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Automated Generation of SSD Stress Tests Using Offline Reinforcement Learning

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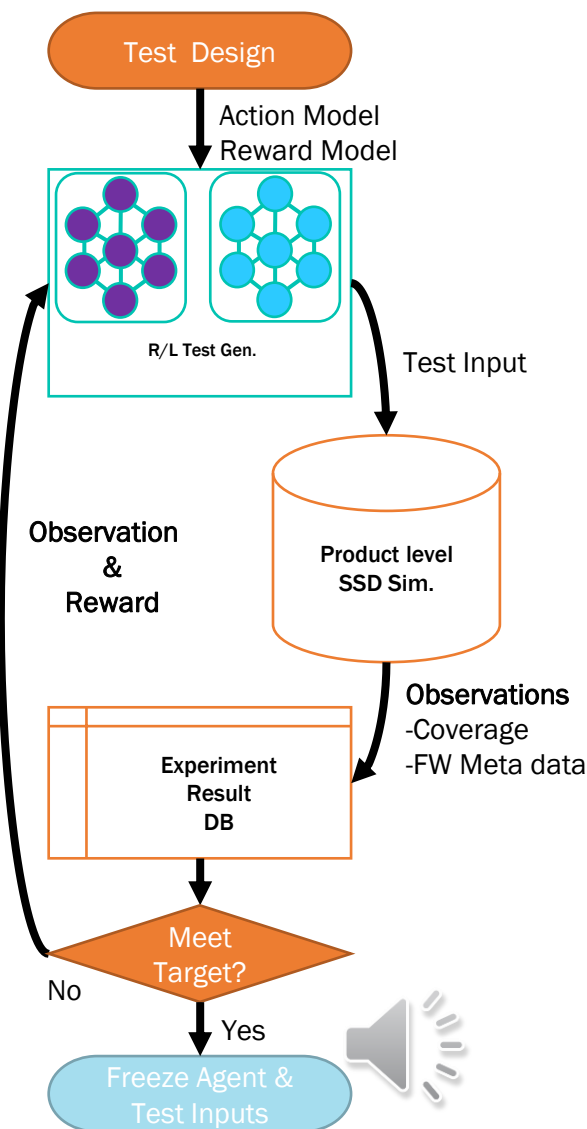
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1 | Would applying R/L be beneficial on SSD stress test design?

- GRAFT : Foundational research for feasibility¹⁾
 - We have discovered that (offline) RL excels in optimizing the path to achieve goals.
- Can it work in real SSD for Enterprise?
 - Strengths
 - Offline RL leverages the replay of experimental data with various reward and observation models.
 - Training and evaluation can operate independently
 - Challenges
 - Increased big data by x100 compared to that of the GRAFT¹⁾ environment
 - Action model conversion of the numerous commands defined in the NVMe.
 - Extensive address space and transfer lengths.
- Can it chase and optimize the stress test target?
 - The goal is to find the shortest write command combination that minimizes the number of free blocks.



1) Y. H. Lee et al., "GRAFT: Graph-Assisted Reinforcement Learning for Automated SSD Firmware Testing," 2023 IEEE/ACM International Conference on Computer Aided Design (ICCAD), San Francisco, CA, USA, 2023, pp. 1-8, doi: 10.1109/ICCAD57390.2023.10323794.

An automated test aimed at swiftly depleting the free blocks of an SSD

- The number of free blocks is the key factor of latency control
 - A shortage of free blocks leads to frequent garbage collection(G/C), resulting in performance degradation.
- SSD Virtual Platform(V.P.)²⁾ : the test vehicle capable of extracting F/W meta data
 - Collecting branch coverage and meta data just after each action executed.



