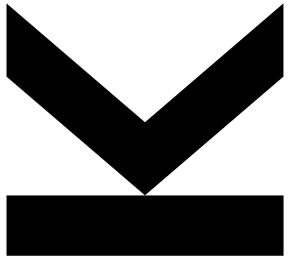
CLOSE-TO-OPTIMAL PLACEMENT AND ROUTING FOR CONTINUOUS-FLOW MICROFLUIDIC BIOCHIPS



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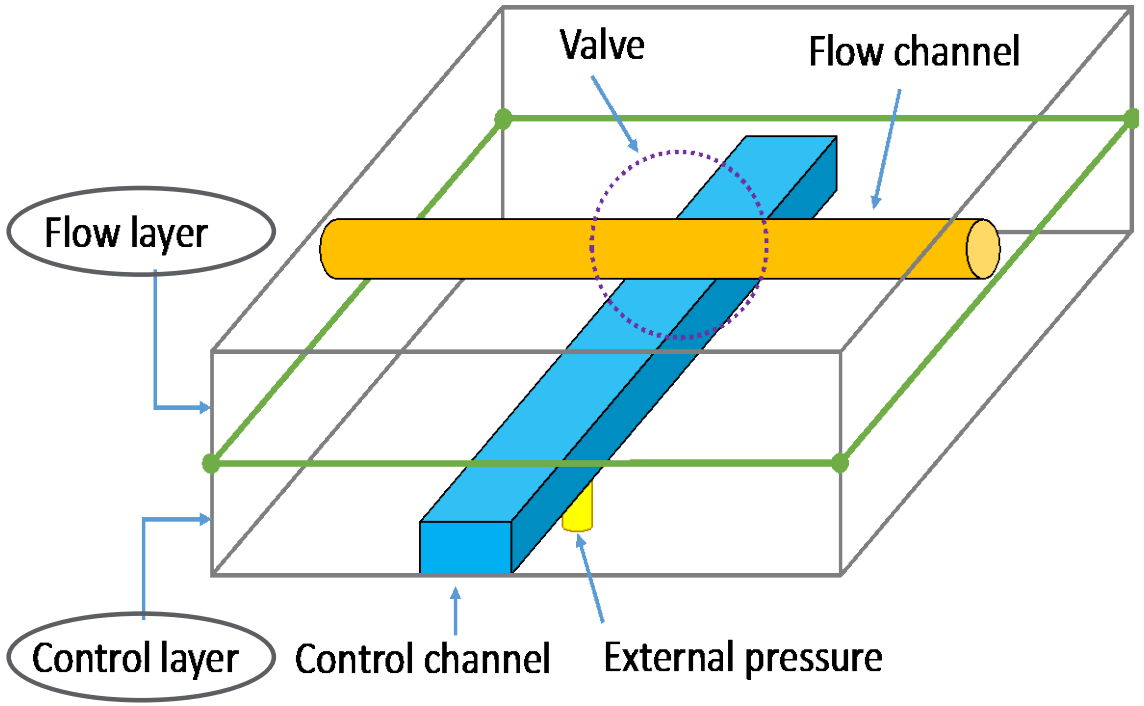
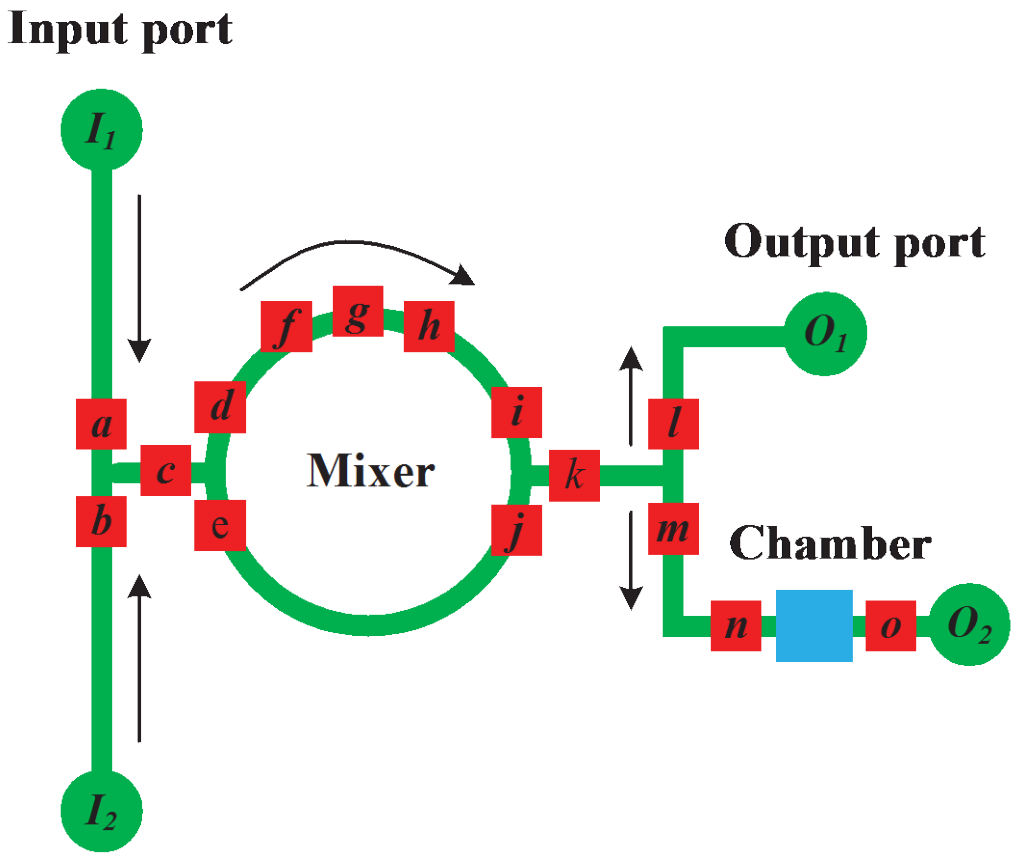
Contact: andreas.grimmer@jku.at

CONTINUOUS-FLOW MICROFLUIDIC BIOCHIP



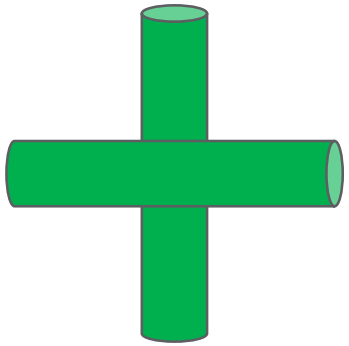
- Two-layer: control- and flow-layer
- Thousands of valves

MIXER COMPONENT



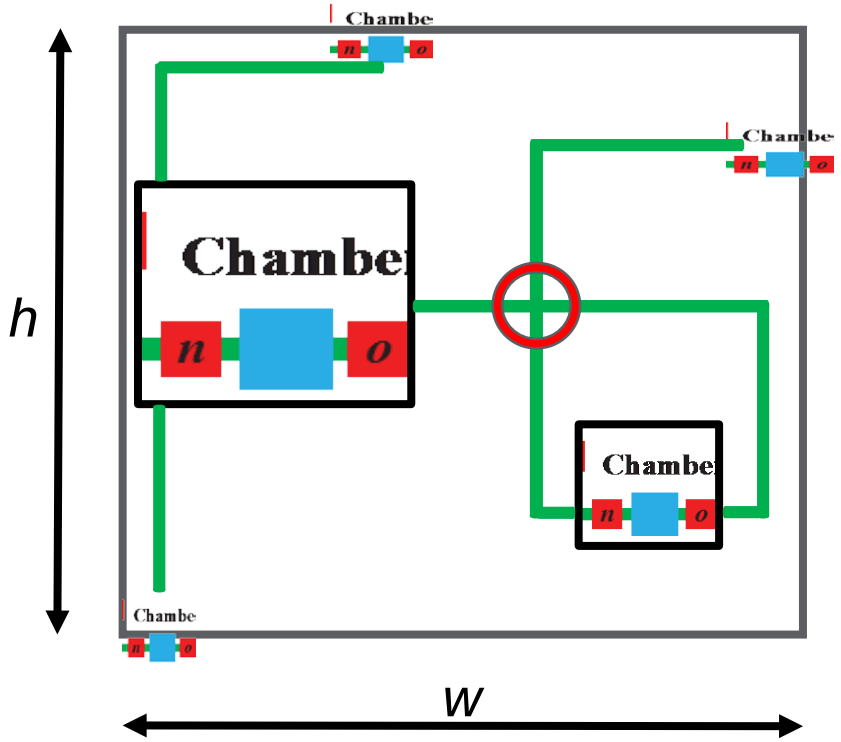
PHYSICAL DESIGN

- Place components
- Route flow channels
- Quality of design:



