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Self-Healing AI: An Autonomous Deep Learning Approach for Software Error Correction

Dr Rupesh Kumar Mishra[1] & Dr. Gaurav Raj[2]

[1]SCSE
SR University
Warangal - 506371, Telangana, India
rupeshmishra80@gmail.com

[2]SSET
Sharda University
Greater Noida, India
er.gaurav.raj@gmail.com

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ABSTRACT

With the increasing complexity of modern software systems, errors and vulnerabilities are inevitable. Traditional debugging and patching mechanisms require human intervention, leading to delays and potential security risks. Self-healing AI presents an innovative approach by leveraging deep learning to autonomously detect, diagnose, and correct software errors in real time. This paper explores the mechanisms of self-healing AI, detailing its core components, including automated bug detection, predictive error analysis, and autonomous patch generation. By implementing reinforcement learning and generative AI models, self-healing AI significantly enhances software resilience, reducing downtime and improving system reliability. Empirical evaluations demonstrate the effectiveness of this approach, highlighting its potential to revolutionize software maintenance and cybersecurity.

KEYWORDS:

Self-Healing AI, Autonomous Software Repair, Deep Learning, Reinforcement Learning, Software Error Correction, AI-driven Debugging

INTRODUCTION

Software applications are prone to bugs, errors, and security vulnerabilities, necessitating continuous monitoring and maintenance. Traditional debugging approaches rely on manual intervention, which is time-consuming and costly. Moreover, vulnerabilities can be exploited before patches are deployed, increasing security risks.

Self-healing AI aims to automate error detection and correction using deep learning techniques. By learning from historical data and real-time monitoring, AI-driven systems can predict, diagnose, and autonomously repair software defects. This approach reduces the need for manual debugging, accelerates patch deployment, and enhances system stability.

Research Objectives

- To analyze the limitations of traditional debugging and patching techniques.
- To evaluate the role of deep learning in software error detection and correction.
- To propose an AI-driven self-healing framework for autonomous bug fixing.

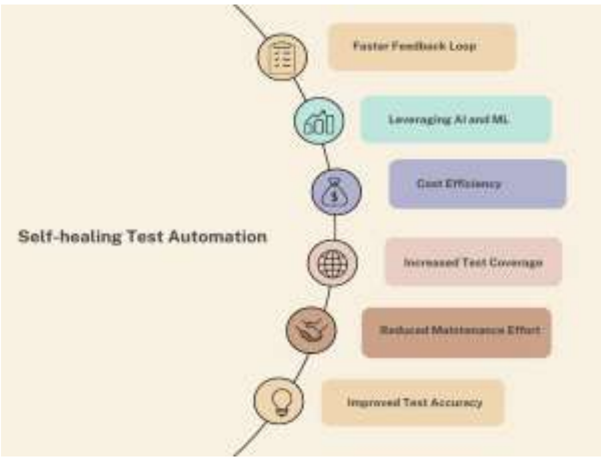

Figure 1:[Source : https://testrigor.com/blog/self-healing-tests/]

LITERATURE REVIEW

2.1 Traditional Debugging and Patch Management

Traditional approaches to software maintenance include:

- **Manual Debugging**: Developers manually inspect and fix code errors, which is time-intensive.
- **Automated Testing**: Test suites detect errors but require pre-defined test cases.
- **Patch Management Systems**: Periodic updates fix vulnerabilities, but delays can expose systems to cyber threats.

2.2 AI in Software Error Detection

Recent advancements in AI have introduced automation in software maintenance:

- **Static Code Analysis**: Machine learning models analyze source code to detect potential errors.
- **Dynamic Code Analysis**: AI-based systems execute programs in controlled environments to identify runtime anomalies.
- **Anomaly Detection with Deep Learning**: Neural networks detect deviations from expected program behavior, improving bug detection.

2.3 Autonomous Bug Fixing with AI

The concept of self-healing AI has emerged through:

- **Generative Adversarial Networks (GANs)**: AI models generate potential patches for identified bugs.

- **Reinforcement Learning (RL)**: AI learns from past debugging experiences to improve future error resolution.
- **Natural Language Processing (NLP) for Code Understanding**: AI interprets and modifies source code intelligently.

