

HW3

Simulated Annealing for the Travelling Salesman Problem

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```
# Load necessary libraries
set.seed(123) # For reproducibility

# Step 1: Generate Random Rewards U_ij
n_cities <- 10
U_ij <- matrix(runif(n_cities * n_cities, 1, 10), nrow = n_cities, ncol = n_cities)
diag(U_ij) <- 0 # No reward for staying in the same city

# Generate rewards for starting from city 0 to each city
U_0k <- runif(n_cities, 1, 10)

# Objective Function: Calculate total reward for a given route
calculate_reward <- function(route, U_ij, U_0k) {
  total_reward <- U_0k[route[1]] # Reward for starting from city 0
  for (i in 1:(length(route) - 1)) {
    total_reward <- total_reward + U_ij[route[i], route[i + 1]]
  }
  return(total_reward)
}

simulated_annealing <- function(U_ij, U_0k, max_iter = 5000, T_init = 100, cooling_rate = 0.99) {
  # Initialize temperature
  T <- T_init

  # Generate initial random route
  current_route <- sample(1:n_cities)
  current_reward <- calculate_reward(current_route, U_ij, U_0k)

  # Track the best solution
  best_route <- current_route
  best_reward <- current_reward
```

```

# Simulated Annealing Loop
for (iter in 1:max_iter) {
  # Generate a neighboring solution: Swap two cities
  new_route <- current_route
  swap_idx <- sample(1:n_cities, 2) # Select two random cities to swap
  new_route[swap_idx] <- new_route[rev(swap_idx)] # Swap cities

  # Calculate reward for the new route
  new_reward <- calculate_reward(new_route, U_ij, U_0k)

  # Acceptance probability (based on temperature and reward difference)
  delta <- new_reward - current_reward
  if (delta > 0 || runif(1) < exp(delta / T)) {
    # Accept the new solution
    current_route <- new_route
    current_reward <- new_reward

    # Update the best solution if the new reward is better
    if (current_reward > best_reward) {
      best_route <- current_route
      best_reward <- current_reward
    }
  }

  # Cool down the temperature
  T <- T * cooling_rate

  # Optional: Print progress every 100 iterations
  if (iter %% 100 == 0) {
    cat("Iteration:", iter, "| Best Reward:", best_reward, "\n")
  }
}

# Return the best route and reward
return(list(best_route = best_route, best_reward = best_reward))
}

```

```

# Step 3: Run Simulated Annealing
result <- simulated_annealing(U_ij, U_0k)

```

```

Iteration: 100 | Best Reward: 78.1565
Iteration: 200 | Best Reward: 78.1565
Iteration: 300 | Best Reward: 78.2857
Iteration: 400 | Best Reward: 80.30408
Iteration: 500 | Best Reward: 80.30408
Iteration: 600 | Best Reward: 83.38379
Iteration: 700 | Best Reward: 83.38379
Iteration: 800 | Best Reward: 83.38379
Iteration: 900 | Best Reward: 83.38379
Iteration: 1000 | Best Reward: 83.38379
Iteration: 1100 | Best Reward: 83.38379
Iteration: 1200 | Best Reward: 83.38379
Iteration: 1300 | Best Reward: 83.38379
Iteration: 1400 | Best Reward: 83.38379

```

```

Iteration: 1500 | Best Reward: 83.38379
Iteration: 1600 | Best Reward: 83.38379
Iteration: 1700 | Best Reward: 83.38379
Iteration: 1800 | Best Reward: 83.38379
Iteration: 1900 | Best Reward: 83.38379
Iteration: 2000 | Best Reward: 83.38379
Iteration: 2100 | Best Reward: 83.38379
Iteration: 2200 | Best Reward: 83.38379
Iteration: 2300 | Best Reward: 83.38379
Iteration: 2400 | Best Reward: 83.38379
Iteration: 2500 | Best Reward: 83.38379
Iteration: 2600 | Best Reward: 83.38379
Iteration: 2700 | Best Reward: 83.38379
Iteration: 2800 | Best Reward: 83.38379
Iteration: 2900 | Best Reward: 83.38379
Iteration: 3000 | Best Reward: 83.38379
Iteration: 3100 | Best Reward: 83.38379
Iteration: 3200 | Best Reward: 83.38379
Iteration: 3300 | Best Reward: 83.38379
Iteration: 3400 | Best Reward: 83.38379
Iteration: 3500 | Best Reward: 83.38379
Iteration: 3600 | Best Reward: 83.38379
Iteration: 3700 | Best Reward: 83.38379
Iteration: 3800 | Best Reward: 83.38379
Iteration: 3900 | Best Reward: 83.38379
Iteration: 4000 | Best Reward: 83.38379
Iteration: 4100 | Best Reward: 83.38379
Iteration: 4200 | Best Reward: 83.38379
Iteration: 4300 | Best Reward: 83.38379
Iteration: 4400 | Best Reward: 83.38379
Iteration: 4500 | Best Reward: 83.38379
Iteration: 4600 | Best Reward: 83.38379
Iteration: 4700 | Best Reward: 83.38379
Iteration: 4800 | Best Reward: 83.38379
Iteration: 4900 | Best Reward: 83.38379
Iteration: 5000 | Best Reward: 83.38379

```

```

# Step 4: Display Results
cat("Optimal Route:", result$best_route, "\n")

```

Optimal Route: 7 10 5 1 8 9 4 3 6 2

```

cat("Maximum Reward:", result$best_reward, "\n")

```

Maximum Reward: 83.38379

```

# Run Simulated Annealing Multiple Times and Store Routes
num_runs <- 50
results <- numeric(num_runs)      # To store rewards
routes <- vector("list", num_runs) # To store routes for each run

