

# **Tugas Besar 01 IF3070 Dasar Inteligensi Artifisial**

## **Penerapan Algoritma Local Search pada**

### **Permasalahan Diagonal Magic Cube**



**Disusun oleh:**

**Kelompok 1**

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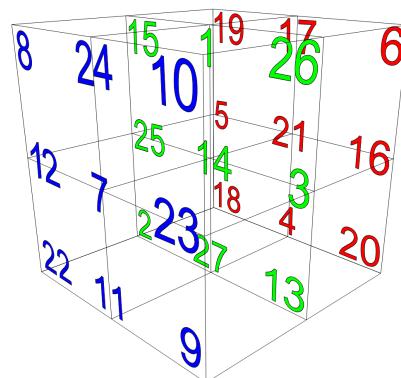
# Bab 1

## Pendahuluan

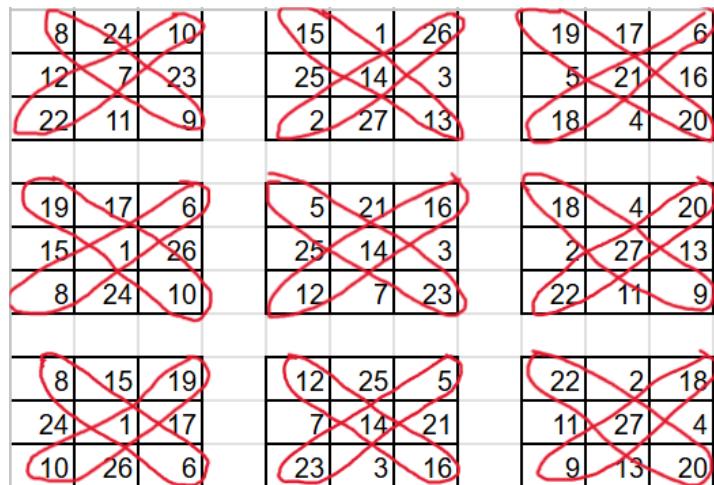
### 1. Definisi Magic Cube

Diagonal magic cube merupakan kubus yang tersusun dari angka 1 hingga  $n^3$  tanpa pengulangan dengan  $n$  adalah panjang sisi pada kubus tersebut. Angka-angka pada tersusun sedemikian rupa sehingga properti-properti berikut terpenuhi:

- Terdapat satu angka yang merupakan magic number dari kubus tersebut (Magic number tidak harus termasuk dalam rentang 1 hingga  $n^3$ , magic number juga bukan termasuk ke dalam angka yang harus dimasukkan ke dalam kubus)
- Jumlah angka-angka untuk setiap baris sama dengan magic number
- Jumlah angka-angka untuk setiap kolom sama dengan magic number
- Jumlah angka-angka untuk setiap tiang sama dengan magic number
- Jumlah angka-angka untuk seluruh diagonal ruang pada kubus sama dengan magic number
- Jumlah angka-angka untuk seluruh diagonal pada suatu potongan bidang dari kubus sama dengan magic number
  - Berikut ilustrasi dari potongan bidang yang ada pada suatu kubus berukuran 3:



- Terdapat 9 potongan bidang, yaitu:



Gambar 1.1 9 potongan bidang

- Diagonal yang dimaksud adalah yang dilingkari warna merah

# Bab 2

## Pembahasan

### 1. Inisialisasi Class

#### 1.1. Cube

##### 1.1.1. Parameter Cube

*Cube* merupakan sebuah *class* bernama *Tensor*. *Class* ini memiliki 4 parameter; *r*, *c*, *h*, *initial\_array*. Variabel *r*, *c*, dan *h* merupakan berapa besar baris, kolom, dan tinggi ( atau level ) dari array lalu variabel *initial\_array* merupakan variabel array yang ingin diubah ke dalam bentuk *class* *Tensor*.

##### 1.1.2. Fungsi Cube

Berikut merupakan fungsi-fungsi penting dalam *cube*.

a. *Initial\_state*

Merupakan fungsi untuk memasukkan angka dari  $0 \leq$  angka  $\leq 125$  secara acak dan pasti unik.

b. *Print\_cube*

Fungsi untuk menampilkan *cube* dalam bentuk array.

c. *Plot\_cube*

Fungsi untuk memvisualisasikan *cube* dalam bentuk 2D per level.

d. *Objective\_function*

Fungsi yang mengembalikan nilai hasil syarat-syarat *diagonal magic cube* dikurangi *magic constant*. Terdapat parameter *square\_error* untuk menentukan pengurangan akan dikuadratkan atau diabsolutkan.

## **1.2. Steepest Descent Hill Climbing**

### **1.2.1. Parameter Steepest Descent Hill Climbing**

Parameter menerima cube sebagai problem space algoritma dan function\_error sebagai penentu square\_error pada *objective funciton*.

### **1.2.2. Fungsi Steepest Descent Hill Climbing**

Berikut merupakan fungsi-fungsi penting dalam algoritma.

- a. Move  
Algoritma penukaran dua posisi nilai dalam cube.
- b. bestNeighbors  
Menghasilkan *best-valued successor* pada *current state*.

## **1.3. Hill-climbing with Sideway move**

### **1.3.1. Parameter Hill-Climbing with Sideway Move**

Parameter menerima cube sebagai problem space algoritma, max\_sideway\_move membatasi pergerakan sideway saat masuk ke dalam *plateau*, dan function\_error sebagai penentu square\_error pada *objective function*.

### **1.3.2. Fungsi Hill-Climbing with Sideway Move**

Berikut merupakan fungsi-fungsi penting dalam sideway move.

- a. Move  
Algoritma penukaran dua posisi nilai dalam cube.
- b. bestNeighbors  
Menghasilkan *best-valued successor* pada *current state*.

## **1.4. Stochastic Hill Climbing**

### **1.4.1. Parameter Stochastic Hill-climbing**

Class Stochastic memiliki parameter; cube, max\_iteration. Cube merupakan parameter cube yang digunakan (problem state) untuk melakukan pencarian. Max\_iteration adalah parameter untuk membatasi jumlah iterasi neighbor.

#### **1.4.2. Fungsi Hill-climbing**

Berikut merupakan fungsi-fungsi penting dalam Stochastic Hill-Climbing.

- a. Move

Algoritma penukaran dua posisi nilai dalam cube.

- b. random\_successor

Fungsi ini menghasilkan tetangga baru dengan memanggil metode randomize\_value dari objek cube

- c. best\_state

Menghasilkan best-valued successor pada current state.

### **1.5. Random Restart Hill Climbing**

#### **1.5.1. Parameter Random Restart**

*Class Random Restart* memiliki parameter; cube, max\_restart.

Cube merupakan parameter cube yang digunakan (problem state) untuk melakukan pencarian. Max\_Restart adalah parameter untuk menentukan jumlah iterasi maksimum untuk menjalankan algoritma.

#### **1.5.2. Fungsi Random Restart**

Berikut merupakan fungsi-fungsi penting dalam Random Restart Hill-Climbing.

- a. Move

Algoritma penukaran dua posisi nilai dalam cube.

- b. best\_state

Menghasilkan best-valued successor pada current state.

### **1.6. Simulated Annealing**

#### **1.6.1. Parameter Simulated Annealing**

*Class Simulated Annealing* memiliki parameter; cube, tmin, tmax, cooling\_schedule, alpha, step\_max, best\_neighbor, dan function\_error.

Cube merupakan parameter cube yang digunakan (problem state) untuk melakukan pencarian. Parameter tmin, tmax, dan step\_max merupakan batasan ‘waktu’ pencarian dilakukan. Step\_max di sini berfungsi saat membatasi temperatur yang selalu mendekati tmin tetapi tidak pernah sampai ke tmin. Variabel cooling\_schedule merupakan variabel bagaimana perlakuan penurunan temperatur terjadi. Terdapat 4 pilihan: *linear additive*, *linear multiplicative*, *quadratic additive*, dan *quadratic multiplicative* yang juga tergantung pada keberadaan variabel *alpha*.

Berikut merupakan persamaan dari keempat cooling schedule.

- Linear Additive

$$T(k) = T_{min} + (T_{max} - T_{min})\left(\frac{n-step}{n}\right)$$

- Linear Multiplicative

$$T(k) = T_{max} - \alpha * step$$

- Quadratic Additive

$$T(k) = T_{min} + (T_{max} - T_{min})\left(\frac{n-step}{n}\right)^2$$

- Quadratic Multiplicative

$$T(k) = \frac{T_{max}}{1 + \alpha(step^2)}$$

Variabel *boolean*, *best\_neighor*, merupakan parameter tambahan di luar parameter penting algoritma *Simulated Annealing*. *Greedy\_move* merupakan parameter yang menentukan bagaimana perpindahan dari 2 posisi *value* dalam cube. Jika *True*, maka algoritma akan mencari perpindahan yang memiliki *energy (objective function)* lebih baik dari sebelumnya.

Variable *function\_error* hanya menentukan pada perlakuan di *objective function*. Terdapat 2 pilihan; squared dan absolute. Jika squared, maka pengurangan antar syarat *diagonal magic cube* dengan *magic constant* akan dikuadratkan. Jika absolute, maka hasil

pengurangan syarat *diagonal magic cube* dengan *magic constant* akan diabsolutkan.

### 1.6.2. Fungsi Simulated Annealing

Berikut merupakan fungsi-fungsi penting dalam Simulated Annealing.

a. Cooling\_linear\_a

Fungsi penerapan dari *linear additive*.

b. Cooling\_linear\_m

Fungsi penerapan dari *linear multiplicative*.

c. Cooling\_quadratic\_a

Fungsi penerapan dari *quadratic additive*.

d. Cooling\_quadratic\_m

Fungsi penerapan dari *quadratic multiplicative*.

e. Move

Fungsi pemindahan posisi 2 angka dalam cube. Terdapat pilihan apakah menggunakan pendekatan *greedy search* atau tidak ( basisnya tidak ).

f. Safe\_exp

Fungsi pembatasan eksponensial pada persamaan peluang  $e^{\frac{-\Delta E}{T}}$  untuk mengatasi jika hasil perhitungan eksponensial mengembalikan angka yang sangat besar.

