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Improving accuracy and adaptability of SSD failure prediction in hyper-scale data centers

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2021 SRCX

Samsung R&D Institute China Xi'an(SRCX) established in 2013 and located in Xi'an High-tech Zone, is the only cutting-edge technology R&D institute of Samsung Electronics in western China.

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Introduction

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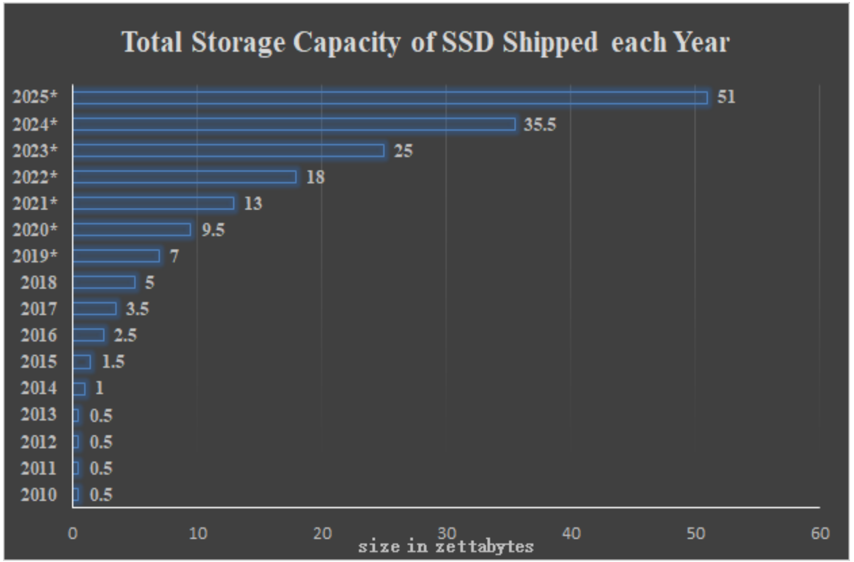
Continuous increasing in SSD population, capacity and density

Decreasing in SSD reliability



SSD reliability: endurance, retention

DC Availability: downtime or even data loss

Introduction

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■ Reactive Fault Tolerance Methods

- Aim to help applications recover from SSD failures
- Problem: Unable to replace failed drives in time.

■ Proactive Failure Prediction Methods

- Failure prediction methods for HDDs
  - ✓ Not applicable to SSDs due to fundamental difference in architecture
- Failure prediction research on SSDs
  - ✓ Research on SSD failure in controlled environment
  - ✓ Study the effect of correlated factor on SSD reliability
  - ✓ Employ ML method to make failure prediction

Introduction

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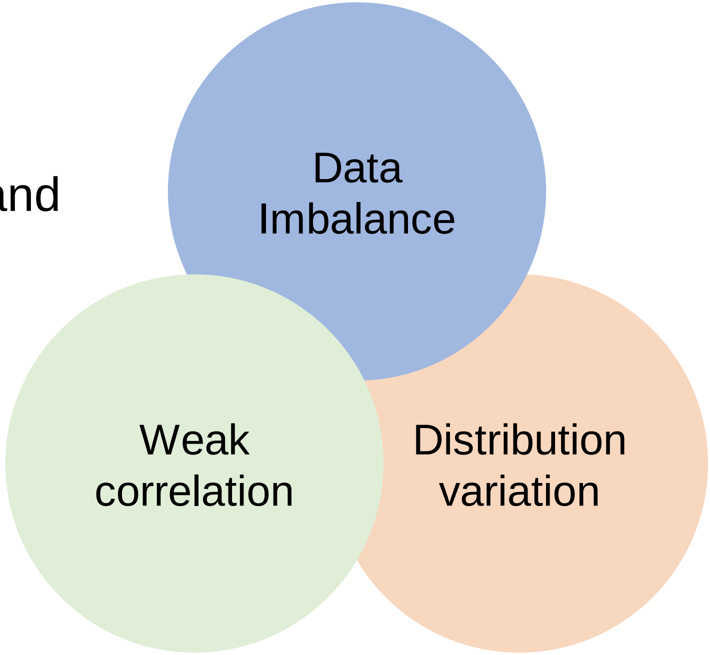
■ Major Challenges in SSD Failure Prediction

