Droplet-Routing-Aware Module Placement for Cross-Referencing Biochips

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Outline

1. Background: Biochip & CAD
2. Problem Formulation & ILP Modeling
3. Experimental Result
4. Conclusion
Background – DMFB and CAD

- **Digital Microfluidic Biochip (DMFB)**
- **Droplet** – Carrier of biochemical reaction material

On-chip resources:
- Dispenser
- Waste reservoir
- Optical detector

Basic operations:
- Mixing
- Dilution
- Optical detection
- Storage

Top-down design flow [Su ICCAD'04]
Chip Spec:
Size
Dispensers
TIME Constraint...

Chip Specification, Assay Description

Placement Problem - Illustration

Time 0-2
Time 2-4
Time 4-6
Time 6-8
After Placement: Routing On Biochip

- Placement will greatly affect the routing:
  - Not a good placement result
  - Should coordinate during routing – downgrade to sequential
  - Also in the biochip routing….  
  - The chip type also affects the routing!
Cross-Referencing Biochip

In Cross-Referencing we apply a sequence of Voltage Assignment

(Cite from [Yuh DAC’08])

Special and hard problem:

- Routing several droplets simultaneously - Electrode Interference
Cross-Referencing Biochip - Block

- Issue of block (confirmed from DukeU)

If applied…

We assume extra-activated cell inside is fine. Still mixing inside

Cannot apply L to column 1~4

- Should be handled during routing.
Previous Work

- [Su DAC’05], [Su DATE’05], [Xu DAC’07], proposed methods based on *Simulated Annealing* (SA), using different representations. Fault-tolerance issue is also considered in their works.

- [Yuh JETC’07] proposed *T-tree based representations* to be used in SA.

- Note that none of them aimed on designing for *Cross-referencing DMFB*.


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Problem Formulation

- **Input:**
  - Scheduling and resource binding result
  - Chip specification:
    - Timing constraint $T$
    - Chip size $W \times H$
    - Optical Detectors
    - Reservoir, dispenser

- **Output:**
  - Placement result, including:
    - Location of modules, reservoir and dispenser
    - Nets
Overview of Our Approach

Chip Spec:
Size
Dispensers
TIME Constraint

Routing & Evaluation

Output

Pins

Pin Generation

Decide dispenser and reservoir location

ILP formulation

\[
M^i_x - M^j_x - X(M^j) + L(c_1 + c_2) > 1
\]

\[
M^j_x - M^i_x - X(M^i) + L(c_1 + 1 - c_2) > 1
\]

\[
M^i_y - M^j_y - Y(M^j) + L(1 - c_1 + c_2) > 1
\]

\[
M^j_y - M^i_y - Y(M^i) + L(2 - c_1 - c_2) > 1
\]
ILP Formulation of Placement

1. Validity constraint
2. Non-overlapping and separation constraint
3. Optical detector constraint
4. Reservoir constraint

- Core idea: how to utilize the properties of Cross-Referencing DMFB?
- Objective function:
  - Sum of extended covered area
1. Validity of modules

Should be inside chip, one space away from boundary (otherwise block reservoir!)
2. Non-overlapping and separation

Guarding ring can be SHARED

Modules cannot overlap if co-exist at some time
3. Optical detector resource constraint

Dt1, Dt2 bound to the same optical detector, should be at the same place!

Time=8~0
Minimize the sum of ECAs: rationale 1 – handles interference issue

- For multiple droplets: reduce the possibilities of interference between routes
ILP - Extended Covered Area (ECA) - cont.

Tries to minimize the overall moves in the whole assay

Rationale 2:

For a single droplet, also minimizes the time 6-8 Manhattan distance of route
Objective

4. Bounding box of routes and objective

Objective = sum of all these ECAs

Subproblem $i+1$
Partition of Problems

- Some benchmarks contain numerous subproblems
- If solve as one ILP
  - # variables: 2069
  - # constraints: 4154
- Split it into several sets
- Output of subproblem i serves as input of subproblem i+1

Example: splitting into two sets
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Experiment Setup

- Environment:
  - lp_solve 5.5
  - Intel 2.4GHz CPU
  - 1.5G Ram

- Four sets of real world benchmarks
  - In-vitro
  - In-vitro2
  - Protein
  - Protein2

- A droplet router for cross-referencing biochip is adapted and used to evaluate the placement result [Xiao ASPDAC’10].
# Experimental Result – Comparison

## Comparison of In-vitro

<table>
<thead>
<tr>
<th>Benchmark</th>
<th># sub*</th>
<th>Size</th>
<th>Routing on [Yuh J ETC’07]</th>
<th>Routing on our placement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max/ Avg. cycle</td>
<td>SSº</td>
</tr>
<tr>
<td>In-vitro</td>
<td>11</td>
<td>16x16</td>
<td>20/ 12.09</td>
<td>12</td>
</tr>
<tr>
<td>In-vitro2</td>
<td>15</td>
<td>14x14</td>
<td>19/ 10.73</td>
<td>23</td>
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<tr>
<td>Protein</td>
<td>64</td>
<td>21x21</td>
<td>20/ 15.52</td>
<td>38</td>
</tr>
<tr>
<td>Protein2</td>
<td>78</td>
<td>13x13</td>
<td>20/ 9.87</td>
<td>40</td>
</tr>
</tbody>
</table>

* #sub: number of subproblems in a benchmark.

o SS=Stalling Steps. Total number of stalling during routing.
Sample Placement Result (*In-Vitro1*)

Subproblem 1:

Subproblem 5:
Harder Case

- From Protein2, small chip size with many on-going modules and nets.

Subproblem 37: five modules, six nets
Conclusion

- An ILP-based routing-aware placement method is presented and evaluated.

- The properties of cross-referencing is beneficial to routing. The objective function is simple but effective, and should be explored MORE.

- To better compare the solution quality, harder bioassay/protocol is needed to perform the placement and routing (both results are 100% routable for the router)
-Thank You -