High-Resolution Unary DAC Unit Cell Sorting Algorithms for Linearity Improvement with Measured Unit Cell Values

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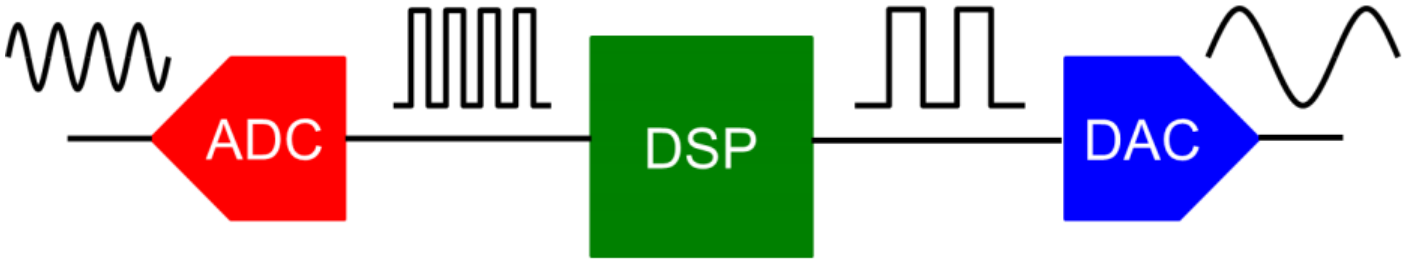
Importance of DAC

- Digital-to-analog converter (DAC) is a key component in modern
- Development of a highly linear DAC



DAC Applications

DAC is everywhere !

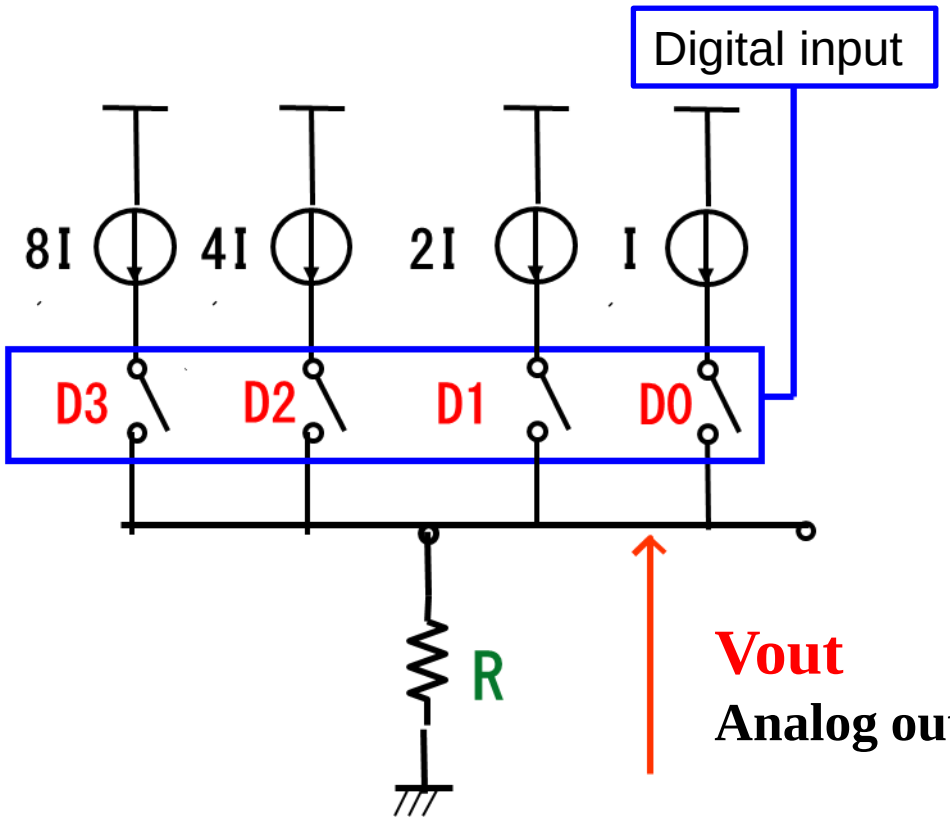
Communication equipment

Electronic measuring instrument

Audio systems

DAC Architecture (1)

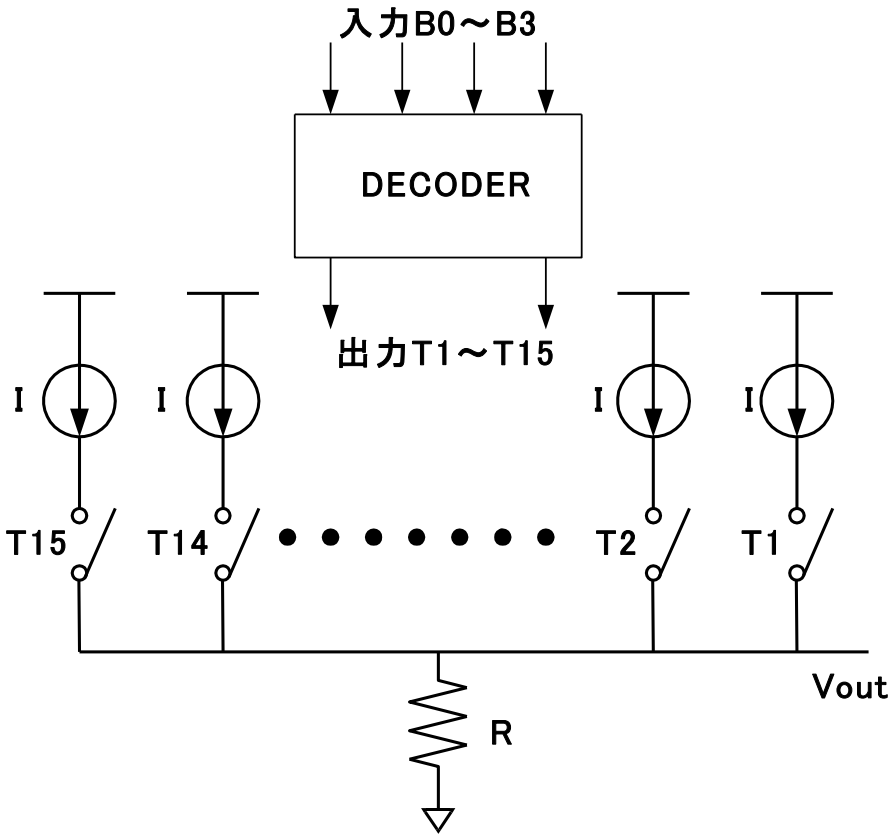
- Binary DAC



- Advantages
  - Small circuit size
  - High sampling rate
- Demerit
  - Glitch is big
  - Monotonicity between inputs and outputs
    ⇒Not secured

DAC Architecture (2)

- Segmented DAC



4-bit segmented DA converter

- Advantages
  - Glitch is small
  - Monotonicity between inputs and outputs ⇒ secure
- Demerit
  - Large circuit scale
  - Sampling speed slightly reduced

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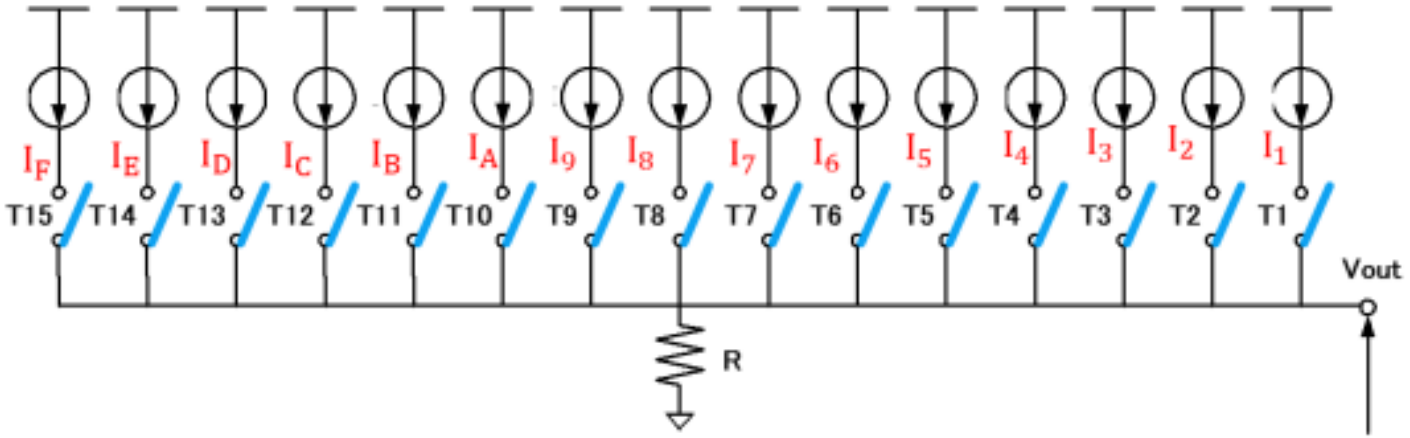
Segmented Current-Steering DAC

- Take out any Vout by operating switches T1 to T15

- For example, When taking out 4V
  1. $V_{out} = R[I_1 + I_2 + I_3 + I_4]$
  2. $V_{out} = R[I_5 + I_6 + I_7 + I_8]$
  3. $V_{out} = R[I_C + I_D + I_E + I_F]$ etc.

