Routing-Based Synthesis of Digital Microfluidic Biochips

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Technical University of Denmark
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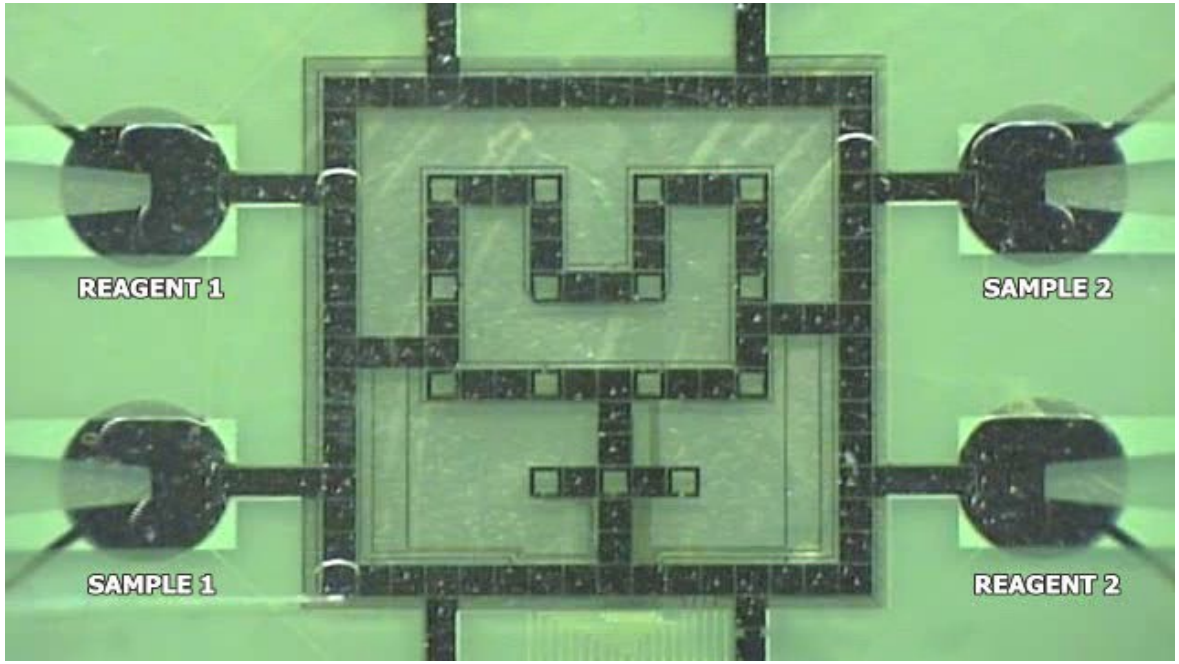
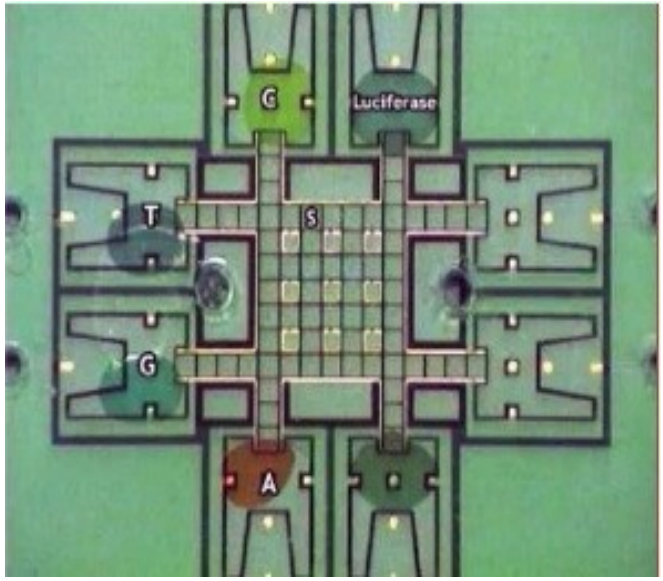
Digital Microfluidic Biochip



Biochip created at Duke University

Microfluidic Biochips

- Applications
  - Sampling and real time testing of air/water for biochemical toxins
  - Detection of adverse atmospheric conditions
  - DNA analysis and sequencing
  - Clinical diagnosis
  - Point of care devices



