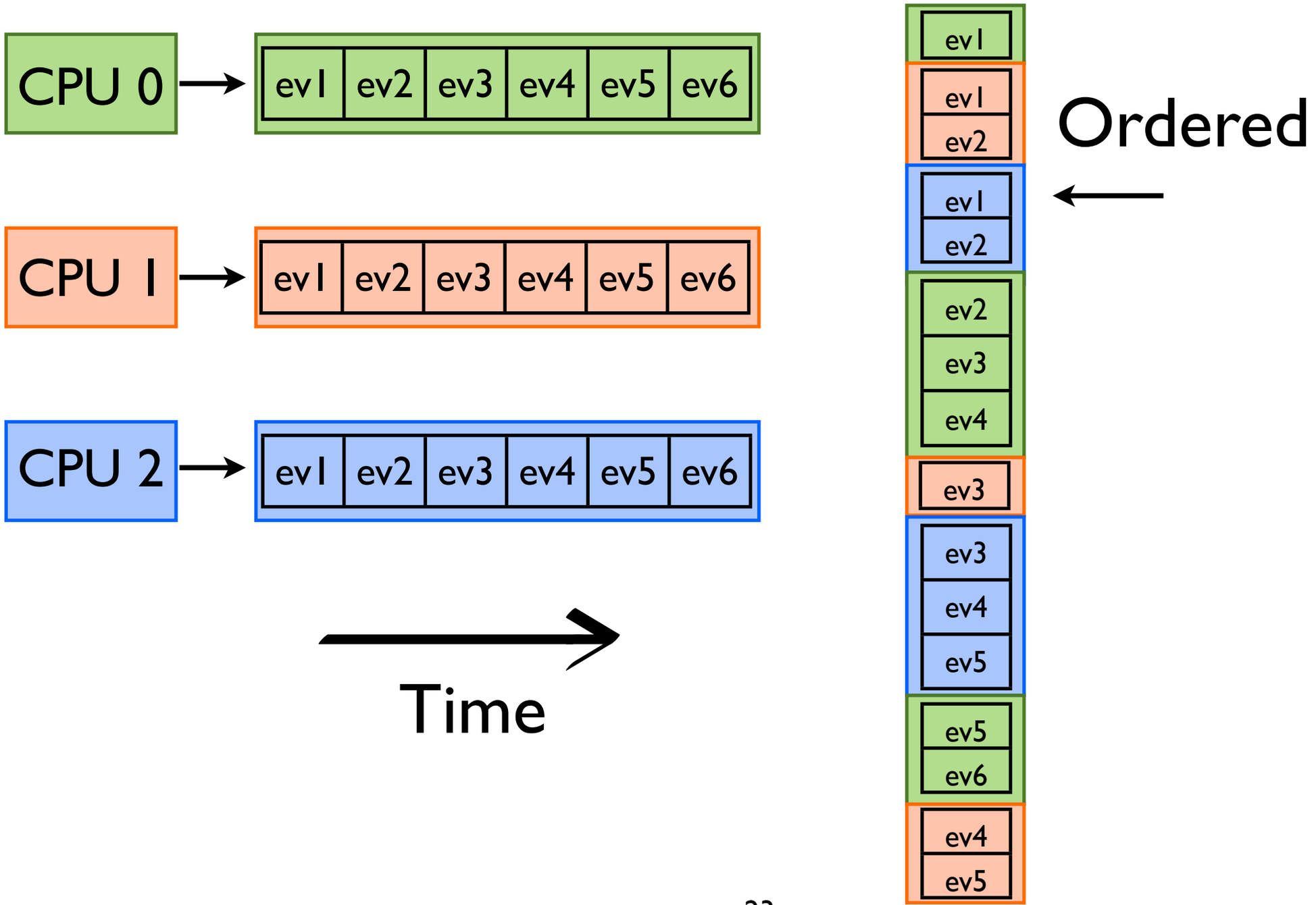
Analysis Framework

Reader - Unordered logs



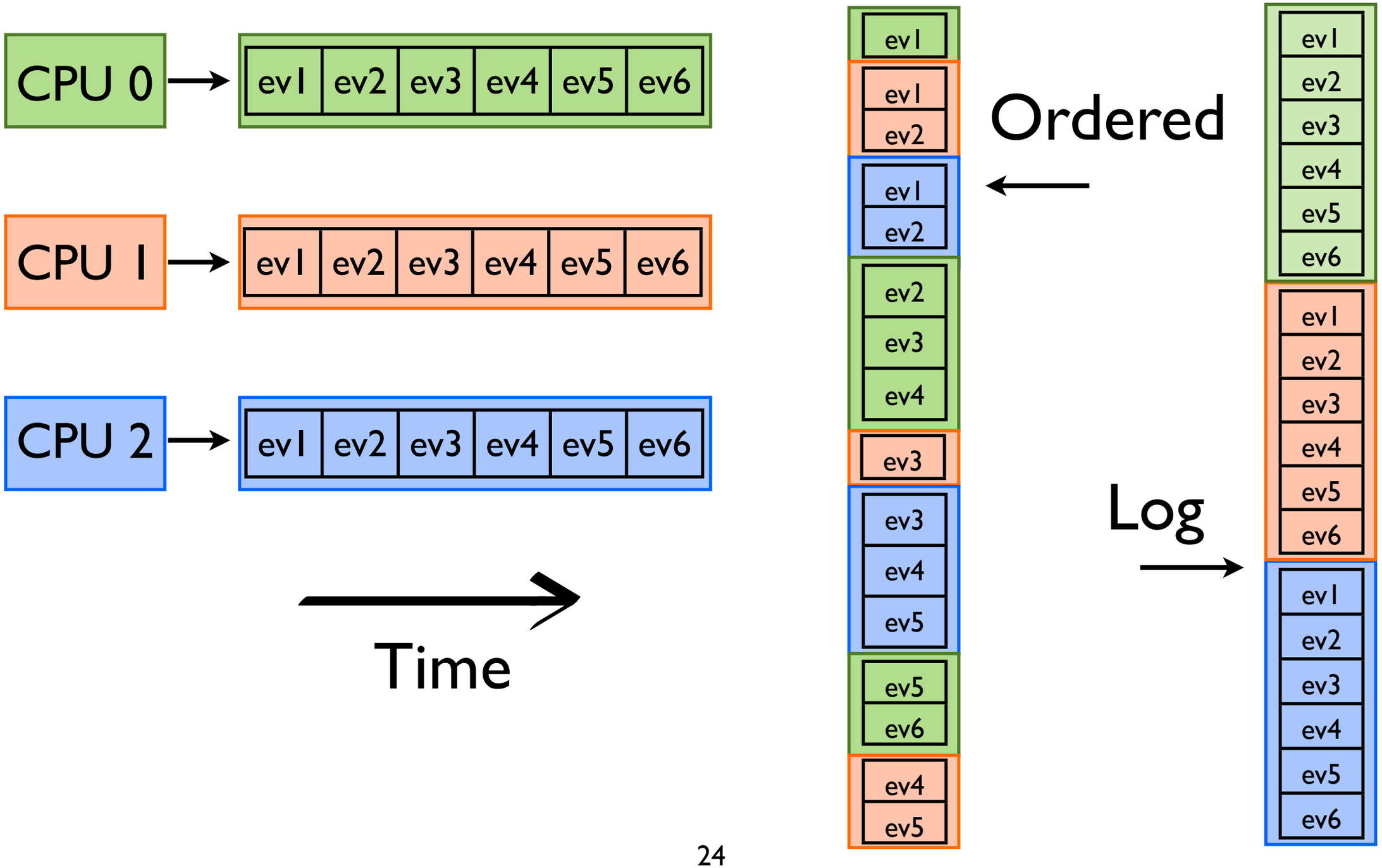
Analysis Framework

Reader - Unordered logs



Analysis Framework

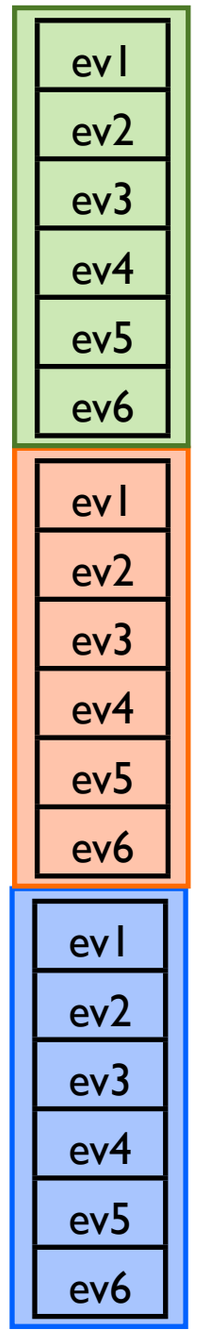
Reader - Unordered logs



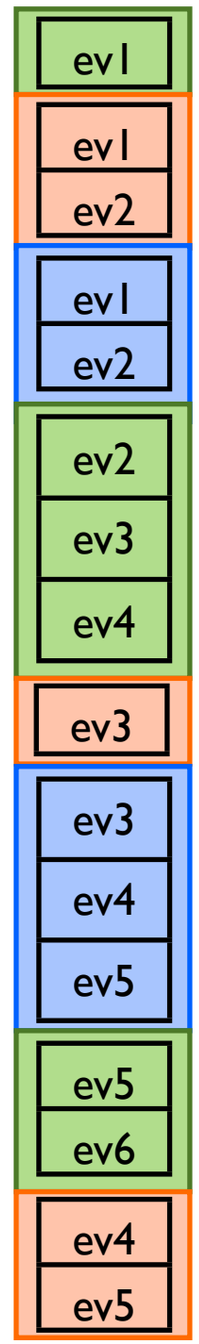
Analysis Framework

Reader - Unordered logs

Unordered logs



Sort ?