In an ideal DAC, these would all have the same value

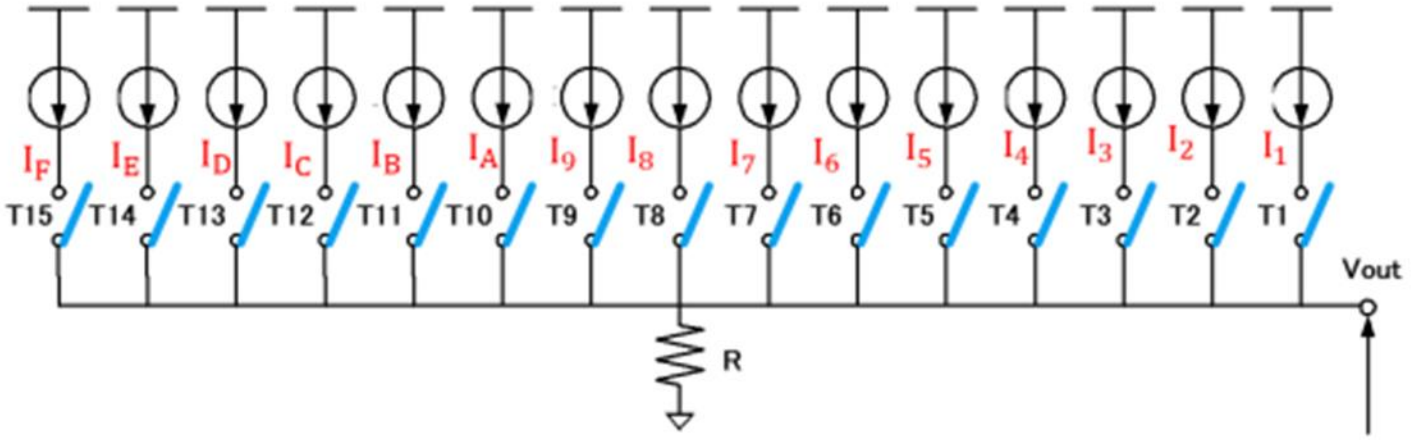


Segmented Current-Steering DAC

- In fact, I_1 to I_F have mismatches and different values

- For example, When taking out 4V
  1. $V_{out} = R[I_1 + I_2 + I_3 + I_4]$
  2. $V_{out} = R[I_5 + I_6 + I_7 + I_8]$
  3. $V_{out} = R[I_C + I_D + I_E + I_F]$ etc.

These are not always the same value !!



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Problem Formulation: Mismatches

- N current sources
- Ideal DAC :

$$I_1 = I_2 = I_3 = \cdots = I_N$$

- Actual DAC : Mismatches among current sources

$$I_1 = I + \Delta I_1 , \quad I_2 = I + \Delta I_2 , \quad I_3 = I + \Delta I_3 , \quad I_4 = I + \Delta I_4 ,$$

$$I_5 = I + \Delta I_5 , \quad I_6 = I + \Delta I_6 , \quad \dots , \quad I_N = I + \Delta I_N$$

I : Average current

$\Delta I_1, \ \Delta I_2, \dots \ \Delta I_N$: Mismatches

Problem Formulation: Selection Order

- Normally add in the order I_1, I_2, I_3, I_4 but if add in the order I_2, I_1, I_4, I_3

Digital Input	Current Output	INL
1	I_1	ΔI_1
2	$I_1 + I_2$	$\Delta I_1 + \Delta I_2$
3	$I_1 + I_2 + I_3$	$\Delta I_1 + \Delta I_2 + \Delta I_3$
4	$I_1 + I_2 + I_3 + I_4$	$\Delta I_1 + \Delta I_2 + \Delta I_3 + \Delta I_4$

Digital Input	Current Output	INL
1	I_2	ΔI_2
2	$I_2 + I_1$	$\Delta I_2 + \Delta I_1$
3	$I_2 + I_1 + I_4$	$\Delta I_2 + \Delta I_1 + \Delta I_4$
4	$I_2 + I_1 + I_4 + I_3$	$\Delta I_2 + \Delta I_1 + \Delta I_4 + \Delta I_3$

Problem Formulation: Evaluation Function

- Current sources with mismatches

$$I_1 = I + \Delta I_1\,, \quad I_2 = I + \Delta I_2\,, \quad I_3 = I + \Delta I_3\,, \quad I_4 = I + \Delta I_4\,,$$
$$I_5 = I + \Delta I_5\,, \quad I_6 = I + \Delta I_6\,, \quad \ldots\,, \quad I_N = I + \Delta I_N$$

- Average current definition

$$I = \frac{1}{N}(I_1 + I_2 + I_3 + \cdots + I_N) \qquad \Delta I_1 + \Delta I_2 + \Delta I_3 + \cdots + \Delta I_N = 0$$

- Definition of evaluation function

$$E = (\Delta I_1)^2 + (\Delta I_1 + \Delta I_2)^2 + \cdots + (\Delta I_1 + \Delta I_2 + \cdots \Delta I_n)^2$$

Algorithm finds the order of switches that minimizes E

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Algorithm Flow

① Start with the one closest to the average

② Randomly select from the current mean error the one that changes sign when added

③ Repeat ② while there is something that can change sign when added

④ When there is nothing left to change the sign during the calculation, stop the calculation and go back to ①

⑤ Once all values have been selected, the actual evaluation is calculated

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Simulation Results Case①

- If the values of each current source are not extremely far from the average and the mismatches are uniformly distributed
- The average value of the seven current sources ⇒ 1
- The difference between each current source
  0.00, -0.01, -0.02, -0.03, 0.01, 0.02, 0.03

Permutation No.	Array contents (add from left to right)	Evaluation
1	-0.0300 -0.0200 -0.0100 -0.0000 0.0100 0.0200 0.0300	0.014
2	-0.0300 -0.0200 -0.0100 -0.0000 0.0100 0.0300 0.0200	0.0135
3	-0.0300 -0.0200 -0.0100 -0.0000 0.0200 0.0100 0.0300	0.0131
4	-0.0300 -0.0200 -0.0100 -0.0000 0.0200 0.0300 0.0100	0.0123
5	-0.0300 -0.0200 -0.0100 -0.0000 0.0300 0.0100 0.0200	0.0119
6	-0.0300 -0.0200 -0.0100 -0.0000 0.0300 0.0200 0.0100	0.0116
7	-0.0300 -0.0200 -0.0100 0.0100 -0.0000 0.0200 0.0300	0.0129
8	-0.0300 -0.0200 -0.0100 0.0100 -0.0000 0.0300 0.0200	0.0124

5033	0.0300 0.0200 0.0100 -0.0100 -0.0000 -0.0300 -0.0200	0.0124
5034	0.0300 0.0200 0.0100 -0.0100 -0.0000 -0.0200 -0.0300	0.0129
5035	0.0300 0.0200 0.0100 -0.0000 -0.0300 -0.0200 -0.0100	0.0116
5036	0.0300 0.0200 0.0100 -0.0000 -0.0300 -0.0100 -0.0200	0.0119
5037	0.0300 0.0200 0.0100 -0.0000 -0.0200 -0.0300 -0.0100	0.0123
5038	0.0300 0.0200 0.0100 -0.0000 -0.0200 -0.0100 -0.0300	0.0131
5039	0.0300 0.0200 0.0100 -0.0000 -0.0100 -0.0300 -0.0200	0.0135
5040	0.0300 0.0200 0.0100 -0.0000 -0.0100 -0.0200 -0.0300	0.014

7 values sorted in ascending order ⇒ Permutation No.1

By permutation enumeration, obtain 5040 (7!) different orders and ratings

Simulation Results Case① Worst

- Worst rating :0.014
- Ascending and descending orders → the worst rated

Table 1. worst rated array content ①

Permutation No.	Array contents (add from left to right)
1	-0.0300 -0.0200 -0.0100 -0.0000 0.0100 0.0200 0.0300
5040	0.0300 0.0200 0.0100 -0.0000 -0.0100 -0.0200 -0.0300

