



## Element Adjustment for Crossover in Evolutionary Algorithm to Solve Continuum Topology Optimization

Kittipong Boonlong

Department of Mechanical Engineering, Faculty of Engineering, Burapha University 169 Long-Hard Bangsaen Road, Tambon  
Saensook, Amphur Muang, Chonburi 20131, Thailand  
E-mail: kittipong@buu.ac.th , Tel : 038-102222 ext. 3385, 3386

### **Abstract**

This paper presents element adjustment in crossover to prevent exchange between effective and useless bits in continuum topology optimization problems. The proposed idea is embedded into a selected multi-objective evolutionary algorithm, the improved strength Pareto evolutionary algorithm (SPEA-II). This idea can also be embedded any types of crossover, it is considerably used in one-point and uniform crossover in this paper. The tested problem is a heat conduction continuum topology optimization problem with 2-3 objectives. The proposed idea is investigated by comparing solutions of any crossover type from with and without the element adjustment. The performance criterion used in this paper is hyper volume (HV), which is a maximum criterion of multi-objective optimization. After simulation runs, by HV results, crossovers with the element adjustment are better than the normal crossovers in any crossover types. Especially, for uniform crossover, the element adjustment much improves performance of the crossover such as it can gain more average HV 2.90% and 23.15% for the problem with 2 and 3 objectives respectively. In addition, the element adjustment can enhance performances of crossover in the problem with 3 objectives more obviously than the problem with 2 objectives. In addition, this idea can also be applied to single-objective continuum topology optimization problems.

**Keywords:** Element Adjustment Crossover, Evolutionary Algorithm, Multi-objective Optimization, Continuum Topology Optimization.

### **1. Introduction**

Genetic algorithm (GA), which is a derivative-free optimizer, is widely used in optimization both in single and multiple objective optimization problems such as [1-3]. It is also well-suited to continuum topology optimization problems, which find optimal layout of structures, since it does not need explicit mathematical

expressions of objective functions and constraints as derivative-based optimizers. A structure of the problems can be simply encoded into a binary string, of which a bit is 0 or 1 representing for empty or material element respectively [4-6]. GA is a population-based evolutionary algorithm which employs crossover to exchange bits between two solutions in order



to obtain two other transformed solutions. Since there are non-effective encoded bits of which representing elements do not affect to objectives of the solution regardless of any bit values in some portions of a structure, there is exchange between effective and non-effective encoded bits. This exchange can lead to the algorithm to poor solutions. Most previous studies do not concern about this weakness such as [5-6]. This paper will propose the element adjustment for evolutionary algorithm that use crossover for solution transformation. This proposed idea is present to avoid the bit exchange in crossover. It is embedded in crossover of a multi-objective evolutionary algorithm (MOEA), GA for multi-objective optimization, which is the improved Pareto evolutionary algorithm (SPEA-II) [7], and tested by a heat conduction multi-objective continuum topology optimization problem.

## 2. Test Case

2D heat transfer problem with the convective boundary [5] is used as the case study (Fig. 1). The domain of this problem is a 1m-thick space of size  $50 \times 50$  mm which is divided into  $20 \times 20$  grids. Therefore, structural encoded chromosome lengths are 400.

Structures are intended to be lightweight configurations that transport heat from a point source  $Q$  at a bottom corner to a thin heating plate placing over the domain such that the temperature in the plate is evenly distributed. A structure has one fixed material element, which is shown by the grey element in Fig. 1. The bottom surface of the element transfers the heat  $Q$  into the structure. There are 3 design objectives which are minimized structural weight,

maximized average temperature and minimized temperature standard deviation  $SD_T$  in the plate. The problems are considered into two cases – 2 and 3 design objectives. The first case is the continuum topology optimization problem with two objectives – minimized structural weight and maximized average temperature. The second case is the optimization problem with all three design objectives as previously stated.

