LogReducer: Identify and Reduce Log Hotspots in Kernel on the Fly

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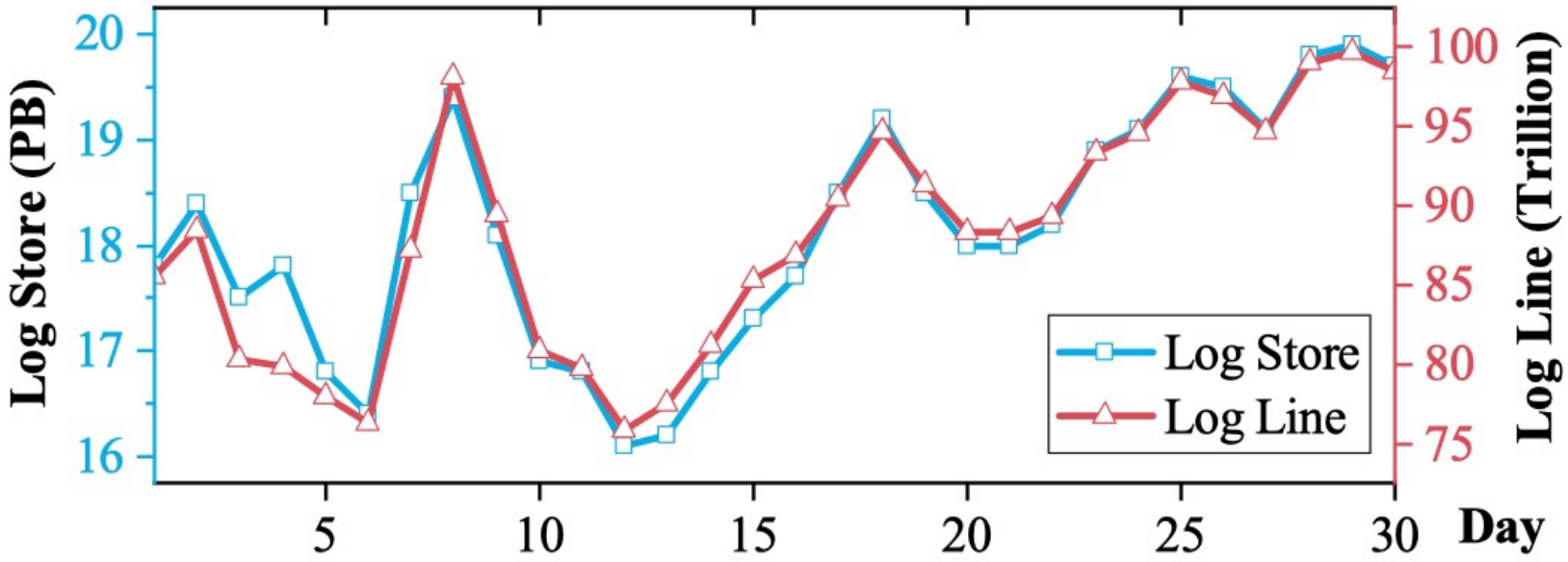
Introduction

- Logs is one of the “Three Pillars of Observability”
  - Check system status
  - Detect anomaly
  - Diagnose root cause

Introduction

- Logs is one of the “Three Pillars of Observability”
- Excessive logging is a double-edged sword
  - **High storage cost**
  - **Huge performance overhead**
  - **Difficult to troubleshoot**



Introduction

- How to reduce massive log amount?
  - Most of the logging overhead is due to **a very small number of log templates**
  - Log hotspot: **a small number of log templates occupy a lot of space**
  - Definition: S is the total storage of a service, and S_i is the storage of a log template

$$\frac{S_i}{S} > \xi$$

Log Format	< level> <service (pid,tid,cid,traceid)> time [code location] log info
Log Statement	MMERR("REQ %s Failed ", id);
Log Message	< 2> <Test (6,6,6,6666)> 11:48:43 66 [test.cpp:Test:6] REQ 6 Failed
Log Template	Error Test test.cpp:Test:6 REQ <ID> Failed

Introduction

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Reducing log hotspots is a cost-effective approach!

Empirical Study

- Research Object
  - WeChat is a large real-world instant messaging system serving billions of users
  - **Top 20 services** with the highest log storage in WeChat
  - **57 log hotspots** and interviewed 19 corresponding service owners
- Research Questions
  - RQ1: How do log hotspots impact **application storage**?
  - RQ2: How do log hotspots impact **application runtime**?
  - RQ3: What are the **root causes** of log hotspots?
  - RQ4: What are the **fixing solutions** of log hotspots?
  - RQ5: **How long** do developers take to fix log hotspots?

Empirical Study

- RQ1: How do log hotspots impact **application storage**?

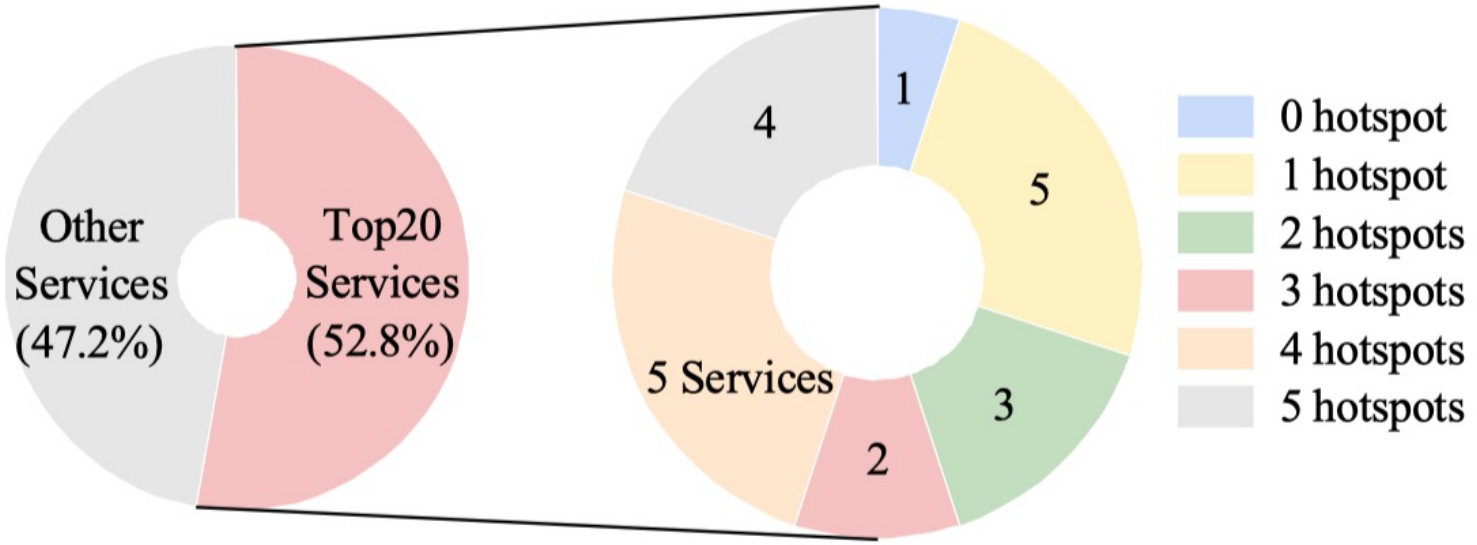


Fig. 5. The top 20 services with the highest storage in WeChat account for 52.8% of the total storage. 19 of the 20 services contain at least one log hotspots.

- ✓ **Top 20 services accounting for 52.8% of the total storage in Wechat**
- ✓ **19 services (19 out of 20) contain at least one log hotspots**

Empirical Study

➢ RQ1: How do log hotspots impact **application storage**?

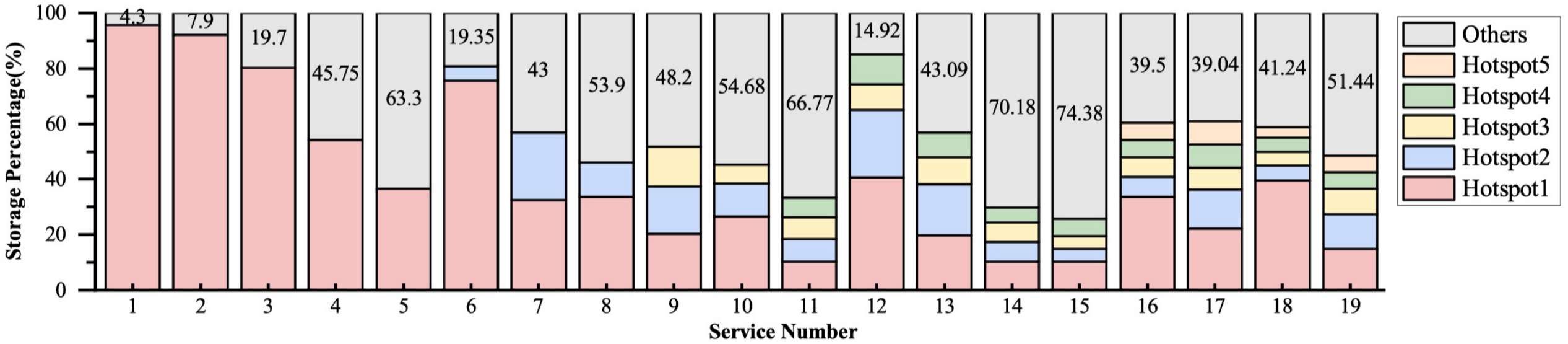


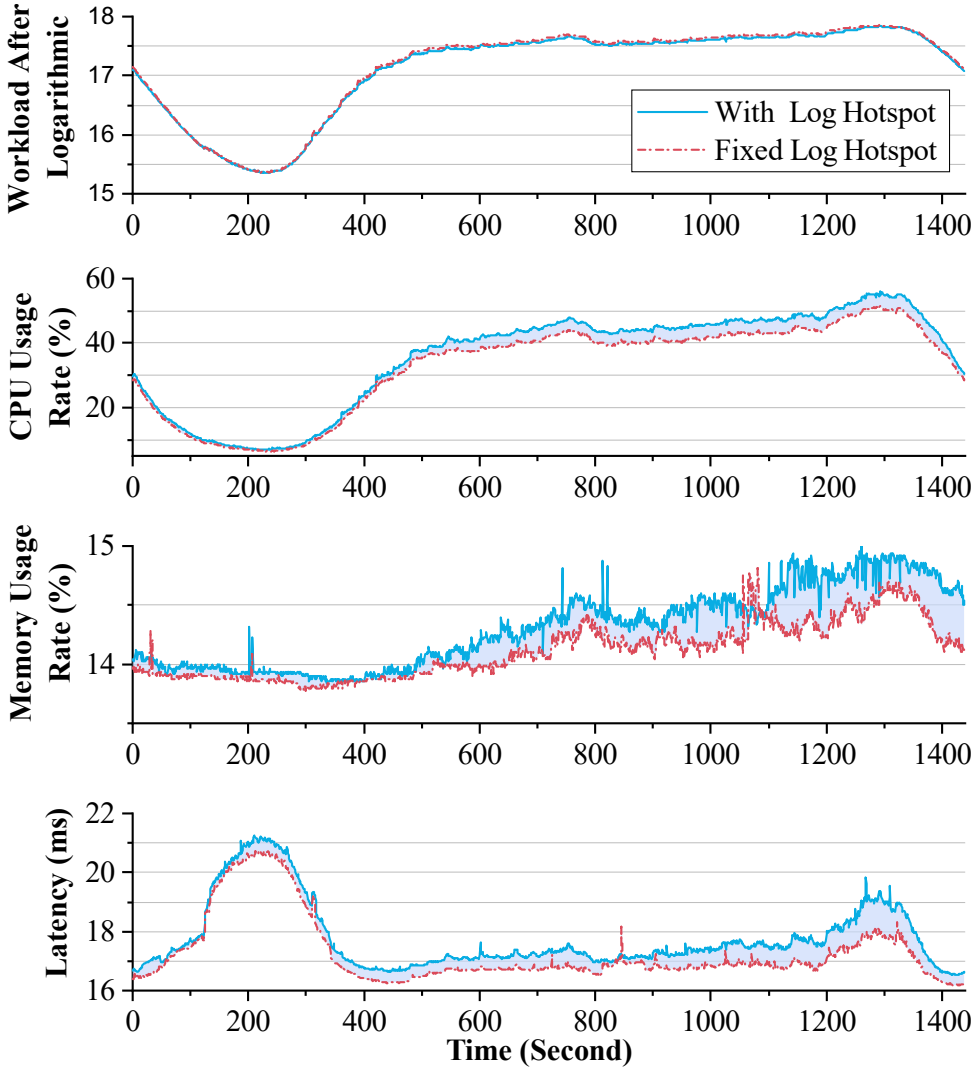
Fig. 6. For services containing at least one log hotspot in Figure 5, log hotspots occupy an average of 57.86% of the corresponding service storage.