## 1.7. Genetic Algorithm

### 1.7.1. Parameter Genetic Algorithm

Class *Genetic Algorithm* memiliki parameter; *cube*, *goal\_cube*, *population\_size*, *generation\_rate*, dan *mutation\_rate*. *Cube* merupakan parameter *cube* yang digunakan (*problem state*) untuk melakukan pencarian. *Goal\_cube* adalah hasil akhir/konfigurasi akhir *cube* yang ingin dicapai. *Population\_size* adalah jumlah populasi atau banyaknya konfigurasi *cube* yang berbeda pada satu generasi. *Generation\_rate*

adalah jumlah atau banyaknya generasi yang ada selama algoritma berlangsung (jumlah maksimal iterasi). Lalu *mutation\_rate* adalah persentase kemungkinan dari sebuah *child* untuk bermutasi. *Mutation\_rate* ditentukan oleh kami sendiri, yakni *mutation rate* sebesar 10%.

### 1.7.2. Fungsi Genetic Algorithm

Berikut merupakan fungsi-fungsi penting dalam Genetic Algorithm.

a. *Crossover*

Fungsi untuk melakukan *crossover* antara satu posisi pada *cube parent1* dengan *cube parent2* secara *random*.

b. *Mutate*

Fungsi untuk melakukan *mutasi* pada angka *random* yang ada di dalam *cube* dan mengubahnya ke angka dari *range* 0-125 secara *random*.

c. *sort\_population\_by\_fitness*

Fungsi untuk mengurutkan konfigurasi-konfigurasi yang ada di *cube* berdasarkan *fitness valuenya* dari yang terkecil ke terbesar.

## 2. Pemilihan Objective Function

Berikut merupakan objective function yang digunakan dalam permasalahan diagonal magic cube beserta penerapannya. Terdapat pilihan untuk mencegah angka negatif pada perbedaan penjumlahan syarat dengan *magic constant*, dapat dikuadratkan atau diabsolutkan. Pada gambar di bawah ini, menggunakan pengkuadratan.

```

# Row, Column, and Level
for i in range(n):
    for j in range(n):
        row_sum = np.sum(self.array[i,j,:])

        Z += (row_sum - self.MC) ** 2
        col_sum = np.sum(self.array[:, :, j])

        Z += (col_sum - self.MC) ** 2

        pillar_sum = np.sum(self.array[:, i, j])
        Z += (pillar_sum - self.MC) ** 2

```

**Gambar 2.1 Penerapan baris, kolom, dan pillar**

- Penjumlahan tiap baris di setiap level sama dengan *magic constant*
- Penjumlahan tiap kolom di setiap level sama dengan *magic constant*
- Penjumlahan pillar sama dengan *magic constant*

```

# Main Diagonal
for level in range(self.h):
    main_diagonal_left = 0
    main_diagonal_right = 0
    for i in range(self.r):
        main_diagonal_left += self.array[level, i, i]
        main_diagonal_right += self.array[level, i, self.h-1-i]
    Z += (main_diagonal_left - self.MC) ** 2
    Z += (main_diagonal_right - self.MC) ** 2

```

**Gambar 2.2 Penerapan diagonal utama**

- Penjumlahan diagonal utama sama dengan *magic constant*

```

# Diagonal Spaces
space_diagonal_left = 0
space_diagonal_right = 0
for i in range(self.max_len()):
    space_diagonal_left += self.array[self.h - (self.h - i), i, i]
    space_diagonal_right += self.array[i, i, self.h - 1 - i]
Z += (space_diagonal_left - self.MC) ** 2
Z += (space_diagonal_right - self.MC) ** 2

```

### Gambar 2.3 Penerapan diagonal utama

- Penjumlahan diagonal bidang sama dengan *magic constant*

```
# Space Summation
for i in range(self.max_len()):
    space_row = 0
    space_col = 0
    for j in range(self.max_len()):
        space_row += self.array[self.h - (self.h - j),i,self.c - (self.c - j)]
        space_col += self.array[self.h - (self.h - j),self.r - (self.r - j),i]
    Z += (space_row - self.MC) ** 2
    Z += (space_col - self.MC) ** 2
```

### Gambar 2.4 Penerapan baris dan kolom antar bidang

- Penjumlahan baris antar bidang sama dengan *magic constant*
- Penjumlahan kolom antar bidang sama dengan *magic constant*

## 3. Penerapan Algoritma Local Search

### 3.1. Steepest Descent Hill Climbing

#### 3.1.1. Pencarian

Tabel 3.1 Tabel pencarian Steepest Descent Hill Climbing

Percobaan pertama	
Parameter	
	<ul style="list-style-type: none"><li>- Cube</li><li>- Function_error: 'absolute'</li></ul>

State awal	<table border="1"> <thead> <tr><th colspan="5">Level 1</th></tr> </thead> <tbody> <tr><td>57</td><td>107</td><td>28</td><td>90</td><td>40</td></tr> <tr><td>97</td><td>91</td><td>36</td><td>86</td><td>73</td></tr> <tr><td>93</td><td>42</td><td>109</td><td>111</td><td>39</td></tr> <tr><td>59</td><td>110</td><td>115</td><td>11</td><td>76</td></tr> <tr><td>12</td><td>96</td><td>121</td><td>62</td><td>20</td></tr> </tbody> </table> <table border="1"> <thead> <tr><th colspan="5">Level 2</th></tr> </thead> <tbody> <tr><td>37</td><td>79</td><td>102</td><td>63</td><td>30</td></tr> <tr><td>15</td><td>85</td><td>53</td><td>51</td><td>65</td></tr> <tr><td>29</td><td>72</td><td>45</td><td>124</td><td>67</td></tr> <tr><td>81</td><td>49</td><td>106</td><td>80</td><td>50</td></tr> <tr><td>47</td><td>34</td><td>17</td><td>24</td><td>77</td></tr> </tbody> </table> <table border="1"> <thead> <tr><th colspan="5">Level 3</th></tr> </thead> <tbody> <tr><td>100</td><td>5</td><td>108</td><td>123</td><td>32</td></tr> <tr><td>54</td><td>1</td><td>101</td><td>83</td><td>25</td></tr> <tr><td>118</td><td>74</td><td>119</td><td>103</td><td>23</td></tr> <tr><td>99</td><td>8</td><td>46</td><td>58</td><td>33</td></tr> <tr><td>16</td><td>38</td><td>68</td><td>113</td><td>18</td></tr> </tbody> </table>	Level 1					57	107	28	90	40	97	91	36	86	73	93	42	109	111	39	59	110	115	11	76	12	96	121	62	20	Level 2					37	79	102	63	30	15	85	53	51	65	29	72	45	124	67	81	49	106	80	50	47	34	17	24	77	Level 3					100	5	108	123	32	54	1	101	83	25	118	74	119	103	23	99	8	46	58	33	16	38	68	113	18																																																													
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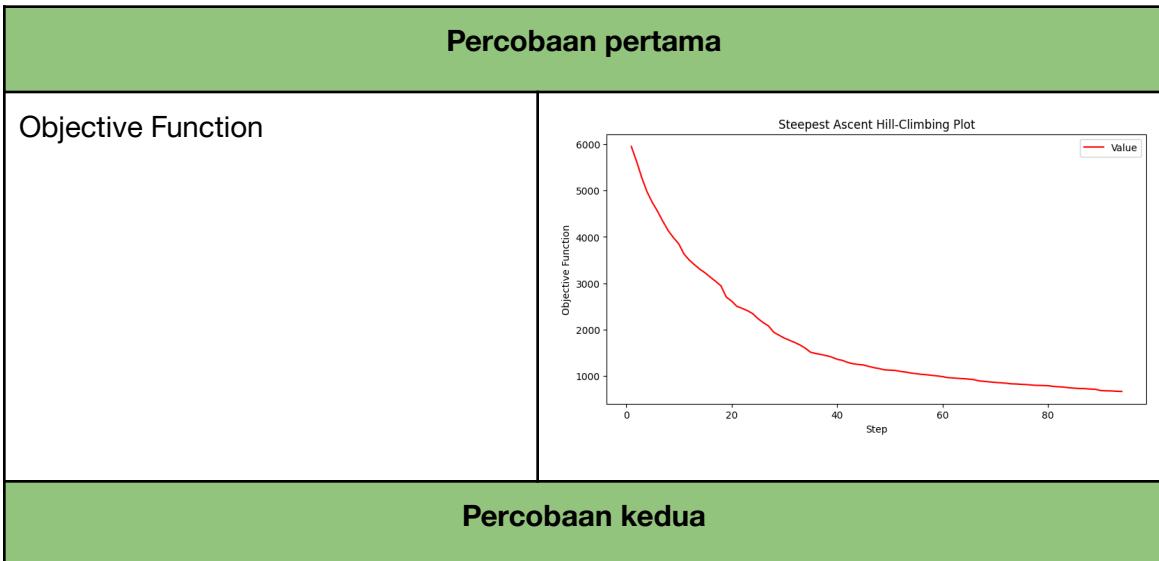
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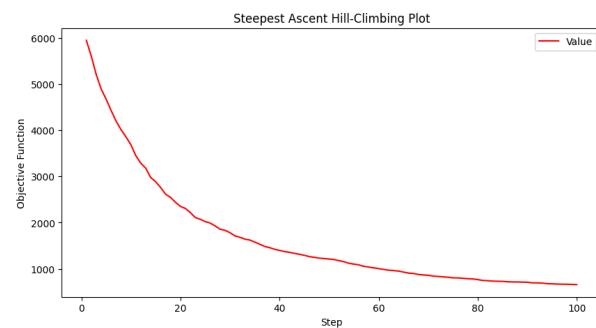
Nilai akhir objective function	<pre>print("best search cube objective function: {steepest.final_states().objective_function()}") ✓ 0.0s best search cube objective function: 814.0</pre> <p>814.0</p>
Banyak iterasi	<pre>+----- RESULTS -----+ iterations: 73 initial Value: 5949.000000 final Value: 814.000000 runtime: 21.0611109999995 seconds +----- END -----+</pre> <p>73</p>

### 3.1.2. Plot

**Tabel 3.2 Plot hasil Steepest Descent Hill Climbing**

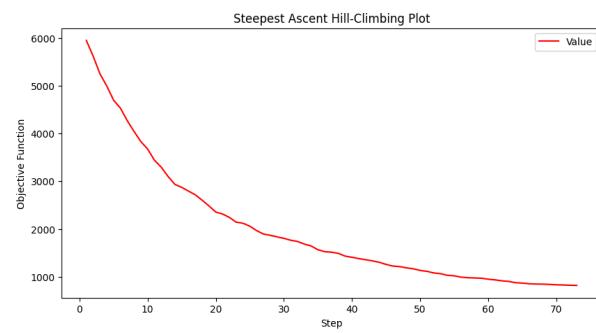


Objective Function



### Percobaan ketiga

Objective Function



#### 3.1.3. Analisis

Dengan melakukan pencarian pada state awal yang sama sebanyak 3 kali, ditemukan hasil algoritma bervariasi. Pada percobaan pertama, didapati hasil akhir 666.0 dengan pengulangan sebanyak 94 kali, percobaan kedua dengan hasil akhir 645.0 dengan pengulangan sebanyak 100 kali, dan percobaan ketiga dengan hasil akhir 814 dengan pengulangan 73 kali. Dapat dilihat bahwa semakin banyak iterasi yang dilakukan algoritma maka akan mengembalikan *objective function* lebih mendekati 0.

