PreFix: Switch Failure Prediction in Datacenter Networks

Sen Yang[4]

Joint work with

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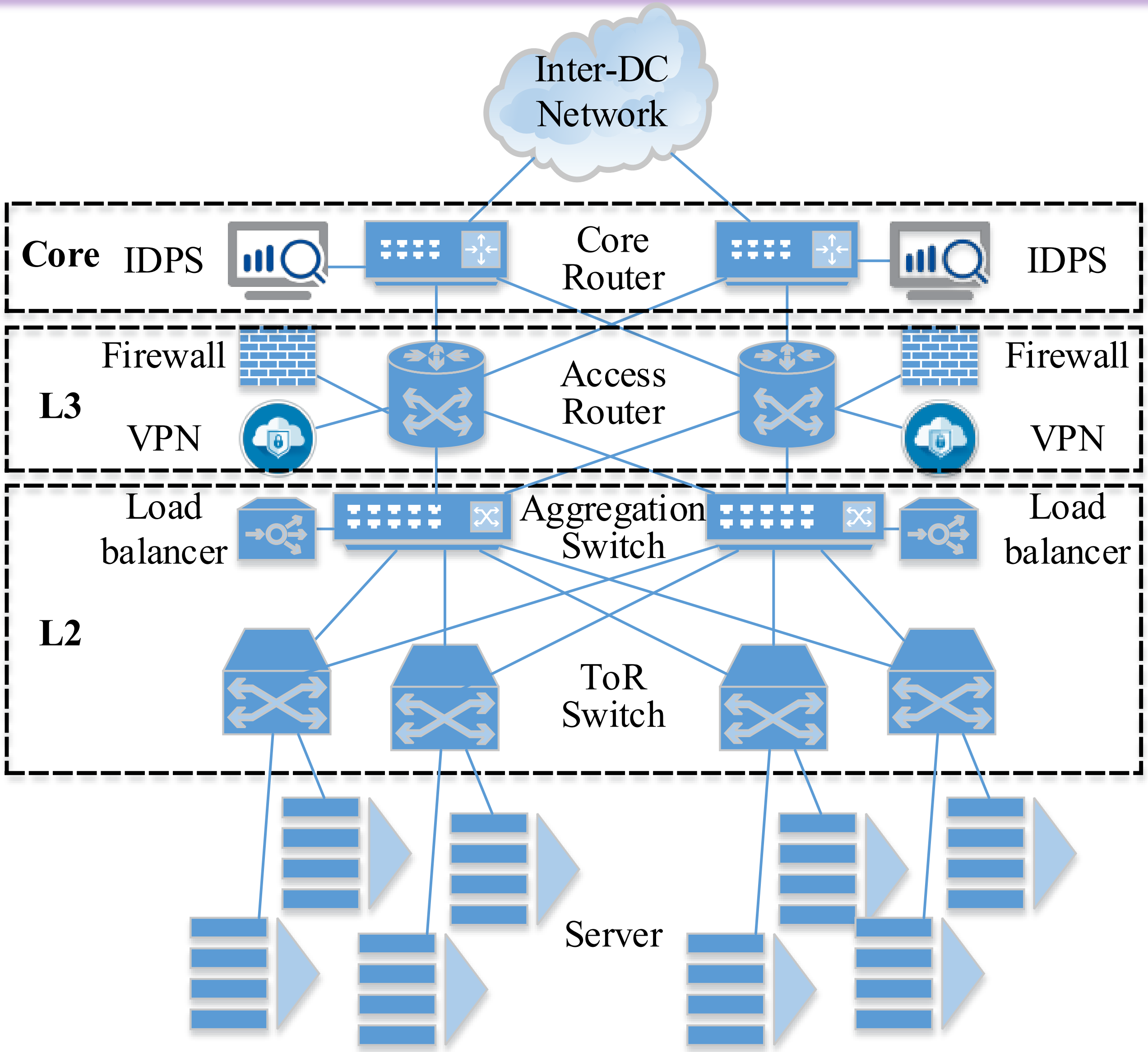
Network Devices in Data Center Networks



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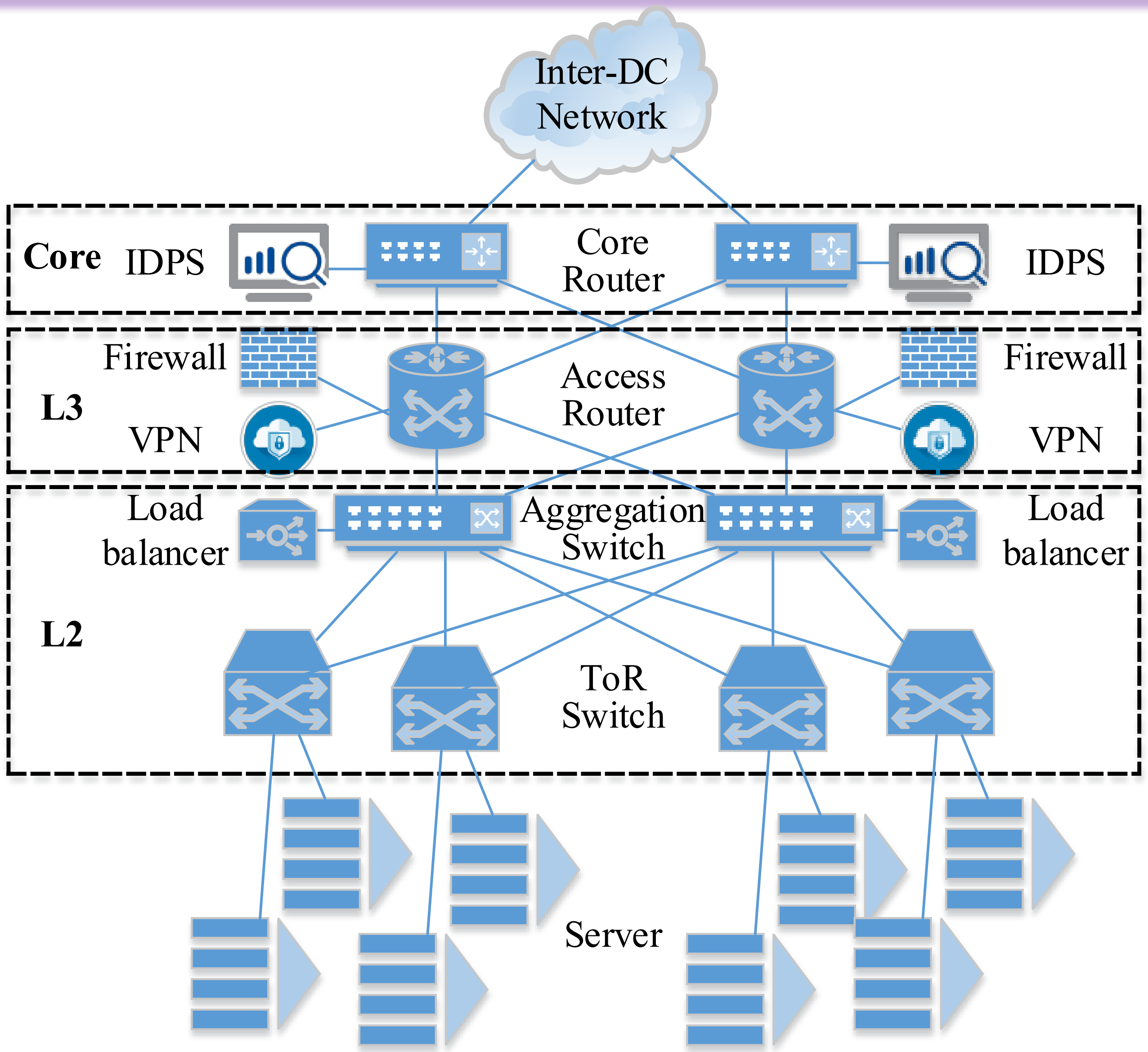