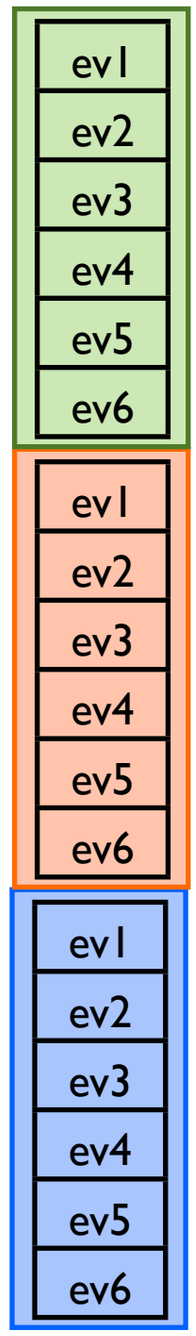


Ordered logs

Analysis Framework

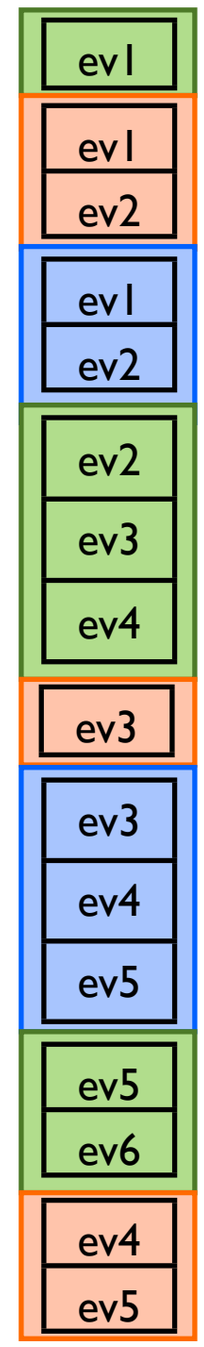
Reader - Unordered logs

Unordered large logs



External Sort ?

d-way Merge Sort

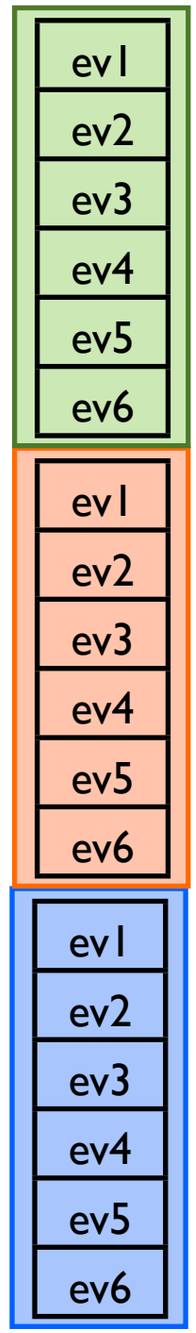


Ordered large logs

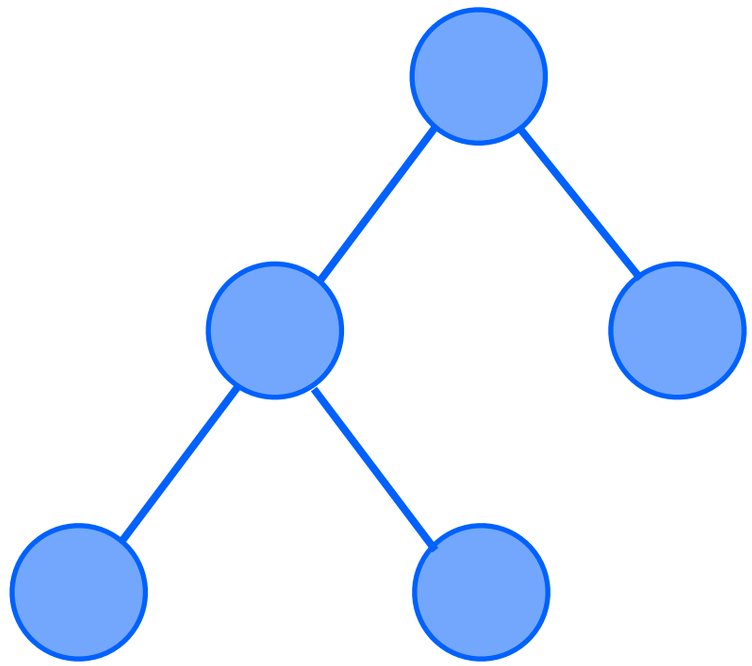
Analysis Framework

Reader - Unordered logs

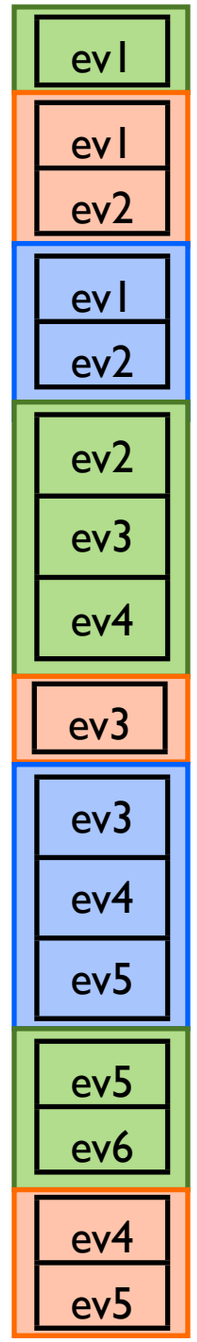
Unordered large logs



d-way Merge



Min-Heap



Ordered large logs

Analysis Framework

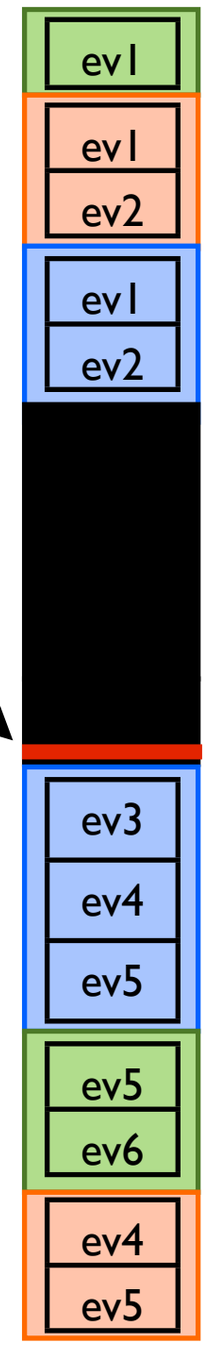
Reader - Caveats

- Two caveats make parsing non-trivial.
  - Events collected in logs not completely ordered.
  - Loss of events during log collection.

Analysis Framework

Reader - Lost Records

- Events come in faster than they can be flushed to disk.
- Xentrace inserts a lost_record event in the logs.
- Interferes with analysis esp. time sensitive.



Analysis Framework

Reader - Lost Records

- Tried different approaches.
  - Increase buffer size.
  - Use Event masks when possible.
  - Fix Xentrace bug.
- Treat lost_records as just another event.
- It's handler notifies other event handlers in execution of its occurrence.
- They deal with it appropriately (discarding analysis, ignoring it completely etc.)

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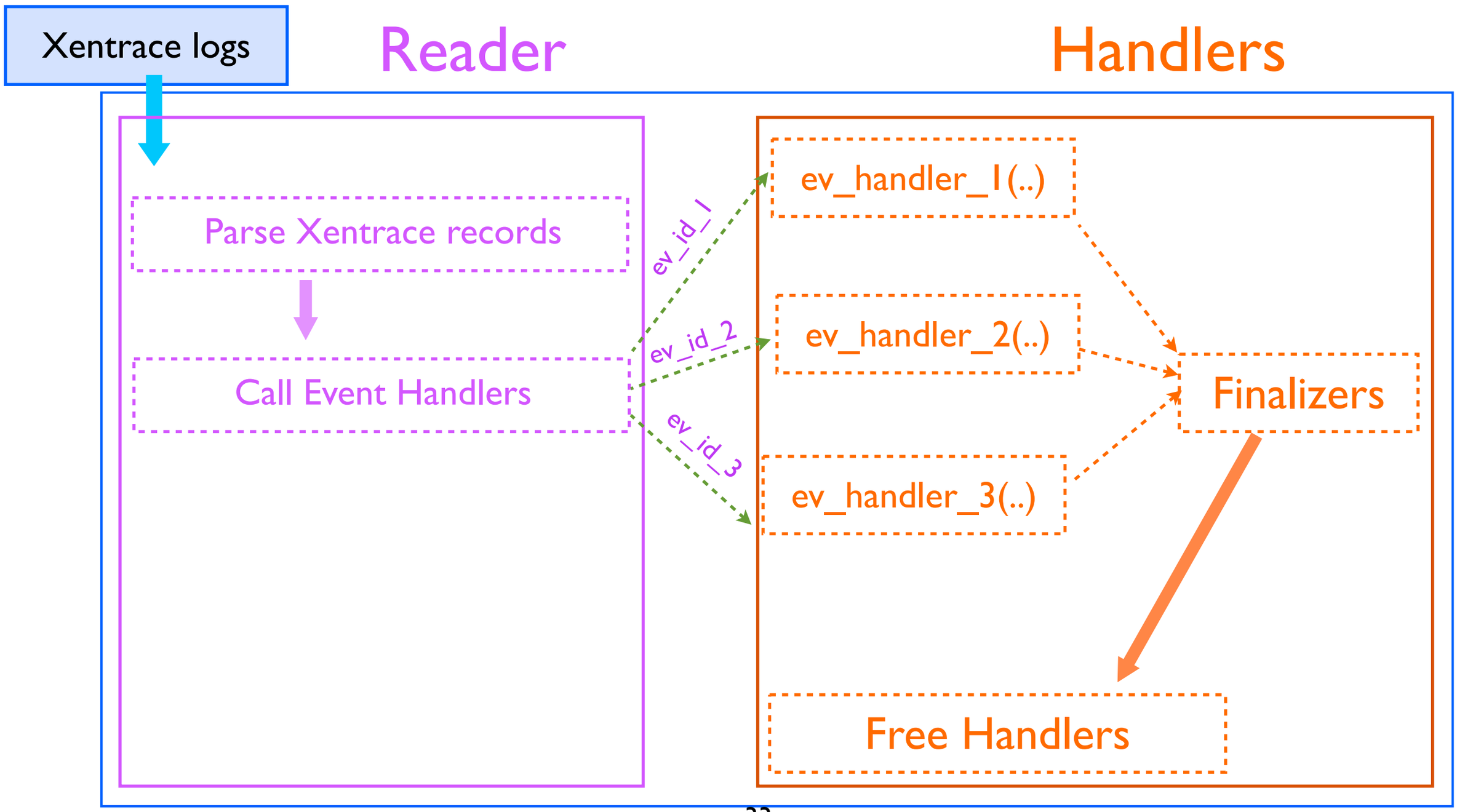
Analyses

- Each tool's analysis logic is made up of Event Handlers.
- Event Handlers registered with Reader.
- Handler needs 3 methods written by the user.
  - Initialize
  - Handle
  - Finalize
  - Ex: Count of Events. Initialize count to 0, increment count, print count at the end.

Analyses

Architecture



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Analysis Algorithms

- Reasoning about performance in virtual environments is *not* always straightforward.
- The user has to follow his instinct or data from another analysis.