- Data imbalance problem
- Weak correlation between SMART attributes and SSD failures
- Variation of SMART attributes distribution



SSD Failure Analysis

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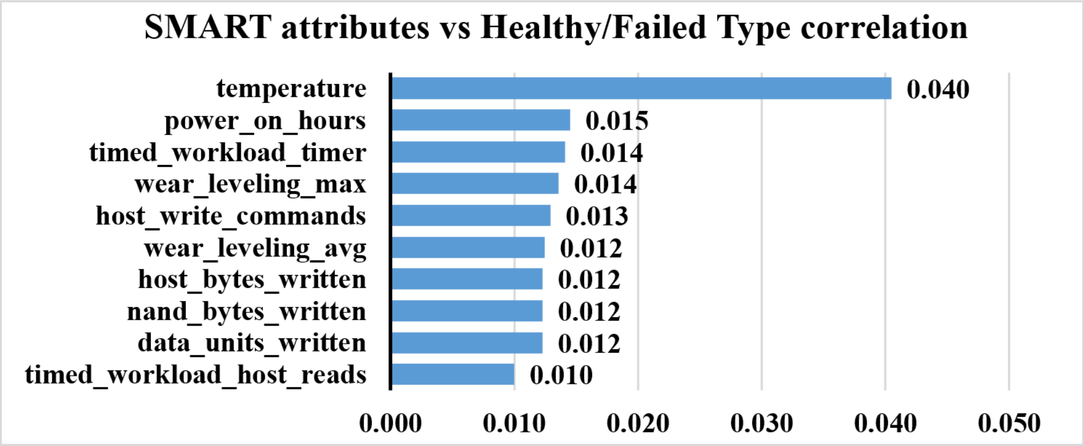
Correlation Analysis

- Reveal a weak correlation between SMART attributes and SSD failures



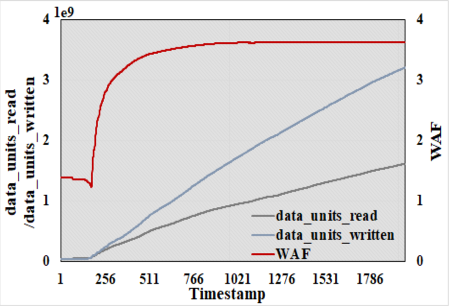
Correlation coefficient of the top 10 most indicative SMART attributes is close to zero

- Need further analysis on time series dependency

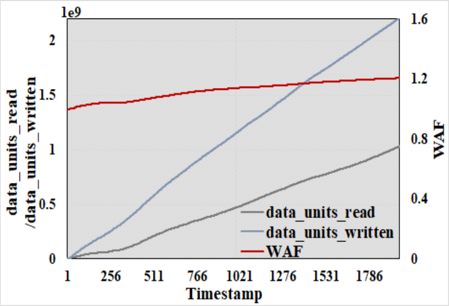
SSD Failure Analysis

■ Time Series Analysis (SSD Drop)

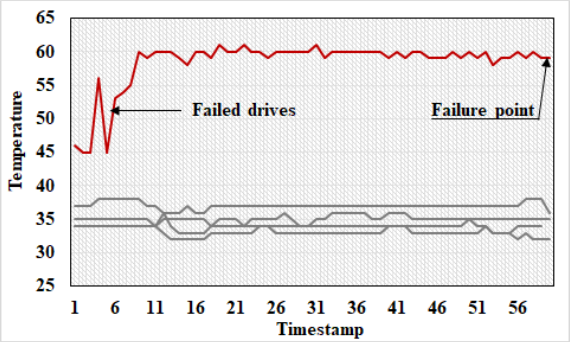
- Distinguish failure pattern on WAF
  - ✓ Healthy SSD: Keep at a stable value
  - ✓ Failed SSD: Increase sharply
- Distinguish failure pattern on temperature
  - ✓ Healthy SSD: Keep at relative low level
  - ✓ Failed SSD: Increase sharply