- Switch
  - Top-of-rack switch
  - Aggregation switch
- Router
  - Access router
  - Core router
- Middle box
  - Firewall
  - Intrusion detection and prevention system (IDPS)
  - Load balancer
  - VPN

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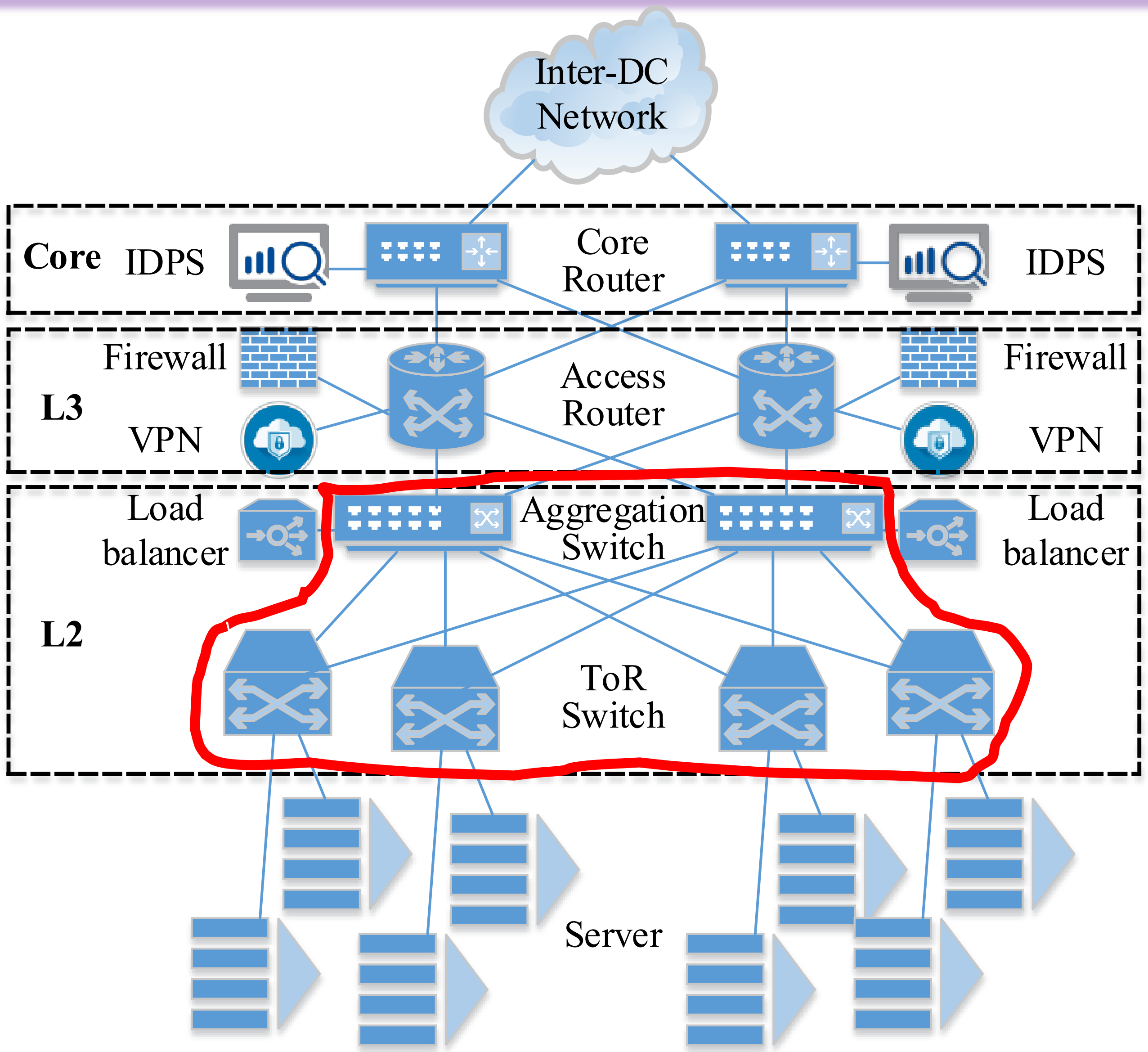

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Scale of Network Devices in Datacenter

Microsoft (C. Guo, et al., SIGCOMM'15)	• Hundreds of thousands to millions of servers • Hundreds of thousands of switches • Millions of cables and fibers