- Types:
  - Continuous flow microfluidic biochips
  - Digital microfluidic biochips

Microfluidic Biochips

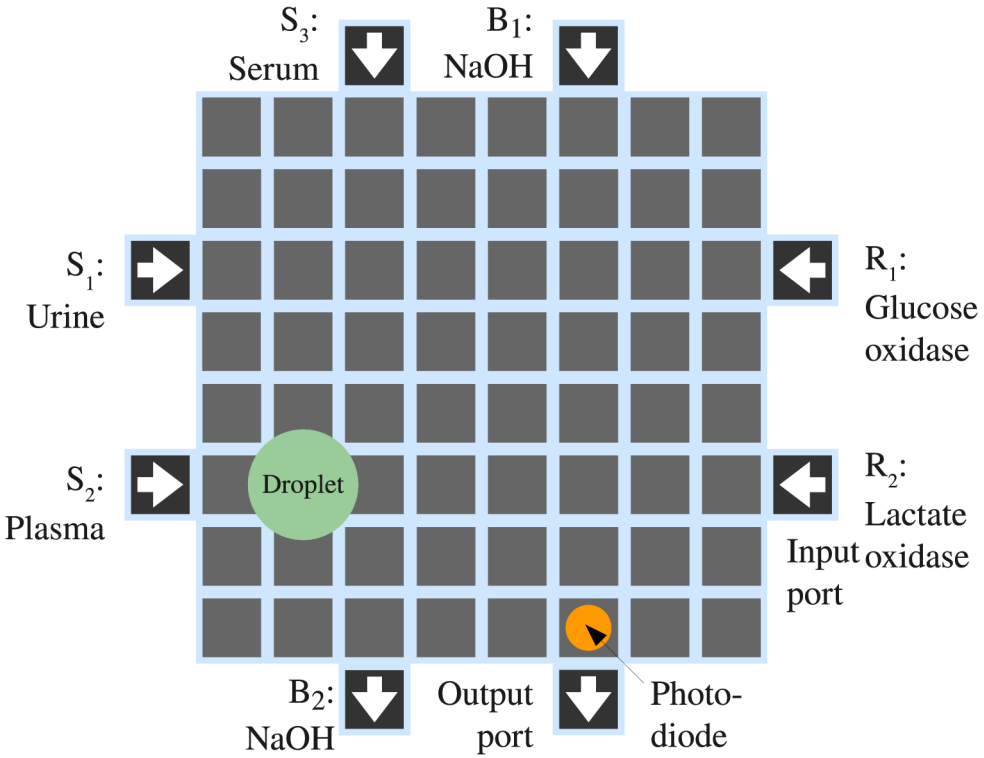
- Advantages:
  - High throughput (reduced sample / reagent consumption)
  - Space (miniaturization)
  - Time (parallelism)
  - Automation (minimal human intervention)

Outline

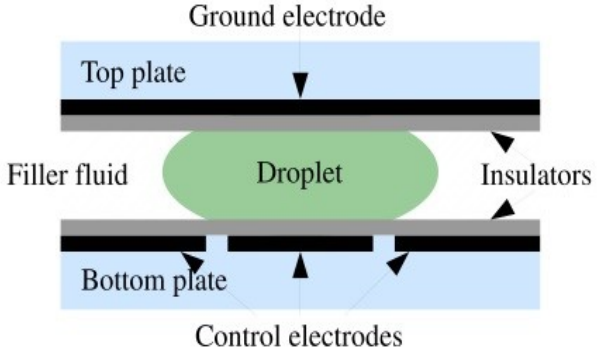
- Motivation
- Architecture
- Typical Design Tasks
- Problem Formulation
- Proposed Solution
  - GRASP-Based Synthesis
- Experimental Evaluation
- Conclusions

Architecture and Working Principles

Biochip architecture



Cell architecture



- Electrowetting-on-dielectric
- Operations:
  - Dispensing
  - Transport
  - Mixing
  - Dilution

