System-Level Modeling and Synthesis Techniques for Flow-Based Microfluidic Large-Scale Integration Biochips

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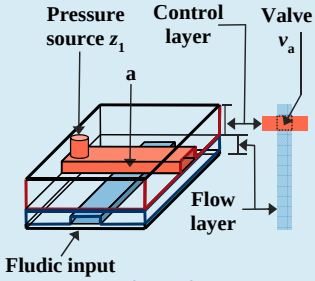
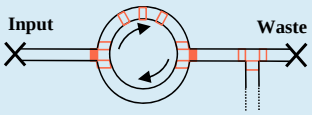
Microfluidic Biochips

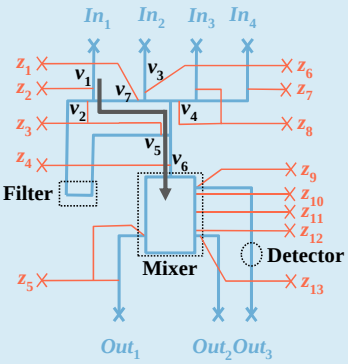
- *Biochips* are replacing conventional biochemical analyzers and are able to integrate on-chip the necessary functionalities for biochemical analysis using *microfluidics*.
- In *Flow-based biochips,* liquid samples of discrete volume flow in the on-chip channel circuitry.
- The *biochip* has two layers (fabricated using soft lithography): flow layer and control layer. The liquid samples are in the flow layer and are manipulated through microvalves in control layer.
- By combining these microvalves, more complex units like mixers, micropumps etc. can be built with hundreds of units being accommodated on a single chip. This approach is called microfluidic Large-Scale Integration (mLSI).



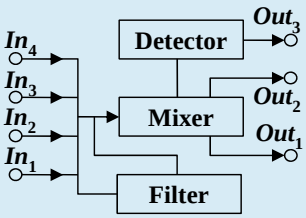
Microvalve



Microfluidic Mixer



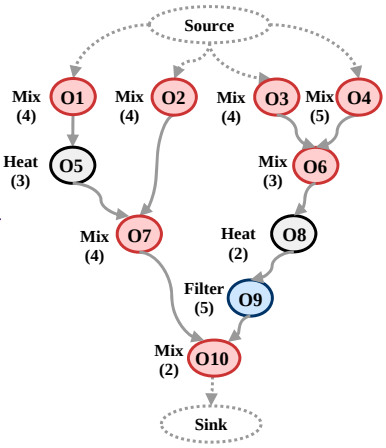
Biochip: Schematic View



Biochip: Functional View

Motivation and Objective

- Currently, biochip designers are using full-custom and bottom-up methodologies involving multiple manual steps for designing chips and executing experiments.
- With chip design complexity on the rise (technology scaling at rapid speed) and multiple assays being run concurrently on a single chip (commercial chip with 25,000 valves and about a million features running 9,216 polymerase chain reactions in parallel), bottom-up manual methodologies are fast becoming inadequate and would not scale for larger, more complex designs.
- *Objective:* Devise a system-level modeling and synthesis framework for flow-based biochips capable of handling larger, more complex designs.



Application Model

Contribution

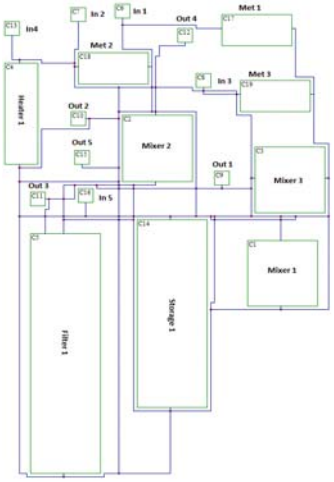
We propose a system-level top-down modeling and synthesis framework in order to synthesize the biochip architecture based on an application and to map the application onto the architecture while minimizing the application completion time and satisfying the constraints (e.g., resource, dependency).

System Model

- Application Model: Directed sequencing graph.
- Architecture Model: We have proposed a topology graph-based approach.

Architectural Synthesis: (Allocation, Placement and Routing)

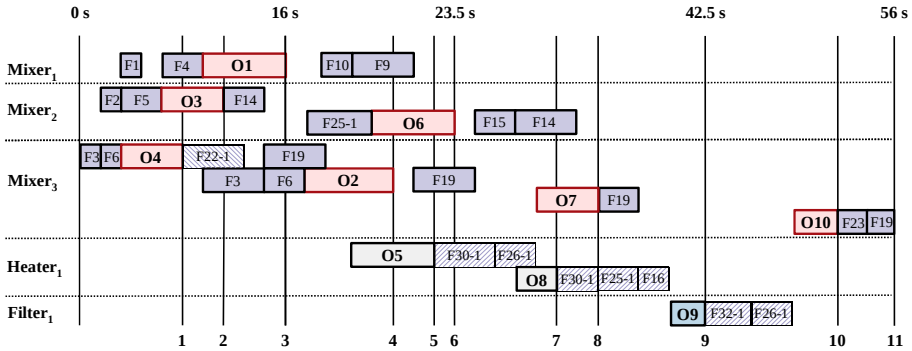
Starting from a given microfluidic component library and a desired application, our synthesis approach automatically synthesizes the biochip architecture aiming to minimize the application completion time.



Architectural Synthesis

Application Mapping: (Binding, Scheduling and Fluid Routing)

- List Scheduling-based binding and scheduling heuristic utilized (we have also proposed a constraint programming based approach for finding the optimal solution).
- Since routing latencies are comparable to operation execution times, thus fluid routing (contention aware edge scheduling) is also taken into account (boxes with labels Fx in figure below) along with the operation scheduling (boxes with labels Ox).
- As an output, we generate the control sequence for a *biochip* controller for auto executing the application on the specified *biochip.*



The proposed framework is targeted at facilitating programmability and automation. It is expected to enable designers to auto-generate chip architecture and to take early design decisions by being able to evaluate their own proposed architecture, minimizing the design cycle time.

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