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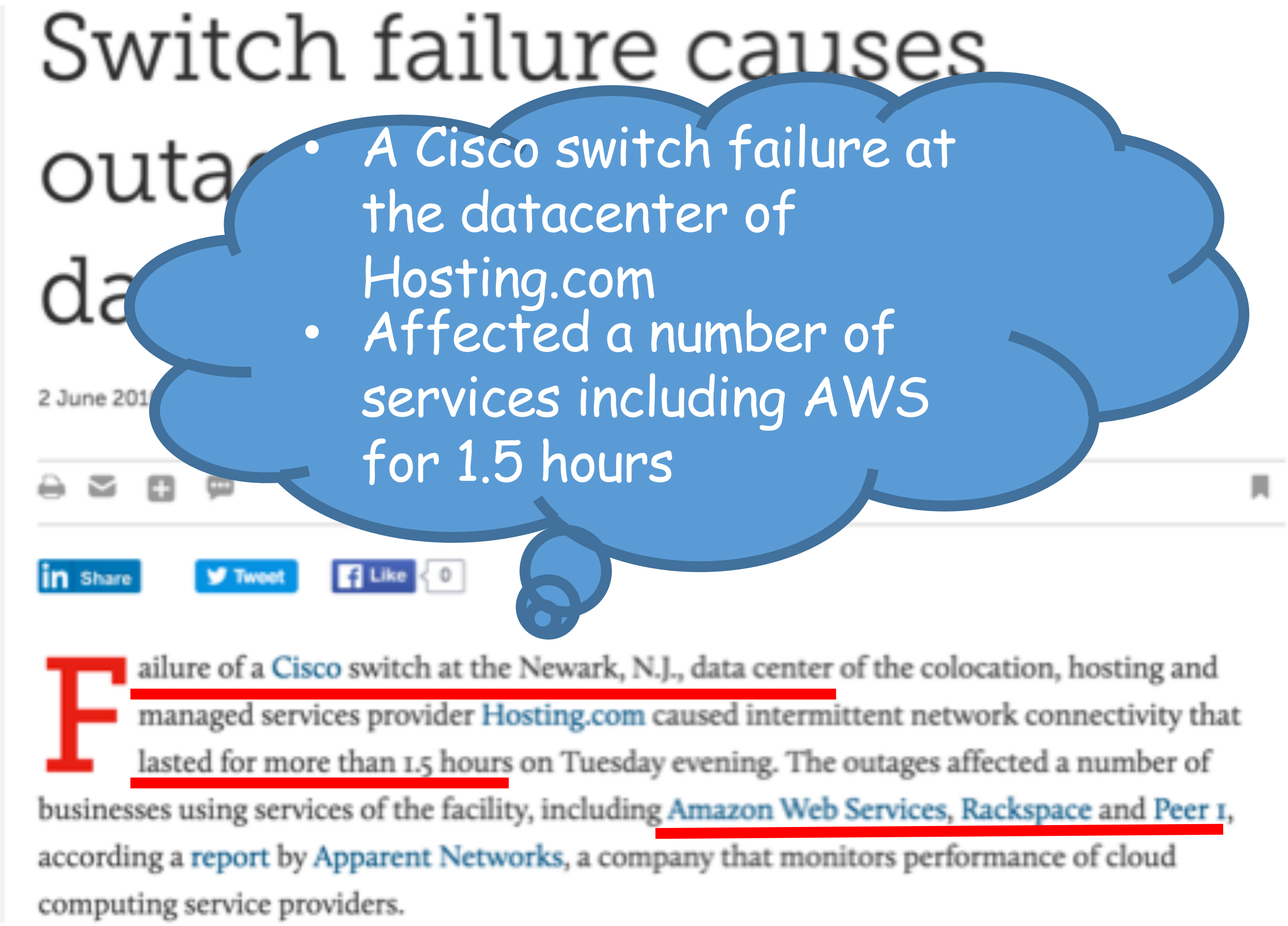
Baidu	• Hundreds of thousands of servers • Tens of thousands of switches
Swich failures are the norm rather than the exception (P. Gill, et al., SIGCOMM'11)	• More than 400 switch failures per year

Switch Failures Lead to Outages


Switch failure causes outa… da…

2 June 201…

Failure of a Cisco switch at the Newark, N.J., data center of the colocation, hosting and managed services provider Hosting.com caused intermittent network connectivity that lasted for more than 1.5 hours on Tuesday evening. The outages affected a number of businesses using services of the facility, including Amazon Web Services, Rackspace and Peer 1, according a report by Apparent Networks, a company that monitors performance of cloud computing service providers.

- A Cisco switch failure at the datacenter of Hosting.com
- Affected a number of services including AWS for 1.5 hours

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Switch failure shuts down computer network at data center

AP By The Associated Press
May 24, 2016 8:49 am

CHESTER, Va. (AP) — The computer network of a data center in Chester went dark after a switch failure.

The Richmond Times-Dispatch (http://bit.ly/20v8U5T) reports that Saturday's outage at the Commonwealth Enterprise Solutions Center affected access to the network by almost every executive br…ch agency the center serves, including the Department of Motor Vehicles.

Email, cellphones and agen… …puter servers in th… …ing outage for inbound and outbound … …the DMV…

- The datacenter network went dark after a switch failure
- Almost every executive branch agency are affected for a few hours

Switch Failure

- "An event that occurs when the switch is not functioning for forwarding traffic" [1]

[1] Gill, P., Jain, N., & Nagappan, N. Understanding network failures in data centers: measurement, analysis, and implications. *ACM SIGCOMM 2011.*

Switch Failure

Observable[1]

- A human
- A server
- Another network device
- If not result in incorrect output, it is not a failure

[1] Salfner, F., Lenk, M., & Malek, M. (2010). A survey of online failure prediction methods. *ACM Computing Surveys (CSUR)*, *42*(3), 10.

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Failure tickets

- Regular expression match with syslogs
- Feedback by Internet services
- Monitoring results of interfaces

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Previous Proposed Solutions

Change the protocols and network topologies

- Aim to automatically failover
- ToR switches do not have hot backups

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Change the protocols and network topologies

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Locate and diagnose failed switches

- Face deployment challenges
- Take time to locate and fix the failed switches
- Drop packets silently and affect services[1]

[1] Guo, C., et al. Pingmesh: A large-scale system for data center network latency measurement and analysis. *ACM SIGCOMM 2015*.

Failure Prediction for Switches

- During runtime
- Near future
- Based on the monitored current switch state
- Mining historical failure cases of switches

Failure Prediction for Switches Based on Syslogs

- Sep 8 15:44:30 192.168.191.85 192.168.191.85 : [SIF]Interface ae3, changed state to down
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Challenges

Noisy signals in syslog data

- Syslogs are highly diverse
  - Across several geographical locations, network layers, protocols, services
  - Normal login events of operators
  - Interface up/downs
  - Failure to send/receive packets
- Rarely contain failure omens

