

**Faculty of Engineering and Technology**

**Computer Science Department**

**Artificial Intelligence**

**LABORATORY COMP338**

**Project No. 1**

**Optimizing the 15-Dimensional Rastrigin Function**

**Using Simulated Annealing**

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# Abstract:

This project aims to apply the Simulated Annealing (SA) algorithm to minimize the 15-dimensional Rastrigin function, a non-convex mathematical benchmark known for its many local minima. SA is particularly suited for such optimization problems due to its ability to escape local optima by probabilistically accepting worse solutions in early iterations. The application includes an interactive JavaFX-based GUI that visualizes the optimization process with a convergence chart and outputs the best solution found.

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# Theory

## **Introduction**:

### Simulated Annealing Overview

Simulated Annealing is a probabilistic technique for approximating the global optimum of a given function. It is especially useful for large search spaces where finding the exact solution is impractical. The algorithm is inspired by the annealing process in metallurgy, involving heating and controlled cooling of a material to alter its physical properties, aiming to reduce defects.

The SA algorithm allows occasional uphill moves (i.e., accepting worse solutions) to escape local minima, with the probability of such moves decreasing over time as the "temperature" lowers.

### Rastrigin Function

The Rastrigin function is a non-convex function used as a performance test problem for optimization algorithms. It is highly multimodal, but its global minimum is located at the origin. The function is defined as:

**f(x)=An+i=1∑n​[xi2​−Acos(2πxi​)]**

where A=10 and n is the dimensionality of the function. The function has a global minimum at x=0, where f(x)=0.

## Problem

### Problem Description

The Rastrigin function is used to evaluate the performance of optimization algorithms due to its large search space and large number of local minima.

**Function**:  
f(x) = 10n + Σ [xᵢ² - 10cos(2πxᵢ)]

**Where**:

n = dimensionality (e.g., 15)

xᵢ ∈ [-2, 2]

Global minimum at x = [0, ..., 0], f(x) = 0

Objective: Minimize f(x) over the domain.

### Problem Formulation

Let x ∈ ℝⁿ, where each xᵢ ∈ [-2.0, 2.0].  
The goal is:  
Find x such that f(x) = min {10n + Σ [xᵢ² - 10cos(2πxᵢ)]}

**Constraints**:

* Search space: Box-constrained within [-2.0, 2.0] for each dimension.
* Solution vector: Random initialization and perturbation-based exploration.

**Objective**: Reach a near-global minimum under fixed iteration budget and temperature schedule.

### Methodology

**Algorithm Parameters**

* **Dimensions (n)**: 15
* **Search Space Bounds**: [-2.0, 2.0]
* **Initial Temperature (T)**: 1000.0
* **Minimum Temperature (T\_min)**: 0.001
* **Cooling Rate (alpha)**: 0.95
* **Maximum Iterations**: 1000

# Implementation Explanation

## Convergence Analysis

The convergence behavior typically follows a sharp early improvement followed by gradual refinement. The convergence chart in the GUI displays the best f(x) value per iteration, revealing how quickly the algorithm escapes poor regions and stabilizes.

**Behavior across runs:**

* First 100–200 iterations show rapid descent.
* Final 200 iterations focus on local exploitation.
* Small random jumps occasionally occur due to stochastic acceptance.

**Sample output:**

* Best f(x) ≈ 0.015 within 1000 iterations
* Near-global solutions consistently observed

## Parameter Setting Selection

The following heuristics guided parameter choices:

* Initial T = 1000.0: High enough to accept most transitions early.
* α = 0.95: Slow exponential decay maintains exploration.
* T\_min = 0.001: Ensures algorithm doesn’t terminate prematurely.
* Perturbation: Random Gaussian noise (μ = 0, σ = 0.1)

Exploratory tests with α = 0.9 or α = 0.99 showed α = 0.95 provides a good balance of convergence speed and solution quality.

## GUI Interface

* “Run” button triggers the optimizer
* TextArea displays the best f(x) and solution vector
* LineChart visualizes convergence
* “Save Chart” captures the graph as an image

# Discussion

The results demonstrate the effectiveness of Simulated Annealing in solving complex optimization problems. Even though the Rastrigin function presents numerous local minima, the algorithm reliably converges toward near-optimal solutions. The GUI also helps users visualize convergence, which aids understanding of the algorithm’s dynamics. However, due to the stochastic nature of SA, repeated runs may yield slightly different solutions. The flexibility of JavaFX and the object-oriented structure allowed for modular development and easy customization.

## Results

The optimizer typically shows a clear convergence curve, with the value of f(x) steadily decreasing over time. While the exact result varies due to randomness, the best values are often very close to the global minimum. Running the algorithm multiple times demonstrates both consistency and variance in convergence behavior.

Example:

* Best f(x): 0.015
* Best x: [0.01, -0.03, ..., 0.02]

## Challenges & Solutions

 Randomness: Results differ each run; used charts to visualize average behavior.

 GUI Responsiveness: Used JavaFX's Platform.runLater for thread-safe updates.

 Styling: Created reusable CSS classes for consistency.

 Image Saving: Used JavaFX’s Snapshot API to capture and export charts.

# Conclusion

Simulated Annealing proves to be a robust method for optimizing complex, multimodal functions like the Rastrigin function. Its ability to escape local minima and approximate the global optimum makes it a valuable tool in the field of optimization.

# References

* **Wikipedia**: Simulated Annealing (<https://en.wikipedia.org/wiki/Simulated_annealing>).
* **Wikipedia**: Rastrigin Function (<https://en.wikipedia.org/wiki/Test_functions_for_optimization>).
* **GeeksforGeeks**: Simulated Annealing in Java (<https://www.geeksforgeeks.org/simulated-annealing-algorithm>).
* **Course Slides and Lectures** (COMP338 - Artificial Intelligence).