Flow channel intersections

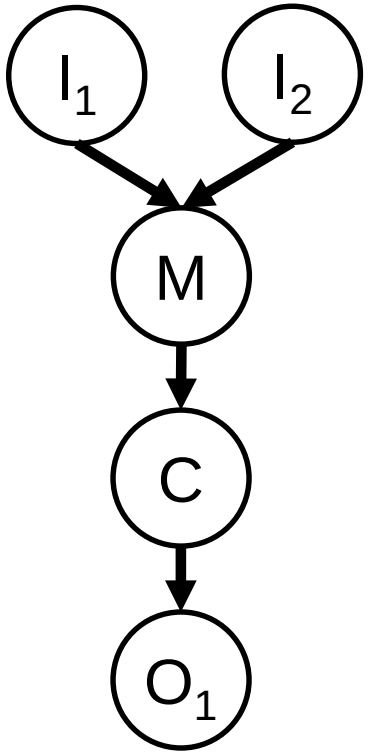
Overall flow channel length



Flow layer size

PHYSICAL DESIGN

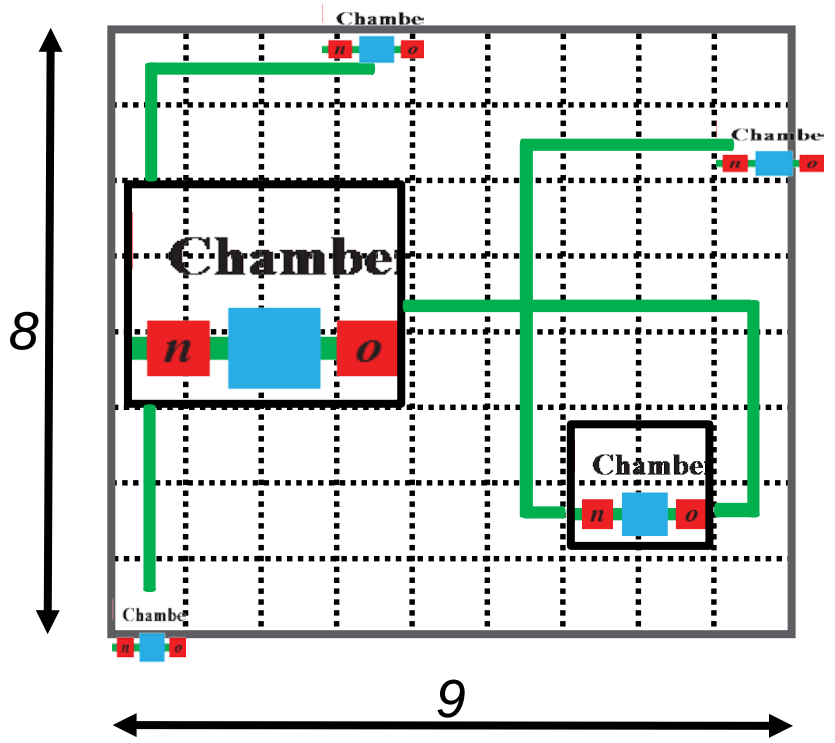
Input



Grid
9 x 8 cells

Resource	**Area**
Mixer	4 x 3
Chamber	2 x 2

Grid

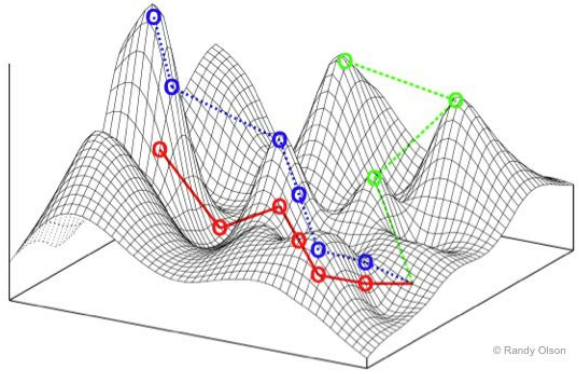


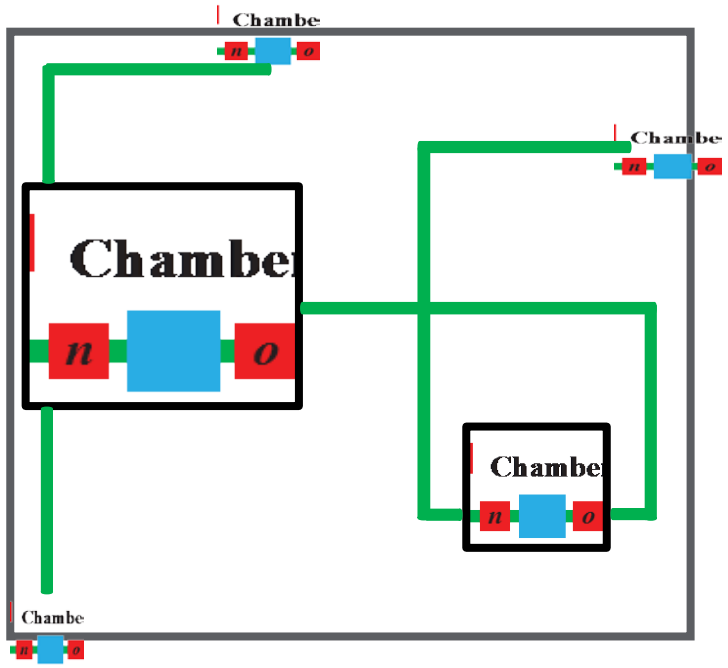
MOTIVATION

- Existing methods for physical design
  - rely on heuristics
  - 2 independent steps:
    placement
    routing

➔ Cannot guarantee quality criteria

➔ Far from being optimal

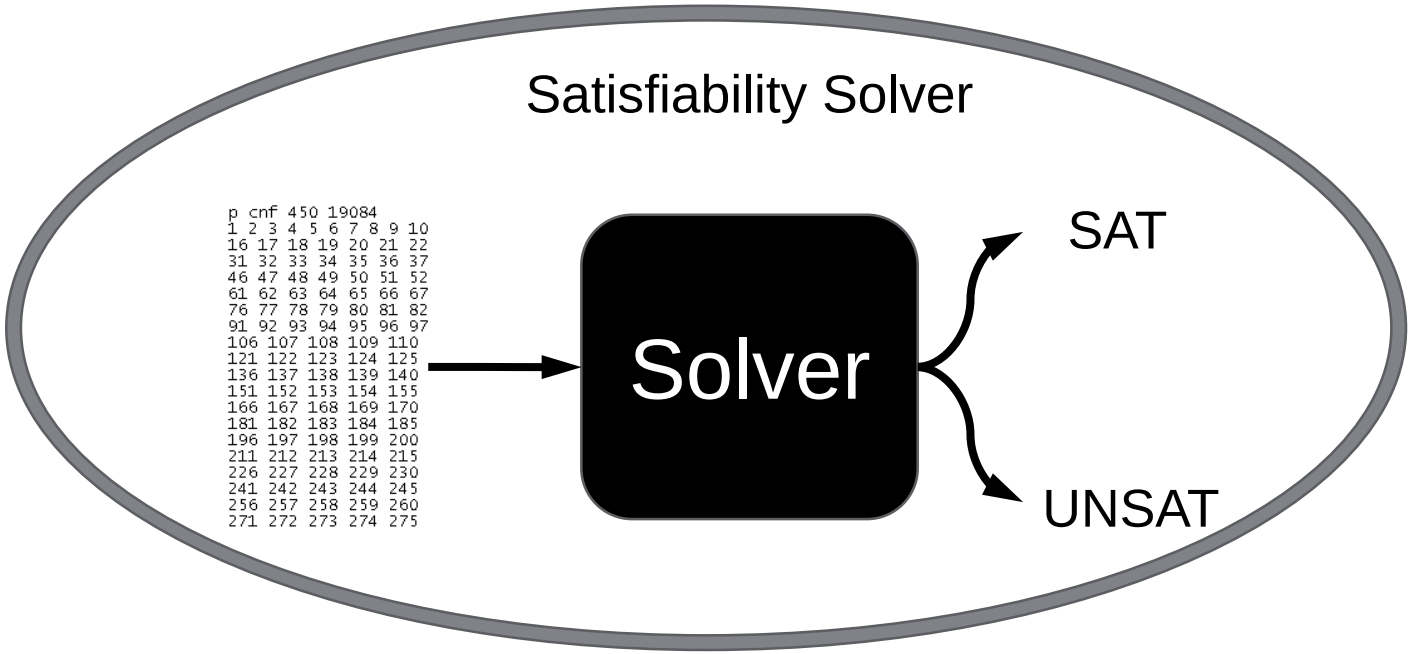




APPROACH

- Consider placement and routing in **single** step (P&R)