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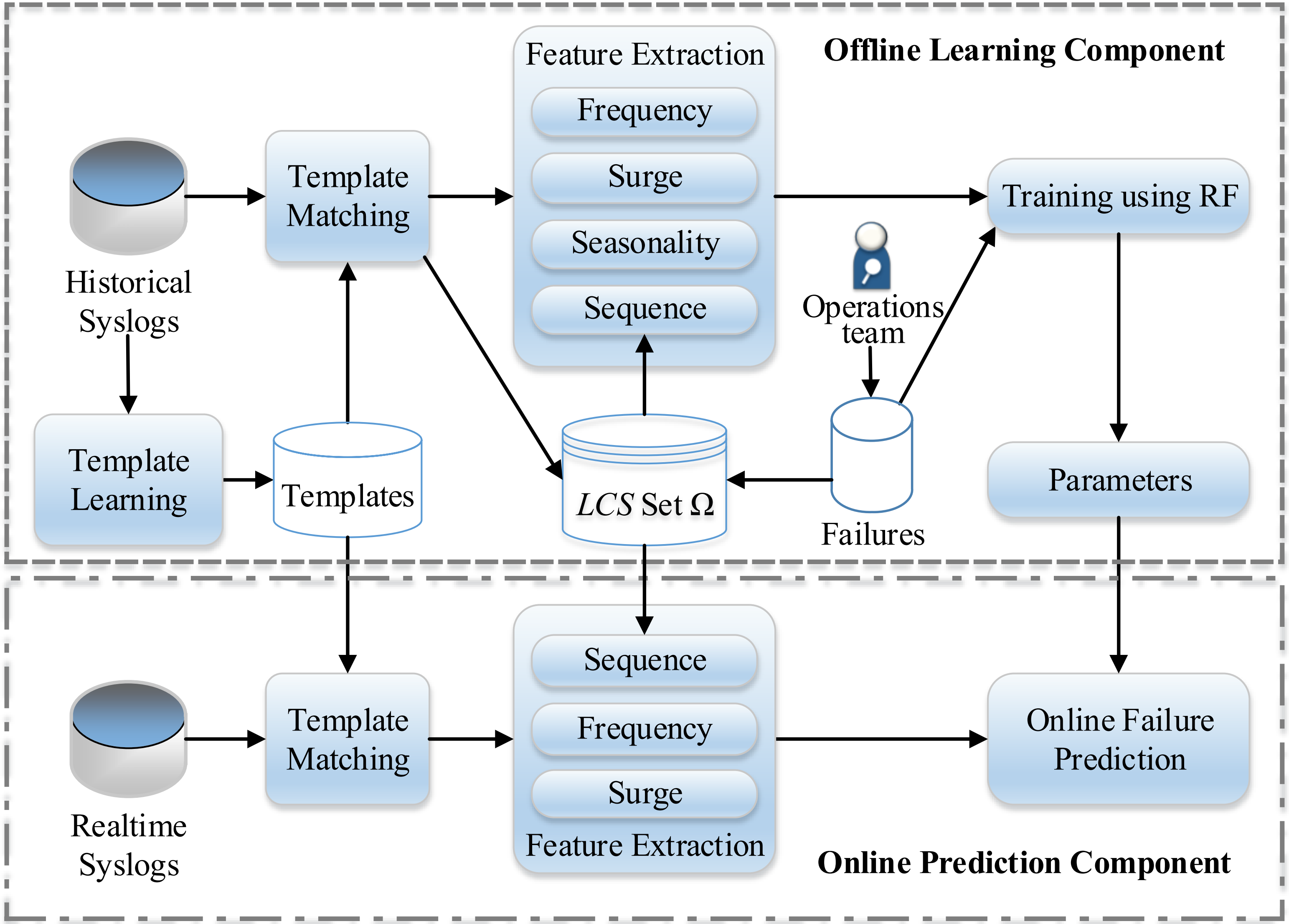
Sample imbalance

- Low failure possibility for a single switch
- Failure omen time bins: failure non-omen time bins =1:72500
- Low false alarms and high recall at the same time

Design Overview



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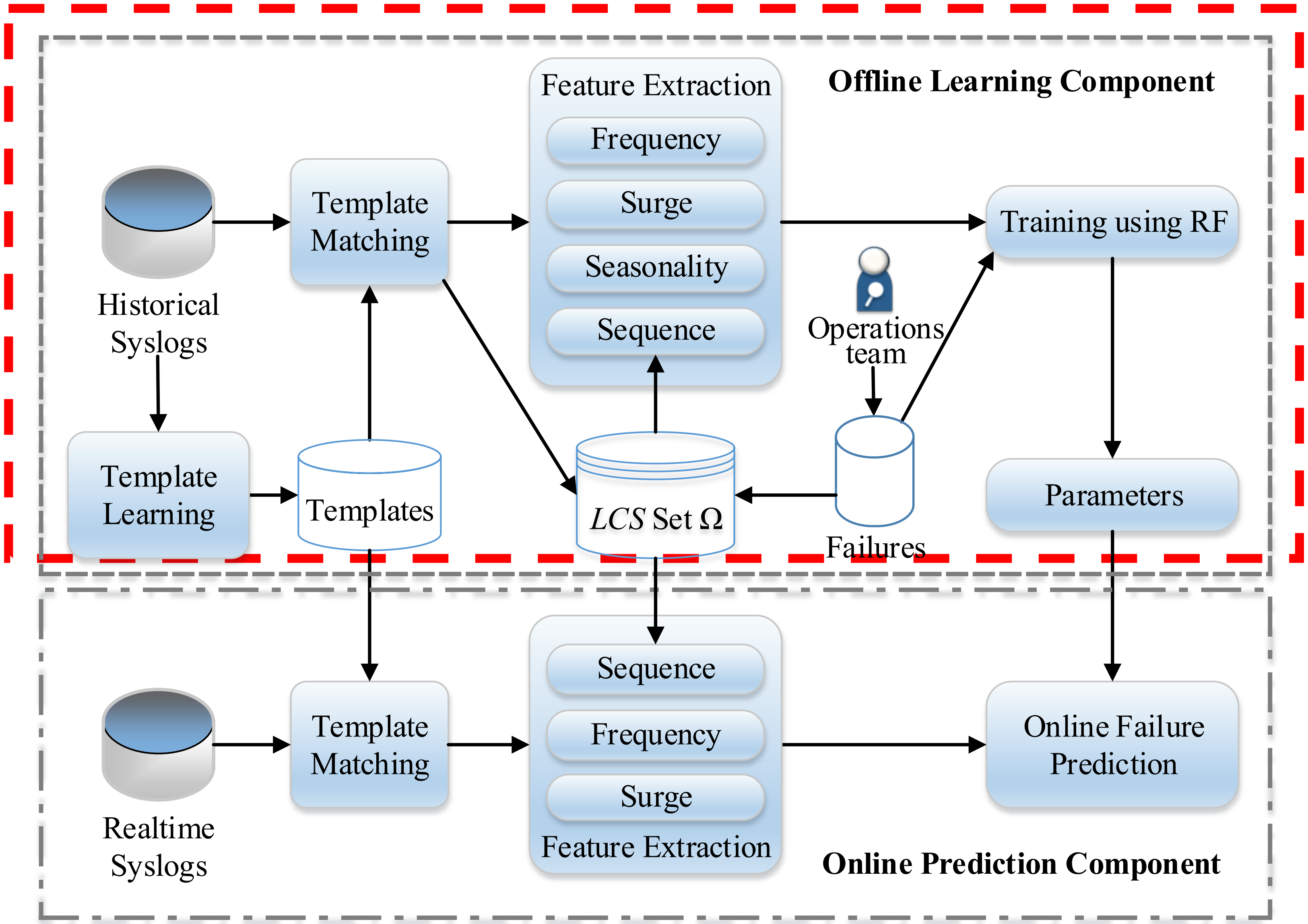

