# A Semantic-aware Representation Framework for Online Log Analysis

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# Outline

# Background

# Internet Services

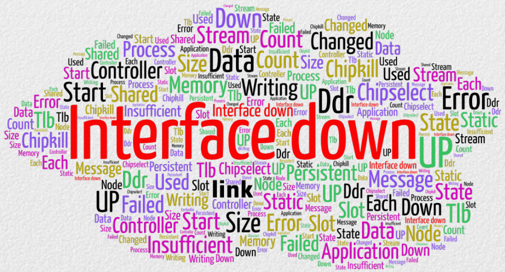
Growing rapidly

Various types of services

Stability are important

# Logs

- Monitoring data:
  - logs, traffic, PV.
- Logs are one of the most valuable data for service management




General

- Every service generates logs

Diverse

- Logs record a vast range of runtime information (7*24)

# Logs

- Logs are unstructured text
  - designed by developers
  - printed by logging statements (e.g., printf())

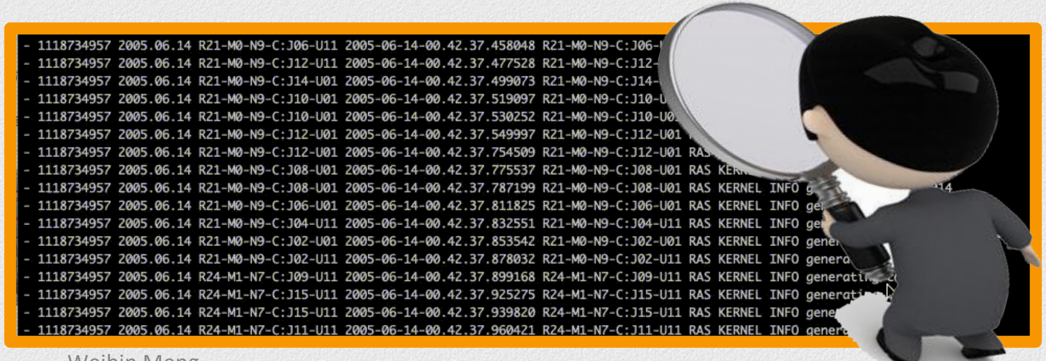
$L_1$. Interface ae3, changed state to down
$L_2$. Interface ae3, changed state to up
$L_3$. Interface ae1, changed status to down
$L_4$. Interface ae1, changed status to up
$L_5$. Vlan-interface vlan22, changed state to down
$L_6$. Vlan-interface vlan22, changed state to up

Logs are similar to nature language

# Manual inspection of logs

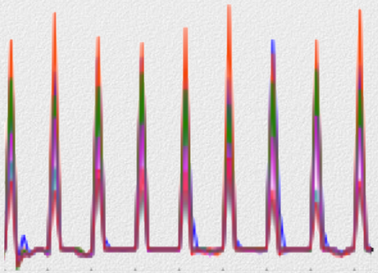
- Manual inspection of logs is impossible
  - A large-scale service is often implemented/maintained by hundreds of developers/operators.
  - The volume of logs is growing rapidly.
  - Traditional way: labor-intensive and time consuming

**Automatic log analysis**

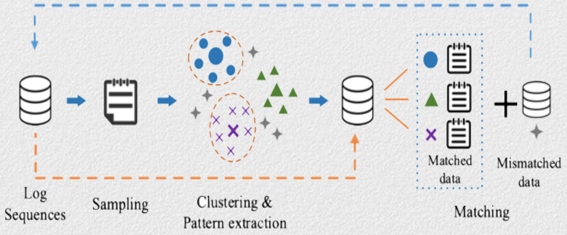


# Automatic log analysis

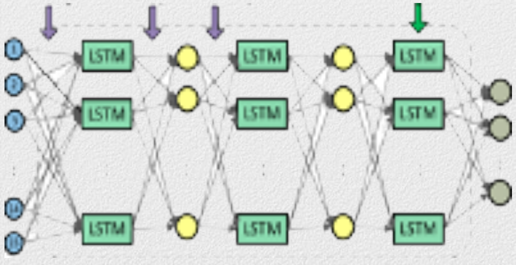
- Automatic log analysis approaches, which are employed for services management, have been widely studied



