High Accuracy Attack Provenance via Binary-Based ExEcution Partition (BEEP)

Kyu Hyung Lee,
Xiangyu Zhang,
Dongyan Xu

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Introduction

- Attack provenance is important
  - Determine the "entry point" of an attack
  - Understand the damage to the victim system

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Introduction

- Previous approaches
  - Generate causal graph by detecting system level dependences

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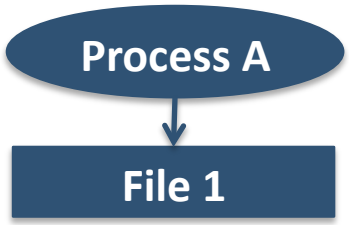
  - Generate causal graph by detecting system level dependences
    - Process <-> File



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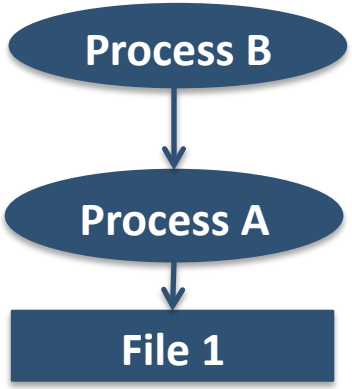

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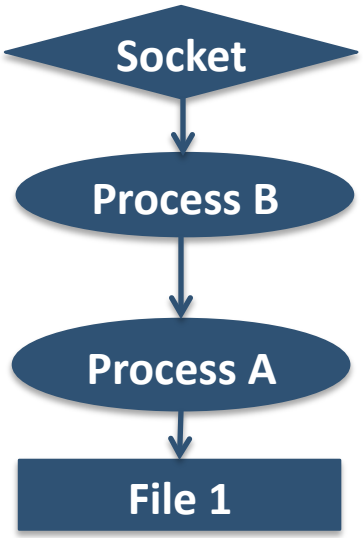

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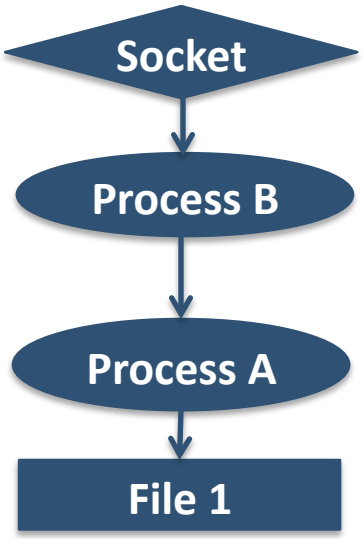

  - Limitations
    - Dependence explosion problem
    - Granularity of "process" is too coarse

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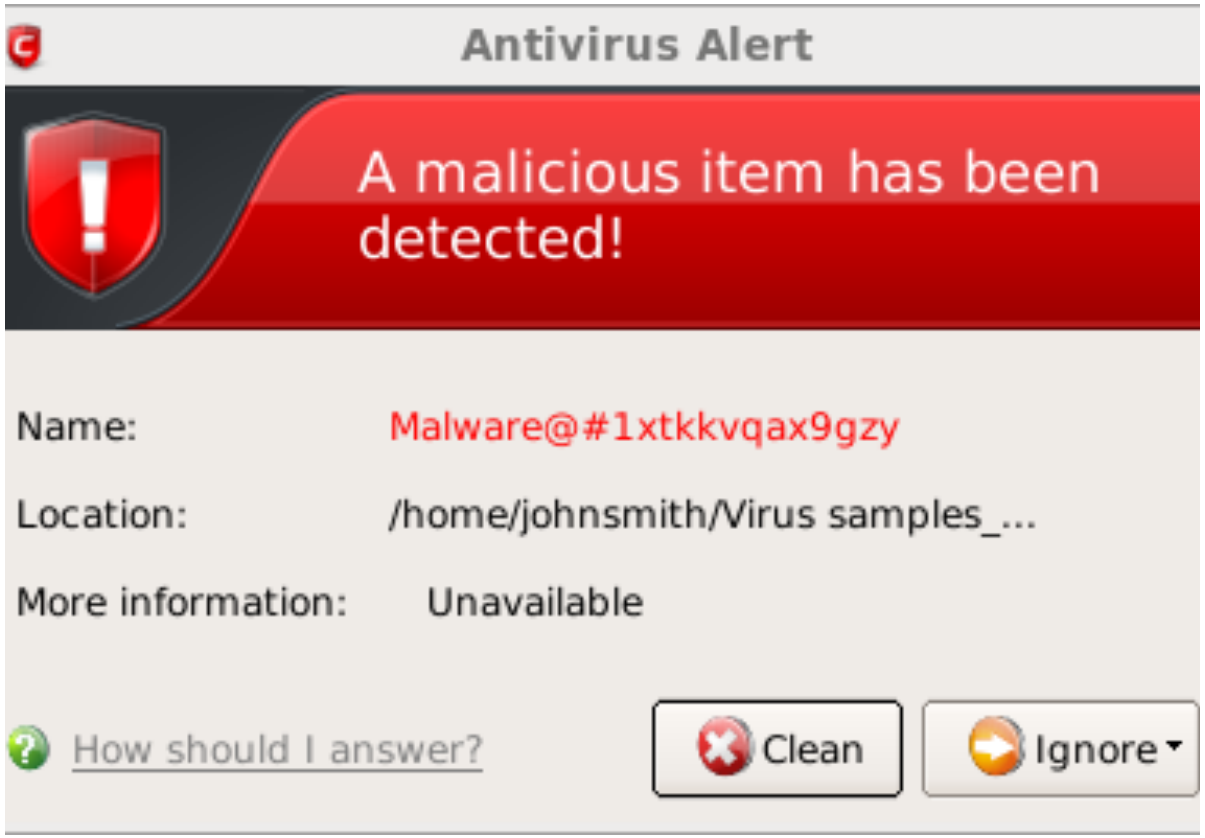

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Malware

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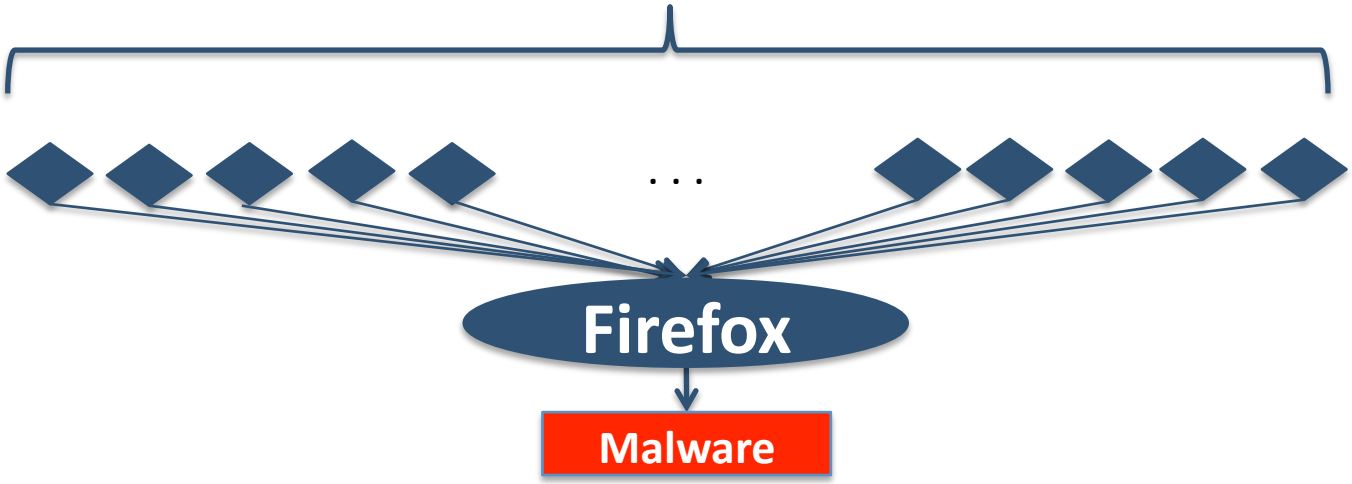
The user visited 11 web sites

Dependence explosion!!

(229 IP Addresses)



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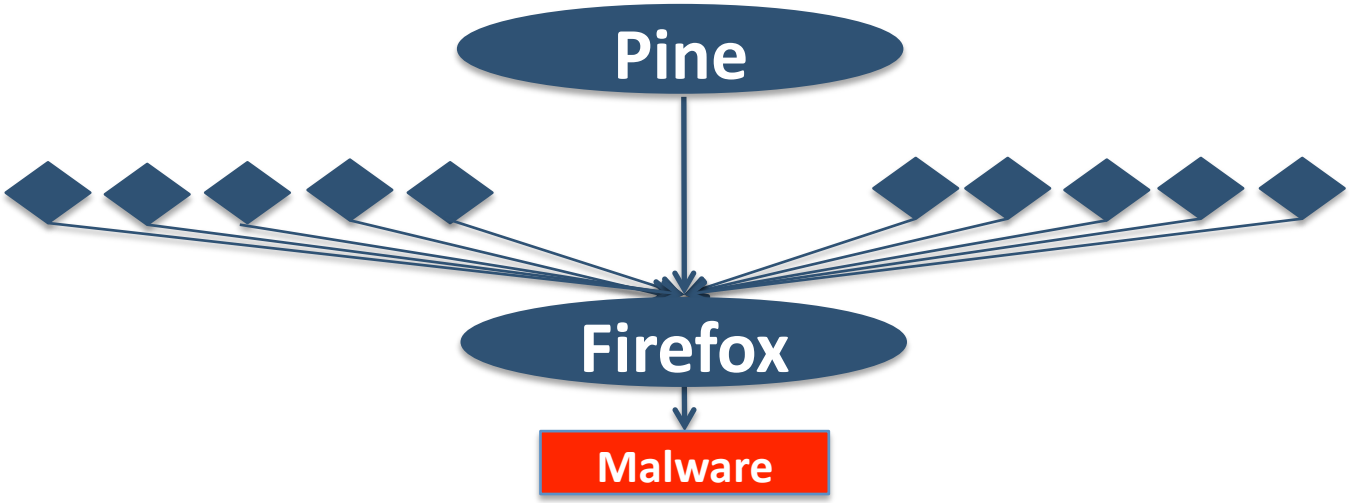

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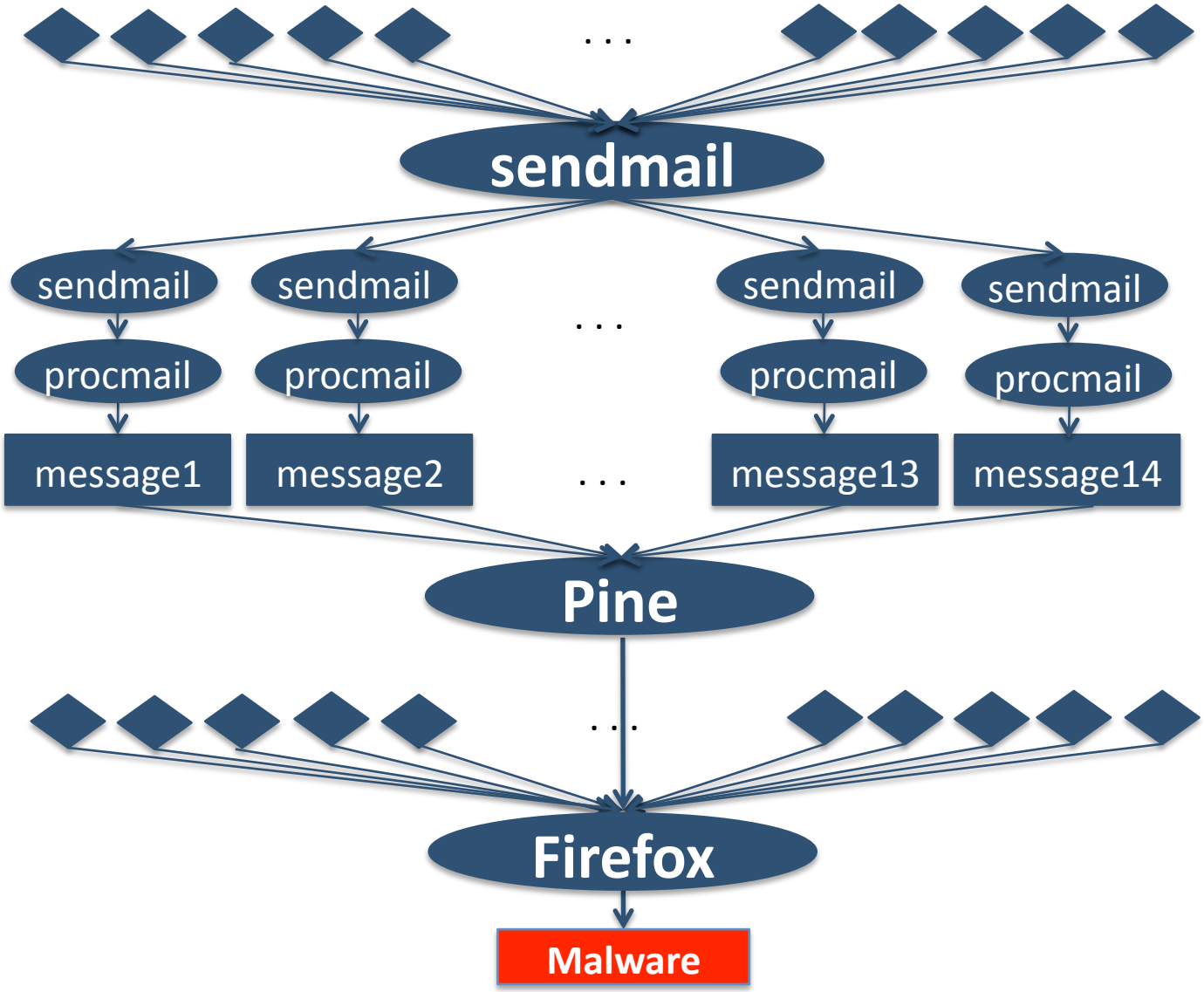