➔ Enormous search space



Search Space Pruning

SYMBOLIC FORMULATION FOR P&R

- Grid: $1 \leq x \leq w$ and $1 \leq y \leq h$
- $V = \{Mixer, Chamber, I_1, I_2, O_1\}$
- For each component $v \in V$:

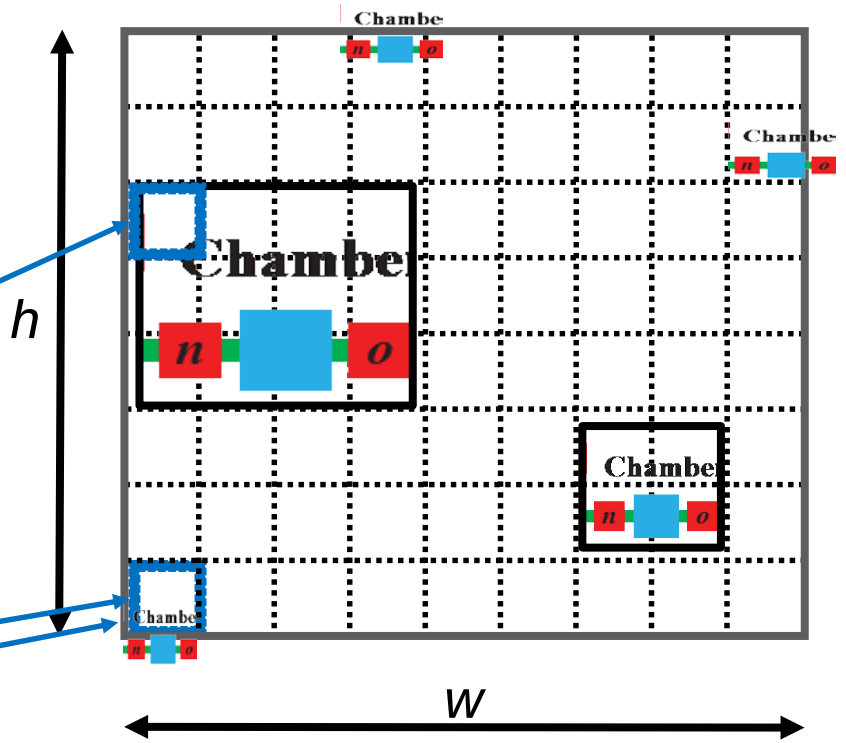
  $vp_{(x,y),v}$

- Example:

  $vp_{(1,6),Mixer} = 1$

  $vp_{(1,1),Mixer} = 0$

  $vp_{(1,1),I_2} = 1$



SYMBOLIC FORMULATION FOR P&R

- $E = \{(I_1, Mixer), (I_2, Mixer), (Mixer, Chamber), (Chamber, O_1)\}$

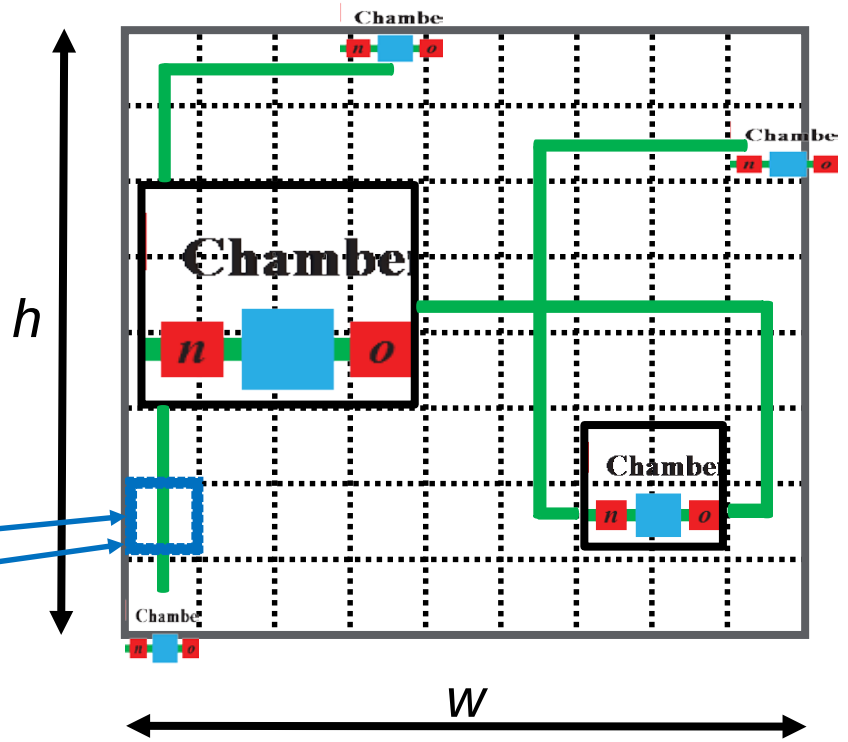
- For each channel $(u, v) \in E$:

  $ep_{(x,y),(u,v)}$

- Example:

  $ep_{(1,2),(I_2,Mixer)} = 1$

  $ep_{(1,2),(I_1,Mixer)} = 0$



CONSTRAINTS FOR P&R

Grid cell can be occupied by

- at most one component

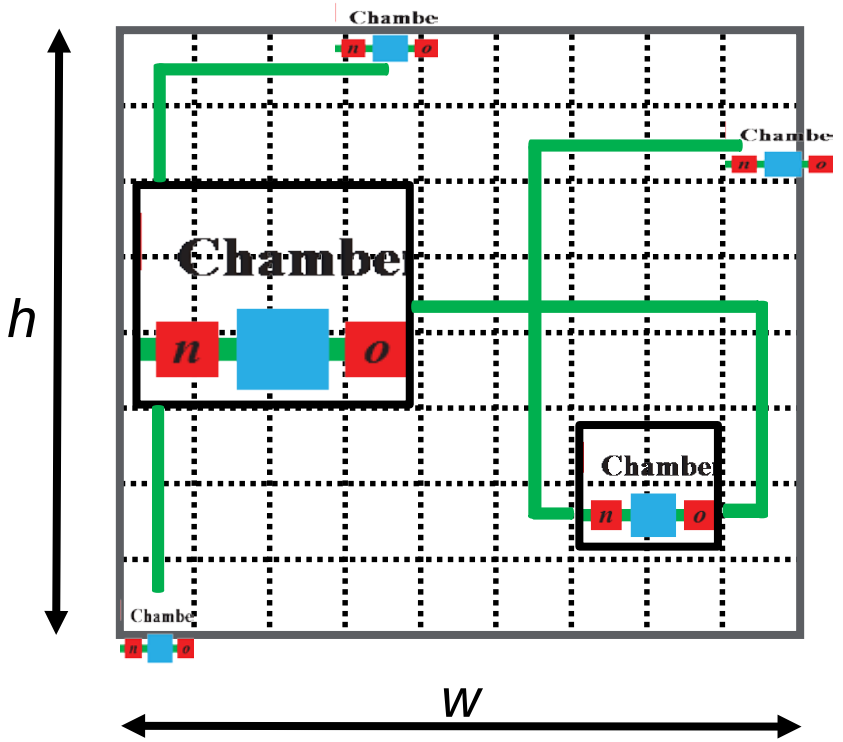
$$\bigwedge_{\substack{1\le x\le w\\ 1\le y\le h}} \left(\sum_{v\in V} vp_{(x,y),v} \le 1 \right)$$

- at most two channels

$$\bigwedge_{\substack{1\le x\le w\\ 1\le y\le h}} \left(\sum_{(u,v)\in E} ep_{(x,y),(u,v)} \le 2 \right)$$

- a component or a channel

$$\bigwedge_{\substack{1\le x\le w\\ 1\le y\le h}} \neg \left(\sum_{v\in V} vp_{(x,y),v} > 0 \wedge \sum_{(u,v)\in E} ep_{(x,y),(u,v)} > 0 \right)$$