Analysis Algorithms

Motivation

- Quantify phenomena observed on virtual setups.
- **U**tilization **S**aturation **E**rrors (USE) methodology [1]

Analysis Algorithms

- CPU Utilization
- CPU Scheduling Latency
- Time in Hypervisor
- Disk I/O
  - Device Driver Queue Status
  - Device Driver Queue Request and Response Latency

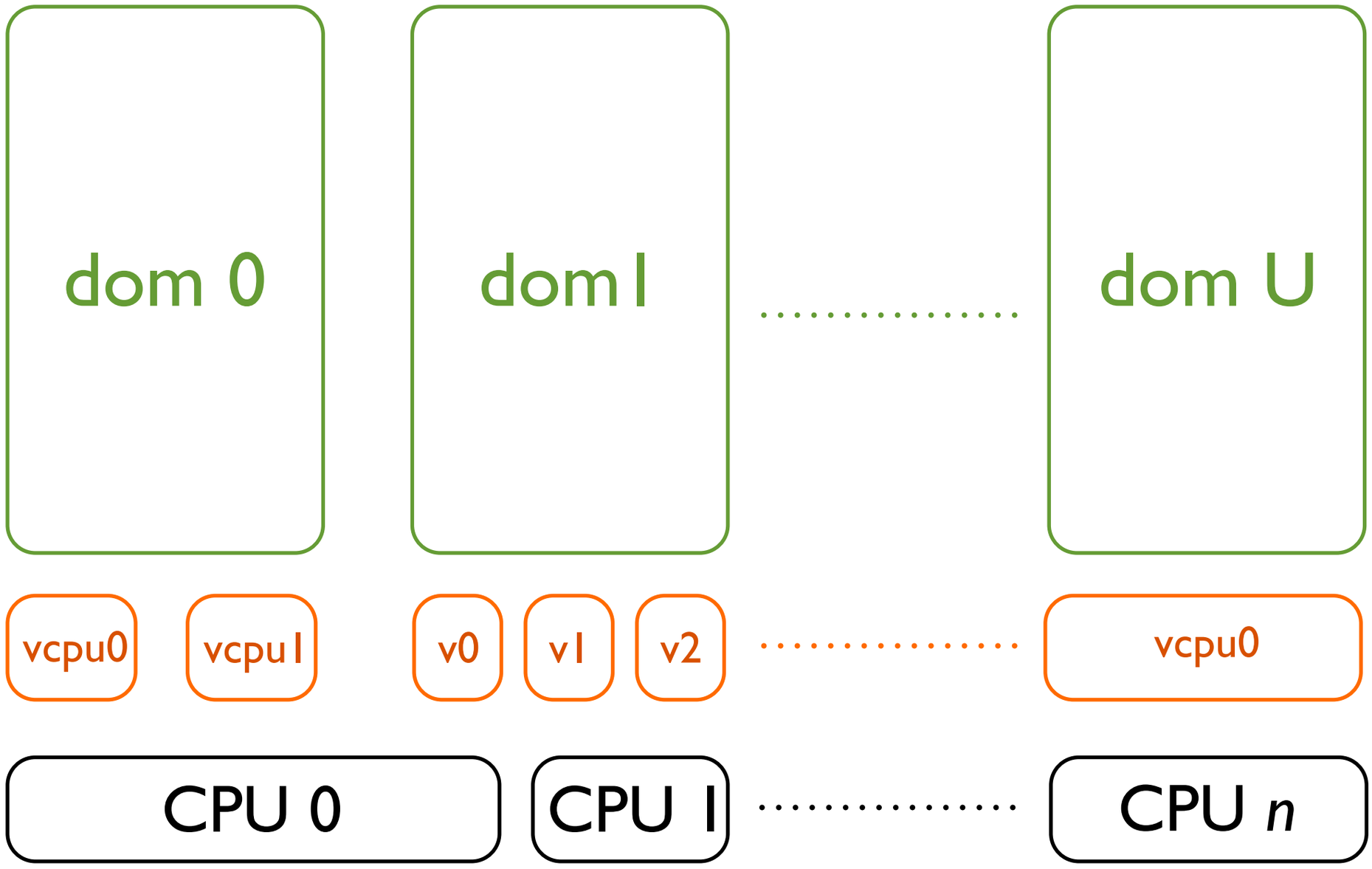
Analysis Algorithms

CPU Utilization - Why ?

- Fine grained CPU utilization information can,
  - Check if hypervisor adheres to Service Level Agreements (SLA) between hosting providers and clients.
  - Detecting unbalanced mapping between physical CPUs and VMs.

Analysis Algorithms

CPU Utilization



Analysis Algorithms

- CPU Utilization
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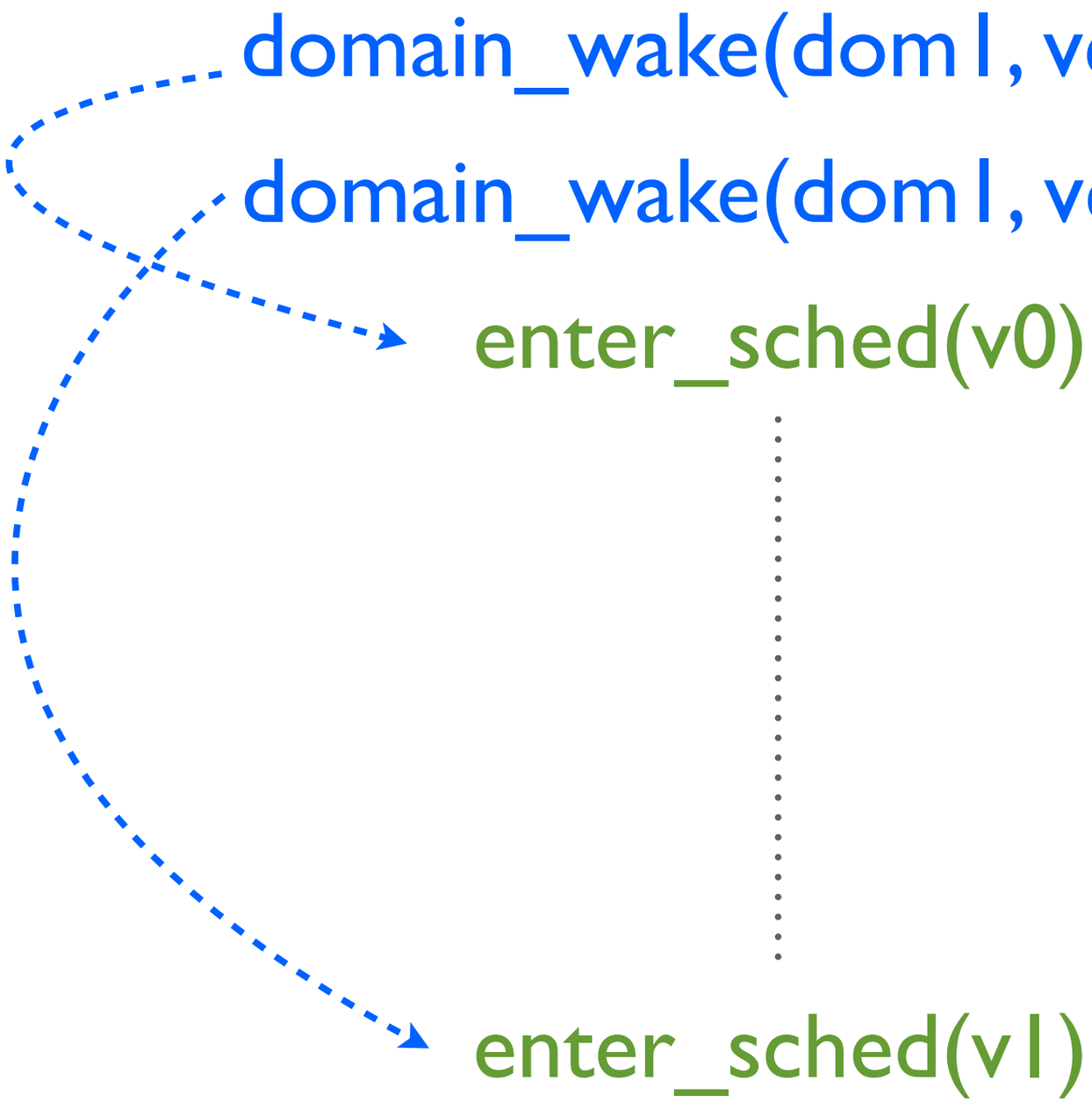
Analysis Algorithms

CPU Scheduling Latency



Analysis Algorithms

CPU Scheduling Latency

- Measures time a VM had to wait to get scheduled since the context switch request was sent out.
- Delay in context switch not only affects CPU bound tasks but also I/O jobs.
  - Since domain needs CPU to process I/O requests/responses.

Analysis Algorithms

CPU Scheduling Latency

- Wait times can increase for a number of reasons,
  - VCPUs are over-scheduled.
  - Physical CPU is always busy.
  - Imbalance in VCPU => CPU affinity.

Analysis Algorithms

CPU Scheduling Latency

```
domId: 0 : CPU Wait Time: 32.677604 (ms)
domId: 1 : CPU Wait Time: 12.826167 (ms)

Total CPU Wait time for all domains: 45.5037771 (ms)

0 - 700 (ns) : 0
700 - 1400 (ns) : 16178
1400 - 2100 (ns) : 12835
2100 - 2800 (ns) : 1384
2800 - 3500 (ns) : 28
3500 - 4200 (ns) : 1
4200 - 4900 (ns) : 0
4900 - 5600 (ns) : 0
5600 - 6300 (ns) : 0
6300 - 7000 (ns) : 0
> 7000 (ns) : 0
```

Analysis Algorithms

- CPU Utilization
- CPU Scheduling Latency
- Time in Hypervisor
- Disk I/O
  - Device Driver Queue Status
  - Device Driver Queue Request and Response Latency

Analysis Algorithms

Time in Hypervisor - Why ?

- CPU utilization data can sometimes be unreliable to infer performance problems from.
- Possible case is when most execution takes place in hypervisor.
  - E.x: When significant amount of time is spent in the hypervisor, executing instructions or performing I/O on behalf of a domain, CPU util data will not show this behavior.
  - E.x: Honoring SLAs. Does SLA include Xen runtime ?