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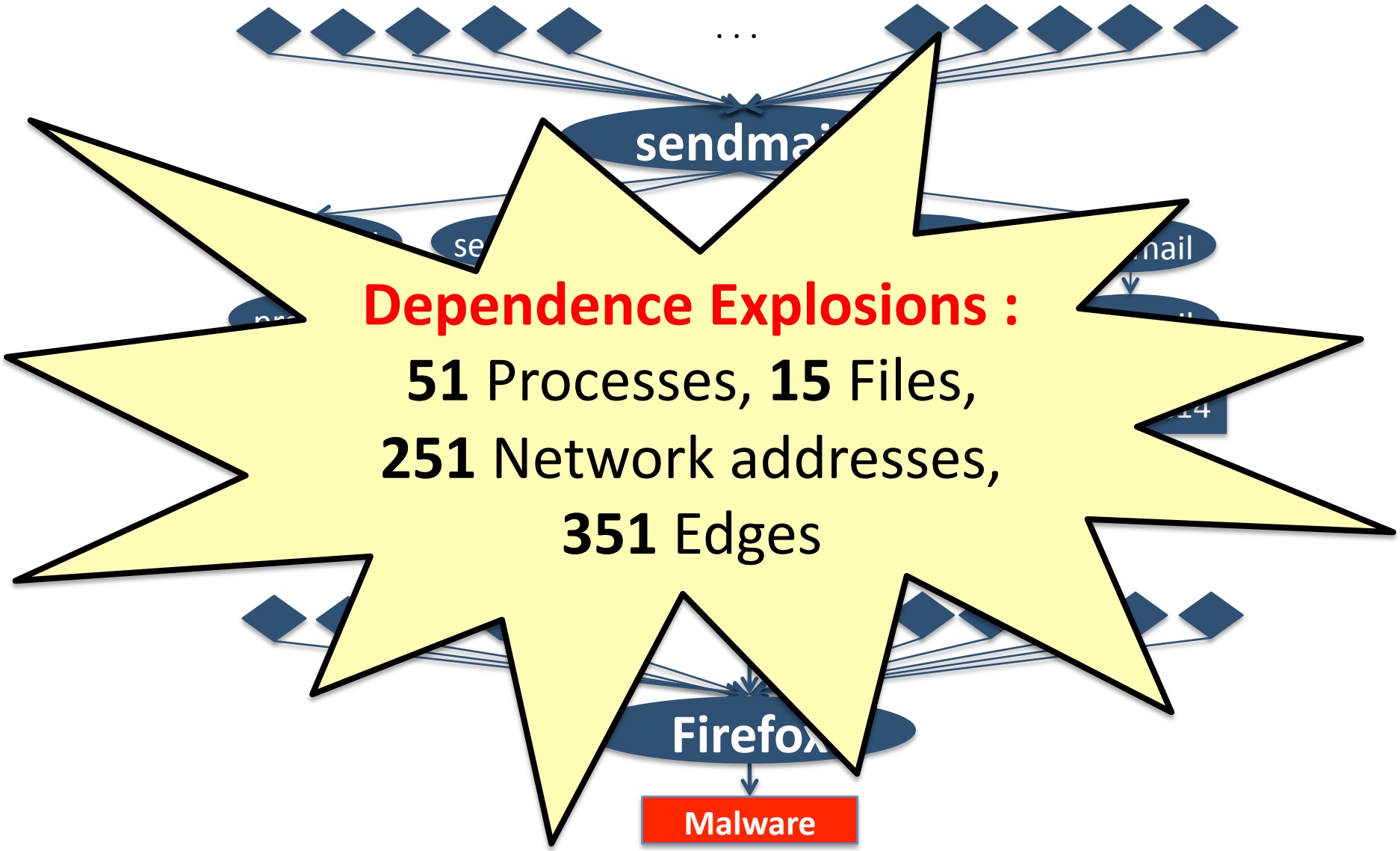

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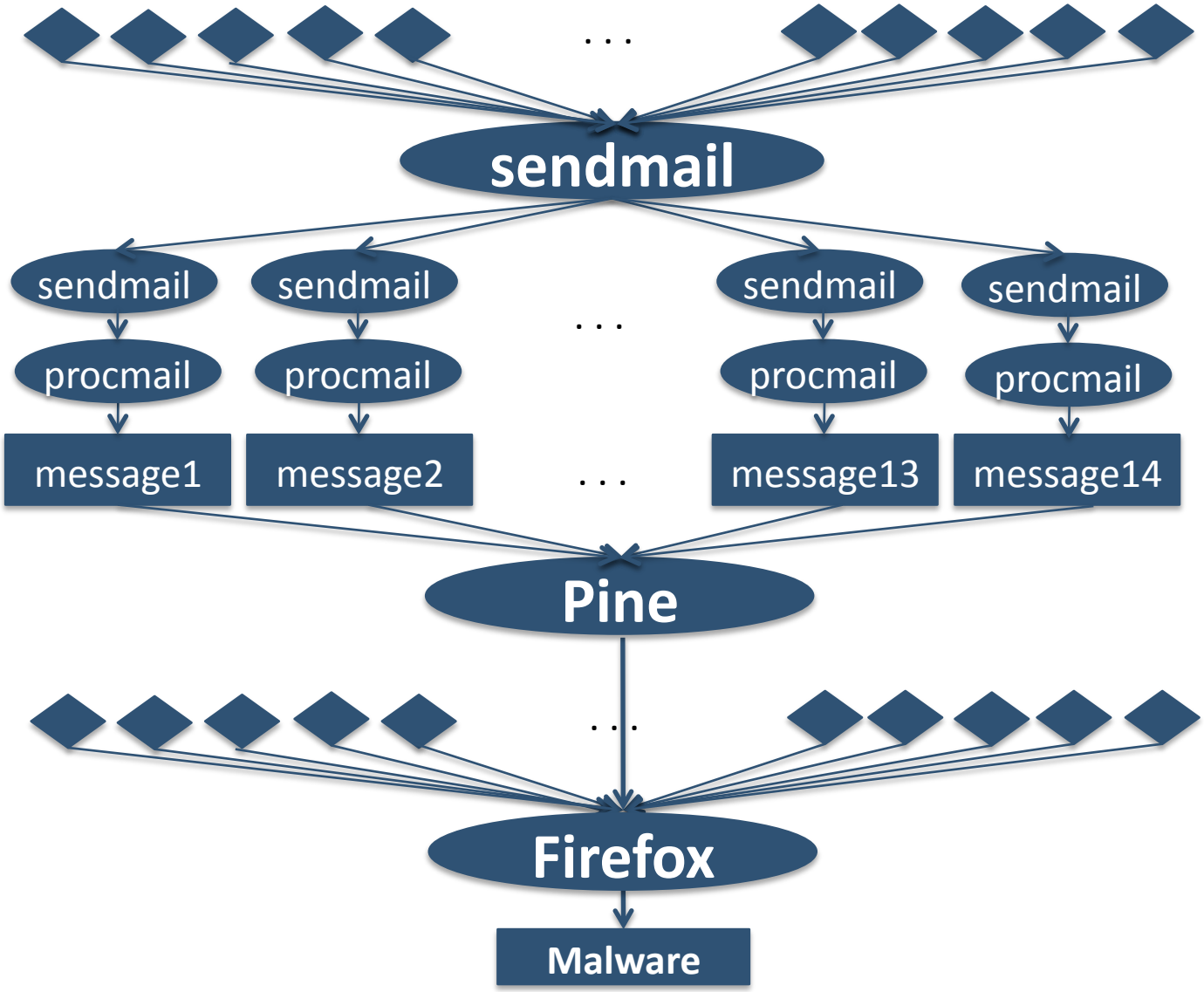

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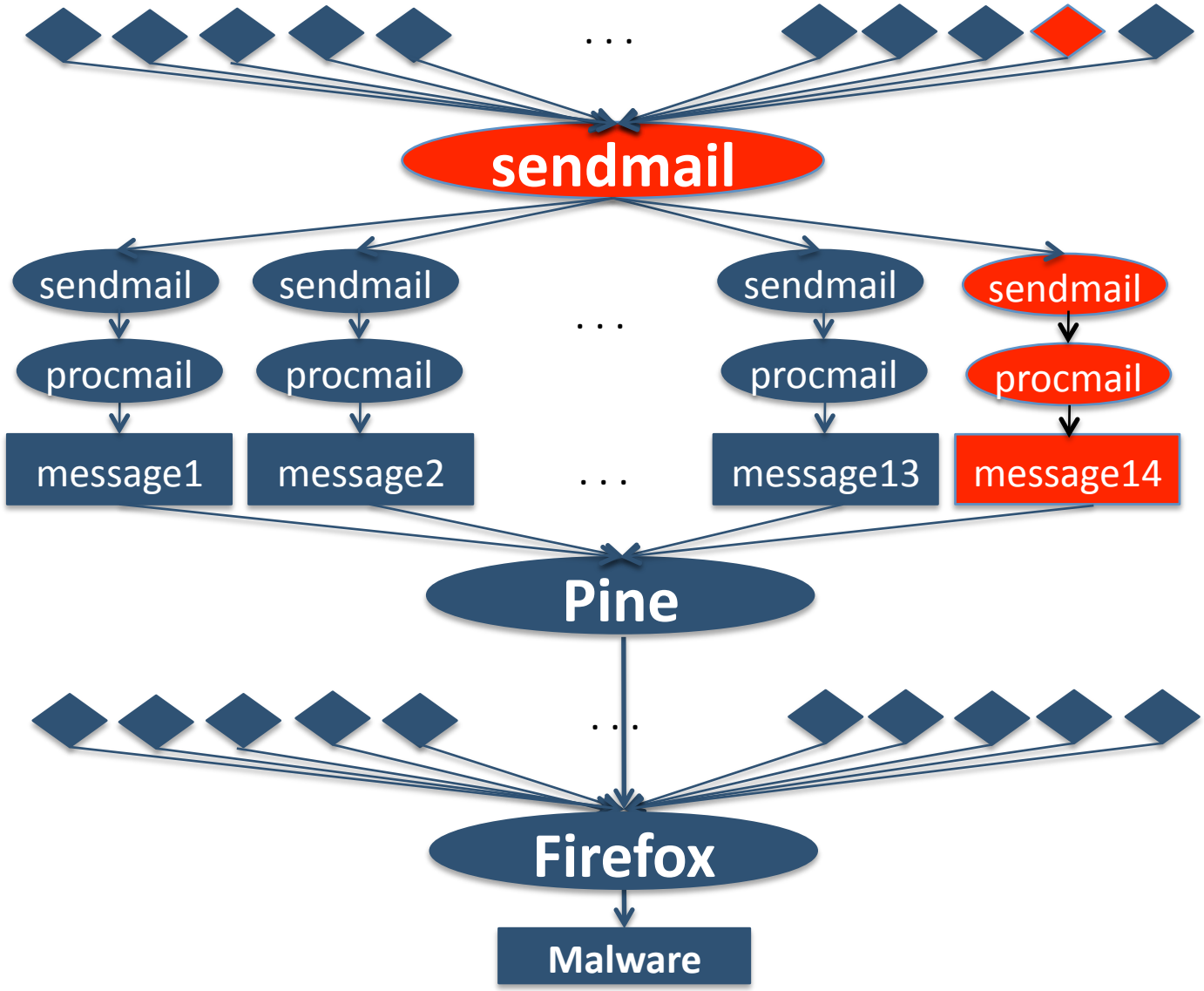

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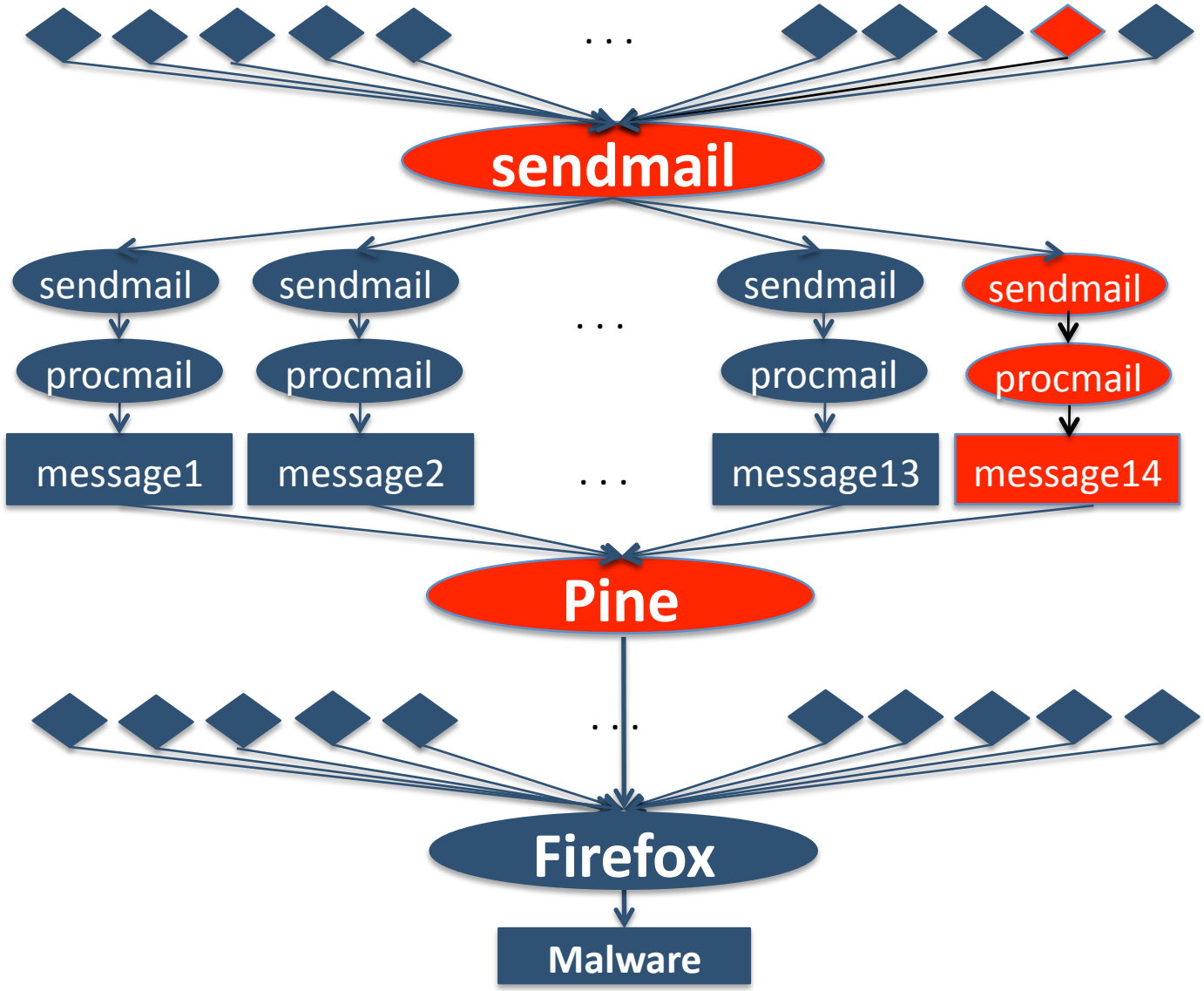