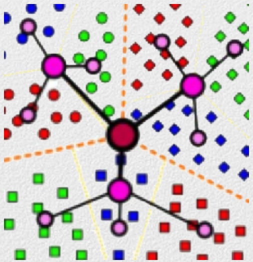
Monitoring
[INFOCOM'19]




Problem Identifying
[FSE'18]




Anomaly detection
[CCS'17]



Failure prediction
[SIGMETRICS'18]

# Log representation

- Most of automatic log analysis require structured input
  - Logs are unstructured text
- Log representation serves as the first step of automatic log analysis
  - Template index
  - Template count vector

→ Lost semantic information

Semantic-aware log representation approach

# Challenges

1 Domain-specific semantic information

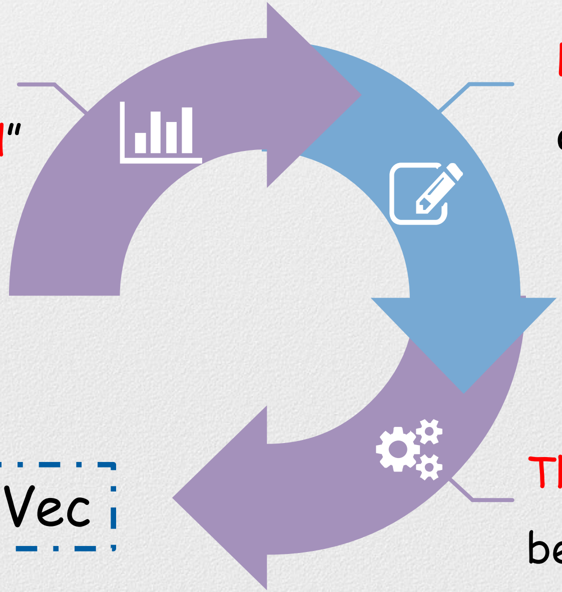
- Logs contain logs of domain-specific words

2 Out-of-vocabulary (OOV) words

- The vocabulary is growing continuously because the service can be upgraded to add new features and fix bugs

# Idea

Original goal of logs: “
logs are for users to read”