a) Failed trend



b) Healthy trend



SSD Failure Analysis

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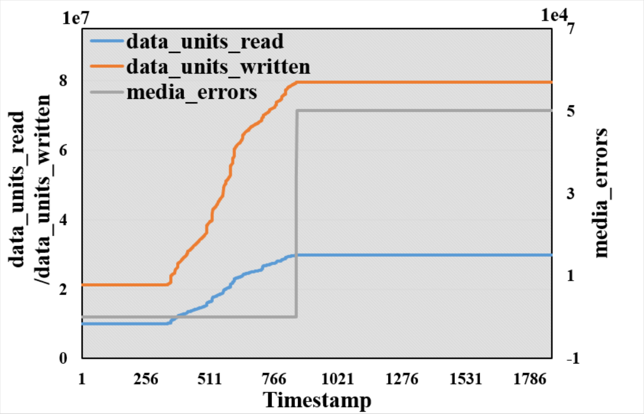
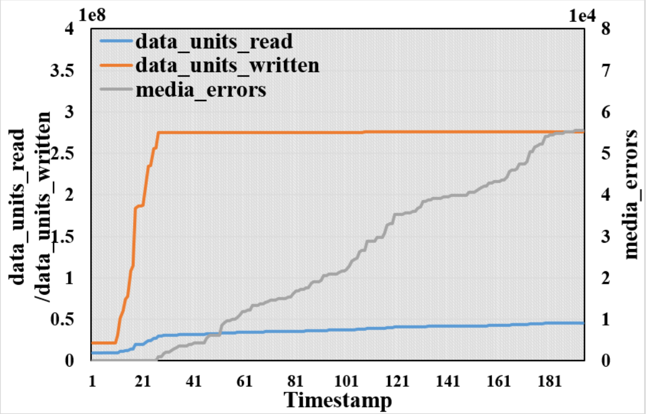
■ Time Series Analysis (Media Error)

- Exhibit distinguish changing trend on the attribute (media_errors)
  - ✓ Healthy SSDs: Always 0
  - ✓ Failed SSDs: Exhibit either gradual or sharp increasing trend



a) Gradual changing trend of the indicator attribute media_errors



b) Sharp increasing trend of the indicator attribute media_error

SSD Failure Analysis

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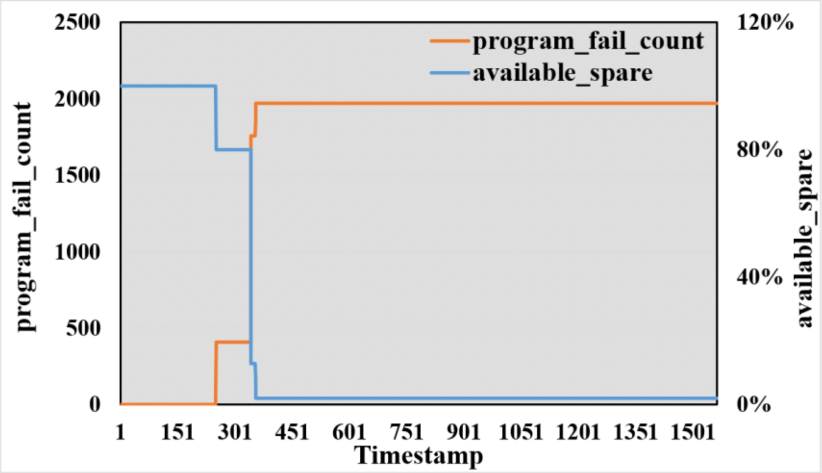
■ Time Series Analysis (Bad Blocks)

Exhibit sharp increasing trend on program_fail_count and decreasing trend on available_sapre

Failure happens when the value of available_spare decreases to a threshold



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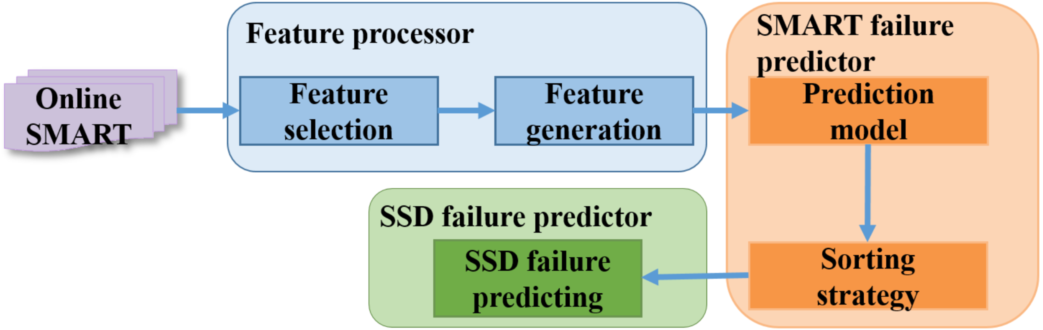
Our Scheme