Architecture and Working Principles

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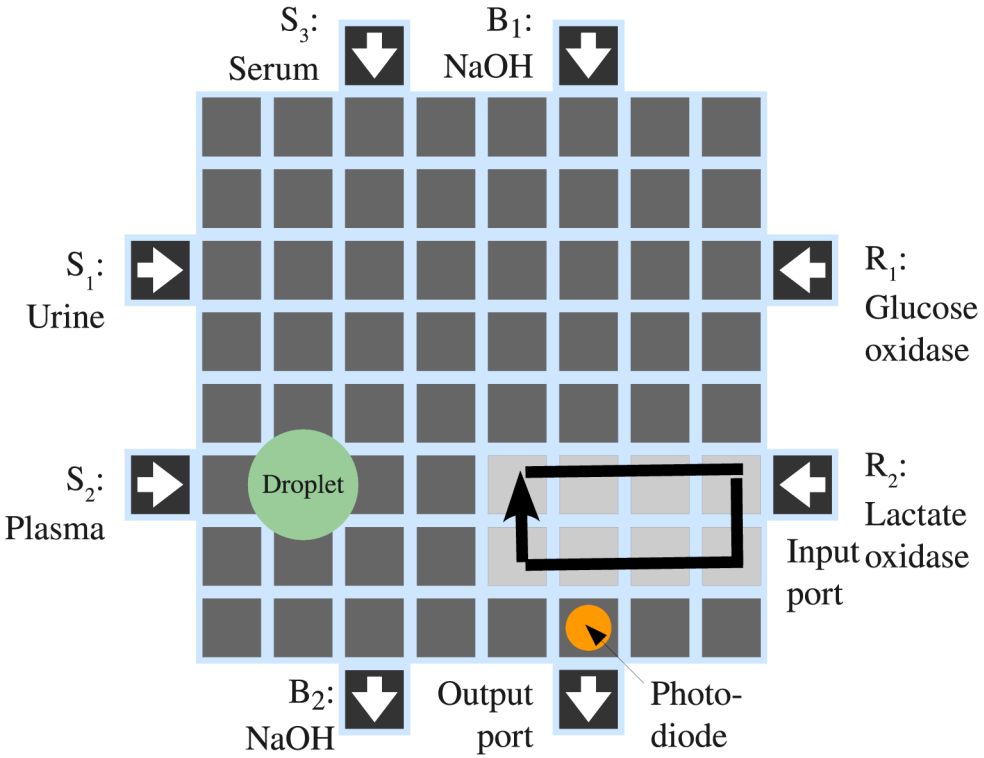

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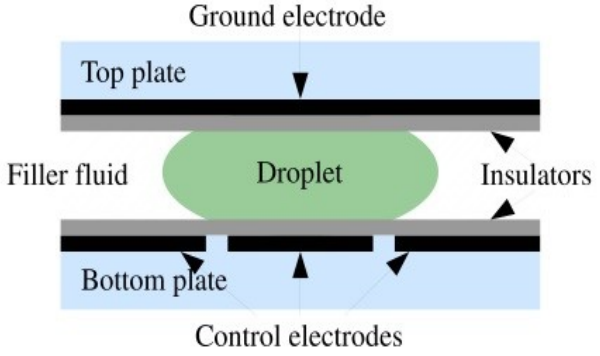