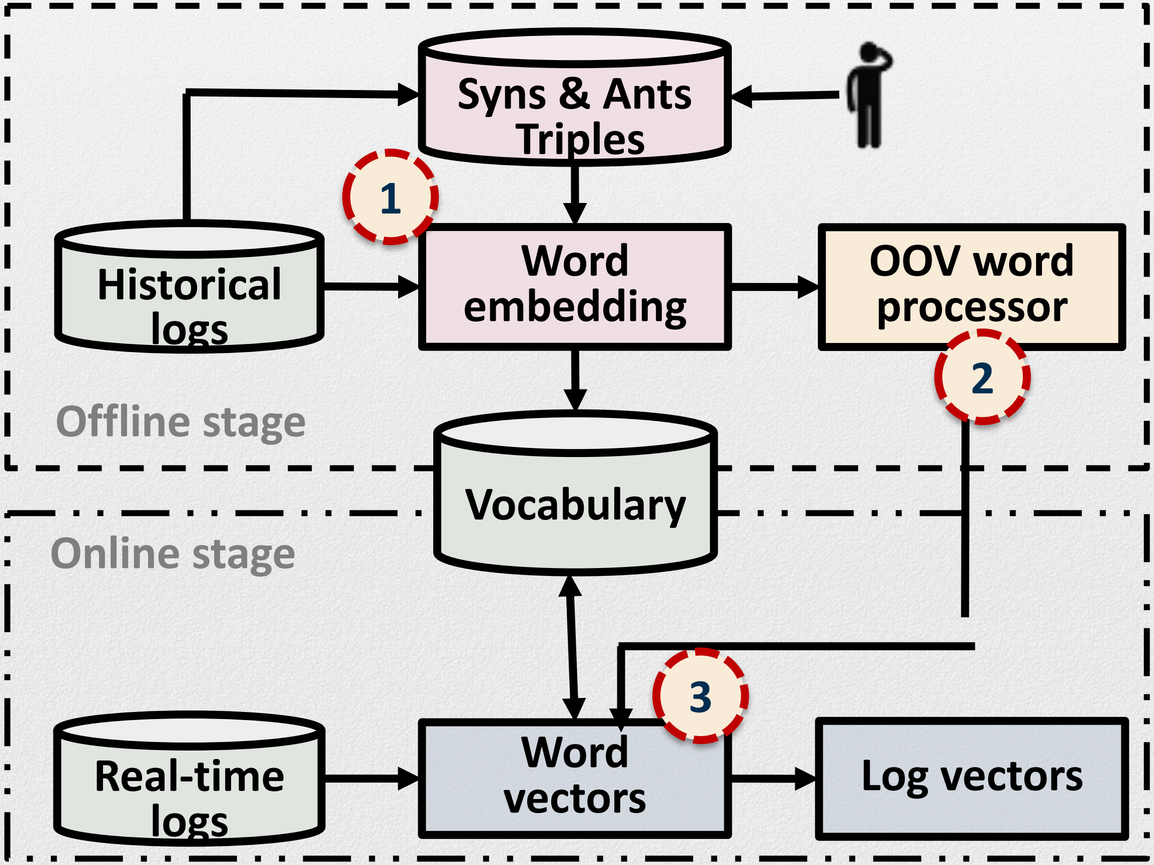
Logs are designed by developers
and “printf”-ed by services

The intuition and methods in NLP can
be applied for log representation

Log2Vec

# Design

# Overview of Log2Vec




1. Log-specific word embedding

2. Out-of-vocabulary word processor

3. Log vector generation

Open source toolkit: https://github.com/WeibinMeng/Log2Vec

# Log-specific semantics

- When embed words of logs, we should consider many information:
  - Antonyms
  - Synonyms
  - Relation triples
  - Others (future work)

**Historical logs:**
$L_1$. Interface ae3, changed state to down
$L_2$. Interface ae3, changed state to up
$L_3$. Interface ae1, changed status to down
$L_4$. Interface ae1, changed status to up
**Real-time logs:**
$L_5$. Vlan-interface vlan22, changed state to down
$L_6$. Vlan-interface vlan22, changed state to up

| **Out-of-vocabulary** | Vlan-interface |
|---|---|
| **Relation triples** | (Interface, changed, state) |
| **Antonym pairs** | (down, up) |
| **Synonym pairs** | (state, status) |

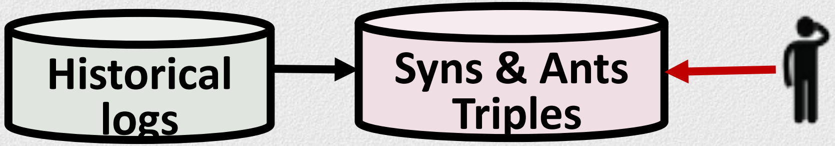
- Traditional word embedding methods (e.g., word2vec) assumes that

words with a similar context tend to have a similar meaning

fail to capture the log-specific meaning

# Prepare log-specific information

- Automatically extract
  - Antonyms & Synonyms
    - Search from WordNet[1], a lexical database for English
  - Triples
    - Dependency tree[2]
- Manually modify



