Simulated Annealing-based Placement for Microfluidic Large Scale Integration (mLSI) Chips

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Outline
Outline
Continuous Flow-Based Microfluidic Biochips

- Channels etched in a substrate control the flow of fluids through a chip
- Performs biology and chemistry experiments (assays)
- Automation and miniaturization benefits speed and accuracy of the assays
Applications

- Biochemical reactions and immunoassays
  - Clinical pathology
- Drug discovery and testing
  - Rapid assay prototyping
- Biochemical terror and hazard detection
- DNA extraction & sequencing
Microfluidic Large Scale Integration (mLSI) Overview

- The valve is the basic unit in Continuous Flow-based Microfluidic Biochips
- Valves can be combined to create more complex components
Microfluidic Large Scale Integration (mLSI) Overview
Outline
Simulated Annealing Based Placement

1. Initially place the components on the chip
2. Randomly move the components
3. Save the best placement so far based on the objective function
4. Accept worse solutions in hopes of climbing out of local minima

http://www.seas.upenn.edu/~andre/courses/C5294S97/notes/day15/day15.html
Outline
Grid Representation

<table>
<thead>
<tr>
<th>Invalid</th>
<th>Input</th>
<th>Invalid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>Center</td>
<td>Input</td>
</tr>
<tr>
<td>Invalid</td>
<td>Output</td>
<td>Invalid</td>
</tr>
</tbody>
</table>

- Grid is separated into regions
  - Input/Output
  - Center
  - Invalid
Regions prevent components from becoming:

- stuck in a corner
- unroutable by blocking ports
Outline
Homogeneous Component Sizes

- Components are initially all considered the same size
- Moves are simple
Heterogeneous Component Sizes

- Components have different sizes
- Moves become more complicated
I/O Padding

- Components are padded the same
I/O Padding

- Components are padded based on number of connections
Move Operations

Two move operations employed; shift and swap

1. Component \( C \) is chosen at random
2. Shift or move is chosen randomly
3. If a shift is chosen
   - A direction is chosen randomly
4. If a move is chosen
   - An end location is chosen randomly
Shift Operation

- If no components lie in the target location...
Shift Operation

- If no components lie in the target location... the shift proceeds.
Shift Operation

- If a component lies in the target location...
Shift Operation

- If a component lies in the target location...the shift is aborted.
Move (Swap) Operation

- If all components in the target region are fully contained within the region...
Move (Swap) Operation

- If all components in the target region are fully contained within the region...the move (swap) proceeds.
Move (Swap) Operation

- If a component lies partially in the target region...
Move (Swap) Operation

- If a component lies partially in the target region... the move (swap) is aborted.
Outline
Initial Placement

- The initial placement to the Simulated Annealing process must be a legal placement
- This placement is then improved iteratively throughout the process
- We propose two initial placement strategies; A random initial placement, and a directed initial placement
Random Initial Placement

1. Components are sorted from largest to smallest
   - This prevents chip becoming unplace-able due to fragmentation
2. Place the next component $C$ at a random location in the appropriate region
3. Process continues until all components are placed, or a component cannot be placed anywhere
Directed Initial Placement

1. Place the first input in the upper left position in the input region of the grid
Directed Initial Placement

1. Place the first input in the upper left position in the input region of the grid

2. Iterate over the list of outgoing edges for the component

3. Place the sink component of each edge nearby in an appropriate region
Directed Initial Placement

1. Place the first input in the upper left position in the input region of the grid
2. Iterate over the list of outgoing edges for the component
3. Place the sink component of each edge nearby in an appropriate region
4. Process continues...
Directed Initial Placement

1. Place the first input in the upper left position in the input region of the grid
2. Iterate over the list of outgoing edges for the component
3. Place the sink component of each edge nearby in an appropriate region
4. Process continues...until all components have been placed.
Outline
Objective Function

- Assesses the quality of the placement solution
- We considered three metrics
  1. Estimated intersections
  2. Total edge length
  3. Sum of squares of each edge length
Estimated Intersections

- Intersections estimation based on straight line from center points of components
Estimated Intersections

- Intersections estimation based on straight line from center points of components
- Additional intersections frequently require switches
- Switches complicate routing and increase I/O
Channel Lengths

- Total length and sum of squares of edges
- Reducing total length reduces chip cost and increases reliability
- Reducing sum of squares of edges more evenly distributes components on chip area
Results

The random initial placement with an even weighting of intersections ($\alpha$) and total channel length ($\beta$) works best.
Results Cont’d

The I/O padding increases the success rate while reducing the number of intersections and the overall channel length.
I/O Region segregation increases the success rate while reducing the number of intersections.
Outline
Summary

- Random initial placement
- Objective function uses intersections and total length evenly weighted
- I/O Padding and I/O region segregation is used
Conclusion

- We describe a Simulated Annealing placement algorithm in detail.
- We show how the changes in objective function, padding, and region segregation impact the success rate of routing.
- We provide the best selection of these metrics based on our experimentation.