Microfluidics Project: Inlet Outlet Combinatorial Search

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1 Introduction and Motivation

Earlier, for defined inlets and outlets, we manipulated inlet spacing to obtain desired sequences of droplets in the outlets. In the study, we considered two types of droplets: A and B, feeding 3 of each to 2 inlets (Inlet1=0 and Inlet2=2). The desired output sequences in Outlet1=10 and Outlet2=12 were ABA and BAB, respectively. It was observed that, for resistance ratio of B:A = 4, irrespective of the size of initial population and number of generations($<$150) we were unable to obtain the desired output since the drops with higher resistance took longer to reach the required outlet than the drops with lower resistance. It was, thus, hypothesised that manipulating the inlet and outlet positions may help in obtaining the desired sequences that would otherwise be difficult to achieve with drops of high resistance.

2 Problem Definition

The problem is to identify a set of source and sink nodes such that, upon running genetic algorithm for 3 generations with an initial population of 80 different spacings we are able to obtain atleast 1 solution spacing which gives us the desired sequence at the chosen sink nodes.

Input to Network:
$AAA \longrightarrow Inlet1$
$BBB \longrightarrow Inlet2$
Output from Network:
$ABA \longrightarrow Outlet1$
$BAB \longrightarrow Outlet2$

Objective: Obtain $Inlet1$, $Inlet2$, $Outlet1$, $Outlet2$ such that Genetic Algorithm converges within 3 generations to provide a solution spacing

Search Space: $Inlet1$, $Inlet2$, $Outlet1$, $Outlet2$ $\in [0, 1, 2 ... 12]$ s.t. $Inlet1 \neq Inlet2 \neq Outlet1 \neq Outlet2$

NOTE: The order of Oulet1 and Outlet2 matter since distinct sequences have been assigned to each. Thus, sink nodes (3,5) $\neq$(5,3). However, the inlet nodes can be exchanged, to avoid repetition.

Number of elements in search space: ${}^{13}\mathrm{C}_2 \cdot {}^{11}\mathrm{C}_2 \cdot 2! = 8580$

3 Methodology and Experiments

1. Select element from search space and initialize network with chosen inlets and outlets and resistance ratio = 4
2. Run GA code with population size of 80 for 3 generations and run simulation for each of the spacings in the population and record maximum fitness of the spacings in the 3rd generation population
3. If maximum fitness = 1, objective is acheived. Record best spacing and current element since it gives desired output. Run simulation for obtained spacing and inlets and outlets to verify.
4. If maximum fitness $<$ 1, choose a different element from search space and repeat.

4 Results and Analysis

On picking the first 600 elements from the search space, the best results obtained are as follows:

Source Node 1	Source Node 2	Sink Node 1	Sink Node 2	Max fitness	Best Output
0	3	2	7	1	010 101
0	3	10	11	1	010 101
0	1	11	7	0.9	001 101
0	3	1	5	0.9	010 011
0	3	1	6	0.9	010 011
0	3	2	6	0.9	010 011
0	3	2	9	0.9	010 011
0	3	2	12	0.9	010 011
0	3	4	9	0.9	010 011
0	3	5	1	0.9	010 011
0	3	5	6	0.9	010 011
0	3	8	9	0.9	010 011
0	3	10	6	0.9	010 011
0	3	10	9	0.9	010 011
0	3	10	12	0.9	010 011
0	4	1	6	0.9	010 011
0	4	7	2	0.9	010 011
0	4	9	2	0.9	010 011
0	4	9	7	0.9	001 101
0	4	11	7	0.9	001 101
0	4	12	2	0.9	010 011

Table 1: Top Results from varying Inlet-Outlet

Using the earlier combination of inlets and outlets after running 150 generations of Genetic Algorithm :

Source Node 1	Source Node 2	Sink Node 1	Sink Node 1	Max fitness	Best Output
0	1	10	12	0.8	001 011

Table 2: Best Solution in previous study

Thus, we see that by changing the inlet and outlet positions we were able to increase the maximum fitness, obtained in 150 generations, in just 3 generations. Sequences that are otherwise difficult to acheive may be acheived by this method.