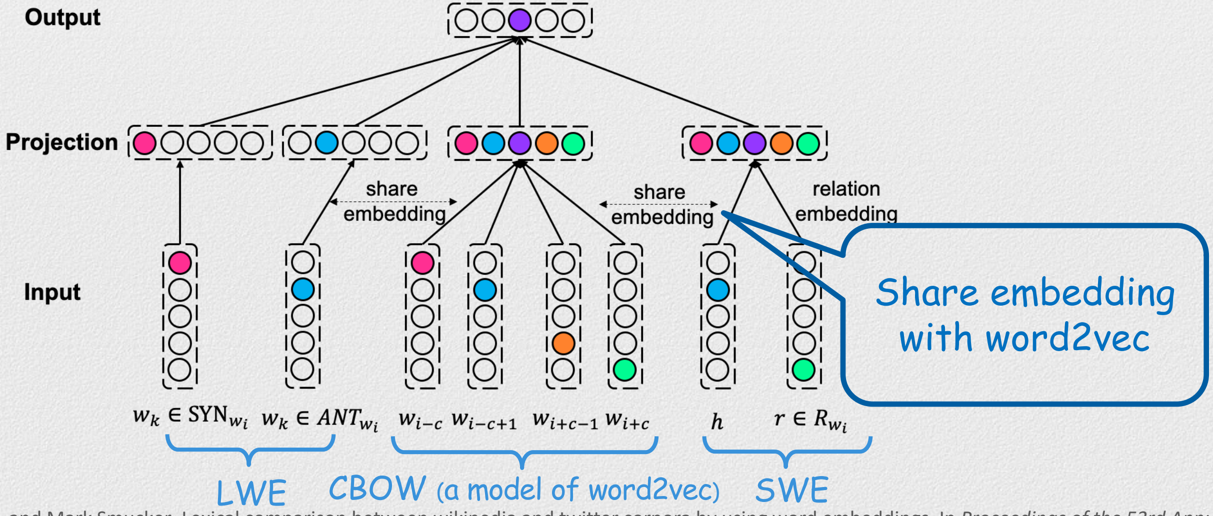

| Relations | Word pairs | | Adding methods |
|---|---|---|---|
| Synonyms | Interface | port | Operators |
| Antonyms | DOWN | UP | WordNet |
| | powerDown | powerUp | Operators |
| Relations | (interface, changed, state) | | Dependency tree |


[1]Fellbaum C. WordNet[J]. The encyclopedia of applied linguistics, 2012.

[2]Culotta A, Sorensen J. Dependency tree kernels for relation extraction[C]//Proceedings of the 42nd Annual Meeting of the Association for Computational Linguistics (ACL-04). 2004: 423-429.

# Log-specific word embedding

- Log-specific word embedding <u>combines</u> two existing methods:
  - Lexical Information word embedding (LWE)[1] -> ants & syns
  - Semantic Word embedding (SWE)[2] -> relation triples




[1]Luchen Tan, Haotian Zhang, Charles Clarke, and Mark Smucker. Lexical comparison between wikipedia and twitter corpora by using word embeddings. In *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing* , pages 657–661, 2015.

[2]/Quan Liu, Hui Jiang, Si Wei, Zhen-Hua Ling, and Yu Hu. Learning semantic word embeddings based on ordinal knowledge constraints. In *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing (Volume 1: Long Papers)*, pages 1501– 1511, 2015.

# OOV processor

- We adopt MIMICK[3] to handle OOV words at runtime.
  - Learn a function from spelling to distributional embeddings.