### 3.2. Hill Climbing with Sideway Move

#### 3.2.1. Pencarian

Tabel 3.3 Tabel pencarian Hill Climbing with Sideway Move

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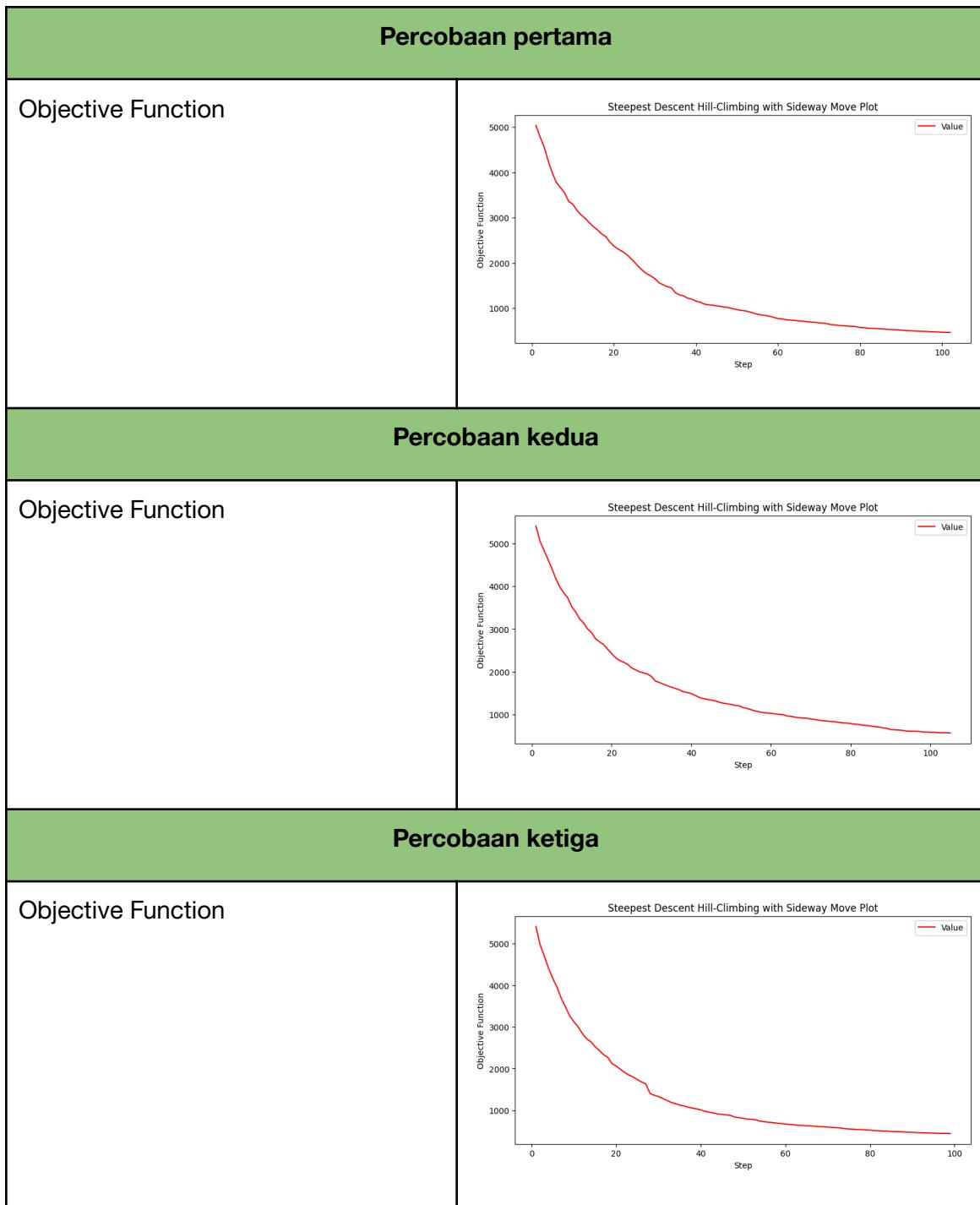
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### 3.2.2. Plot

Tabel 3.4 Plot hasil Hill Climbing with Sideway Move



### 3.2.3. Analisis

Dengan melakukan pencarian pada state awal yang sama sebanyak 3 kali, ditemukan hasil algoritma bervariasi dan juga tidak ditemukannya terjebak dalam kondisi *plateau*. Tidak adanya sideway move memunculkan hipotesis bahwa selama swap, algoritma tidak pernah menghasilkan neighbours state yang memiliki nilai yang sama dengan current state value. Hal ini menyebabkan algoritma bekerja seperti Steepest Descent Hill-Climbing.

## 3.3. Stochastic Hill Climbing

### 3.3.1. Pencarian

Tabel 3.5 Tabel pencarian Stochastic Hill Climbing

Percobaan pertama																																																																																
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125	56	55	87	16																																																																																																																																																			
69	8	23	39	107																																																																																																																																																			
Level 3																																																																																																																																																							
110	67	97	26	75																																																																																																																																																			
99	31	29	47	62																																																																																																																																																			
101	104	20	111	76																																																																																																																																																			
19	102	106	12	37																																																																																																																																																			
7	96	118	105	90																																																																																																																																																			
Level 4																																																																																																																																																							
65	21	41	25	48																																																																																																																																																			
74	14	88	73	100																																																																																																																																																			
83	18	82	94	24																																																																																																																																																			
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35	124	93	109	86																																																																																																																																																			
Level 5																																																																																																																																																							
103	46	6	44	79																																																																																																																																																			
89	95	32	4	64																																																																																																																																																			
123	1	71	49	34																																																																																																																																																			
40	116	122	52	112																																																																																																																																																			
27	22	72	45	70																																																																																																																																																			

Nilai akhir objective function

```
SHC.results()
✓ 0.0s
+----- RESULTS -----
Best step: 36
final Value: 5262.000000
+----- END -----+
```

5262

### Percobaan ketiga

#### Parameter

- Cube
- Max\_iterations: 1000

State awal

4	9	98	21	75
36	71	119	76	121
84	106	97	8	110
26	51	85	30	102
42	53	54	113	38

88	101	22	13	58
82	60	73	29	105
14	17	118	5	56
19	46	95	34	78
25	32	69	48	81

55	15	77	64	72
86	31	87	111	117
20	109	49	83	7
50	67	100	11	37
2	66	114	41	24

116	18	103	115	39
45	68	52	108	28
61	59	112	89	124
10	47	40	90	44
122	1	23	63	74

92	123	104	79	120
33	91	35	70	12
16	62	27	99	57
3	6	94	107	80
125	65	43	93	96

Nilai awal objective function

```
print(f"initial objective function value: {SHC_cube.objective_function()}")
✓ 0.0s
initial objective function value: 6108.0
```

6108

Durasi

```
SHC = Stochastic(cube=SHC_cube)
```

✓ 1.8s

Initial Value: 6108.0

Step 1: Chosen Neighbor Value: 5914.0; Best Value: 6108.0  
 Step 2: Chosen Neighbor Value: 5821.0; Best Value: 5914.0  
 Step 12: Chosen Neighbor Value: 5609.0; Best Value: 5821.0  
 Step 20: Chosen Neighbor Value: 5566.0; Best Value: 5609.0  
 Step 72: Chosen Neighbor Value: 5458.0; Best Value: 5566.0  
 Step 90: Chosen Neighbor Value: 5438.0; Best Value: 5458.0  
 Step 124: Chosen Neighbor Value: 5423.0; Best Value: 5438.0  
 Step 134: Chosen Neighbor Value: 5393.0; Best Value: 5423.0  
 Step 143: Chosen Neighbor Value: 5303.0; Best Value: 5393.0  
 Step 179: Chosen Neighbor Value: 5146.0; Best Value: 5303.0  
 Step 223: Chosen Neighbor Value: 5137.0; Best Value: 5146.0  
 Step 302: Chosen Neighbor Value: 5045.0; Best Value: 5137.0  
 Step 332: Chosen Neighbor Value: 4468.0; Best Value: 5045.0