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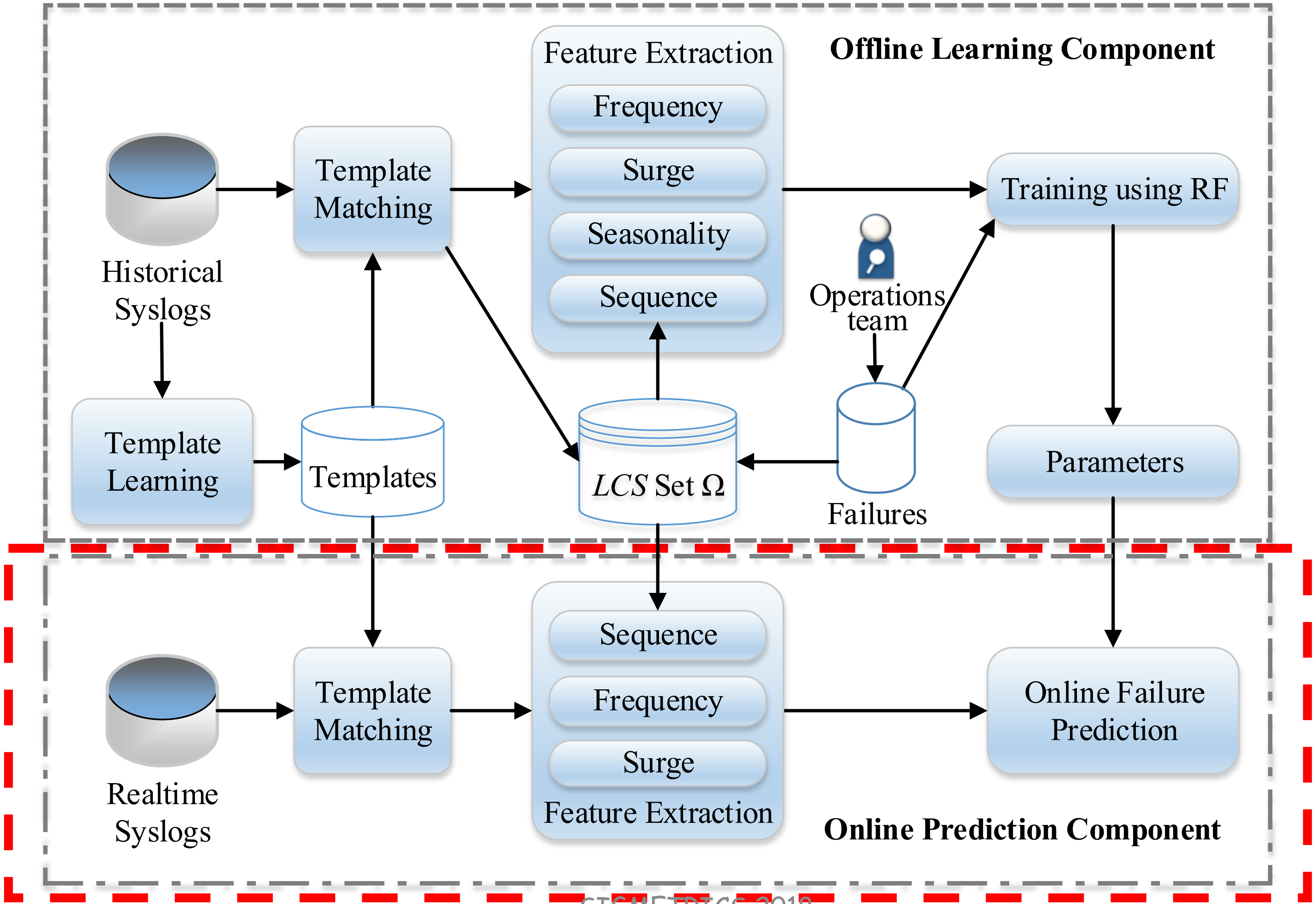
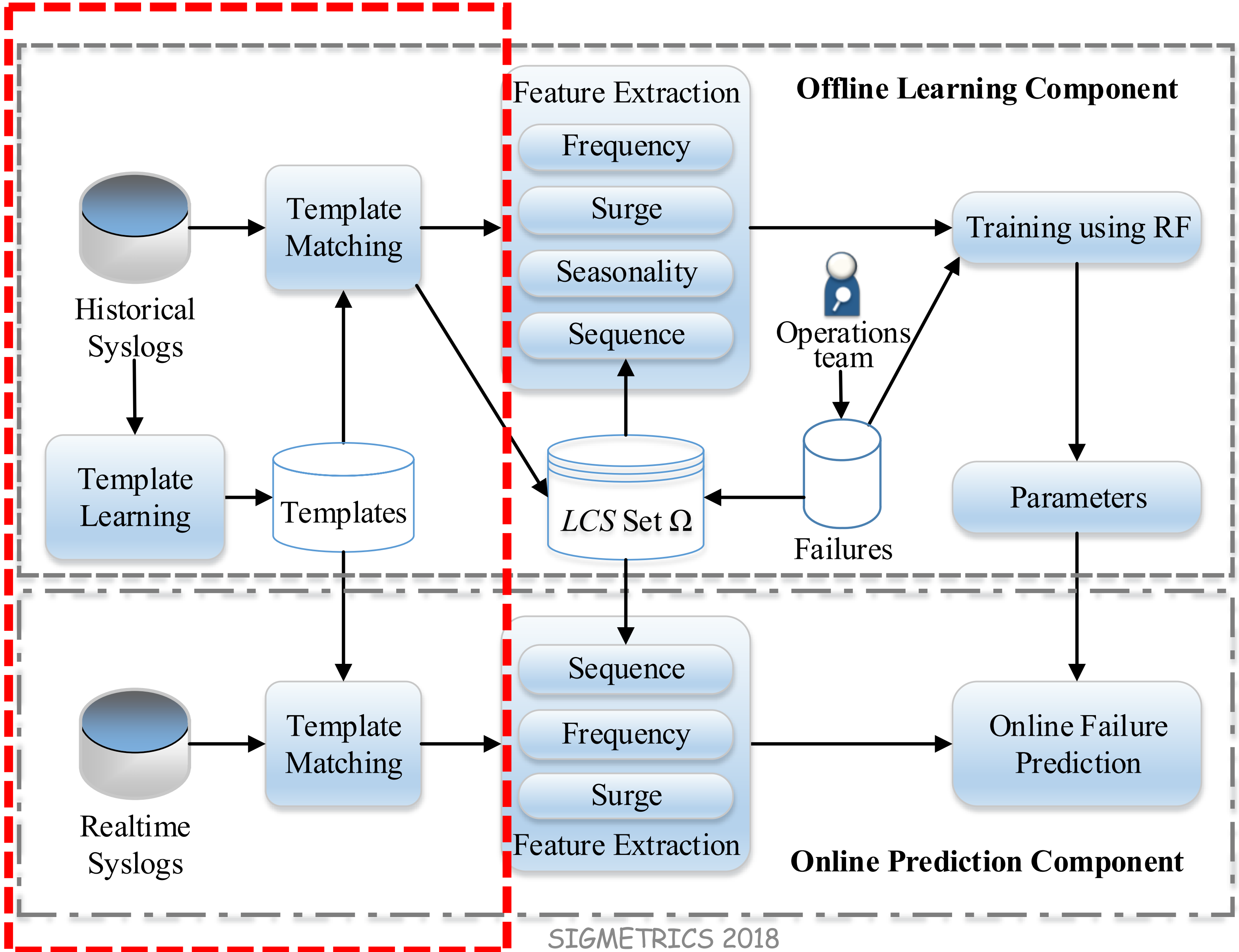