✓ **Log hotspots occupy an average of 57.86% of corresponding storage**

✓ **One log hotspot occupied 95.7% of the storage for the service**

Empirical Study

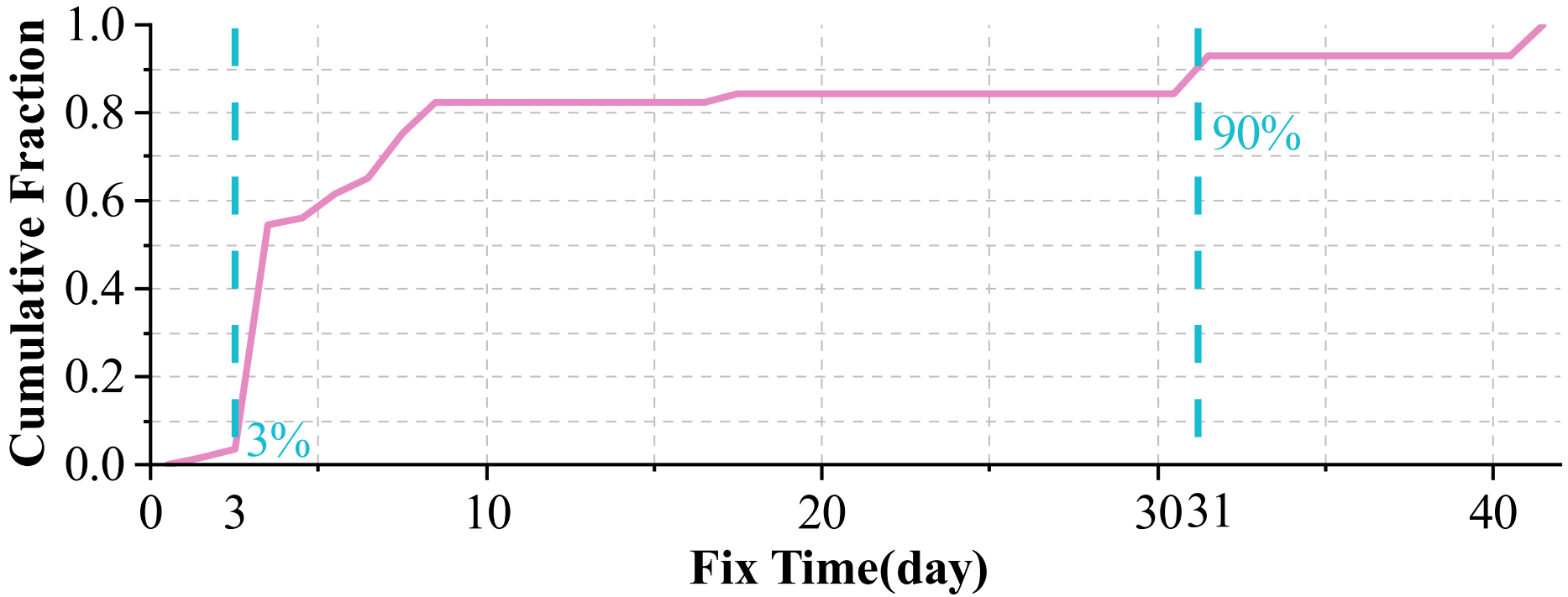
- RQ2: How do log hotspots impact **application runtime**?
  - New version only modifies the logging statements compared to the old version



- ✓ **Log volume dropped from 162 TB to 3.66 TB**
- ✓ **Service with log hotspots consumed up to 5.18% more CPU (58 cores in total)**
- ✓ **Service with log hotspots suffered up to 3% more response latency**

Empirical Study

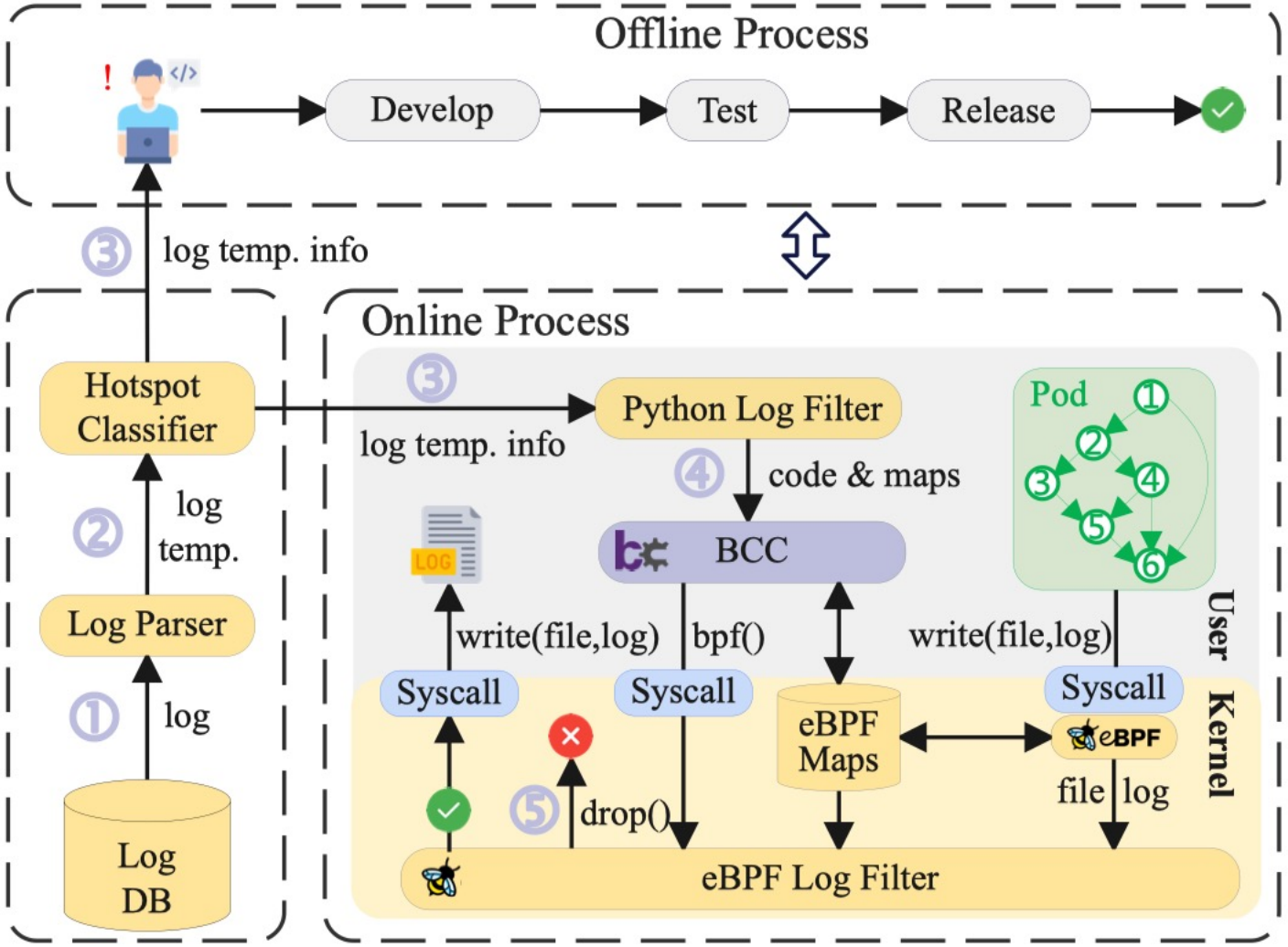
➢ RQ5: **How long** do developers take to fix log hotspots?



✓ **For 97% of log hotspots, developers need at least 3 days and on average 9 days to fix them**

LogReducer Approach

- LogReducer is a **non-intrusive** and **language-independent** framework for filtering log hotspots
  - **Offline Process**: alert developers to fix log hotspots
  - **Online Process**: filter log hotspots in the Linux kernel



LogReducer Offline Process

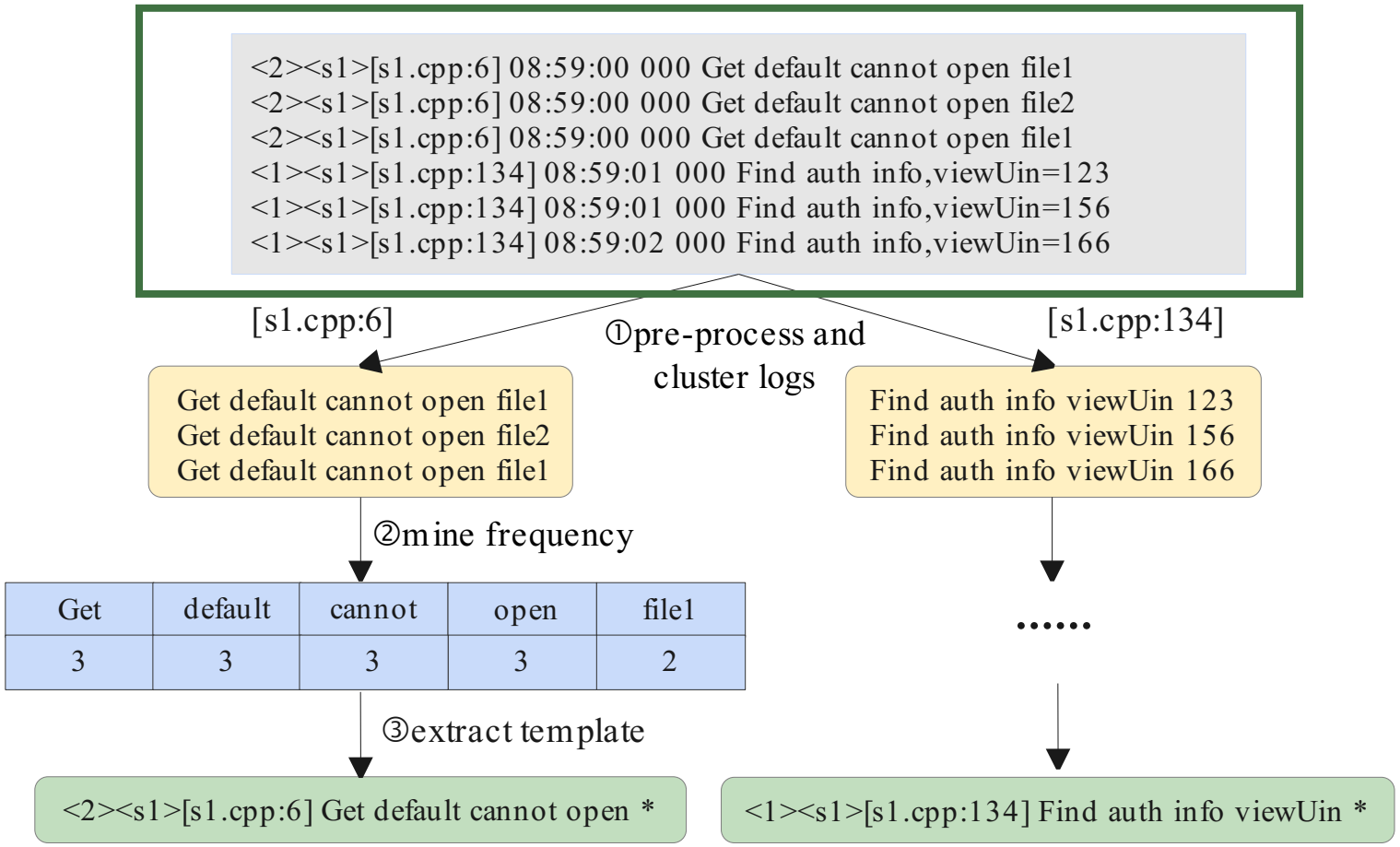
1. Log Parser: combine **log signature matching and frequency analysis** to parse logs
   - Log signature: strings that can uniquely identify a logging statement
   - We use **location of log statement** as log signature
     - ✓ Location of log statement **precisely bound** to log statement
     - ✓ **Insert location** into the log message based on log frameworks is **easy**

```
# Java Log 4j
<PatternLayout pattern="%d %-5p %c [%F:%L] - %m%n"/>

# C++ log4cplus
log4cplus::tstring pattern = LOG4CPLUS_TEXT("%D{%Y/%m/%d %H:%M:%S,%Q} %-5p
- [%l] %m %n");

# Golang Zap
logger := zap.New(core, zap.AddCaller())
```