CONSTRAINTS FOR P&R

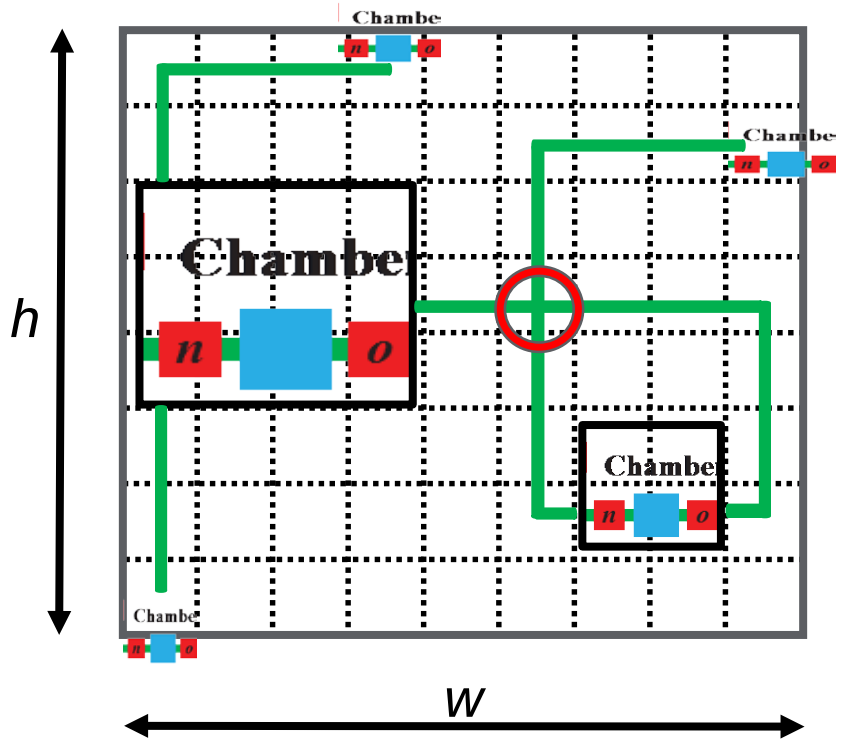
- Constraints for placing components
- Constraints for routing channels

- Enforcing the **designer's** constraints:
  - ☐ Maximal channel intersections:

$$\sum_{\substack{1\le x\le w\\ 1\le y\le h}} \left(\sum_{(u,v)\in E} ep_{(x,y),(u,v)}=2 \right) \le maxIntersections$$

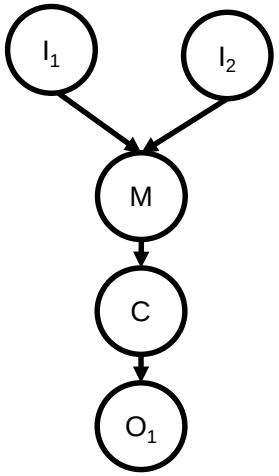
  - ☐ Maximal channel length:

$$\sum_{\substack{1\le x\le w\\ 1\le y\le h}} \left(\sum_{(u,v)\in E} ep_{(x,y),(u,v)} \right) \le maxLength$$



SAT-PROCEDURE FOR OPTIMAL P&R

Inputs



Grid
9 x 8 cells

Resource	**Area**
Mixer	4 x 3
Chamber	2 x 2

Designer's constraints

0 Int.
1 Int.
⋮
n Int.

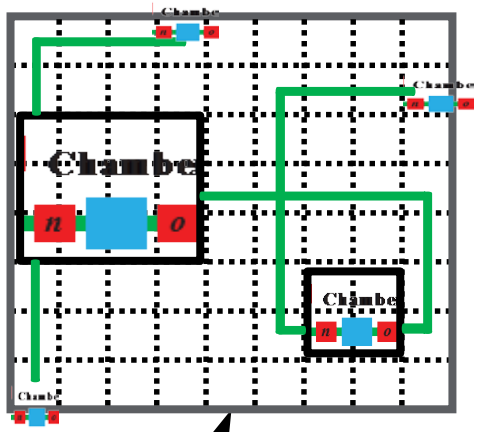
UNSAT

```
p cnf 450 19084
1 2 3 4 5 6 7 8 9 10
16 17 18 19 20 21 22
31 32 33 34 35 36 37
46 47 48 49 50 51 52
61 62 63 64 65 66 67
76 77 78 79 80 81 82
91 92 93 94 95 96 97
106 107 108 109 110
121 122 123 124 125
136 137 138 139 140
151 152 153 154 155
166 167 168 169 170
181 182 183 184 185
196 197 198 199 200
211 212 213 214 215
226 227 228 229 230
241 242 243 244 245
256 257 258 259 260
271 272 273 274 275
```

Solver

SAT

Solution



APPROACH

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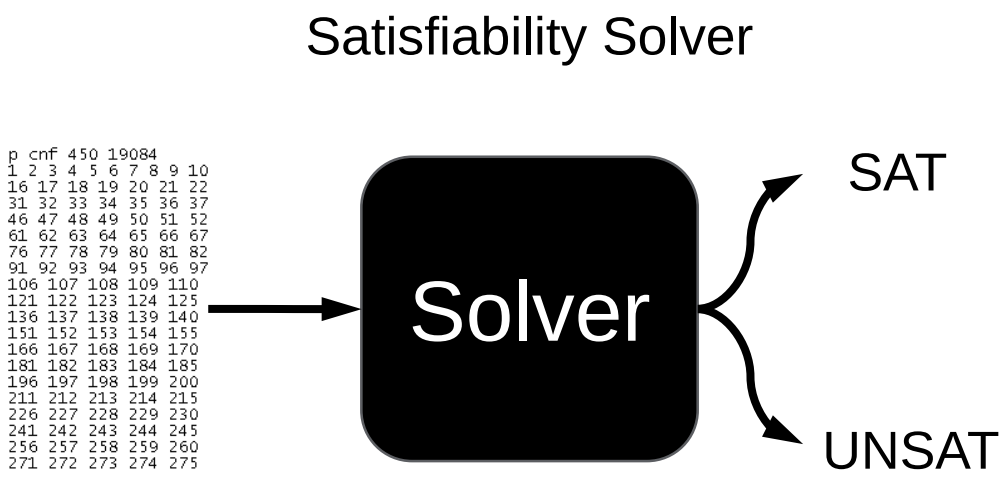
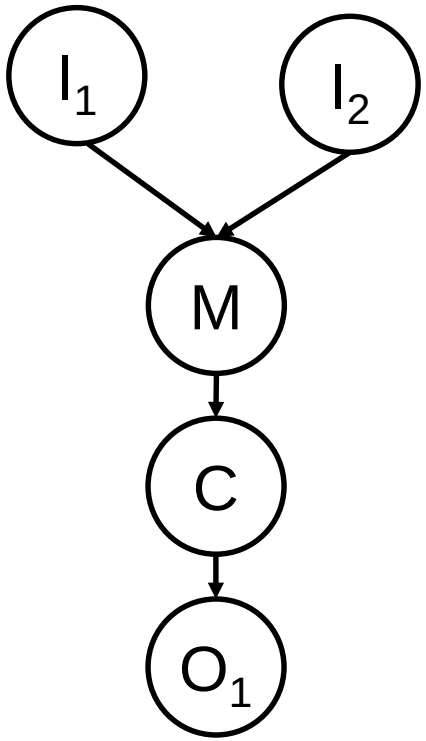
➔ Enormous search space