for (i in 1:num_runs) {
  result <- simulated_annealing(U_ij, U_0k)
  results[i] <- result$best_reward  # Store best reward
  routes[[i]] <- result$best_route  # Store corresponding best route
  # cat("Run:", i, "| Best Reward:", results[i], "\n")
}

```

}

Iteration: 100	Best Reward: 79.88506
Iteration: 200	Best Reward: 79.88506
Iteration: 300	Best Reward: 79.88506
Iteration: 400	Best Reward: 79.88506
Iteration: 500	Best Reward: 84.27356
Iteration: 600	Best Reward: 84.27356
Iteration: 700	Best Reward: 84.27356
Iteration: 800	Best Reward: 84.27356
Iteration: 900	Best Reward: 84.27356
Iteration: 1000	Best Reward: 84.27356
Iteration: 1100	Best Reward: 84.27356
Iteration: 1200	Best Reward: 84.27356
Iteration: 1300	Best Reward: 84.27356
Iteration: 1400	Best Reward: 84.27356
Iteration: 1500	Best Reward: 84.27356
Iteration: 1600	Best Reward: 84.27356
Iteration: 1700	Best Reward: 84.27356
Iteration: 1800	Best Reward: 84.27356
Iteration: 1900	Best Reward: 84.27356
Iteration: 2000	Best Reward: 84.27356
Iteration: 2100	Best Reward: 84.27356
Iteration: 2200	Best Reward: 84.27356
Iteration: 2300	Best Reward: 84.27356
Iteration: 2400	Best Reward: 84.27356
Iteration: 2500	Best Reward: 84.27356
Iteration: 2600	Best Reward: 84.27356
Iteration: 2700	Best Reward: 84.27356
Iteration: 2800	Best Reward: 84.27356
Iteration: 2900	Best Reward: 84.27356
Iteration: 3000	Best Reward: 84.27356
Iteration: 3100	Best Reward: 84.27356
Iteration: 3200	Best Reward: 84.27356
Iteration: 3300	Best Reward: 84.27356
Iteration: 3400	Best Reward: 84.27356
Iteration: 3500	Best Reward: 84.27356
Iteration: 3600	Best Reward: 84.27356
Iteration: 3700	Best Reward: 84.27356
Iteration: 3800	Best Reward: 84.27356
Iteration: 3900	Best Reward: 84.27356
Iteration: 4000	Best Reward: 84.27356
Iteration: 4100	Best Reward: 84.27356
Iteration: 4200	Best Reward: 84.27356
Iteration: 4300	Best Reward: 84.27356
Iteration: 4400	Best Reward: 84.27356
Iteration: 4500	Best Reward: 84.27356
Iteration: 4600	Best Reward: 84.27356
Iteration: 4700	Best Reward: 84.27356
Iteration: 4800	Best Reward: 84.27356
Iteration: 4900	Best Reward: 84.27356
Iteration: 5000	Best Reward: 84.27356
Iteration: 100	Best Reward: 74.64439
Iteration: 200	Best Reward: 80.65887

Iteration: 300	Best Reward: 80.65887
Iteration: 400	Best Reward: 82.45087
Iteration: 500	Best Reward: 86.7212
Iteration: 600	Best Reward: 86.7212
Iteration: 700	Best Reward: 86.7212
Iteration: 800	Best Reward: 86.7212
Iteration: 900	Best Reward: 86.7212
Iteration: 1000	Best Reward: 86.7212
Iteration: 1100	Best Reward: 86.7212
Iteration: 1200	Best Reward: 86.7212
Iteration: 1300	Best Reward: 86.7212
Iteration: 1400	Best Reward: 86.7212
Iteration: 1500	Best Reward: 86.7212
Iteration: 1600	Best Reward: 86.7212
Iteration: 1700	Best Reward: 86.7212
Iteration: 1800	Best Reward: 86.7212
Iteration: 1900	Best Reward: 86.7212
Iteration: 2000	Best Reward: 86.7212
Iteration: 2100	Best Reward: 86.7212
Iteration: 2200	Best Reward: 86.7212
Iteration: 2300	Best Reward: 86.7212
Iteration: 2400	Best Reward: 86.7212
Iteration: 2500	Best Reward: 86.7212
Iteration: 2600	Best Reward: 86.7212
Iteration: 2700	Best Reward: 86.7212
Iteration: 2800	Best Reward: 86.7212
Iteration: 2900	Best Reward: 86.7212
Iteration: 3000	Best Reward: 86.7212
Iteration: 3100	Best Reward: 86.7212
Iteration: 3200	Best Reward: 86.7212
Iteration: 3300	Best Reward: 86.7212
Iteration: 3400	Best Reward: 86.7212
Iteration: 3500	Best Reward: 86.7212
Iteration: 3600	Best Reward: 86.7212
Iteration: 3700	Best Reward: 86.7212
Iteration: 3800	Best Reward: 86.7212
Iteration: 3900	Best Reward: 86.7212
Iteration: 4000	Best Reward: 86.7212
Iteration: 4100	Best Reward: 86.7212
Iteration: 4200	Best Reward: 86.7212
Iteration: 4300	Best Reward: 86.7212
Iteration: 4400	Best Reward: 86.7212
Iteration: 4500	Best Reward: 86.7212
Iteration: 4600	Best Reward: 86.7212
Iteration: 4700	Best Reward: 86.7212
Iteration: 4800	Best Reward: 86.7212
Iteration: 4900	Best Reward: 86.7212
Iteration: 5000	Best Reward: 86.7212
Iteration: 100	Best Reward: 69.25479
Iteration: 200	Best Reward: 76.65909
Iteration: 300	Best Reward: 81.83477
Iteration: 400	Best Reward: 81.83477
Iteration: 500	Best Reward: 81.83477
Iteration: 600	Best Reward: 84.67777

Iteration: 700	Best Reward: 84.67777
Iteration: 800	Best Reward: 84.67777
Iteration: 900	Best Reward: 84.67777
Iteration: 1000	Best Reward: 84.67777
Iteration: 1100	Best Reward: 84.67777
Iteration: 1200	Best Reward: 84.67777
Iteration: 1300	Best Reward: 84.67777
Iteration: 1400	Best Reward: 84.67777
Iteration: 1500	Best Reward: 84.67777
Iteration: 1600	Best Reward: 84.67777
Iteration: 1700	Best Reward: 84.67777
Iteration: 1800	Best Reward: 84.67777
Iteration: 1900	Best Reward: 84.67777
Iteration: 2000	Best Reward: 84.67777
Iteration: 2100	Best Reward: 84.67777
Iteration: 2200	Best Reward: 84.67777
Iteration: 2300	Best Reward: 84.67777
Iteration: 2400	Best Reward: 84.67777
Iteration: 2500	Best Reward: 84.67777
Iteration: 2600	Best Reward: 84.67777
Iteration: 2700	Best Reward: 84.67777
Iteration: 2800	Best Reward: 84.67777
Iteration: 2900	Best Reward: 84.67777
Iteration: 3000	Best Reward: 84.67777
Iteration: 3100	Best Reward: 84.67777
Iteration: 3200	Best Reward: 84.67777
Iteration: 3300	Best Reward: 84.67777
Iteration: 3400	Best Reward: 84.67777
Iteration: 3500	Best Reward: 84.67777
Iteration: 3600	Best Reward: 84.67777
Iteration: 3700	Best Reward: 84.67777
Iteration: 3800	Best Reward: 84.67777
Iteration: 3900	Best Reward: 84.67777
Iteration: 4000	Best Reward: 84.67777
Iteration: 4100	Best Reward: 84.67777
Iteration: 4200	Best Reward: 84.67777
Iteration: 4300	Best Reward: 84.67777
Iteration: 4400	Best Reward: 84.67777
Iteration: 4500	Best Reward: 84.67777
Iteration: 4600	Best Reward: 84.67777
Iteration: 4700	Best Reward: 84.67777
Iteration: 4800	Best Reward: 84.67777
Iteration: 4900	Best Reward: 84.67777
Iteration: 5000	Best Reward: 84.67777
Iteration: 100	Best Reward: 69.28418
Iteration: 200	Best Reward: 70.72776
Iteration: 300	Best Reward: 75.90575
Iteration: 400	Best Reward: 76.78849
Iteration: 500	Best Reward: 80.53134
Iteration: 600	Best Reward: 81.47435
Iteration: 700	Best Reward: 81.47435
Iteration: 800	Best Reward: 81.47435
Iteration: 900	Best Reward: 81.47435
Iteration: 1000	Best Reward: 81.47435

Iteration: 1100	Best Reward: 81.47435
Iteration: 1200	Best Reward: 81.47435
Iteration: 1300	Best Reward: 81.47435
Iteration: 1400	Best Reward: 81.47435
Iteration: 1500	Best Reward: 81.47435
Iteration: 1600	Best Reward: 81.47435
Iteration: 1700	Best Reward: 81.47435
Iteration: 1800	Best Reward: 81.47435
Iteration: 1900	Best Reward: 81.47435
Iteration: 2000	Best Reward: 81.47435
Iteration: 2100	Best Reward: 81.47435
Iteration: 2200	Best Reward: 81.47435
Iteration: 2300	Best Reward: 81.47435
Iteration: 2400	Best Reward: 81.47435
Iteration: 2500	Best Reward: 81.47435
Iteration: 2600	Best Reward: 81.47435
Iteration: 2700	Best Reward: 81.47435
Iteration: 2800	Best Reward: 81.47435
Iteration: 2900	Best Reward: 81.47435
Iteration: 3000	Best Reward: 81.47435
Iteration: 3100	Best Reward: 81.47435
Iteration: 3200	Best Reward: 81.47435
Iteration: 3300	Best Reward: 81.47435
Iteration: 3400	Best Reward: 81.47435
Iteration: 3500	Best Reward: 81.47435
Iteration: 3600	Best Reward: 81.47435
Iteration: 3700	Best Reward: 81.47435
Iteration: 3800	Best Reward: 81.47435
Iteration: 3900	Best Reward: 81.47435
Iteration: 4000	Best Reward: 81.47435
Iteration: 4100	Best Reward: 81.47435
Iteration: 4200	Best Reward: 81.47435
Iteration: 4300	Best Reward: 81.47435
Iteration: 4400	Best Reward: 81.47435
Iteration: 4500	Best Reward: 81.47435
Iteration: 4600	Best Reward: 81.47435
Iteration: 4700	Best Reward: 81.47435
Iteration: 4800	Best Reward: 81.47435
Iteration: 4900	Best Reward: 81.47435
Iteration: 5000	Best Reward: 81.47435
Iteration: 100	Best Reward: 72.03829
Iteration: 200	Best Reward: 81.52582
Iteration: 300	Best Reward: 81.52582
Iteration: 400	Best Reward: 81.52582
Iteration: 500	Best Reward: 81.95705
Iteration: 600	Best Reward: 81.95705
Iteration: 700	Best Reward: 81.95705
Iteration: 800	Best Reward: 81.95705
Iteration: 900	Best Reward: 81.95705
Iteration: 1000	Best Reward: 81.95705
Iteration: 1100	Best Reward: 81.95705
Iteration: 1200	Best Reward: 81.95705
Iteration: 1300	Best Reward: 81.95705
Iteration: 1400	Best Reward: 81.95705

Iteration: 1500	Best Reward: 81.95705
Iteration: 1600	Best Reward: 81.95705
Iteration: 1700	Best Reward: 81.95705
Iteration: 1800	Best Reward: 81.95705
Iteration: 1900	Best Reward: 81.95705
Iteration: 2000	Best Reward: 81.95705
Iteration: 2100	Best Reward: 81.95705
Iteration: 2200	Best Reward: 81.95705
Iteration: 2300	Best Reward: 81.95705
Iteration: 2400	Best Reward: 81.95705
Iteration: 2500	Best Reward: 81.95705
Iteration: 2600	Best Reward: 81.95705
Iteration: 2700	Best Reward: 81.95705
Iteration: 2800	Best Reward: 81.95705
Iteration: 2900	Best Reward: 81.95705
Iteration: 3000	Best Reward: 81.95705
Iteration: 3100	Best Reward: 81.95705
Iteration: 3200	Best Reward: 81.95705
Iteration: 3300	Best Reward: 81.95705
Iteration: 3400	Best Reward: 81.95705
Iteration: 3500	Best Reward: 81.95705
Iteration: 3600	Best Reward: 81.95705
Iteration: 3700	Best Reward: 81.95705
Iteration: 3800	Best Reward: 81.95705
Iteration: 3900	Best Reward: 81.95705
Iteration: 4000	Best Reward: 81.95705
Iteration: 4100	Best Reward: 81.95705
Iteration: 4200	Best Reward: 81.95705
Iteration: 4300	Best Reward: 81.95705
Iteration: 4400	Best Reward: 81.95705
Iteration: 4500	Best Reward: 81.95705
Iteration: 4600	Best Reward: 81.95705
Iteration: 4700	Best Reward: 81.95705
Iteration: 4800	Best Reward: 81.95705
Iteration: 4900	Best Reward: 81.95705
Iteration: 5000	Best Reward: 81.95705
Iteration: 100	Best Reward: 74.54295
Iteration: 200	Best Reward: 80.31917
Iteration: 300	Best Reward: 80.31917
Iteration: 400	Best Reward: 80.31917
Iteration: 500	Best Reward: 82.88245
Iteration: 600	Best Reward: 82.88245
Iteration: 700	Best Reward: 82.88245
Iteration: 800	Best Reward: 82.88245
Iteration: 900	Best Reward: 82.88245
Iteration: 1000	Best Reward: 82.88245
Iteration: 1100	Best Reward: 82.88245
Iteration: 1200	Best Reward: 82.88245
Iteration: 1300	Best Reward: 82.88245
Iteration: 1400	Best Reward: 82.88245
Iteration: 1500	Best Reward: 82.88245
Iteration: 1600	Best Reward: 82.88245
Iteration: 1700	Best Reward: 82.88245
Iteration: 1800	Best Reward: 82.88245

Iteration: 1900	Best Reward: 82.88245
Iteration: 2000	Best Reward: 82.88245
Iteration: 2100	Best Reward: 82.88245
Iteration: 2200	Best Reward: 82.88245
Iteration: 2300	Best Reward: 82.88245
Iteration: 2400	Best Reward: 82.88245
Iteration: 2500	Best Reward: 82.88245
Iteration: 2600	Best Reward: 82.88245
Iteration: 2700	Best Reward: 82.88245
Iteration: 2800	Best Reward: 82.88245
Iteration: 2900	Best Reward: 82.88245
Iteration: 3000	Best Reward: 82.88245
Iteration: 3100	Best Reward: 82.88245
Iteration: 3200	Best Reward: 82.88245
Iteration: 3300	Best Reward: 82.88245
Iteration: 3400	Best Reward: 82.88245
Iteration: 3500	Best Reward: 82.88245
Iteration: 3600	Best Reward: 82.88245
Iteration: 3700	Best Reward: 82.88245
Iteration: 3800	Best Reward: 82.88245
Iteration: 3900	Best Reward: 82.88245
Iteration: 4000	Best Reward: 82.88245
Iteration: 4100	Best Reward: 82.88245
Iteration: 4200	Best Reward: 82.88245
Iteration: 4300	Best Reward: 82.88245
Iteration: 4400	Best Reward: 82.88245
Iteration: 4500	Best Reward: 82.88245
Iteration: 4600	Best Reward: 82.88245
Iteration: 4700	Best Reward: 82.88245
Iteration: 4800	Best Reward: 82.88245
Iteration: 4900	Best Reward: 82.88245
Iteration: 5000	Best Reward: 82.88245
Iteration: 100	Best Reward: 75.22535
Iteration: 200	Best Reward: 75.22535
Iteration: 300	Best Reward: 75.22535
Iteration: 400	Best Reward: 79.47423
Iteration: 500	Best Reward: 83.95166
Iteration: 600	Best Reward: 83.95166
Iteration: 700	Best Reward: 83.95166
Iteration: 800	Best Reward: 89.50594
Iteration: 900	Best Reward: 89.50594
Iteration: 1000	Best Reward: 89.50594
Iteration: 1100	Best Reward: 89.50594
Iteration: 1200	Best Reward: 89.50594
Iteration: 1300	Best Reward: 89.50594
Iteration: 1400	Best Reward: 89.50594