LogReducer Offline Process

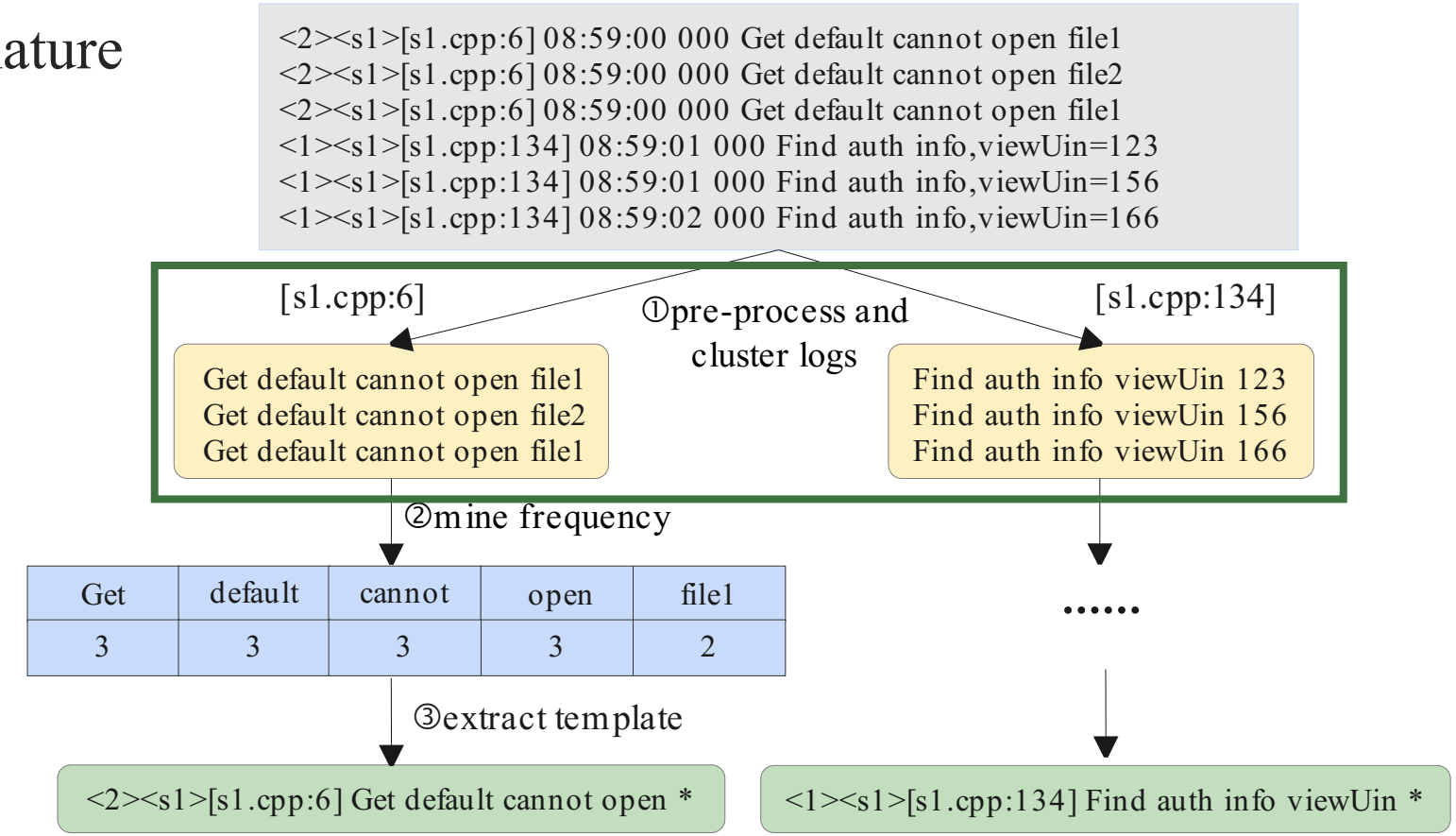
1. Log Parser: combine **log signature matching and frequency analysis** to parse logs

   ① Extract the **log level, service name, and log signature**



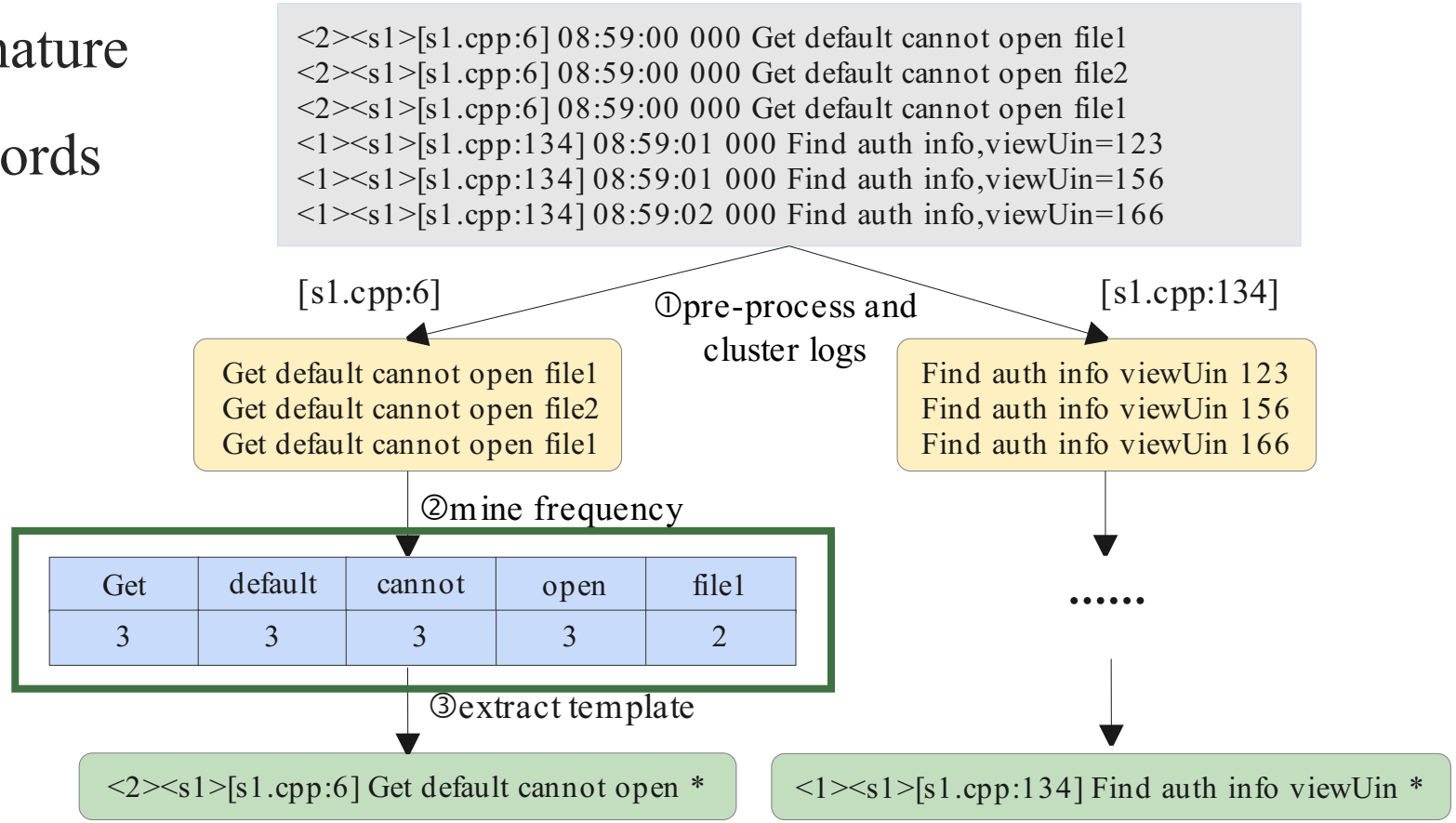
LogReducer Offline Process

1. Log Parser: combine log signature matching and frequency analysis to parse logs
   - ① Extract log level, service name, and log signature
   - ② **Cluster** logs based on log signature



LogReducer Offline Process

1. Log Parser: combine log signature matching and frequency analysis to parse logs
   - ① Extract the log level, service name, and log signature
   - ② Cluster logs based on log signature
   - ③ Build a **frequency table** of words