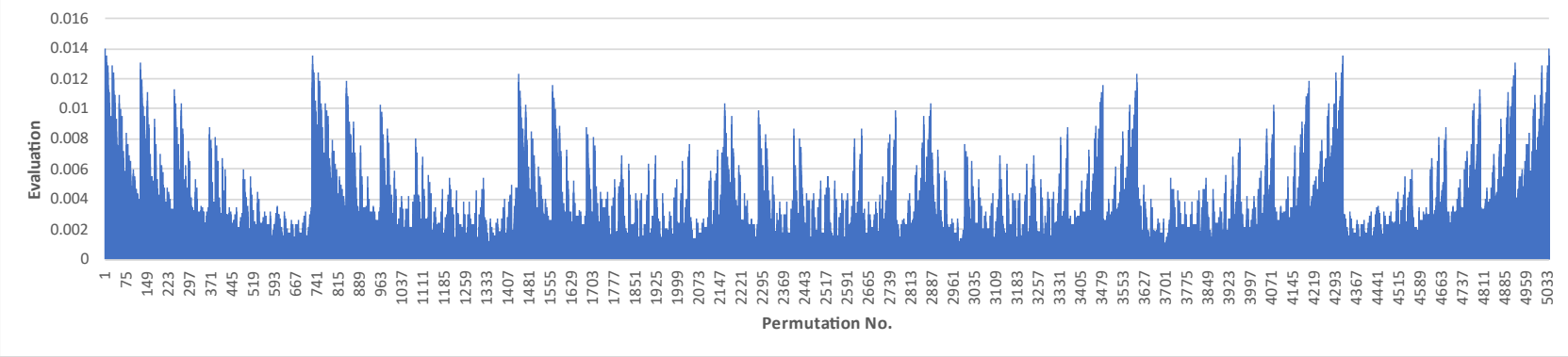


Figure 1. 7! Graph of patterns evaluation ①

Simulation Results Case① Best

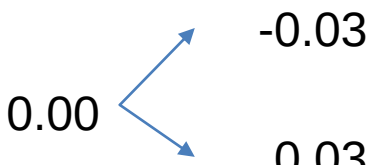
- Best rating：0.0008
- All in all, the 12 patterns of lining up was the highest rated
- Patterns outside the red box ⇒ The reverse order of patterns inside the red box.

Table 2. most highly rated array content ②

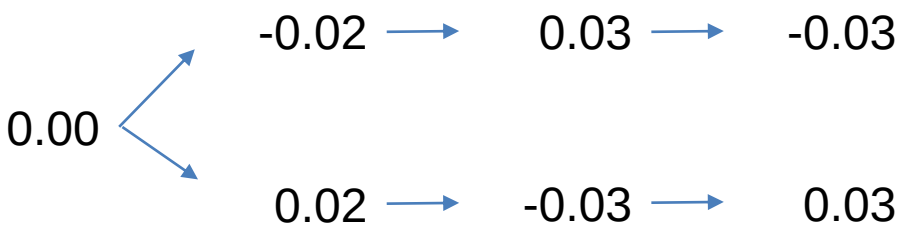
Permutation No.	Array contents (add from left to right)
1940	-0.0100 0.0200 -0.0300 0.0300 -0.0200 0.0100 -0.0000
1964	-0.0100 0.0200 -0.0200 0.0300 -0.0300 0.0100 -0.0000
2060	-0.0100 0.0300 -0.0300 0.0200 -0.0200 0.0100 -0.0000
2477	-0.0000 -0.0100 0.0200 -0.0300 0.0300 -0.0200 0.0100
2483	-0.0000 -0.0100 0.0200 -0.0200 0.0300 -0.0300 0.0100
2501	-0.0000 -0.0100 0.0300 -0.0300 0.0200 -0.0200 0.0100
2540	-0.0000 0.0100 -0.0300 0.0300 -0.0200 0.0200 -0.0100
2558	-0.0000 0.0100 -0.0200 0.0200 -0.0300 0.0300 -0.0100
2564	-0.0000 0.0100 -0.0200 0.0300 -0.0300 0.0200 -0.0100
2981	0.0100 -0.0300 0.0300 -0.0200 0.0200 -0.0100 -0.0000
3077	0.0100 -0.0200 0.0200 -0.0300 0.0300 -0.0100 -0.0000
3101	0.0100 -0.0200 0.0300 -0.0300 0.0200 -0.0100 -0.0000

Algorithm Use in Case① Stop

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  0.00, -0.01, -0.02, -0.03, 0.01, 0.02, 0.03
- Start at 0.00 : the closest to the mean



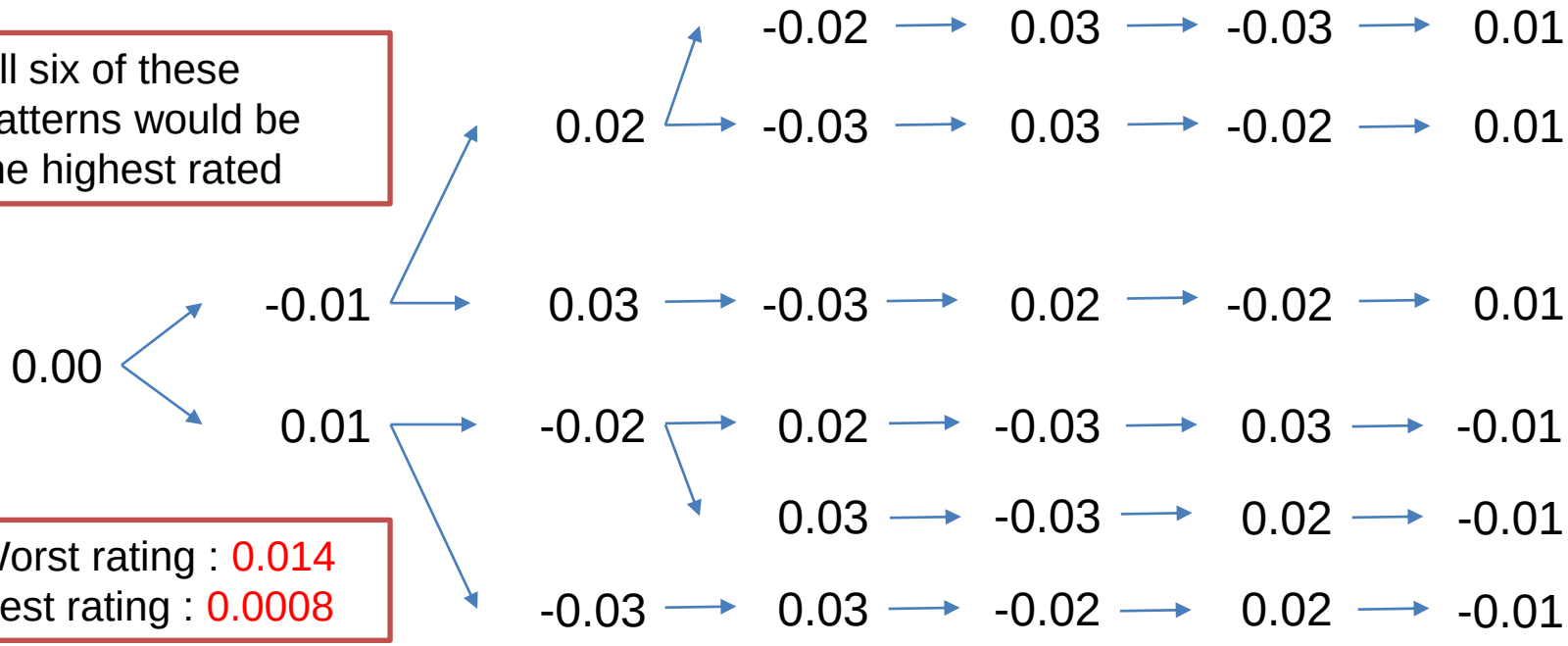
These patterns
interrupt the computation
Nothing to change the sign



Algorithm Use in Case① Success

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  0.00, -0.01, -0.02, -0.03, 0.01, 0.02, 0.03
- Start at 0.00 : the closest to the mean

All six of these patterns would be the highest rated



Worst rating : 0.014
Best rating : 0.0008

Simulation Results Case②

- If the values for each current source are not extremely far from the mean, but the distribution of mismatches is somewhat less uniform
- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.032, -0.024, -0.011, 0.001, 0.012, 0.021, 0.033

Permutation No.	Array contents (add from left to right)	Evaluation
1	-0.0320 -0.0240 -0.0110 0.0010 0.0120 0.0210 0.0330	0.01701
2	-0.0320 -0.0240 -0.0110 0.0010 0.0120 0.0330 0.0210	0.016362
3	-0.0320 -0.0240 -0.0110 0.0010 0.0210 0.0120 0.0330	0.016119
4	-0.0320 -0.0240 -0.0110 0.0010 0.0210 0.0330 0.0120	0.015174
5	-0.0320 -0.0240 -0.0110 0.0010 0.0330 0.0120 0.0210	0.014535
6	-0.0320 -0.0240 -0.0110 0.0010 0.0330 0.0210 0.0120	0.014238
7	-0.0320 -0.0240 -0.0110 0.0120 0.0010 0.0210 0.0330	0.015679
8	-0.0320 -0.0240 -0.0110 0.0120 0.0010 0.0330 0.0210	0.015031