Iteration: 1500	Best Reward: 89.50594
Iteration: 1600	Best Reward: 89.50594
Iteration: 1700	Best Reward: 89.50594
Iteration: 1800	Best Reward: 89.50594
Iteration: 1900	Best Reward: 89.50594
Iteration: 2000	Best Reward: 89.50594
Iteration: 2100	Best Reward: 89.50594
Iteration: 2200	Best Reward: 89.50594

Iteration: 2300	Best Reward: 89.50594
Iteration: 2400	Best Reward: 89.50594
Iteration: 2500	Best Reward: 89.50594
Iteration: 2600	Best Reward: 89.50594
Iteration: 2700	Best Reward: 89.50594
Iteration: 2800	Best Reward: 89.50594
Iteration: 2900	Best Reward: 89.50594
Iteration: 3000	Best Reward: 89.50594
Iteration: 3100	Best Reward: 89.50594
Iteration: 3200	Best Reward: 89.50594
Iteration: 3300	Best Reward: 89.50594
Iteration: 3400	Best Reward: 89.50594
Iteration: 3500	Best Reward: 89.50594
Iteration: 3600	Best Reward: 89.50594
Iteration: 3700	Best Reward: 89.50594
Iteration: 3800	Best Reward: 89.50594
Iteration: 3900	Best Reward: 89.50594
Iteration: 4000	Best Reward: 89.50594
Iteration: 4100	Best Reward: 89.50594
Iteration: 4200	Best Reward: 89.50594
Iteration: 4300	Best Reward: 89.50594
Iteration: 4400	Best Reward: 89.50594
Iteration: 4500	Best Reward: 89.50594
Iteration: 4600	Best Reward: 89.50594
Iteration: 4700	Best Reward: 89.50594
Iteration: 4800	Best Reward: 89.50594
Iteration: 4900	Best Reward: 89.50594
Iteration: 5000	Best Reward: 89.50594
Iteration: 100	Best Reward: 74.02895
Iteration: 200	Best Reward: 78.18587
Iteration: 300	Best Reward: 78.64713
Iteration: 400	Best Reward: 80.74455
Iteration: 500	Best Reward: 82.45087
Iteration: 600	Best Reward: 83.46015
Iteration: 700	Best Reward: 83.46015
Iteration: 800	Best Reward: 83.46015
Iteration: 900	Best Reward: 83.46015
Iteration: 1000	Best Reward: 83.46015
Iteration: 1100	Best Reward: 83.46015
Iteration: 1200	Best Reward: 83.46015
Iteration: 1300	Best Reward: 83.46015
Iteration: 1400	Best Reward: 83.46015
Iteration: 1500	Best Reward: 83.46015
Iteration: 1600	Best Reward: 83.46015
Iteration: 1700	Best Reward: 83.46015
Iteration: 1800	Best Reward: 83.46015
Iteration: 1900	Best Reward: 83.46015
Iteration: 2000	Best Reward: 83.46015
Iteration: 2100	Best Reward: 83.46015
Iteration: 2200	Best Reward: 83.46015
Iteration: 2300	Best Reward: 83.46015
Iteration: 2400	Best Reward: 83.46015
Iteration: 2500	Best Reward: 83.46015
Iteration: 2600	Best Reward: 83.46015

Iteration: 2700	Best Reward: 83.46015
Iteration: 2800	Best Reward: 83.46015
Iteration: 2900	Best Reward: 83.46015
Iteration: 3000	Best Reward: 83.46015
Iteration: 3100	Best Reward: 83.46015
Iteration: 3200	Best Reward: 83.46015
Iteration: 3300	Best Reward: 83.46015
Iteration: 3400	Best Reward: 83.46015
Iteration: 3500	Best Reward: 83.46015
Iteration: 3600	Best Reward: 83.46015
Iteration: 3700	Best Reward: 83.46015
Iteration: 3800	Best Reward: 83.46015
Iteration: 3900	Best Reward: 83.46015
Iteration: 4000	Best Reward: 83.46015
Iteration: 4100	Best Reward: 83.46015
Iteration: 4200	Best Reward: 83.46015
Iteration: 4300	Best Reward: 83.46015
Iteration: 4400	Best Reward: 83.46015
Iteration: 4500	Best Reward: 83.46015
Iteration: 4600	Best Reward: 83.46015
Iteration: 4700	Best Reward: 83.46015
Iteration: 4800	Best Reward: 83.46015
Iteration: 4900	Best Reward: 83.46015
Iteration: 5000	Best Reward: 83.46015
Iteration: 100	Best Reward: 72.18649
Iteration: 200	Best Reward: 72.18649
Iteration: 300	Best Reward: 79.13341
Iteration: 400	Best Reward: 81.97279
Iteration: 500	Best Reward: 83.42032
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Iteration: 800	Best Reward: 83.42032
Iteration: 900	Best Reward: 83.42032
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Iteration: 3000	Best Reward: 83.42032

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Iteration: 3200	Best Reward: 83.42032
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Iteration: 300	Best Reward: 78.47777
Iteration: 400	Best Reward: 81.33289
Iteration: 500	Best Reward: 82.83325
Iteration: 600	Best Reward: 85.23039
Iteration: 700	Best Reward: 85.23039
Iteration: 800	Best Reward: 85.23039
Iteration: 900	Best Reward: 85.23039
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Iteration: 4500	Best Reward: 89.50594
Iteration: 4600	Best Reward: 89.50594
Iteration: 4700	Best Reward: 89.50594
Iteration: 4800	Best Reward: 89.50594
Iteration: 4900	Best Reward: 89.50594
Iteration: 5000	Best Reward: 89.50594

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Iteration: 200	Best Reward: 79.05677
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Iteration: 400	Best Reward: 79.45212

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Iteration: 700	Best Reward: 79.45212
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Iteration: 200	Best Reward: 73.31073
Iteration: 300	Best Reward: 78.9476
Iteration: 400	Best Reward: 84.07554
Iteration: 500	Best Reward: 84.07554
Iteration: 600	Best Reward: 84.07554
Iteration: 700	Best Reward: 85.19039
Iteration: 800	Best Reward: 85.19039

Iteration: 900 | Best Reward: 85.19039
Iteration: 1000 | Best Reward: 85.19039
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Iteration: 400 | Best Reward: 77.62293
Iteration: 500 | Best Reward: 81.66378
Iteration: 600 | Best Reward: 84.54947
Iteration: 700 | Best Reward: 84.54947
Iteration: 800 | Best Reward: 84.54947
Iteration: 900 | Best Reward: 84.54947
Iteration: 1000 | Best Reward: 84.54947
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Iteration: 1200 | Best Reward: 84.54947

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Iteration: 4600	Best Reward: 84.54947
Iteration: 4700	Best Reward: 84.54947
Iteration: 4800	Best Reward: 84.54947
Iteration: 4900	Best Reward: 84.54947
Iteration: 5000	Best Reward: 84.54947
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Iteration: 200	Best Reward: 74.46539
Iteration: 300	Best Reward: 75.86693
Iteration: 400	Best Reward: 83.73579
Iteration: 500	Best Reward: 86.6601
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Iteration: 1500	Best Reward: 86.6601
Iteration: 1600	Best Reward: 86.6601

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Iteration: 5000	Best Reward: 86.6601
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Iteration: 200	Best Reward: 80.53209
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Iteration: 600	Best Reward: 83.73616
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Iteration: 2000	Best Reward: 83.73616

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Iteration: 2200	Best Reward: 83.73616
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Iteration: 2100	Best Reward: 82.83808
Iteration: 2200	Best Reward: 82.83808
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Iteration: 3900	Best Reward: 86.03059
Iteration: 4000	Best Reward: 86.03059
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Iteration: 4700	Best Reward: 84.30292
Iteration: 4800	Best Reward: 84.30292

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Iteration: 4600	Best Reward: 81.85985
Iteration: 4700	Best Reward: 81.85985
Iteration: 4800	Best Reward: 81.85985
Iteration: 4900	Best Reward: 81.85985
Iteration: 5000	Best Reward: 81.85985
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Iteration: 200	Best Reward: 76.27664

Iteration: 300	Best Reward: 76.27664
Iteration: 400	Best Reward: 84.81004
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Iteration: 4500	Best Reward: 86.6601
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Iteration: 4700	Best Reward: 86.6601
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Iteration: 200	Best Reward: 81.75484
Iteration: 300	Best Reward: 81.75484
Iteration: 400	Best Reward: 81.75484
Iteration: 500	Best Reward: 83.43926
Iteration: 600	Best Reward: 86.56495

Iteration: 700 | Best Reward: 86.56495
Iteration: 800 | Best Reward: 86.56495
Iteration: 900 | Best Reward: 86.56495
Iteration: 1000 | Best Reward: 86.56495
Iteration: 1100 | Best Reward: 86.56495
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Iteration: 900 | Best Reward: 83.43926
Iteration: 1000 | Best Reward: 83.43926

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Iteration: 400	Best Reward: 80.70257
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Iteration: 4700	Best Reward: 83.8489
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Iteration: 800	Best Reward: 83.43618
Iteration: 900	Best Reward: 83.43618
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Iteration: 1200	Best Reward: 83.43618
Iteration: 1300	Best Reward: 83.43618
Iteration: 1400	Best Reward: 83.43618
Iteration: 1500	Best Reward: 83.43618
Iteration: 1600	Best Reward: 83.43618
Iteration: 1700	Best Reward: 83.43618
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Iteration: 4100	Best Reward: 83.43618
Iteration: 4200	Best Reward: 83.43618
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Iteration: 4500	Best Reward: 83.43618
Iteration: 4600	Best Reward: 83.43618

Iteration: 4700	Best Reward: 83.43618
Iteration: 4800	Best Reward: 83.43618
Iteration: 4900	Best Reward: 83.43618
Iteration: 5000	Best Reward: 83.43618
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Iteration: 200	Best Reward: 73.05052
Iteration: 300	Best Reward: 75.33336
Iteration: 400	Best Reward: 78.99536
Iteration: 500	Best Reward: 82.33842
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Iteration: 700	Best Reward: 82.33842
Iteration: 800	Best Reward: 82.33842
Iteration: 900	Best Reward: 82.33842
Iteration: 1000	Best Reward: 82.33842
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Iteration: 4600	Best Reward: 82.33842
Iteration: 4700	Best Reward: 82.33842
Iteration: 4800	Best Reward: 82.33842
Iteration: 4900	Best Reward: 82.33842
Iteration: 5000	Best Reward: 82.33842

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Iteration: 200	Best Reward: 75.15703
Iteration: 300	Best Reward: 80.06375
Iteration: 400	Best Reward: 80.17193
Iteration: 500	Best Reward: 85.19039
Iteration: 600	Best Reward: 86.20552
Iteration: 700	Best Reward: 86.20552
Iteration: 800	Best Reward: 86.20552
Iteration: 900	Best Reward: 86.20552
Iteration: 1000	Best Reward: 86.20552
Iteration: 1100	Best Reward: 86.20552
Iteration: 1200	Best Reward: 86.20552
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Iteration: 4600	Best Reward: 86.20552
Iteration: 4700	Best Reward: 86.20552
Iteration: 4800	Best Reward: 86.20552
Iteration: 4900	Best Reward: 86.20552
Iteration: 5000	Best Reward: 86.20552
Iteration: 100	Best Reward: 77.95186
Iteration: 200	Best Reward: 77.95186
Iteration: 300	Best Reward: 77.95186
Iteration: 400	Best Reward: 83.34037

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Iteration: 700	Best Reward: 86.50575
Iteration: 800	Best Reward: 86.50575
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Iteration: 1000	Best Reward: 86.50575
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Iteration: 200	Best Reward: 81.62382
Iteration: 300	Best Reward: 81.62382
Iteration: 400	Best Reward: 81.62382
Iteration: 500	Best Reward: 83.9515
Iteration: 600	Best Reward: 84.10418
Iteration: 700	Best Reward: 84.10418
Iteration: 800	Best Reward: 84.10418

Iteration: 900 | Best Reward: 84.10418
Iteration: 1000 | Best Reward: 84.10418
Iteration: 1100 | Best Reward: 84.10418
Iteration: 1200 | Best Reward: 84.10418
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Iteration: 100 | Best Reward: 77.54501
Iteration: 200 | Best Reward: 79.07488
Iteration: 300 | Best Reward: 79.25107
Iteration: 400 | Best Reward: 81.11344
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Iteration: 600 | Best Reward: 81.11344
Iteration: 700 | Best Reward: 81.11344
Iteration: 800 | Best Reward: 81.11344
Iteration: 900 | Best Reward: 81.11344
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Iteration: 1200 | Best Reward: 81.11344

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Iteration: 1300	Best Reward: 80.57923
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Iteration: 2000	Best Reward: 83.04821

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Iteration: 3000	Best Reward: 81.07631
Iteration: 3100	Best Reward: 81.07631
Iteration: 3200	Best Reward: 81.07631