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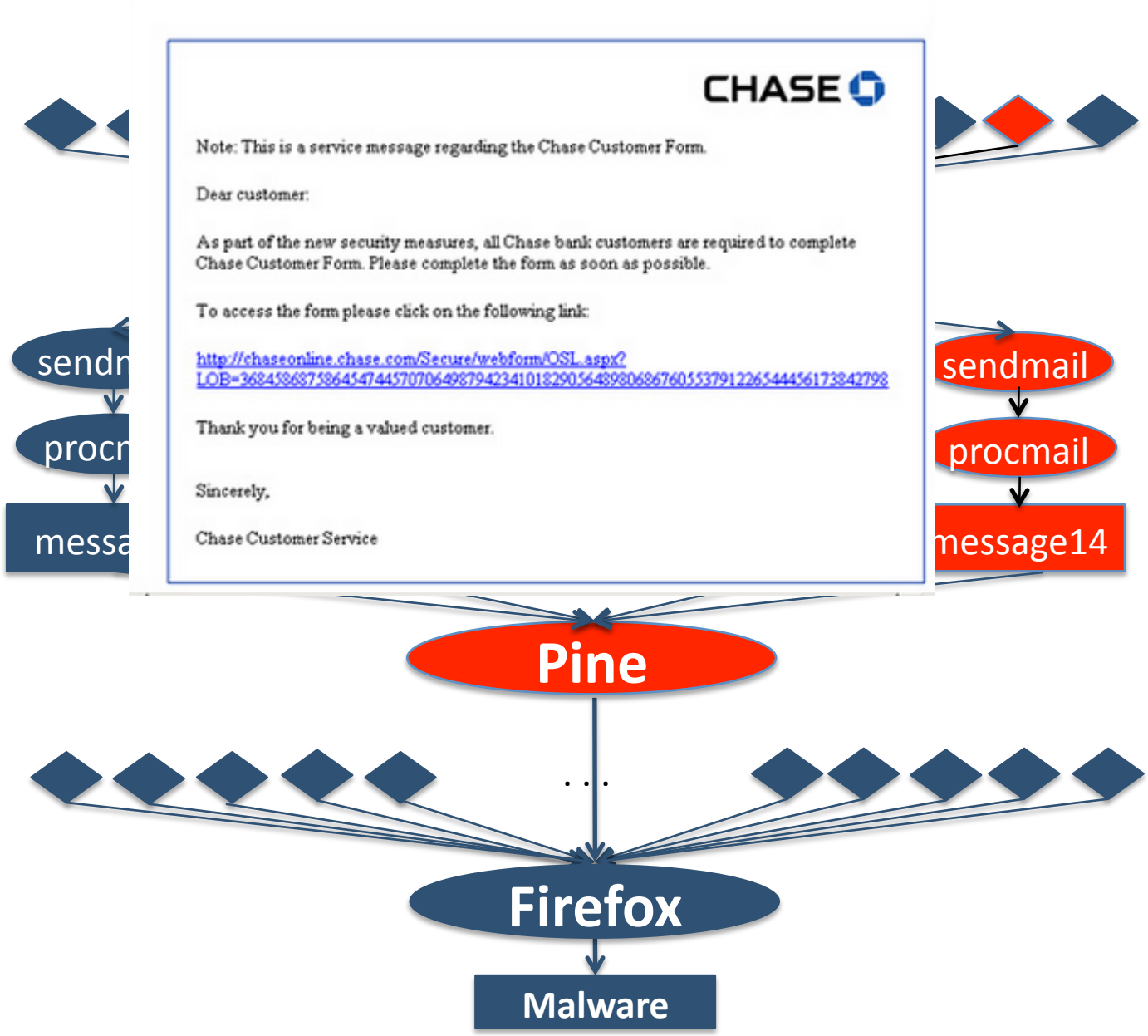

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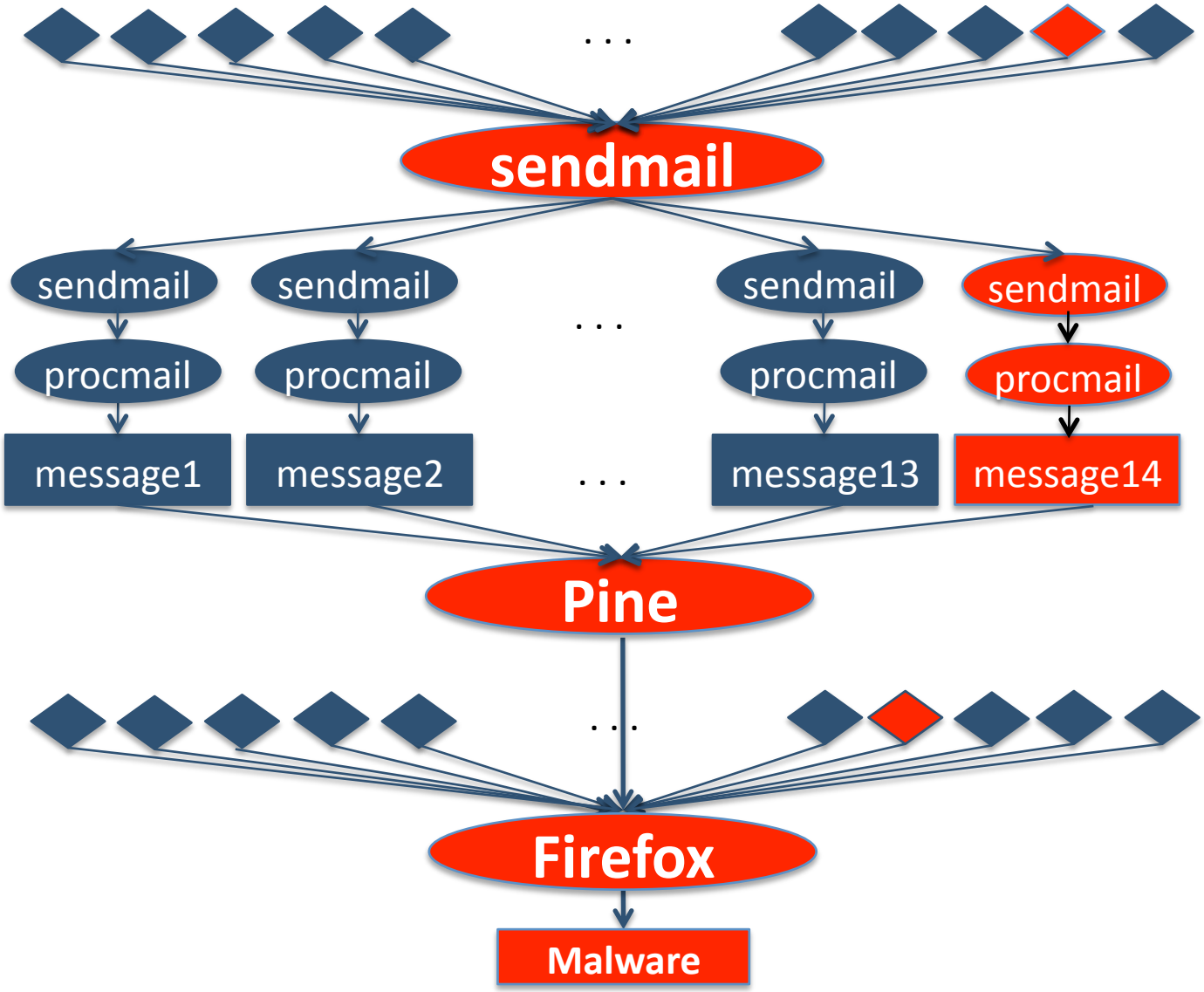

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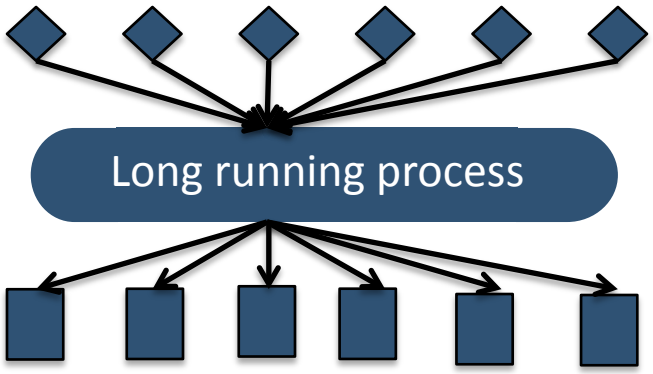
BEEP : Our Approach

- Finer-grained subject : Execution "UNIT"
  - Dynamically partition the execution of a process into **autonomous** execution segments



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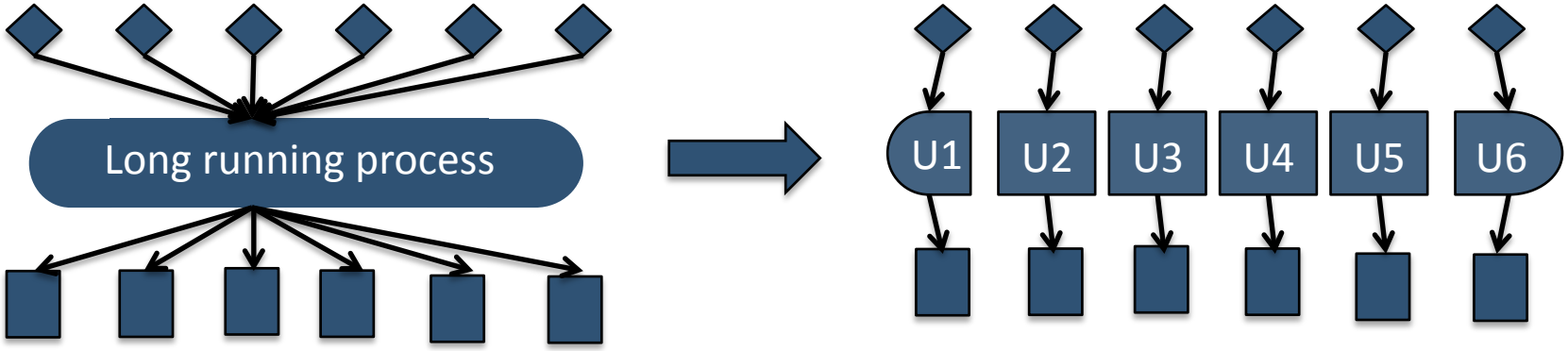

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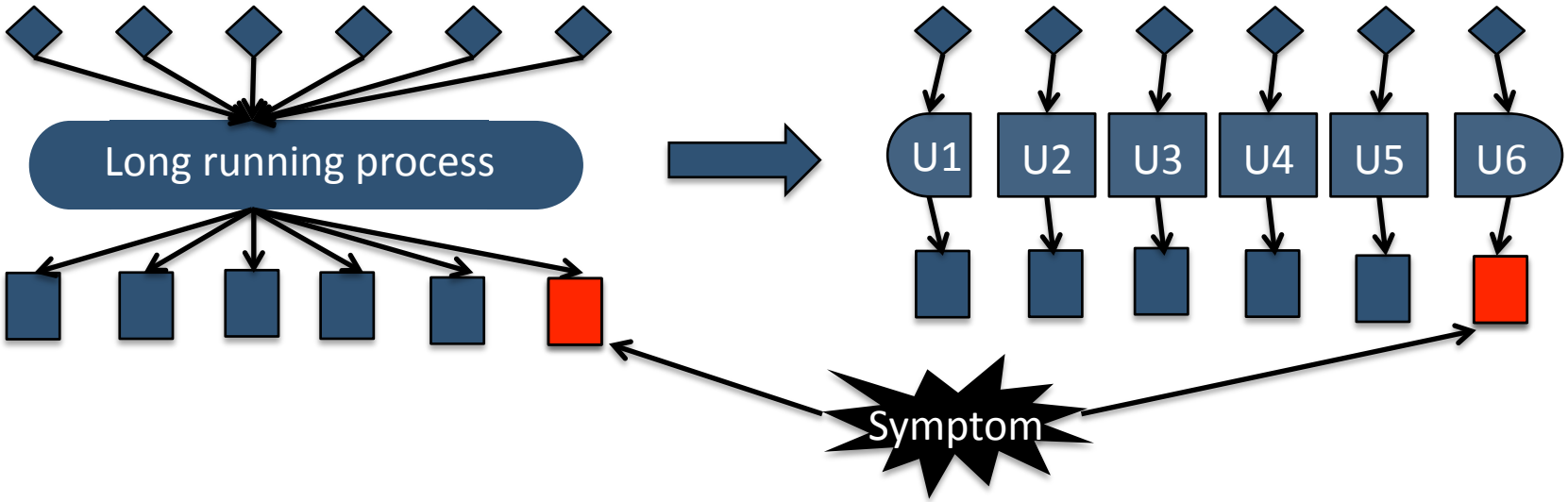

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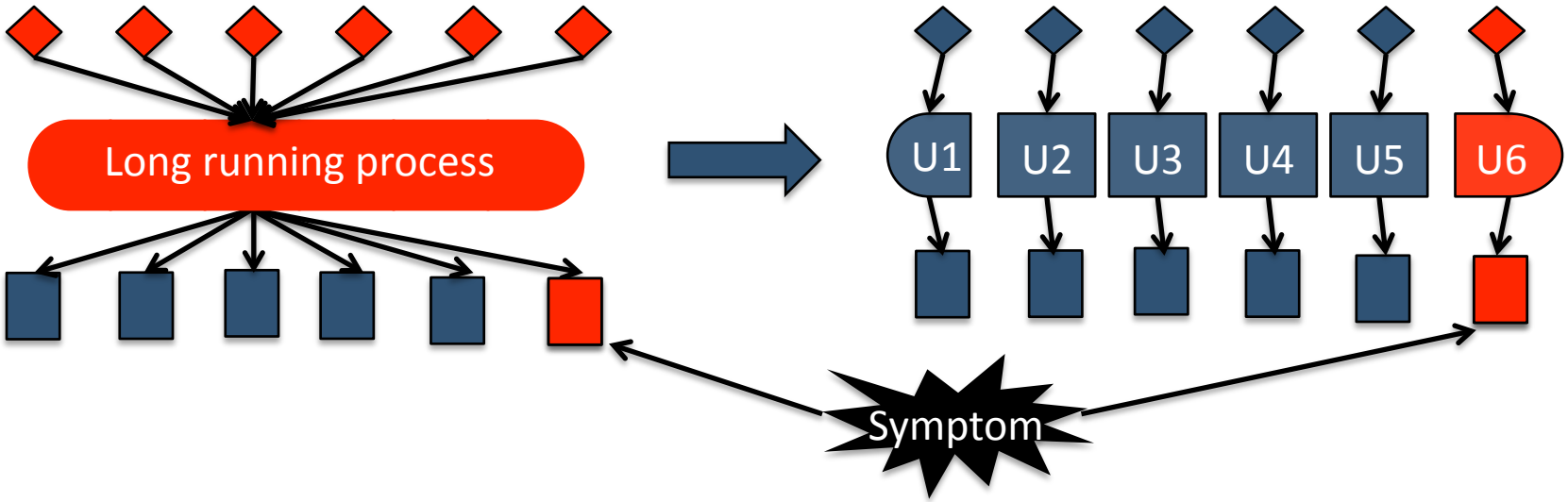

