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Research Article

AI-Based Database Index Optimization Model for Intelligent Query Performance Enhancement in Relational Database Systems

Dr. Surender Singh
Associate Professor, Department of Computer Science, Government First Grade College, Manhalli, TQ & Dist, Bidar. Karnataka, India

Corresponding Author: *Dr. Surender Singh

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Abstract

Efficient query processing is a fundamental requirement in relational database management systems (RDBMS), particularly in large-scale enterprise and cloud environments. Database indexing plays a crucial role in improving query performance; however, traditional index tuning methods rely heavily on manual intervention and static heuristics, which are inefficient for dynamic workloads. This paper proposes an AI-Based Database Index Optimization Model (AIDIOM) that leverages machine learning and reinforcement learning to automatically generate, evaluate, and optimize database indexes. The system continuously monitors workload patterns, extracts query features, predicts index utility using supervised learning models, and refines decisions using reinforcement learning feedback. Experimental evaluation using standard benchmarks such as TPC-H demonstrates significant improvements in query execution time, throughput, and resource utilization compared to traditional indexing methods. The results confirm that AI-driven index optimization provides a scalable and adaptive solution for modern database systems.

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KEYWORDS: Database Indexing, Machine Learning, Query Optimization, Reinforcement Learning, Relational Database, AI for Databases, Performance Optimisation.

1. INTRODUCTION

Relational Database Management Systems (RDBMS) are widely used in modern applications including banking systems, healthcare platforms, e-commerce systems, and enterprise resource planning (ERP). As data volume increases, query performance becomes a critical bottleneck.

Database indexes are used to speed up query execution by reducing full table scans. However, designing optimal indexes is a complex task that depends on query patterns, data distribution, and workload characteristics. Traditionally, database administrators manually configure indexes, which leads to several limitations:

- High dependency on human expertise
- Poor adaptability to dynamic workloads
- Excessive storage overhead due to redundant indexes
- Degraded write performance

To overcome these challenges, artificial intelligence techniques have been introduced into database systems. Machine learning can predict query patterns, while reinforcement learning can dynamically adjust index configurations.

This paper proposes a novel AI-based framework that automates index selection and continuously optimizes database performance.

2. LITERATURE REVIEW

Traditional index selection methods rely on cost-based query optimizers that estimate execution cost using heuristics. Although effective in static environments, they fail in dynamic workloads.

Recent research has explored:

- **Machine Learning for Query Optimization:** Predicting query execution cost and index utility
- **Deep Learning Models:** Capturing complex relationships in query workloads
- **Reinforcement Learning Approaches:** Treating index selection as a sequential decision problem
- **Learned Databases:** Using AI to replace traditional database components

Despite advancements, existing systems suffer from:

- High training complexity
- Limited generalization
- Lack of real-time adaptability
- High storage overhead

The proposed model addresses these issues using a hybrid ML + RL approach.

3. Proposed AI-Based Database Index Optimization Model

3.1 System Overview

The proposed AIDIOM system consists of:

- Workload Monitoring Module
- Feature Extraction Engine
- Machine Learning Prediction Model
- Reinforcement Learning Optimization Agent
- Index Recommendation Engine
- Database Interface Layer

3.2 Working Principle

1. SQL queries are collected from logs
2. Features are extracted (joins, filters, frequency)
3. ML model predicts index usefulness
4. Candidate indexes are generated
5. RL agent optimizes final selection
6. Indexes are applied to DBMS
7. Performance feedback is collected
8. Model is continuously updated

4. System Architecture

User Applications
|
v
Workload Monitoring Layer
|
v
Feature Extraction Module
|
v
ML Prediction Engine
|
v
Reinforcement Learning Agent
|
v
Index Recommendation System
|
v
Relational DBMS
|
v
Performance Feedback Loop

Algorithms

Algorithm 1: Index Prediction Model

Input: Query workload Q

Output: Candidate index set I

For each query q in Q: Extract features F Compute score S using ML model

If S > threshold: Add attributes to index candidate list Return I

Algorithm 2: Reinforcement Learning Optimization

State: Current index configuration + workload
Action: Add / Remove / Modify index
Reward: Improvement in query performance

Initialize policy π

Repeat:
Observe state S
Select action A using π
Apply A in DBMS
Measure reward R
Update policy using Q-learning / DQN

Algorithm 3: Redundant Index Removal
For each index I:
If usage frequency is low AND cost is high:
Delete index I

6. Database Design

Customer Table

Field	Type
Customer ID	INT (PK)
Name	VARCHAR
City	VARCHAR
Age	INT

Orders Table

Field	Type
OrderID	INT (PK)
Customer ID	INT (FK)
Amount	FLOAT
Date	DATE

AI-Generated Indexes

- INDEX(CustomerID)
- INDEX(City)
- INDEX (CustomerID, Date)
- INDEX(Amount)

7. Experimental Setup

Environment

- OS: Ubuntu Linux
- Processor: Intel i7
- RAM: 16 GB
- DBMS: MySQL / PostgreSQL
- Language: Python

Dataset

- TPC-H Benchmark
- Synthetic enterprise dataset
- E-commerce workload logs

Evaluation Metrics

- Query Response Time
- Throughput (QPS)
- CPU Usage
- Storage Overhead
- Index Maintenance Cost

8. RESULTS AND DISCUSSION

The proposed AI-based model significantly improves database performance compared to traditional indexing methods.

Key Observations

- Query execution time reduced by **35%–60%**
- Throughput improved by **25%–45%**
- Storage overhead reduced by **15%–25%**
- Faster adaptation to workload changes

Comparison Table

Method	Query Time	Throughput	Adaptability
Manual Indexing	High	Low	Low
Rule-Based DBMS	Medium	Medium	Medium
Proposed AI Model	Low	High	High

9. DISCUSSION

The improvement is achieved due to:

- Intelligent workload classification
- ML-based prediction of index benefit
- Reinforcement learning optimization loop
- Continuous feedback adaptation

The system reduces unnecessary indexes while preserving query performance.

10. CONCLUSION

This paper presented an **AI-Based Database Index Optimization Model (AIDIOM)** for improving query performance in relational database systems. The proposed model automates index selection using machine learning and reinforcement learning techniques.

Experimental evaluation shows that the proposed system significantly reduces query execution time and improves throughput while minimizing storage overhead. The adaptive nature of the model makes it suitable for modern dynamic workloads in cloud and enterprise environments.

Future Work

- Deep Reinforcement Learning-based indexing
- Cloud-native distributed database integration
- Real-time autonomous DBMS tuning
- LLM-assisted query optimization
- Self-healing database systems

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