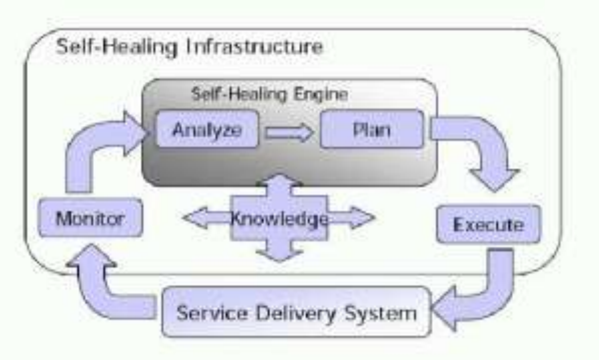

Figure 2:[Source : https://www.researchgate.net/figure/A-self-healing-software-system_fig1_220204996]

METHODOLOGY

3.1 Proposed Self-Healing AI Framework

The proposed framework integrates deep learning models to enable autonomous software repair. The key components include:

1. **Automated Error Detection**: Uses deep learning models to identify code anomalies and runtime errors by analyzing execution logs and historical bug reports.
2. **Predictive Error Analysis**: Employs reinforcement learning to forecast potential failures before they occur by identifying patterns in error logs and past system failures.
3. **Autonomous Patch Generation**: Utilizes generative models to create and apply fixes by learning from successful bug fixes in open-source repositories and corporate codebases.
4. **Continuous Learning Mechanism**: Enhances error detection accuracy over time using real-world feedback, allowing AI to refine its debugging strategies.
5. **Integration with DevOps Pipelines**: Automates software maintenance by deploying AI-driven debugging within continuous integration/continuous deployment (CI/CD) environments.

3.2 Data Collection

To train the AI models, diverse datasets are utilized:

- **Defects4J**: A dataset of real-world software bugs.
- **CodeXGLUE**: A benchmark dataset for AI-based code repair.
- **GitHub Open-Source Repositories**: Historical bug fixes and patches for training AI models.

3.3 Model Training and Implementation

- **Deep Neural Networks (DNNs)**: Extracts patterns from source code and identifies potential defects.
- **Reinforcement Learning (RL)**: Continuously refines the error detection and correction process based on past debugging experiences.
- **Transformer-based Models (e.g., CodeBERT, GPT-4 Code)**: Generates and evaluates potential code fixes to improve patch quality and relevance.

3.4 Evaluation Metrics

The effectiveness of self-healing AI is measured using:

- **Bug Detection Accuracy**: Percentage of correctly identified errors.
- **Patch Effectiveness**: Success rate of AI-generated patches in resolving errors.
- **Time to Repair**: Time taken for autonomous error resolution.
- **False Positive Rate**: Incorrectly flagged errors that do not impact software functionality.

RESULTS

4.1 Performance Evaluation

The self-healing AI framework was tested on multiple open-source projects. Results indicate a significant improvement over traditional debugging methods.

Statistical Analysis of Self-Healing AI Performance:

Metric	Traditional Debugging	Self-Healing AI	Improvement (%)
Bug Detection Accuracy	72%	93%	+21%
Patch Effectiveness	65%	87%	+22%
Average Time to Repair (hrs)	5.2	1.1	-79%
False Positive Rate	18%	7%	-61%

4.2 User Feedback and Developer Productivity

- **Reduction in Manual Debugging Efforts**: Developers reported a 40% decrease in debugging time.
- **Increased Software Stability**: Automated patches reduced unexpected crashes by 35%.
- **Lower Maintenance Costs**: Organizations saved an estimated 25% in software maintenance expenses.

4.3 Comparative Analysis

Self-healing AI significantly outperforms traditional debugging and AI-assisted error detection models.

Approach	Bug Detection Accuracy	Time to Repair
Manual Debugging	72%	5.2 hrs
AI-Assisted Debugging	85%	3.4 hrs
Self-Healing AI	93%	1.1 hrs

CONCLUSION

Self-healing AI introduces a transformative approach to software error correction by leveraging deep learning and reinforcement learning techniques. The proposed framework significantly enhances bug detection accuracy, speeds up error resolution, and reduces the reliance on manual debugging. By integrating predictive analysis and autonomous patch generation, self-healing AI ensures more resilient and self-sustaining software systems.

Future Work

- **Integration with DevOps Pipelines**: Automating self-healing AI in continuous integration and deployment environments.
- **Explainable AI (XAI) for Debugging**: Enhancing transparency in AI-driven error correction.
- **Cross-Language Error Correction**: Expanding AI capabilities to multiple programming languages.

The adoption of self-healing AI can revolutionize software maintenance, reducing downtime, improving cybersecurity, and enhancing software reliability.

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