1.8 seconds

State akhir

Level 1

4	9	98	21	75
36	71	119	76	121
84	106	97	8	110
26	51	85	30	102
42	53	54	113	38

Level 2

88	101	22	13	58
82	60	73	29	105
14	17	118	5	56
19	46	95	34	78
25	32	69	48	81

Level 3

55	15	77	64	72
86	31	87	111	117
20	109	49	83	7
50	67	100	11	37
2	66	114	41	24

Level 4

116	18	103	115	39
45	68	52	108	28
61	59	112	89	124
10	47	40	90	44
122	1	23	63	74

Level 5

92	123	104	79	120
33	91	35	70	12
16	62	27	99	57
3	6	94	107	80
125	65	43	93	96

Nilai akhir objective function

```
SHC = Stochastic(cube=SHC_cube)
```

✓ 1.8s

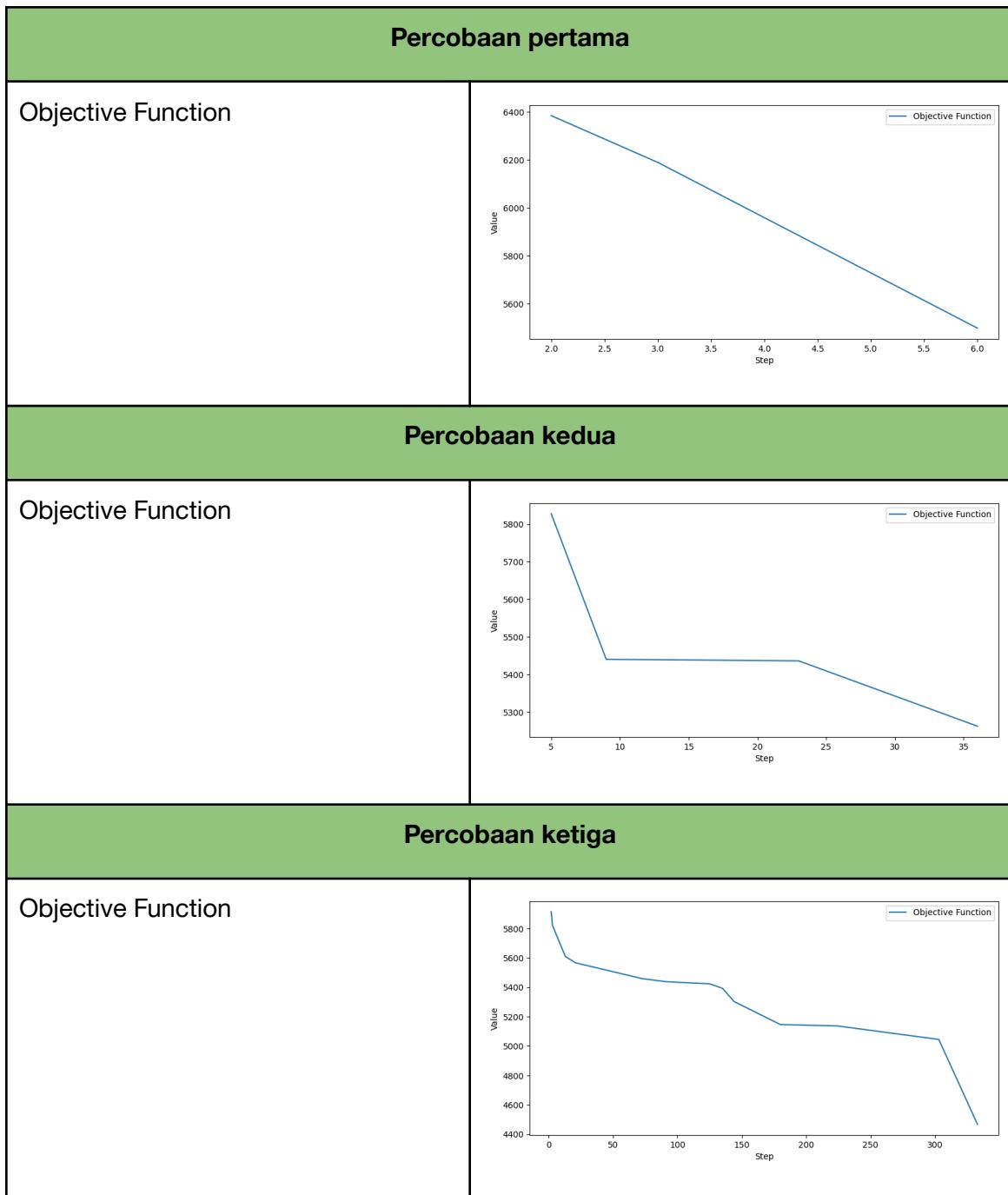
Initial Value: 6108.0

Step 1: Chosen Neighbor Value: 5914.0; Best Value: 6108.0  
 Step 2: Chosen Neighbor Value: 5821.0; Best Value: 5914.0  
 Step 12: Chosen Neighbor Value: 5609.0; Best Value: 5821.0  
 Step 20: Chosen Neighbor Value: 5566.0; Best Value: 5609.0  
 Step 72: Chosen Neighbor Value: 5458.0; Best Value: 5566.0  
 Step 90: Chosen Neighbor Value: 5438.0; Best Value: 5458.0  
 Step 124: Chosen Neighbor Value: 5423.0; Best Value: 5438.0  
 Step 134: Chosen Neighbor Value: 5393.0; Best Value: 5423.0  
 Step 143: Chosen Neighbor Value: 5303.0; Best Value: 5393.0  
 Step 179: Chosen Neighbor Value: 5146.0; Best Value: 5303.0  
 Step 223: Chosen Neighbor Value: 5137.0; Best Value: 5146.0  
 Step 302: Chosen Neighbor Value: 5045.0; Best Value: 5137.0  
 Step 332: Chosen Neighbor Value: 4468.0; Best Value: 5045.0

4468

### 3.3.2. Plot

Tabel 3.6 Plot hasil Stochastic Hill Climbing



### 3.3.3. Analisis

Dari ketiga percobaan yang diamati, objective function value dari percobaan dengan max\_iteration terbanyak mendapatkan nilai objective function terkecil. Karena, max\_iteration yang banyak algoritma stochastic hill-climb dapat mengeksplorasi lebih banyak neighbor, dan kemungkinan untuk menemukan best neighbor semakin besar. Durasi stochastic hill-climb juga bertambah sesuai dengan bertambahnya max\_iteration, namun perubahannya tidak signifikan.

## 3.4. Random Restart Hill Climbing

### 3.4.1. Pencarian

Tabel 3.9 Tabel pencarian Random Restart

Percobaan pertama																																																																																
Parameter	-																																																																															
State awal	<ul style="list-style-type: none"><li>- Cube</li><li>- Max_restart: 10</li></ul>																																																																															
	Level 1	Level 2	Level 3																																																																													
	<table border="1"><tr><td>70</td><td>52</td><td>32</td><td>64</td><td>12</td></tr><tr><td>102</td><td>89</td><td>6</td><td>92</td><td>18</td></tr><tr><td>26</td><td>19</td><td>17</td><td>30</td><td>81</td></tr><tr><td>104</td><td>66</td><td>72</td><td>117</td><td>119</td></tr><tr><td>125</td><td>95</td><td>69</td><td>65</td><td>60</td></tr></table>	70	52	32	64	12	102	89	6	92	18	26	19	17	30	81	104	66	72	117	119	125	95	69	65	60	<table border="1"><tr><td>90</td><td>1</td><td>28</td><td>59</td><td>96</td></tr><tr><td>61</td><td>33</td><td>21</td><td>9</td><td>15</td></tr><tr><td>54</td><td>99</td><td>48</td><td>35</td><td>38</td></tr><tr><td>77</td><td>105</td><td>63</td><td>91</td><td>55</td></tr><tr><td>13</td><td>49</td><td>23</td><td>40</td><td>74</td></tr></table>	90	1	28	59	96	61	33	21	9	15	54	99	48	35	38	77	105	63	91	55	13	49	23	40	74	<table border="1"><tr><td>36</td><td>108</td><td>20</td><td>53</td><td>120</td></tr><tr><td>118</td><td>103</td><td>123</td><td>75</td><td>114</td></tr><tr><td>110</td><td>94</td><td>115</td><td>44</td><td>97</td></tr><tr><td>79</td><td>98</td><td>11</td><td>7</td><td>4</td></tr><tr><td>62</td><td>3</td><td>46</td><td>25</td><td>107</td></tr></table>	36	108	20	53	120	118	103	123	75	114	110	94	115	44	97	79	98	11	7	4	62	3	46	25	107		
70	52	32	64	12																																																																												
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104	66	72	117	119																																																																												
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90	1	28	59	96																																																																												
61	33	21	9	15																																																																												
54	99	48	35	38																																																																												
77	105	63	91	55																																																																												
13	49	23	40	74																																																																												
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118	103	123	75	114																																																																												
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79	98	11	7	4																																																																												
62	3	46	25	107																																																																												
	Level 4	Level 5																																																																														
	<table border="1"><tr><td>41</td><td>51</td><td>24</td><td>10</td><td>93</td></tr><tr><td>37</td><td>100</td><td>50</td><td>68</td><td>5</td></tr><tr><td>34</td><td>101</td><td>42</td><td>56</td><td>31</td></tr><tr><td>113</td><td>82</td><td>22</td><td>47</td><td>122</td></tr><tr><td>14</td><td>27</td><td>109</td><td>29</td><td>116</td></tr></table>	41	51	24	10	93	37	100	50	68	5	34	101	42	56	31	113	82	22	47	122	14	27	109	29	116	<table border="1"><tr><td>124</td><td>85</td><td>45</td><td>84</td><td>67</td></tr><tr><td>86</td><td>73</td><td>16</td><td>106</td><td>8</td></tr><tr><td>43</td><td>76</td><td>71</td><td>88</td><td>83</td></tr><tr><td>87</td><td>58</td><td>78</td><td>80</td><td>57</td></tr><tr><td>2</td><td>111</td><td>121</td><td>112</td><td>39</td></tr></table>	124	85	45	84	67	86	73	16	106	8	43	76	71	88	83	87	58	78	80	57	2	111	121	112	39																												
41	51	24	10	93																																																																												
37	100	50	68	5																																																																												
34	101	42	56	31																																																																												
113	82	22	47	122																																																																												
14	27	109	29	116																																																																												
124	85	45	84	67																																																																												
86	73	16	106	8																																																																												
43	76	71	88	83																																																																												
87	58	78	80	57																																																																												
2	111	121	112	39																																																																												
Nilai awal objective function	<pre>print(f"initial objective function value: {RR_cube.objective_function()}") ✓ 0.0s initial objective function value: 6517.0</pre>																																																																															
	6517																																																																															

Durasi

```
RR = Random_restart(cube=RR_cube,max_restart=10)
✓ 0.6s

Initial Value: 6517.0

Restart: 1

Initial Value: 6517.0

Step 1: Choosen Neighbor Value: 4924.0; Best Value: 6517.0
Iteration Value: 4924.0

Best Value: 4924.0

Restart: 2

Initial Value: 6517.0

Step 1: Choosen Neighbor Value: 5978.0; Best Value: 6517.0
Step 2: Choosen Neighbor Value: 5168.0; Best Value: 5978.0
Iteration Value: 5168.0

Best Value: 4924.0
```

0.6 seconds

State akhir

Level 1					Level 2					Level 3				
12	81	122	64	48	120	102	30	93	96	4	91	44	53	60
89	85	72	28	18	90	33	77	82	31	109	39	104	49	6
55	19	68	69	119	61	99	123	37	42	110	26	47	34	97
5	84	58	114	23	59	101	75	3	98	63	45	108	70	65
125	95	25	36	103	13	7	27	111	15	46	1	117	54	107

Level 4					Level 5				
41	10	24	94	74	112	20	100	50	106
115	105	32	38	116	8	124	29	17	118
87	73	11	67	80	43	76	71	83	88
113	92	22	57	35	51	66	14	9	52
79	78	21	16	62	2	86	121	40	56

Nilai akhir objective function

```
[34] RR.results()
✓ 0.0s
+----- RESULTS -----
Best iteration: 2
final Value: 4590.000000
+----- END -----+
```