- Feature processor: apply feature selection and generation method based on analysis result
- SMART feature predictor: propose RUS_ensemble method and sorting strategy
- SSD failure predictor: develop time window based SSD failure prediction method

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■ Feature Processor

- Raw features are selected and new features are generated based on failure analysis result

Selected raw features	Generated new features
data_units_read	data_units_read_diff
data_units_written	data_units_written_diff
nand_bytes_written	WAF
host_bytes_written	
Temperature	temperature_diff
power_on_hours	-
media_errors	-
available_spare	-
program_fail_count	-

Selected raw features

✓ Eight features indicative at least one type of failure

✓ One time indicator power_on_hours

Generated new features

✓ Differential features: capture time series related information

✓ WAF features: an indicative feature for bad blocks related failures

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SMART Failure Predictor

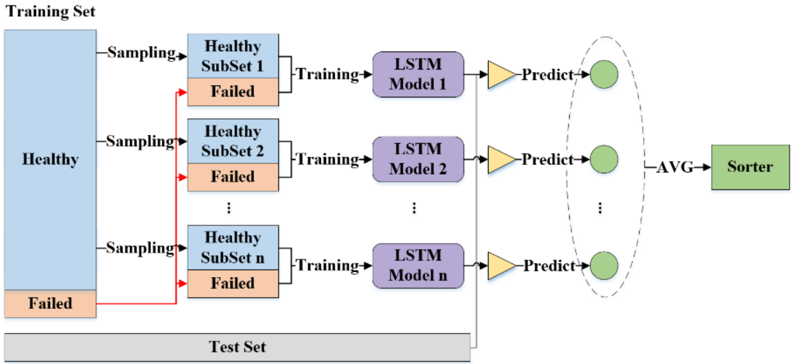
- RUS_Ensemble prediction method is proposed to solve the data imbalance problem

Solving data imbalance

Each base model is trained on a relative balanced dataset
- Whole failed data
- 1/n of the healthy data

Avoiding data information loss

n base models are trained
- Splitting healthy data into n folds
- Each fold sampled by one base model
- Integrating the information of n base models by voting



Method

SMART Failure Predictor

- Sorting strategy is proposed to solve the distribution variation problem

Assumes:

- ✓ Daily failure ratio of SSDs and SMART observations is stable
- ✓ There is no obvious fluctuation in the distribution of SMART attributes within a day

Steps:

- ✓ Categorize the SMART observations according to collection date
- ✓ For each collection date, sort the SMART observations in descending order according to the risk score obtained from RUS_Ensemble model
- ✓ Give failure prediction for the top P percent of observations

Method

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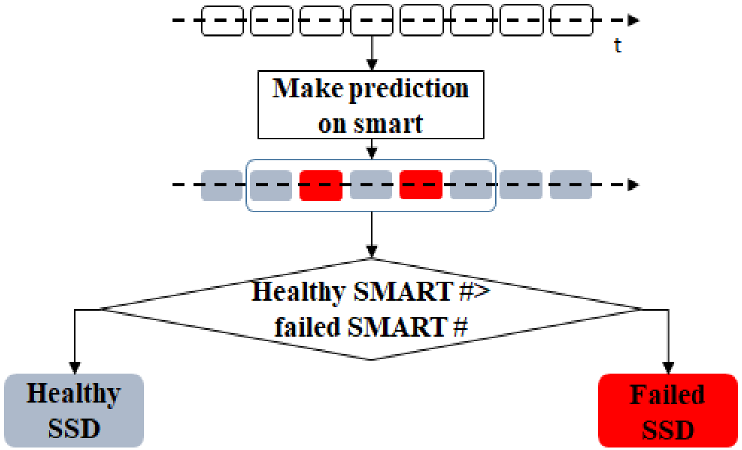
■ SSD Failure Predictor