LogReducer Offline Process

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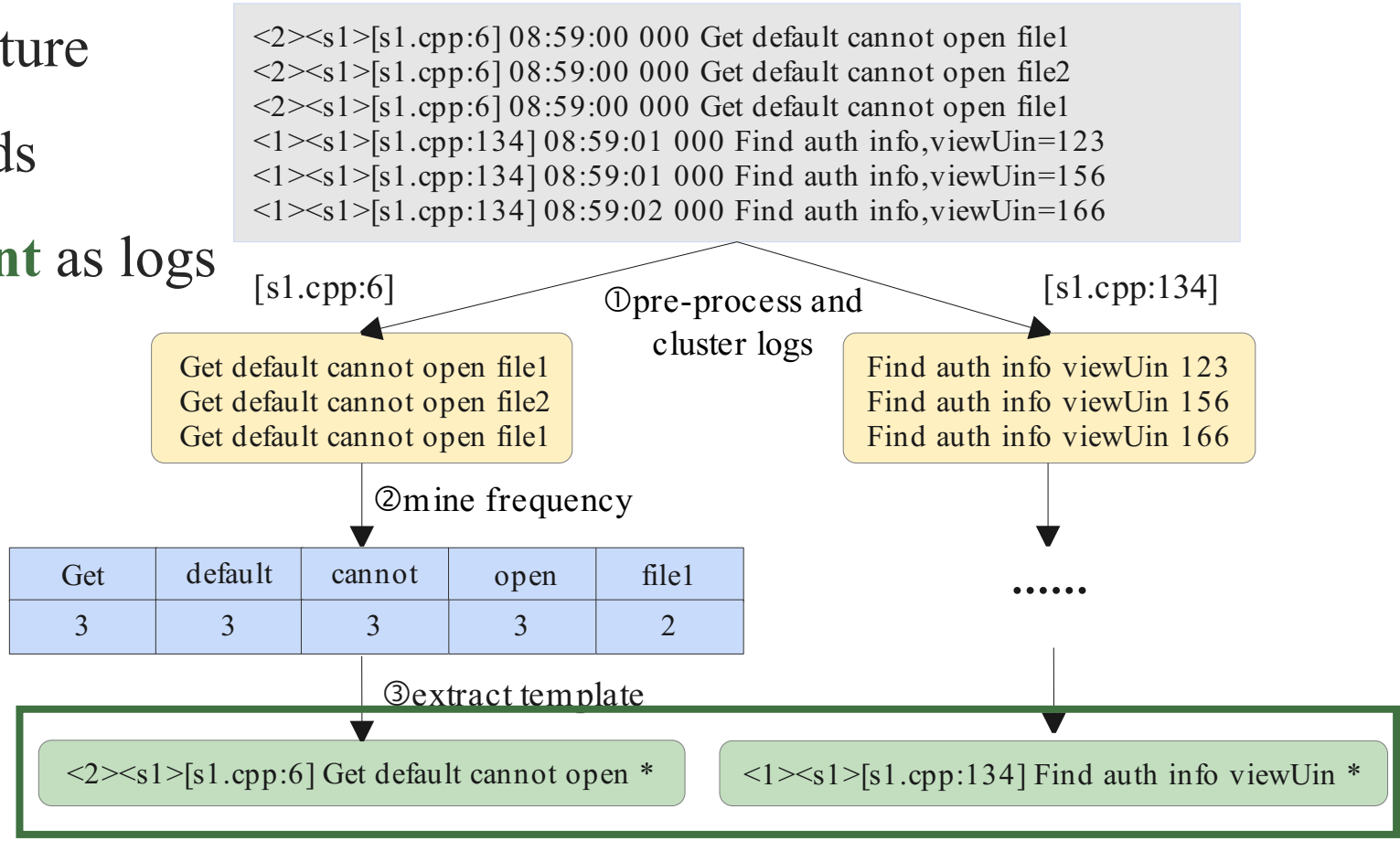
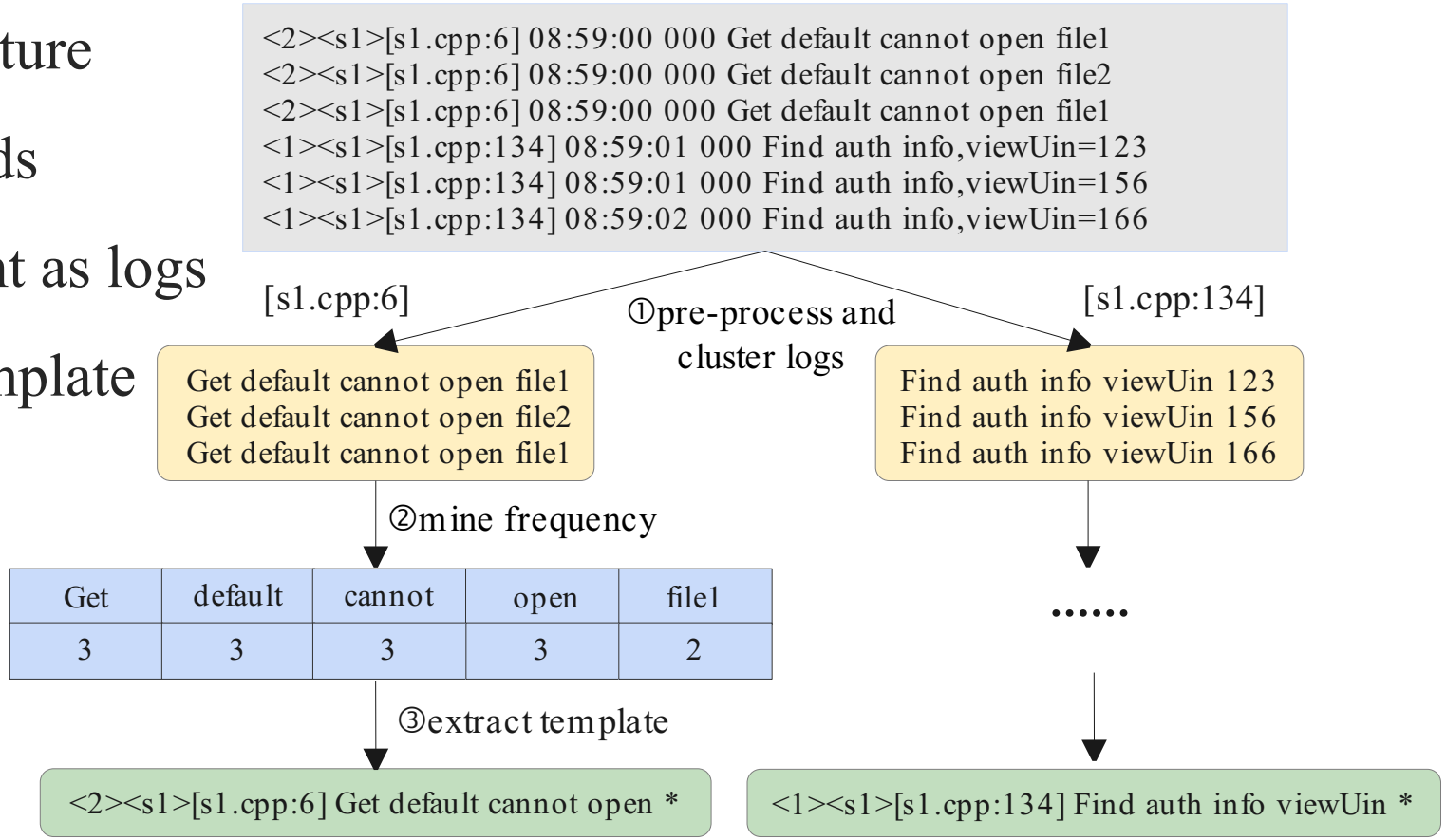
   - ① Extract the log level, service name, and log signature
   - ② Cluster logs based on log signature
   - ③ Build a frequency table of words
   - ④ Seek words with the **same count** as logs



LogReducer Offline Process

1. Log Parser: combine log signature matching and frequency analysis to parse logs
   - ① Extract the log level, service name, and log signature
   - ② Cluster logs based on log signature
   - ③ Build a frequency table of words
   - ④ Seek words with the same count as logs
   - ⑤ **Obtain storage** of each log template



LogReducer Offline Process

1. Log Parser: combine log signature matching and frequency analysis to parse logs
2. Hotspot Classifier:

   ① Identify log hotspots from all log templates

$$\frac{S_i}{S} > \xi \qquad \xi = 0.05$$

   ② Trigger log reduction process if log hotspots exist

LogReducer Offline Process

1. Log Parser: combine log signature matching and frequency analysis to parse logs
2. Hotspot Classifier: Identify log hotspots from all log templates
3. **Alert developers** with log hotspots

Log Reducer

Date	OssID	Level	Template	Location	Storage	Storage Ratic	Rows	Rows Ratio	Log Length	Log detail
2023-04-10	19118	ERROR	new S[redacted]cene ...	[redacted]essionBuffer:3594	45.7 TiB	4.43%	14.3 Bil	0.389%	3672	detail
2023-04-10	19118	IMPT	ret_fla[redacted]ast_s...	[redacted]ess:3316	41.2 TiB	3.99%	13.9 Bil	0.377%	3411	detail
2023-04-10	19118	ERROR	CALL [redacted]ionKe...	[redacted]277	38.6 TiB	3.73%	10.1 Bil	0.274%	4391	detail
2023-04-10	19118	ERROR	DBG r[redacted]ot_rev...	[redacted]kingReqCtxAdapterV2:1141	34.0 TiB	3.29%	10.9 Bil	0.296%	3581	detail
2023-04-10	19118	IMPT	ERR T[redacted]	[redacted]	29.8 TiB	2.88%	190 Bil	5.17%	179	detail
2023-04-10	19118	IMPT	CALL [redacted]	[redacted]s:38	29.1 TiB	2.82%	8.58 Bil	0.233%	3890	detail
2023-04-10	19118	ERROR	resp B[redacted]	[redacted]Process:97	25.5 TiB	2.47%	8.60 Bil	0.234%	3397	detail
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2023-04-10	19118	IMPT	MMFI[redacted]clipo...	[redacted]Log:7223	18.7 TiB	1.81%	13.9 Bil	0.379%	1535	detail

LogReducer Offline Process

1. Log Parser: combine log signature matching and frequency analysis to parse logs
2. Hotspot Classifier: Identify log hotspots from all log templates
3. Alert developers with log hotspots
4. Developers release new version

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LogReducer Offline Process Result

- We applied LogReducer offline process in WeChat since April 14, 2022
- Log storage in WeChat dropped from **19.7 PB to 12.0 PB** per day

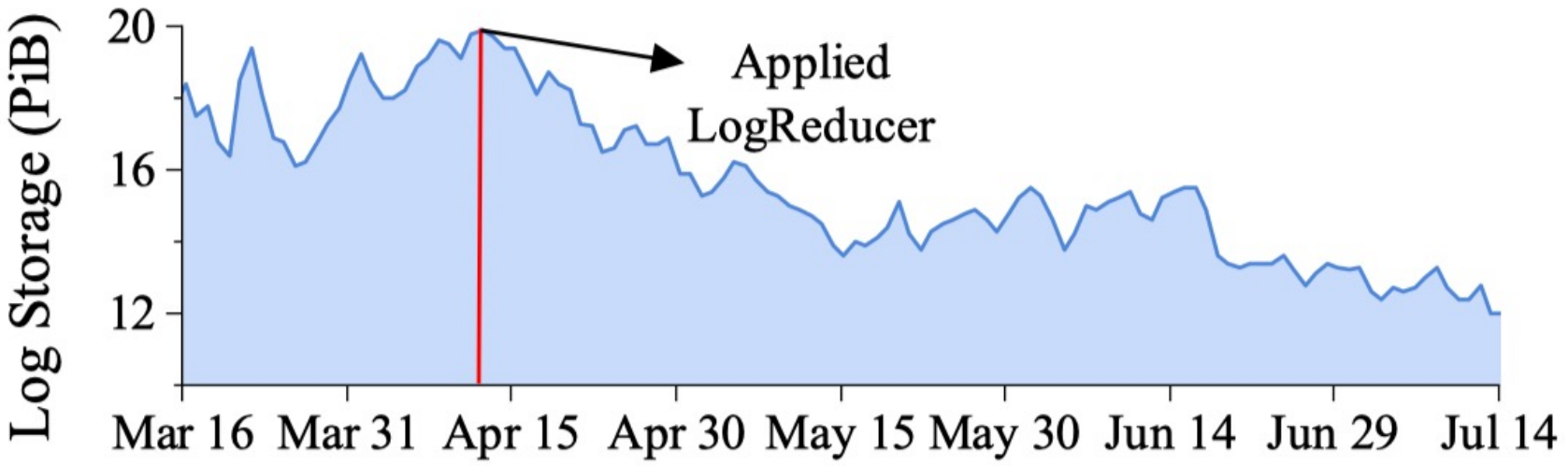
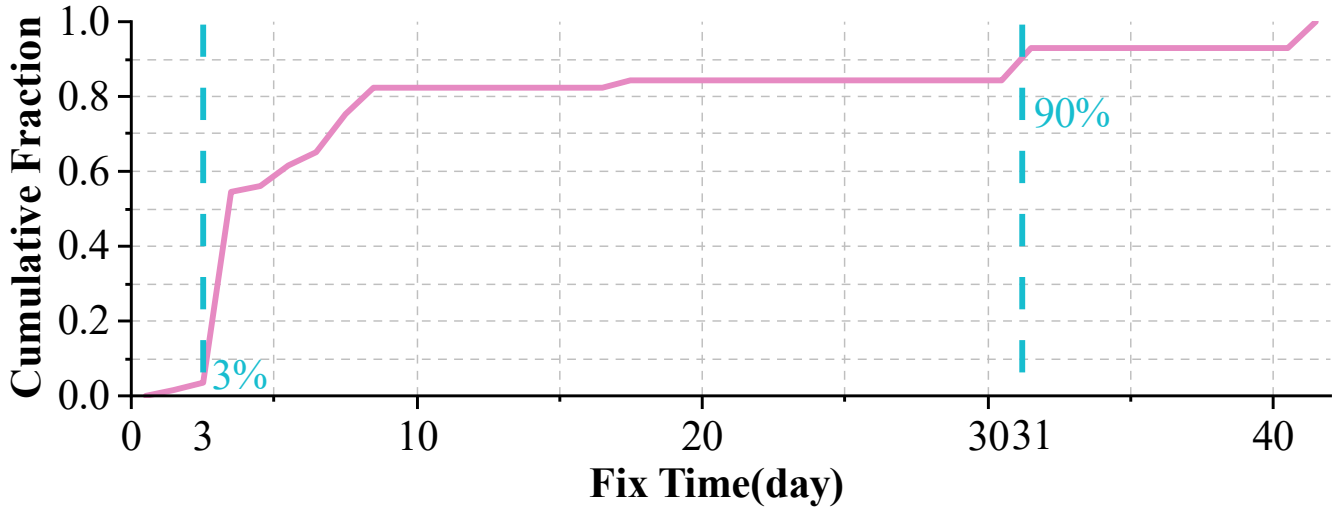


Fig. 17. Changes in the log storage of WeChat from Mar 16 to Jul 14 in 2022.