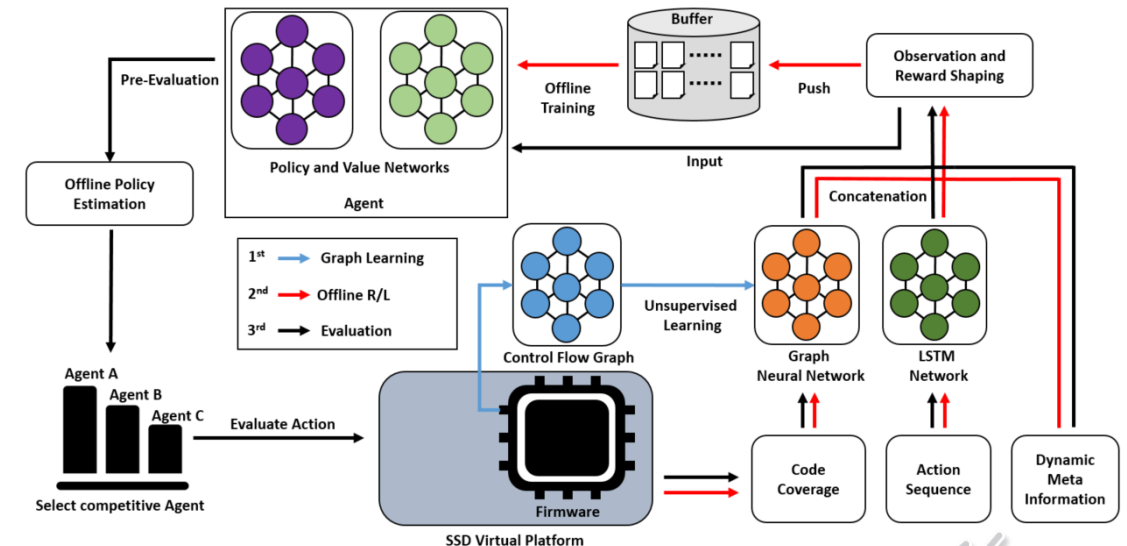
Observation/Reward Model

- Transforming control flow graph into GNN model.
- Designing a reward on target function.



Loop-Back Training Framework

- Gathering initial data by applying random actions to the SSD V.P.
- Training several agents and select promising agents by off-policy estimation.
- Collecting data on a sequence of actions generated by the policy network and pushing them into the training data set additionally.



The GRAFT Architecture for stress test

2) Beomchan Park, et al, A Stand-alone Virtual Platform Runnable at Unified Time Domain as NVMe SSD Full-System Simulator, Engineer Track, 2023 IEEE Design Automation Conference, <https://60dac.conference-program.com/presentation/?id=RESEARCH519&sess=sess242>

3 | The design of action model is crucial

- To apply (offline) RL to actual SSD, it's crucial to appropriately determine the quantity and degrees of freedom within the action set based on the product's characteristics.
- The appropriate action model for SSDs should be designed to effectively differentiate address space, transfer length, and the characteristics of I/O operations.
- In this experiment, a total of 24 actions were structured as a set for write operations.



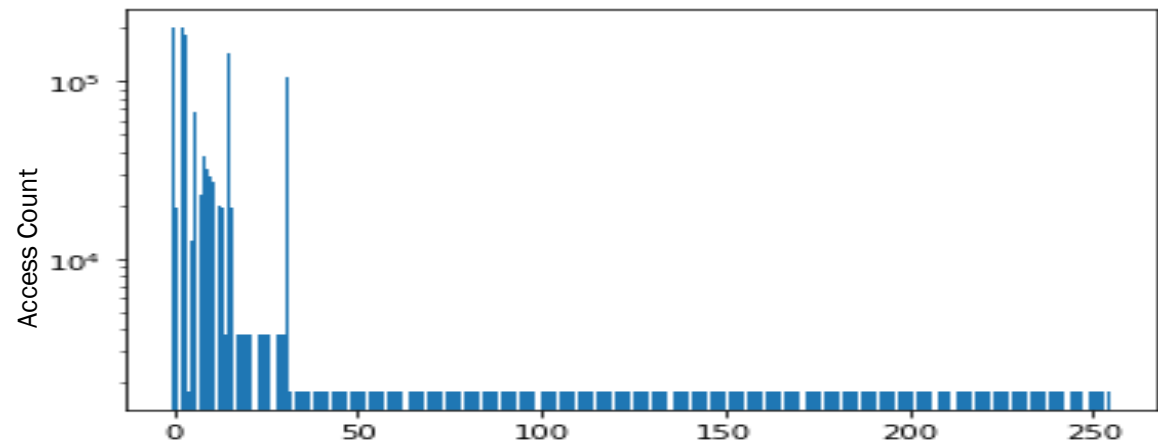
Spatial Locality

Write operations occurring within a specific time unit do not exhibit significant differences in address.



Temporal Locality

I/O data is divided into frequently accessed 'hot' data and less accessed 'cold' data.