DOWNSCALING



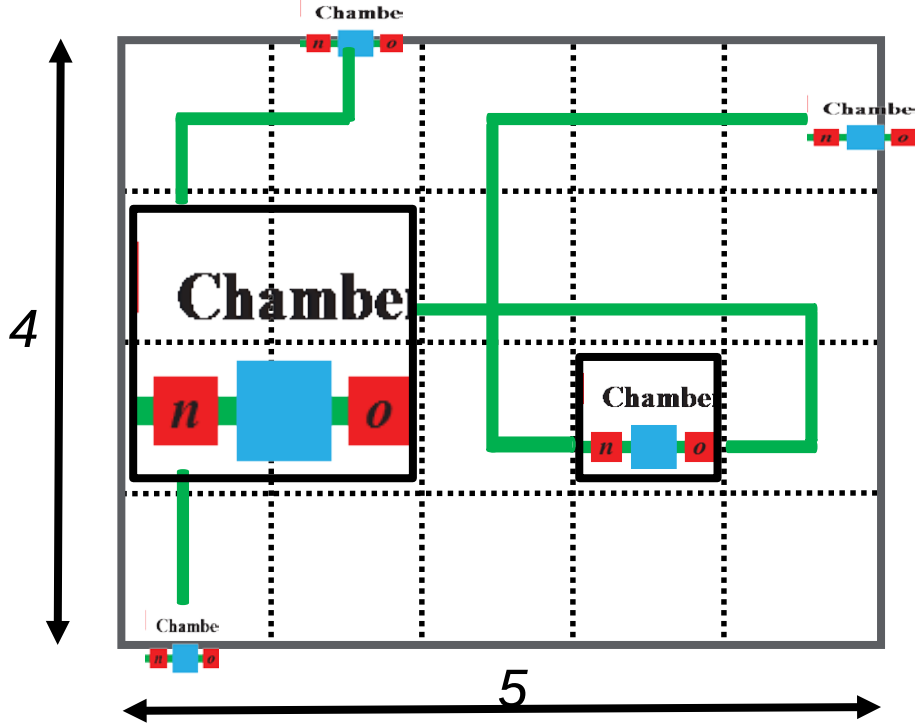
Grid
9 x 8 cells

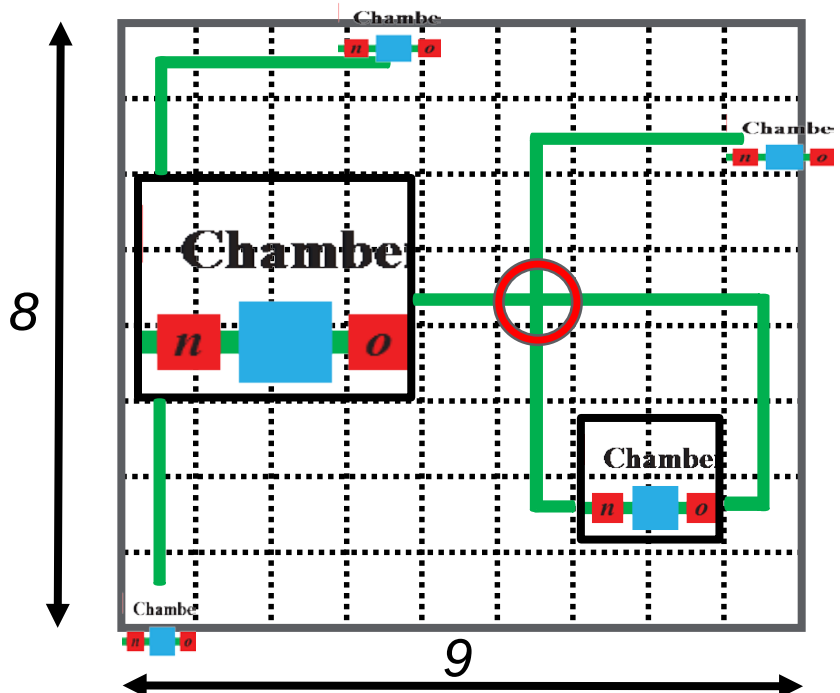
Resource	**Area**
Mixer	4 x 3
Chamber	2 x 2

/ 2

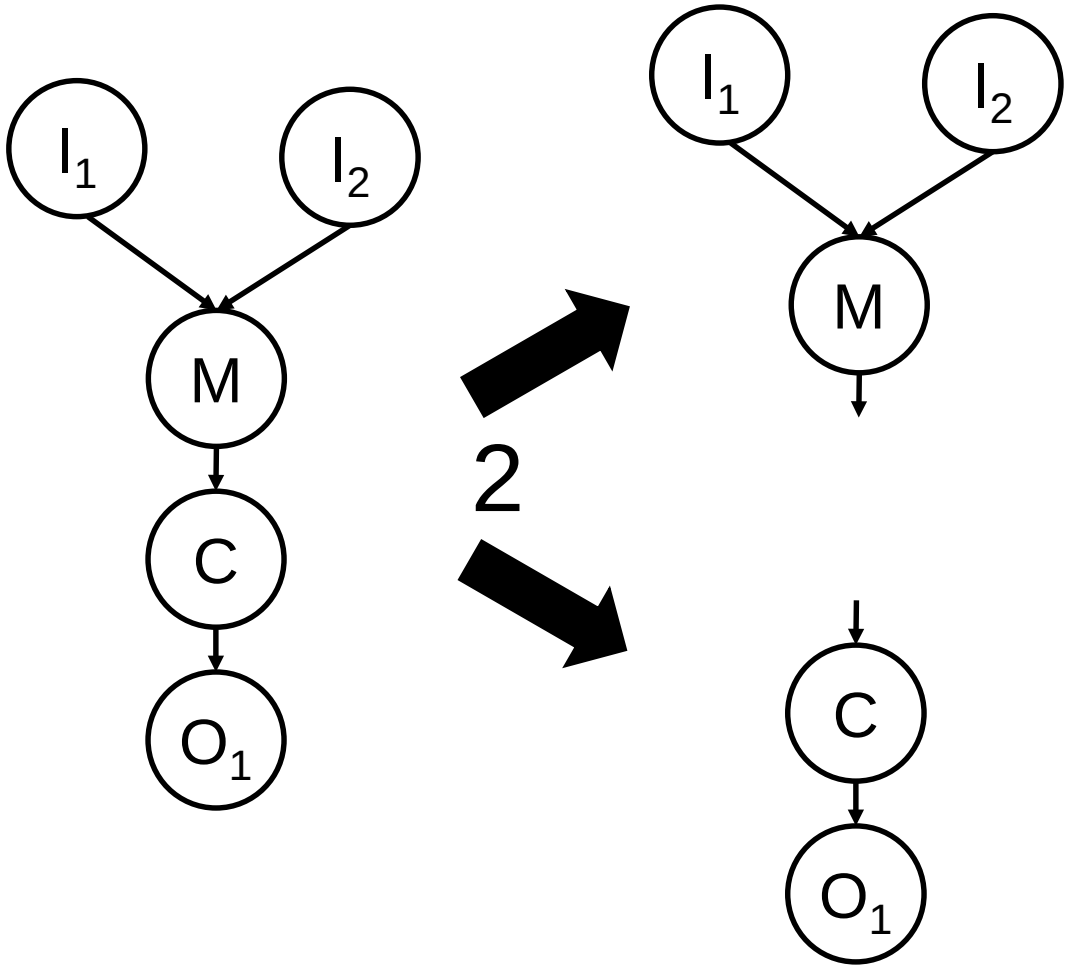
Grid
5 x 4 cells

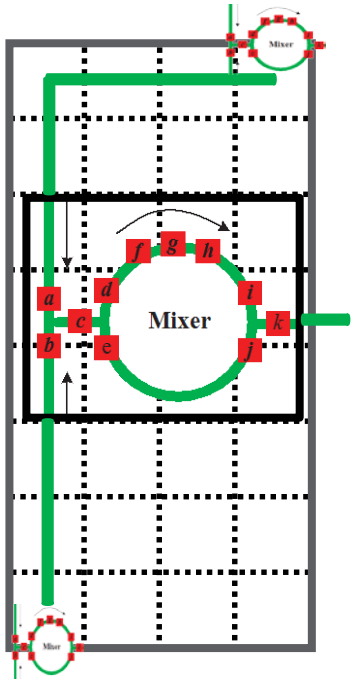
Resource	**Area**
Mixer	2 x 2
Chamber	1 x 1