Design Overview

S. Zhang *et al.*, "Syslog processing for switch failure diagnosis and prediction in datacenter networks," IEEE/ACM IWQOS 2017.



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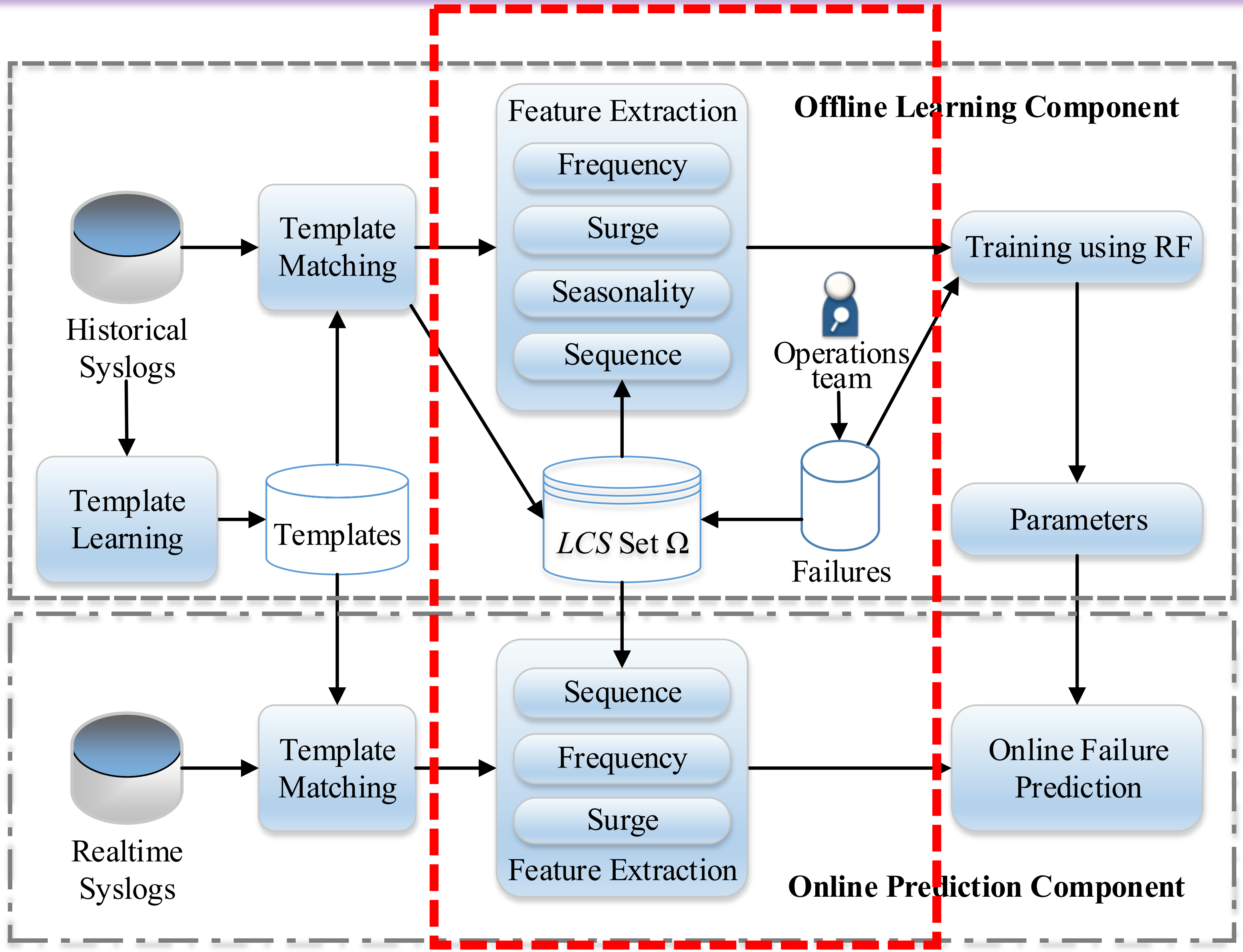

Feature Extraction

Sequence

Several failures share common syslog sequences

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Sequence, Surge → **Failure omens**