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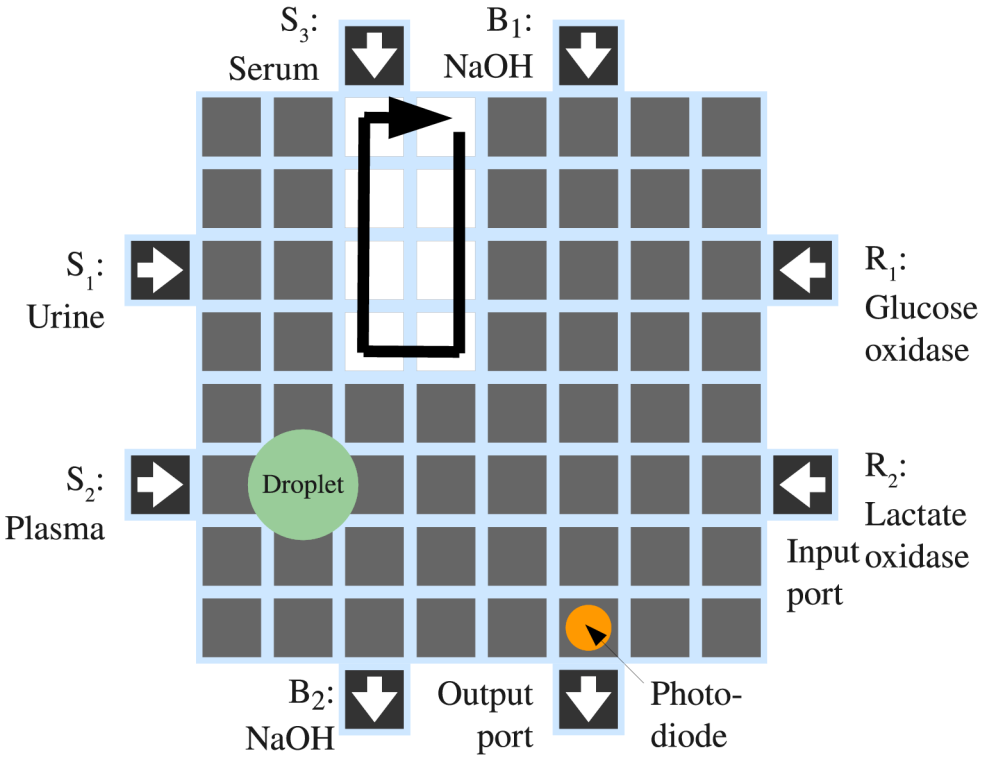

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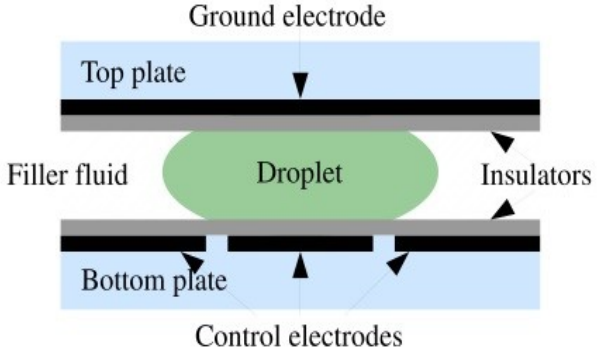

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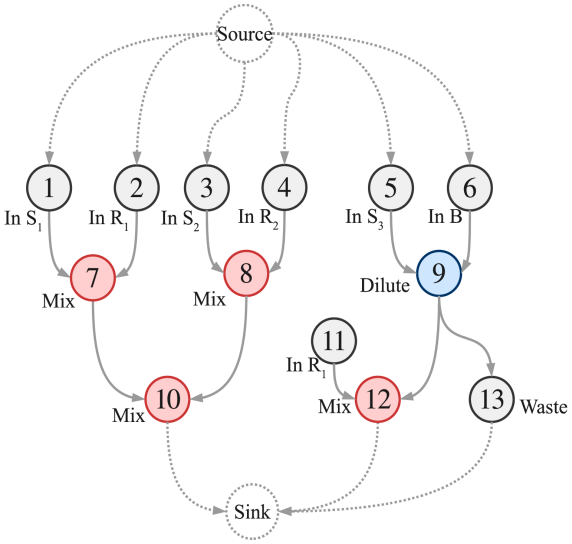
Module-Based Design Tasks



Operation	Area(cells)	Time(s)
Mix/Dlt	2x4	2.8
Mix/Dlt	1x4	4.6
Mix/Dlt	2x3	5.6
Mix/Dlt	2x2	9.96

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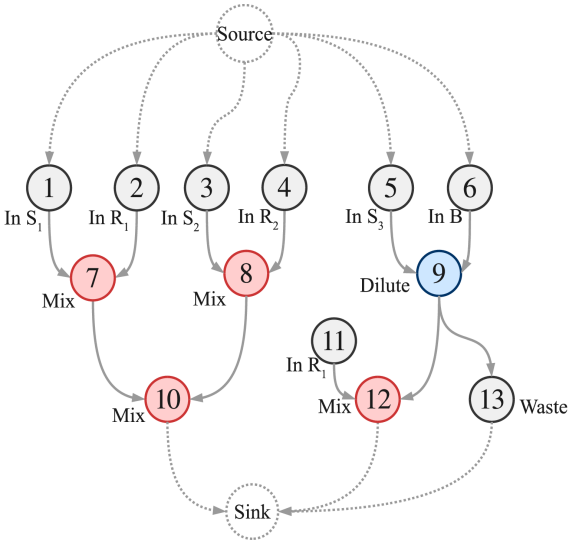