```
Iteration: 3300 | Best Reward: 81.07631
Iteration: 3400 | Best Reward: 81.07631
Iteration: 3500 | Best Reward: 81.07631
Iteration: 3600 | Best Reward: 81.07631
Iteration: 3700 | Best Reward: 81.07631
Iteration: 3800 | Best Reward: 81.07631
Iteration: 3900 | Best Reward: 81.07631
Iteration: 4000 | Best Reward: 81.07631
Iteration: 4100 | Best Reward: 81.07631
Iteration: 4200 | Best Reward: 81.07631
Iteration: 4300 | Best Reward: 81.07631
Iteration: 4400 | Best Reward: 81.07631
Iteration: 4500 | Best Reward: 81.07631
Iteration: 4600 | Best Reward: 81.07631
Iteration: 4700 | Best Reward: 81.07631
Iteration: 4800 | Best Reward: 81.07631
Iteration: 4900 | Best Reward: 81.07631
Iteration: 5000 | Best Reward: 81.07631
```

```
# Find the Maximum Reward and Its Route
max_reward <- max(results)
best_run_index <- which.max(results) # Index of the maximum reward
best_route <- routes[[best_run_index]] # Retrieve the route for the max reward

# Print Results
cat("\nAll Best Rewards Across Runs:", results, "\n")
```

```
All Best Rewards Across Runs: 84.27356 86.7212 84.67777 81.47435 81.95705 82.88245 89.50594 83.46015 83.42032
```

```
cat("Maximum Reward:", max_reward, "\n")
```

```
Maximum Reward: 89.62038
```

```
cat("Best Route Corresponding to Maximum Reward:", best_route, "\n")
```

```
Best Route Corresponding to Maximum Reward: 7 10 5 1 2 4 3 8 9 6
```

Visualization

Visualizations can help you better understand the **performance of the Simulated Annealing (SA) algorithm**, analyze the solution quality, and visualize the traveling salesman route. Here are several visualization approaches you can use in R:

1. Visualize the Convergence of Rewards

Plot the **progression of rewards** (best rewards) over iterations to analyze how the SA algorithm converges.

Code:

Modify the Simulated Annealing function to **track rewards** at each iteration and then plot them.

```
# Simulated Annealing with Reward Tracking
simulated_annealing_with_tracking <- function(U_ij, U_0k, max_iter = 5000, T_init = 100, cooling_rate = 0.99) {
  T <- T_init
```

```

current_route <- sample(1:n_cities)
current_reward <- calculate_reward(current_route, U_ij, U_0k)
best_route <- current_route
best_reward <- current_reward

reward_progress <- numeric(max_iter) # Track reward progression

for (iter in 1:max_iter) {
  new_route <- current_route
  swap_idx <- sample(1:n_cities, 2)
  new_route[swap_idx] <- new_route[rev(swap_idx)]
  new_reward <- calculate_reward(new_route, U_ij, U_0k)

  delta <- new_reward - current_reward
  if (delta > 0 || runif(1) < exp(delta / T)) {
    current_route <- new_route
    current_reward <- new_reward
    if (current_reward > best_reward) {
      best_reward <- current_reward
    }
  }

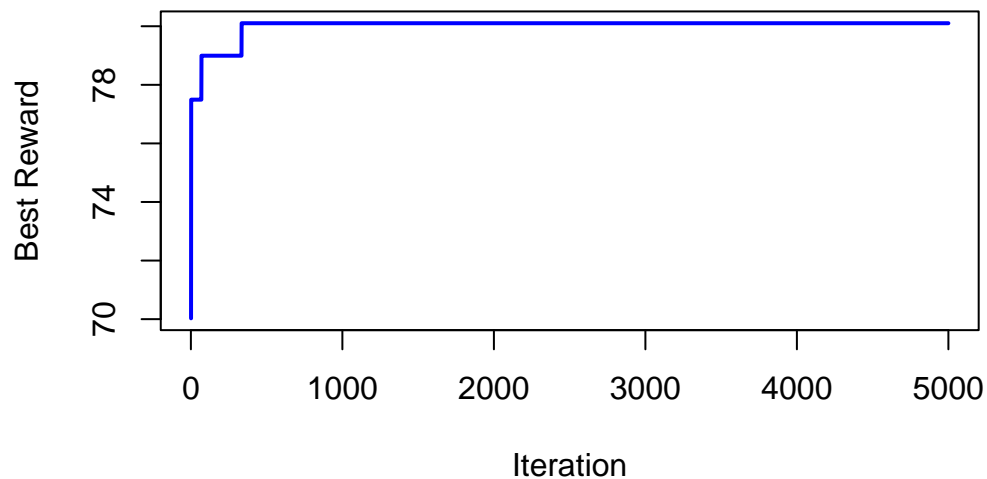
  reward_progress[iter] <- best_reward # Record the best reward so far
  T <- T * cooling_rate
}

return(list(best_route = best_route, best_reward = best_reward, reward_progress = reward_progress))
}

# Run SA with tracking
result <- simulated_annealing_with_tracking(U_ij, U_0k)
par(mfrow=c(1,1))
# Plot the Reward Progression
plot(result$reward_progress, type = "l", col = "blue", lwd = 2,
      xlab = "Iteration", ylab = "Best Reward",
      main = "Convergence of Simulated Annealing")

```

Convergence of Simulated Annealing



What It Shows:

- The x-axis represents the number of iterations.
- The y-axis shows the best reward achieved so far.
- The curve indicates how the SA algorithm converges to the best solution over time.

2. Compare Rewards Across Multiple Runs

Plot a **bar chart** or **boxplot** to compare the best rewards obtained in multiple runs of the SA algorithm.

Code:

```
# Run SA Multiple Times and Collect Results
num_runs <- 10
results <- numeric(num_runs)

for (i in 1:num_runs) {
  result <- simulated_annealing(U_ij, U_0k)
  results[i] <- result$best_reward
}
```

