Detect & Adapt: A Resiliency Enhancement Mechanism for Space Computing Platforms

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Motivation

- Applications of space systems:
  - Navigation
  - Communication
  - Weather forecast
  - Remote sensing
- Heterogeneous Compute Platforms (HCP):
  - CPU
  - GPU
  - FPGA
  - DSP
- HCP lacks in built-in security features

Spacecraft*

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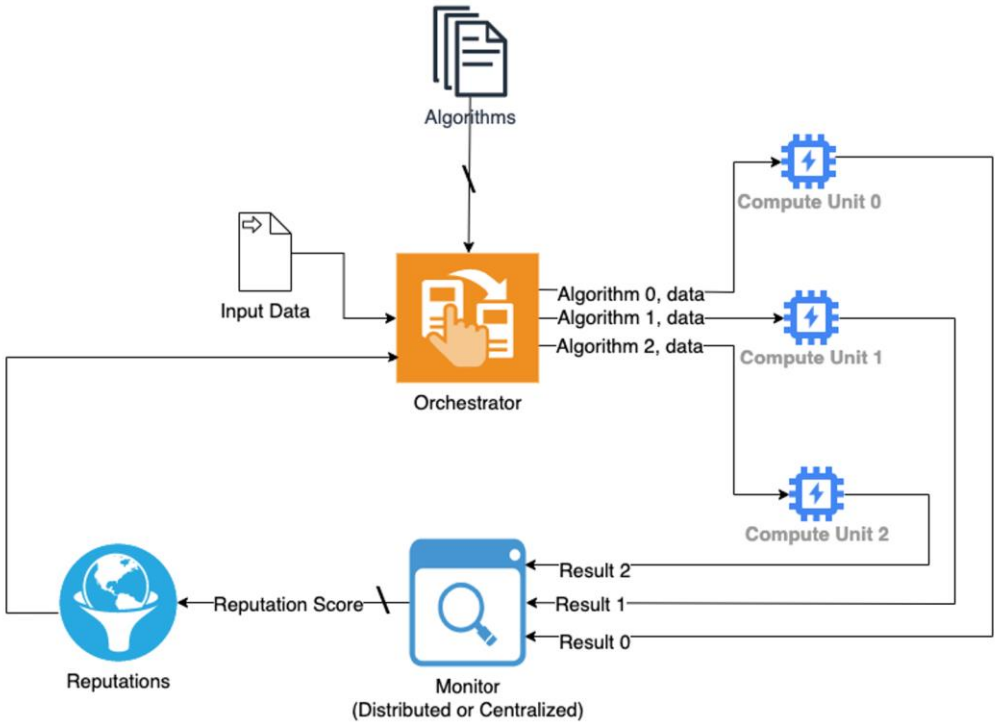
*https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.sierraspace.com%2Fnewsroom%2Fpress-releases%2Fsierra-space-and-ibm-collaborate-on-space-technology-and-software-platforms%2F&psig=AOvVaw1WCSZ-0fDGEDeuPY1ckW7f&ust=1701970010624000&source=images&cd=vfe&opi=89978449&ved=0CBQQjhxqFwoTCPC5g8Gq-4IDFQAAAAAdAAAAABAE

Introduction

- Applications of HCP outside of space mission: critical infrastructure, autonomous vehicles, edge AI [LLH+22].
- HCP integrates different processing units into single chip.
- Provides efficient computing in terms of performance and power consumption.
- HCP executes computation without the supervision of any central entity.
- Gap exists in the literature regarding the security features of HCP platform in space systems [SMM+21, Cas10, VHJ19, MBH+21, ZLZT21].
- There is a pressing need to explore ways to develop security solutions for the HCP-based computing environment.

Heterogeneous Computing: Orchestration & Monitoring

- Orchestrator assigns:
  - Data, algorithm, and task.
- Compute units:
  - Execute task.
  - Send the result to the monitor.
- Monitor:
  - Verifies results from each compute unit.
  - Outputs the final compute result.
  - Evaluates performance of each compute unit.
  - Sends the evaluation summary to the orchestrator.



Proposed HCP orchestration & Monitoring Mechanism.