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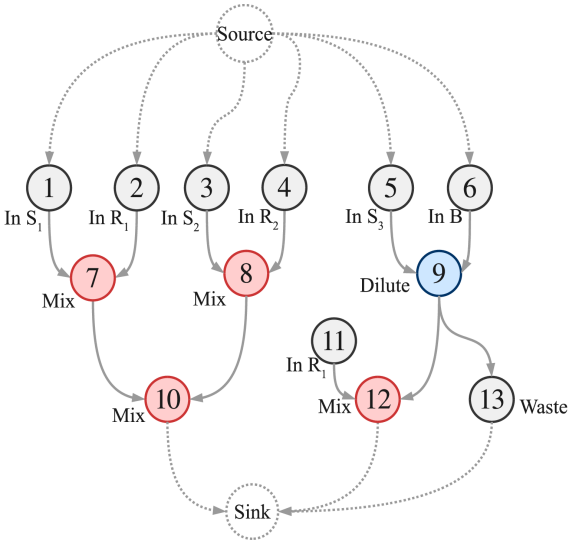

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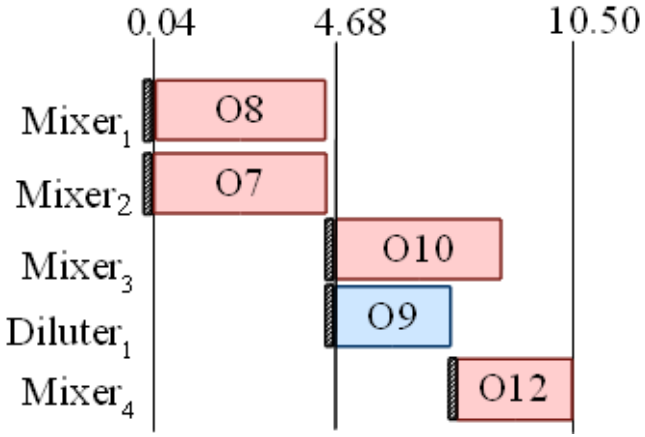

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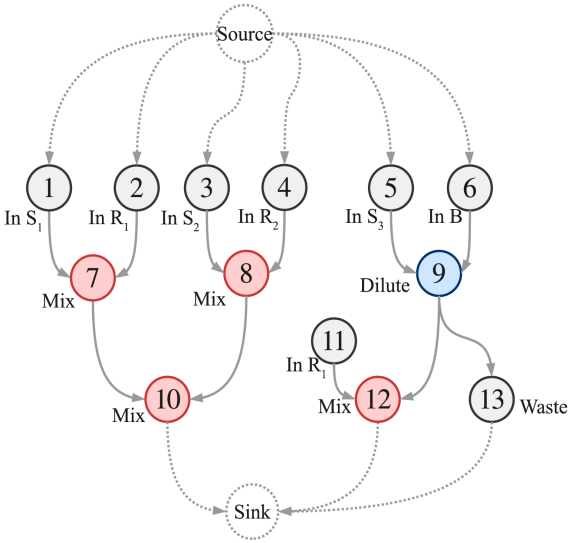