39.08% decrease

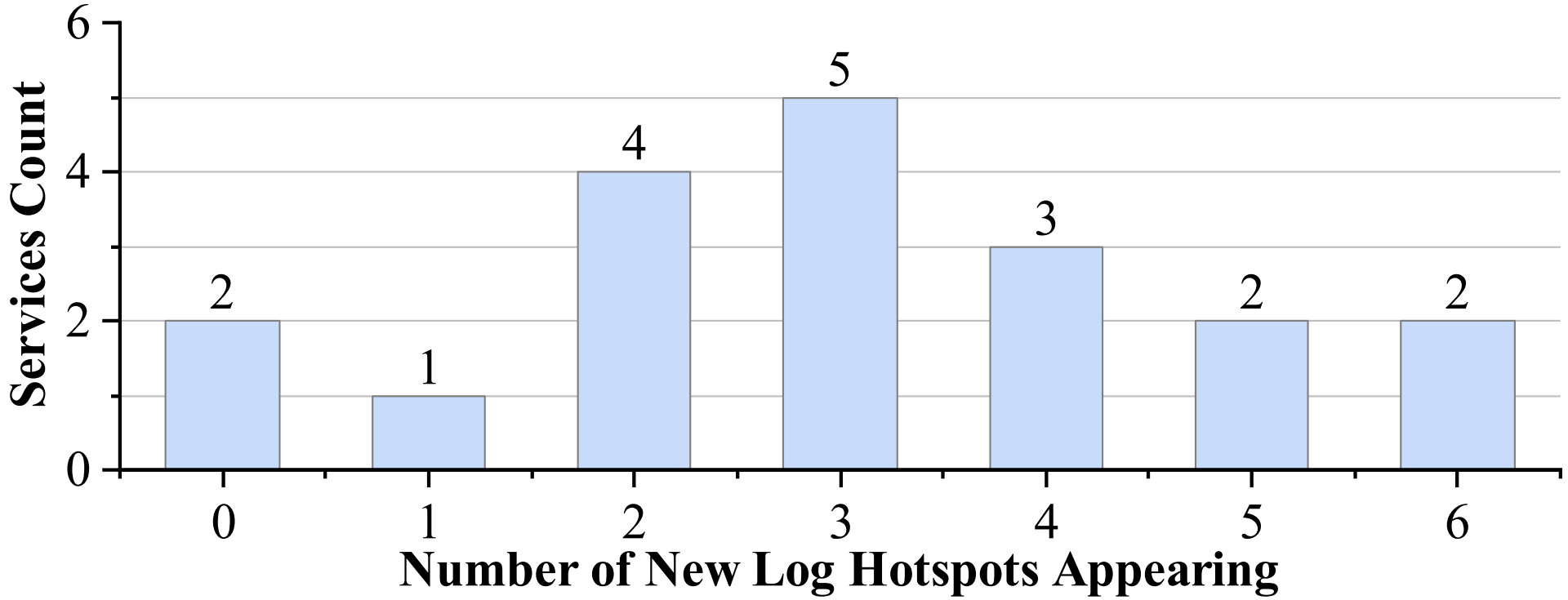
LogReducer Online Process

- Limitation of offline process
  - Fixing log hotspots **takes a long time**
    - ✓ Developers need **an average of 9 days** to fix log hotspots
    - ✓ Release new version until next new feature release
    - ✓ Canary change takes a long time
    - ✓ Holiday effect



LogReducer Online Process

- Limitation of offline process
  - Fixing log hotspots takes a long time
  - **New log hotspots appear frequently**



LogReducer Online Process

- Services are affected by log hotspots **until new version is released**
- Can we **avoid influence** of log hotspots before fixing them?

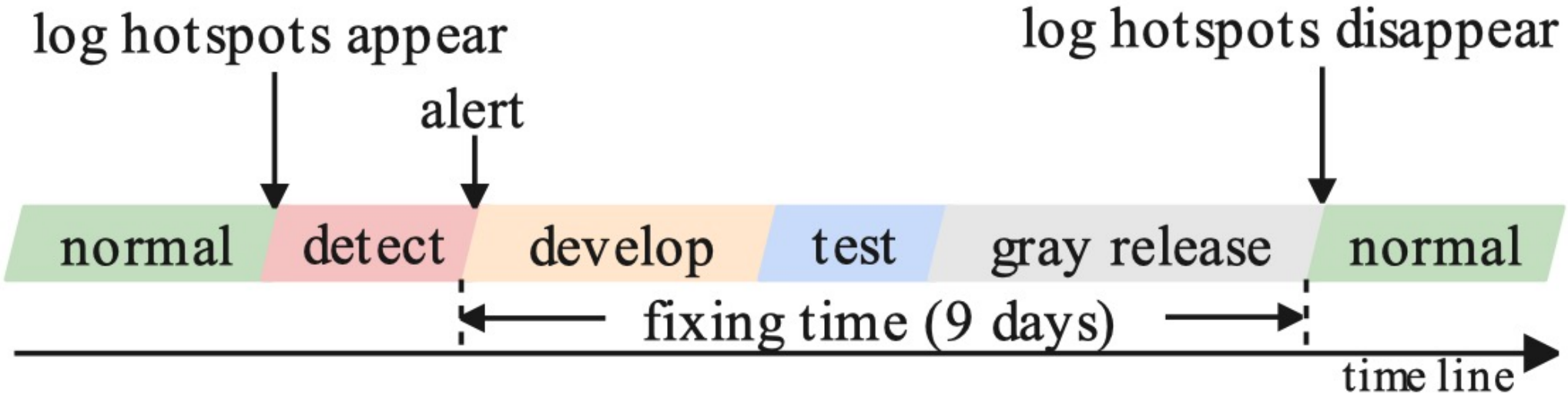
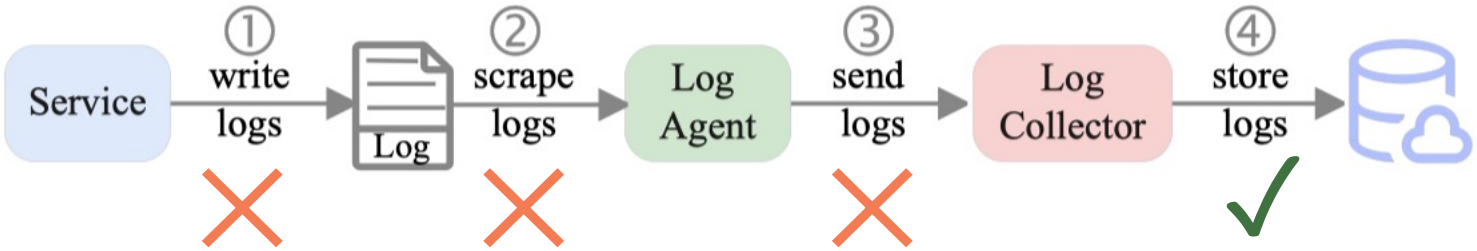


Fig. 2. Process of log hotspot identification and reduction.

LogReducer Online Process

- Can we avoid the impact of log hotspots before fixing them?
  - Filter log hotspots in **log collector**
    - Reduce storage costs
    - **Cannot reduce printing overhead**
    - **Cannot reduce network transmission overhead**



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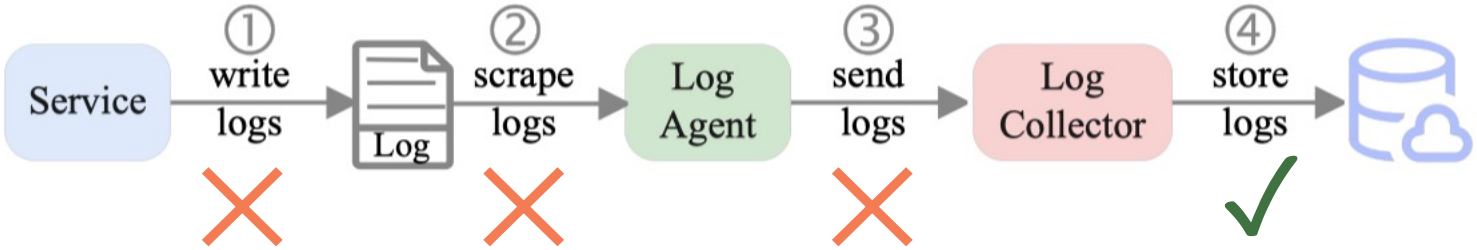
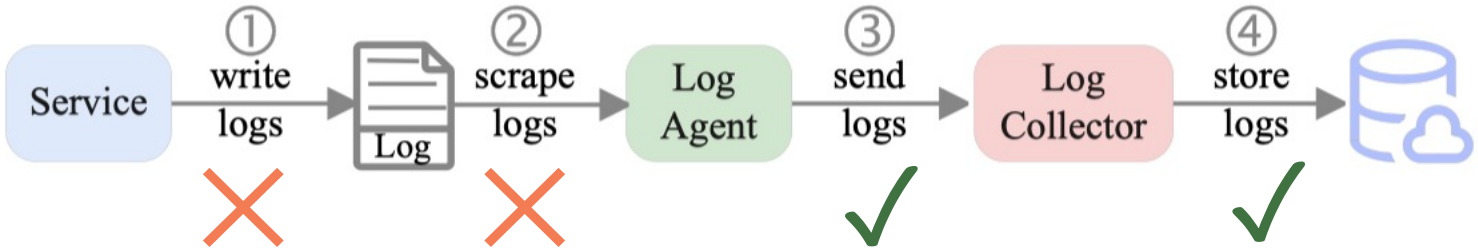


LogReducer Online Process

- Can we avoid the impact of log hotspots before fixing them?
  - Filter log hotspots in log collector
  - Filter log hotspots in **log agent**
    - Filter logs by configuring log agent
    - Reduce storage costs
    - Reduce network transmission overhead
    - **Cannot reduce printing overhead**
    - **Inefficient matching logs in user space**

```
output.elasticsearch:
  hosts: ['host:port']
  username: user
  password: pwd
  indices:
    - index: "filebeat-log-%{+yyyyMMdd}"
      when.regexp:
          msg: "foo.*"
```

Regular expression of log in Filebeat



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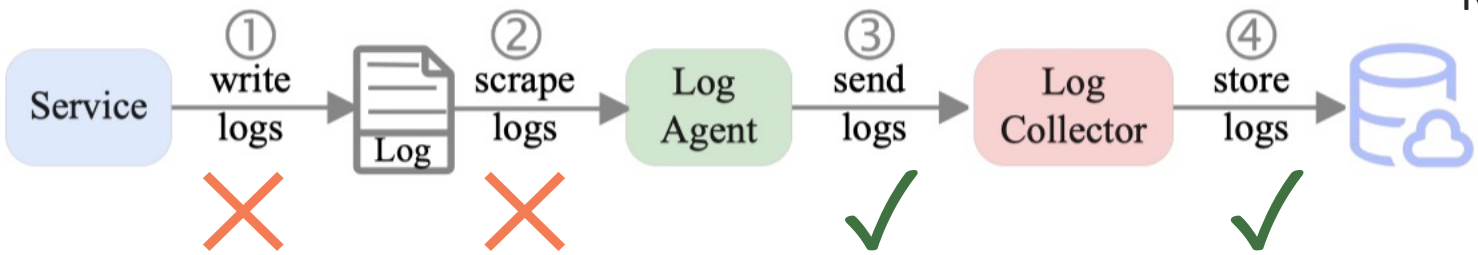
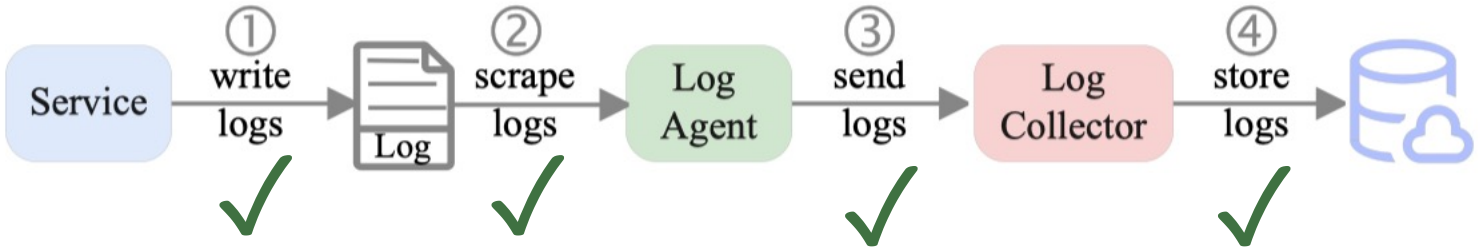