5033	0.0330 0.0210 0.0120 -0.0110 0.0010 -0.0320 -0.0240	0.015098
5034	0.0330 0.0210 0.0120 -0.0110 0.0010 -0.0240 -0.0320	0.015546
5035	0.0330 0.0210 0.0120 0.0010 -0.0320 -0.0240 -0.0110	0.014196
5036	0.0330 0.0210 0.0120 0.0010 -0.0320 -0.0110 -0.0240	0.014651
5037	0.0330 0.0210 0.0120 0.0010 -0.0240 -0.0320 -0.0110	0.01482
5038	0.0330 0.0210 0.0120 0.0010 -0.0240 -0.0110 -0.0320	0.015723
5039	0.0330 0.0210 0.0120 0.0010 -0.0110 -0.0320 -0.0240	0.016562
5040	0.0330 0.0210 0.0120 0.0010 -0.0110 -0.0240 -0.0320	0.01701

Simulation Results Case② Worst

- Worst rating：0.01701
- Ascending and descending orders → the worst rated

Table 3. worst rated array content ②

Permutation No.	Array contents (add from left to right)
1	-0.0320 -0.0240 -0.0110 0.0010 0.0120 0.0210 0.0330
5040	0.0330 0.0210 0.0120 0.0010 -0.0110 -0.0240 -0.0320

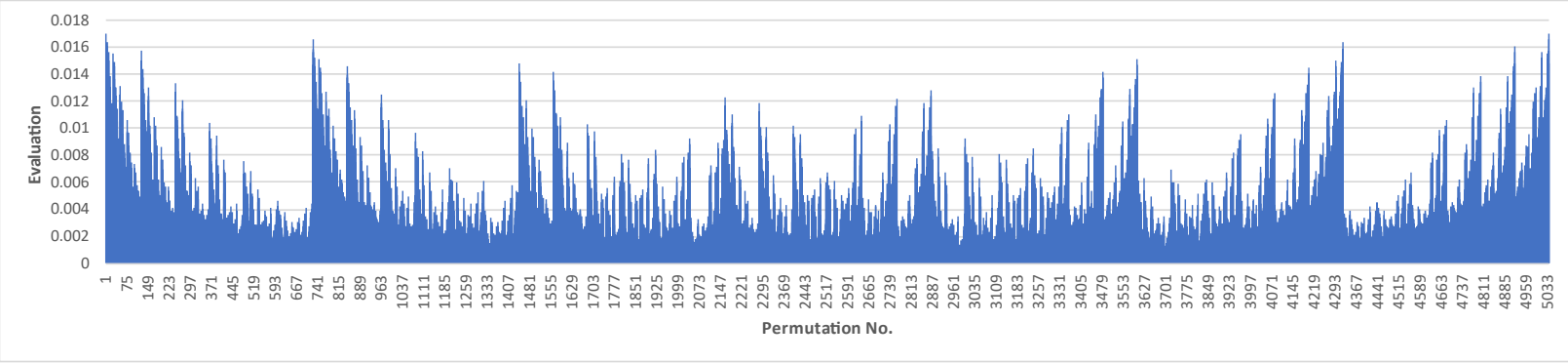


Figure 2. 7! Graph of patterns evaluation ②

Simulation Results Case② Best

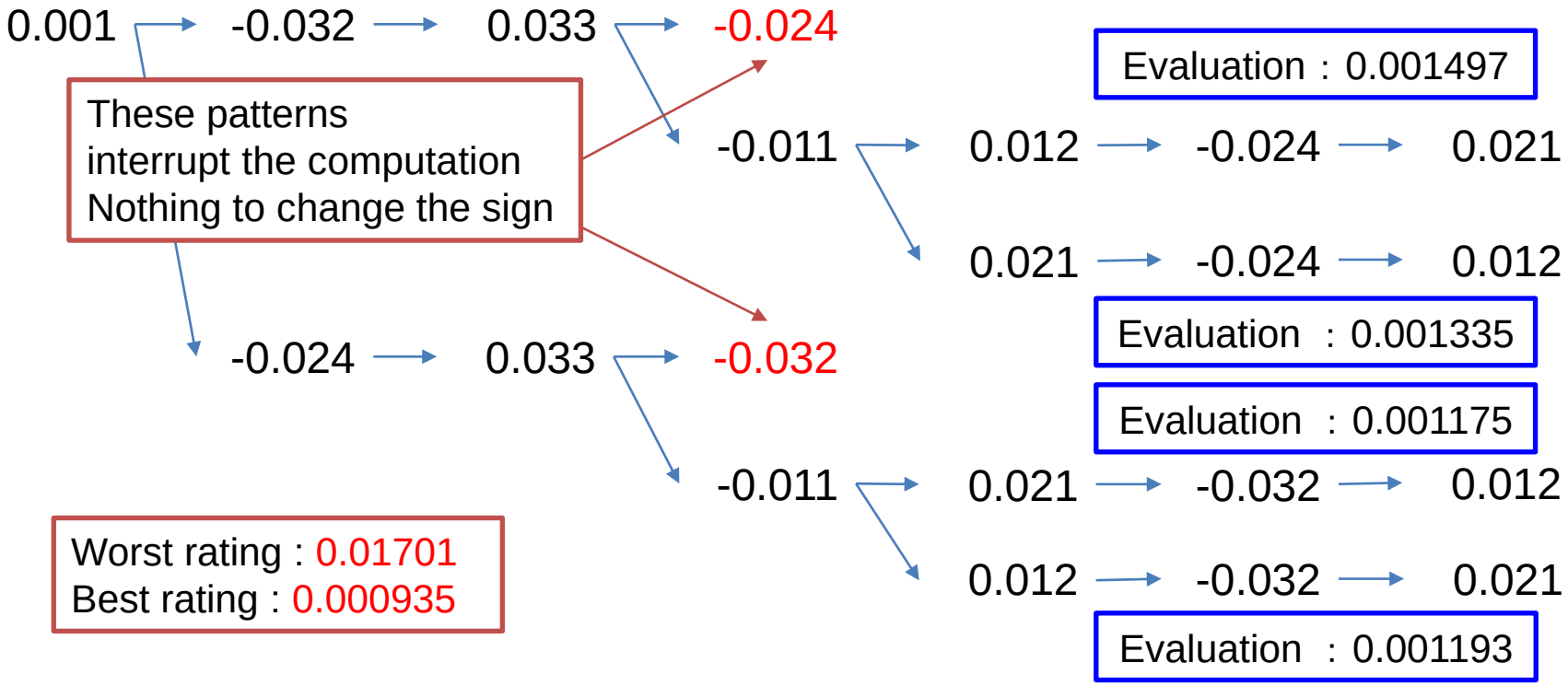
- Best rating ：0.000935
- Two patterns were rated best
- The second pattern ⇒ the reverse of the first

Table 4. most highly rated array content ②

Permutation No.	Array contents (add from left to right)
2483	0.0010 -0.0110 0.0210 -0.0240 0.0330 -0.0320 0.0120
2981	0.0120 -0.0320 0.0330 -0.0240 0.0210 -0.0110 0.0010