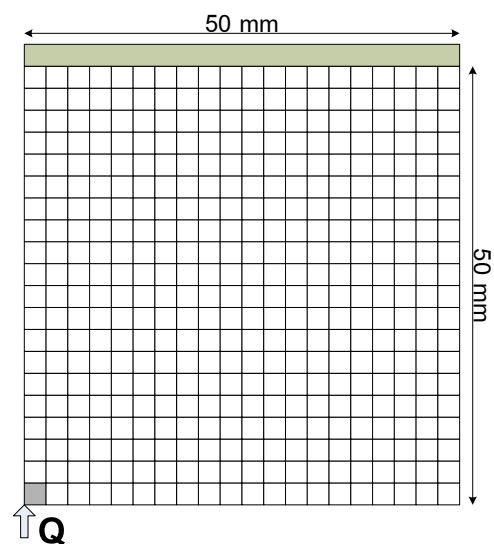


Fig. 1 Test case

## 3. Element Adjustment for Crossover

In objective calculation of the continuum topology optimization problems, an individual  $i$ , of which corresponding structure is shown in left-hand side of Fig. 2, the elements in region number 1-5 are non-effective elements which do not affect to objectives of the individual  $i$  regardless of any bit value '0' or '1'. On the other hand, the elements in region A are effective elements which affect to its objectives. Thereafter, objectives of the individual  $i$  is evaluated by the structure without the material blocks in the non-effective regions 1-5 which is shown in the right-hand side of Fig. 2.

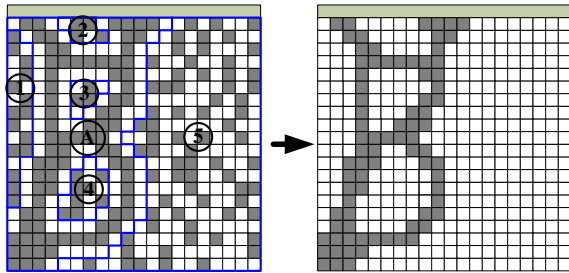


Fig. 2 Objective calculation

The element adjustment for crossover is proposed to avoid exchange between non-effective and effective elements of any two parent solutions. The discussion of the idea can be described by crossover of two parents in Fig. 3. The first parent has 1 effective region labeled 'A1' and 1 non-effective region labeled 'N1' while the second parent has 1 effective region labeled 'A2' and 2 non-effective regions labeled 'N2'.

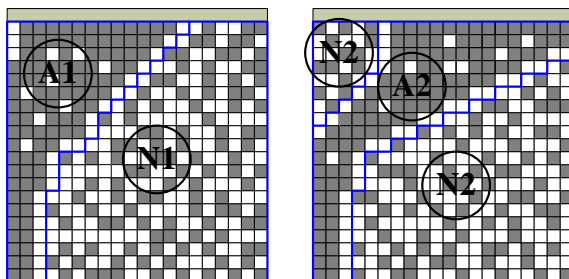


Fig. 3 Two parents with effective and non-effective elements to be performed crossover

After comparison of effectiveness of elements of both parents before crossover, there are 4 regions need to be considered – A1N2 representing effective region in the first parent and non-effective region in the second one, A1A2 representing effective region in both parents, N1A2, and N1N2, as shown in Fig. 4.

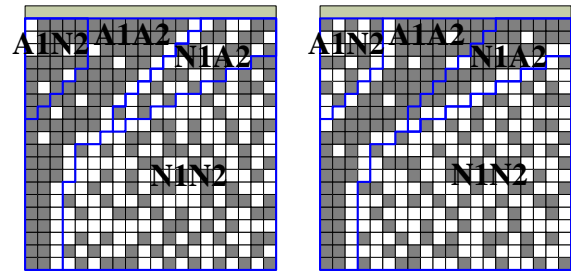


Fig. 4 Compared elements of two parents

In order to avoid the exchange between effective and non-effective elements of two parents, the regions A1N2 and N1A2 in Fig. 4, the non-effective elements in these 2 regions need to change to be same as their structure that is used for objective calculation previously described. For region A1N2, the non-effective elements in the second parent are changed to empty elements as its calculated structure (right side of Fig. 5). Similarly, the non-effective elements in the first parent are changed to empty elements as its calculated structure (left side of Fig. 5). However, elements in the regions A1A2 and N1N1 are considerably remained because there is no opportunity of exchange between effective and non-effective elements in these regions. Thus resulting offspring of these two parents in Fig. 3 are obtained from crossover of the corresponding parents in Fig. 5 in usual way.

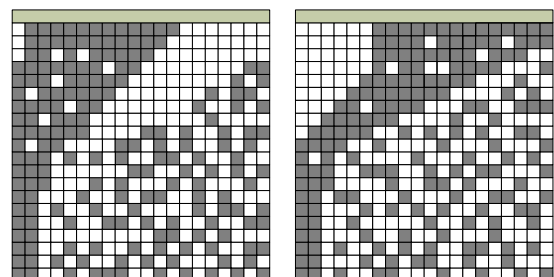


Fig. 5 Two corresponding parents to be performed crossover



#### 4. Results and Discussions

In order to test the proposed element adjustment for crossover, there are 2 types of crossovers – one-point and uniform crossovers with the problem with 2 and 3 design objectives. The parameter setting of the tests is shown in Table 1.

