Optimization of Energy Efficiency and Execution Time in Cloud Computing

Using MILP, Simulated Annealing, Genetic Algorithms, and Multi-Objective Goal Programming

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August 15, 2024

Introduction

- As cloud computing grows, so does energy consumption in data centers, leading to increased operational costs and CO_2 emissions.
- This project explores how optimization techniques can enhance energy efficiency and reduce execution time in cloud environments.

Problem Statement

Objective: To minimize energy consumption and execution time in a cloud computing environment.

Key Features:

- CPU usage
- Memory usage
- Network traffic
- Power consumption
- Number of executed instructions
- Execution time
- Task type, priority, and status

Mixed Integer Linear Programming (MILP) - Part 1

Objective: Minimize the total cost of energy consumption and execution time.

Decision Variables:

- x_{it}: Binary variable indicating whether task i is scheduled to run at time t.
- r_{ij}: Continuous variable representing the amount of resource j allocated to task i.

Parameters:

- $R_j^{\max}$: Maximum available amount of resource j.
- α, β: Weights assigned to energy consumption and execution time.

Mixed Integer Linear Programming (MILP) - Part 2

Objective Function:

$$\text{Minimize } Z = \alpha \times \text{Energy Consumption} + \beta \times \text{Execution Time}$$

Subject to:

$$\sum_i r_{ij} \times x_{it} \leq R_j^{\max}, \quad \forall j, t$$

$$\sum_t x_{it} = 1, \quad \forall i$$

$$x_{it} \in \{0, 1\}, \quad r_{ij} \geq 0$$

Simulated Annealing (SA)

Objective: Iteratively minimize energy consumption and execution time by exploring different configurations.

Parameters:

- S: Current solution.
- T: Temperature parameter controlling acceptance of worse solutions.
- ΔE: Change in cost between current and new solution.

Steps:

- Start with an initial solution S and initial temperature T.
- For each iteration, generate a new solution S' in the the neighborhood of S.
- Compute the change in cost $\Delta E = E(S') - E(S)$.
- If $\Delta E < 0$, accept S'. Else, accept S' with probability $\exp(-\Delta E/T)$.
- Decrease the temperature T and repeat until convergence.

Genetic Algorithms (GA)

Objective: Evolve task allocation strategies to minimize energy consumption and optimize execution time.

Parameters:

- f(chromosome): Fitness function evaluating energy consumption and execution time.
- w_1, w_2: Weights for energy consumption and execution time in the fitness function.

Steps:

- Initialize a population of chromosomes (task allocations).
- Evaluate fitness: $f(\text{chromosome}) = w_1 \times \text{Energy Consumption} + w_2 \times \text{Execution Time}$.
- Selection: Choose the fittest chromosomes.
- Crossover: Create offspring by combining pairs of chromosomes.
- Mutation: Introduce small changes to chromosomes.
- Repeat until convergence or maximum iterations.

Multi-Objective Goal Programming (MOGP)

Objective: Balance multiple goals like minimizing energy consumption and execution time.

Parameters:

- G_1: Goal to minimize energy consumption.
- G_2: Goal to minimize execution time.
- d^+, d^-: Deviation variables for each goal.
- w_1, w_2: Weights for deviations in the objective function.

Formulation:

- Define Goals: G_1 - Minimize Energy, G_2 - Minimize Execution Time.
- Formulate deviation variables (d^+ and d^-) for each goal.
- Minimize the weighted sum of deviations:
  Minimize $Z = w_1 \times d_1^+ + w_2 \times d_2^-$.
- Subject to: Goal constraints, resource constraints.

Implementation Strategy

- Implement the problem using R, with focus on data preprocessing, algorithm application, and evaluation metrics.
- **Data Preparation**: Extract and normalize key features from the dataset.
- **Algorithm Application**: Apply MILP, SA, GA, and MOGP to optimize the objectives.

Expected Outcomes

- Anticipated results include improved energy efficiency, reduced execution time, and insights into trade-offs between objectives.
- Evaluation will be based on how well the optimization techniques balance energy consumption and execution time.