**Historical logs:**

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$L_2$. Interface ae3, changed state to up
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**Real-time logs:**

$L_5$. Vlan-interface vlan22, changed state to down
$L_6$. Vlan-interface vlan22, changed state to up

| | |
|---|---|
| **Out-of-vocabulary** | Vlan-interface |
| **Relation triples** | (interface, changed, state) |
| **Antonym pairs** | (down, up) |
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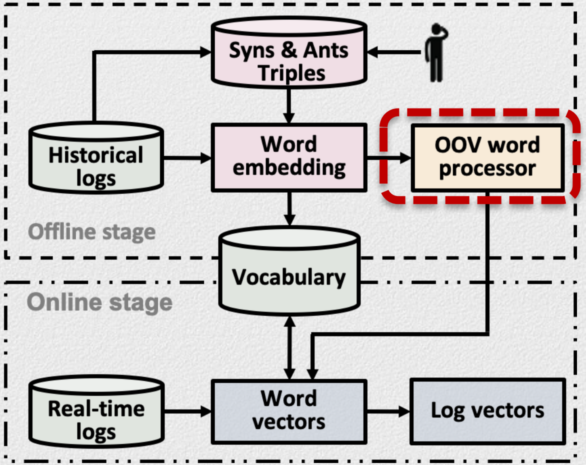
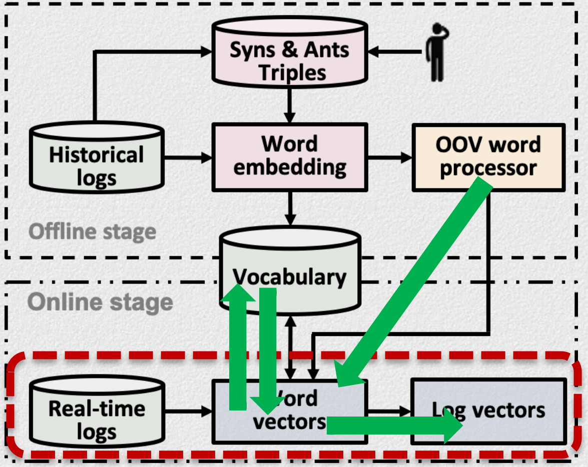



[3].Yuval Pinter, Robert Guthrie, and Jacob Eisenstein. Mimicking word embeddings using subword rnns. In Proceedings of the 2017 Conference on Empirical Methods in Natural Language Processing (EMNLP), pages 102–112, 2017.

# Log vector generation (Online stage)

1. Determine whether each word in logs is in vocabulary
2. Convert existing words to word vectors
3. Assign a new embedding vector to the OOV word
4. Calculate the log vector by averaging of its word vectors.



# Evaluation

# Experimental setting

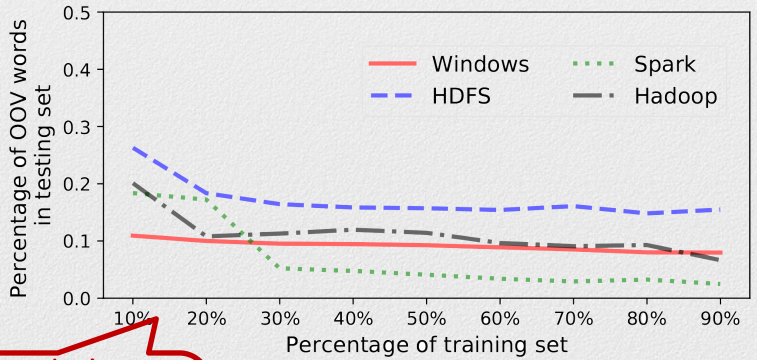
- Datasets:

| Datasets | Description | # of logs |
|---|---|---|
| HPC | High performance cluster | 433,489 |
| HDFS | Hadoop distributed file system | 11,175,629 |
| ZooKeeper | ZooKeeper service | 74,380 |
| Hadoop | Hadoop MapReduce job | 394,308 |