```
Iteration: 100 | Best Reward: 76.41255
Iteration: 200 | Best Reward: 76.41255
Iteration: 300 | Best Reward: 76.41255
Iteration: 400 | Best Reward: 77.82642
Iteration: 500 | Best Reward: 83.87931
Iteration: 600 | Best Reward: 83.87931
Iteration: 700 | Best Reward: 83.87931
Iteration: 800 | Best Reward: 83.87931
Iteration: 900 | Best Reward: 83.87931
Iteration: 1000 | Best Reward: 83.87931
Iteration: 1100 | Best Reward: 83.87931
Iteration: 1200 | Best Reward: 83.87931
Iteration: 1300 | Best Reward: 83.87931
Iteration: 1400 | Best Reward: 83.87931
```

Iteration: 1500	Best Reward: 83.87931
Iteration: 1600	Best Reward: 83.87931
Iteration: 1700	Best Reward: 83.87931
Iteration: 1800	Best Reward: 83.87931
Iteration: 1900	Best Reward: 83.87931
Iteration: 2000	Best Reward: 83.87931
Iteration: 2100	Best Reward: 83.87931
Iteration: 2200	Best Reward: 83.87931
Iteration: 2300	Best Reward: 83.87931
Iteration: 2400	Best Reward: 83.87931
Iteration: 2500	Best Reward: 83.87931
Iteration: 2600	Best Reward: 83.87931
Iteration: 2700	Best Reward: 83.87931
Iteration: 2800	Best Reward: 83.87931
Iteration: 2900	Best Reward: 83.87931
Iteration: 3000	Best Reward: 83.87931
Iteration: 3100	Best Reward: 83.87931
Iteration: 3200	Best Reward: 83.87931
Iteration: 3300	Best Reward: 83.87931
Iteration: 3400	Best Reward: 83.87931
Iteration: 3500	Best Reward: 83.87931
Iteration: 3600	Best Reward: 83.87931
Iteration: 3700	Best Reward: 83.87931
Iteration: 3800	Best Reward: 83.87931
Iteration: 3900	Best Reward: 83.87931
Iteration: 4000	Best Reward: 83.87931
Iteration: 4100	Best Reward: 83.87931
Iteration: 4200	Best Reward: 83.87931
Iteration: 4300	Best Reward: 83.87931
Iteration: 4400	Best Reward: 83.87931
Iteration: 4500	Best Reward: 83.87931
Iteration: 4600	Best Reward: 83.87931
Iteration: 4700	Best Reward: 83.87931
Iteration: 4800	Best Reward: 83.87931
Iteration: 4900	Best Reward: 83.87931
Iteration: 5000	Best Reward: 83.87931
Iteration: 100	Best Reward: 73.91817
Iteration: 200	Best Reward: 75.32983
Iteration: 300	Best Reward: 76.61076
Iteration: 400	Best Reward: 76.72211
Iteration: 500	Best Reward: 83.76884
Iteration: 600	Best Reward: 85.20129
Iteration: 700	Best Reward: 85.20129
Iteration: 800	Best Reward: 85.20129
Iteration: 900	Best Reward: 85.20129
Iteration: 1000	Best Reward: 85.20129
Iteration: 1100	Best Reward: 85.20129
Iteration: 1200	Best Reward: 85.20129
Iteration: 1300	Best Reward: 85.20129
Iteration: 1400	Best Reward: 85.20129
Iteration: 1500	Best Reward: 85.20129
Iteration: 1600	Best Reward: 85.20129
Iteration: 1700	Best Reward: 85.20129
Iteration: 1800	Best Reward: 85.20129

Iteration: 1900	Best Reward: 85.20129
Iteration: 2000	Best Reward: 85.20129
Iteration: 2100	Best Reward: 85.20129
Iteration: 2200	Best Reward: 85.20129
Iteration: 2300	Best Reward: 85.20129
Iteration: 2400	Best Reward: 85.20129
Iteration: 2500	Best Reward: 85.20129
Iteration: 2600	Best Reward: 85.20129
Iteration: 2700	Best Reward: 85.20129
Iteration: 2800	Best Reward: 85.20129
Iteration: 2900	Best Reward: 85.20129
Iteration: 3000	Best Reward: 85.20129
Iteration: 3100	Best Reward: 85.20129
Iteration: 3200	Best Reward: 85.20129
Iteration: 3300	Best Reward: 85.20129
Iteration: 3400	Best Reward: 85.20129
Iteration: 3500	Best Reward: 85.20129
Iteration: 3600	Best Reward: 85.20129
Iteration: 3700	Best Reward: 85.20129
Iteration: 3800	Best Reward: 85.20129
Iteration: 3900	Best Reward: 85.20129
Iteration: 4000	Best Reward: 85.20129
Iteration: 4100	Best Reward: 85.20129
Iteration: 4200	Best Reward: 85.20129
Iteration: 4300	Best Reward: 85.20129
Iteration: 4400	Best Reward: 85.20129
Iteration: 4500	Best Reward: 85.20129
Iteration: 4600	Best Reward: 85.20129
Iteration: 4700	Best Reward: 85.20129
Iteration: 4800	Best Reward: 85.20129
Iteration: 4900	Best Reward: 85.20129
Iteration: 5000	Best Reward: 85.20129
Iteration: 100	Best Reward: 76.92922
Iteration: 200	Best Reward: 76.92922
Iteration: 300	Best Reward: 77.36723
Iteration: 400	Best Reward: 78.11592
Iteration: 500	Best Reward: 80.29864
Iteration: 600	Best Reward: 84.75333
Iteration: 700	Best Reward: 84.75333
Iteration: 800	Best Reward: 84.75333
Iteration: 900	Best Reward: 84.75333
Iteration: 1000	Best Reward: 84.75333
Iteration: 1100	Best Reward: 84.75333
Iteration: 1200	Best Reward: 84.75333
Iteration: 1300	Best Reward: 84.75333
Iteration: 1400	Best Reward: 84.75333
Iteration: 1500	Best Reward: 84.75333
Iteration: 1600	Best Reward: 84.75333
Iteration: 1700	Best Reward: 84.75333
Iteration: 1800	Best Reward: 84.75333
Iteration: 1900	Best Reward: 84.75333
Iteration: 2000	Best Reward: 84.75333
Iteration: 2100	Best Reward: 84.75333
Iteration: 2200	Best Reward: 84.75333

Iteration: 2300	Best Reward: 84.75333
Iteration: 2400	Best Reward: 84.75333
Iteration: 2500	Best Reward: 84.75333
Iteration: 2600	Best Reward: 84.75333
Iteration: 2700	Best Reward: 84.75333
Iteration: 2800	Best Reward: 84.75333
Iteration: 2900	Best Reward: 84.75333
Iteration: 3000	Best Reward: 84.75333
Iteration: 3100	Best Reward: 84.75333
Iteration: 3200	Best Reward: 84.75333
Iteration: 3300	Best Reward: 84.75333
Iteration: 3400	Best Reward: 84.75333
Iteration: 3500	Best Reward: 84.75333
Iteration: 3600	Best Reward: 84.75333
Iteration: 3700	Best Reward: 84.75333
Iteration: 3800	Best Reward: 84.75333
Iteration: 3900	Best Reward: 84.75333
Iteration: 4000	Best Reward: 84.75333
Iteration: 4100	Best Reward: 84.75333
Iteration: 4200	Best Reward: 84.75333
Iteration: 4300	Best Reward: 84.75333
Iteration: 4400	Best Reward: 84.75333
Iteration: 4500	Best Reward: 84.75333
Iteration: 4600	Best Reward: 84.75333
Iteration: 4700	Best Reward: 84.75333
Iteration: 4800	Best Reward: 84.75333
Iteration: 4900	Best Reward: 84.75333
Iteration: 5000	Best Reward: 84.75333
Iteration: 100	Best Reward: 75.10872
Iteration: 200	Best Reward: 76.82645
Iteration: 300	Best Reward: 76.82645
Iteration: 400	Best Reward: 80.17637
Iteration: 500	Best Reward: 83.38379
Iteration: 600	Best Reward: 83.38379
Iteration: 700	Best Reward: 83.38379
Iteration: 800	Best Reward: 83.38379
Iteration: 900	Best Reward: 83.38379
Iteration: 1000	Best Reward: 83.38379
Iteration: 1100	Best Reward: 83.38379
Iteration: 1200	Best Reward: 83.38379
Iteration: 1300	Best Reward: 83.38379
Iteration: 1400	Best Reward: 83.38379
Iteration: 1500	Best Reward: 83.38379
Iteration: 1600	Best Reward: 83.38379
Iteration: 1700	Best Reward: 83.38379
Iteration: 1800	Best Reward: 83.38379
Iteration: 1900	Best Reward: 83.38379
Iteration: 2000	Best Reward: 83.38379
Iteration: 2100	Best Reward: 83.38379
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Iteration: 4100	Best Reward: 83.38379
Iteration: 4200	Best Reward: 83.38379
Iteration: 4300	Best Reward: 83.38379
Iteration: 4400	Best Reward: 83.38379
Iteration: 4500	Best Reward: 83.38379
Iteration: 4600	Best Reward: 83.38379
Iteration: 4700	Best Reward: 83.38379
Iteration: 4800	Best Reward: 83.38379
Iteration: 4900	Best Reward: 83.38379
Iteration: 5000	Best Reward: 83.38379
Iteration: 100	Best Reward: 73.10367
Iteration: 200	Best Reward: 73.10367
Iteration: 300	Best Reward: 85.32101
Iteration: 400	Best Reward: 85.99693
Iteration: 500	Best Reward: 88.06009
Iteration: 600	Best Reward: 88.06009
Iteration: 700	Best Reward: 88.06009
Iteration: 800	Best Reward: 88.06009
Iteration: 900	Best Reward: 88.06009
Iteration: 1000	Best Reward: 88.06009
Iteration: 1100	Best Reward: 88.06009
Iteration: 1200	Best Reward: 88.06009
Iteration: 1300	Best Reward: 88.06009
Iteration: 1400	Best Reward: 88.06009
Iteration: 1500	Best Reward: 88.06009
Iteration: 1600	Best Reward: 88.06009
Iteration: 1700	Best Reward: 88.06009
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Iteration: 4700	Best Reward: 88.06009
Iteration: 4800	Best Reward: 88.06009
Iteration: 4900	Best Reward: 88.06009
Iteration: 5000	Best Reward: 88.06009
Iteration: 100	Best Reward: 73.62617
Iteration: 200	Best Reward: 73.62617
Iteration: 300	Best Reward: 73.62617
Iteration: 400	Best Reward: 78.18854
Iteration: 500	Best Reward: 84.44138
Iteration: 600	Best Reward: 84.44138
Iteration: 700	Best Reward: 84.44138
Iteration: 800	Best Reward: 84.44138
Iteration: 900	Best Reward: 84.44138
Iteration: 1000	Best Reward: 84.44138
Iteration: 1100	Best Reward: 84.44138
Iteration: 1200	Best Reward: 84.44138
Iteration: 1300	Best Reward: 84.44138
Iteration: 1400	Best Reward: 84.44138
Iteration: 1500	Best Reward: 84.44138
Iteration: 1600	Best Reward: 84.44138
Iteration: 1700	Best Reward: 84.44138
Iteration: 1800	Best Reward: 84.44138
Iteration: 1900	Best Reward: 84.44138
Iteration: 2000	Best Reward: 84.44138
Iteration: 2100	Best Reward: 84.44138
Iteration: 2200	Best Reward: 84.44138
Iteration: 2300	Best Reward: 84.44138
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Iteration: 2500	Best Reward: 84.44138
Iteration: 2600	Best Reward: 84.44138