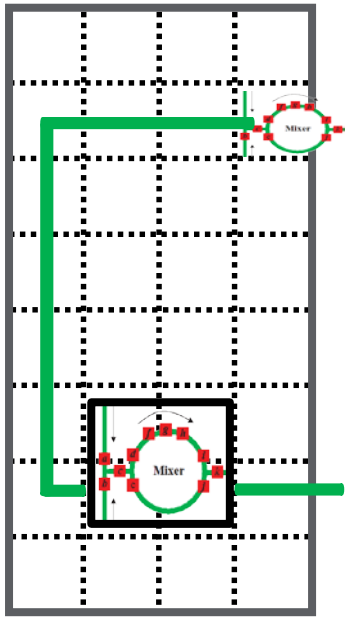


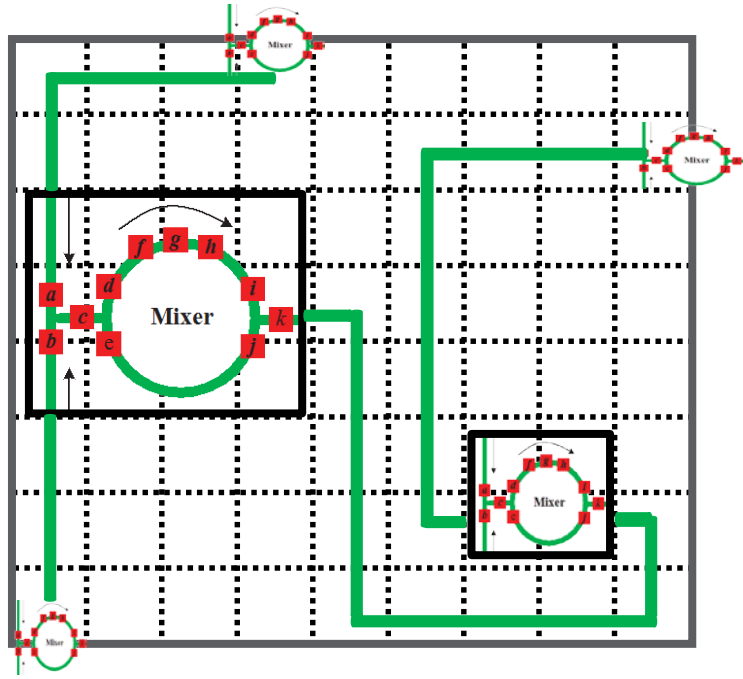


PARTITIONING

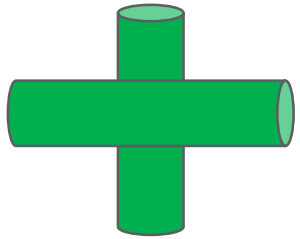


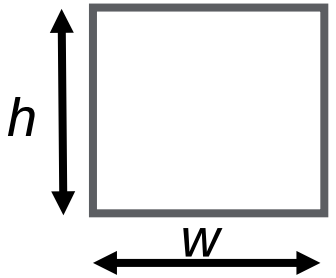


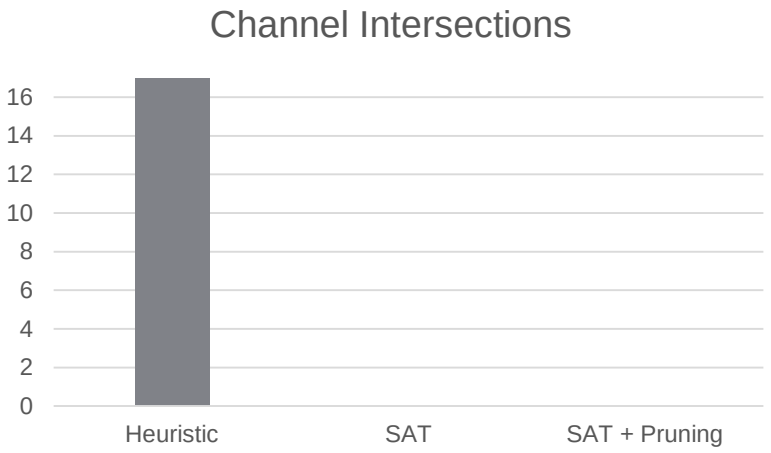


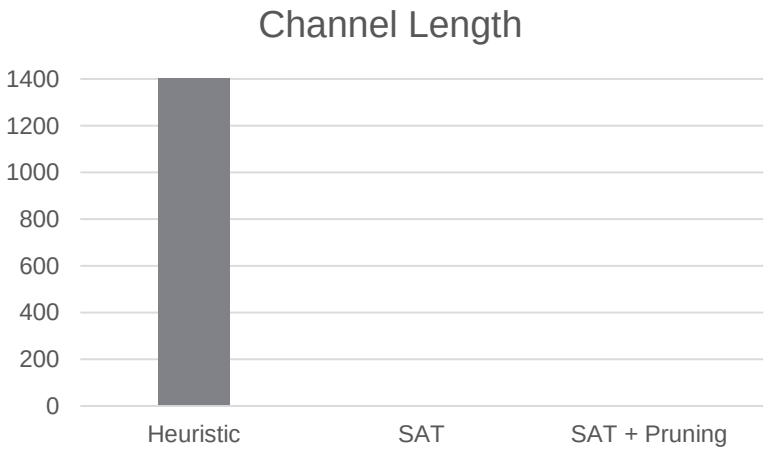


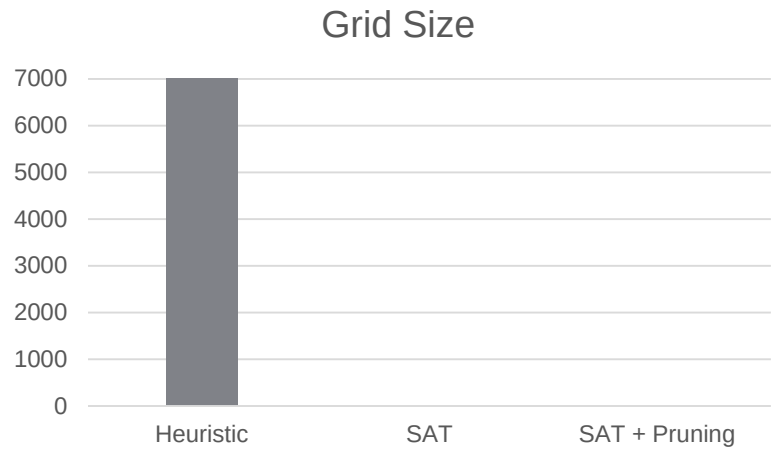
EVALUTATION – SMALL BENCHMARK





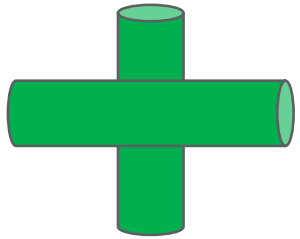


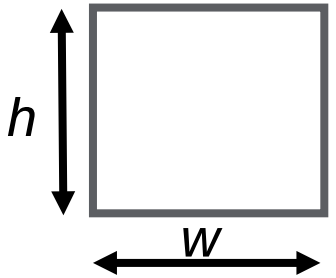


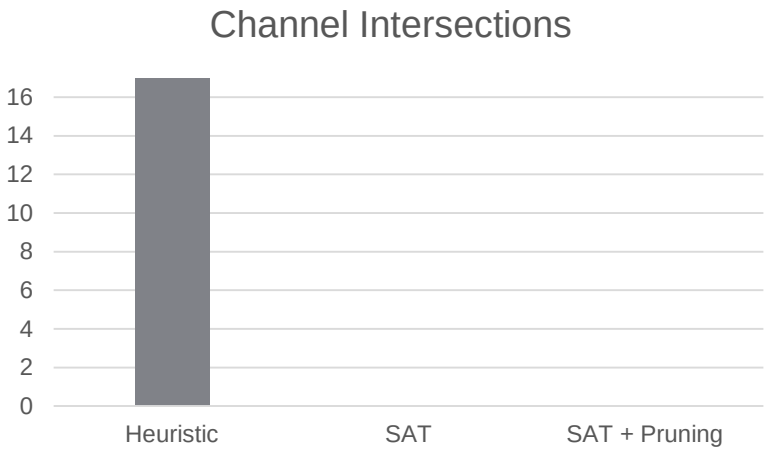


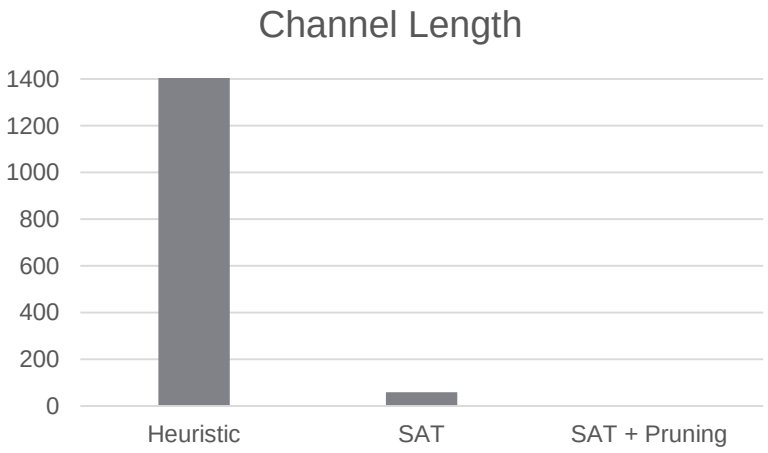
Heuristic: Q. Wang, Y. Ru, H. Yao, T.-Y. Ho, and Y. Cai. Sequence-pair-based placement and routing for flow-based microfluidic biochips. In *ASP-DAC*, 2016.

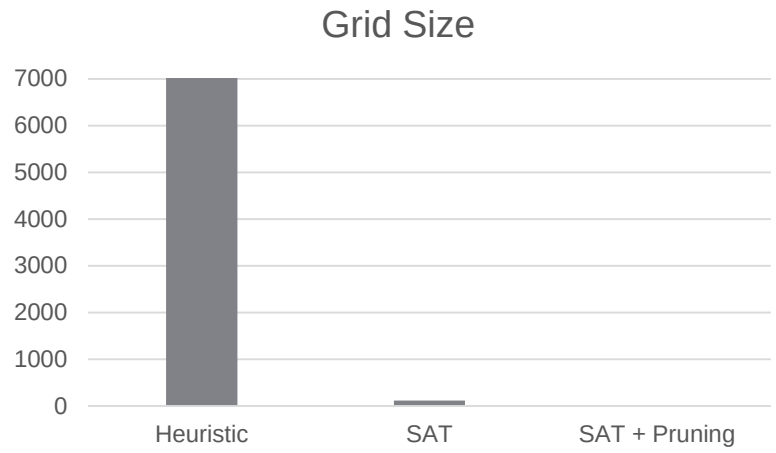
EVALUTATION – SMALL BENCHMARK











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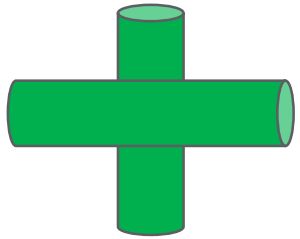