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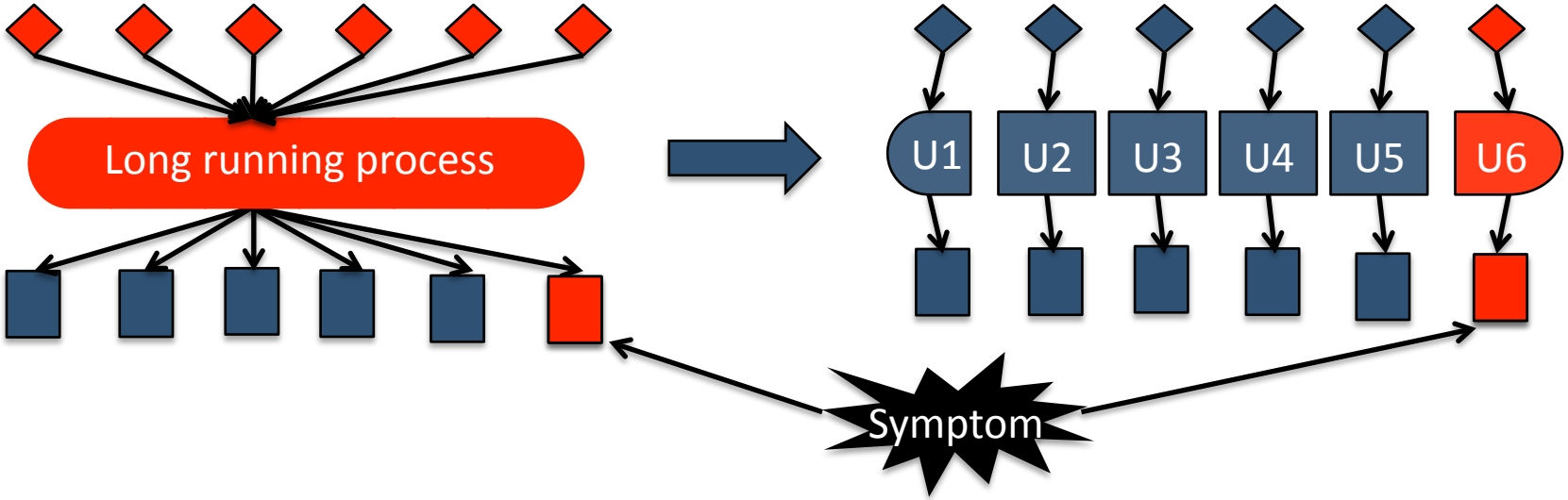

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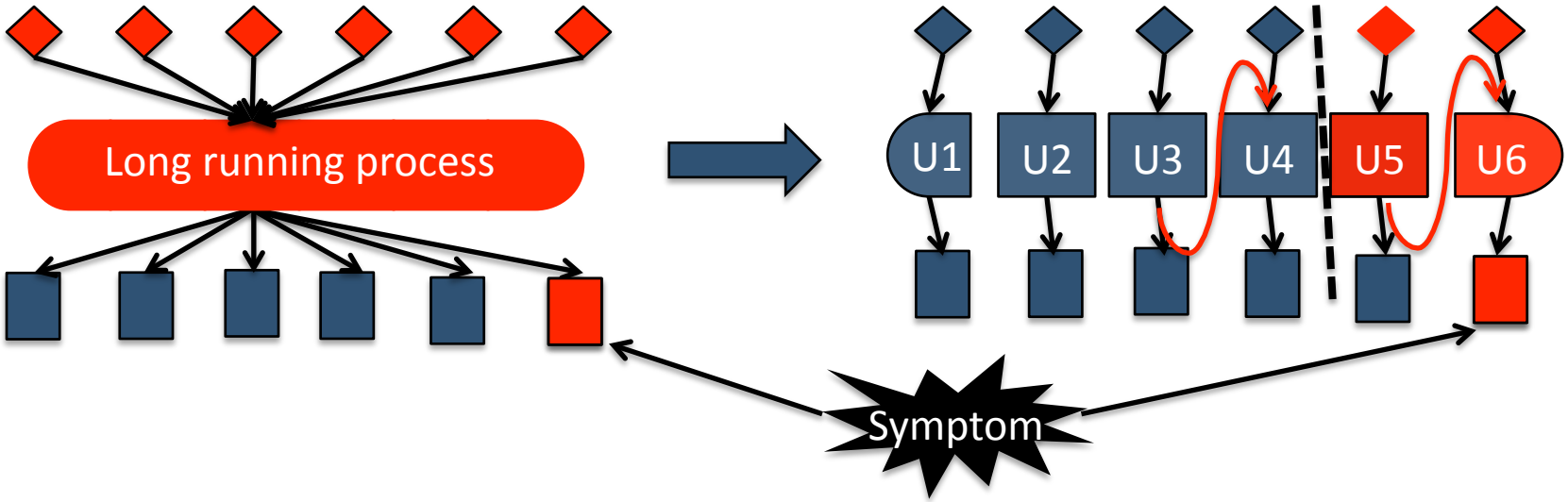

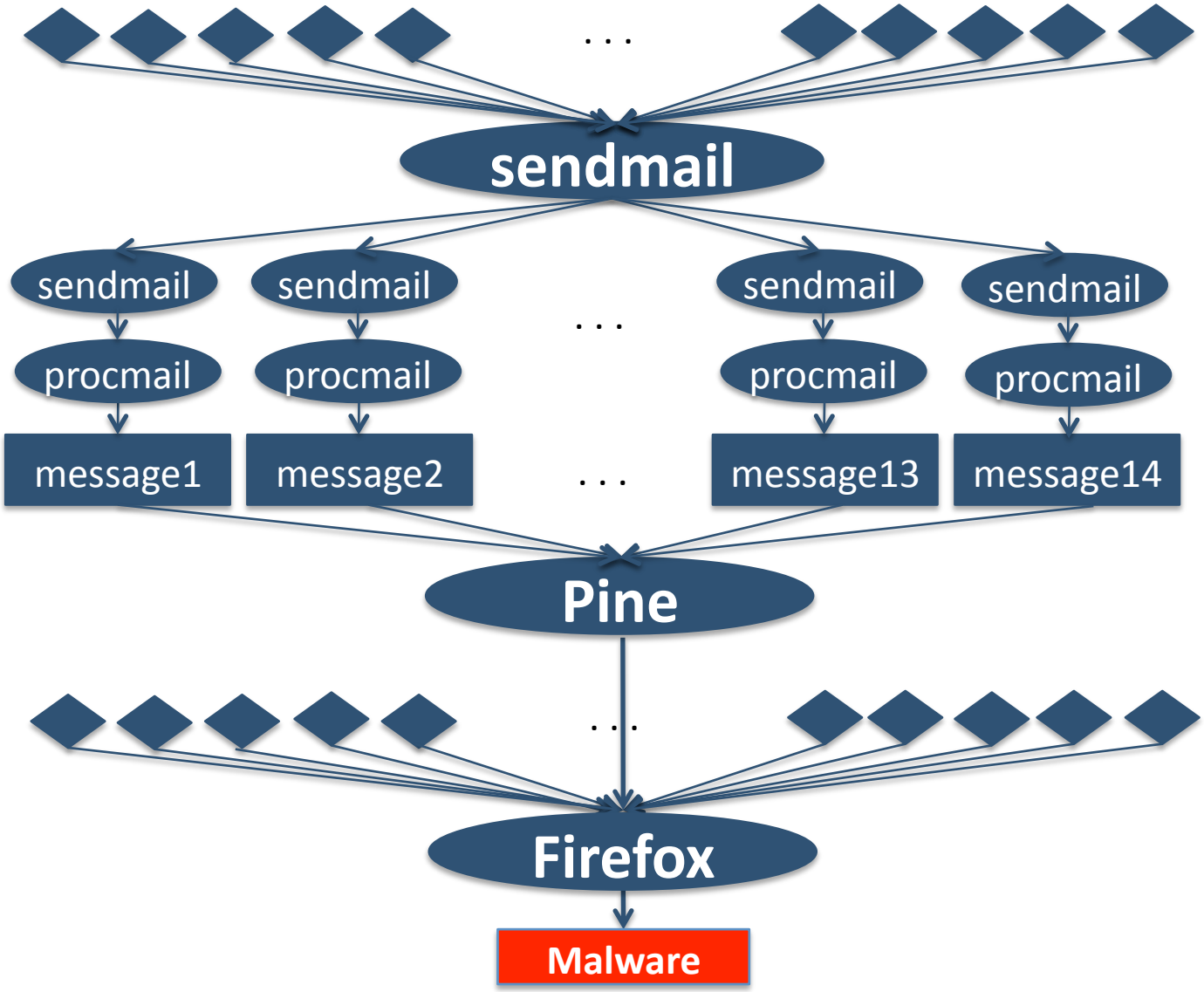

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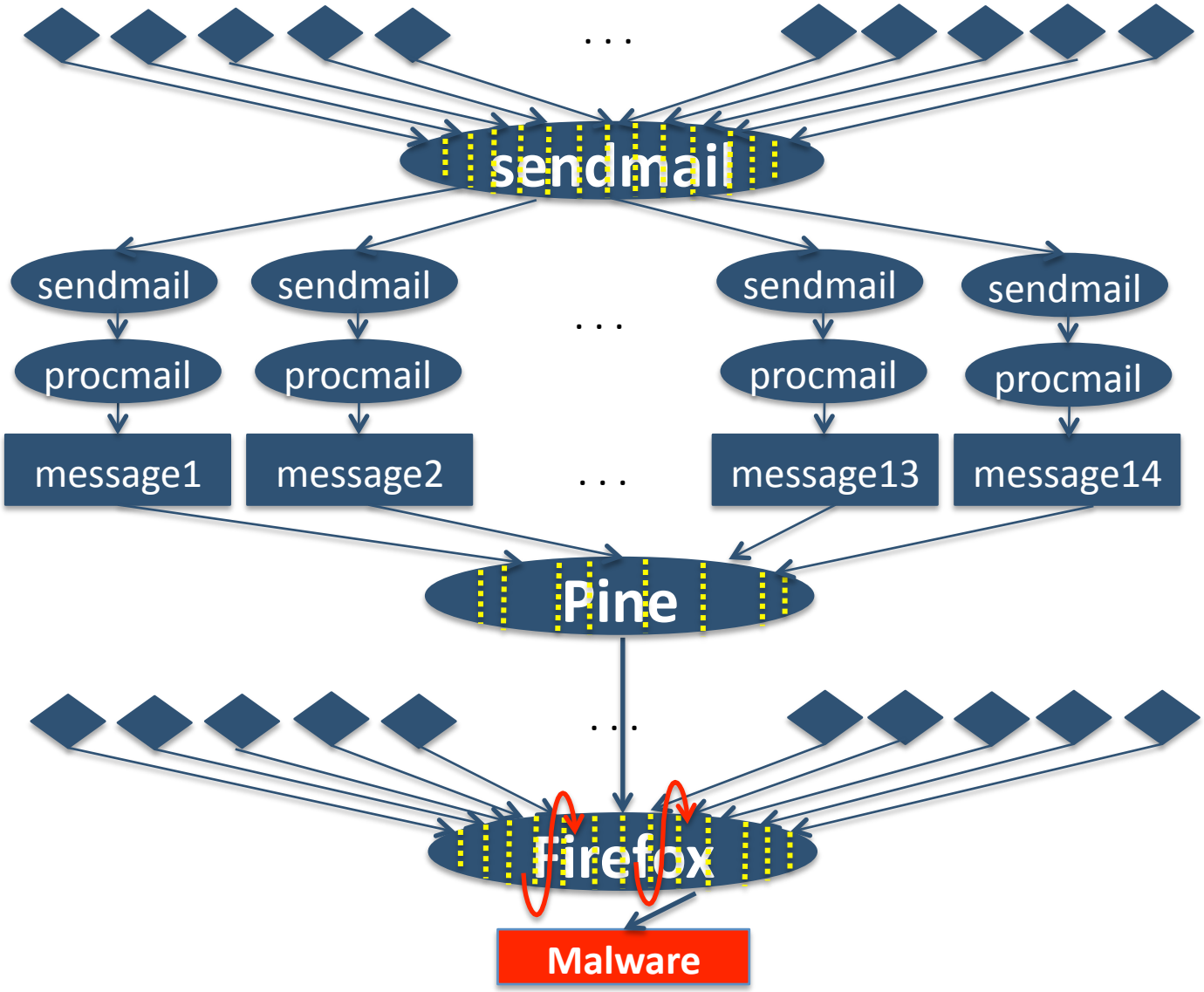