Iteration: 2700	Best Reward: 84.44138
Iteration: 2800	Best Reward: 84.44138
Iteration: 2900	Best Reward: 84.44138
Iteration: 3000	Best Reward: 84.44138
Iteration: 3100	Best Reward: 84.44138
Iteration: 3200	Best Reward: 84.44138
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Iteration: 3400	Best Reward: 84.44138

Iteration: 3500	Best Reward: 84.44138
Iteration: 3600	Best Reward: 84.44138
Iteration: 3700	Best Reward: 84.44138
Iteration: 3800	Best Reward: 84.44138
Iteration: 3900	Best Reward: 84.44138
Iteration: 4000	Best Reward: 84.44138
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Iteration: 4200	Best Reward: 84.44138
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Iteration: 4700	Best Reward: 84.44138
Iteration: 4800	Best Reward: 84.44138
Iteration: 4900	Best Reward: 84.44138
Iteration: 5000	Best Reward: 84.44138
Iteration: 100	Best Reward: 70.83032
Iteration: 200	Best Reward: 81.28242
Iteration: 300	Best Reward: 81.28242
Iteration: 400	Best Reward: 81.98132
Iteration: 500	Best Reward: 85.5178
Iteration: 600	Best Reward: 87.48678
Iteration: 700	Best Reward: 87.48678
Iteration: 800	Best Reward: 87.48678
Iteration: 900	Best Reward: 87.48678
Iteration: 1000	Best Reward: 87.48678
Iteration: 1100	Best Reward: 87.48678
Iteration: 1200	Best Reward: 87.48678
Iteration: 1300	Best Reward: 87.48678
Iteration: 1400	Best Reward: 87.48678
Iteration: 1500	Best Reward: 87.48678
Iteration: 1600	Best Reward: 87.48678
Iteration: 1700	Best Reward: 87.48678
Iteration: 1800	Best Reward: 87.48678
Iteration: 1900	Best Reward: 87.48678
Iteration: 2000	Best Reward: 87.48678
Iteration: 2100	Best Reward: 87.48678
Iteration: 2200	Best Reward: 87.48678
Iteration: 2300	Best Reward: 87.48678
Iteration: 2400	Best Reward: 87.48678
Iteration: 2500	Best Reward: 87.48678
Iteration: 2600	Best Reward: 87.48678
Iteration: 2700	Best Reward: 87.48678
Iteration: 2800	Best Reward: 87.48678
Iteration: 2900	Best Reward: 87.48678
Iteration: 3000	Best Reward: 87.48678
Iteration: 3100	Best Reward: 87.48678
Iteration: 3200	Best Reward: 87.48678
Iteration: 3300	Best Reward: 87.48678
Iteration: 3400	Best Reward: 87.48678
Iteration: 3500	Best Reward: 87.48678
Iteration: 3600	Best Reward: 87.48678
Iteration: 3700	Best Reward: 87.48678
Iteration: 3800	Best Reward: 87.48678

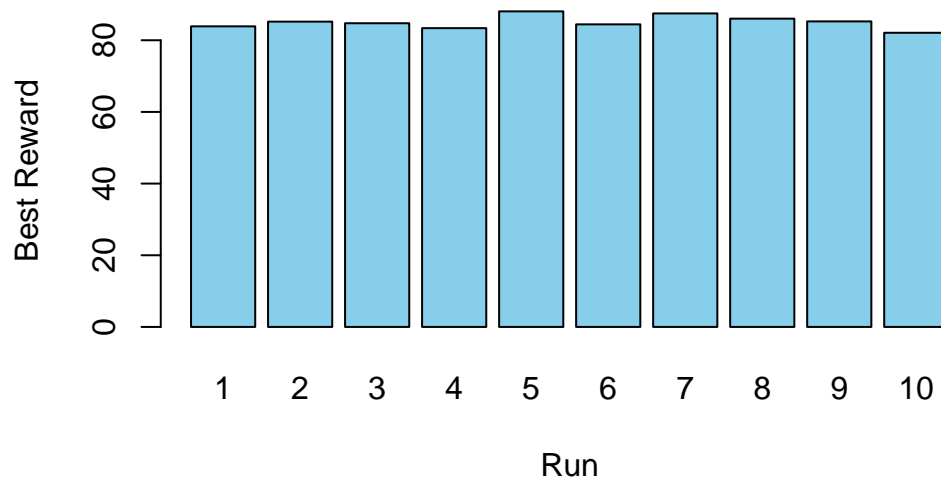
Iteration: 3900	Best Reward: 87.48678
Iteration: 4000	Best Reward: 87.48678
Iteration: 4100	Best Reward: 87.48678
Iteration: 4200	Best Reward: 87.48678
Iteration: 4300	Best Reward: 87.48678
Iteration: 4400	Best Reward: 87.48678
Iteration: 4500	Best Reward: 87.48678
Iteration: 4600	Best Reward: 87.48678
Iteration: 4700	Best Reward: 87.48678
Iteration: 4800	Best Reward: 87.48678
Iteration: 4900	Best Reward: 87.48678
Iteration: 5000	Best Reward: 87.48678
Iteration: 100	Best Reward: 71.8094
Iteration: 200	Best Reward: 73.95808
Iteration: 300	Best Reward: 74.65609
Iteration: 400	Best Reward: 83.36096
Iteration: 500	Best Reward: 84.06161
Iteration: 600	Best Reward: 86.03059
Iteration: 700	Best Reward: 86.03059
Iteration: 800	Best Reward: 86.03059
Iteration: 900	Best Reward: 86.03059
Iteration: 1000	Best Reward: 86.03059
Iteration: 1100	Best Reward: 86.03059
Iteration: 1200	Best Reward: 86.03059
Iteration: 1300	Best Reward: 86.03059
Iteration: 1400	Best Reward: 86.03059
Iteration: 1500	Best Reward: 86.03059
Iteration: 1600	Best Reward: 86.03059
Iteration: 1700	Best Reward: 86.03059
Iteration: 1800	Best Reward: 86.03059
Iteration: 1900	Best Reward: 86.03059
Iteration: 2000	Best Reward: 86.03059
Iteration: 2100	Best Reward: 86.03059
Iteration: 2200	Best Reward: 86.03059
Iteration: 2300	Best Reward: 86.03059
Iteration: 2400	Best Reward: 86.03059
Iteration: 2500	Best Reward: 86.03059
Iteration: 2600	Best Reward: 86.03059
Iteration: 2700	Best Reward: 86.03059
Iteration: 2800	Best Reward: 86.03059
Iteration: 2900	Best Reward: 86.03059
Iteration: 3000	Best Reward: 86.03059
Iteration: 3100	Best Reward: 86.03059
Iteration: 3200	Best Reward: 86.03059
Iteration: 3300	Best Reward: 86.03059
Iteration: 3400	Best Reward: 86.03059
Iteration: 3500	Best Reward: 86.03059
Iteration: 3600	Best Reward: 86.03059
Iteration: 3700	Best Reward: 86.03059
Iteration: 3800	Best Reward: 86.03059
Iteration: 3900	Best Reward: 86.03059
Iteration: 4000	Best Reward: 86.03059
Iteration: 4100	Best Reward: 86.03059
Iteration: 4200	Best Reward: 86.03059

Iteration: 4300	Best Reward: 86.03059
Iteration: 4400	Best Reward: 86.03059
Iteration: 4500	Best Reward: 86.03059
Iteration: 4600	Best Reward: 86.03059
Iteration: 4700	Best Reward: 86.03059
Iteration: 4800	Best Reward: 86.03059
Iteration: 4900	Best Reward: 86.03059
Iteration: 5000	Best Reward: 86.03059
Iteration: 100	Best Reward: 78.79711
Iteration: 200	Best Reward: 78.79711
Iteration: 300	Best Reward: 78.79711
Iteration: 400	Best Reward: 81.77521
Iteration: 500	Best Reward: 84.0914
Iteration: 600	Best Reward: 85.26508
Iteration: 700	Best Reward: 85.26508
Iteration: 800	Best Reward: 85.26508
Iteration: 900	Best Reward: 85.26508
Iteration: 1000	Best Reward: 85.26508
Iteration: 1100	Best Reward: 85.26508
Iteration: 1200	Best Reward: 85.26508
Iteration: 1300	Best Reward: 85.26508
Iteration: 1400	Best Reward: 85.26508
Iteration: 1500	Best Reward: 85.26508
Iteration: 1600	Best Reward: 85.26508
Iteration: 1700	Best Reward: 85.26508
Iteration: 1800	Best Reward: 85.26508
Iteration: 1900	Best Reward: 85.26508
Iteration: 2000	Best Reward: 85.26508
Iteration: 2100	Best Reward: 85.26508
Iteration: 2200	Best Reward: 85.26508
Iteration: 2300	Best Reward: 85.26508
Iteration: 2400	Best Reward: 85.26508
Iteration: 2500	Best Reward: 85.26508
Iteration: 2600	Best Reward: 85.26508
Iteration: 2700	Best Reward: 85.26508
Iteration: 2800	Best Reward: 85.26508
Iteration: 2900	Best Reward: 85.26508
Iteration: 3000	Best Reward: 85.26508
Iteration: 3100	Best Reward: 85.26508
Iteration: 3200	Best Reward: 85.26508
Iteration: 3300	Best Reward: 85.26508
Iteration: 3400	Best Reward: 85.26508
Iteration: 3500	Best Reward: 85.26508
Iteration: 3600	Best Reward: 85.26508
Iteration: 3700	Best Reward: 85.26508
Iteration: 3800	Best Reward: 85.26508
Iteration: 3900	Best Reward: 85.26508
Iteration: 4000	Best Reward: 85.26508
Iteration: 4100	Best Reward: 85.26508
Iteration: 4200	Best Reward: 85.26508
Iteration: 4300	Best Reward: 85.26508
Iteration: 4400	Best Reward: 85.26508
Iteration: 4500	Best Reward: 85.26508
Iteration: 4600	Best Reward: 85.26508

Iteration: 4700	Best Reward: 85.26508
Iteration: 4800	Best Reward: 85.26508
Iteration: 4900	Best Reward: 85.26508
Iteration: 5000	Best Reward: 85.26508
Iteration: 100	Best Reward: 72.38271
Iteration: 200	Best Reward: 72.55967
Iteration: 300	Best Reward: 78.63899
Iteration: 400	Best Reward: 79.46186
Iteration: 500	Best Reward: 81.80466
Iteration: 600	Best Reward: 81.80466
Iteration: 700	Best Reward: 82.08803
Iteration: 800	Best Reward: 82.08803
Iteration: 900	Best Reward: 82.08803
Iteration: 1000	Best Reward: 82.08803
Iteration: 1100	Best Reward: 82.08803
Iteration: 1200	Best Reward: 82.08803
Iteration: 1300	Best Reward: 82.08803
Iteration: 1400	Best Reward: 82.08803
Iteration: 1500	Best Reward: 82.08803
Iteration: 1600	Best Reward: 82.08803
Iteration: 1700	Best Reward: 82.08803
Iteration: 1800	Best Reward: 82.08803
Iteration: 1900	Best Reward: 82.08803
Iteration: 2000	Best Reward: 82.08803
Iteration: 2100	Best Reward: 82.08803
Iteration: 2200	Best Reward: 82.08803
Iteration: 2300	Best Reward: 82.08803
Iteration: 2400	Best Reward: 82.08803
Iteration: 2500	Best Reward: 82.08803
Iteration: 2600	Best Reward: 82.08803
Iteration: 2700	Best Reward: 82.08803
Iteration: 2800	Best Reward: 82.08803
Iteration: 2900	Best Reward: 82.08803
Iteration: 3000	Best Reward: 82.08803
Iteration: 3100	Best Reward: 82.08803
Iteration: 3200	Best Reward: 82.08803
Iteration: 3300	Best Reward: 82.08803
Iteration: 3400	Best Reward: 82.08803
Iteration: 3500	Best Reward: 82.08803
Iteration: 3600	Best Reward: 82.08803
Iteration: 3700	Best Reward: 82.08803
Iteration: 3800	Best Reward: 82.08803
Iteration: 3900	Best Reward: 82.08803
Iteration: 4000	Best Reward: 82.08803
Iteration: 4100	Best Reward: 82.08803
Iteration: 4200	Best Reward: 82.08803
Iteration: 4300	Best Reward: 82.08803
Iteration: 4400	Best Reward: 82.08803
Iteration: 4500	Best Reward: 82.08803
Iteration: 4600	Best Reward: 82.08803
Iteration: 4700	Best Reward: 82.08803
Iteration: 4800	Best Reward: 82.08803
Iteration: 4900	Best Reward: 82.08803
Iteration: 5000	Best Reward: 82.08803

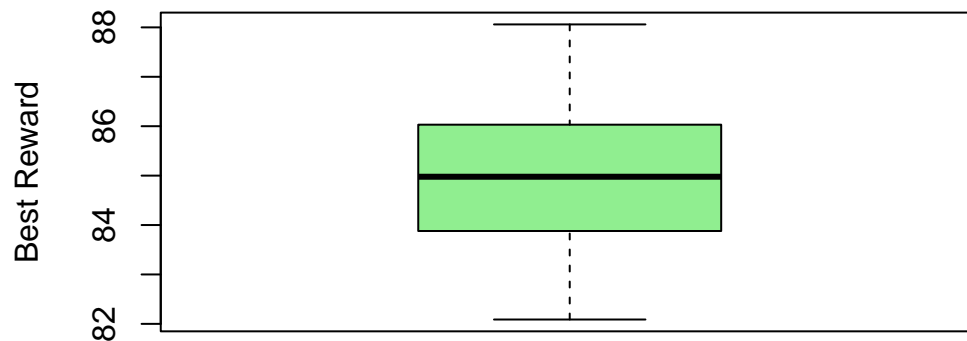
```
# Bar Plot of Rewards Across Runs
barplot(results, col = "skyblue", names.arg = 1:num_runs,
        xlab = "Run", ylab = "Best Reward",
        main = "Best Rewards Across Multiple Runs of SA")
```

Best Rewards Across Multiple Runs of SA