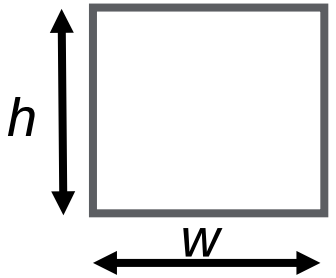

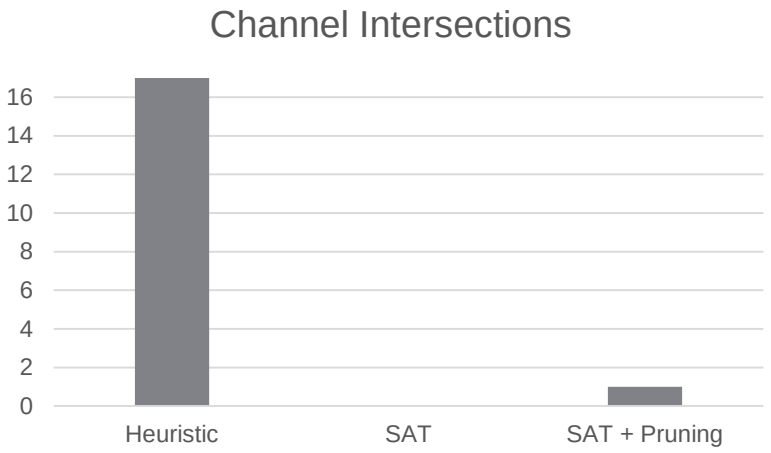

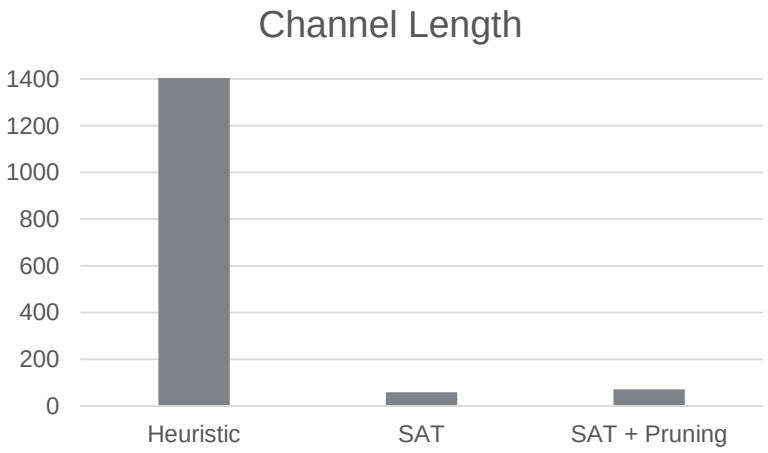

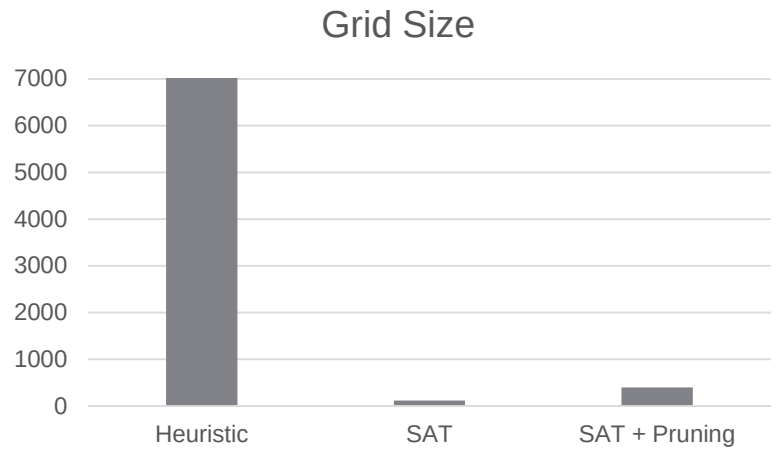

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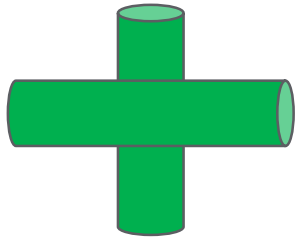
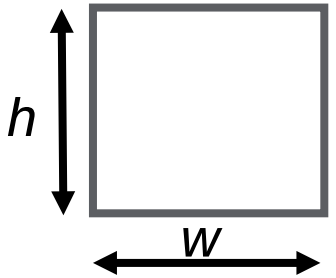
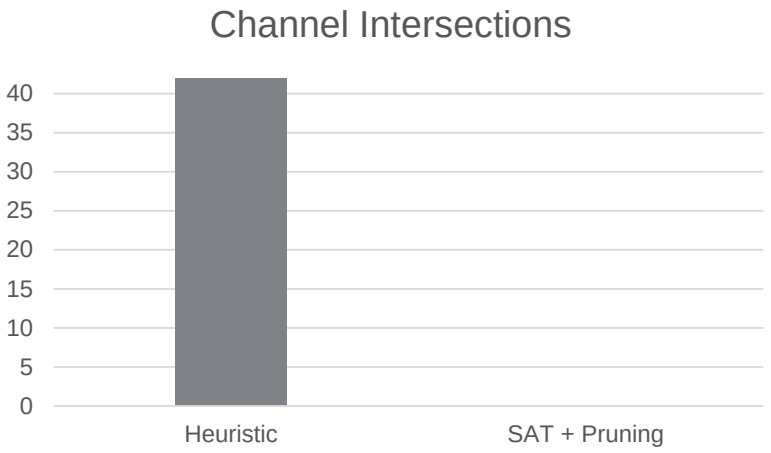
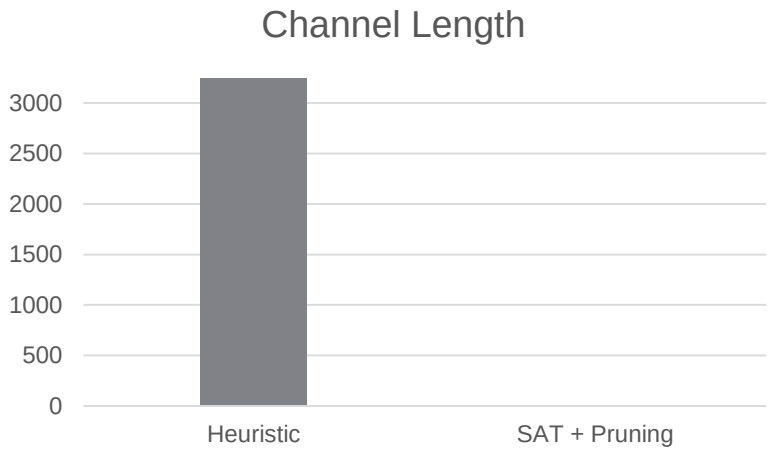
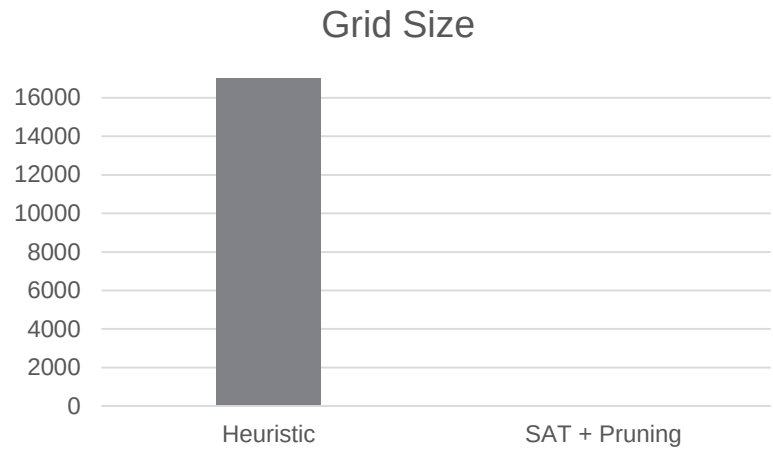
EVALUTATION – PROTEIN SPLIT











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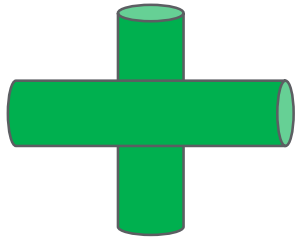