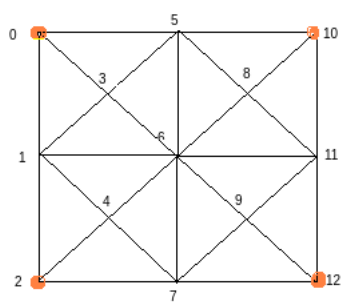

Figure 1: Original Network with inlets at 0,2 and outlets at 10,12

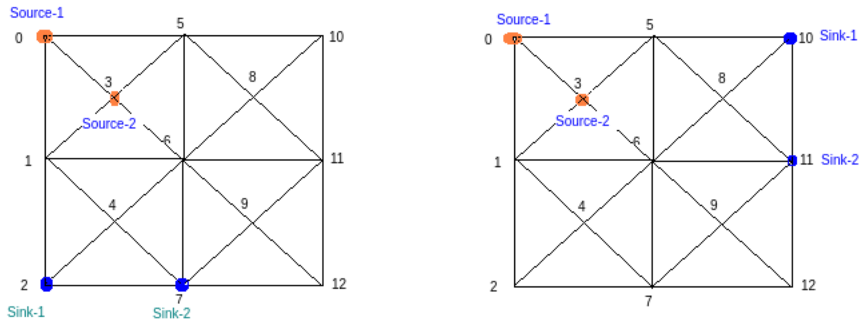

Figure 2: Solution Networks with maximum fitness value = 1

In the original network, shown in Figure 1, the the two outlets are placed in a similar manner for both the inlets - the one with low resistance as well as the high resistance. To obtain the desired sequences, i.e., ABA in outlet1 and BAB in outlet2, high resistance drop B from node 2 has to reach the diagonally opposite node 10, before the low resistant drop A reaches it, even though it moves significantly faster and the node is close to it. For this, the space between two A drops needs to be very high such that it reaches the outlet only after drop B has reached. Instead, it is easier to move the outlets closer to drop B so that it has lesser distance to cover, which it can do slowly. From Figure 2, we see that the obtained solution outlets (among the first 600 iterations) are equivalent (0,3,2,7)$\simeq$(0,3,10,11) in terms of distances between the outlets and inlets. These solutions move the inlet for high resistance drops closer to the outlets such that the slow moving drop B is able to reach in time to provide the exact desired sequences. From the similarity of the two solutions, we can predict other possible solutions with equivalently placed inlets and outlets such as (1,4,11,12), (10,8,7,12), (7,9,5,10), etc.