Analysis Algorithms

Time in Hypervisor

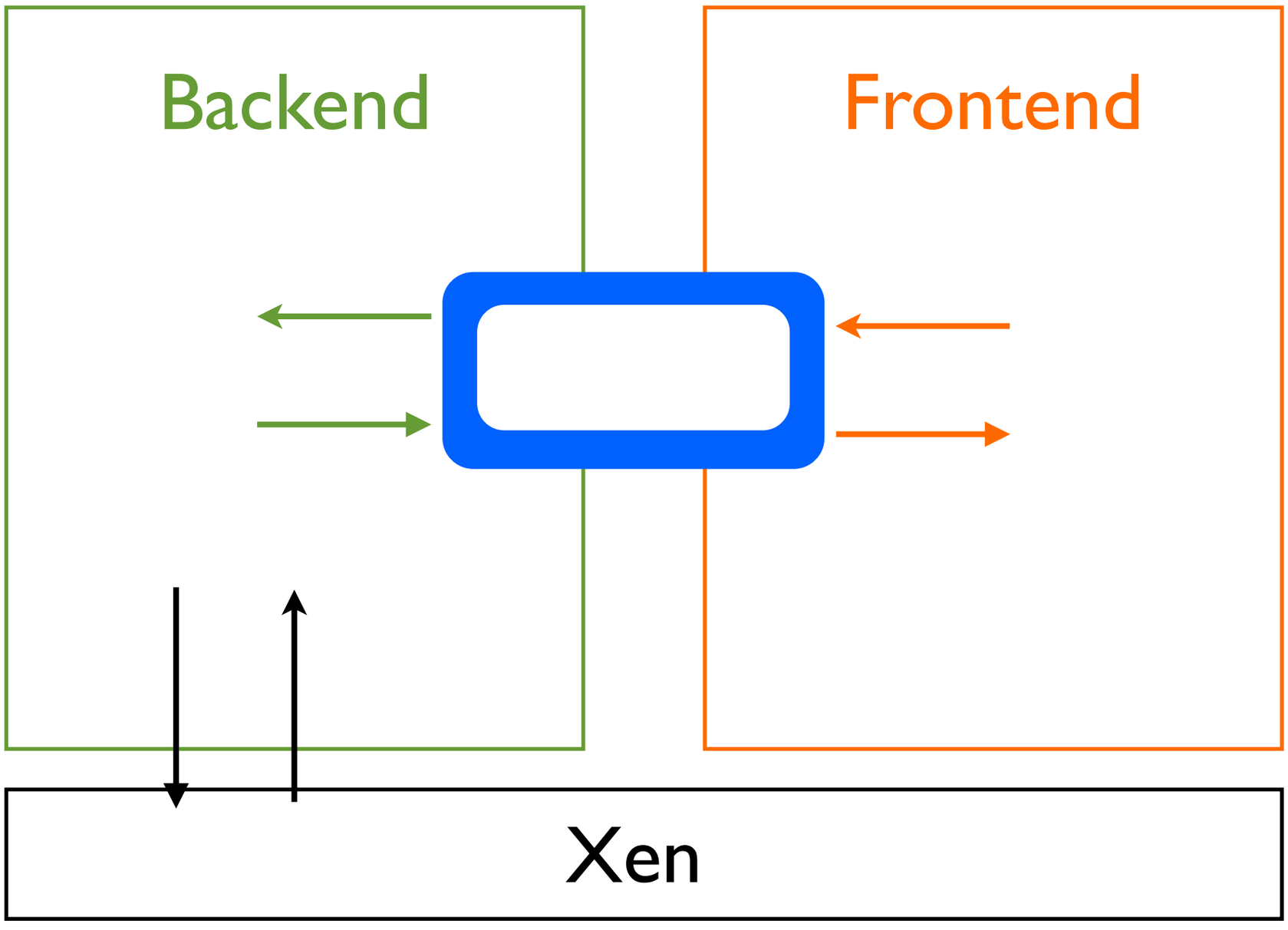
```
Total of 0 lost_record events encountered

Total time spent in Domain        0 : CPU 1 =          307.576 (ms)
Total time spent in Domain IDLE   : CPU 1 =        35333.512 (ms)
Total time spent in Domain        0 : CPU 0 =          731.296 (ms)
Total time spent in Domain IDLE   : CPU 0 =        34436.609 (ms)
Total time spent in Domain        1 : CPU 2 =        19116.232 (ms)
Total time spent in Domain IDLE   : CPU 2 =        16480.766 (ms)

Total time spent in Xen:         715.835 (ms)
```

Analysis Algorithms

- CPU Utilization
- CPU Scheduling Latency
- Time in Hypervisor
- **Disk I/O**
  - Device Driver Queue Status
  - Device Driver Queue Request and Response Latency

Analysis Algorithms

Disk I/O - Split Device Driver Model



Analysis Algorithms

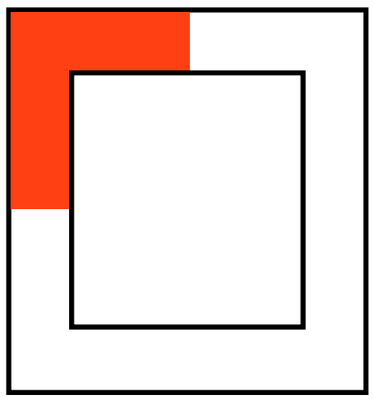
Disk I/O - Why ?

- Performance impact of split device drivers on Disk I/O.

Analysis Algorithms

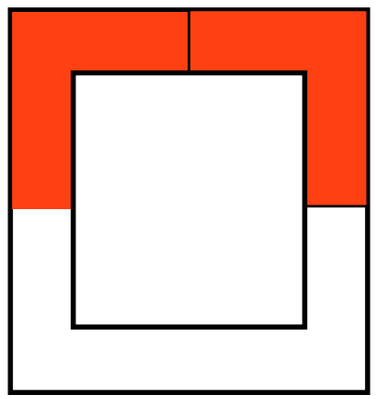
Disk I/O - Shared Ring Buffer [2]