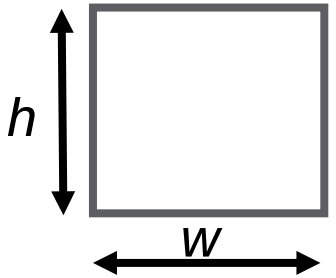

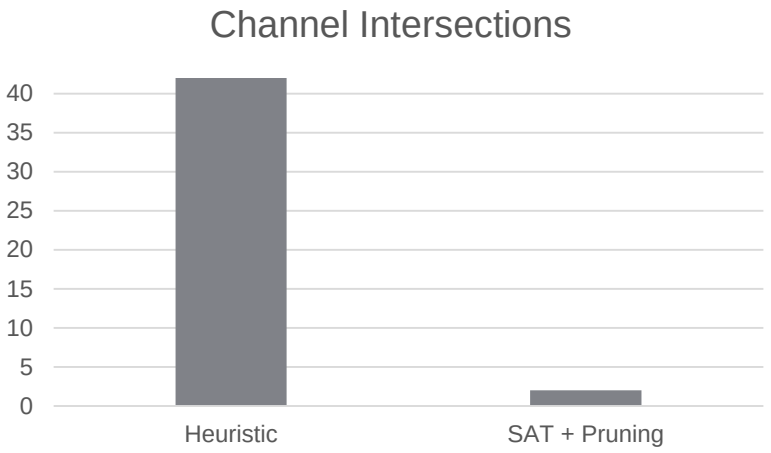

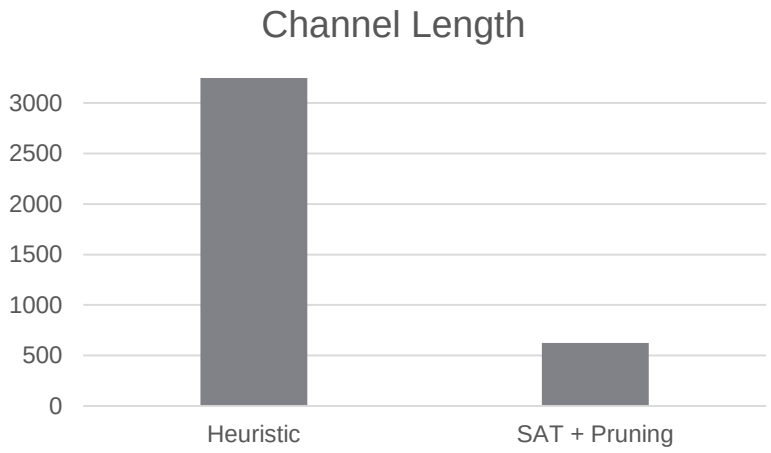

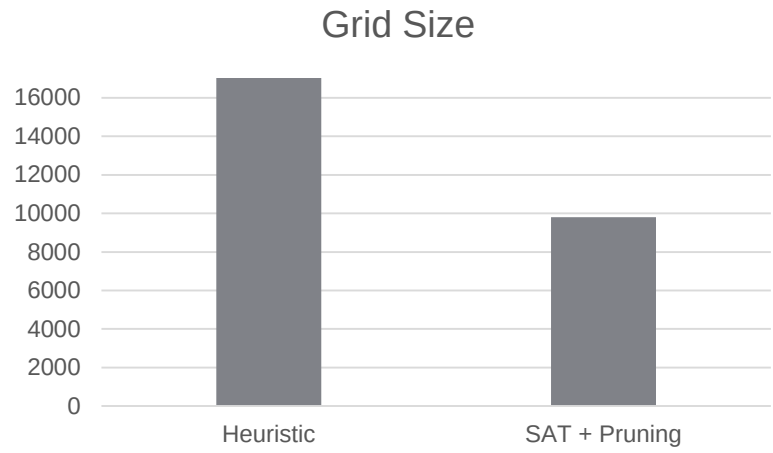

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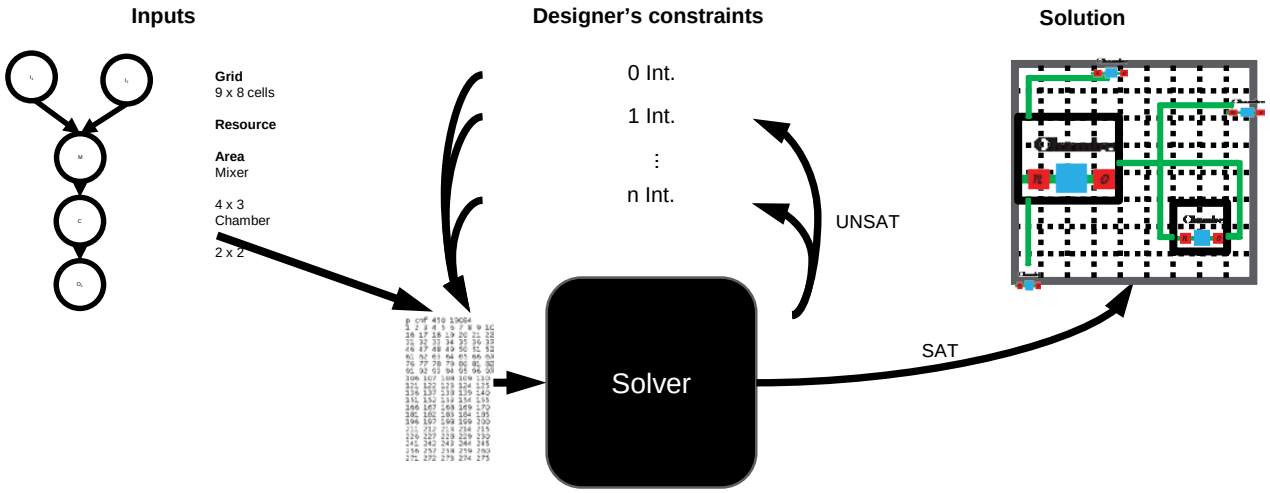
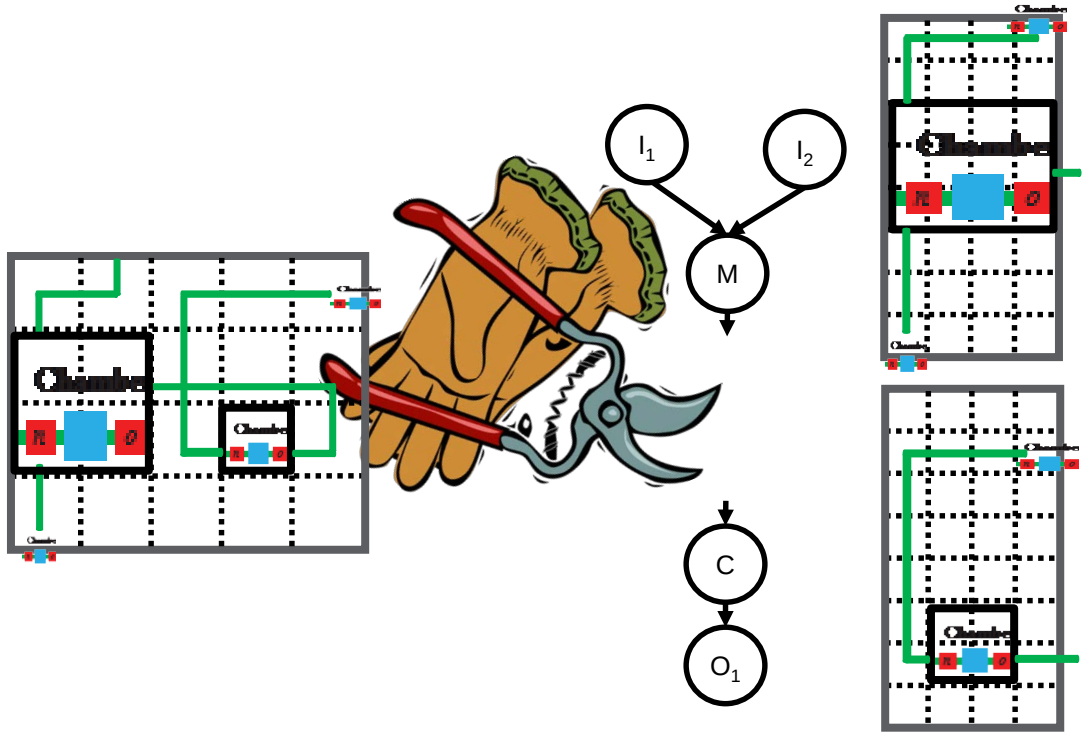
CONCLUSION

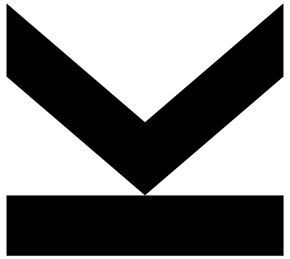
Satisfiability Solver



Search Space Pruning



CLOSE-TO-OPTIMAL PLACEMENT AND ROUTING FOR CONTINUOUS-FLOW MICROFLUIDIC BIOCHIPS



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