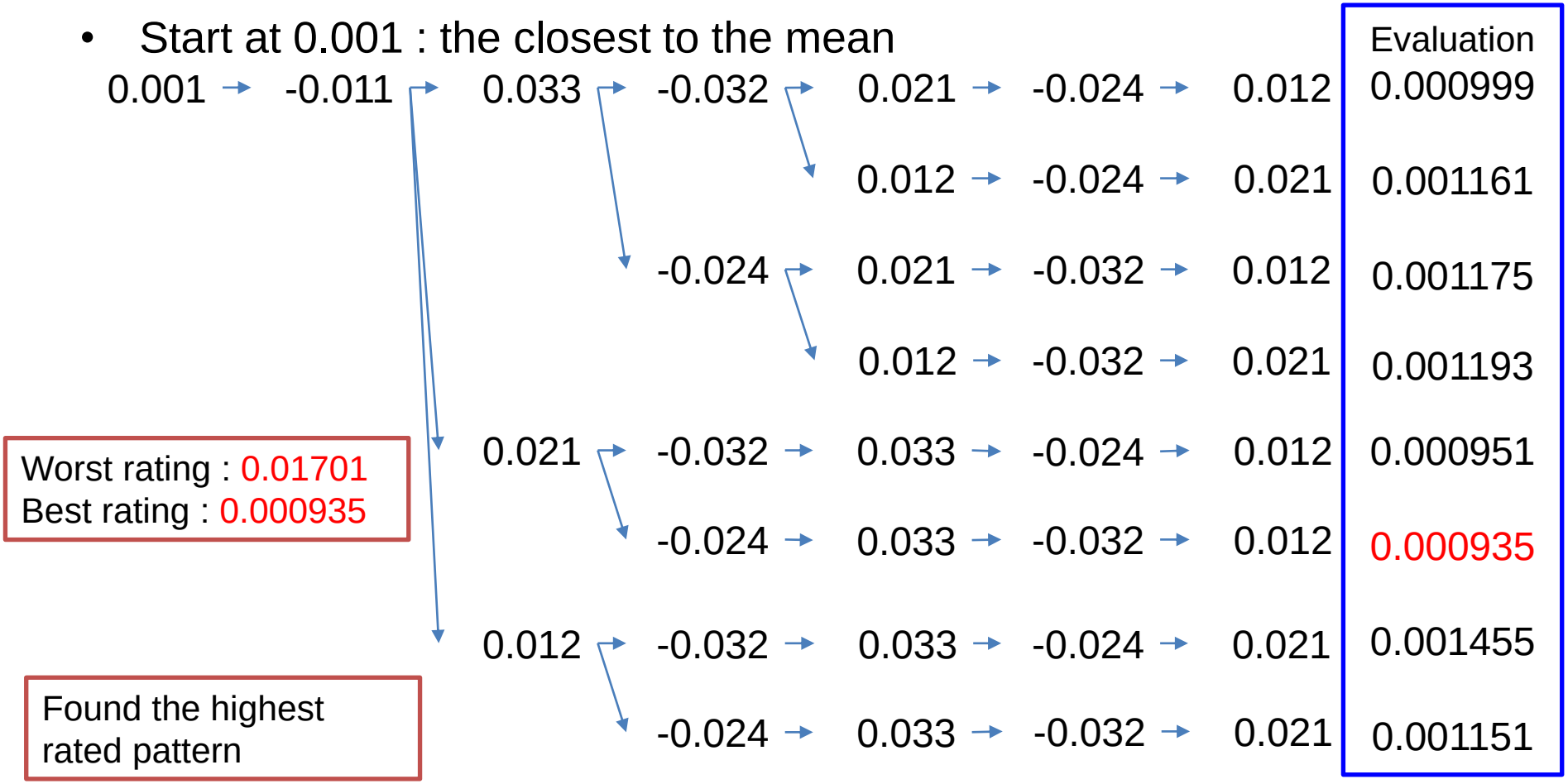
Algorithm Use in Case② Stop and Success

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.032, -0.024, -0.011, 0.001, 0.012, 0.021, 0.033
- Start at 0.001 : the closest to the mean



Algorithm Use in Case② Success

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.032, -0.024, -0.011, 0.001, 0.012, 0.021, 0.033
- Start at 0.001 : the closest to the mean



Simulation Results Case③

- If the values of each current source are extremely far from the mean and the distribution of mismatches is not uniform
- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.070, -0.021, -0.020, -0.001, 0.001, 0.013, 0.080

Permutation No.	Array contents (add from left to right)	Evaluation
1	-0.0700 -0.0210 -0.0020 -0.0010 0.0010 0.0130 0.0800	0.045715
2	-0.0700 -0.0210 -0.0020 -0.0010 0.0010 0.0800 0.0130	0.039484
3	-0.0700 -0.0210 -0.0020 -0.0010 0.0130 0.0010 0.0800	0.043627
4	-0.0700 -0.0210 -0.0020 -0.0010 0.0130 0.0800 0.0010	0.037228
5	-0.0700 -0.0210 -0.0020 -0.0010 0.0800 0.0010 0.0130	0.031031
6	-0.0700 -0.0210 -0.0020 -0.0010 0.0800 0.0130 0.0010	0.030863
7	-0.0700 -0.0210 -0.0020 0.0010 -0.0010 0.0130 0.0800	0.045343
8	-0.0700 -0.0210 -0.0020 0.0010 -0.0010 0.0800 0.0130	0.039112

5033	0.0800 0.0130 0.0010 -0.0020 -0.0010 -0.0700 -0.0210	0.041071
5034	0.0800 0.0130 0.0010 -0.0020 -0.0010 -0.0210 -0.0700	0.04553
5035	0.0800 0.0130 0.0010 -0.0010 -0.0700 -0.0210 -0.0020	0.033067
5036	0.0800 0.0130 0.0010 -0.0010 -0.0700 -0.0020 -0.0210	0.033504
5037	0.0800 0.0130 0.0010 -0.0010 -0.0210 -0.0700 -0.0020	0.037722
5038	0.0800 0.0130 0.0010 -0.0010 -0.0210 -0.0020 -0.0700	0.042618
5039	0.0800 0.0130 0.0010 -0.0010 -0.0020 -0.0700 -0.0210	0.041256
5040	0.0800 0.0130 0.0010 -0.0010 -0.0020 -0.0210 -0.0700	0.045715

Simulation Results Case③ Worst

- Worst rating :0.045715
- Ascending and descending orders → the worst rated

Table 5. worst rated array content ③

Permutation No.	Array contents (add from left to right)
1	-0.0700 -0.0210 -0.0020 -0.0010 0.0010 0.0130 0.0800
5040	0.0800 0.0130 0.0010 -0.0010 -0.0020 -0.0210 -0.0700

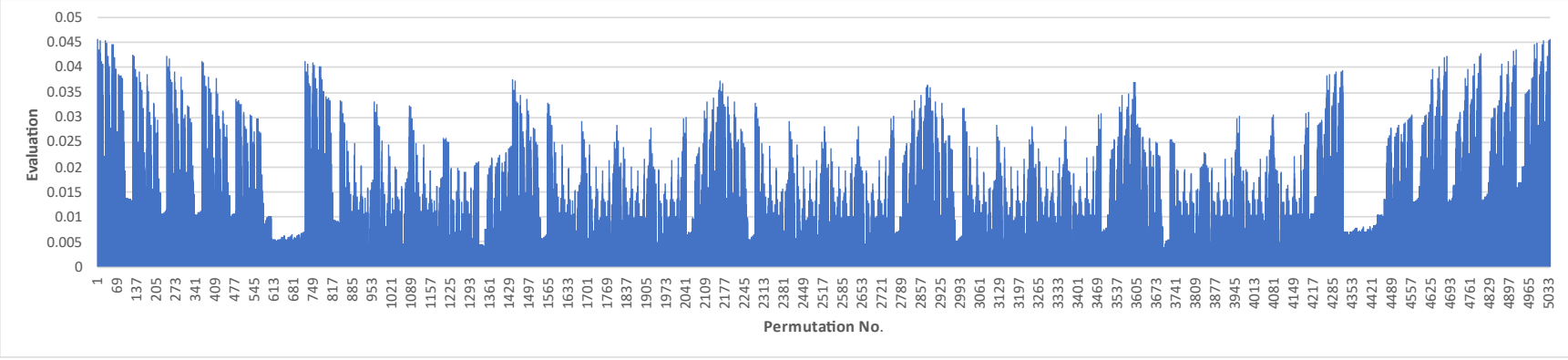


Figure 3. 7! Graph of patterns evaluation ③

Simulation Results Case③ Best

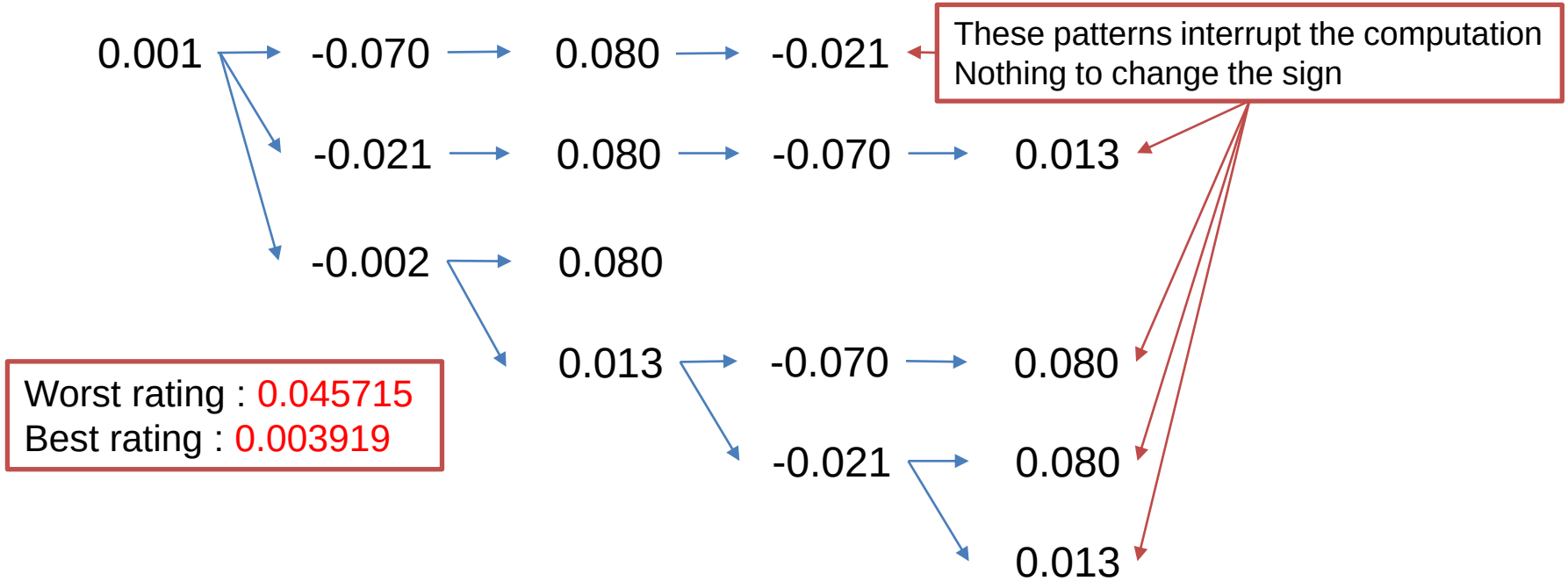
- Best rating ：0.003919
- Two patterns were rated best
- The second pattern ⇒ the reverse of the first

