Coordinating Multiple Droplets in Digital Microfluidic Systems

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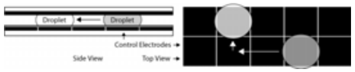
Digital Microfluidic Systems (DMFS)

Digital microfluidics: Manipulate discrete droplets

Goal: Creating miniature, versatile, biochemical laboratory on a microchip ("lab on a chip")

Advantages: Reprogrammable and reconfigurable, can process biochemical analyses in parallel



Planar array DMFS

Droplet operations: input, output, move, mix, split

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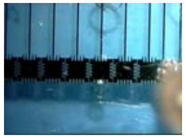
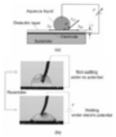
Electrowetting

- Droplet dispensing and moving (Pollack, Fair, Shenderov, 2000)





- Droplet volume: nanoliter-microliter
- Droplet speed: 12-25 cm/sec
- Electrode size: 0.5-1.5 mm length

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Overview of Approach

Goal: Create a general purpose reprogrammable DMFS

Design: Generate array layout semi-automatically using modular components

Routing: Simple algorithms to route droplets to perform different operations

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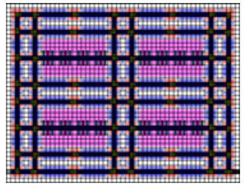
Array Layout Design

Design array layout using a set of modular 'virtual components' so it is usable for many analyses, sequentially or in parallel



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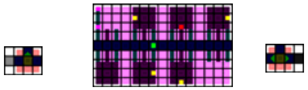
Functional Components

There are three components dedicated to performing 'useful' operations: the source, the sink, and the work area



source work area sink

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Transport Components

•There are three transport components: the street, the connector, and the intersection

•They are responsible for getting the droplets to where they need to go

street intersection connector

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Droplet Routing

•Must route droplets to components to perform necessary operations

•We employ a deflection routing variant of the Open Shortest Path First (OSPF) network routing algorithm

•Each intersection constructs a graph of network and runs Dijkstra's shortest paths algorithm on it. It then stores routing table with its shortest path information.

•Deflection routing: If shortest path exit is blocked, intersection selects another exit

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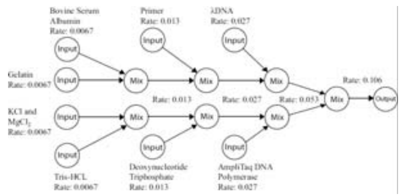
DNA Polymerase Chain Reaction (PCR)



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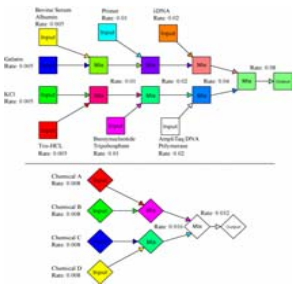
Multiple Parallel Reactions

Can perform multiple reactions in parallel



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Limited Row-Column Addressing

•Individual cells of array are not directly addressable

•Only entire rows or columns can be activated, and only electrodes at intersections of activated rows and columns will be turned on

•Simplifies hardware, but complicates droplet control

•Fan, Hashi, and Kim 2003; Bohringer 2004

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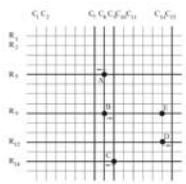
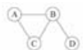
Example





- Cannot simultaneously move droplets A, B, and C
- Cannot simultaneously move droplets B and D

- Developed graph coloring algorithm for coordination

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Summary

•An approach for general purpose DMFS

•Array layout design based on modular components in a tile pattern

•Coordinated motion of droplets achieved using routing algorithms

•Can run multiple reactions in parallel

•Can perform row-column addressing

•Animations: www.cs.rpi.edu/~sakella/microfluidics

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