```
# Boxplot for Overall Reward Distribution
boxplot(results, col = "lightgreen",
        ylab = "Best Reward",
        main = "Distribution of Best Rewards Across Runs")
```

Distribution of Best Rewards Across Runs



What It Shows:

- The **bar chart** compares the best rewards for each run.
- The **boxplot** shows the spread (range, median, outliers) of the best rewards across all runs.

3. Visualize the Optimal Route (Traveling Salesman Path)

If you assume that each city has coordinates (e.g., generated randomly), you can visualize the **salesman's route** on a 2D plane.

Code:

```
# Generate Random Coordinates for Cities
set.seed(123)
city_coords <- data.frame(x = runif(n_cities, 0, 100),
                          y = runif(n_cities, 0, 100))
city_coords <- rbind(c(50, 50), city_coords) # Add city 0 at center (50, 50)

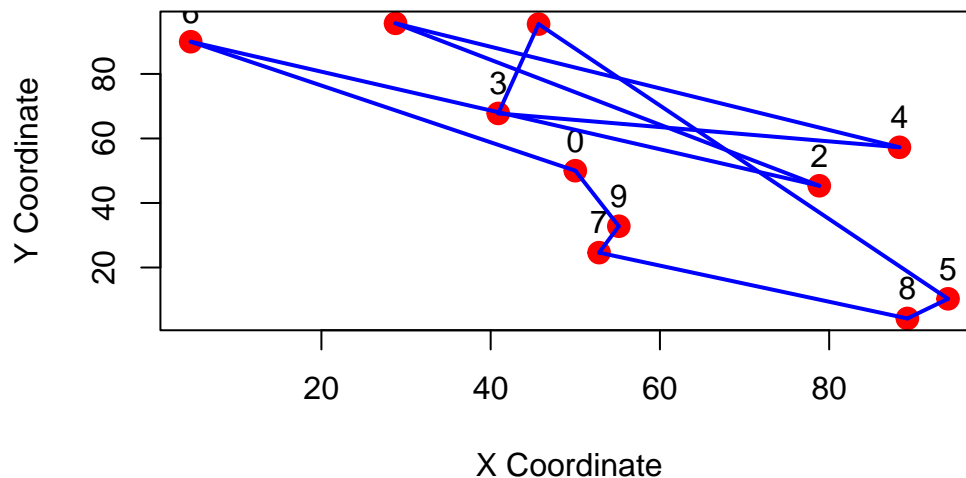
# Function to Plot the Salesman's Route
plot_route <- function(route, coords) {
  # Create a complete route (start at city 0, visit all cities, return to city 0)
  complete_route <- c(0, route, 0)

  # Plot the cities
  plot(coords$x, coords$y, pch = 19, col = "red", cex = 1.5,
        xlab = "X Coordinate", ylab = "Y Coordinate",
        main = "Traveling Salesman Optimal Route")
  text(coords$x, coords$y, labels = 0:n_cities, pos = 3)

  # Draw the path
  for (i in 1:(length(complete_route) - 1)) {
    city_from <- complete_route[i] + 1 # Adjust for 0-based index
    city_to <- complete_route[i + 1] + 1
    segments(coords$x[city_from], coords$y[city_from],
             coords$x[city_to], coords$y[city_to], col = "blue", lwd = 2)
  }
}

# Visualize the Best Route
plot_route(result$best_route, city_coords)
```

Traveling Salesman Optimal Route



What It Shows:

- The **red points** represent the cities, with city 0 as the starting point.
- The **blue lines** show the optimal path taken by the salesman to visit all cities and return to the starting city.

- Labels (0 to 10) indicate city indices.

4. Visualize Temperature Decay

Plot the **temperature decay schedule** used in Simulated Annealing to understand how the search becomes more “constrained” over time.

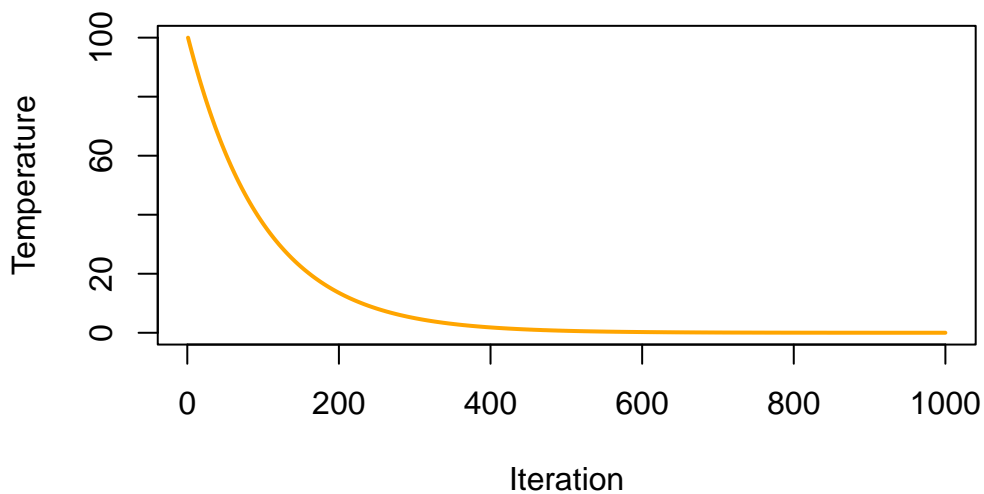
Code:

```
# Simulated Temperature Decay
max_iter <- 1000
T_init <- 100
cooling_rate <- 0.99
temperature <- numeric(max_iter)

# Simulate Temperature Decay
T <- T_init
for (i in 1:max_iter) {
  temperature[i] <- T
  T <- T * cooling_rate
}

# Plot Temperature Decay
plot(1:max_iter, temperature, type = "l", col = "orange", lwd = 2,
     xlab = "Iteration", ylab = "Temperature",
     main = "Temperature Decay in Simulated Annealing")
```

Temperature Decay in Simulated Annealing



What It Shows:

- The curve shows how the **temperature** decreases over iterations.
- A slower cooling rate (e.g., 0.995) leads to a gentler decay, allowing more exploration.

5. Compare Routes Visually

If you run the algorithm multiple times, you can compare the **routes** visually by plotting the paths for different runs.

For example:

```
# Compare Routes for Multiple Runs
par(mfrow = c(1, 2)) # Plot 4 routes in a 2x2 grid