Table 6. most highly rated array content ③

Permutation No.	Array contents (add from left to right)
2444	-0.0010 -0.0020 -0.0210 0.0800 -0.0700 0.0130 0.0010
3379	0.0010 0.0130 -0.0700 0.0800 -0.0210 -0.0020 -0.0010

Algorithm Use in Case③ Stop

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.070, -0.021, -0.020, -0.001, 0.001, 0.013, 0.080
- Start at 0.001 : the closest to the mean



Simulation Results Case④

- If the values for each current source are extremely far from the mean and the distribution of mismatches is somewhat uneven
- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.100, -0.085, -0.056, 0.022, 0.052, 0.077, 0.090

Permutation No.	Array contents (add from left to right)	Evaluation
1	-0.1000 -0.0850 -0.0560 0.0220 0.0520 0.0770 0.0900	0.186256
2	-0.1000 -0.0850 -0.0560 0.0220 0.0520 0.0900 0.0770	0.184085
3	-0.1000 -0.0850 -0.0560 0.0220 0.0770 0.0520 0.0900	0.178531
4	-0.1000 -0.0850 -0.0560 0.0220 0.0770 0.0900 0.0520	0.173135
5	-0.1000 -0.0850 -0.0560 0.0220 0.0900 0.0520 0.0770	0.172837
6	-0.1000 -0.0850 -0.0560 0.0220 0.0900 0.0770 0.0520	0.169612
7	-0.1000 -0.0850 -0.0560 0.0520 0.0220 0.0770 0.0900	0.174016
8	-0.1000 -0.0850 -0.0560 0.0520 0.0220 0.0900 0.0770	0.171845

5033	0.0900 0.0770 0.0520 -0.0560 0.0220 -0.1000 -0.0850	0.151969
5034	0.0900 0.0770 0.0520 -0.0560 0.0220 -0.0850 -0.1000	0.154744
5035	0.0900 0.0770 0.0520 0.0220 -0.1000 -0.0850 -0.0560	0.165048
5036	0.0900 0.0770 0.0520 0.0220 -0.1000 -0.0560 -0.0850	0.169137
5037	0.0900 0.0770 0.0520 0.0220 -0.0850 -0.1000 -0.0560	0.169503
5038	0.0900 0.0770 0.0520 0.0220 -0.0850 -0.0560 -0.1000	0.176367
5039	0.0900 0.0770 0.0520 0.0220 -0.0560 -0.1000 -0.0850	0.183481
5040	0.0900 0.0770 0.0520 0.0220 -0.0560 -0.0850 -0.1000	0.186256

Simulation Results Case④ Worst

- Worst rating :0.186256
- Ascending and descending orders → the worst rated

Table 7. worst rated array content ④

Permutation No.	Array contents (add from left to right)
1	-0.1000 -0.0850 -0.0560 0.0220 0.0520 0.0770 0.0900
5040	0.0900 0.0770 0.0520 0.0220 -0.0560 -0.0850 -0.1000

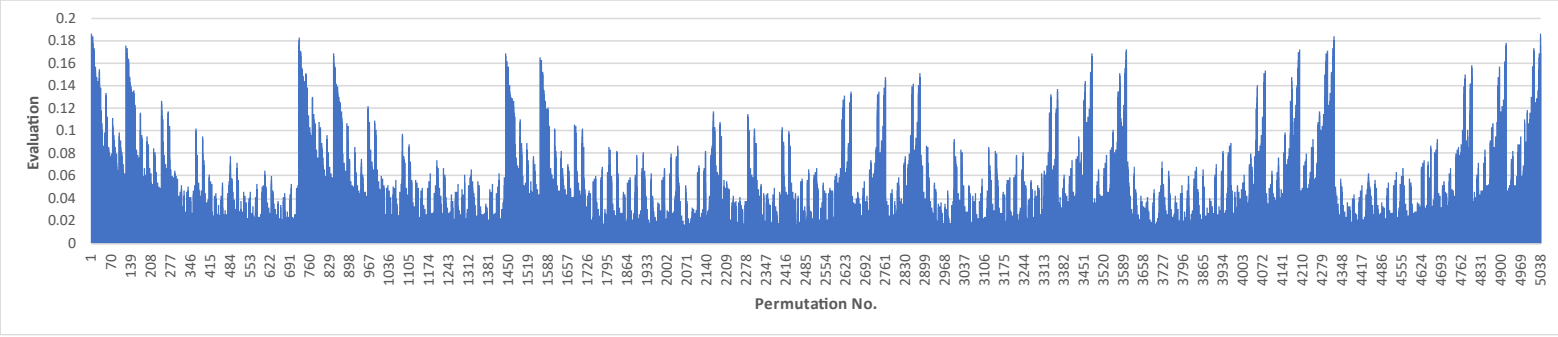


Figure 4. 7! Graph of patterns evaluation ④

Simulation Results Case④ Best

- Best rating ：0.010261
- Two patterns were rated best
- The second pattern ⇒ the reverse of the first

Table 8. most highly rated array content ④

Permutation No.	Array contents (add from left to right)
2483	0.0220 -0.0560 0.0770 -0.0850 0.0900 -0.1000 0.0520
2981	0.0520 -0.1000 0.0900 -0.0850 0.0770 -0.0560 0.0220

Algorithm Use in Case④ Success

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.100, -0.085, -0.056, 0.022, 0.052, 0.077, 0.090
- Start at 0.022 : the closest to the mean

							Evaluation
0.022 →	-0.100 →	0.090 →	-0.085 →	0.077 →	-0.056 →	0.052	0.014761
			-0.056 →	0.077 →	-0.085 →	0.052	0.012441
				0.052 →	-0.085 →	0.077	0.014641
-0.085 →	0.090 →	-0.100 →	0.077 →	-0.056 →	0.052		0.013231
		-0.056 →	0.077 →	-0.100 →	0.052		0.011031
			0.052 →	-0.100 →	0.077		0.012481
0.077 →	-0.100 →	0.090 →	-0.056 →	0.052			0.014765
		-0.056 →	0.090 →	-0.100 →	0.052		0.011421
			0.052 →	-0.100 →	0.090		0.014613

Worst rating : 0.186256
Best rating : 0.010261

Algorithm Use in Case④ Success

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.100, -0.085, -0.056, 0.022, 0.052, 0.077, 0.090
- Start at 0.022 : the closest to the mean

							Evaluation
0.022	→ -0.056	→ 0.090	→ -0.100	→ 0.077	→ -0.085	→ 0.052	0.010505
				→ 0.052	→ -0.085	→ 0.077	0.012705
			→ -0.085	→ 0.077	→ -0.100	→ 0.052	0.010625
				→ 0.052	→ -0.100	→ 0.077	0.012075
		→ 0.077	→ -0.100	→ 0.090	→ -0.085	→ 0.052	0.010531
			→ -0.085	→ 0.090	→ -0.100	→ 0.052	0.010261
				→ 0.052	→ -0.100	→ 0.090	0.013453
		→ 0.052	→ -0.100	→ 0.090	→ -0.085	→ 0.077	0.014681
			→ -0.085	→ 0.090	→ -0.100	→ 0.077	0.012911
				→ 0.077	→ -0.100	→ 0.090	0.014653

Worst rating : 0.186256
Best rating : 0.010261

Simulation Results Case⑤

- If the values of each current source are not extremely far from the average value and there are overlapping values in the mismatch
- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.030, -0.022, -0.017, 0.013, 0.013, 0.013, 0.030

Permutation No.	Array contents (add from left to right)	Evaluation
1	-0.0300 -0.0220 -0.0170 0.0130 0.0130 0.0130 0.0300	0.01425
2	-0.0300 -0.0220 -0.0170 0.0130 0.0130 0.0300 0.0130	0.013519
3	-0.0300 -0.0220 -0.0170 0.0130 0.0300 0.0130 0.0130	0.012346
4	-0.0300 -0.0220 -0.0170 0.0300 0.0130 0.0130 0.0130	0.010731
5	-0.0300 -0.0220 0.0130 -0.0170 0.0130 0.0130 0.0300	0.01101
6	-0.0300 -0.0220 0.0130 -0.0170 0.0130 0.0300 0.0130	0.010279
7	-0.0300 -0.0220 0.0130 -0.0170 0.0300 0.0130 0.0130	0.009106
8	-0.0300 -0.0220 0.0130 0.0130 -0.0170 0.0130 0.0300	0.00855