4590

## Percobaan kedua

Parameter

- Cube
- Max\_restart: 100

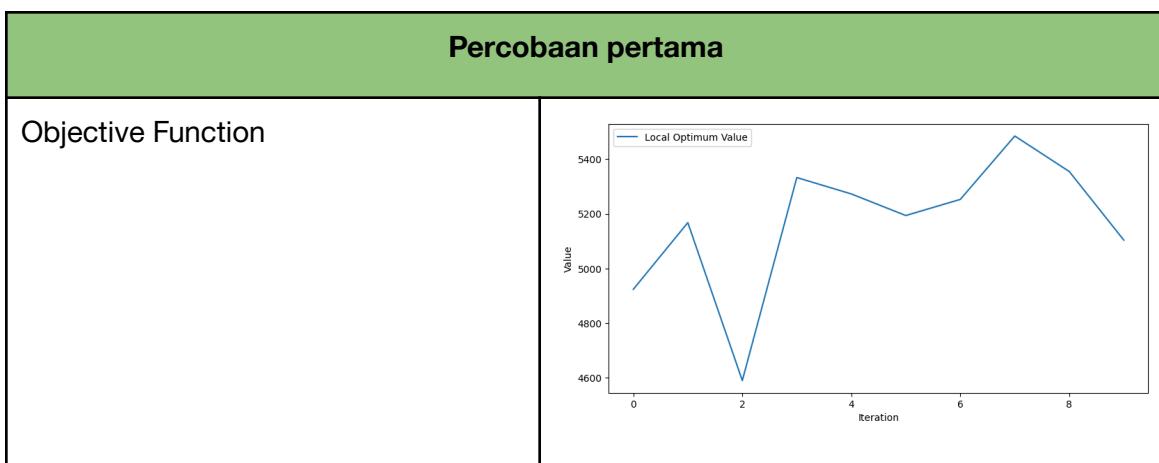
<p><b>State awal</b></p>	<table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 1</th> </tr> </thead> <tbody> <tr><td>13</td><td>38</td><td>56</td><td>16</td><td>10</td></tr> <tr><td>59</td><td>24</td><td>69</td><td>96</td><td>75</td></tr> <tr><td>91</td><td>32</td><td>76</td><td>51</td><td>12</td></tr> <tr><td>19</td><td>22</td><td>115</td><td>11</td><td>78</td></tr> <tr><td>52</td><td>79</td><td>105</td><td>63</td><td>77</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 2</th> </tr> </thead> <tbody> <tr><td>8</td><td>40</td><td>48</td><td>108</td><td>2</td></tr> <tr><td>87</td><td>85</td><td>89</td><td>101</td><td>50</td></tr> <tr><td>93</td><td>118</td><td>49</td><td>107</td><td>25</td></tr> <tr><td>99</td><td>26</td><td>9</td><td>14</td><td>65</td></tr> <tr><td>102</td><td>98</td><td>3</td><td>35</td><td>74</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 3</th> </tr> </thead> <tbody> <tr><td>104</td><td>64</td><td>94</td><td>15</td><td>61</td></tr> <tr><td>124</td><td>28</td><td>120</td><td>95</td><td>36</td></tr> <tr><td>45</td><td>97</td><td>80</td><td>86</td><td>7</td></tr> <tr><td>18</td><td>82</td><td>113</td><td>55</td><td>46</td></tr> <tr><td>92</td><td>57</td><td>44</td><td>67</td><td>81</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 4</th> </tr> </thead> <tbody> <tr><td>111</td><td>21</td><td>114</td><td>68</td><td>30</td></tr> <tr><td>41</td><td>70</td><td>54</td><td>83</td><td>106</td></tr> <tr><td>119</td><td>116</td><td>42</td><td>90</td><td>110</td></tr> <tr><td>109</td><td>100</td><td>4</td><td>6</td><td>1</td></tr> <tr><td>53</td><td>43</td><td>121</td><td>88</td><td>84</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 5</th> </tr> </thead> <tbody> <tr><td>71</td><td>112</td><td>5</td><td>103</td><td>31</td></tr> <tr><td>20</td><td>58</td><td>27</td><td>125</td><td>66</td></tr> <tr><td>39</td><td>23</td><td>29</td><td>17</td><td>34</td></tr> <tr><td>62</td><td>117</td><td>122</td><td>73</td><td>33</td></tr> <tr><td>72</td><td>47</td><td>123</td><td>60</td><td>37</td></tr> </tbody> </table>	Level 1					13	38	56	16	10	59	24	69	96	75	91	32	76	51	12	19	22	115	11	78	52	79	105	63	77	Level 2					8	40	48	108	2	87	85	89	101	50	93	118	49	107	25	99	26	9	14	65	102	98	3	35	74	Level 3					104	64	94	15	61	124	28	120	95	36	45	97	80	86	7	18	82	113	55	46	92	57	44	67	81	Level 4					111	21	114	68	30	41	70	54	83	106	119	116	42	90	110	109	100	4	6	1	53	43	121	88	84	Level 5					71	112	5	103	31	20	58	27	125	66	39	23	29	17	34	62	117	122	73	33	72	47	123	60	37
Level 1																																																																																																																																																							
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93	118	49	107	25																																																																																																																																																			
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18	82	113	55	46																																																																																																																																																			
92	57	44	67	81																																																																																																																																																			
Level 4																																																																																																																																																							
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39	23	29	17	34																																																																																																																																																			
62	117	122	73	33																																																																																																																																																			
72	47	123	60	37																																																																																																																																																			
<p><b>Nilai awal objective function</b></p>	<pre>print("initial objective function value: " + str(RR_cube.objective_function())) ✓ 0s initial objective function value: 6083.0</pre>																																																																																																																																																						
6083																																																																																																																																																							
<p><b>Durasi</b></p>	<pre>RR = Random_restart(cube=RR_cube,max_restart=100) ✓ 3.7s Initial Value: 6083.0 Restart: 1 Initial Value: 6083.0 Step 1: Chosen Neighbor Value: 5893.0; Best Value: 6083.0 Step 2: Chosen Neighbor Value: 5364.0; Best Value: 5893.0 Iteration Value: 5364.0 Best Value: 5364.0 Restart: 2 Initial Value: 6083.0 Step 1: Chosen Neighbor Value: 5326.0; Best Value: 6083.0 Iteration Value: 5326.0 Best Value: 5326.0</pre>																																																																																																																																																						
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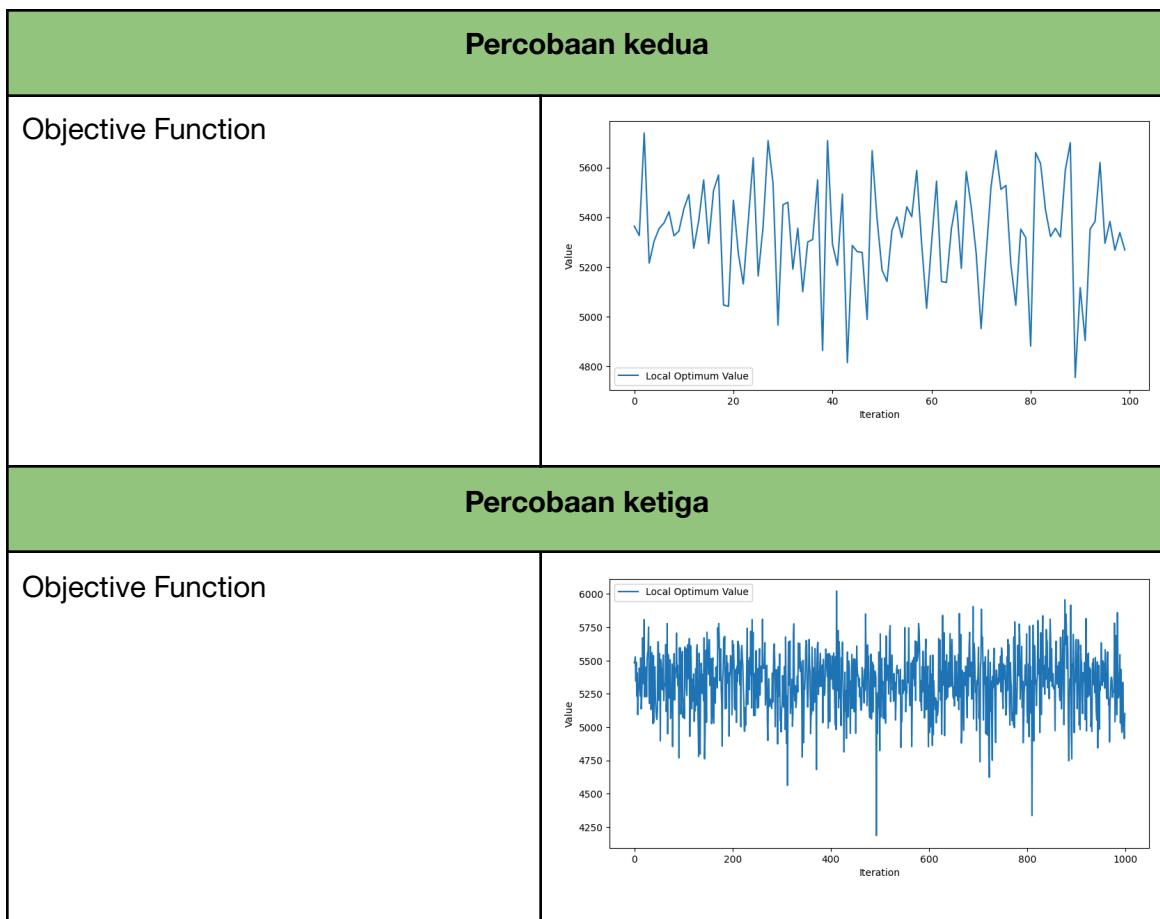
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Durasi	<pre>RR = Random_restart(cube=RR_cube,max_restart=1000) ✓ 44.3s Initial Value: 7056.0 Restart: 1 Initial Value: 7056.0 Step 1: Choosen Neighbor Value: 5731.0; Best Value: 7056.0 Step 2: Choosen Neighbor Value: 5483.0; Best Value: 5731.0 Iteration Value: 5483.0 Best Value: 5483.0 Restart: 2 Initial Value: 7056.0</pre>																																																																																																																																									