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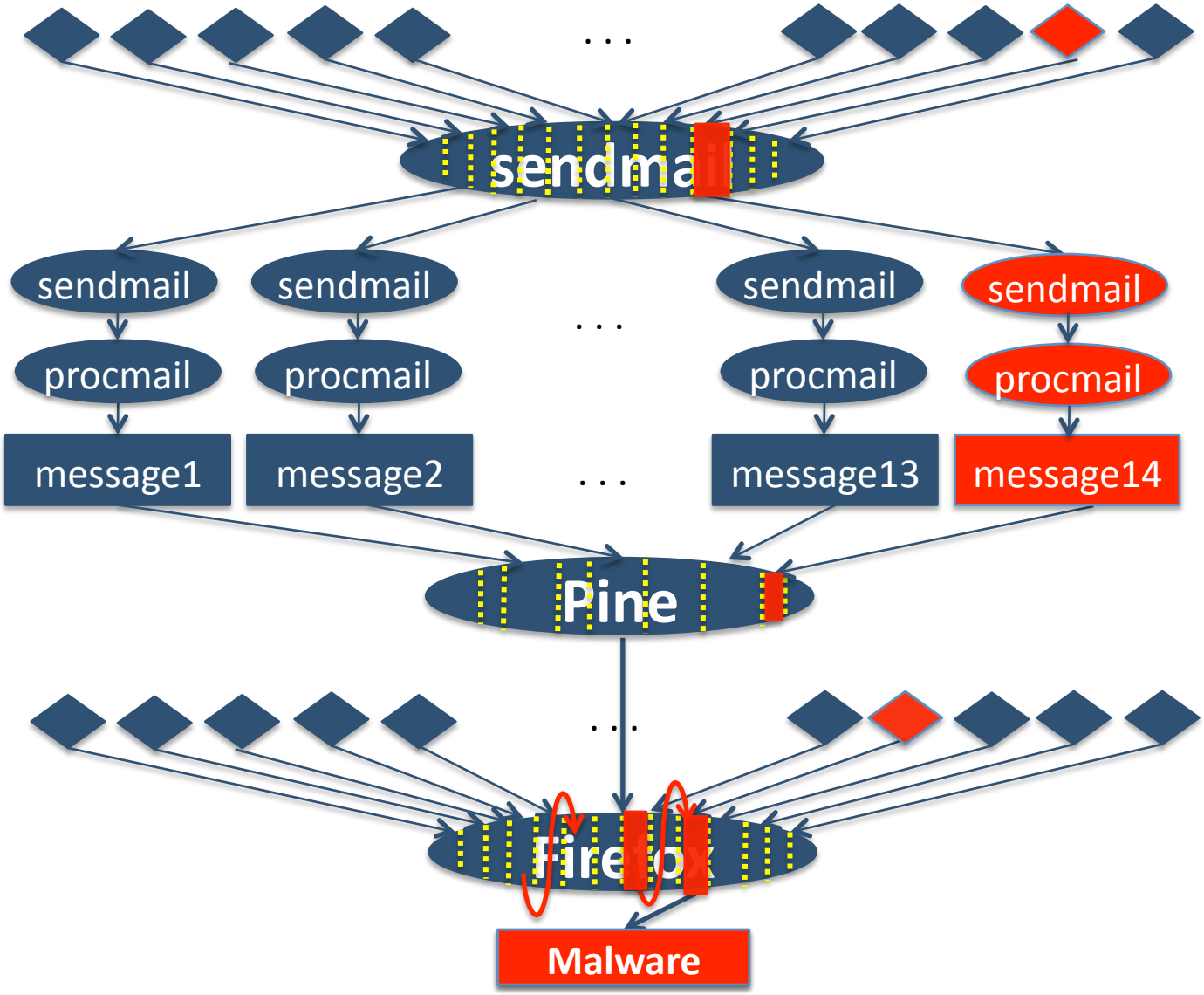

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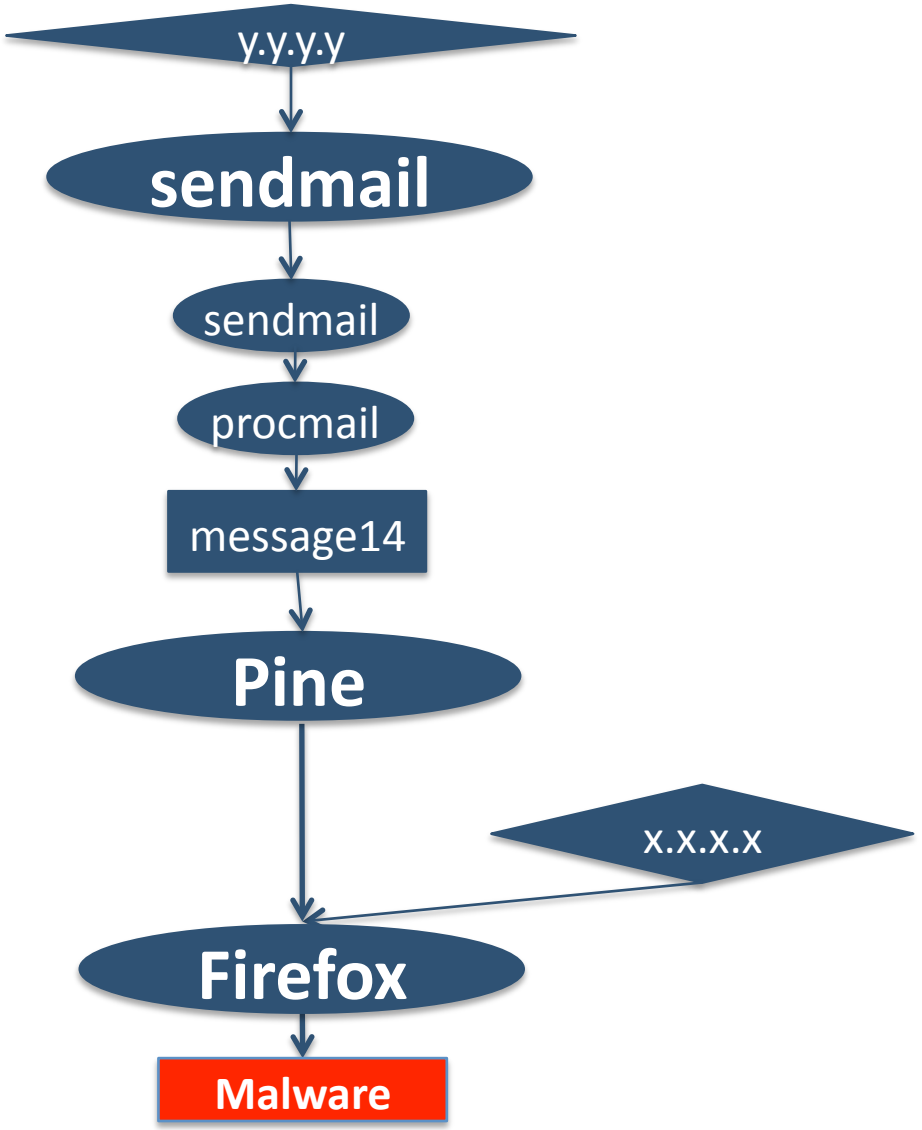

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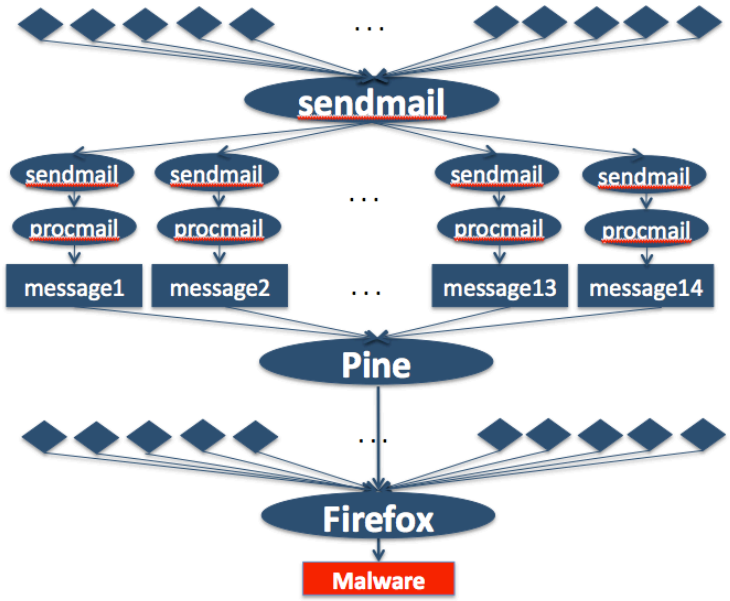

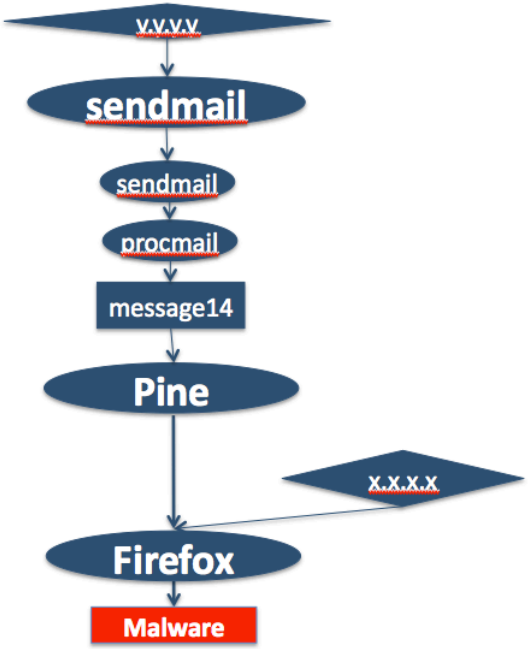

Previous Approach :

51 Processes, **15** Files,

251 Network addresses, **351** Edges

16.3 times smaller

BEEP :

10 Processes, **2** Files,

6 Network addresses, **23** Edges

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BEEP : Our Approach

- **BEEP** : **B**inary-based **E**x**E**cution **P**artition
  - Without source code
  - Reverse engineer units and unit dependences
  - Negligible runtime overhead (1.4% max.)
  - Low space overhead (12.28% avg.)
  - Effective (40.93 times smaller causal graph)

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Outline

- Identifying UNITs
- Inter-UNIT Dependences
- How BEEP Works
- Experimental Results
- Conclusion

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- **Identifying UNITs**
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Identifying Units

	Category	Total Applications	Loop structured Applications
Servers	Web server	13	13
	Mail server	8	8
	FTP server	6	6
	SSHD server	2	2
	DNS server	9	9
	Database server	4	4
	Proxy server	2	2
	Media server	5	5
	Directory server	3	3
	Version control server	2	2
	Remote desktop server	2	2
UI Programs	Web browser	5	5
	E-mail client	5	5
	FTP client	5	5
	Office	2	2
	Text Editor	3	3
	Image tool	4	4
	Audio player	2	2
	Video player	4	4
	P2P program	6	6
	Messanger	2	2
	File manager	2	2
	Shell program	3	3

Identifying Units

	Category	Total Applications	Loop structured Applications
	Web server	13	13
	Mail server	8	8
	FTP server	6	6
	SSHD server	2	2
	DNS server	0	0
	Proxy server	2	2
	Media server	5	5
	Version control server	3	3
	Remote desktop server	2	2
	E-mail client	5	5
	FTP client	5	5
	Office	2	2
UI Programs	Text Editor	3	3
	Image tool	4	4
	Audio player	2	2
	Video player	4	4
	P2P program	6	6
	Messanger	2	2
	File manager	2	2
	Shell program	3	3

Characteristics of long running programs

- ✔ Driven by **external requests**
- ✔ Dominated by **event processing loops**

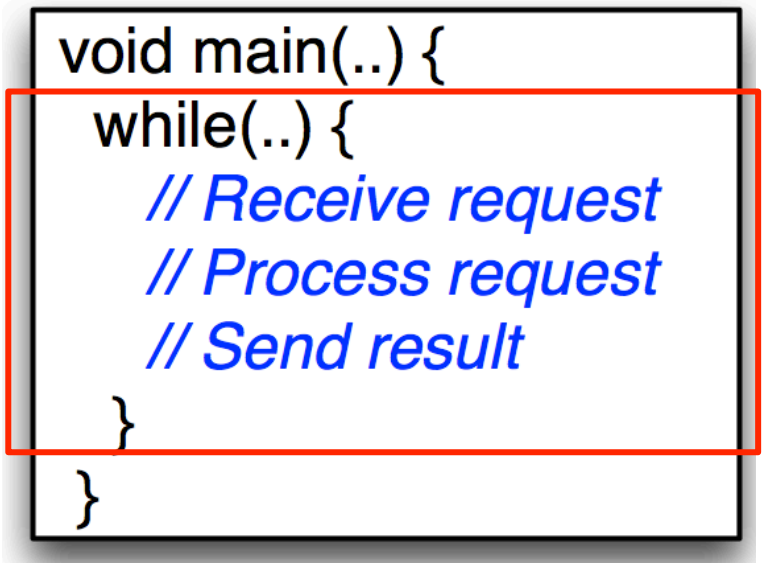
Identifying Units

- Event processing loop

```
void main(..) {
  while(..) {
     // Receive request
     // Process request
     // Send result
   }
}
```

Identifying Units

- Event processing loop



Execution Unit :

Iteration of event processing loop

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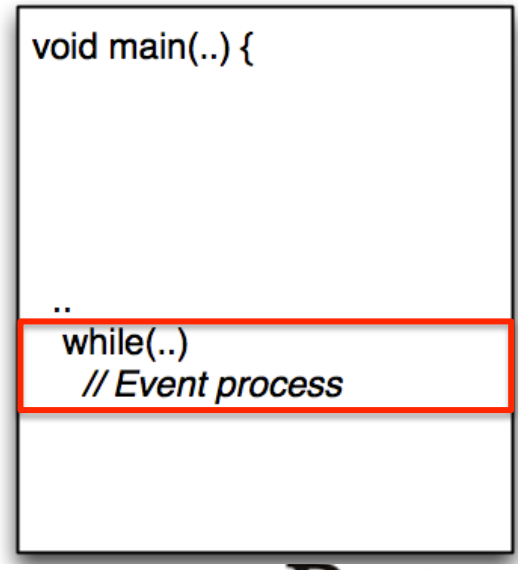
Identifying Units

- Detecting Unit Loops
  - High level loop



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Identifying Units

- Detecting Unit Loops
  - High level loop

```
void main(..) {
  while(..)
    // Argument handling
  ..
  while(..)
    // Memory pool initialize
  ..
  while(..)
    // Event process

  while(..)
    // Free allocated memory
```

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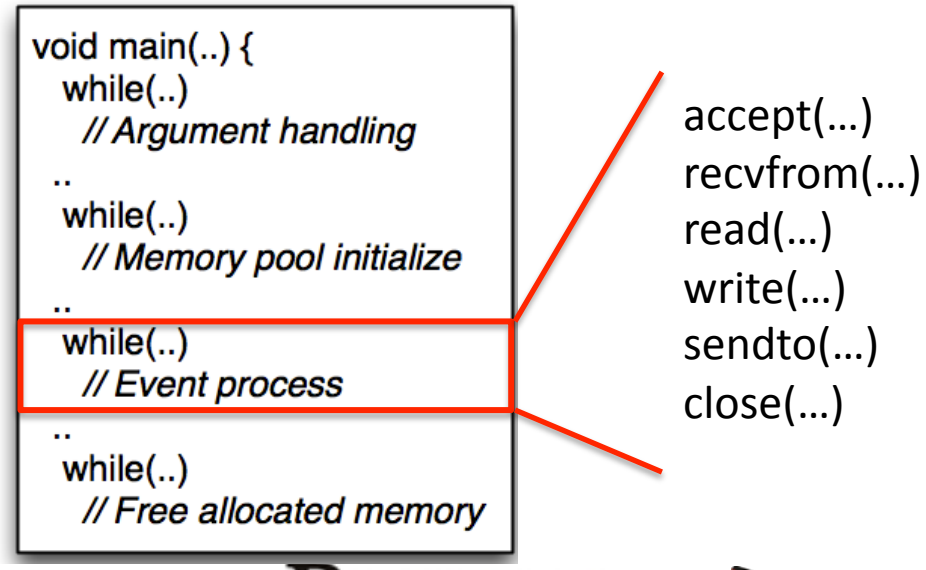
Identifying Units

- Detecting Unit Loops
  - High level loop
  - Receive inputs and produce outputs



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- **Inter-UNIT Dependences**
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Inter-Unit Dependences