833	0.0300 0.0130 0.0130 -0.0170 0.0130 -0.0300 -0.0220	0.010594
834	0.0300 0.0130 0.0130 -0.0170 0.0130 -0.0220 -0.0300	0.01101
835	0.0300 0.0130 0.0130 0.0130 -0.0300 -0.0220 -0.0170	0.012456
836	0.0300 0.0130 0.0130 0.0130 -0.0300 -0.0170 -0.0220	0.012651
837	0.0300 0.0130 0.0130 0.0130 -0.0220 -0.0300 -0.0170	0.013144
838	0.0300 0.0130 0.0130 0.0130 -0.0220 -0.0170 -0.0300	0.013755
839	0.0300 0.0130 0.0130 0.0130 -0.0170 -0.0300 -0.0220	0.013834
840	0.0300 0.0130 0.0130 0.0130 -0.0170 -0.0220 -0.0300	0.01425

Since it is a duplicate permutation

$$\frac{7!}{3!} = 840 \text{ patterns}$$

Simulation Results Case⑤ Worst

- Worst rating :0.01425
- Ascending and descending orders → the worst rated

Table 9. worst rated array content ⑤

Permutation No.	Array contents (add from left to right)
1	-0.0300 -0.0220 -0.0170 0.0130 0.0130 0.0130 0.0300
840	0.0300 0.0130 0.0130 0.0130 -0.0170 -0.0220 -0.0300

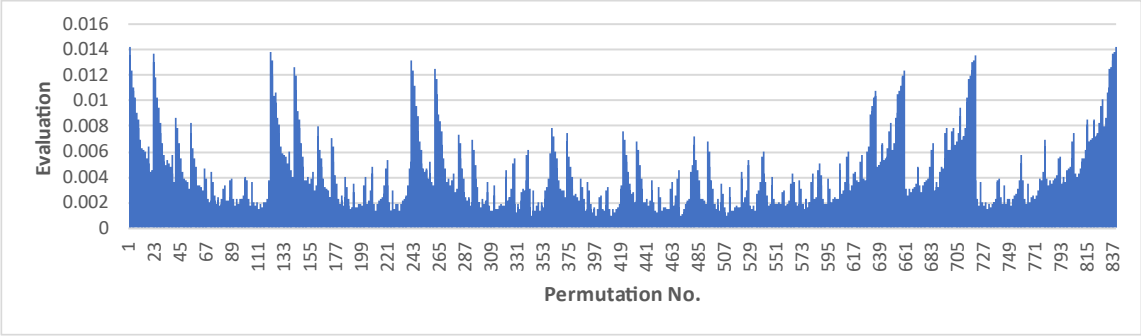


Figure 5. graph of evaluation Case ⑤

Simulation Results Case⑤ Best

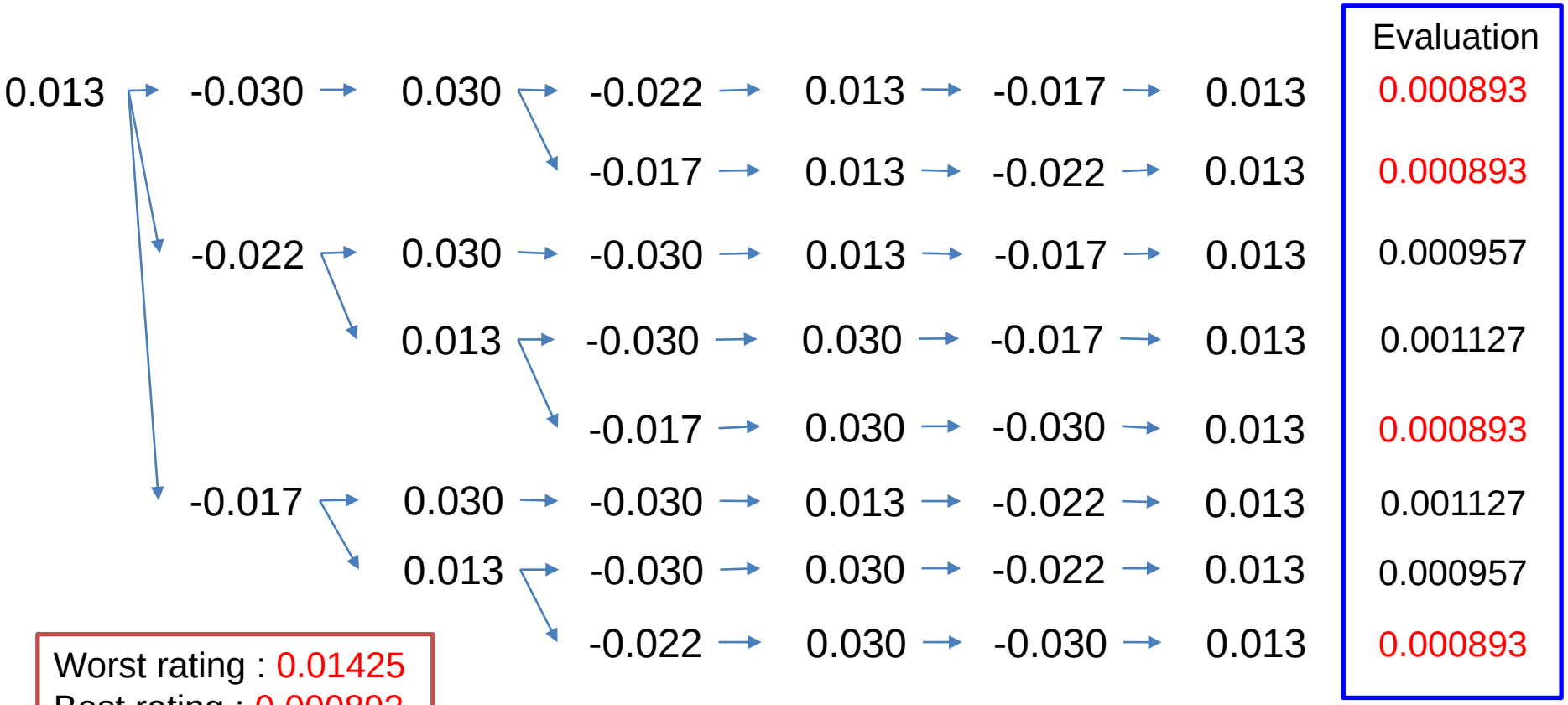
- Best rating ：0.000893
- Four patterns of alignment were the best rated
- The third and fourth patterns ⇒ The reverse order of the second and first patterns, respectively

Table 10. most highly rated array content ⑤

Permutation No.	Array contents (add from left to right)
410	0.0130 -0.0300 0.0300 -0.0220 0.0130 -0.0170 0.0130
413	0.0130 -0.0300 0.0300 -0.0170 0.0130 -0.0220 0.0130
455	0.0130 -0.0220 0.0130 -0.0170 0.0300 -0.0300 0.0130
515	0.0130 -0.0170 0.0130 -0.0220 0.0300 -0.0300 0.0130

Algorithm Use in Case⑤ Success

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.030, -0.022, -0.017, 0.013, 0.013, 0.013, 0.030
- Start at 0.013 : the closest to the mean



Simulation Results Case⑥

- If each current source has a value that is extremely far from the average value and the values overlap
- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.070, -0.021, -0.017, 0.027, 0.027, 0.027, 0.027

Permutation No.	Array contents (add from left to right)	Evaluation
1	-0.0700 -0.0210 -0.0170 0.0270 0.0270 0.0270 0.0270	0.035051
2	-0.0700 -0.0210 0.0270 -0.0170 0.0270 0.0270 0.0270	0.027483
3	-0.0700 -0.0210 0.0270 0.0270 -0.0170 0.0270 0.0270	0.022291
4	-0.0700 -0.0210 0.0270 0.0270 0.0270 -0.0170 0.0270	0.019475
5	-0.0700 -0.0210 0.0270 0.0270 0.0270 0.0270 -0.0170	0.019035
6	-0.0700 -0.0170 -0.0210 0.0270 0.0270 0.0270 0.0270	0.034339
7	-0.0700 -0.0170 0.0270 -0.0210 0.0270 0.0270 0.0270	0.026275
8	-0.0700 -0.0170 0.0270 0.0270 -0.0210 0.0270 0.0270	0.020803

203	0.0270 0.0270 0.0270 -0.0170 0.0270 -0.0700 -0.0210	0.023024
204	0.0270 0.0270 0.0270 -0.0170 0.0270 -0.0210 -0.0700	0.027483
205	0.0270 0.0270 0.0270 0.0270 -0.0700 -0.0210 -0.0170	0.023603
206	0.0270 0.0270 0.0270 0.0270 -0.0700 -0.0170 -0.0210	0.023755
207	0.0270 0.0270 0.0270 0.0270 -0.0210 -0.0700 -0.0170	0.029728
208	0.0270 0.0270 0.0270 0.0270 -0.0210 -0.0170 -0.0700	0.034339
209	0.0270 0.0270 0.0270 0.0270 -0.0170 -0.0700 -0.0210	0.030592
210	0.0270 0.0270 0.0270 0.0270 -0.0170 -0.0210 -0.0700	0.035051

Since it is a duplicate permutation

$$\frac{7!}{4!} = 210 \text{ patterns}$$

Simulation Results Case⑥ Worst

- Worst rating :0.035051
- Ascending and descending orders → the worst rated

Table 11. worst rated array content ⑥

Permutation No.	Array contents (add from left to right)
1	-0.0700 -0.0210 -0.0170 0.0270 0.0270 0.0270 0.0270
210	0.0270 0.0270 0.0270 0.0270 -0.0170 -0.0210 -0.0700