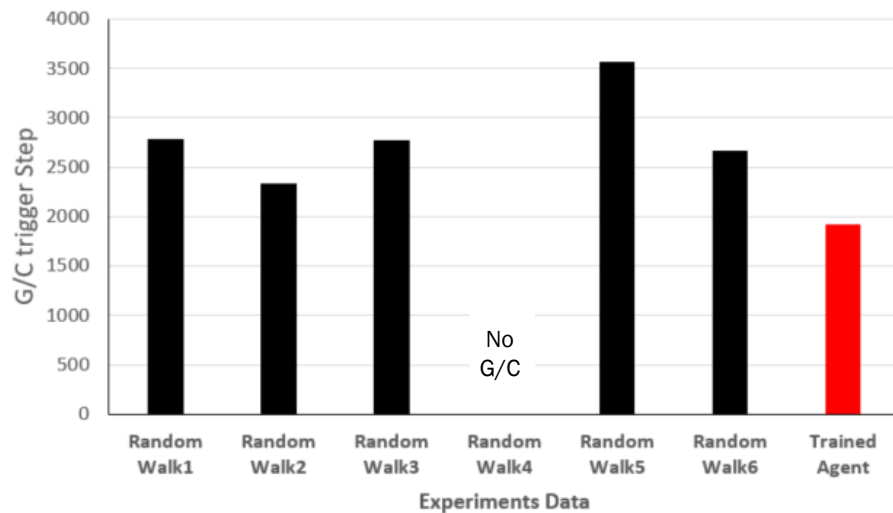
Address space is divided into bins.

During random execution of the proposed action set, display the histogram showing the frequencies of actions

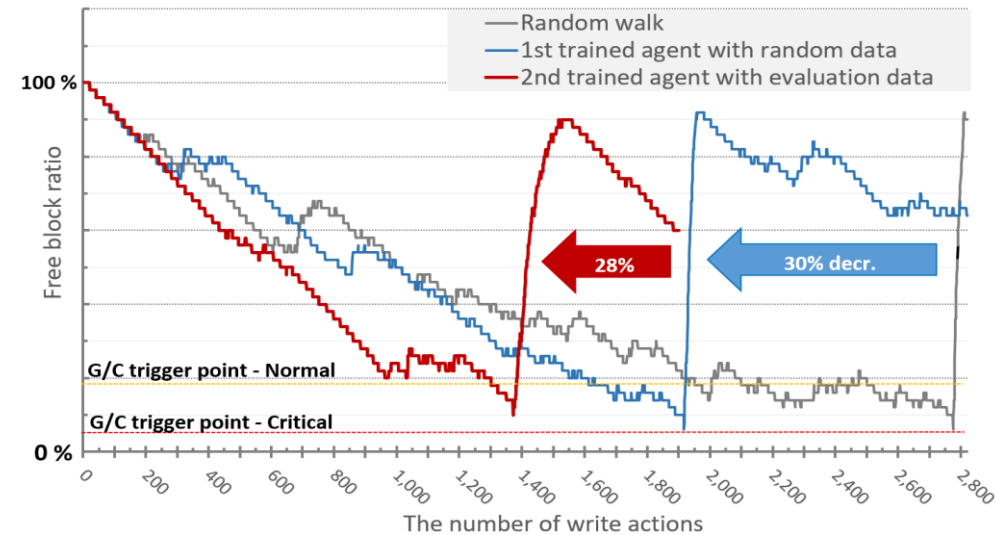


By leveraging R/L, optimal sequences were found within randomly generated test data.

- Re-training from generated data by multiple trained agents leads further performance enhancement.



- Gathering tens of random walk data with defined action model.
- Selecting affordable agent by off-policy estimation technique.



- only at the 1st training, the number of actions required to reach the same G/C stress level was reduced by 30%.
- In the 2nd training phase including action set refinement, G/C trigger point was shortened by 28% using the 1st results.

At the product-level SSD testing, the efficacy of employing (offline) RL methodologies was validated

- RL technology might alter the methodologies of test design
 - Offline RL is suitable for test generation due to the data reusability rooted in the essence of the algorithm.
- The test engineer can focus on designing suitable action and observation models aligned with the objectives.
- Future plans
 - This methodology is slated for application in generating tests aimed at reducing the manifestation time of defects that are challenging to reproduce.