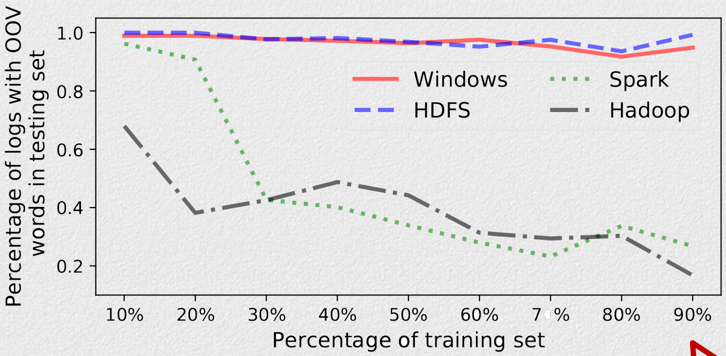
- Experimental setup:
  - Linux server with Intel Xeon 2.40 GHz CPU

# Measurement of OOV

- To highlight the challenge in processing OOV words
  - Generate training sets with the percentage of original logs ranging from 10% to 90% and regard the remaining logs as the testing set




Measurements of OOV words




Measurement of logs with OOV words

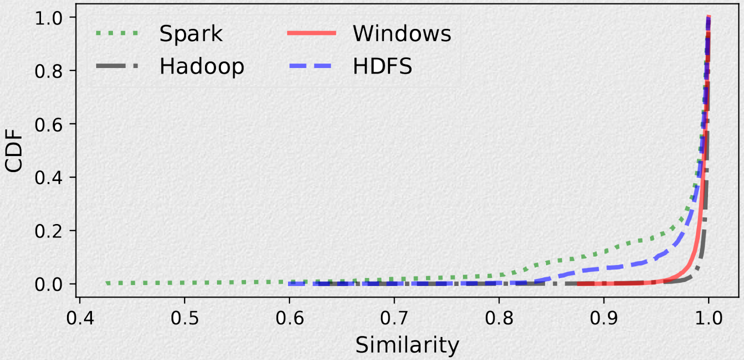
OOV words has a big percentage when trained on a smaller sample

It's important to handle OOV words

Always more than 90% logs contain OOV words in Spark/Windows

# Evaluation of OOV processor

- Randomly select a word in each log
- Changed one of the letters to make the word as an OOV
- Test the similarity between the changed log and the original log




Distribution of Logs' Similarity

| Dataset | Spark | HDFS | Windows | Hadoop |
|---|---|---|---|---|
| Similarity | 0.964 | 0.984 | 0.993 | 0.996 |

Average similarity when Log2Vec processes logs with OOV words

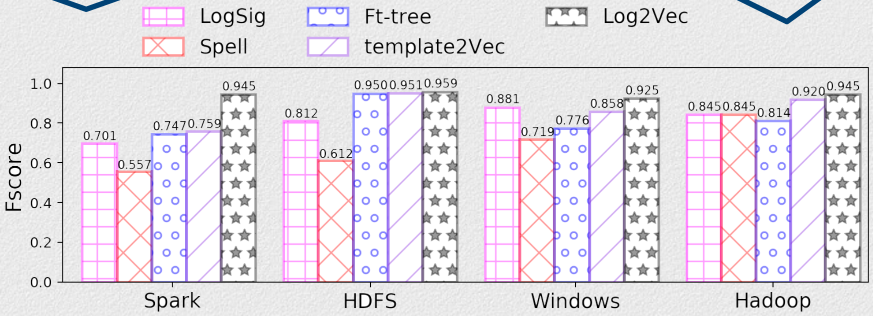
# Log-based service management task

- Online log classification
  - Baselines: LogSig, FT-tree, Spell, template2Vec
  - Divide: 50% training set and 50% testing set

Average Fscore of Log2Vec is 0.944

Average Fscore of baselines 0.745

Log2Vec is stable




Comparison of log classification when use 50% training logs

# Summary

# Summary

Log2Vec | OOV processor | Open-source toolkit | Experiments

- **Log2Vec**: Semantic-aware representation framework for online log analysis
- **OOV processor**: A mechanism for generating OOV word embeddings when new types of logs appear
- **Open-source toolkit**: We have open-sourced Log2Vec,
- **Experiments**: The results are excellent

# Thanks

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Open source toolkit: https://github.com/WeibinMeng/Log2Vec