LogReducer Online Process

- Can we reduce the impact of log hotspots before fixing them?
  - Filter log hotspots in log collector
  - Filter log hotspots in log agent
  - Filter log hotspots **in the Linux kernel**
    - Reduce **storage costs and network transmission overhead**
    - Reduce **printing overhead**
    - **Reduce user and kernel switching, efficient kernel matching of logs**
    - **Non-intrusive, programming language independent**



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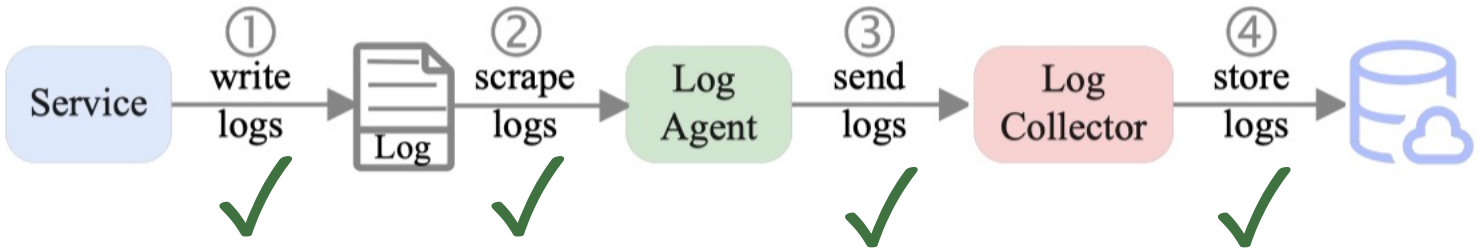
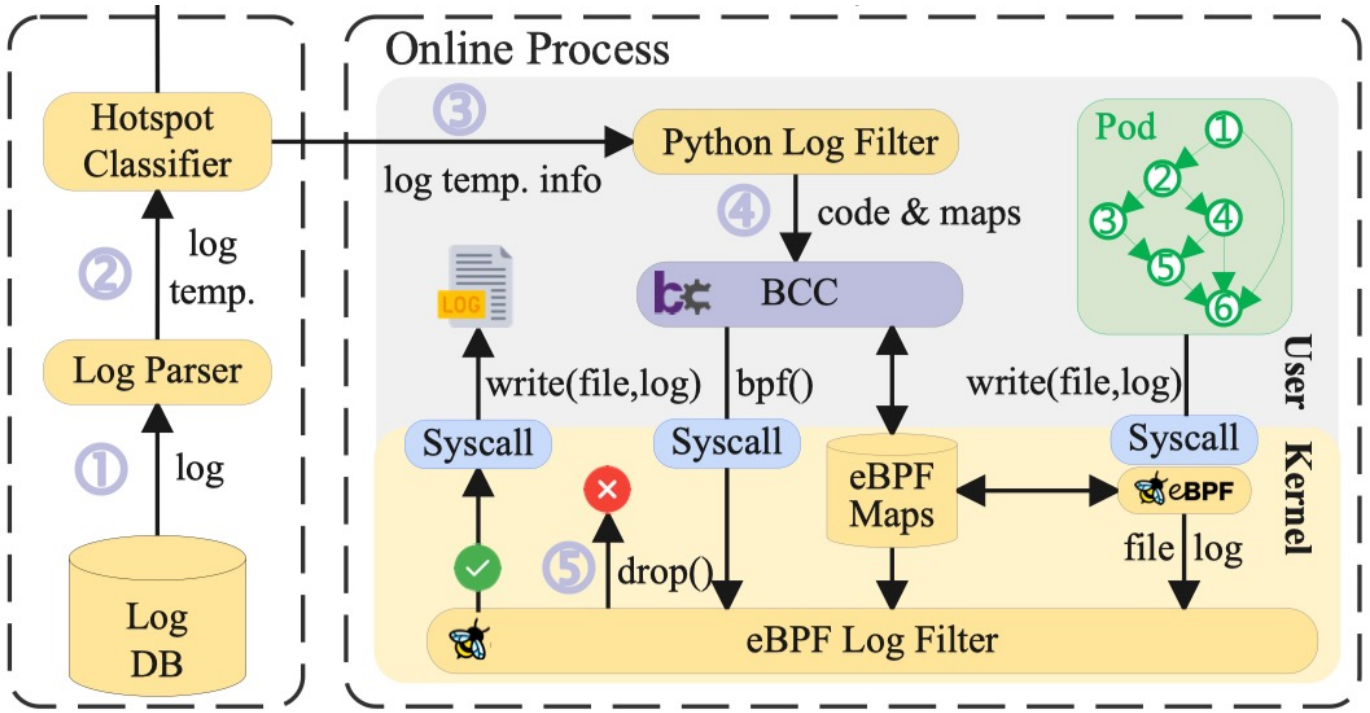


LogReducer Online Process

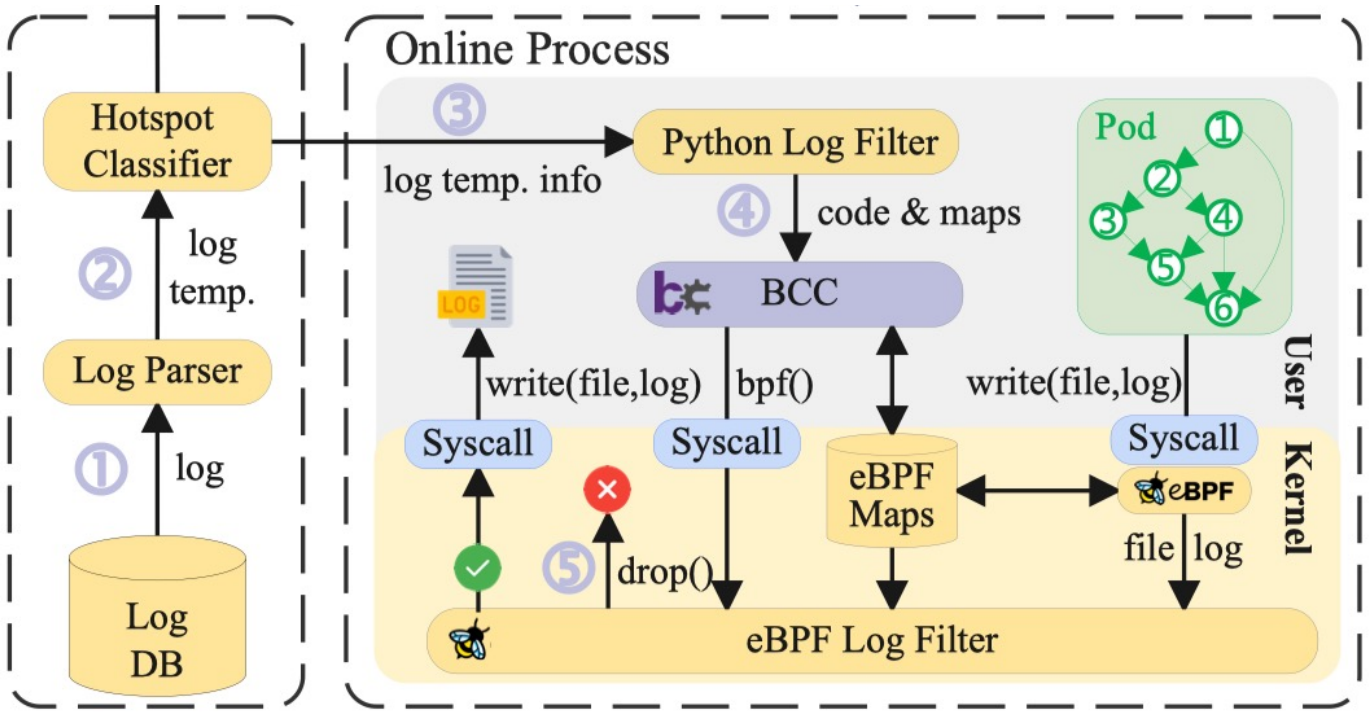
- Online Log Filter: **filter log hotspots in the Linux kernel with with extended Berkeley Packet Filter (eBPF)**

  ③ *Hotspot Classifier* triggers Online Log Filter



LogReducer Online Process

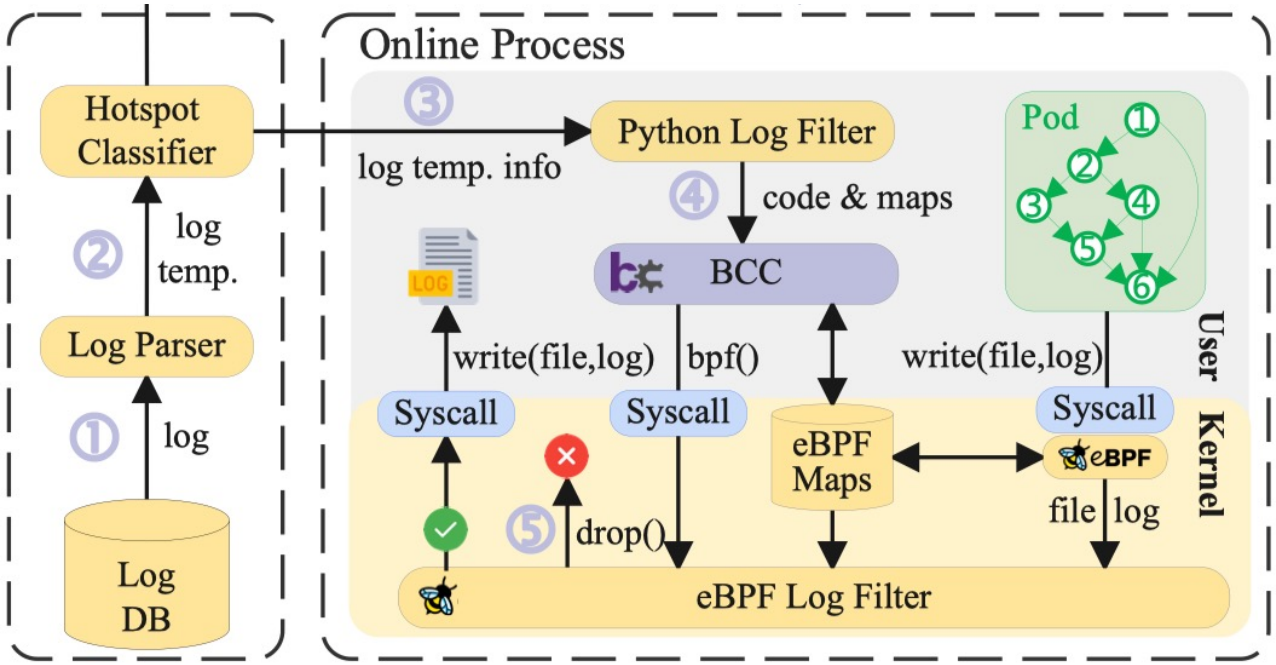
- Online Log Filter: **filter log hotspots in the Linux kernel with eBPF**
  - ③ *Hotspot Classifier* triggers Online Log Filter
  - ④ *Python Log Filter* loads **eBPF code and log signature** into kernel space