1



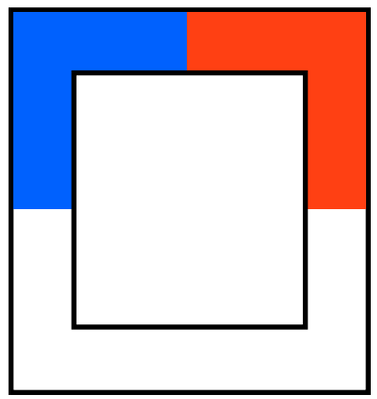
DomU writes Req 1

2



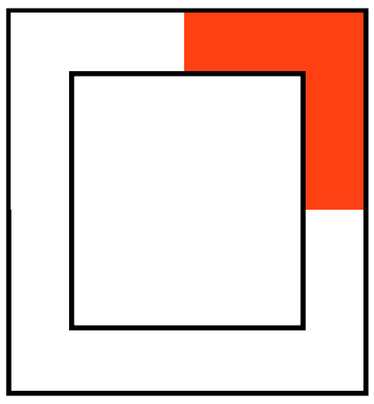
DomU writes Req 2

3



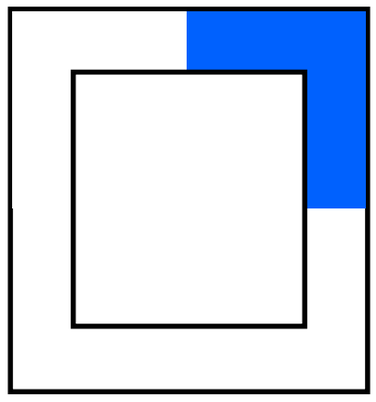
Dom0 writes Resp 1

4



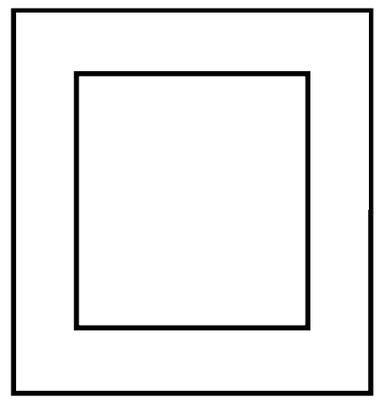
DomU reads Resp 1

5



Dom0 writes Resp 2

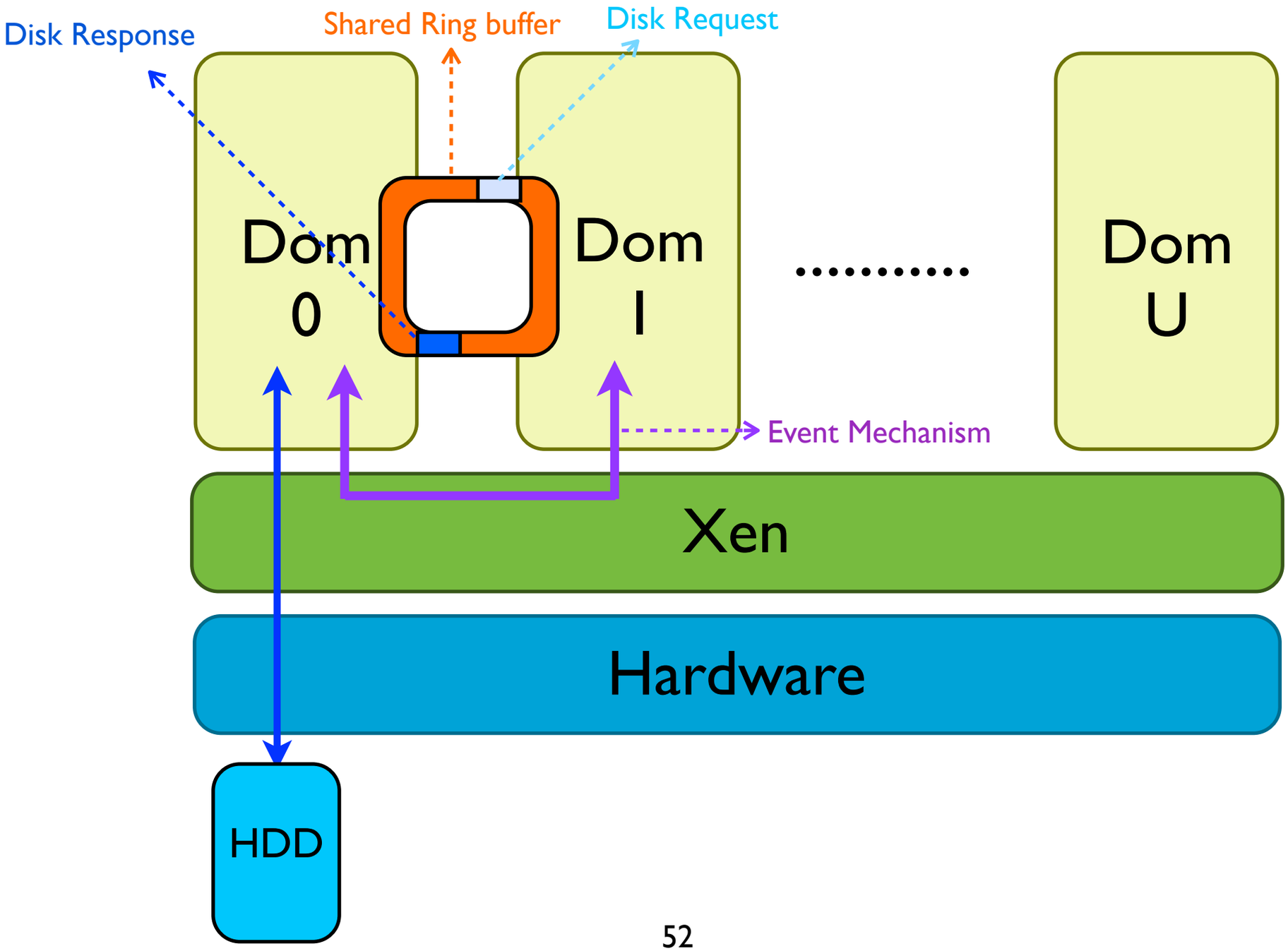
6



DomU reads Resp 2

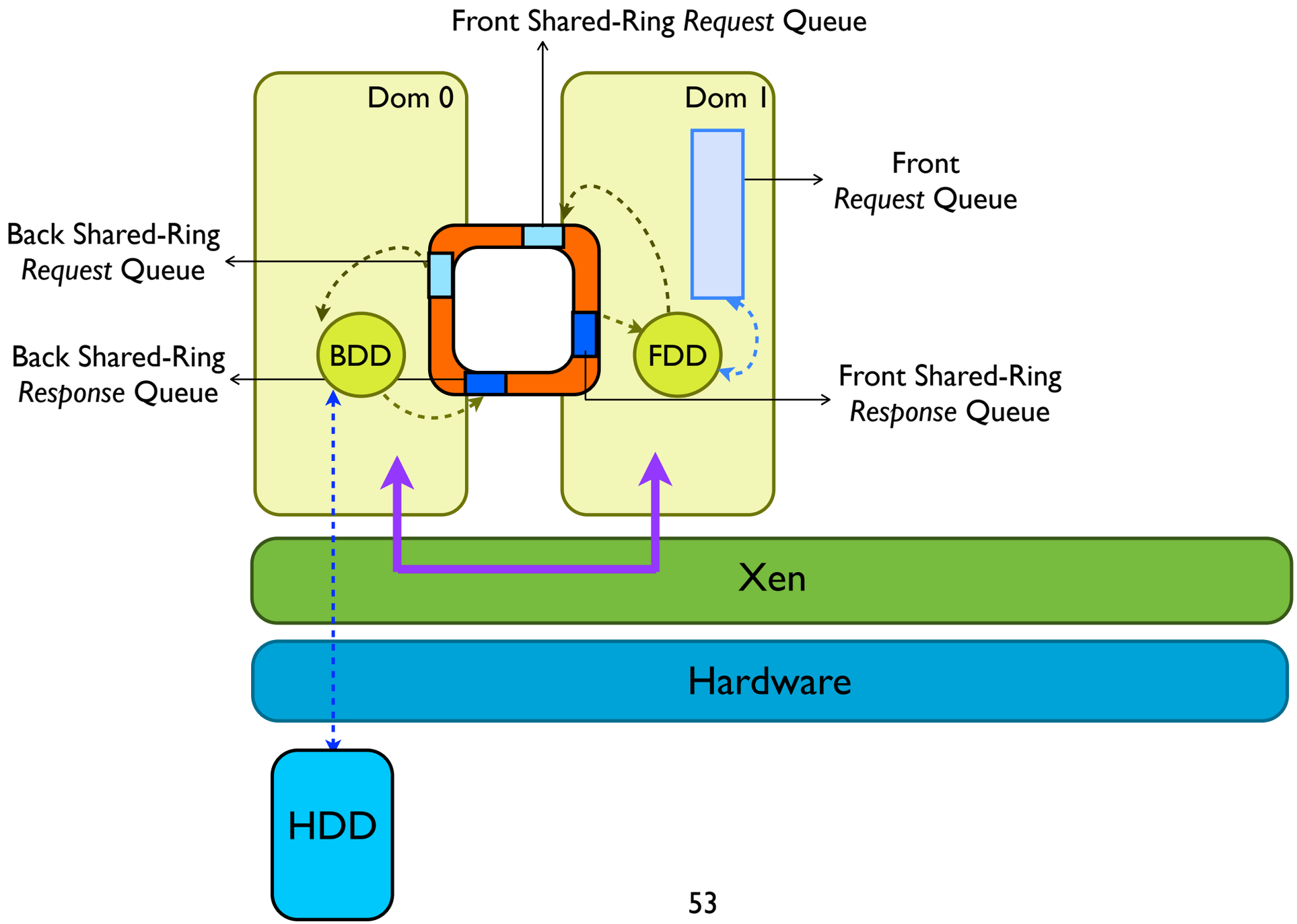
Analysis Algorithms

Disk I/O - Simplified



Analysis Algorithms

Disk I/O - Device Driver Queues



Analysis Algorithms

Disk I/O - Device Driver Queue States

- Blocked : Cannot process requests to/from queue.
  - Unable to add new requests to queue or
  - Queue is empty.
- Unblocked : Can enqueue new incoming requests.

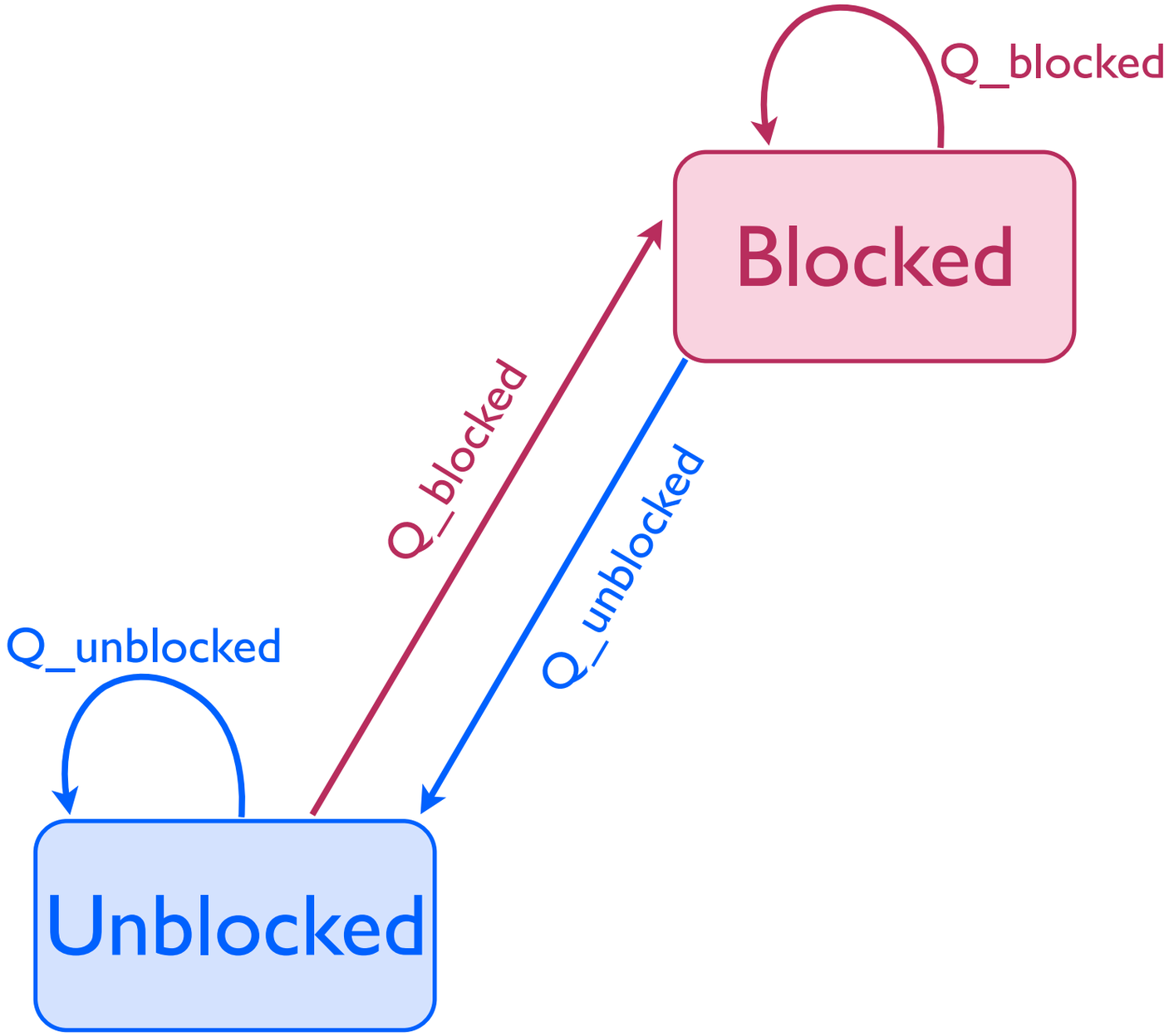
Analysis Algorithms

Disk I/O - Device Driver Queue States

- Intuition was that a queue blocked for a long time would block the entire pipeline.