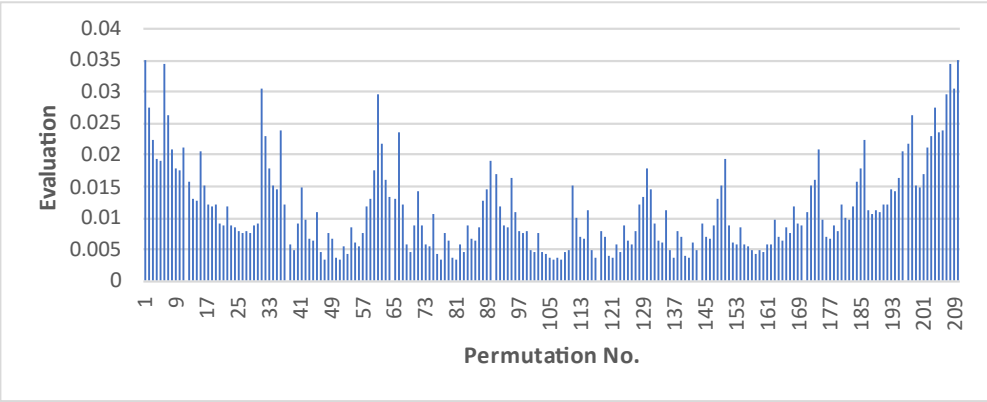


Figure 6. graph of evaluation Case ⑥

Simulation Results Case⑥ Best

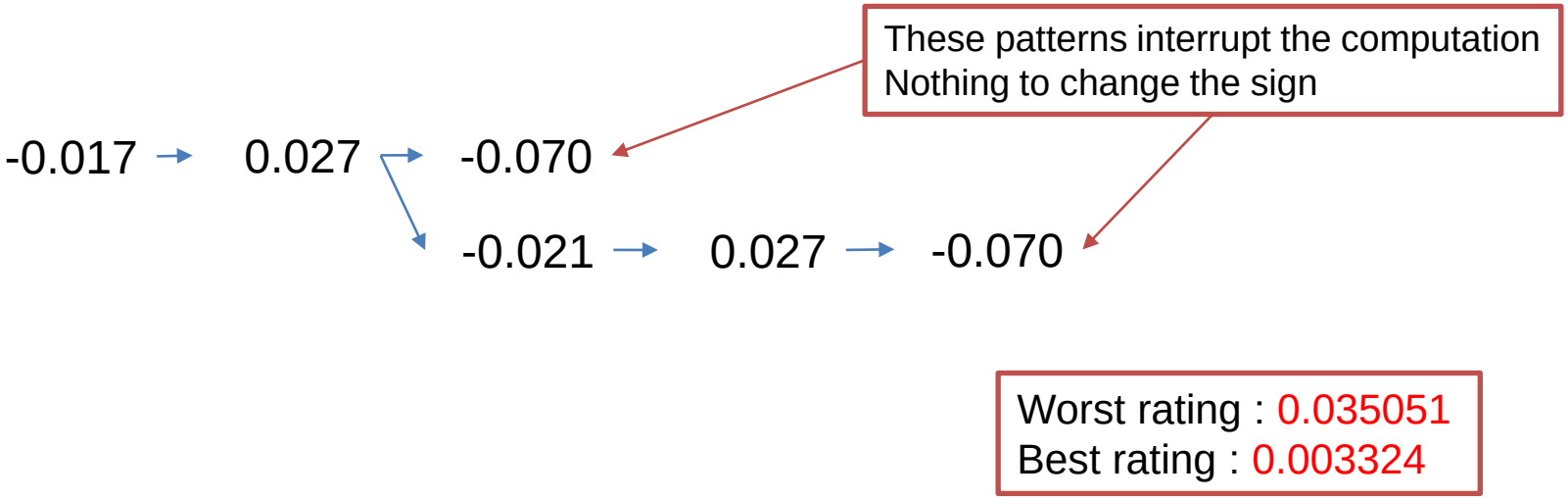
- Best rating ：0.003324
- Two patterns were rated best
- The second pattern ⇒ the reverse of the first

Table 12. most highly rated array content ⑥

Permutation No.	Array contents (add from left to right)
51	-0.0210 0.0270 0.0270 -0.0700 0.0270 0.0270 -0.0170
81	-0.0170 0.0270 0.0270 -0.0700 0.0270 0.0270 -0.0210

Algorithm Use in Case⑥ Stop

- The average value of the seven current sources ⇒ 1
- The difference between each current source
  -0.070, -0.021, -0.017, 0.027, 0.027, 0.027, 0.027
- Start at -0.017 : the closest to the mean



Box-and-whisker diagram of all cases

- In cases ③ and ⑥, the algorithm did not work

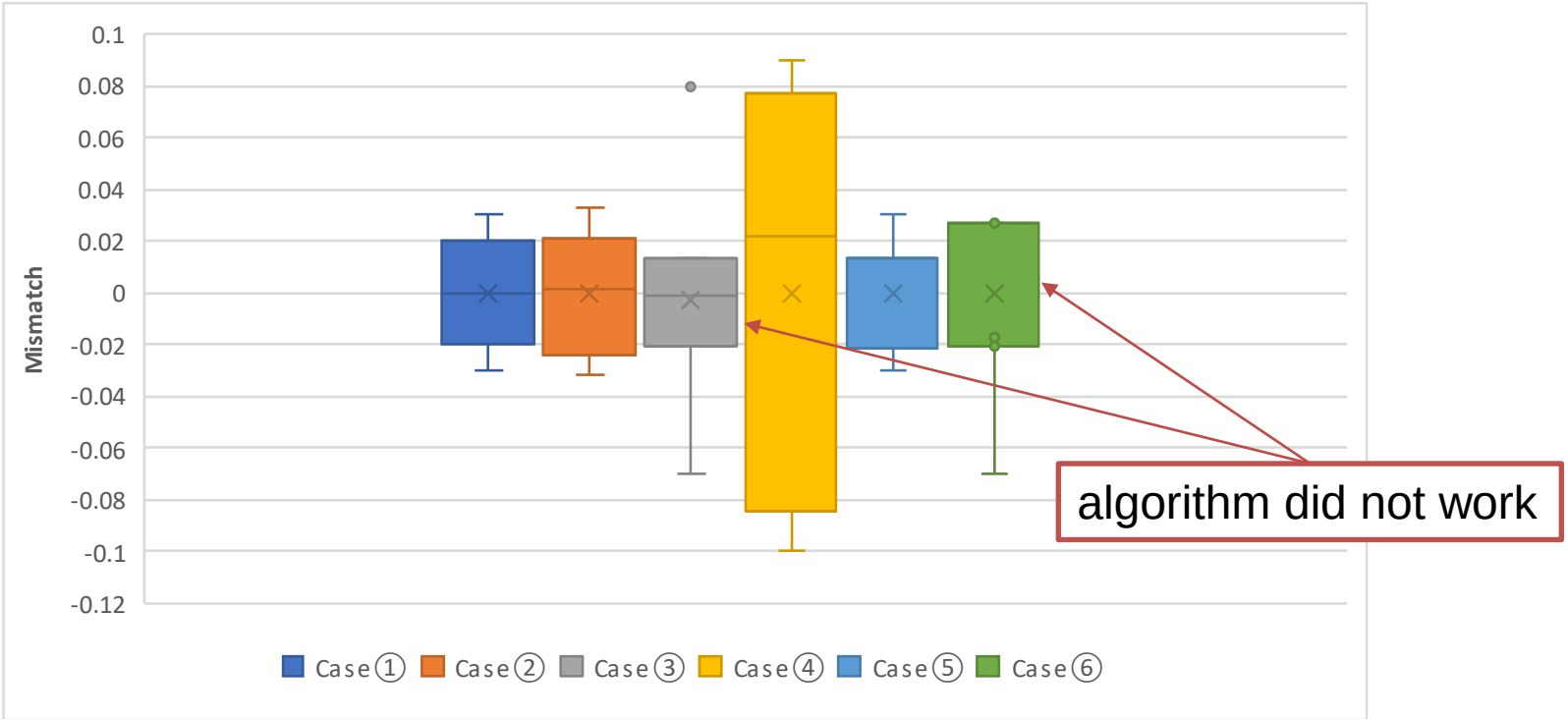


Figure 7. box-and-whisker view of each case

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- Research Background
- Segmented Current-Steering DAC
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- Conclusion

Conclusion

- Linearity degradation problem due to unit cell mismatch in Segment DAC
  - Consider an approach that suppresses degradation by sub-optimizing the selection order
- For 8-bit DAC
  - Selection order combination ⇒ 255! patterns
- Proposed an algorithm to easily obtain a sub-optimal selection order
  - Simulation verified with 3-bit DAC
- Future Tasks
  - Simulation verification with 8-bit DAC
  - Ensure that the algorithm always works

Thank you for listening