LogReducer Online Process

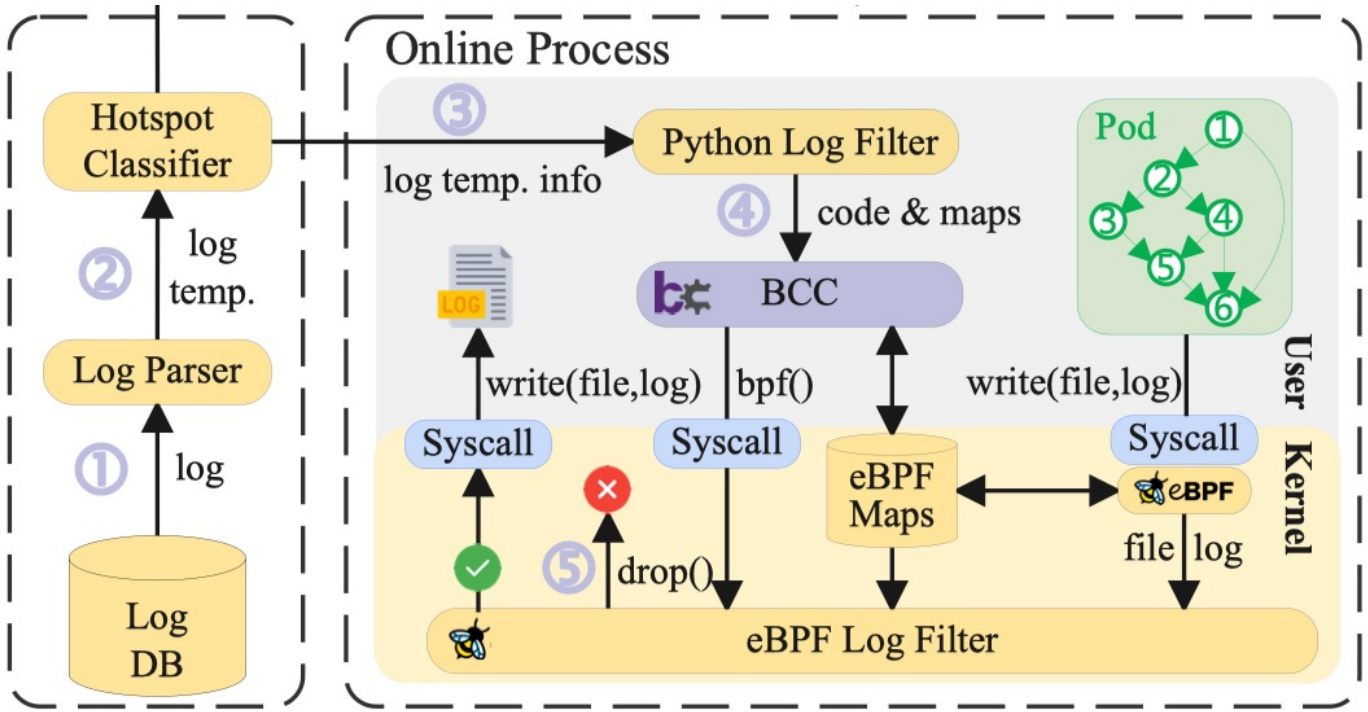
- Online Log Filter: **filter log hotspots in the Linux kernel with eBPF**
  - ③ *Hotspot Classifier* triggers Online Log Filter
  - ④ *Python Log Filter* loads eBPF code and log hotspots into kernel space
  - ⑤ *eBPF Log Filter* **intercepts sys_write() syscall, matches log signature** and **drops log hotspots** in the kernel

Log signature: [s1.cpp:6]	
11:45:00 [s1.cpp:6] Hello world	**drop**
11:45:00 [s1.cpp:2] Hello Melbourne	**write**
11:45:00 [s1.cpp:6] Hello world	**drop**



LogReducer Online Process

- Online Log Filter implementation [1]
  - Python 3.6 and BCC 0.24
  - Linux Kernel v5.4
  - CONFIG_BPF_KPROBE_OVERRIDE = y
- Benchmark design
  - Golang (go.uber.org/zap)
  - Python (nb_log)
  - Java (log4j2)
  - C++ (log4cplus)
- Overhead Measure
  - bpftool-prog



1 https://github.com/IntelligentDDS/LogReducer

LogReducer Online Process Result

- The overhead for Log Filter under different log volumes

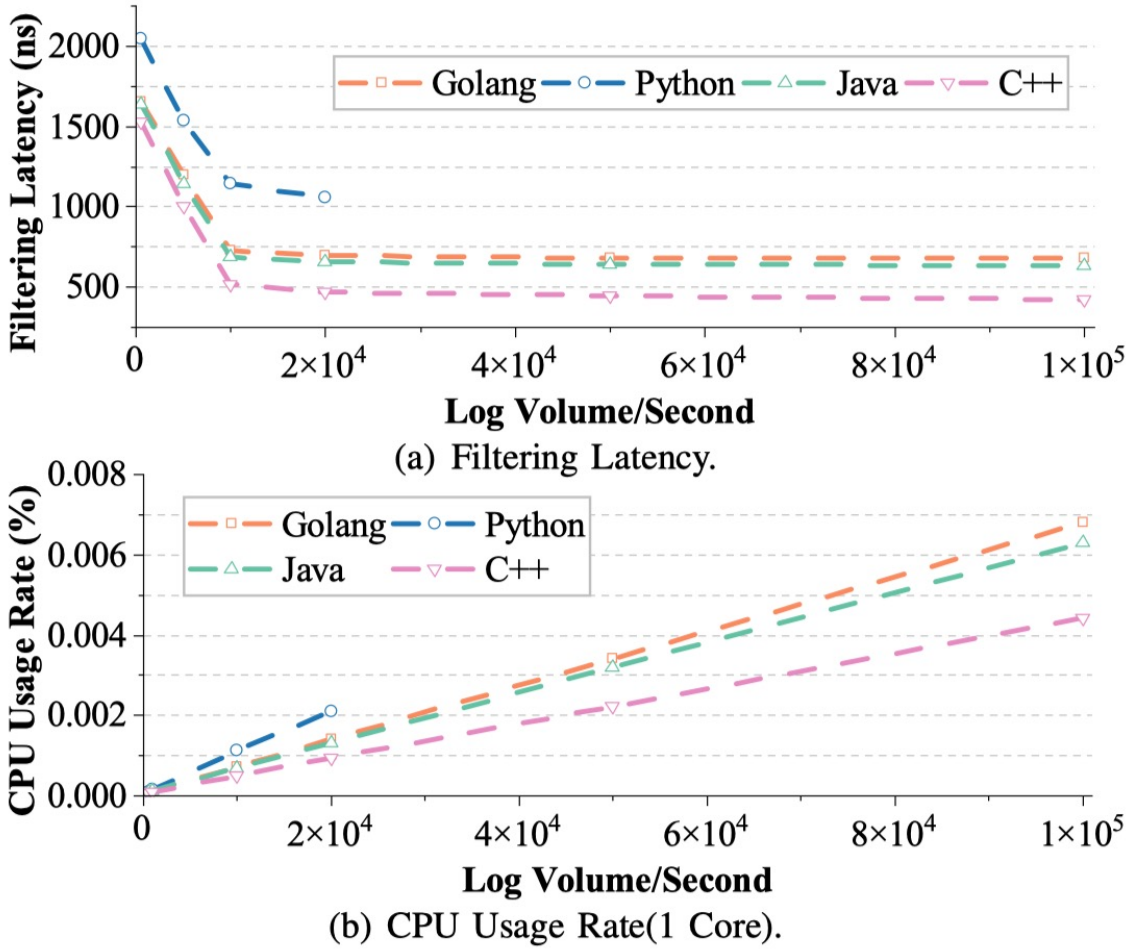
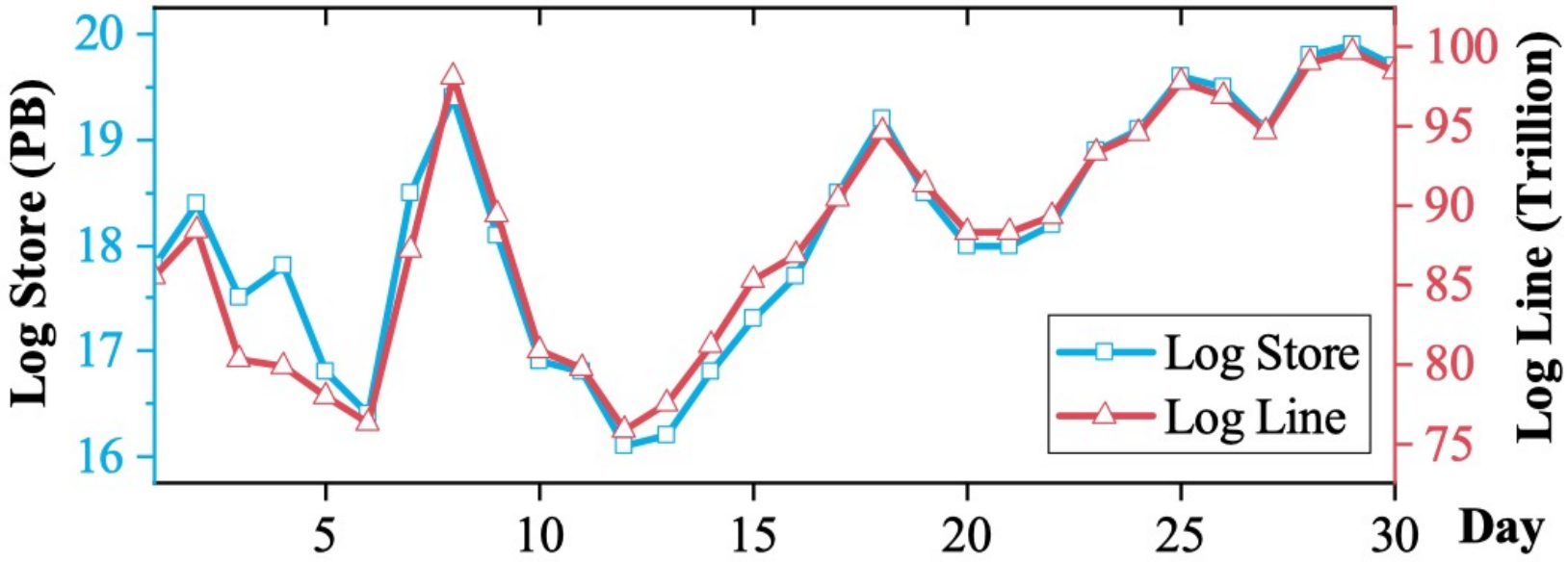


Fig. 14. The overhead for Log Filter in *LogReducer* when filtering log hotspots in kernel under different log volumes of 20 chars per log length.

- ✓ **Increase latency by about 500 nanoseconds when filtering 100,000 logs per second**
- ✓ **Consume 0.008% additional CPU utilization of 1 CPU core**

Conclusion

- Logs is one of the “Three Pillars of Observability”
- Excessive logging is a double-edged sword
  - **High storage cost**
  - **Huge performance overhead**
  - **Difficult to troubleshoot**



Conclusion

- Logs is one of the "Three Pillars of Observability"
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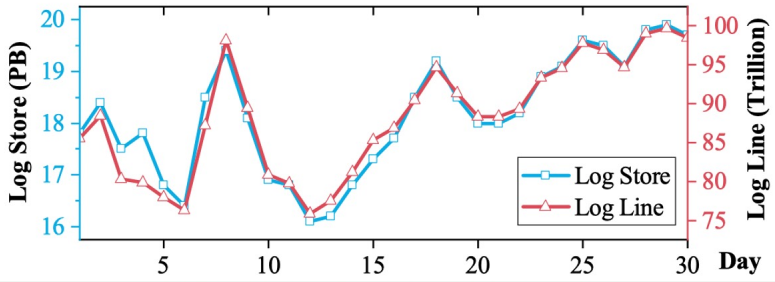

Conclusion

- Research Object
  - WeChat is a large real-world instant messaging system serving billions of users
  - **Top 20 services** with the highest log storage in WeChat
  - **57 log hotspots** and interviewed 19 corresponding service owners
- Research Questions
  - RQ1: How do log hotspots impact **application storage**?
  - RQ2: How do log hotspots impact **application runtime**?
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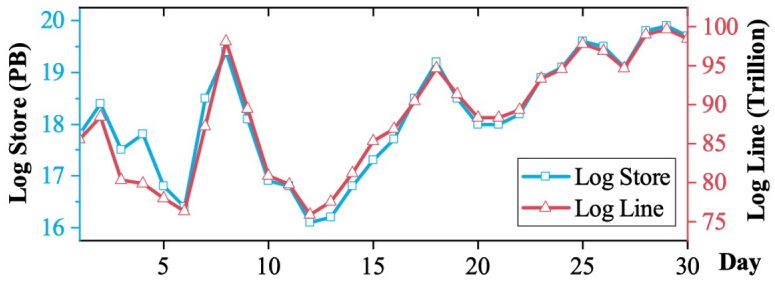