- A unit alone may not correspond to a semantically independent sub-execution

Inter-Unit Dependences

```
593   void *listener_thread(..) {
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631     while(1) {
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742       req=accept_func(..);
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768       ap_queue_push(req);
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798     } // while end
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810   } // listener_thread end
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```
820   void *worker_thread(..) {
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842     while(!worker_may_exit) {
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<Apache-2.2.21> - **Multi-thread**

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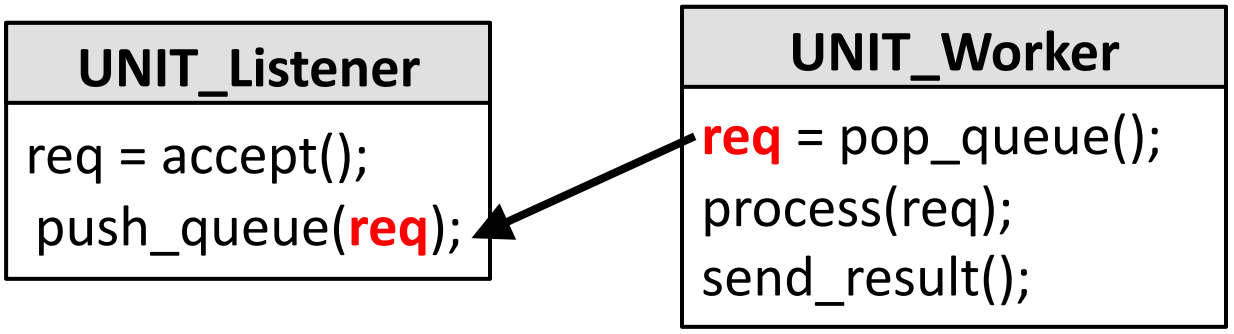

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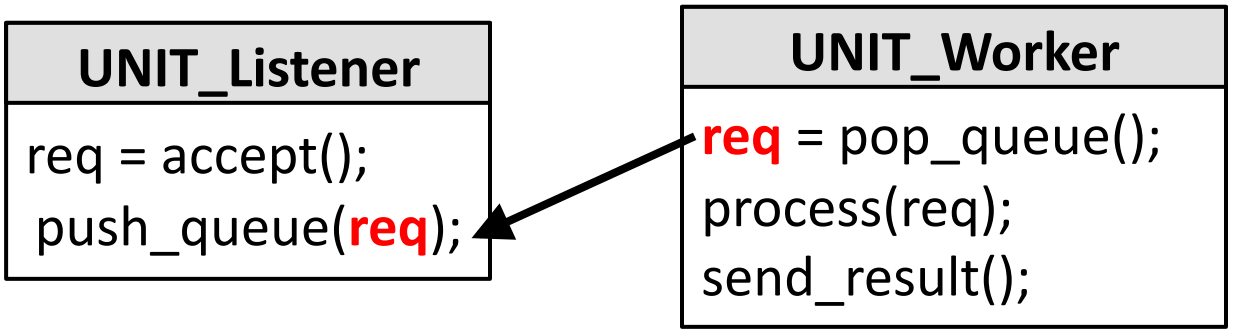
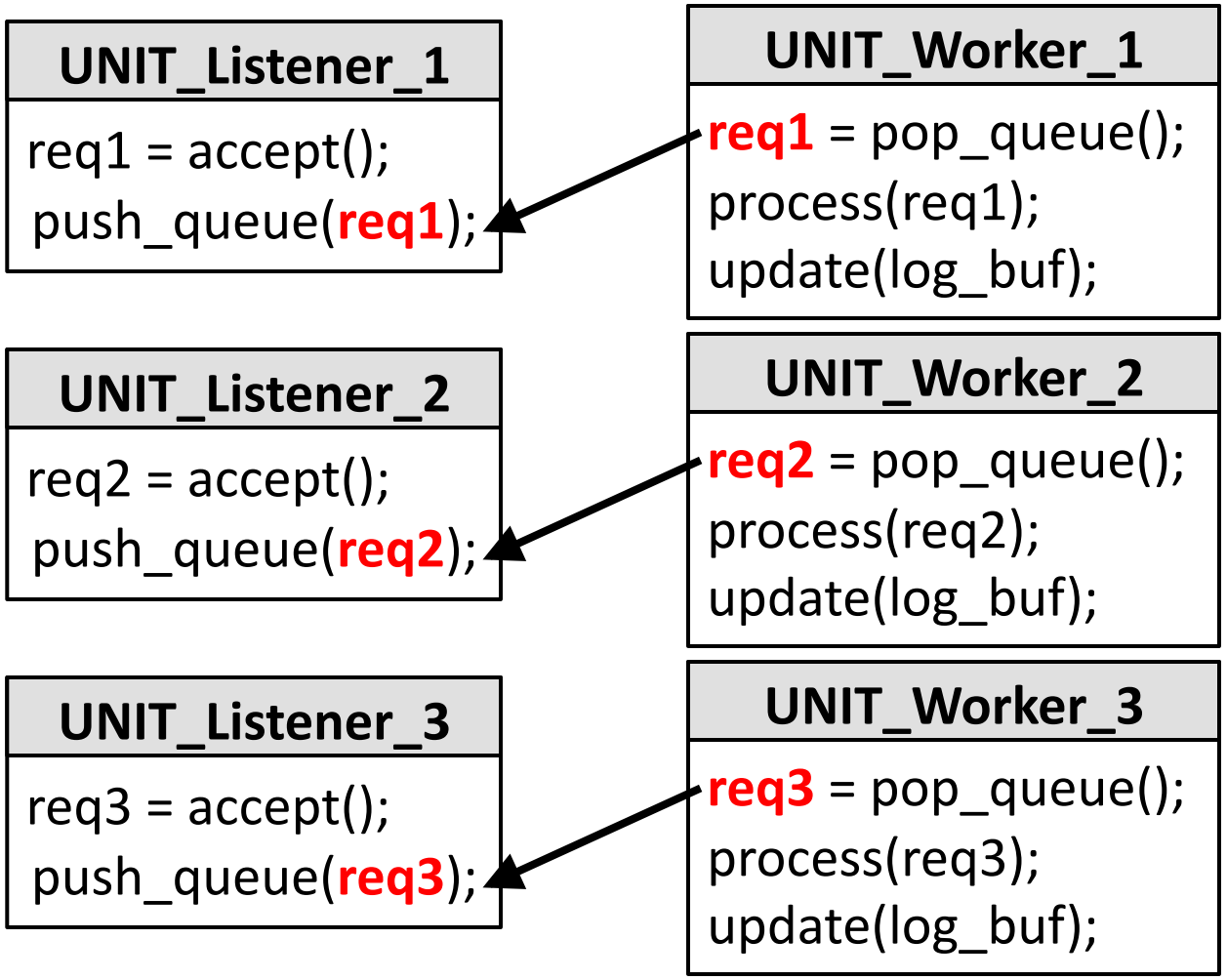


  - Dependences through workflow object
    - Ex) queue - enqueue, dequeue

Inter-Unit Dependences



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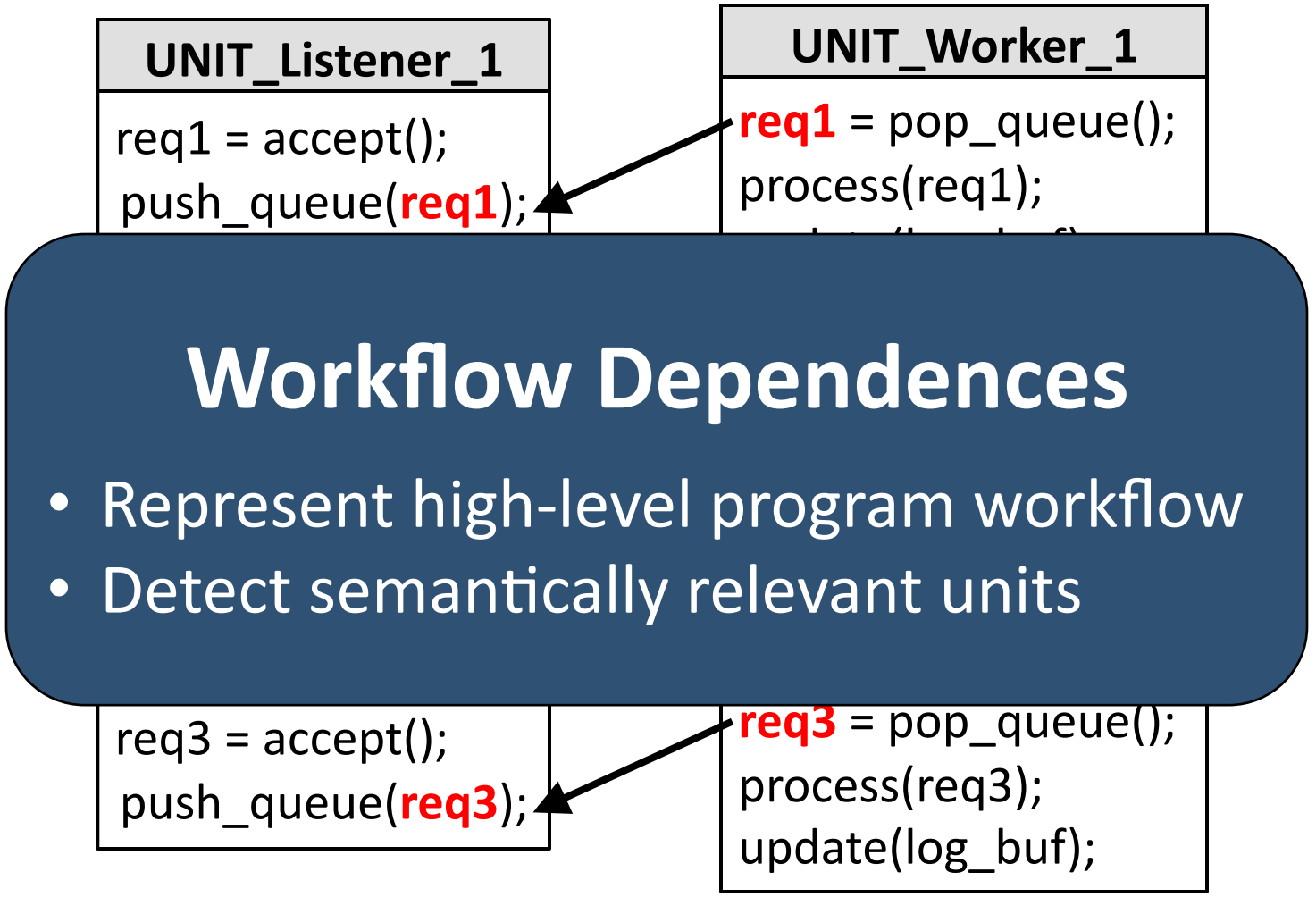

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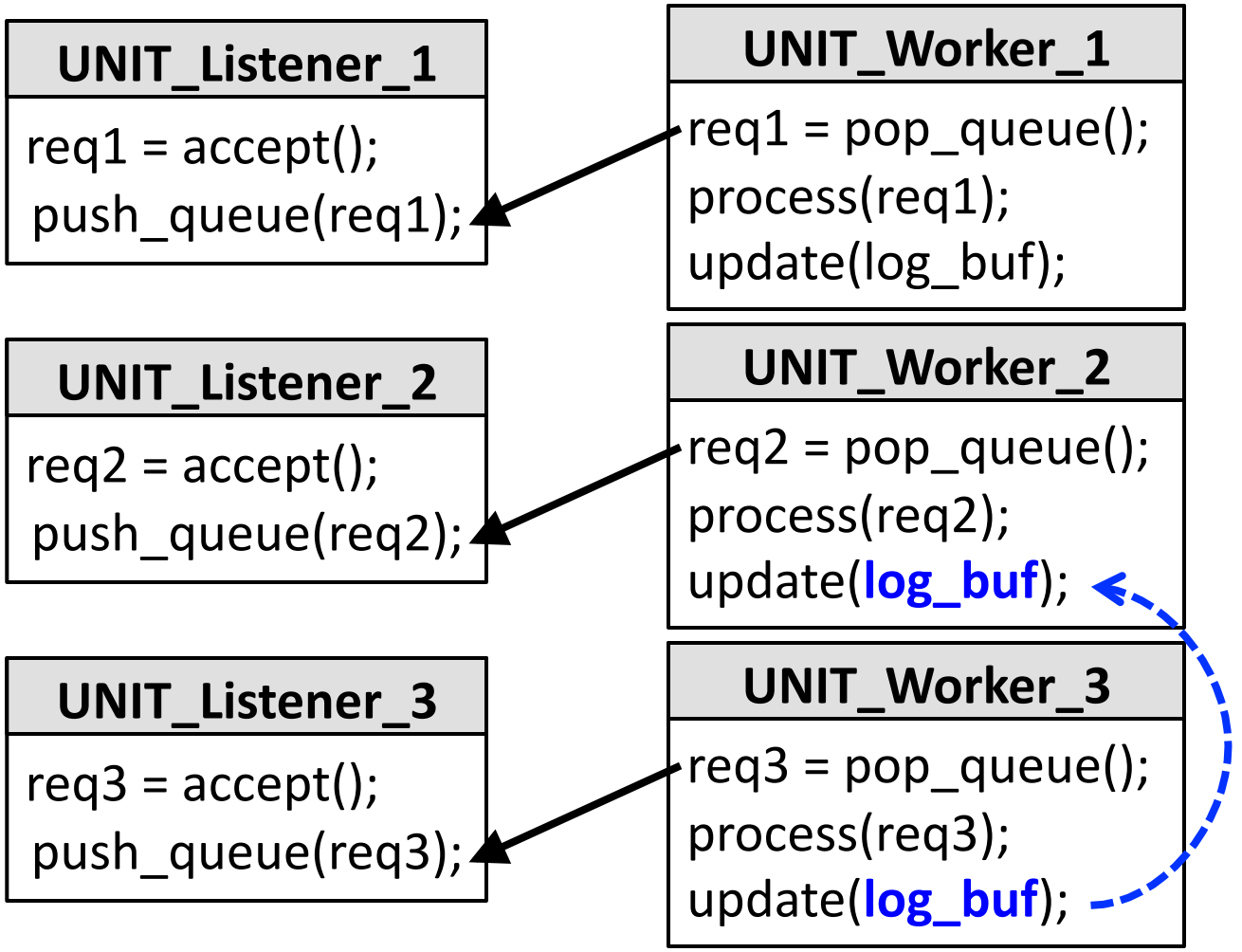

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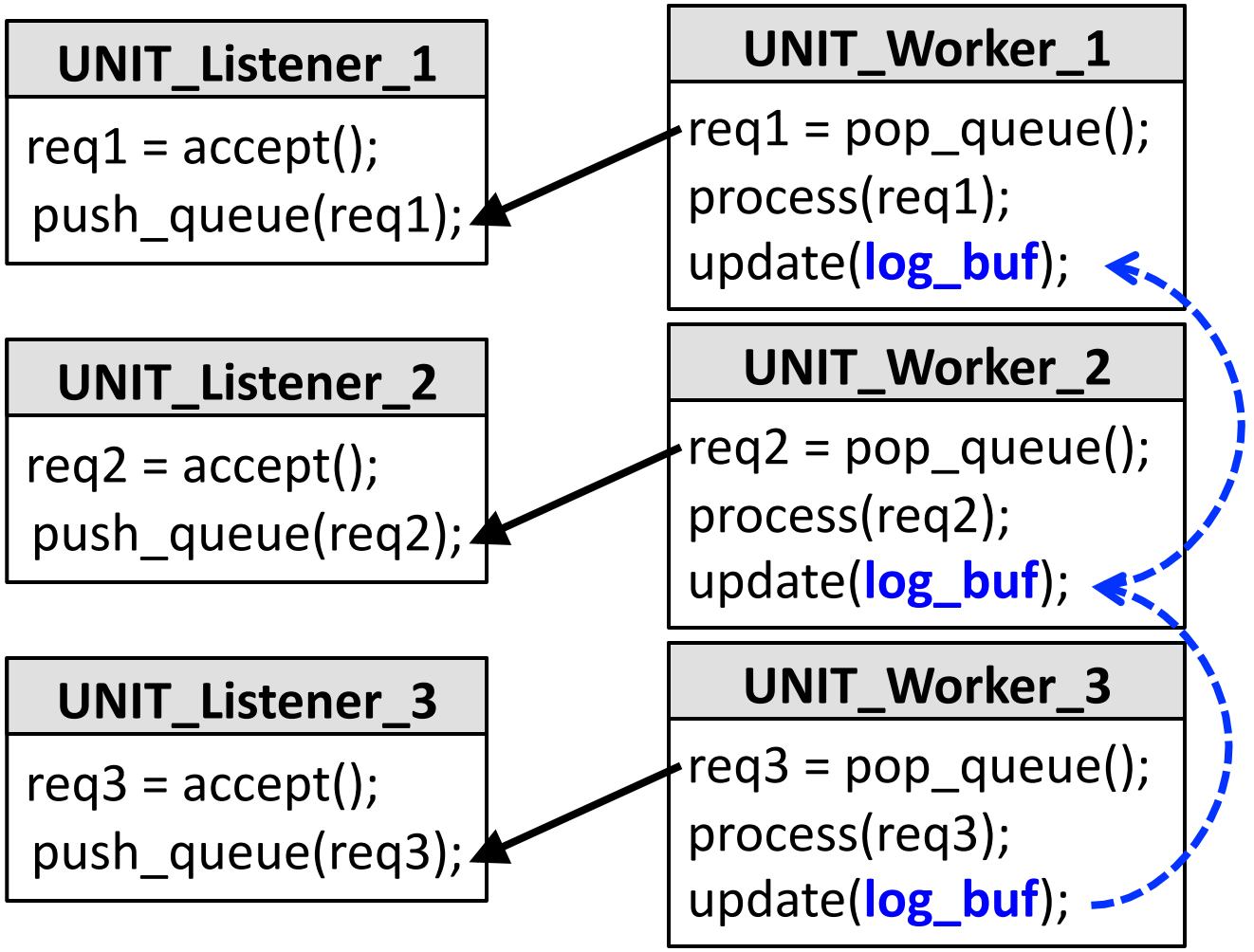
Inter-Unit Dependences



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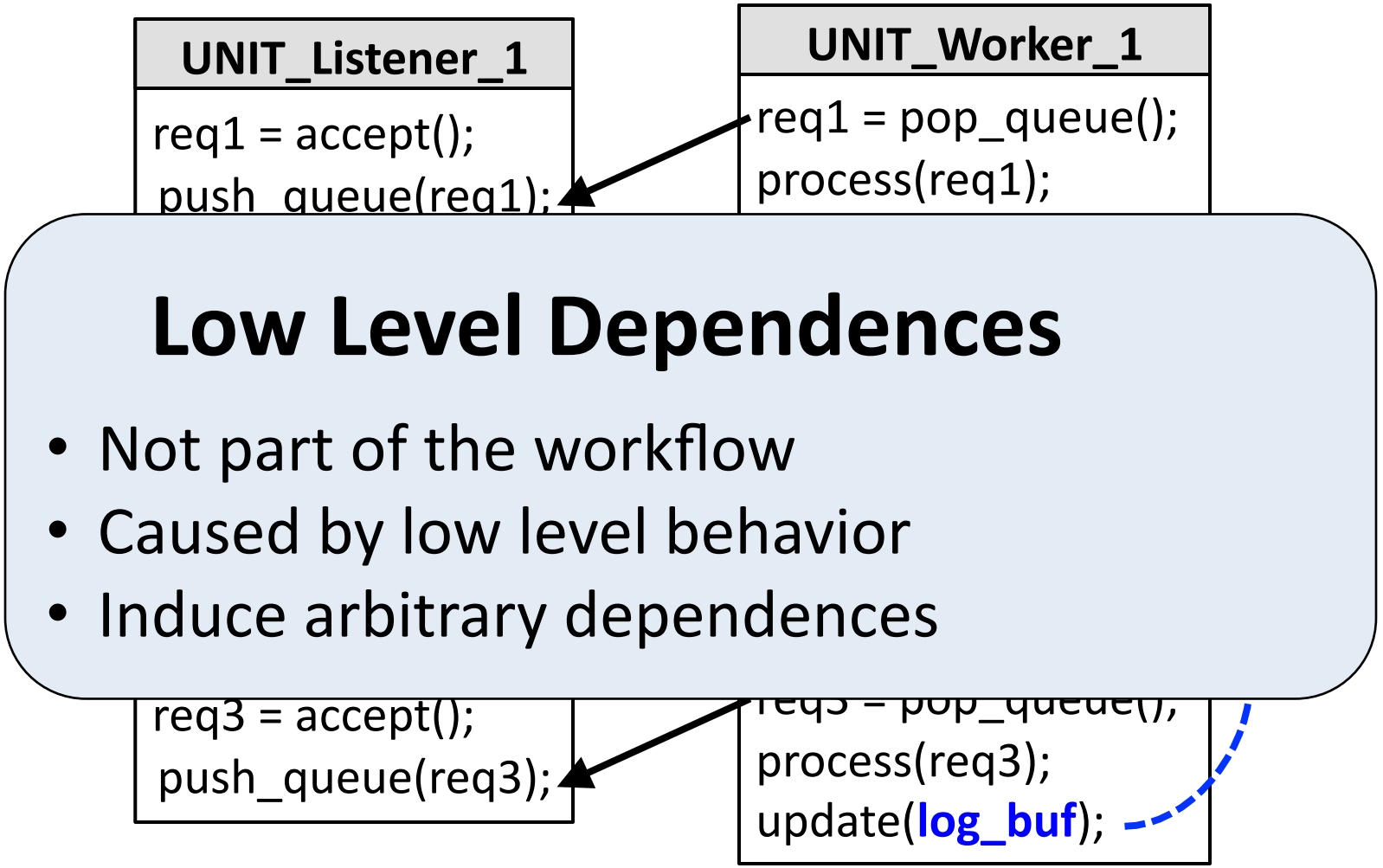

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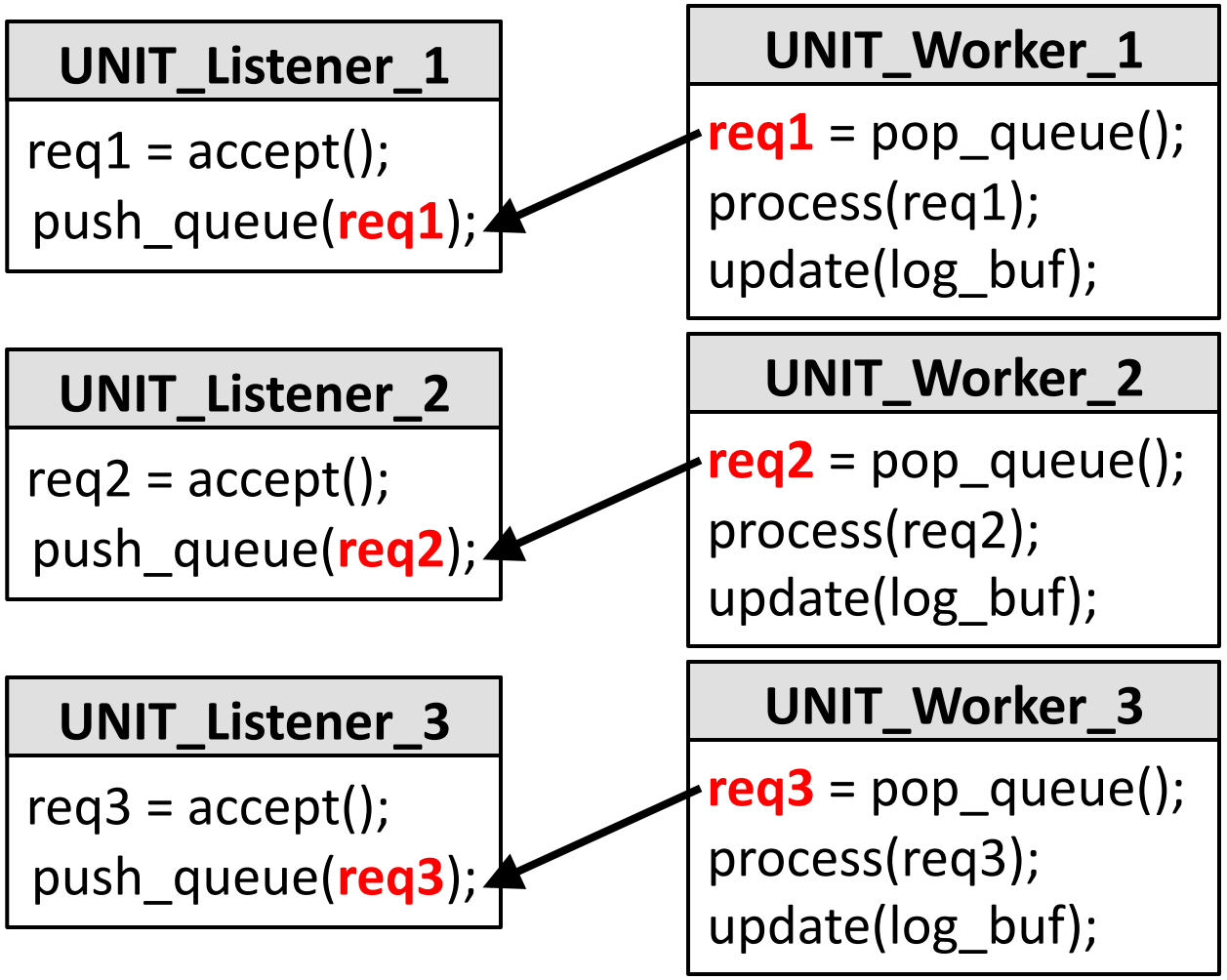
Inter-Unit Dependences



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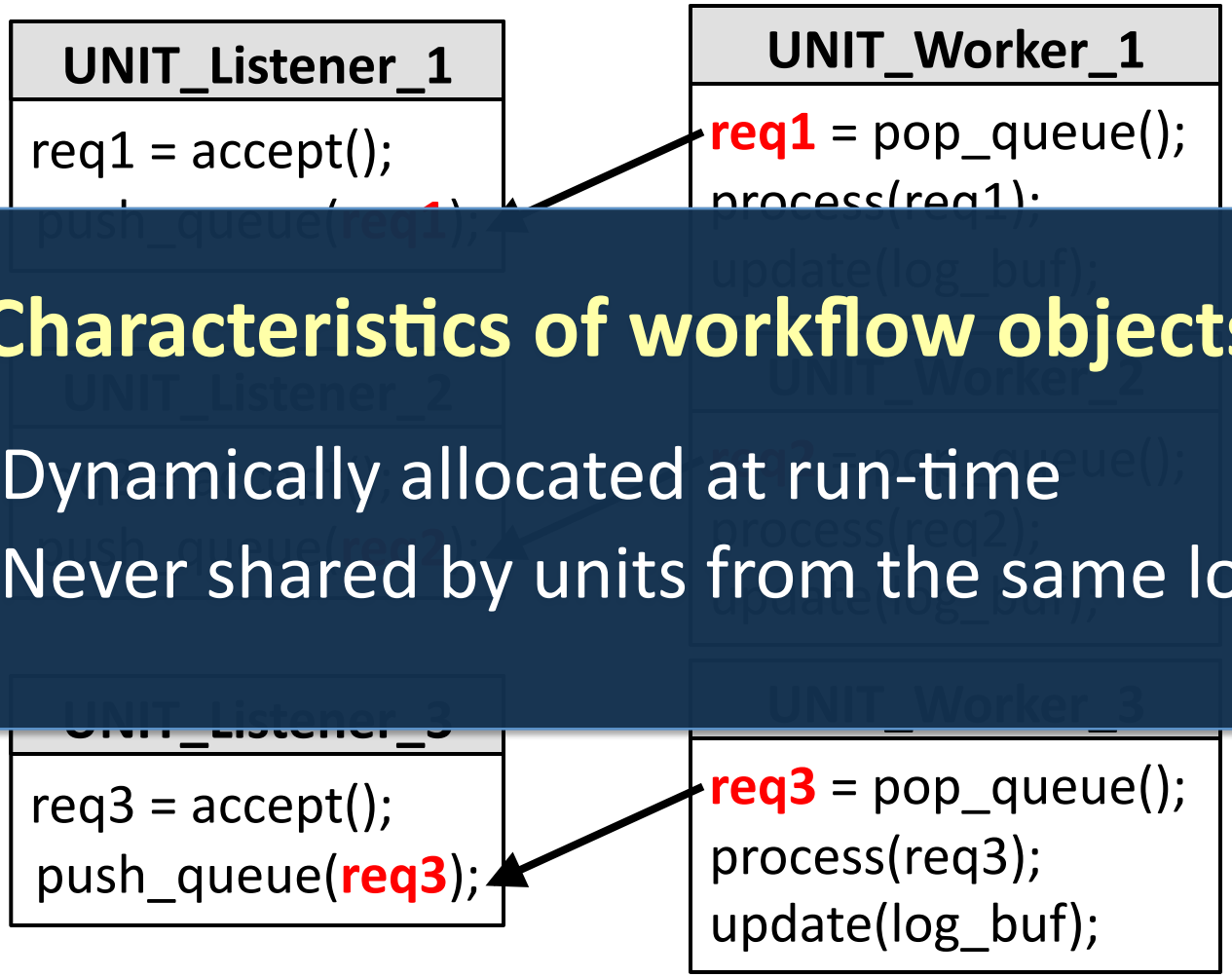

Characteristics of workflow objects