Table 1 Parameter Setting

Parameters	Setting and Value
Crossover method	One-point and uniform crossovers
Crossover rate	9 values – 0.60, 0.65, ..., 0.95, 1.00
Mutation method	Flip-bit Mutation with probability of 0.01
Employed MOEA	SPEA-II
Number of Generation	1,000
Number of Repeated Runs	30

After simulation runs, a maximization criterion, hyper volume (HV) [8] is used for numerical performance comparison. The values of HV are shown in Table 2 – Table 5. Fig. 6 and Fig. 7 show objective front and 12 selected non-dominated solutions from one run with the proposed idea of the problem with 2 objectives and Fig. 8 show 12 selected non-dominated solutions from one run with the proposed idea of the problem with 3 objectives.

Table 2 HV from one-point crossover in the problem with 2 objectives

Xover Prob.	Normal 1p-xover	Sel.Ele. 1p-xover	% improved
0.60	559.6756	563.8520	0.7462
0.65	559.4847	566.2349	1.2065
0.70	561.6431	567.3290	1.0124
0.75	557.7046	566.3216	1.5451
0.80	558.3138	564.5297	1.1133
0.85	557.7175	567.3313	1.7238
0.90	564.1423	565.1294	0.1750
0.95	558.8285	563.0890	0.7624
1.00	558.3565	561.2397	0.5164
<b>Average of % improved</b>			<b>0.9779</b>

Table 3 HV from uniform crossover in the problem with 2 objectives

Xover Prob.	Normal 1p-xover	Sel.Ele. 1p-xover	% improved
0.60	527.5912	547.4559	3.7652
0.65	521.7760	538.2621	3.1596
0.70	523.3009	558.3138	6.6908
0.75	530.2578	534.2135	0.7460
0.80	523.3404	537.4679	2.6995
0.85	523.2904	537.8971	2.7913
0.90	525.6848	534.7546	1.7253
0.95	518.5677	535.3197	3.2304
1.00	524.9178	531.7383	1.2994
<b>Average of % improved</b>			<b>2.9008</b>



Table 4 HV from one-point crossover in the problem with 3 objectives

Xover Prob.	Normal 1p-xover	Sel.Ele. 1p-xover	% improved
0.60	95.9284	103.7833	8.1883
0.65	100.9672	107.9600	6.9258
0.70	102.8750	108.7451	5.7060
0.75	104.0212	111.2029	6.9041
0.80	106.3750	112.1243	5.4048
0.85	107.3898	114.4831	6.6051
0.90	108.1465	115.0082	6.3448
0.95	109.7907	115.3375	5.0521
1.00	109.5470	115.7785	5.6884
<b>Average of % improved</b>			<b>6.3133</b>

Table 5 HV from uniform crossover in the problem with 3 objectives

Xover Prob.	Normal 1p-xover	Sel.Ele. 1p-xover	% improved
0.60	69.3920	87.1903	25.6489
0.65	71.4353	89.0144	24.6084
0.70	72.4126	93.0102	28.4448
0.75	76.1316	94.2122	23.7490
0.80	79.0014	96.0616	21.5948
0.85	80.4185	98.1139	22.0043
0.90	80.3683	97.4144	21.2100
0.95	78.1302	98.2157	25.7078
1.00	76.4753	88.2684	15.4208
<b>Average of % improved</b>			<b>23.1543</b>

After simulation runs, the element adjustment can gain more HV averagely

0.9779% for one-point crossover, and 2.9008% for uniform crossovers, in the problem with 2 objectives and 6.3133% for one-point crossover, and 2.9008% for uniform crossovers, in the problem with 3 objectives.