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State akhir	<table border="1"> <thead> <tr> <th colspan="5">Level 1</th> <th colspan="5">Level 2</th> <th colspan="5">Level 3</th> </tr> </thead> <tbody> <tr><td>96</td><td>56</td><td>36</td><td>71</td><td>84</td><td>93</td><td>111</td><td>30</td><td>81</td><td>77</td><td>65</td><td>44</td><td>51</td><td>101</td><td>59</td></tr> <tr><td>97</td><td>90</td><td>75</td><td>14</td><td>61</td><td>47</td><td>4</td><td>66</td><td>28</td><td>60</td><td>37</td><td>120</td><td>53</td><td>116</td><td>25</td></tr> <tr><td>100</td><td>38</td><td>21</td><td>124</td><td>88</td><td>107</td><td>41</td><td>109</td><td>18</td><td>33</td><td>6</td><td>54</td><td>67</td><td>103</td><td>98</td></tr> <tr><td>106</td><td>102</td><td>118</td><td>40</td><td>19</td><td>34</td><td>31</td><td>10</td><td>80</td><td>86</td><td>122</td><td>26</td><td>52</td><td>3</td><td>99</td></tr> <tr><td>24</td><td>72</td><td>17</td><td>104</td><td>94</td><td>35</td><td>23</td><td>105</td><td>69</td><td>117</td><td>91</td><td>119</td><td>70</td><td>45</td><td>11</td></tr> </tbody> </table> <table border="1"> <thead> <tr> <th colspan="5">Level 4</th> <th colspan="5">Level 5</th> </tr> </thead> <tbody> <tr><td>12</td><td>64</td><td>39</td><td>125</td><td>1</td><td>78</td><td>114</td><td>15</td><td>7</td><td>57</td><td>55</td><td>115</td><td>83</td><td>2</td><td>42</td></tr> <tr><td>95</td><td>85</td><td>8</td><td>121</td><td>123</td><td>13</td><td>48</td><td>82</td><td>113</td><td>89</td><td>46</td><td>73</td><td>43</td><td>49</td><td>68</td></tr> <tr><td>76</td><td>79</td><td>74</td><td>5</td><td>50</td><td>29</td><td>62</td><td>112</td><td>9</td><td>16</td><td>110</td><td>27</td><td>22</td><td>58</td><td>92</td></tr> <tr><td>87</td><td>32</td><td>108</td><td>63</td><td>20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> </tbody> </table>	Level 1					Level 2					Level 3					96	56	36	71	84	93	111	30	81	77	65	44	51	101	59	97	90	75	14	61	47	4	66	28	60	37	120	53	116	25	100	38	21	124	88	107	41	109	18	33	6	54	67	103	98	106	102	118	40	19	34	31	10	80	86	122	26	52	3	99	24	72	17	104	94	35	23	105	69	117	91	119	70	45	11	Level 4					Level 5					12	64	39	125	1	78	114	15	7	57	55	115	83	2	42	95	85	8	121	123	13	48	82	113	89	46	73	43	49	68	76	79	74	5	50	29	62	112	9	16	110	27	22	58	92	87	32	108	63	20										
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Nilai akhir objective function	<pre> RR.results() ✓ 0.0s +----- RESULTS -----+ Best iteration: 493 final Value: 4186.000000 +----- END -----+ </pre> <p>4186</p>																																																																																																																																																																

### 3.4.2. Plot

Tabel 3.10 Plot hasil Random Restart





### 3.4.3. Analisis

Dari ketiga percobaan yang diamati, objective function value dari percobaan dengan max\_restart terbanyak mendapatkan nilai objective function terkecil. Karena, max\_restart yang banyak algoritma Random Restart hill-climb melakukan iterasi berkali-kali sampai max\_restart. Semakin banyak max\_restart, algoritma memiliki peluang yang lebih besar untuk menemukan best\_state, dari restart-restart yang dilakukan. Durasi Random Restart hill-climb juga bertambah sesuai dengan bertambahnya max\_restart, dan perbedaan waktu antara ketiga

percobaan cukup signifikan. Hal ini dikarenakan di setiap restart, masih dilakukan iterasi sendiri sampai mencapai local optimum.

### **3.5. Simulated Annealing**

### **3.5.1. Pencarian**

### Tabel 3.11 Tabel pencarian Simulated Annealing

Percobaan pertama																																																																																																																																																							
Parameter	<ul style="list-style-type: none"> <li>- Cube</li> <li>- Tmin: 0</li> <li>- Tmax: 10000</li> <li>- Step_max: 10000</li> <li>- Cooling_schedule: quadratic</li> <li>- Alpha: 0.99</li> <li>- best_neighbor: True</li> <li>- Function_error: absolute</li> </ul>																																																																																																																																																						
State awal	<table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 1</th> </tr> </thead> <tbody> <tr><td>93</td><td>30</td><td>14</td><td>52</td><td>34</td></tr> <tr><td>32</td><td>24</td><td>23</td><td>110</td><td>25</td></tr> <tr><td>72</td><td>98</td><td>47</td><td>10</td><td>120</td></tr> <tr><td>119</td><td>62</td><td>41</td><td>11</td><td>28</td></tr> <tr><td>33</td><td>102</td><td>68</td><td>61</td><td>101</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 2</th> </tr> </thead> <tbody> <tr><td>39</td><td>15</td><td>113</td><td>76</td><td>67</td></tr> <tr><td>2</td><td>92</td><td>90</td><td>26</td><td>106</td></tr> <tr><td>115</td><td>59</td><td>71</td><td>103</td><td>6</td></tr> <tr><td>121</td><td>75</td><td>74</td><td>94</td><td>114</td></tr> <tr><td>5</td><td>58</td><td>112</td><td>57</td><td>46</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 3</th> </tr> </thead> <tbody> <tr><td>22</td><td>73</td><td>54</td><td>84</td><td>88</td></tr> <tr><td>107</td><td>19</td><td>60</td><td>64</td><td>122</td></tr> <tr><td>63</td><td>31</td><td>85</td><td>125</td><td>100</td></tr> <tr><td>49</td><td>29</td><td>18</td><td>66</td><td>48</td></tr> <tr><td>53</td><td>13</td><td>108</td><td>111</td><td>124</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 4</th> </tr> </thead> <tbody> <tr><td>38</td><td>123</td><td>118</td><td>7</td><td>4</td></tr> <tr><td>40</td><td>9</td><td>27</td><td>117</td><td>104</td></tr> <tr><td>50</td><td>91</td><td>42</td><td>17</td><td>97</td></tr> <tr><td>37</td><td>105</td><td>36</td><td>80</td><td>21</td></tr> <tr><td>87</td><td>51</td><td>1</td><td>96</td><td>55</td></tr> </tbody> </table> <table border="1" style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 5</th> </tr> </thead> <tbody> <tr><td>78</td><td>20</td><td>44</td><td>45</td><td>109</td></tr> <tr><td>8</td><td>83</td><td>69</td><td>70</td><td>89</td></tr> <tr><td>116</td><td>99</td><td>79</td><td>77</td><td>35</td></tr> <tr><td>3</td><td>95</td><td>86</td><td>82</td><td>65</td></tr> <tr><td>81</td><td>43</td><td>16</td><td>12</td><td>56</td></tr> </tbody> </table>	Level 1					93	30	14	52	34	32	24	23	110	25	72	98	47	10	120	119	62	41	11	28	33	102	68	61	101	Level 2					39	15	113	76	67	2	92	90	26	106	115	59	71	103	6	121	75	74	94	114	5	58	112	57	46	Level 3					22	73	54	84	88	107	19	60	64	122	63	31	85	125	100	49	29	18	66	48	53	13	108	111	124	Level 4					38	123	118	7	4	40	9	27	117	104	50	91	42	17	97	37	105	36	80	21	87	51	1	96	55	Level 5					78	20	44	45	109	8	83	69	70	89	116	99	79	77	35	3	95	86	82	65	81	43	16	12	56
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Nilai awal objective function	<pre> print("initial objective function: {SA_cube.objective_function(square_error=False)}") ✓ 0.0s initial objective function: 4907.0 </pre>																																																																																																																																																						

	4907.0																																																																																																																																																						
Durasi	<pre>SA = SimulatedAnnealing(cube=SA_cube, tmax=10000, tmin=0, step_max=10000, cooling_schedule="quadratic", alpha=0.99, best_neighbor=True, function_error="absolute") ✓ 1m 40.5s</pre> <p>1: 42 Minutes</p>																																																																																																																																																						
State akhir	<table style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 1</th> <th colspan="5">Level 2</th> <th colspan="5">Level 3</th> </tr> </thead> <tbody> <tr> <td>49</td><td>46</td><td>15</td><td>111</td><td>94</td> <td>106</td><td>34</td><td>16</td><td>90</td><td>67</td> <td>21</td><td>85</td><td>104</td><td>72</td><td>33</td> </tr> <tr> <td>47</td><td>55</td><td>113</td><td>98</td><td>4</td> <td>5</td><td>108</td><td>69</td><td>35</td><td>97</td> <td>105</td><td>82</td><td>40</td><td>9</td><td>80</td> </tr> <tr> <td>68</td><td>75</td><td>52</td><td>10</td><td>109</td> <td>53</td><td>84</td><td>38</td><td>121</td><td>19</td> <td>89</td><td>28</td><td>73</td><td>32</td><td>92</td> </tr> <tr> <td>114</td><td>18</td><td>101</td><td>79</td><td>2</td> <td>31</td><td>27</td><td>99</td><td>48</td><td>112</td> <td>12</td><td>110</td><td>3</td><td>102</td><td>78</td> </tr> <tr> <td>45</td><td>120</td><td>26</td><td>17</td><td>107</td> <td>116</td><td>60</td><td>96</td><td>24</td><td>20</td> <td>91</td><td>11</td><td>93</td><td>100</td><td>30</td> </tr> </tbody> </table> <table style="margin-bottom: 10px;"> <thead> <tr> <th colspan="5">Level 4</th> <th colspan="5">Level 5</th> </tr> </thead> <tbody> <tr> <td>77</td><td>103</td><td>119</td><td>8</td><td>7</td> <td>61</td><td>51</td><td>57</td><td>25</td><td>118</td> </tr> <tr> <td>44</td><td>6</td><td>36</td><td>115</td><td>117</td> <td>124</td><td>62</td><td>54</td><td>58</td><td>14</td> </tr> <tr> <td>42</td><td>64</td><td>74</td><td>66</td><td>70</td> <td>65</td><td>59</td><td>83</td><td>86</td><td>23</td> </tr> <tr> <td>125</td><td>76</td><td>71</td><td>43</td><td>1</td> <td>22</td><td>87</td><td>41</td><td>50</td><td>123</td> </tr> <tr> <td>29</td><td>63</td><td>13</td><td>81</td><td>122</td> <td>39</td><td>56</td><td>88</td><td>95</td><td>37</td> </tr> </tbody> </table>	Level 1					Level 2					Level 3					49	46	15	111	94	106	34	16	90	67	21	85	104	72	33	47	55	113	98	4	5	108	69	35	97	105	82	40	9	80	68	75	52	10	109	53	84	38	121	19	89	28	73	32	92	114	18	101	79	2	31	27	99	48	112	12	110	3	102	78	45	120	26	17	107	116	60	96	24	20	91	11	93	100	30	Level 4					Level 5					77	103	119	8	7	61	51	57	25	118	44	6	36	115	117	124	62	54	58	14	42	64	74	66	70	65	59	83	86	23	125	76	71	43	1	22	87	41	50	123	29	63	13	81	122	39	56	88	95	37
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29	63	13	81	122	39	56	88	95	37																																																																																																																																														
Nilai akhir objective function	<pre>+----- RESULTS -----+ cooling sched.: quadratic multiplicative initial temp: 10000 final temp: 0.0001010303050402979 final step: 10000  initial energy: 4907.000  final energy: 447.000 energy differences: 4460.000  frequency stuck: 72 ratio stuck: 0.0072  runtime: 102.511 seconds +----- END -----+</pre> <p>447.0</p>																																																																																																																																																						