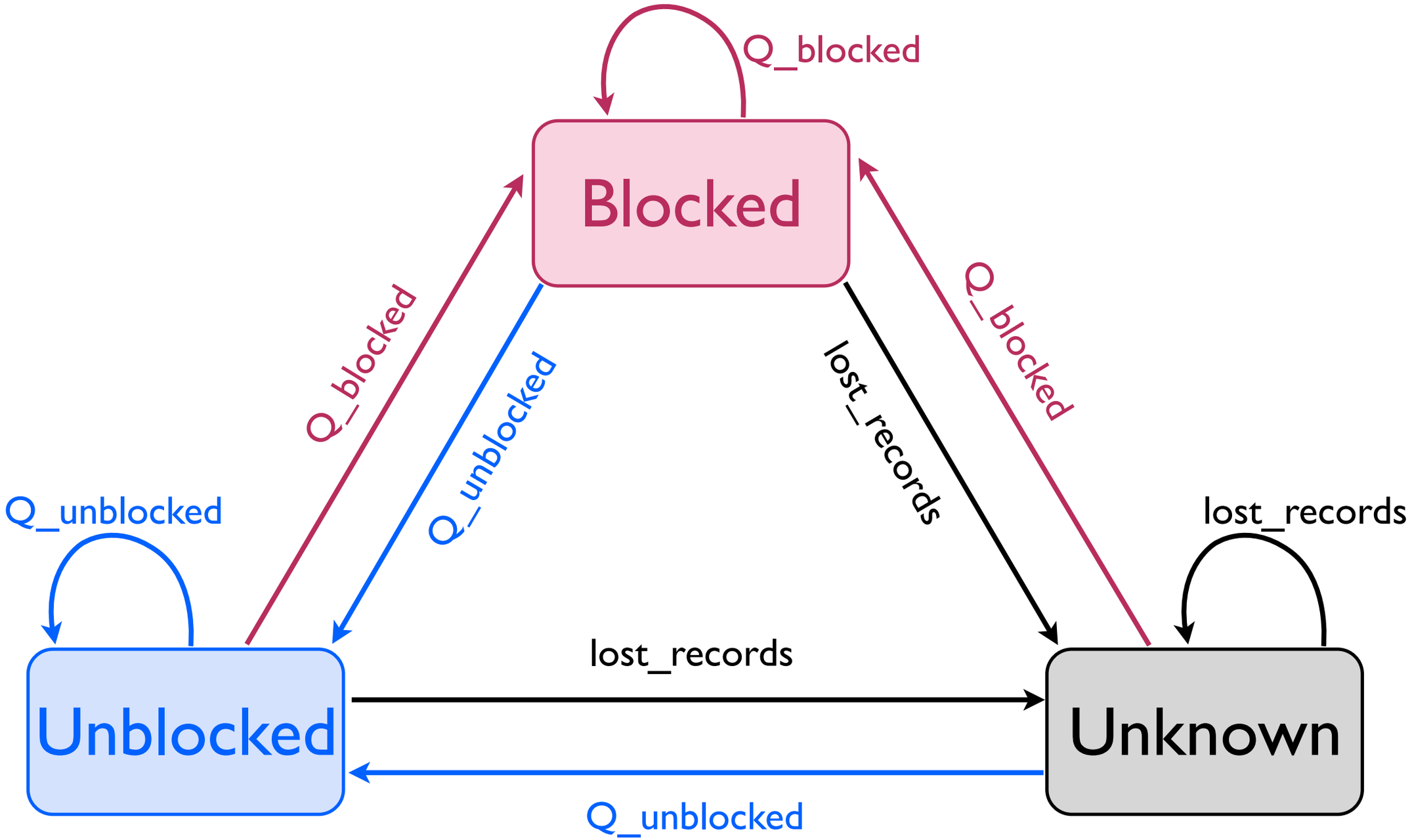
Analysis Algorithms

Disk I/O - Device Driver Queue States



Analysis Algorithms

Disk I/O - Device Driver Queue States



Analysis Algorithms

Disk I/O - Observations

- Blocked
  - Unbuffered : 99 % - All queues
  - Buffered : 50 % - Frontend request queue, 99 % rest.
    - Buffer cache enables faster request processing at frontend.
- Disk I/O so slow, virtualization overheads negligible.

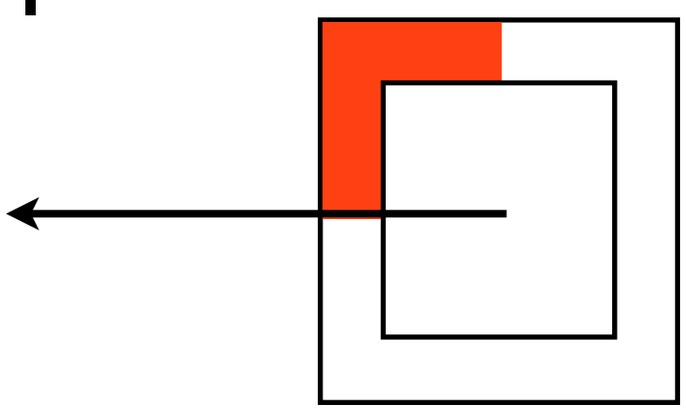
Analysis Algorithms

- CPU Utilization
- CPU Scheduling Latency
- Time in Hypervisor
- Disk I/O
  - Device Driver Queue Status
  - Device Driver Queue Request and Response Latency

