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# Undergraduate Research Program

**<Computer Science>**

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| **Research Duration:** | Summer 2025 (June – August 2025) |
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| **Title of Project:** | <Improving Durability and Reliability in Phase-Change Memories Using Adaptive Learning Algorithms> |

## Goals and Objectives of the Project, Expectations and Outcomes

Describe briefly what students can expect to learn by participating in this project.

As dynamic random-access memory (DRAM) and other current transistor-based memories approach their scalability limits, the search for alternative storage methods becomes increasingly urgent. Phase-change memory (PCM) emerges as a promising candidate due to its scalability, fast access time, and zero leakage power compared to many existing memory technologies. Despite its potential, there are several research challenges that need to be addressed to make PCM a viable option for widespread use.

Here are some of the key research challenges in PCM:

### 1. Write Energy and Write Endurance

- **Problem**: PCM cells have limited write cycles before they degrade. It also requires high energy and time to switch the phase of the material (from amorphous to crystalline and vice versa), leading to higher energy consumption and slower write speeds compared to other memory technologies.
- **Research Focus**: Improving the techniques to enhance the endurance of PCM cells. This includes

developing more efficient write algorithms that minimize cell wear.

- Developing methods to reduce energy consumption and increase the speed of write operations. This can involve optimizing the phase-change process, improving thermal management, and using advanced control algorithms, which result in enhanced durability and extended lifetime of the memory.

### 2. Reliability and Error Correction

- **Problem**: Storing multiple bits per cell (MLC) increases storage density but also introduces complexity in accurately writing multiple levels of resistance and can bring write errors.
- **Research Focus**: Enhancing the precision of write mechanisms and developing robust error correction algorithms to support MLC operation.
- Developing advanced error correction codes and fault-tolerant memory architectures to ensure data integrity and reliability.

**Project Goals and Objectives:**

This project includes two main goals to address the above challenges:

**Goal 1:** Propose an adaptive learning algorithm for enhanced durability in Phase Change Memory. We need to focus on the following steps:

1. **Optimize Write Processes**: Develop and implement an innovative approach using adaptive learning techniques to optimize the write processes of PCM.
2. **Dynamic Parameter Adjustment**: Create a system that dynamically adjusts write process parameters based on real-time operating conditions and device characteristics to maximize performance while minimizing energy consumption and wear-out.
3. **Develop a Learning-Based System**: Implement a learning-based system that continuously monitors and analyzes write process performance metrics, such as write latency, energy consumption, and endurance.
4. **Machine Learning Integration**: Employ machine learning algorithms, such as reinforcement learning and deep neural networks, to model the relationships between write process parameters and performance metrics and predict optimal settings in real-time.
5. **Experimental Validation**: Conduct experimental evaluations to demonstrate the effectiveness of the proposed method.

**Goal 2:** Propose energy-efficient and reliable error correction codes for MLC PCM using machine learning-based algorithms. For goal 2, it is required to focus on:

1. **Enhance Error Correction in MLC PCM**: Develop an innovative approach to improve error correction mechanisms specifically tailored for Multi-Level Cell (MLC) PCM using machine learning techniques.
2. **Leverage Machine Learning for Error Correction**: Utilize machine learning algorithms to analyze and predict error occurrences, thereby enhancing the error correction process.
3. **Develop a Predictive Error Correction Model**: Train a machine learning model using historical MLC PCM data to accurately predict and correct errors based on complex relationships between input parameters and error correction outcomes. For historical MLC PCM data, we can consider using simulation tools to generate data. Full-system simulators like NVmain and Gem5 can be configured to simulate the behavior of MLC PCM under various conditions.
4. **Utilize Advanced Machine Learning Techniques**: Employ advanced machine learning methods, such as AdaBoost and ensemble techniques, to capture intricate patterns in MLC PCM data and improve error correction performance.
5. **Experimental Validation**: Conduct experimental evaluations to demonstrate the effectiveness of the proposed method.

**Undergraduate students will participate in the following activities:**

Students can participate in the research activities focused on optimizing write processes for phase change memories, as well as the enhancement of error correction mechanisms in Multi-Level Cell (MLC) PCM using machine learning techniques in several ways like: Literature Review, Data Collection and Preprocessing, Model Training, System Implementation, and Experimental Evaluation.

**Expected Outcomes of both Goals 1 and 2:**

1. **Improved Write Efficiency**: Achieve significant improvements in write process efficiency, reducing write latency and energy consumption for NVMs.
2. **Enhanced Device Reliability**: Increase the reliability and endurance of memory by optimizing write processes to minimize wear-out effects.
3. **Real-Time Adaptation**: Develop a system capable of real-time adaptation to varying operating conditions, such as temperature variations and voltage fluctuations.
4. **Comprehensive Performance Analysis**: Produce a comprehensive analysis of the relationships between write process parameters and performance metrics through machine learning models.
5. **Scalable Optimization Solution**: Deliver a flexible and robust optimization solution applicable to a wide range of NVM technologies and use cases.
6. **Long-Term Data-Driven Optimization**: Establish a system that continuously refines its optimization strategies based on historical data and user feedback, ensuring long-term improvements in memory system performance and longevity.
7. **Improved Error Correction Accuracy**: Achieve significant improvements in the accuracy of error correction for MLC PCM, leading to more reliable data storage and retrieval.
8. **Enhanced Reliability**: Increase the reliability of MLC PCM devices by reducing the susceptibility to write errors and variability in cell behavior.
9. **Effective Utilization of Machine Learning**: Develop a robust machine learning model that can predict and correct errors based on observed patterns in MLC PCM data.

10. **Tailored Error Correction Model**: Create a predictive error correction model specifically designed for the unique challenges of MLC PCM, ensuring better performance compared to traditional error correction methods.
11. **Advanced Data Analysis**: Utilize ensemble machine learning techniques to effectively analyze complex relationships in MLC PCM data, leading to improved error correction mechanisms.
12. **Practical Implementation**: Demonstrate the practical implementation and effectiveness of the machine learning-based error correction method through experimental validation.
13. **Publication and Dissemination**: Publish the research findings in conferences, contributing to the advancement of knowledge in the field of memory systems and adaptive learning algorithms.

By participating in these research activities, students can gain hands-on experience in machine learning, working with full-system simulators, data analysis, and system development, while also contributing to advancements in error correction mechanisms for MLC PCM technology. Additionally, they can develop critical thinking skills and problem-solving abilities by tackling challenges related to optimizing write processes in next-generation memory systems. Furthermore, they have the potential to author or co-author research papers and presentations, thereby enhancing their academic and professional portfolios.

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