### Frekuensi stuck

```
+----- RESULTS -----+
cooling sched.: quadratic multiplicative
initial temp: 10000
final temp: 0.0001010303050402979
final step: 10000

initial energy: 4907.000

final energy: 447.000
energy differences: 4460.000

frequency stuck: 72
ratio stuck: 0.0072

runtime: 102.511 seconds
+----- END -----+
```

72

### Percobaan kedua

#### Parameter

- Cube
- Tmin: 0
- Tmax: 1000
- Step\_max: 10000
- Cooling\_schedule: linear
- Alpha: 0.99
- best\_neighbor: True
- Function\_error: absolute

#### State awal

Level 1					Level 2					Level 3				
93	30	14	52	34	39	15	113	76	67	22	73	54	84	88
32	24	23	110	25	2	92	90	26	106	107	19	60	64	122
72	98	47	10	120	115	59	71	103	6	63	31	85	125	100
119	62	41	11	28	121	75	74	94	114	49	29	18	66	48
33	102	68	61	101	5	58	112	57	46	53	13	108	111	124

Level 4					Level 5				
38	123	118	7	4	78	20	44	45	109
40	9	27	117	104	8	83	69	70	89
50	91	42	17	97	116	99	79	77	35
37	105	36	80	21	3	95	86	82	65
87	51	1	96	55	81	43	16	12	56

Nilai awal objective function	<pre>print(f"initial objective function: {SA_cube.objective_function(square_error=False)}") ✓ 0.0s initial objective function: 4907.0</pre>																																																																																																																																																																															
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Durasi	<pre>SA = Simulated[{"cube":SA_cube,tmax=10000,tmin=0,step_max=10000,cooling_schedule="linear",alpha=0.99,best_neighbor=True,function_error="absolute"}] ✓ 1m 30.5s</pre>																																																																																																																																																																															
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	<ul style="list-style-type: none"> <li>- Tmin: 0</li> <li>- Tmax: 10000</li> <li>- Step_max: 10000</li> <li>- Cooling_schedule: quadratic</li> <li>- Alpha: 0.99</li> <li>- best_neighbor: False</li> <li>- Function_error: absolute</li> </ul>																																																																																																																																									
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Nilai awal objective function	<pre style="background-color: black; color: cyan; padding: 5px;"> print(f"initial objective function: {SA_cube.objective_function(square_error)}") ✓ 0.0s initial objective function: 4907.0 </pre> <p style="color: cyan; margin-top: 10px;">4907.0</p>																																																																																																																																									
Durasi	<pre style="background-color: black; color: cyan; padding: 5px;"> Simulated(cube=SA_cube,tmax=10000,tmin=0,step_max=10000,cooling_schedule="quadratic",alpha=0.99,best_neighbor=False,function_error="absolute") ✓ 7.6s </pre> <p style="color: cyan; margin-top: 10px;">7.6 seconds</p>																																																																																																																																									

State akhir

Level 1					Level 2					Level 3				
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81	57	43	125	9	10	53	117	21	119	90	70	44	4	105
31	27	37	99	121	94	116	73	24	5	67	17	84	120	25
69	52	107	28	55	108	79	11	77	39	106	110	16	42	41
23	97	101	12	83	20	62	86	89	56	46	3	109	64	93

Level 4					Level 5				
80	78	114	29	15	35	38	75	51	113
63	13	48	118	68	71	122	65	47	14
26	112	91	2	76	98	36	33	66	85
22	58	61	74	102	8	18	123	95	72
124	49	1	88	54	103	104	19	60	30

Nilai akhir objective function

```
+----- RESULTS -----+
cooling sched.: quadratic multiplicative
initial temp: 10000
final temp: 0.0001010303050402979
final step: 10000

initial energy: 4907.000

final energy: 483.000
energy differences: 4424.000

frequency stuck: 94
ratio stuck: 0.0094

runtime: 7.812 seconds
+----- END -----+
```

483.0

Frekuensi stuck

```
+----- RESULTS -----+
cooling sched.: quadratic multiplicative
initial temp: 10000
final temp: 0.0001010303050402979
final step: 10000

initial energy: 4907.000

final energy: 483.000
energy differences: 4424.000

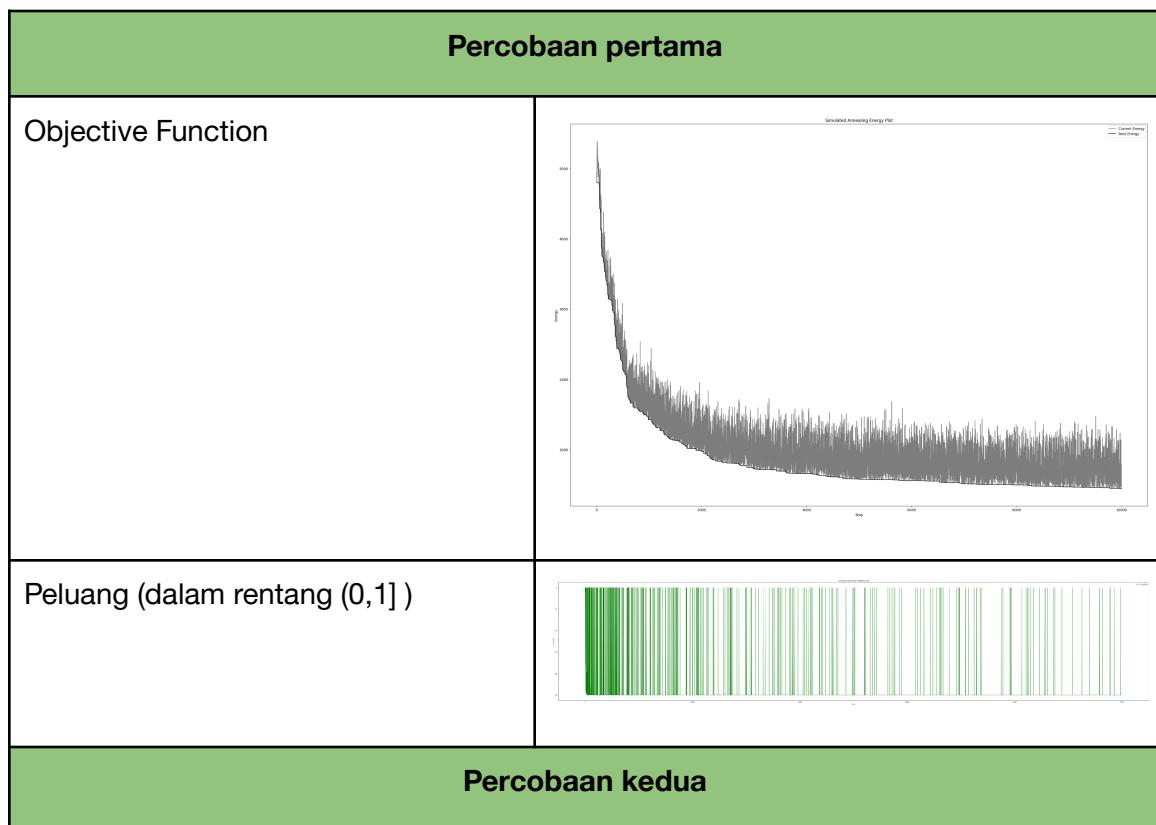
frequency stuck: 94
ratio stuck: 0.0094

runtime: 7.812 seconds
+----- END -----+
```

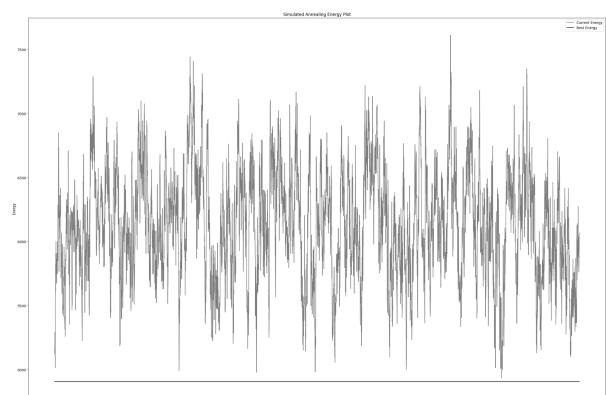
94

### 3.5.2. Plot

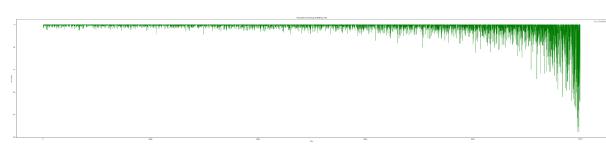
Tabel 3.12 Plot hasil Simulated Annealing



Objective Function

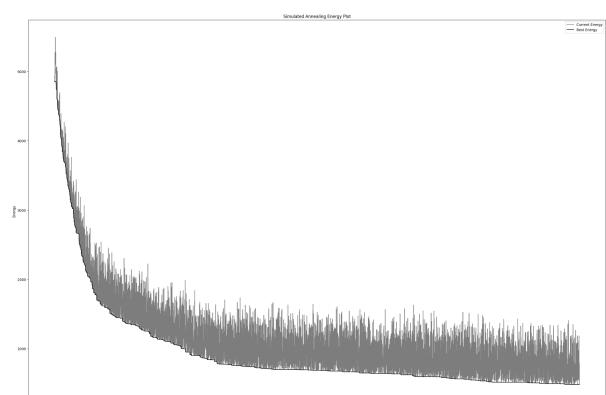


Peluang (dalam rentang (0,1] )