for (i in 1:4) {
  result <- simulated_annealing(U_ij, U_0k)
  cat("Run:", i, "| Best Reward:", result$best_reward, "\n")
  plot_route(result$best_route, city_coords)
}
```

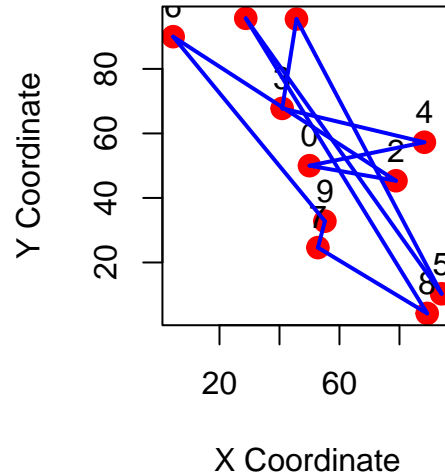
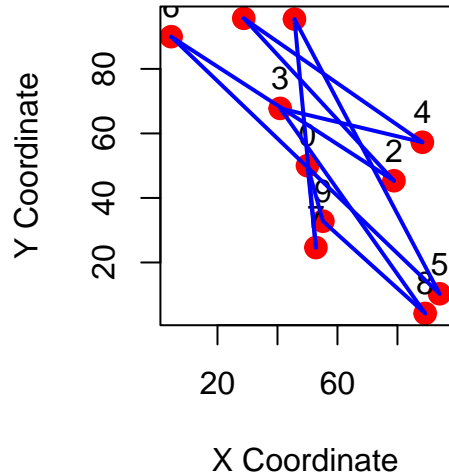
Iteration: 100	Best Reward: 76.461
Iteration: 200	Best Reward: 77.16748
Iteration: 300	Best Reward: 79.39732
Iteration: 400	Best Reward: 79.39732
Iteration: 500	Best Reward: 85.27749
Iteration: 600	Best Reward: 85.27749
Iteration: 700	Best Reward: 85.27749
Iteration: 800	Best Reward: 85.27749
Iteration: 900	Best Reward: 85.27749
Iteration: 1000	Best Reward: 85.27749
Iteration: 1100	Best Reward: 85.27749
Iteration: 1200	Best Reward: 85.27749
Iteration: 1300	Best Reward: 85.27749
Iteration: 1400	Best Reward: 85.27749
Iteration: 1500	Best Reward: 85.27749
Iteration: 1600	Best Reward: 85.27749
Iteration: 1700	Best Reward: 85.27749
Iteration: 1800	Best Reward: 85.27749
Iteration: 1900	Best Reward: 85.27749
Iteration: 2000	Best Reward: 85.27749
Iteration: 2100	Best Reward: 85.27749
Iteration: 2200	Best Reward: 85.27749
Iteration: 2300	Best Reward: 85.27749
Iteration: 2400	Best Reward: 85.27749
Iteration: 2500	Best Reward: 85.27749
Iteration: 2600	Best Reward: 85.27749
Iteration: 2700	Best Reward: 85.27749
Iteration: 2800	Best Reward: 85.27749
Iteration: 2900	Best Reward: 85.27749
Iteration: 3000	Best Reward: 85.27749
Iteration: 3100	Best Reward: 85.27749
Iteration: 3200	Best Reward: 85.27749
Iteration: 3300	Best Reward: 85.27749
Iteration: 3400	Best Reward: 85.27749
Iteration: 3500	Best Reward: 85.27749
Iteration: 3600	Best Reward: 85.27749
Iteration: 3700	Best Reward: 85.27749
Iteration: 3800	Best Reward: 85.27749
Iteration: 3900	Best Reward: 85.27749
Iteration: 4000	Best Reward: 85.27749

Iteration: 4100 | Best Reward: 85.27749
Iteration: 4200 | Best Reward: 85.27749
Iteration: 4300 | Best Reward: 85.27749
Iteration: 4400 | Best Reward: 85.27749
Iteration: 4500 | Best Reward: 85.27749
Iteration: 4600 | Best Reward: 85.27749
Iteration: 4700 | Best Reward: 85.27749
Iteration: 4800 | Best Reward: 85.27749
Iteration: 4900 | Best Reward: 85.27749
Iteration: 5000 | Best Reward: 85.27749
Run: 1 | Best Reward: 85.27749

Iteration: 100 | Best Reward: 76.07987
Iteration: 200 | Best Reward: 76.07987
Iteration: 300 | Best Reward: 79.04991
Iteration: 400 | Best Reward: 81.64505
Iteration: 500 | Best Reward: 81.66489
Iteration: 600 | Best Reward: 85.93522
Iteration: 700 | Best Reward: 85.93522
Iteration: 800 | Best Reward: 85.93522
Iteration: 900 | Best Reward: 85.93522
Iteration: 1000 | Best Reward: 85.93522
Iteration: 1100 | Best Reward: 85.93522
Iteration: 1200 | Best Reward: 85.93522
Iteration: 1300 | Best Reward: 85.93522
Iteration: 1400 | Best Reward: 85.93522
Iteration: 1500 | Best Reward: 85.93522
Iteration: 1600 | Best Reward: 85.93522
Iteration: 1700 | Best Reward: 85.93522
Iteration: 1800 | Best Reward: 85.93522
Iteration: 1900 | Best Reward: 85.93522
Iteration: 2000 | Best Reward: 85.93522
Iteration: 2100 | Best Reward: 85.93522
Iteration: 2200 | Best Reward: 85.93522
Iteration: 2300 | Best Reward: 85.93522
Iteration: 2400 | Best Reward: 85.93522
Iteration: 2500 | Best Reward: 85.93522
Iteration: 2600 | Best Reward: 85.93522
Iteration: 2700 | Best Reward: 85.93522
Iteration: 2800 | Best Reward: 85.93522
Iteration: 2900 | Best Reward: 85.93522
Iteration: 3000 | Best Reward: 85.93522
Iteration: 3100 | Best Reward: 85.93522
Iteration: 3200 | Best Reward: 85.93522
Iteration: 3300 | Best Reward: 85.93522
Iteration: 3400 | Best Reward: 85.93522
Iteration: 3500 | Best Reward: 85.93522
Iteration: 3600 | Best Reward: 85.93522
Iteration: 3700 | Best Reward: 85.93522
Iteration: 3800 | Best Reward: 85.93522
Iteration: 3900 | Best Reward: 85.93522
Iteration: 4000 | Best Reward: 85.93522
Iteration: 4100 | Best Reward: 85.93522
Iteration: 4200 | Best Reward: 85.93522
Iteration: 4300 | Best Reward: 85.93522

Iteration: 4400 | Best Reward: 85.93522
 Iteration: 4500 | Best Reward: 85.93522
 Iteration: 4600 | Best Reward: 85.93522
 Iteration: 4700 | Best Reward: 85.93522
 Iteration: 4800 | Best Reward: 85.93522
 Iteration: 4900 | Best Reward: 85.93522
 Iteration: 5000 | Best Reward: 85.93522
 Run: 2 | Best Reward: 85.93522

Traveling Salesman Optimal RTraveling Salesman Optimal R



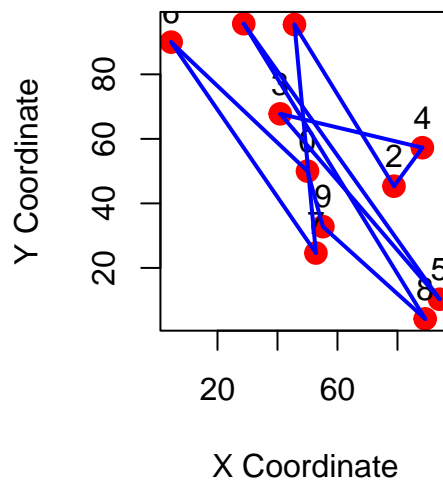
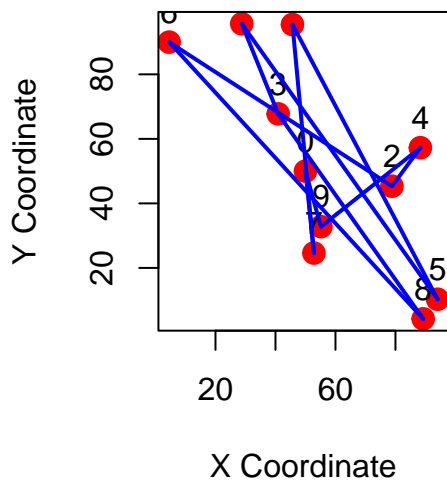
Iteration: 100 | Best Reward: 72.93876
 Iteration: 200 | Best Reward: 84.25599
 Iteration: 300 | Best Reward: 84.25599
 Iteration: 400 | Best Reward: 84.25599
 Iteration: 500 | Best Reward: 84.25599
 Iteration: 600 | Best Reward: 84.25599
 Iteration: 700 | Best Reward: 84.25599
 Iteration: 800 | Best Reward: 85.94539
 Iteration: 900 | Best Reward: 85.94539
 Iteration: 1000 | Best Reward: 85.94539
 Iteration: 1100 | Best Reward: 85.94539
 Iteration: 1200 | Best Reward: 85.94539
 Iteration: 1300 | Best Reward: 85.94539
 Iteration: 1400 | Best Reward: 85.94539
 Iteration: 1500 | Best Reward: 85.94539
 Iteration: 1600 | Best Reward: 85.94539
 Iteration: 1700 | Best Reward: 85.94539
 Iteration: 1800 | Best Reward: 85.94539
 Iteration: 1900 | Best Reward: 85.94539
 Iteration: 2000 | Best Reward: 85.94539
 Iteration: 2100 | Best Reward: 85.94539
 Iteration: 2200 | Best Reward: 85.94539
 Iteration: 2300 | Best Reward: 85.94539
 Iteration: 2400 | Best Reward: 85.94539
 Iteration: 2500 | Best Reward: 85.94539
 Iteration: 2600 | Best Reward: 85.94539
 Iteration: 2700 | Best Reward: 85.94539

Iteration: 2800 | Best Reward: 85.94539
Iteration: 2900 | Best Reward: 85.94539
Iteration: 3000 | Best Reward: 85.94539
Iteration: 3100 | Best Reward: 85.94539
Iteration: 3200 | Best Reward: 85.94539
Iteration: 3300 | Best Reward: 85.94539
Iteration: 3400 | Best Reward: 85.94539
Iteration: 3500 | Best Reward: 85.94539
Iteration: 3600 | Best Reward: 85.94539
Iteration: 3700 | Best Reward: 85.94539
Iteration: 3800 | Best Reward: 85.94539
Iteration: 3900 | Best Reward: 85.94539
Iteration: 4000 | Best Reward: 85.94539
Iteration: 4100 | Best Reward: 85.94539
Iteration: 4200 | Best Reward: 85.94539
Iteration: 4300 | Best Reward: 85.94539
Iteration: 4400 | Best Reward: 85.94539
Iteration: 4500 | Best Reward: 85.94539
Iteration: 4600 | Best Reward: 85.94539
Iteration: 4700 | Best Reward: 85.94539
Iteration: 4800 | Best Reward: 85.94539
Iteration: 4900 | Best Reward: 85.94539
Iteration: 5000 | Best Reward: 85.94539
Run: 3 | Best Reward: 85.94539

Iteration: 100 | Best Reward: 75.43029
Iteration: 200 | Best Reward: 75.43029
Iteration: 300 | Best Reward: 81.76556
Iteration: 400 | Best Reward: 81.76556
Iteration: 500 | Best Reward: 81.76556
Iteration: 600 | Best Reward: 81.76556
Iteration: 700 | Best Reward: 81.76556
Iteration: 800 | Best Reward: 81.76556
Iteration: 900 | Best Reward: 81.76556
Iteration: 1000 | Best Reward: 81.76556
Iteration: 1100 | Best Reward: 81.76556
Iteration: 1200 | Best Reward: 81.76556
Iteration: 1300 | Best Reward: 81.76556
Iteration: 1400 | Best Reward: 81.76556
Iteration: 1500 | Best Reward: 81.76556
Iteration: 1600 | Best Reward: 81.76556
Iteration: 1700 | Best Reward: 81.76556
Iteration: 1800 | Best Reward: 81.76556
Iteration: 1900 | Best Reward: 81.76556
Iteration: 2000 | Best Reward: 81.76556
Iteration: 2100 | Best Reward: 81.76556
Iteration: 2200 | Best Reward: 81.76556
Iteration: 2300 | Best Reward: 81.76556
Iteration: 2400 | Best Reward: 81.76556
Iteration: 2500 | Best Reward: 81.76556
Iteration: 2600 | Best Reward: 81.76556
Iteration: 2700 | Best Reward: 81.76556
Iteration: 2800 | Best Reward: 81.76556
Iteration: 2900 | Best Reward: 81.76556
Iteration: 3000 | Best Reward: 81.76556

Iteration: 3100 | Best Reward: 81.76556
 Iteration: 3200 | Best Reward: 81.76556
 Iteration: 3300 | Best Reward: 81.76556
 Iteration: 3400 | Best Reward: 81.76556
 Iteration: 3500 | Best Reward: 81.76556
 Iteration: 3600 | Best Reward: 81.76556
 Iteration: 3700 | Best Reward: 81.76556
 Iteration: 3800 | Best Reward: 81.76556
 Iteration: 3900 | Best Reward: 81.76556
 Iteration: 4000 | Best Reward: 81.76556
 Iteration: 4100 | Best Reward: 81.76556
 Iteration: 4200 | Best Reward: 81.76556
 Iteration: 4300 | Best Reward: 81.76556
 Iteration: 4400 | Best Reward: 81.76556
 Iteration: 4500 | Best Reward: 81.76556
 Iteration: 4600 | Best Reward: 81.76556
 Iteration: 4700 | Best Reward: 81.76556
 Iteration: 4800 | Best Reward: 81.76556
 Iteration: 4900 | Best Reward: 81.76556
 Iteration: 5000 | Best Reward: 81.76556
 Run: 4 | Best Reward: 81.76556

Traveling Salesman Optimal RTraveling Salesman Optimal R



```
par(mfrow = c(1, 1)) # Reset plot layout
```

What It Shows:

- Each plot shows a route from a different run.
- You can visually check if the routes are similar or significantly different.

Summary of Visualizations

1. **Convergence Plot:** Visualize how rewards improve over iterations.
2. **Bar Chart/Boxplot:** Compare best rewards across multiple runs.
3. **Traveling Salesman Route:** Visualize the optimal path on a 2D plane with city coordinates.

4. **Temperature Decay:** Show how the temperature decreases over time.
5. **Route Comparison:** Plot routes from multiple runs for visual comparison.