- Purpose: Avoid false alarm to decrease FPR
- Step:
  - ✓ Arrange SMART logs in time axis
  - ✓ Slide time window in time axis
  - ✓ Make failure prediction for SSD based on the health/failure type of SMART logs in window



Result and Analysis

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Settings

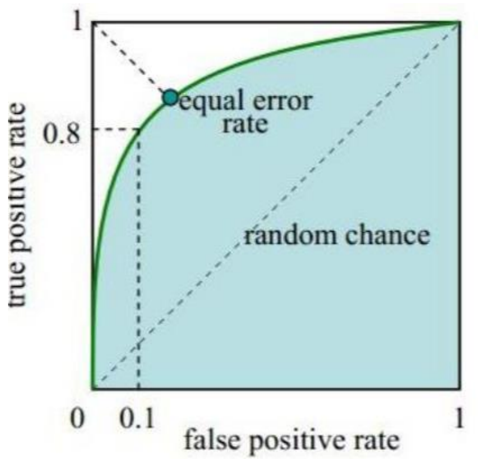
- Dataset：
  - ✓ Healthy drives: 100,000,
  - ✓ Failed drives: 114
  - ✓ Collection period: about one year
- Comparisons: 1) Bayes 2) RF 3) GBDT 4) LSTM

Evaluation Metrics

$$TPR = \frac{TP}{TP + FN}$$

$$FPR = \frac{FP}{FP + TN}$$

AUC（Area Under Curve of ROC）



Result and Analysis

■ Accurate Prediction of SSD Failures

	TPR(%)	FPR(%)	AUC
Bayes	23.810	9.811	0.473
RF	9.523	0.00403	0.584
GBDT	4.762	0.00134	0.439
LSTM	9.524	0.00941	0.751
RUS_Ensemble	38.095	0.758	0.755

- ✓ Prior works fall short either in low TPR or high FPR
- ✓ The main contribution of our work is improve TPR while keep FPR less than 1%

Result and Analysis

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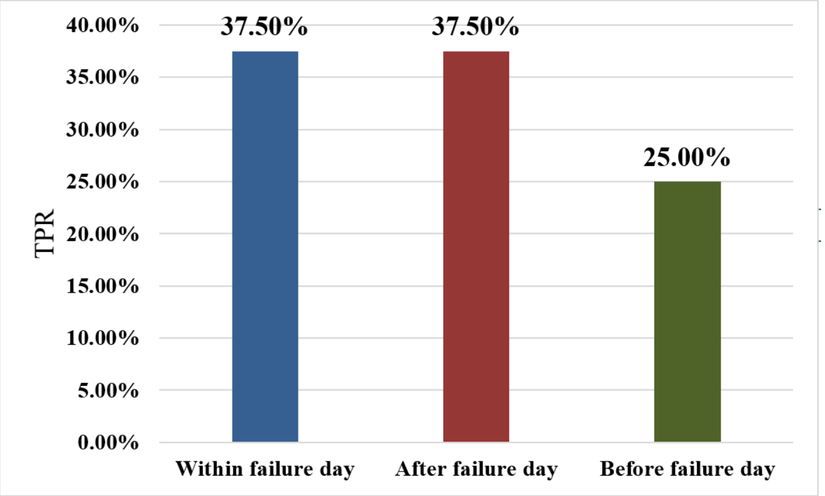
■ Prediction Time Analysis

- 25% true positive drives are predicated ahead of the failure day
- 37.5% true positive drives are predicted behind the failure day
- 37.5% true positive drives are predicted within the failure day



Change point on SMART attributes of failed drives always occurs only a few hours before or several days after the failure day

Conclusion

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- **Provide a comprehensive study of SSD failure analysis**
  - ✓ Conduct time series analysis and present failure pattern for each type SSD failures
- **Propose a novel SSD failure prediction scheme improving TPR by 28% and bring about very low FPR which is 1%**
  - ✓ Select correlated raw features and generate new features in feature processor module to construct indicative representation
  - ✓ Propose RUS_ensemble prediction method and sorting strategy for SMART failure prediction
  - ✓ Develop a time window based SSD failure prediction method

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