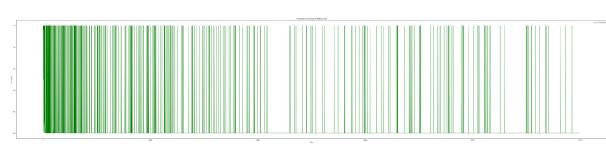


### Percobaan ketiga

Objective Function



Peluang (dalam rentang (0,1] )



#### 3.5.3. Analisis

Ketiga percobaan memiliki kesamaan pada temperatur, step, dan function\_error. Parameter yang diubah adalah cooling schedule dan best neighbors. Algoritma percobaan ketiga memiliki hasil yang mirip dengan percobaan pertama dengan waktu yang sangat lebih cepat (

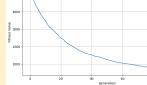
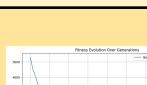
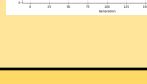
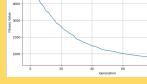
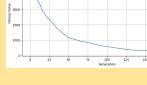
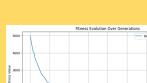
perbandingan 7 detik dan 1:42 menit ). Pada plot, percobaan pertama dan ketiga menghasilkan plot yang sama, yaitu dari value tinggi ke rendah. Hal ini sesuai dengan konsep dari simulated annealing yang akan eksplorasi tetapi saat mencapai akhir akan lebih memilih yang menguntungkan. Secara probabilitas, dapat dilihat pada step awal banyak mengambil neighbor ( probabilitas 1 ) tetapi makin lama sudah semakin jarang. Untuk percobaan kedua merupakan percobaan terburuk karena menghasilkan value yang buruk dan memakan waktu yang lama juga saat eksplorasi.

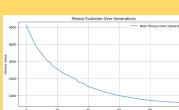
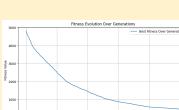
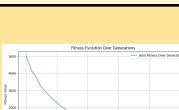
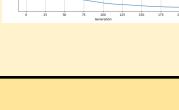
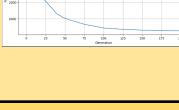
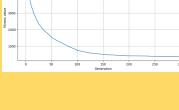
### 3.6. Genetic Algorithm

#### 3.6.1. Pencarian

**Tabel 3.13 Tabel pencarian Genetic Algorithm**

Percobaan	State awal	Objective Function	Kode warna										
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2	<table border="1"> <tr> <td>Level 1</td> <td>Level 2</td> <td>Level 3</td> </tr> <tr> <td>25 32 55 85 110 45 109 111 51 162 77 30 122 59 129 67 86 2 115 94 80 23 24 78 165</td> <td>131 74 79 19 34 43 61 125 10 99 39 57 3 44 79 15 92 37 66 112 115 111 111 107 25</td> <td>37 49 91 31 118 78 49 103 73 104 65 49 97 109 103 36 127 53 89 66 1 104 12 30 75</td> </tr> </table> <table border="1"> <tr> <td>Level 4</td> <td>Level 5</td> </tr> <tr> <td>64 81 21 32 4 87 22 46 96 163 47 55 49 66 145 90 17 63 58 145 82 166 79 103 162</td> <td>125 214 5 72 38 90 9 51 14 18 69 49 103 27 27 96 19 56 40 40 54 71 13 6 34</td> </tr> </table>	Level 1	Level 2	Level 3	25 32 55 85 110 45 109 111 51 162 77 30 122 59 129 67 86 2 115 94 80 23 24 78 165	131 74 79 19 34 43 61 125 10 99 39 57 3 44 79 15 92 37 66 112 115 111 111 107 25	37 49 91 31 118 78 49 103 73 104 65 49 97 109 103 36 127 53 89 66 1 104 12 30 75	Level 4	Level 5	64 81 21 32 4 87 22 46 96 163 47 55 49 66 145 90 17 63 58 145 82 166 79 103 162	125 214 5 72 38 90 9 51 14 18 69 49 103 27 27 96 19 56 40 40 54 71 13 6 34	6735.0	
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### 3.6.2. Analisis

Tabel 3.14 Tabel analisis Genetic Algorithm populasi terhadap generasi

Population/Generation	Rata Rata Objective function	Rata rata waktu
100/100	577	10.86s
100/200	436	21.13s
100/300	320	31.5s
300/100	515.667	50.9s
300/200	271	1m 40s
300/300	277.333	2m 12s
500/100	463.333	1m 55s
500/200	317	4m 7s
500/300	322.333	6m 22s

**Tabel 3.15 Tabel analisis Genetic Algorithm generasi terhadap populasi**

Generation/Population	Rata Rata Objective function	Rata rata waktu
100/100	577	10.86s
100/300	515.667	50.9s
100/500	463.333	1m 55s
200/100	436	21.13s
200/300	271	1m 40s
200/500	317	4m 7s
300/100	320	31.5s
300/300	277.333	2m 12s
300/500	322.333	6m 22s

Pada percobaan menggunakan Genetic Algorithm, kami melakukan 3 percobaan dengan variasi 3 *initial state* yang berbeda, dengan masing-masing *initial state* diuji dengan populasi dan generasi yang beragam sebagai parameternya. Hasil dari setiap percobaan dirata-ratakan dan hasilnya dapat dilihat pada tabel 3.14 dan tabel 3.15. Dari kedua tabel tersebut, dapat kita ketahui bahwa dengan populasi yang sama, semakin banyak generasi yang ada maka algoritma akan semakin mendapatkan objective function yang lebih baik. Pada kasus ini, objective function yang diinginkan adalah mendekati 0. Namun dikarenakan iterasi yang semakin banyak, maka algoritma akan membutuhkan proses yang lebih lama dikarenakan banyaknya iterasi dan proses sorting yang dilakukan secara terus menerus di setiap iterasi.

Namun berdasarkan tabel 3.15, dapat kita ketahui bahwa dengan generasi yang sama namun populasi yang beragam, belum tentu dapat membuat

algoritma mendapatkan objective function yang lebih baik. Hal ini dikarenakan, semakin banyak populasi maka akan semakin banyak “anak” yang ada yang dihasilkan oleh parents. Namun anak yang semakin banyak ini belum tentu mampu menghasilkan anak yang lebih baik pada jumlah generasi yang sama. Jumlah populasi yang semakin banyak juga tentunya akan memakan waktu yang lebih lama juga karena proses algoritmanya yang cukup berat.

## Bab 3

### Kesimpulan dan Saran

Tabel 3.1 Tabel Hasil Percobaan tiap Algoritma

Nama Algoritma	Initial State Value	Final State Value	Durasi
Steepest Descent Hill Climbing	5949.0	666.0	24.4 s
	5949.0	645.0	26.9 s
	5949.0	814.0	19.7 s
Hill-climbing with Sideway move	5327.0	464.0	23.6 s
	5820.0	567.0	24.8 s
	5820.0	442.0	24.9 s
Stochastic Hill Climbing	6869.0	5498.0	0.0s
	5903.0	5262.0	0.1s
	6108.0	4468.0	1.8s
Random Restart Hill Climbing	6517.0	4590.0	0.6s
	6083.0	4574.0	3.7s
	7056.0	4186.0	44.3s
Simulated Annealing	4907.0	447.0	1m 42s
	4907.0	4907.0	1m 30s
	4907.0	483.0	7 s
Genetic Algorithm	6114.0	262.0	1m 40s

	6735.0	273.0	1m 39s
	5828.0	278	1m 40s

Berdasarkan percobaan, ditemukan bahwa *Genetic Algorithm* menghasilkan *value* terbaik dibandingkan dengan algoritma lainnya. Dengan variasi initial state, algoritma ini tetap bisa memberikan value yang baik secara konstan. Untuk algoritma *Stochastic Hill-Climbing* dan *Random Restart Hill-Climbing* memberikan value terburuk jika dibandingkan dengan algoritma lainnya. Berdasarkan hasil percobaan ini, *Genetic Algorithm* merupakan algoritma *local search* terbaik untuk menyelesaikan permasaanah *diagonal magic cube*.

Untuk perbaikan yang dapat dilakukan adalah sebagai berikut.

1. Memaksimalkan algoritma Stochastic dan Random Restart Hill-Climbing. Hal ini untuk memastikan bahwa hasil buruk yang diberikan adalah karena kesalahan teknis pada program. Sehingga final state kedua algoritma bisa lebih baik.
2. Memastikan bahwa memang tidak ada keadaan *plateau* sehingga percobaan pada *Hill Climbing* with Sideway move dapat divalidasi kebenaran tidak adanya penggunaan sideway move
3. Memperbaiki move function dengan best neighbor pada Simulated Annealing. Move function secara acak lebih memberikan hasil yang baik dan efisien dibandingkan dengan best neighbor yang diharapkan dapat memaksimalkan algoritma pencarian
4. Memperbaiki cooling schedule linear multiplicative pada *Simulated Annealing* karena hasil yang diberikan tidak menggambarkan konsep *Simulated Annealing* yang akan terus menurun *value* algoritma
5. Eksplorasi cooling schedule selain linear dan quadratic untuk menambah cara penurunan temperature
6. Modifikasi search dengan menggabungkan beberapa search yang memungkinkan untuk digabungkan
7. Melakukan segmentasi populasi dan memilih random dari segmentasi tersebut lalu pilih terbaik berdasarkan fitness function untuk dijadikan parent pada *Genetic Algorithm*. Ini

untuk menyelesaikan kemungkinan bahwa 2 parent yang buruk akan menghasilkan anak yang unggul

## Bab 4

### Pembagian Tugas

Tabel 4.1 Pembagian Tugas

Nama	NIM	Tugas
Jeremy Deandito	18222112	<ul style="list-style-type: none"><li>- Pengeroaan algoritma</li><li>    Genetic Algorithm</li></ul>
Nathaniel Liady	18222114	<ul style="list-style-type: none"><li>- Pengeroaan algoritma</li><li>    Hill Climbing</li><li>- Pengeroaan algoritma</li><li>    Random-Restart Hill Climbing</li><li>- Pengeroaan algoritma</li><li>    Stochastic Hill Climbing</li></ul>
Gabriel Marcellino	18222115	<ul style="list-style-type: none"><li>- Pengeroaan algoritma</li><li>    Steepest Descent Hill Climbing</li><li>- Pengeroaan algoritma</li><li>    Hill Climbing with Sideway Move</li><li>- Pengeroaan algoritma</li><li>    Simulated Annealing</li></ul>
Nicolas Jeremy	18222135	<ul style="list-style-type: none"><li>- Pengeroaan algoritma</li><li>    Genetic Algorithm</li></ul>

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