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→ **Non-failure omens**

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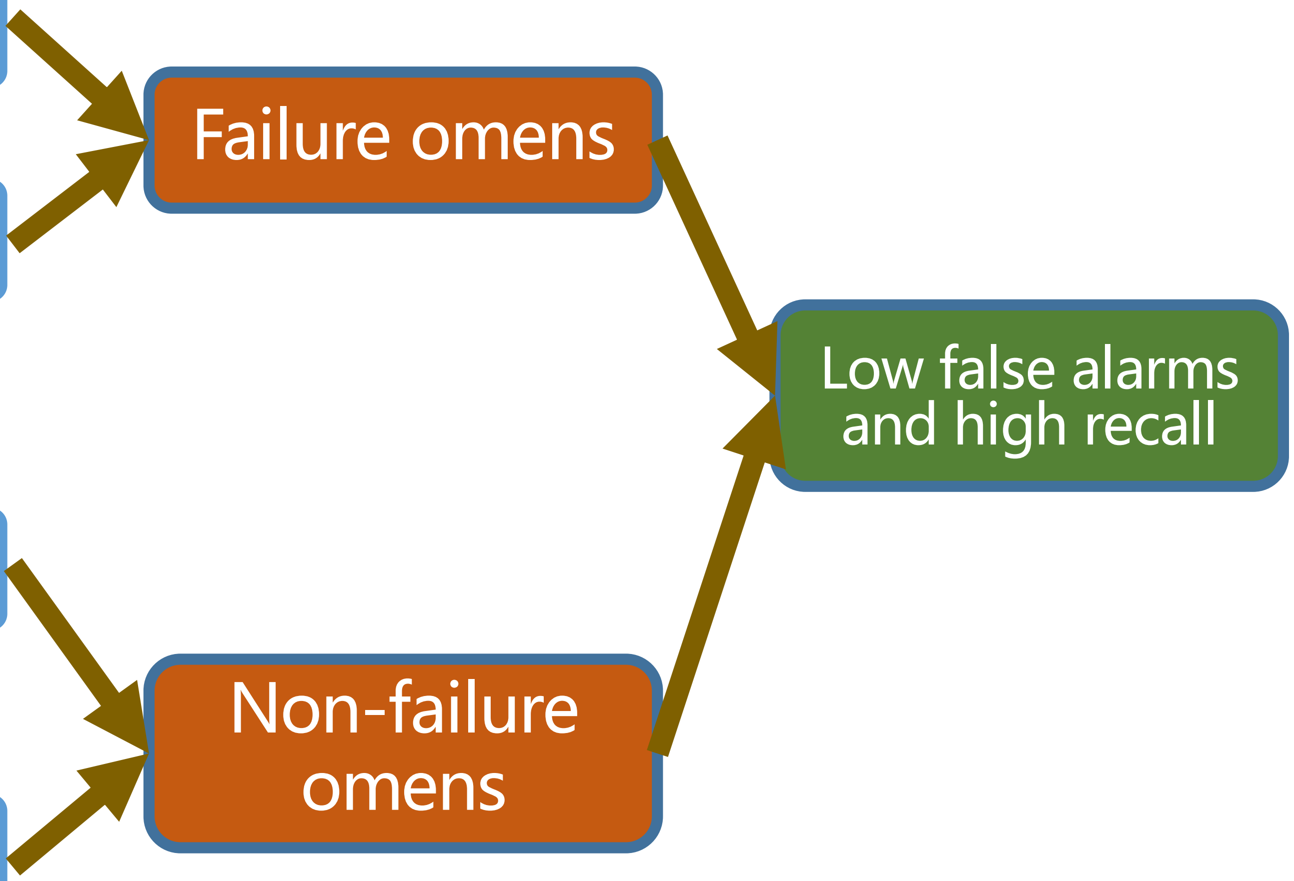

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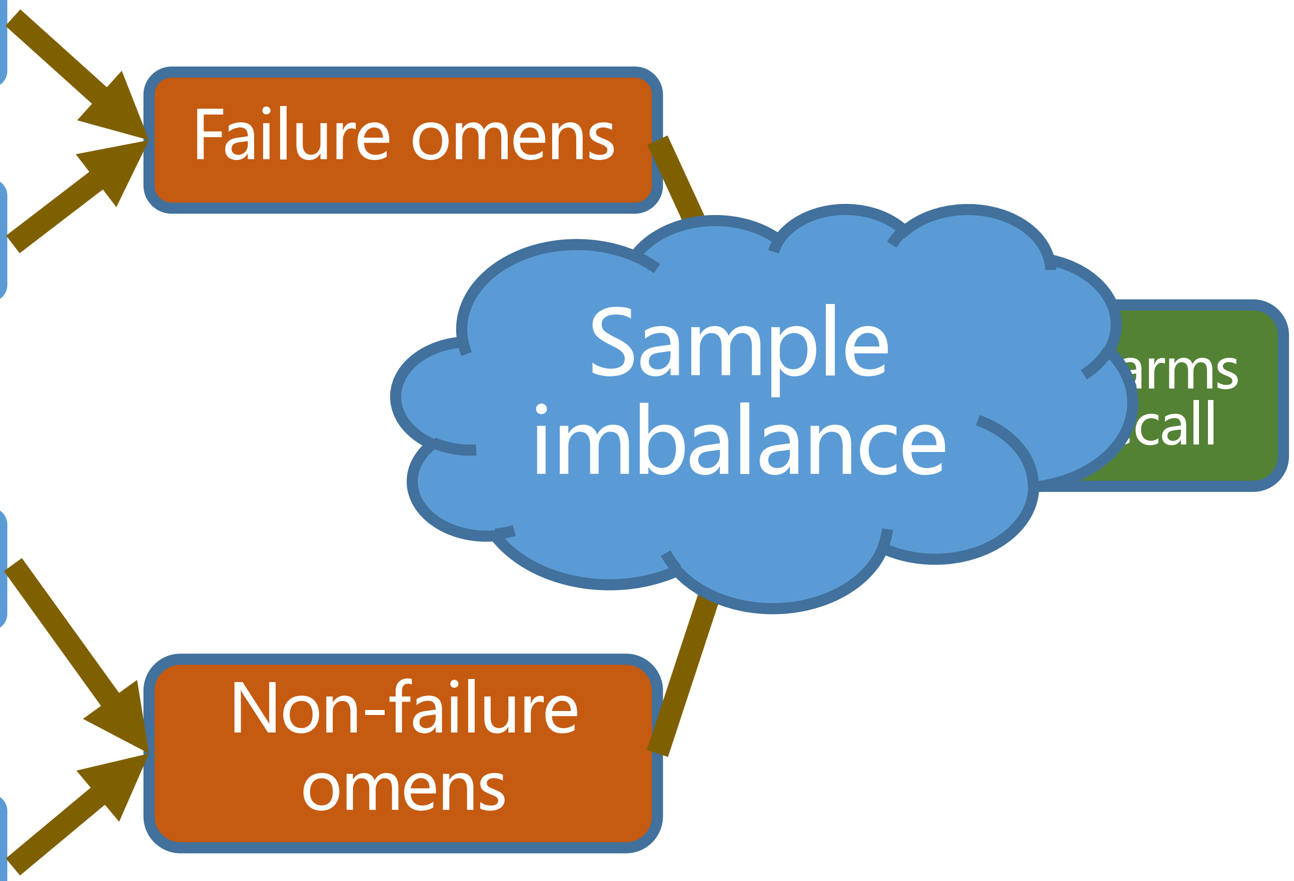

Syslogs Before a Failure (Within 2 Hours)

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Transfer to Template Tag Sequence

- The syslogs before failure 1 (2h)
  - 48 49 46 47 63 48 49 46 47 62 62 48 49 63 46 47 62

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- The syslogs before failure 2 (2h)
  - 0 48 48 48 48 48 46 46 46 46 46 48 48 46 46 48 46 48 48 46 46 48 48 46 46 48 46 48 49 63 51 50 46 47 62 48 48 46 46 51 50 51 50 48 49 48 49 63 51 46 47 50 63 46 47 48 49 62 62 46 47 62 48 49 46 47 62 48 49 63 51 50 46 47 62 56 57 58 59 44

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- The syslogs before failure 3 (2h)
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Insights of the above examples

Syslogs before failures do share common subsequences

The sequence feature is helpful for predicting failures

Irrelevant syslogs (noises) exist before failures

Noise signals should be excluded

The LCS^2 method

- LCS^2
  - First step: filter noises and get longest common subsequences (LCSes)
  - Second step: measure the similarity