- ✔ Dynamically allocated at run-time
- ✔ Never shared by units from the same loop

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Outline

- Identifying UNITs
- Inter-UNIT Dependences
- **How BEEP Works**
- Experimental Results
- Conclusion

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How BEEP Works

Static Analysis

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How BEEP Works

Static Analysis

Training Runs

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How BEEP Works

Static Analysis

Training Runs

Instrumentation

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How BEEP Works

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Outline

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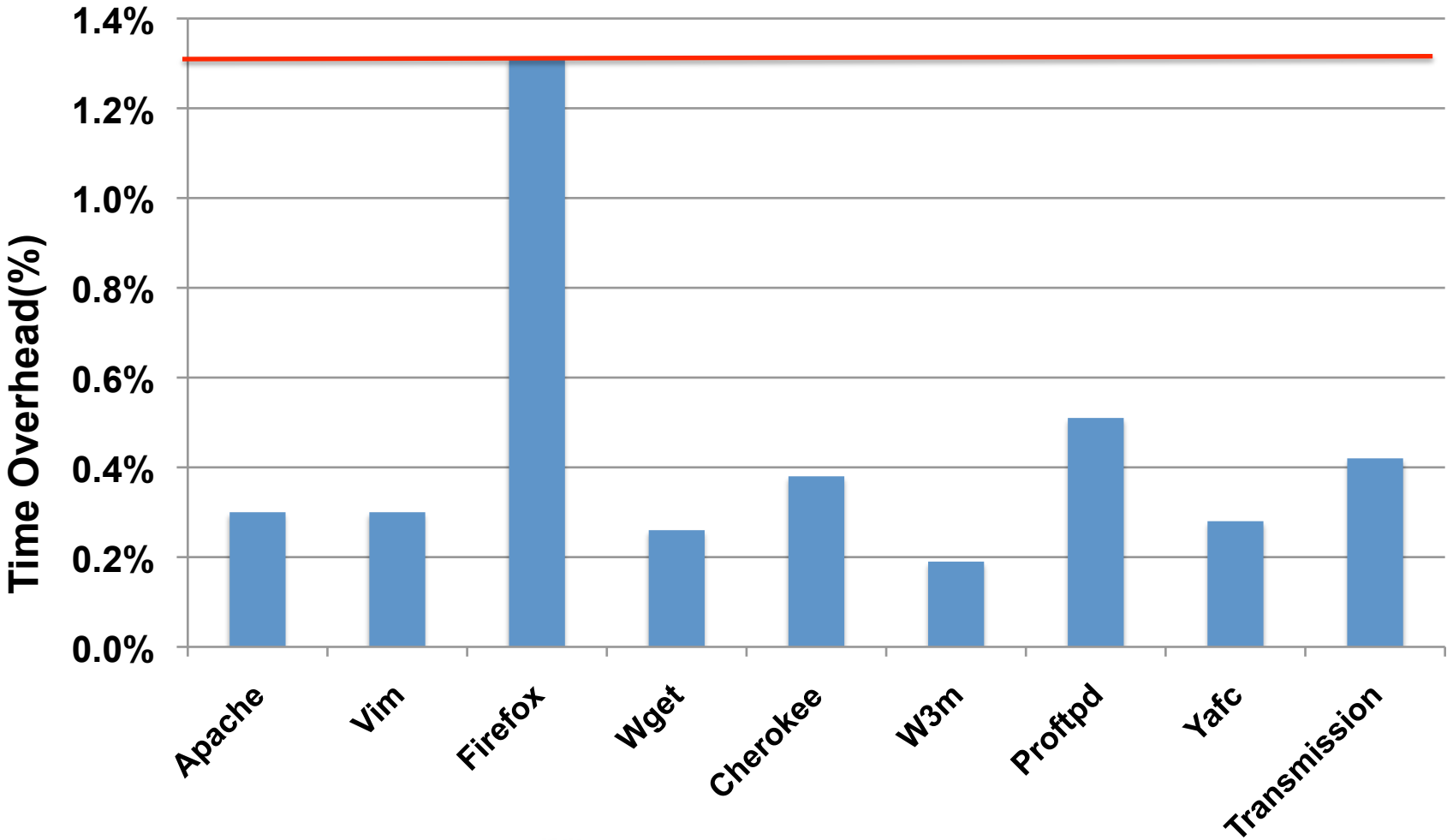
Logging Overhead (Time)



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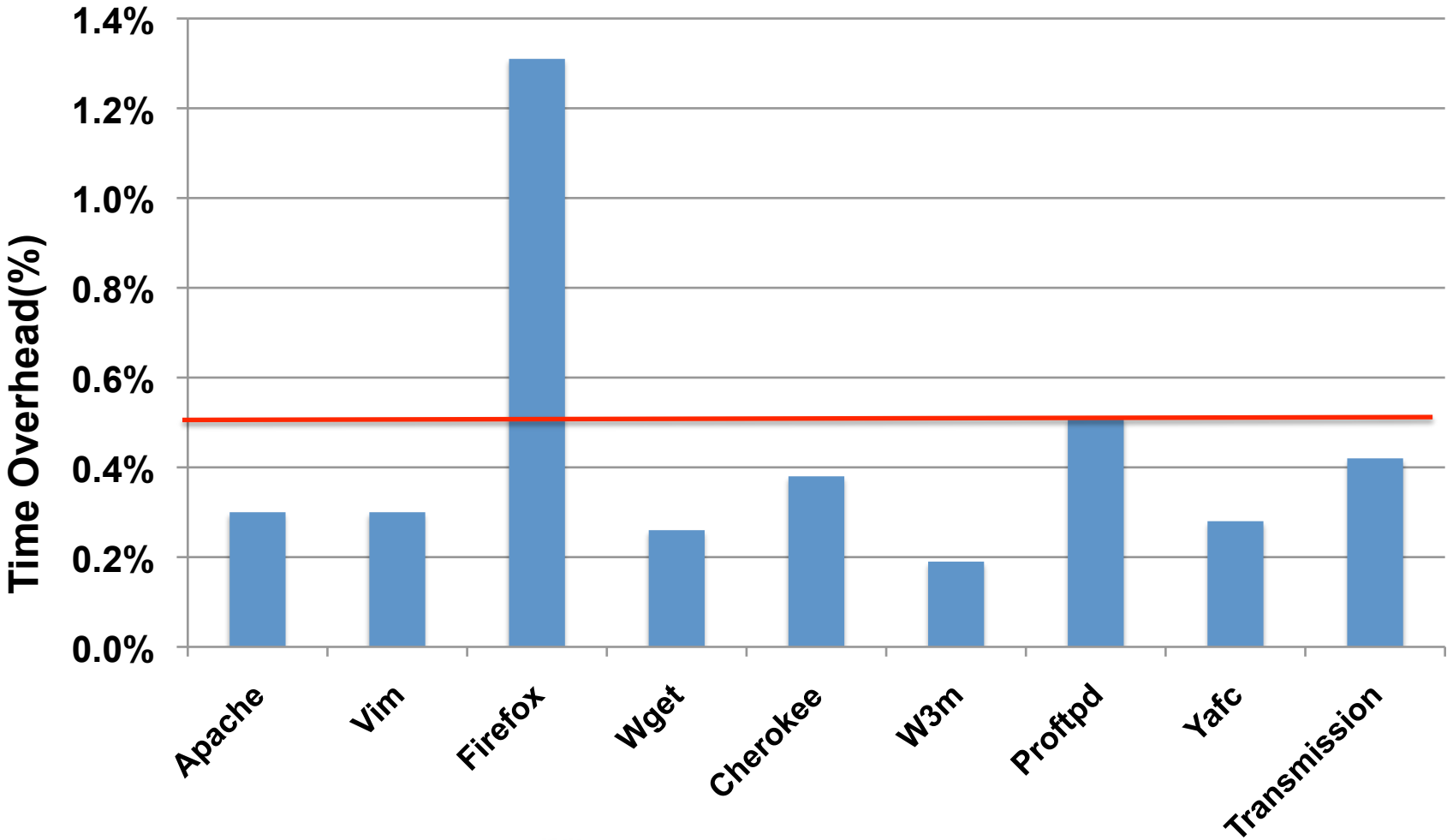
Logging Overhead (Time)



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Logging Overhead (Space)

App	Log Size (MB)		Space Overhead (%)
	Original	Instrumented	
Apache	0.227	0.278	22.4%
Vim	85.75	89.4	4.2%
Firefox	46.12	63.25	37.1%
Cherokee	1.1	1.126	2.2%
W3M	26.88	28.39	5.6%
Proftpd	0.54	0.56	2.3%
Wget	17.47	17.48	0.6%
Yafc	7.29	7.41	1.6%
Transmission	4.92	5.37	9.1%
Pine	5.62	6.21	10.5%
Bash	0.63	0.64	0.6%
MC	1.56	1.67	6.9%
Sshd	2.2	2.22	0.8%
Sendmail	0.214	0.22	2.8%

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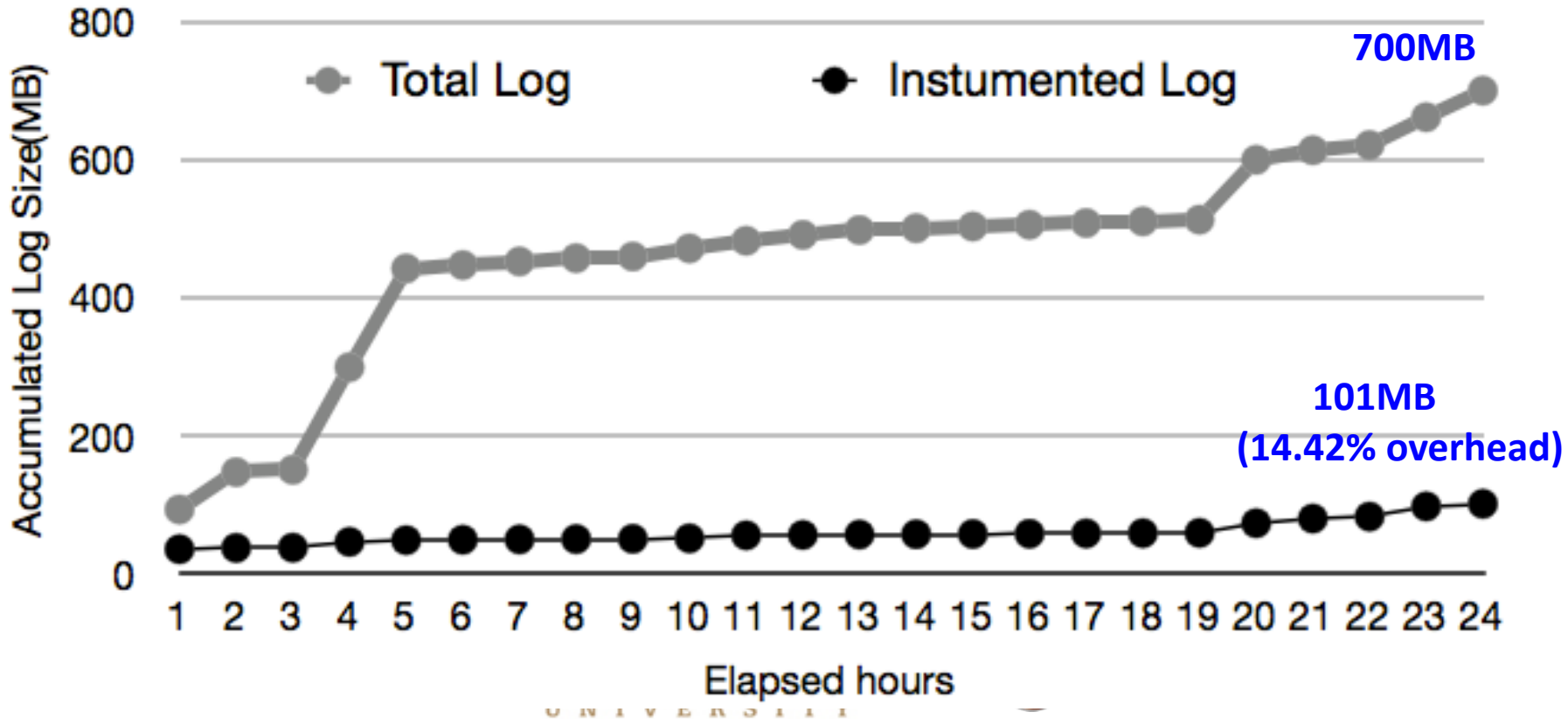
Logging Overhead (One day)

Server programs	UI programs
Sshd-5.9, Sendmail-8.12.11 Proftpd-1.3.4, Apache-2.2.21 Cherokee-1.2.1	Wget-1.13, W3m-0.5.2, Pine-4.64, MC-4.6.1, Vim-7.3, Bash-4.2, Firefox-11, Yafc-1.1.1, Transmission-2.6



Effectiveness

- Attack Ramification
  - 332 times smaller