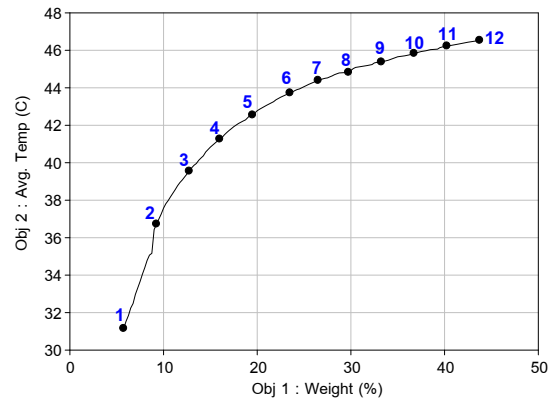


Fig. 6 Objectives front of non-dominate solutions

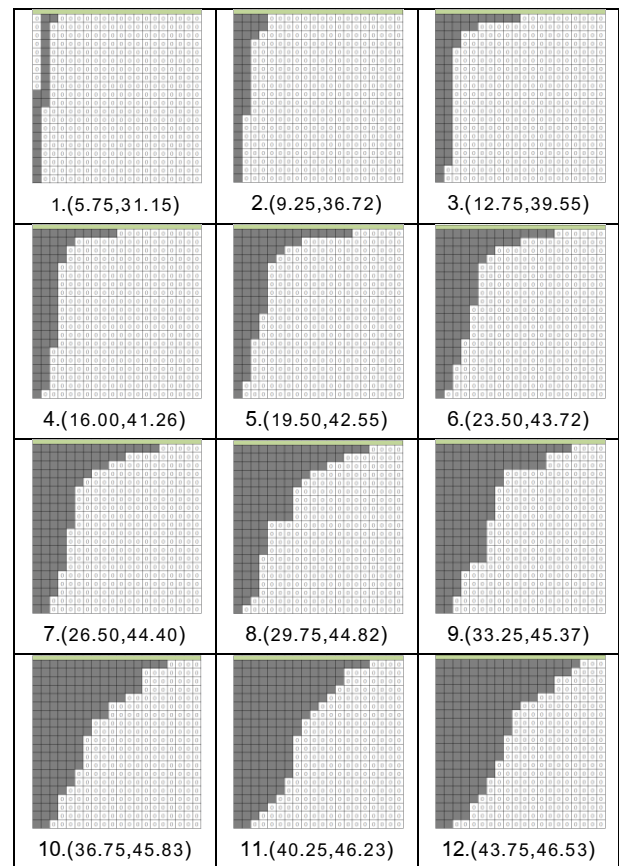


Fig. 7 Topologies of non-dominate Solutions of two objectives problem.

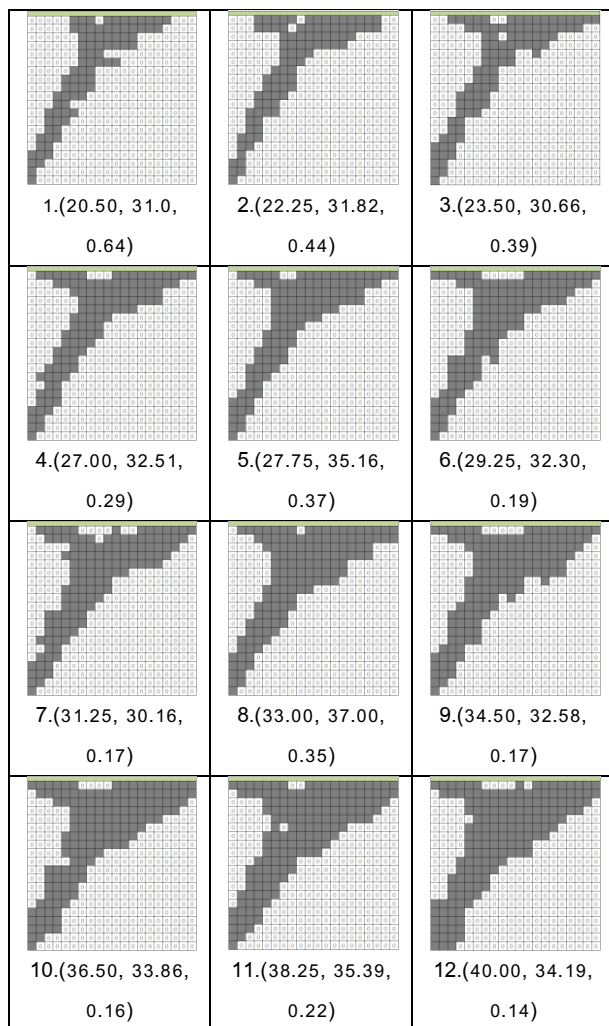


Fig. 8 Topologies of non-dominate Solutions of two objectives problem.