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- We applied LogReducer offline process in WeChat since April 14, 2022
- Log storage in WeChat dropped from **19.7 PB to 12.0 PB** per day

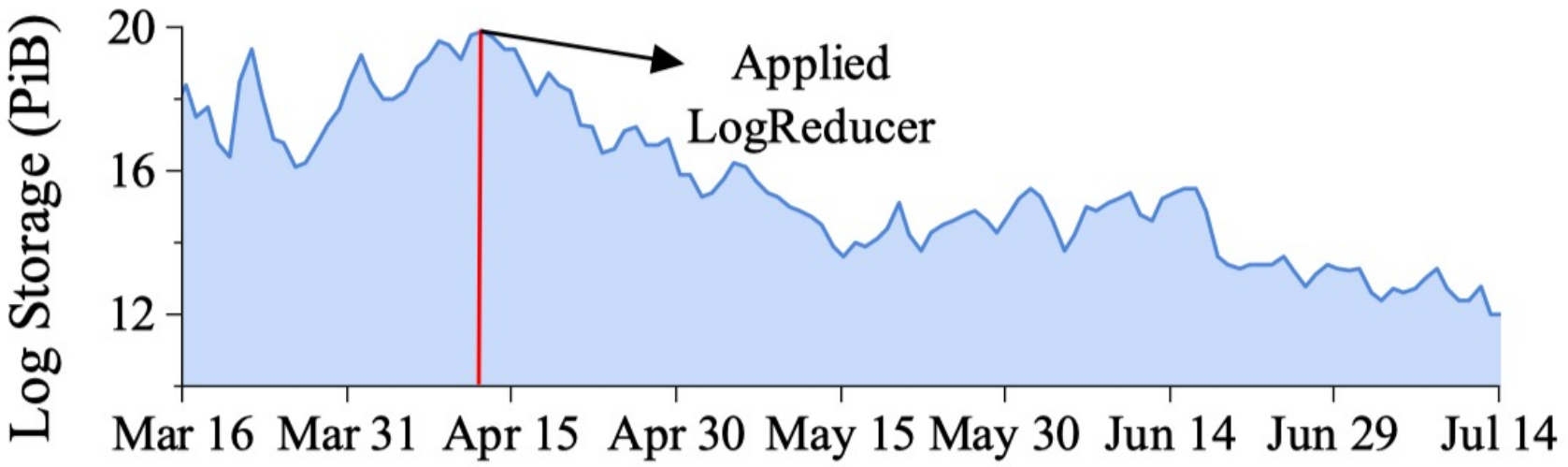

Fig. 17. Changes in the log storage of WeChat from Mar 16 to Jul 14 in 2022.

39.08% decrease

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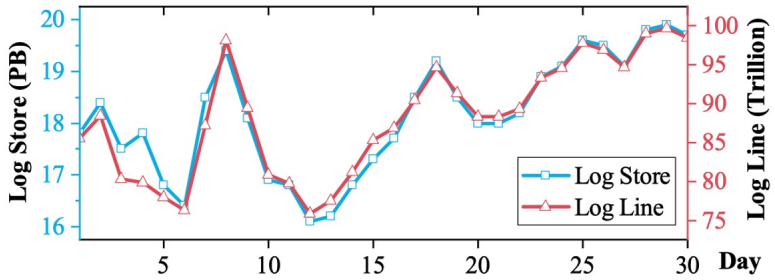

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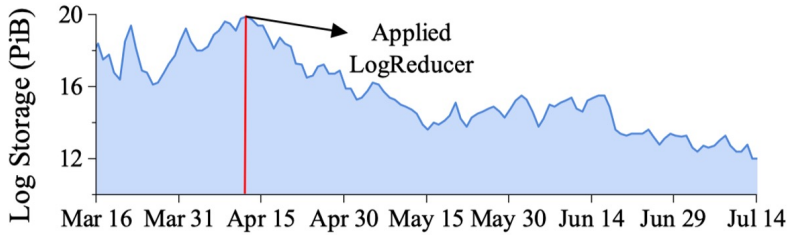

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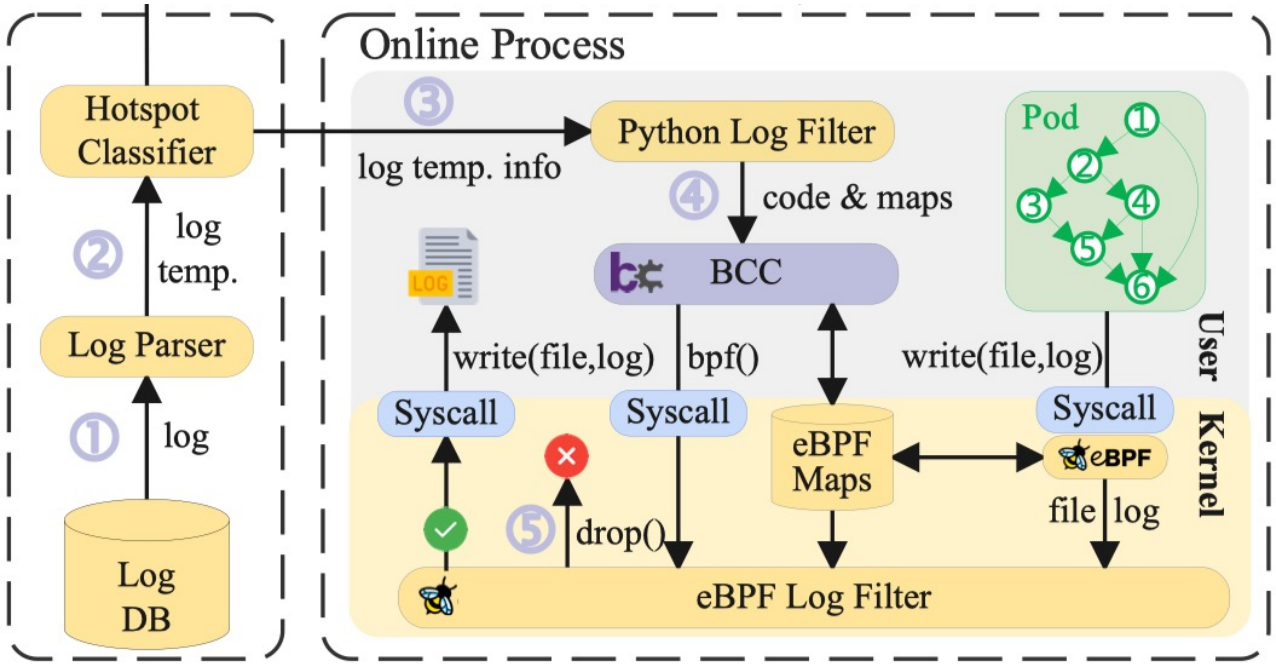
- Online Log Filter: **filter log hotspots in the Linux kernel with eBPF**
  - ③ *Hotspot Classifier* triggers Online Log Filter
  - ④ *Python Log Filter* loads eBPF code and log hotspots into kernel space
  - ⑤ *eBPF Log Filter* **intercepts sys_write() syscall, matches log signature** and **drops log hotspots** in the kernel

Log signature: [s1.cpp:6]	
11:45:00 [s1.cpp:6] Hello world	**drop**
11:45:00 [s1.cpp:2] Hello Melbourne	**write**
11:45:00 [s1.cpp:6] Hello world	**drop**



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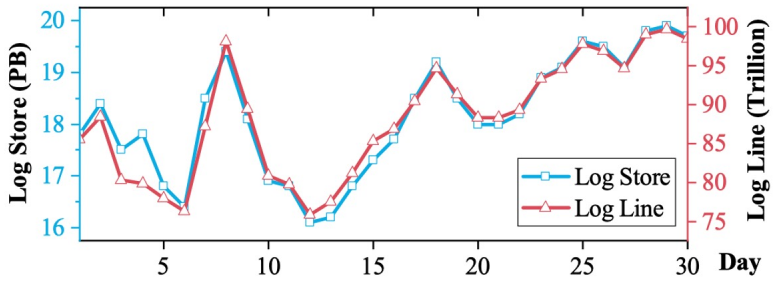

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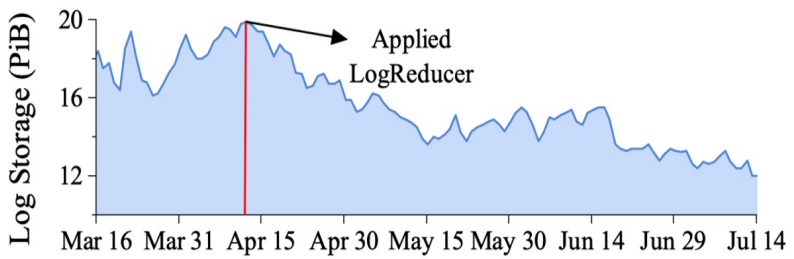

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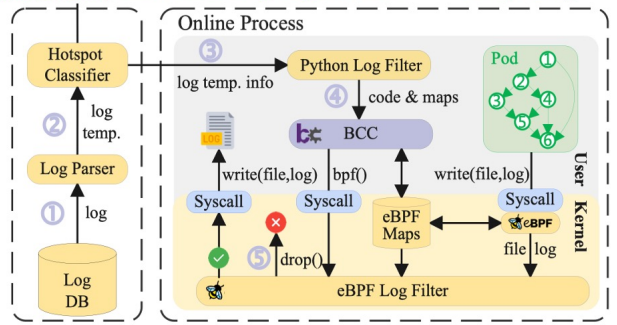

中山大學 SUN YAT-SEN UNIVERSITY

WeChat

ICSE2023

Thank you !

Q & A

Homepage

WeChat Official Accounts

https://yuxiaoba.github.io
yugb5@mail2.sysu.edu.cn
https://github.com/IntelligentDDS/LogReducer

Supplementary

- RQ3: What are the **root causes** of log hotspots?
  - We interview developers to obtain **root causes** and summarized their type

TABLE I
STATISTICS OF ROOT CAUSE FOR LOG HOTSPOTS.

Root Cause \ Metric	Distribution		Fixing Time(day)		
	Count	%	Mean	Std	Med
Incorrect Log Level	**23**	**40.35**	10.91	**11.28**	5
Forgotten Test Log	13	22.8	4.76	1.87	4
Dependent Module Fault	6	10.5	2.83	0.408	3
Dependent Package Log	5	8.77	3	0	3
Incorrect Log Dye	4	7.01	**41**	0	**41**
Reasonable Hotspot	3	5.26	5	2.0	5
Self-Module Fault	2	3.5	2	1.41	2
Others	1	1.75	3	0	3
Total	57	100	9.31	11.83	3

- ✓ **Incorrect Log Level (40.3%)**
- ✓ **Forgotten Test Log (22.8%)**
- ✓ **Dependent Fault (10.5%)**
- ✓ **Dependent Package Log (8%)**

Supplementary

- RQ4: What are the **fixing solutions** of log hotspots?
  - We interview developers to obtain **fixing solutions** and summarized their type

TABLE II
STATISTICS OF ROOT CAUSE FOR LOG HOTSPOTS.

Root Cause \ Metric	Distribution		Fixing Time(day)		
	Count	%	Mean	Std	Med
Correct Log Level	**18**	**31.57**	11.77	**12.68**	3
Delete Log Statement	17	29.82	5.76	2.07	7
Fix Module Fault	9	15.78	2.66	0.7	3
Turn on Log Dye	6	10.52	3	0	3
Correct Log Dye	4	7.01	**41**	0	**41**
Merge Log Statement	2	3.5	4	1.41	4
Reduce Log Length	1	1.75	7	0	7
Total	57	100	9.31	11.83	3

- ✓ **Correct Log Level (31.5%)**
- ✓ **Delete Log Statement (29.8%)**
- ✓ **Fix Module Fault (15.7%)**
- ✓ **Turn on Log Dye (10.5%)**

Supplementary

- eBPF can run sandboxed programs in Linux kernel
  - eBPF programs are event-driven and are run when the kernel passes a certain hook point