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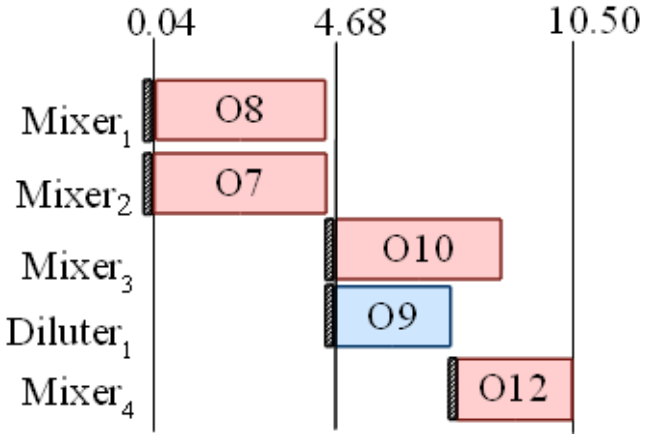
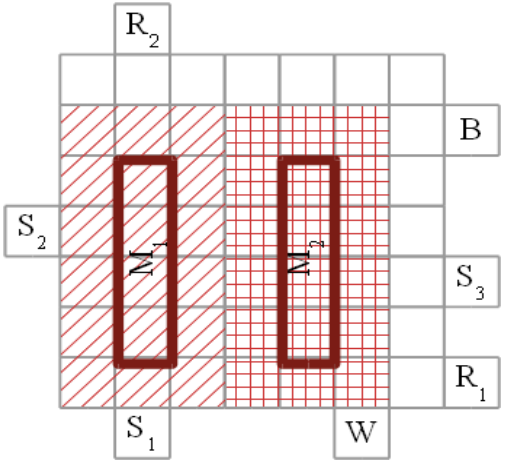
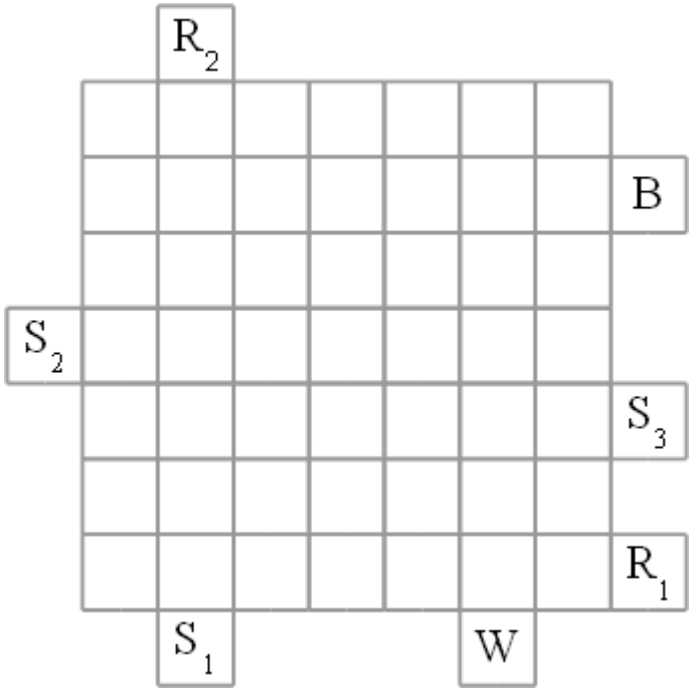
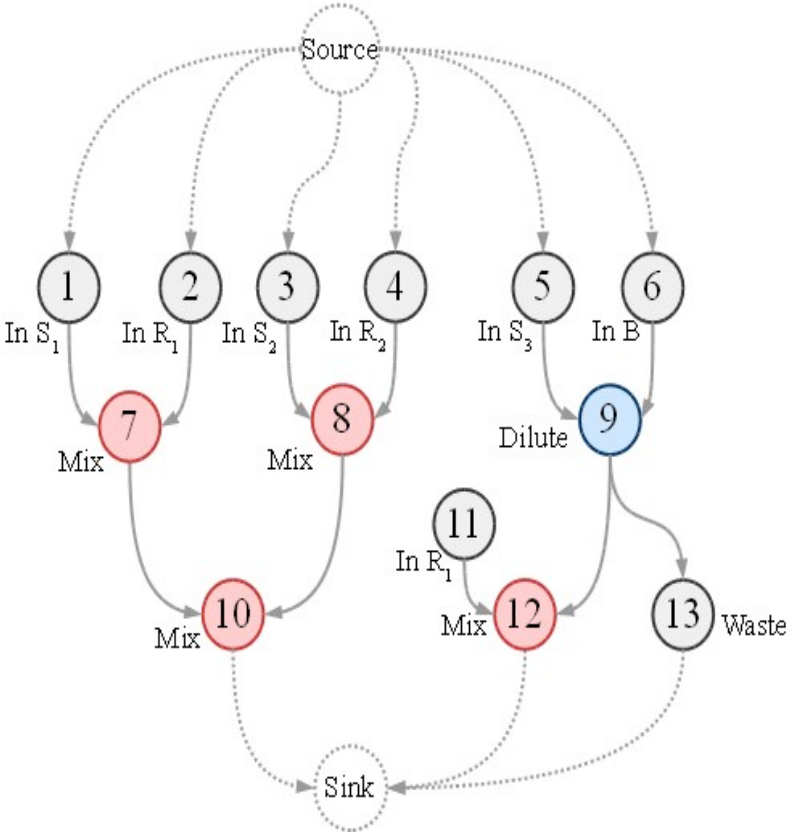