4.1 Exploration of Results

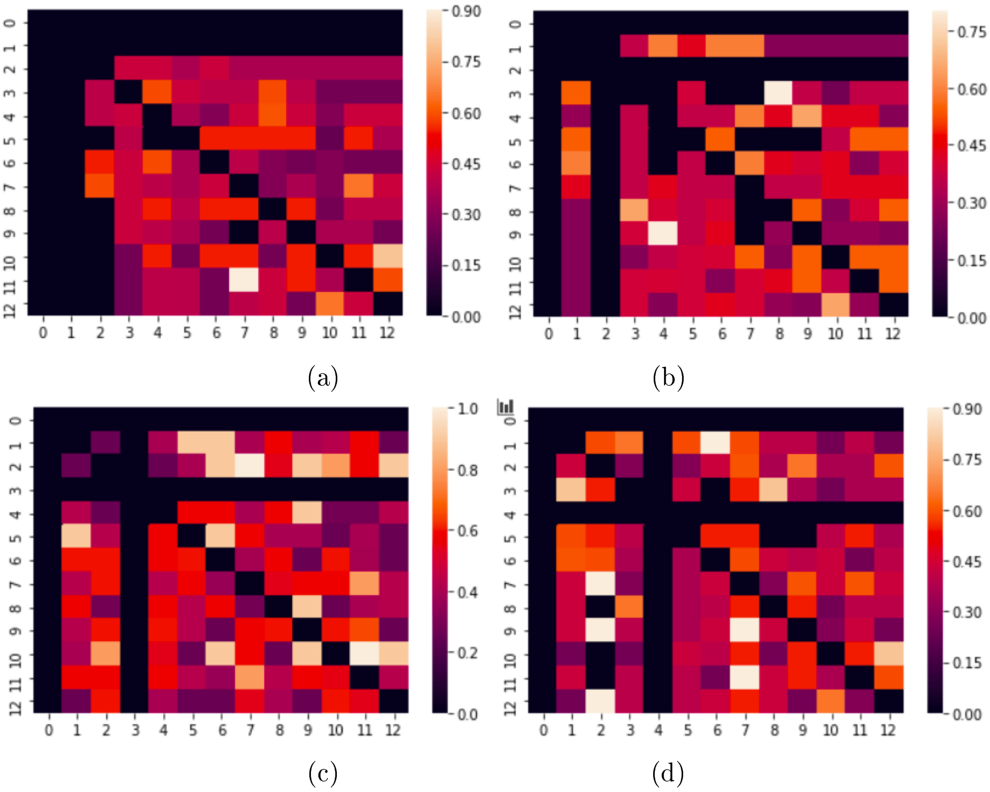

Figure 3: Heatmaps showing fitness values in colours for all outlet combinations for (a) Inlets: (0,1) (b) Inlets: (0,2) (c) Inlets: (0,3) (d) Inlets: (0,4)

1. In Figure 3, three types of elements in the search space result in black squares (max fitness = 0)[1] in the heatmap:
   (a) We see that for inlets (i,j), the ith and jth rows and columns are dark elements shown to have zero fitness. This is the case because these elements are not a part of the search space because a single node cannot serve as both an outlet and inlet.
   (b) Further, the diagonal elements (i,i) are also dark since a single node cannot serve as two outlets.
   (c) The remaining elements that are dark are those in which the output at the 2 outlets is the same as the input from the 2 corresponding two inlets. The fitness function has explicitly been designed to give these a fitness value of 0.
2. From the figure we observe that different outlet combinations result in different values of maximum fitness. A maximum fitness value of 1 is observed only in Figure 3(c).
3. As expected, the heatmaps are not symmetric across the diagonal, this is because, each outlet has been assigned a particular sequence and for the same inlets and output sequence specifications, the drops would have to travel to different outlets if they were interchanged.
4. In all the figures, we see that purple and red elements ($\sim 0.3 - 0.6$) occur in groups or chains (one beside the other) while white ($\sim 0.8 - 1$), orange($\sim 0.6 - 0.75$), and violet ($\sim 0.1 - 0.2$) tend to occur singularly more often than not. This tells us that, if some outlet combination (i,j) results in a maximum fitness value of ($\sim 0.3 - 0.6$) after 3 generations of GA, there is a good chance of the neighbouring outlet combinations in the search space, i.e., (i-1,j), (i,j-1), (i-1,j-1), (i+1,j), (i,j+1), (i+1,j+1), (i-1, j+1), (i+1, j-1), if feasible, also resulting in a maximum fitness value in the same range.

[1] Identified in Step 2 in Section 3

5. Finally, we also notice that the number of elements in the search space resulting in outlet sequences being the same as the inlet sequences (Case 1(c)) has some negative correlation with the maximum fitness value acheived with that inlet combination. The Spearman Correlation coeffcient of this sample, in Table 3, is -0.94868, indicating highly negative correlation. A larger sample size may be taken to validate this hypothesis further.

Inlet Combination	Number of elements with Fitness = 0 (case 1(c))	Maximum Fitness Value
(0,1)	7	0.9
(0,2)	10	0.8
(0,3)	0	1
(0,4)	6	0.9

Table 3: Table indicating correlation between number of squares with fitness 0 and maximum fitness value