The LCS^2 method

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  - First step: filter noises and get longest common subsequences (LCSes)
  - Second step: measure the similarity
- Filter noises and get LCSes
  - Seq 1: 48 49 46 47 63 48 49 46 47 62 62 48 49 63 46 47 62
  - Seq 2: 48 48 49 49 63 63 46 46 47 47 62 62 56 56 57 57 58 58 59 59
  - Seq 3: 50 62 48 49 46 47 62 48 49 63 46 47 62 56 57 58 59 48 49 63 46 47 62 48 49 46 47 48 49 63 51 46 47 50 62 62
  - Seq 1 ∩ Seq 2: 48 48 49 49 63 46 47 62
  - Seq 1 ∩ Seq 3: 48 49 46 47 63 48 49 46 47 62 48 49 63 46 47 62
  - Seq 2 ∩ Seq 3: 48 48 49 49 63 46 46 47 47 62 62

Ω

The LCS^2 method

- LCS^2
  - First step: filter noises and get longest common subsequences (LCSes)
  - Second step: measure the similarity
- Measure the similarity
  - Measure the similarity between current sequence and omen sequences
  - For each LCS_i in Ω
    - LCS_{ci} is the LCS between the current sequence and LCS_i
    - Calculate the ratio of the length of LCS_{ci} to that of LCS_i, R_i
    - Apply $\max(R_i)$ as the sequential feature score of the current sequence

The LCS² method

- LCS²
  - First step: filter noises and get longest common subsequences (LCSes)
  - Second step: measure the similarity
- Advantages
  - Computationally efficient
  - Filter noises from failure omen sequences

Evaluation Experiments

- Switches
  - Three switch models
  - 9397 switches
  - 20+ data centers
  - 2-year period
- Switch failures
  - 415 switch failures
  - 1694 failure omen time bins

Evaluation Experiments

Switch model	Method	Precision	Recall	$F1$	FPR
M1	PreFix	87.35%	74.36%	80.33%	2.49×10^{-5}
	SKSVM	8.25%	76.09%	14.89%	1.96×10^{-3}
	HSMM	32.27%	95.3%	48.21%	4.63×10^{-4}
M2	PreFix	59.79%	58.59%	59.18%	5.43×10^{-6}
	SKSVM	4.47%	8.72%	5.91%	2.57×10^{-5}
	HSMM	0.28%	60.58%	0.56%	2.94×10^{-3}
M3	PreFix	84.00%	52.50%	64.61%	2.48×10^{-5}
	SKSVM	0.79%	91.91%	1.58%	2.85×10^{-2}
	HSMM	26.32%	11.11%	15.63%	7.72×10^{-5}

Evaluation Experiments

Average recall: 61.81% , mean time between false alarms (for a single switch): 8494 days(23.3 years)

Switch model	Method	Precision	Recall	$F1$	FPR
	HSMM	26.32%	11.11%	15.63%	7.72×10^{-5}

Conclusion

Challenges

- Noisy signals in syslog data
- Sample imbalance

Four features

- Sequence, seasonality, surge and frequency
- LCS^2 method

Evaluation

- Real-world data

Future work

- Switch failure prediction across different switch models

Thank you!

Q&A

zhangsl@nankai.edu.cn

Backups

Focus on switch hardware failures

External problems

- Power supply down

Configuration problems

- VPN tunneling errors

Hardware failures

- Crash induced by hardware errors
- Line card crash
- Entire switch crash

Software crash

- Due to bugs

Generated by operators and other devices

Automatically recover (via a reboot)

Detailed information for the three models of switches

Switch model	# failures	# failed switches	# switches in total	# Omen time bins	# Non-omen time bins
M1	228	131	2223	1273	5,516,435
M2	48	30	3288	317	22, 997, 509
M3	139	31	3886	164	660, 736

Comparison of the Importance of the Four Features

Table 10. Normalized node impurity decrease of the features in the RF model

Switch model	Sequence	Frequency&Seasonality	Surge&Seasonality
M1	22.29%	51.14%	26.57%
M2	19.09%	50.25%	30.65%
M3	42.81%	36.86%	20.33%

Model of Syslog-based Switch Failure Prediction

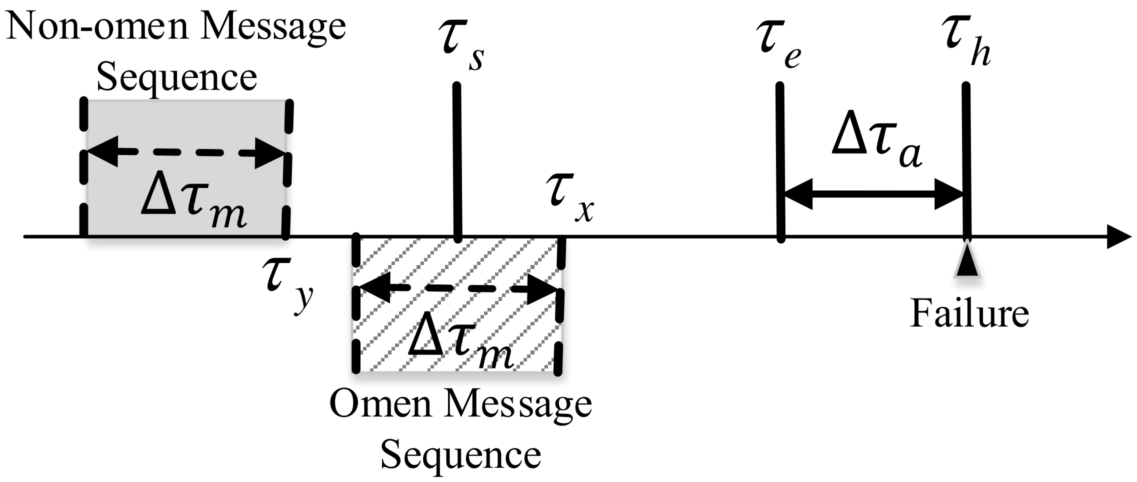

Fig. 2. The model of switch failure prediction. For a given switch failure that occurred at τ_h, our objective is to predict the failure during $[\tau_s, \tau_e]$. τ_e is $\Delta\tau_a$ before τ_h because network operators need no more than $\Delta\tau_a$ time to react to a positive failure prediction. In the offline learning procedure, given the failure at τ_h, for any τ_x in $[\tau_s, \tau_e]$, the syslog message sequence in $[\tau_x - \Delta\tau_m, \tau_x]$ is labeled as an omen message sequence, while the syslog message sequence in $[\tau_y - \Delta\tau_m, \tau_y]$ is labeled as a non-omen message sequence when $\tau_y \notin [\tau_s, \tau_h]$.