	# of Processes	# of Files	# of Sockets	# of Edges
Previous approach	348	512	0	2,135
BEEP	4	1	0	4

- Information Stealing
  - 7.8 times smaller

	# of Processes	# of Files	# of Sockets	# of Edges
Previous approach	2	11	38	51
BEEP	2	4	1	6

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Related Works

- Coarse-grained analysis

  [S. T. King et al. '03], [A. Goel et al. '05]

- Whole system replay

  [T. Kim et al. '10], [R. Chandra et al. '11]

- Coarse-grained + instruction logging

  [X. Wang et al. '09], [P. Barham et al. '04]

- Instruction level information flow

  [H. Yin et al. '07], [B. C. Tak et al. '09]

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Conclusion

- **BEEP** : **B**inary-based **E**x**E**cution **P**artition
  - Highly accurate provenance tracing technique
    - Fine-grained autonomous units
    - Reverse engineer units and unit dependences
    - Without source code
  - Negligible runtime overhead (1.4% max.)
  - Low space overhead (12.28% avg.)
  - Effective (40.93 times smaller causal graph)

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Q & A

Unit Loop Detection

- Missing unit loops
  - Undesirable unification of dependences
    - –May cause false dependences
    - –Does not affect correctness
- Including bogus loops
  - Unit dependence analysis will detect the causal dependences between two loops
    - –Cause additional overhead
    - –Does not affect correctness

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Unit Dependence Detection

- Missing unit dependences
  - BEEP detects the workflow dependences
    - As long as trainings cover "some" of instructions
- Including low level dependences
  - May lead to bogus inter-unit dependences
    - Does not affect correctness

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