By hyper volume criterion, it seems that the element adjustment can enhance performance of SPEA-II for the heat conduction problem especially in case of high number of objectives and uniform crossover. Comparing HV values of one-point and uniform crossover, it found that the element adjust can more significantly improve performance of SPEA-II for uniform crossover than for one-point crossover. Moreover, overall HV values of one-point crossover are better than that of uniform crossover. This shows that exchange between

effective and non-effective elements may cause poor solutions because uniform crossover considers exchanging elements in every element but one-point crossover considers exchanging elements in one portion of structure. Therefore, uniform crossover has more possibility of the exchange between effective and non-effective elements than one-point crossover. By introducing the element adjustment into uniform crossover, the element adjustment can improve much HV because it can prevent the element exchange.

From Fig. 7, optimized structures of heat conduction problem with 2 objective conduct heat  $Q$  at the fixed element (Fig. 1), then try to transfer the heat directly in vertical direction for minimizing used elements. The optimized structures also try to distribute from right to left elements in top rows before transfer heat into the plate. Additionally, they try to reduce surface area as much as possible in order to reduce heat loss to environment.

For the problem with 3 objectives, optimized structures transfer heat into middle elements in top rows, and distribute the heat to a plate in order to reduce temperature standard deviation  $SD_T$  in the plate. In addition, they have convective surface below middle portion of the plate, in which temperature is higher than other portions, to transfer heat to the surroundings in order to reduce temperature in the portion and the  $SD_T$  in the plate.

## 5. Conclusions

This paper presents element adjustment in crossover to prevent exchange between effective and useless bits in continuum topology



optimization problems. The proposed idea is embedded into a selected multi-objective evolutionary algorithm which is the improved strength Pareto evolutionary algorithm (SPEA-II). This idea is embedded in one-point and uniform crossover and tested with a heat conduction problem with 2-3 objectives. After simulation runs, by HV results crossovers with the element adjustment contribute better the normal crossovers in any crossover types. Especially, for uniform crossover, the element adjustment much improves performance of the crossover. In addition, the element adjustment can enhance performances of crossover in the problem with 3 objectives more obviously than the problem with 2 objectives. Thus it can conclude that the element adjustment can improve performance of evolutionary algorithm in multi-objective continuum topology optimization problems. In addition, this idea can also be applied to single-objective continuum topology optimization problems.

## 6. References

- [1] Liang, Y. and Leung, K.W. (2011). Genetic Algorithm with adaptive elitist-population strategies for multimodal function optimization, *Applied Soft Computing*, vol.11(2), March 2011, pp. 2017 – 2034.
- [2] Zhao, J. and Wang, L. (2011). Center Based Genetic Algorithm and its application to the stiffness equivalence of the aircraft wing, *Expert Systems with Applications*, vol.38(5), May 2011, pp. 6254-6261.
- [3] Safikhani, H., Hajiloo, A., and Ranjbar, M.A. (2011). Modeling and multi-objective optimization of cyclone separators using CFD and genetic algorithms, *Computers & Chemical Engineering*, vol. 35(6), 9 June 2011, pp. 1064-1071.
- [4] Wang, N.F. and Tai, K. (2010). Target matching problems and an adaptive constraint strategy for multiobjective design optimization using genetic algorithms, *Computers & Structures*, vol.88(19-20), October 2010, pp. 1064-1076.
- [5] Boonlong, K. (2011). Adaptive Mutation in Multi-objective Evolutionary Algorithm for Continuum Topology Optimization, paper presented in the 15th International Annual Symposium on Computational Science and Engineering (ANSCSE15), Bangkok University, Thailand.
- [6] Boonlong, K., Maneeratana, K. and Chaiyaratana, N. (2010). Progressive Refinement Solution Search for Multi-objective Continuum Topology Optimization Problems, paper presented in the 24th conference of the Mechanical Engineering Network of Thailand (ME-NETT 24), Ubon Ratchathani, Thailand.
- [7] Zitzler, E., Laumanns, M., and Thiele, L. (2002). SPEA-II: Improving the strength Pareto evolutionary algorithm. *TIK-Report No. 103*, Computer Engineering and Networks Laboratory (TIK), Swiss Federal Institute of Technology (ETH), Zurich, Switzerland.
- [8] Purshouse, R. (2003). On the evolutionary optimization of many objectives, Ph.D. dissertation, Univ. Sheffield, Sheffield, U.K.