Analysis Algorithms

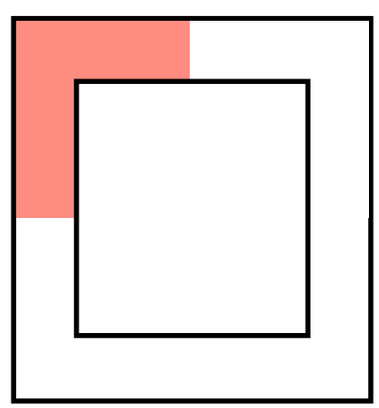
Queue Latency - Simplified

1



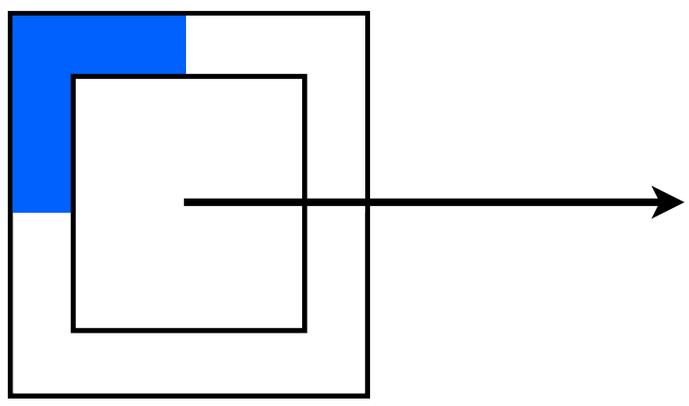
DomU writes Req & notifies Dom0

2



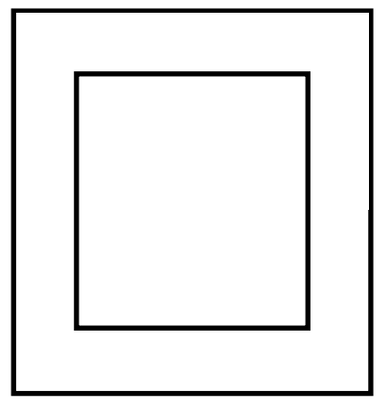
Dom0 reads Req

3



Dom0 writes Resp & notifies DomU

4

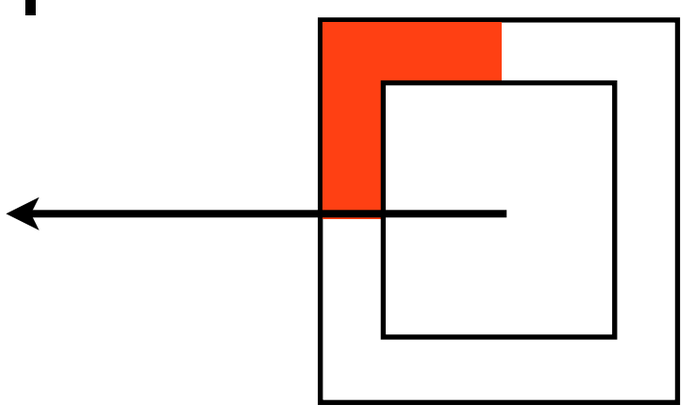


DomU reads Resp

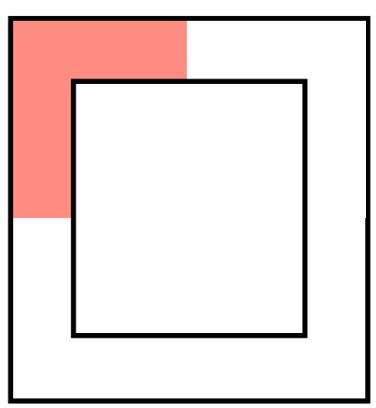
Analysis Algorithms

Queue Latency - Simplified

1



2



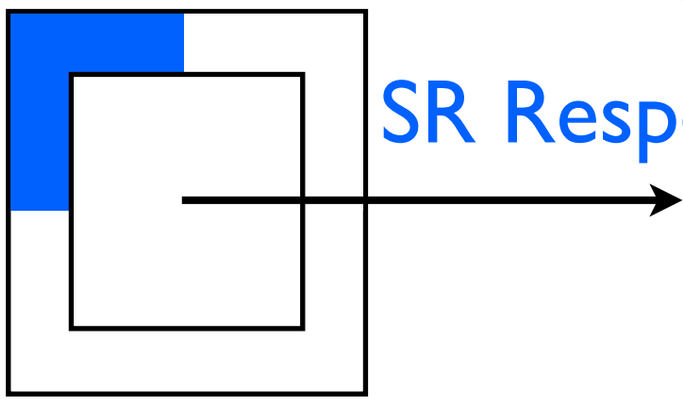
$t_2 - t_1$

SR Request Latency

DomU writes Req & notifies Dom0

Dom0 reads Req

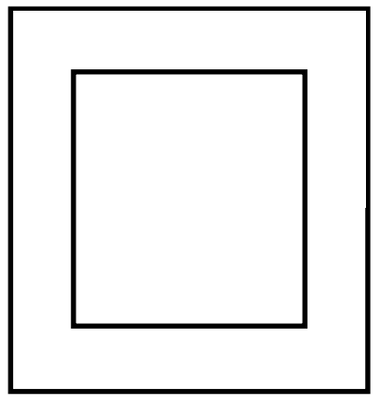
3



$t_4 - t_3$

SR Response Latency

4

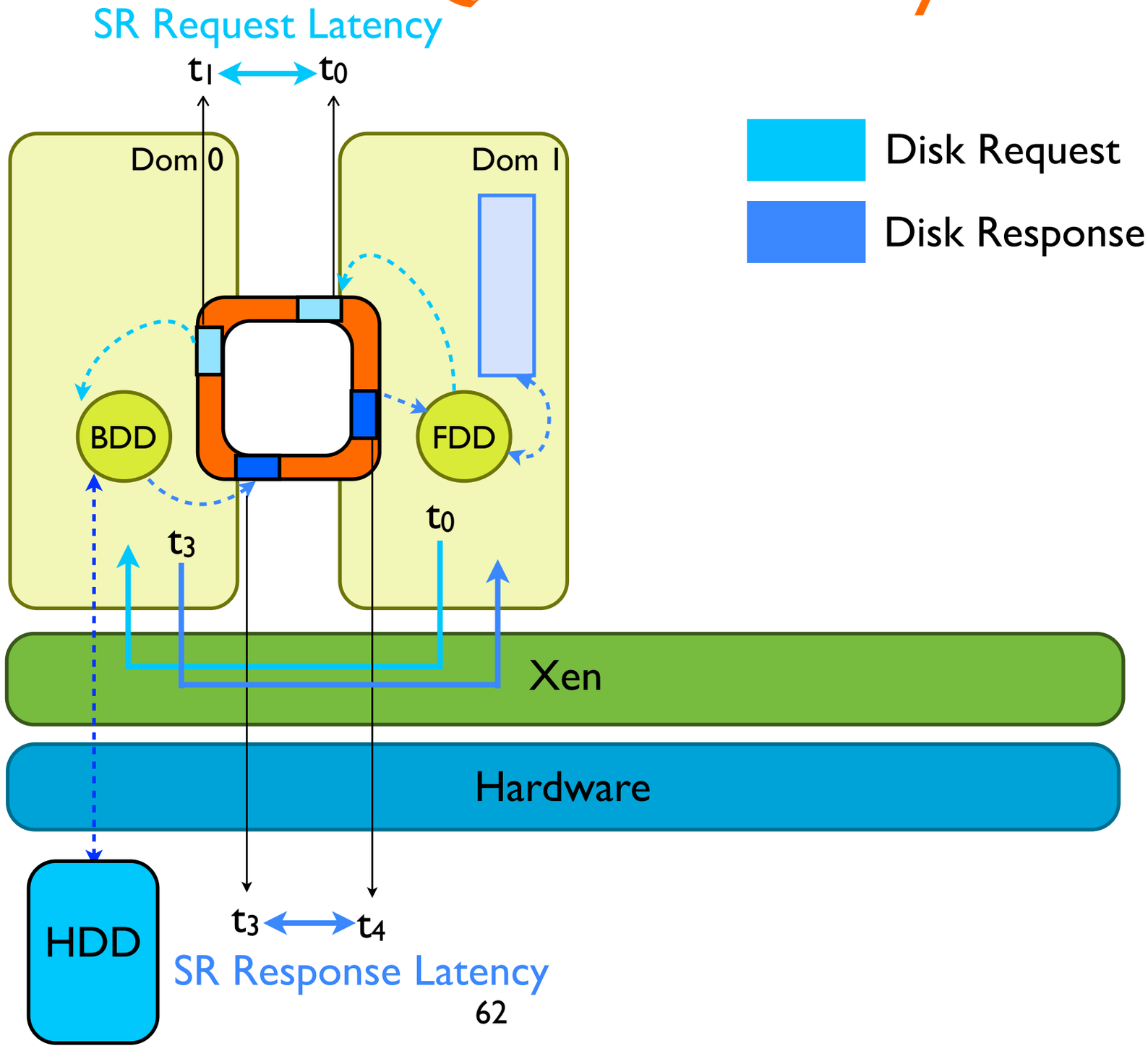


Dom0 writes Resp & notifies DomU

DomU reads Resp

Analysis Algorithms

Disk I/O - Queue Latency



Analysis Algorithms

Queue Latency - Results

SR Response Latency >> SR Request Latency

approx. 2 order of magnitudes greater for buffered i/o

Analysis Algorithms

Queue Latency - Results

QUEUE TIMES

==========

Queue BLOCKED: Unable to add new requests to queue or queue empty.
Queue UNBLOCKED: Can enqueue new incoming requests.

Front Request Queue Unblocked : 1492.834 (ms) ; Blocked : 1070.552 (ms)

Back Request Queue Unblocked : 150.473 (ms) ; Blocked : 3795.210 (ms)

Front Shared Ring Resp Queue Unblocked : 108.448 (ms) ; Blocked : 3837.193 (ms)

QUEUE WAIT TIMES

==========

Back Request Queue Wait Time : 1.380 (ms)

Back Response Queue Wait Time : 86.446 (ms)

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  - Reader
  - Analyses
- Analysis Algorithms
- Composibility

Composibility

Problem

Analysis : Average queue blocked times on domain 0

Composibility

Problem

Analysis : Average queue blocked times on domain 0

- Disk I/O analysis
- Averaging function
- Logic from CPU utilization

Composibility

Problem

Analysis : Average queue blocked times on domain 0

- Disk I/O analysis
- Averaging function
- Logic from CPU utilization

→ New Tool

Lots of duplication of effort

Composibility

Overview

- Framework, so far, gives us stand alone tools for focussed analysis.
- Composibility gives agility to this framework.

Composibility

Overview

- Ability to reuse analysis algorithms logic for different event types.
- Easy to combine analysis tool outputs without having to rewrite large part of logic.

Compose new analysis
using reusable parts.

Composibility

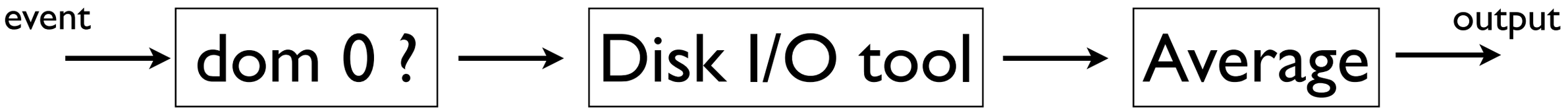
Overview

- Ability to reuse analysis algorithms logic for different event types.
    - Stages
- Easy to combine analysis tool outputs without having to rewrite large parts of logic.
    - Operators

Composibility

Pipeline

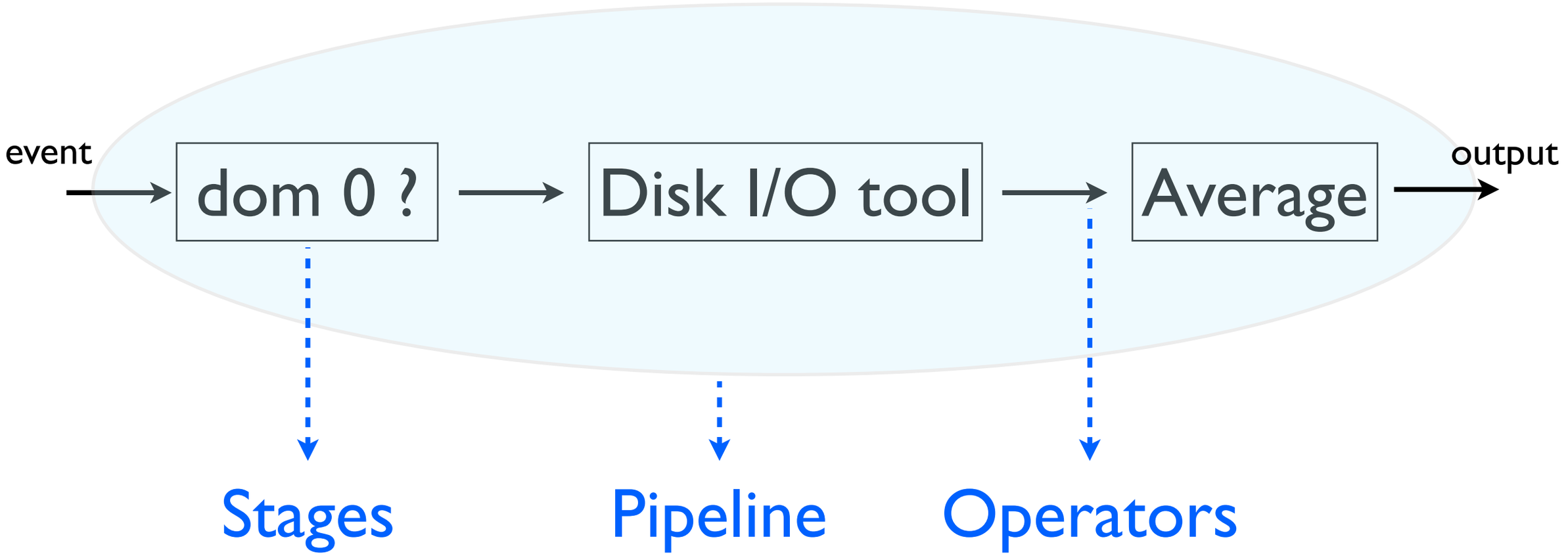
Analysis : Average queue blocked times on domain 0



Composibility

Pipeline

Analysis : Average queue blocked times on domain 0



Composibility

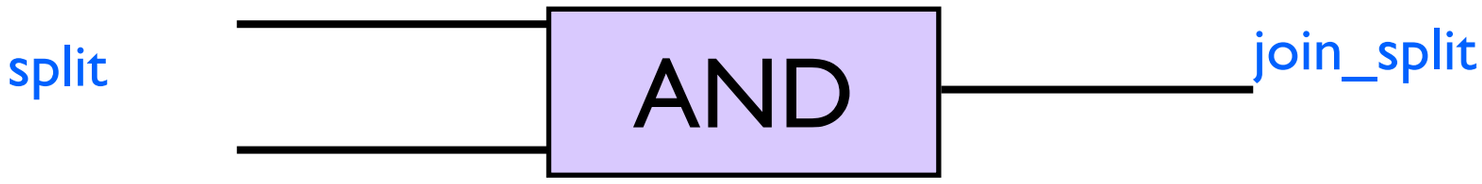
Pipeline - Operators

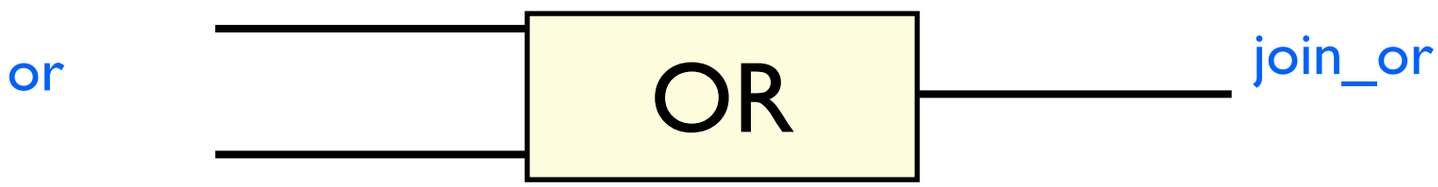
- Pipe (|) : Connects a single stage to another.
- Split (+) : Connects a single stage to multiple stages. Executes all stages.
- Or (or) : Connects a single stage to multiple stages. Executes stages until valid return.
- Join : Connects multiple stages to a single stage. Either wait for a single connected stage to pass a valid event (JOIN_OR) or wait for all the connected stages to pass a successful event (JOIN_SPLIT).

Syntax ideas inspired from "*A Universal Calculus for Streaming Processing Languages*" [3]

Composibility

Pipeline - Operators Simplified





Composibility

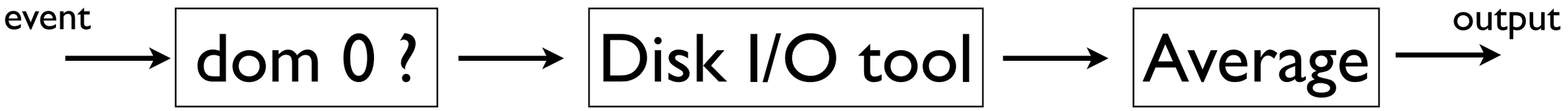
Pipeline - Stages

- Reusable and independent analysis components.
- Input: One or more events.
- Output : Same event, new event with results from execution or invalid event.
- If invalid event returned, break from Pipeline.