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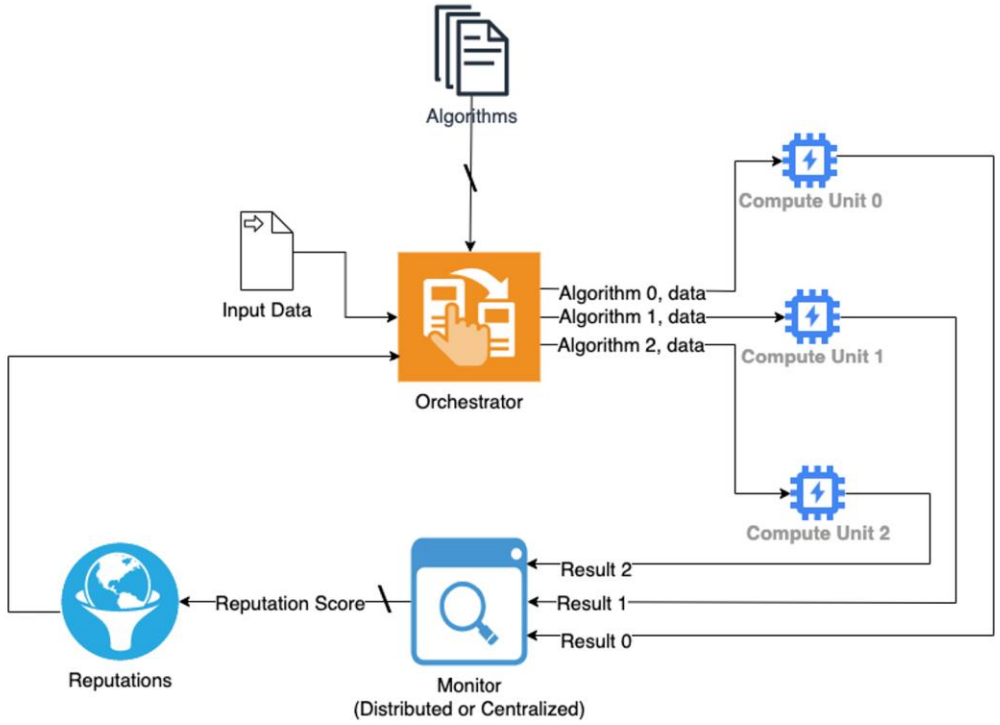
Heterogeneous Computing: Threat Model

- Trustworthy:
  - Orchestrator.
  - Monitor.

- Attacks:
  - Manipulation of results.
  - Degradation of performance.

- Manipulation of results:
  - Data manipulation.
  - Output alteration.
  - Packet drop.

- Degradation of performance:
  - Algorithmic trojan (exploits worst case complexity of an algorithm).
  - Memory leakage.



Proposed HCP orchestration & Monitoring Mechanism.

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Heterogeneous Computing: Computing Strategy

- ***Computation Partition:***
  - Partitioning a computation task into multiple sub-tasks.
  - Monitor combines the result of each subtask.
- ***Triple Modular Redundancy:***
  - Three compute units perform an identical task/sub-task, using the same algorithm or execution process.
- ***Triple Modular Diversity:***
  - Three compute units performing identical tasks/sub-tasks but with different task execution processes/algorithms.
- ***Hybrid Strategy:***
  - Both the algorithm and compute unit can change over time.
  - Can be performed consistently with the three other methods stated above.

Heterogeneous Computing: Hierarchical Detection

- ***Hierarchical Detection:***
  - Sequence of multiple detection strategies.
- ***Brute Force Approach:***
  - Monitor checks each small segment of results from compute units.
- ***Probabilistic Approach:***
  - Monitor checks certain portions (consecutive or discrete) of output result from compute units.
- ***Fingerprinting:***
  - Monitor accumulates execution statistics, such as memory usage, computation time consumed, etc.
- ***Hashing based Approach:***
  - Matches hash value of correct output (ideally partial).
- ***Attribute-based Checksum Approach:***
  - Monitor matches attributes of output results.

Heterogeneous Computing: Orchestration

- ***Machine Learning based Adaptive Orchestration:***
  - Data driven model.
  - Supervised or reinforcement learning.
- ***Rule based Adaptation:***
  - Follows certain rules to change orchestration process based on performance data provided by the monitor.
- ***Random Orchestration (Baseline):***
  - Orchestrator randomly assigns task to compute units.
  - Unresponsive to any adversarial incident.
- ***Round-robin Orchestration(Baseline):***
  - Assigns tasks in round robin manner.
  - Unresponsive to any adversarial incident.

Conclusion & Future Works

- ***Observation:***
  - *We conducted preliminary experiments using a **sorting application**, and it shows that the platform can **defend** against abnormalities satisfactorily even if approximately **two-thirds** of the compute units are **under attack**. We have not considered colluding attacks in the experiments yet. We used **baseline** orchestration mechanisms in the experiments.*
- ***Targeted applications:***
  - Sorting.
  - Compression.
  - Gradient descent calculation.
  - Machine learning algorithm.

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