Composibility

Pipeline

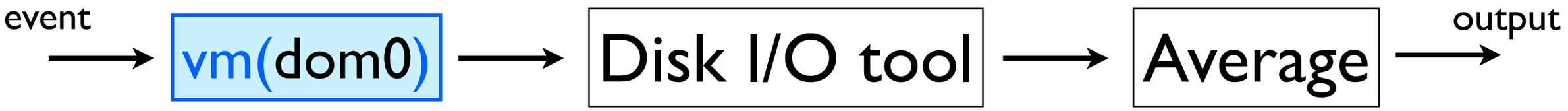
Analysis : Average queue blocked times on domain 0



Composibility

Pipeline

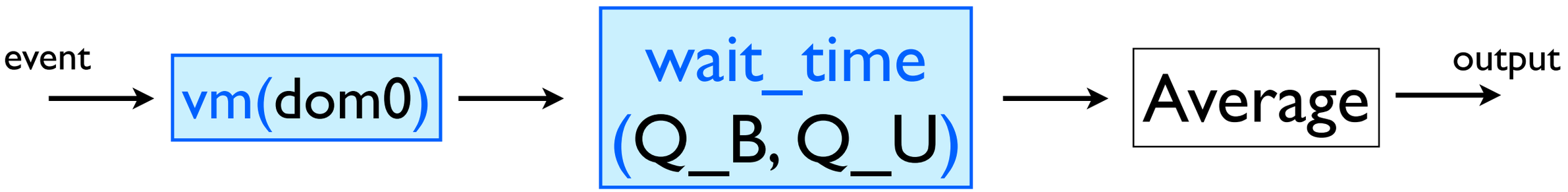
Analysis : Average queue blocked times on domain 0



Composibility

Pipeline

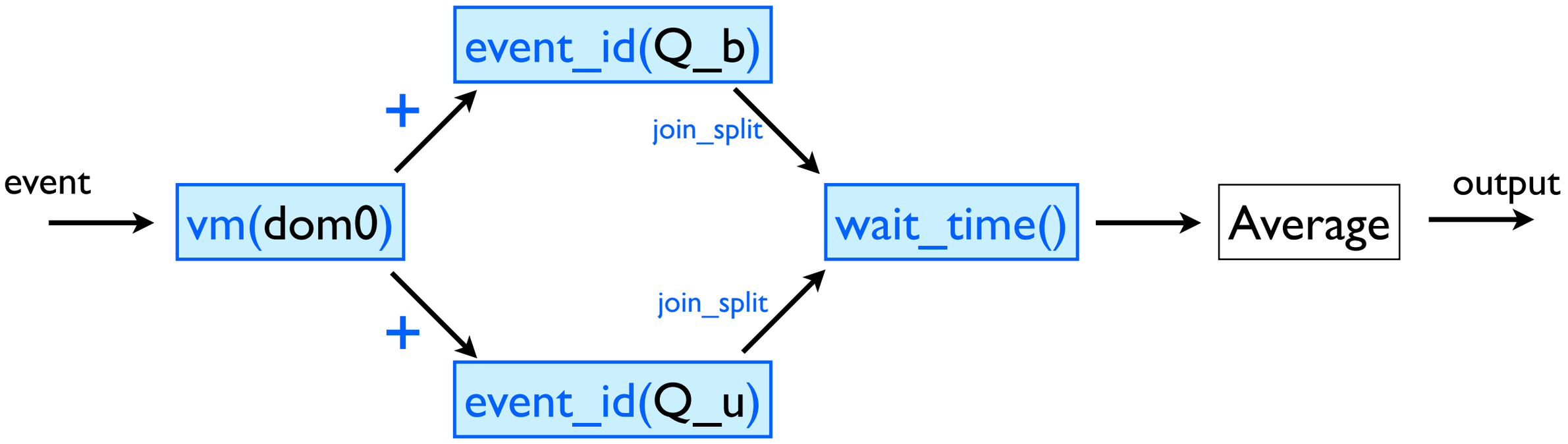
Analysis : Average queue blocked times on domain 0



Composibility

Pipeline

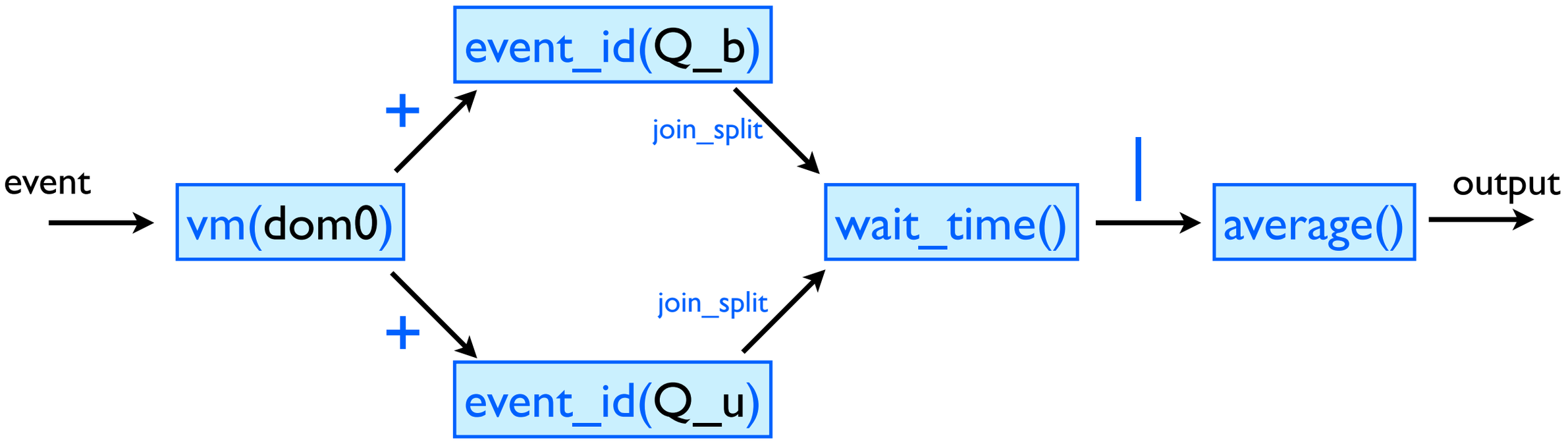
Analysis : Average queue blocked times on domain 0



Composibility

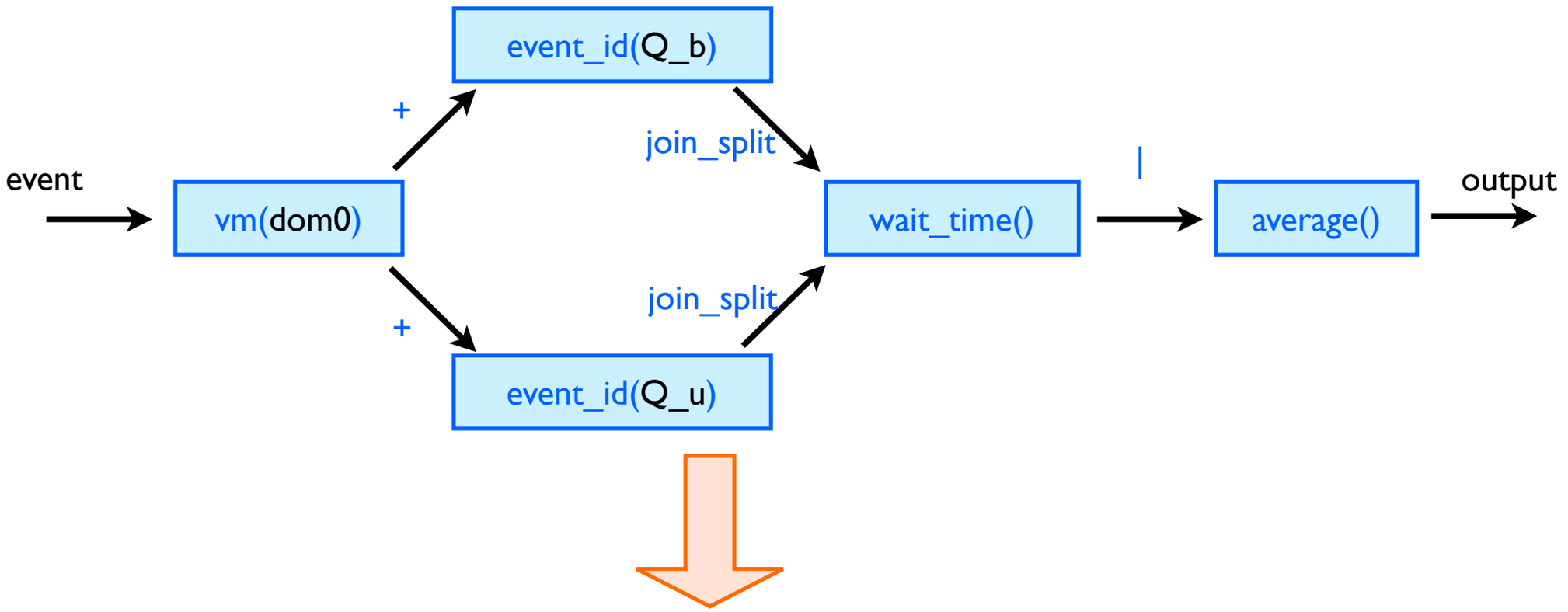
Pipeline

Analysis : Average queue blocked times on domain 0



Composibility

Pipeline - Syntax



vm(dom0) | event_id(Q_b) + event_id(Q_u) | wait_time() | average()

Composibility

Pipeline - Runtime

vm(dom0) | event_id(Q_b) + event_id(Q_u) | wait_time() | average()


```
s1 = create_stage(vm, dom0);
s2 = create_stage(event_id, Q_b);
s3 = create_stage(event_id, Q_u);
s4 = create_stage(wait_time, NULL);
s5 = create_stage(average, NULL);

split(s1, s2);
split(s1, s3);
join(s2, s4, JOIN_SPLIT);
join(s3, s4, JOIN_SPLIT);
pipe(s4, s5);

while(!feof(fp))
{
        parse_next_event(&ev);
        execute_pipe(s1, ev);
}
```

Composibility

Summary

- Reusable and independent analysis components - Stages
- Connect stages using Operators.
- Compose Pipeline using Stages and Operators

Demo

- If time permits ??

Conclusion

- Goals met.
  - Easier to build tools for fine grained performance analysis of Xen - Reader & Analyses
  - Build complex analysis tools in a short time - Composibility

Thank You

Q & A

References

- [1] USE method (*http://dtrace.org/blogs/brendan/2012/02/29/the-use-method/*)
- [2] Xen reference guide
- [3] R. Soule, M. Hirzel, R. Grimm. A Universal Calculus of Streaming Languages. *ESOP 10*.
- [4] Vembyr. (*http://code.google.com/p/vembyr/*)