Placement & Routing



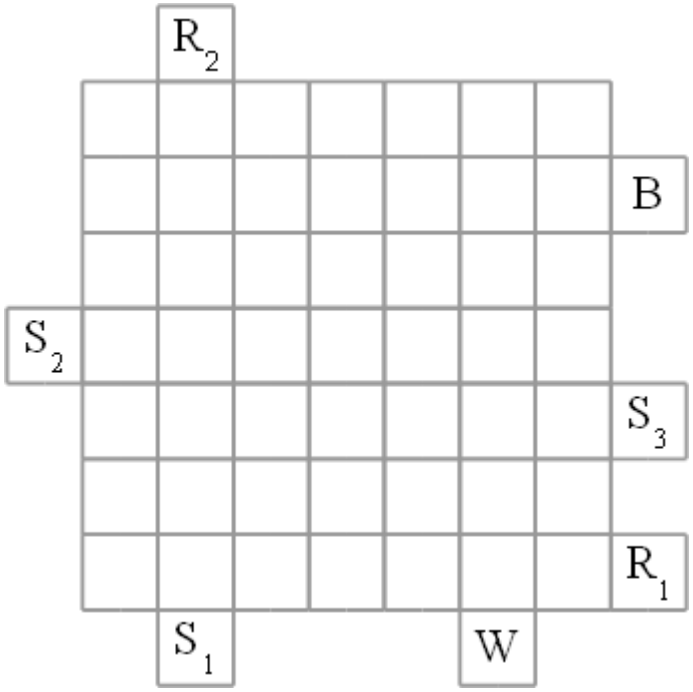
Module-Based Synthesis

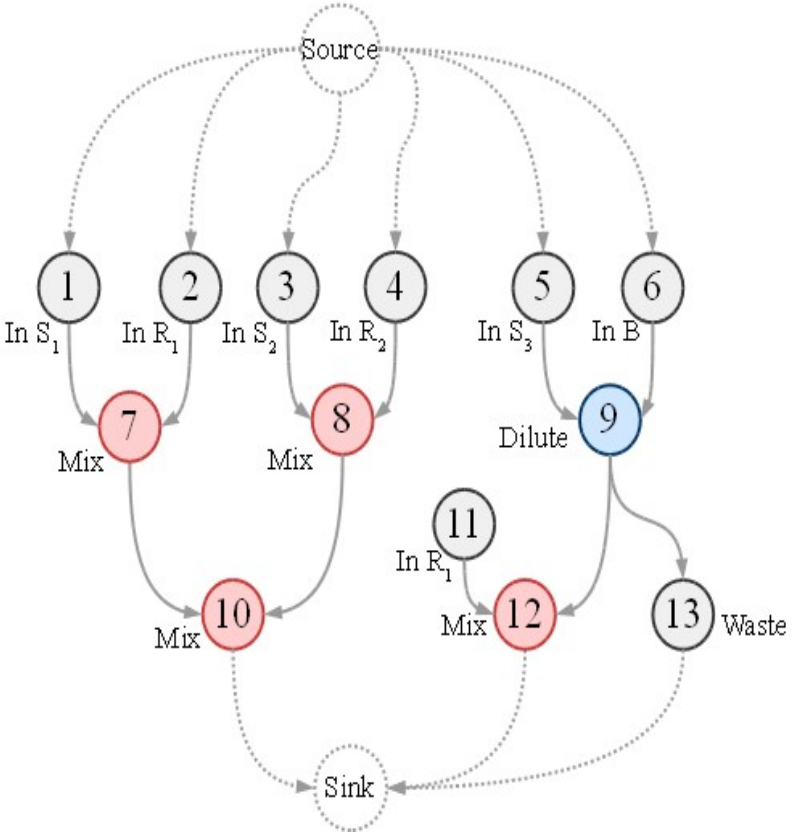




Module-Based Synthesis

O7
O8
O9





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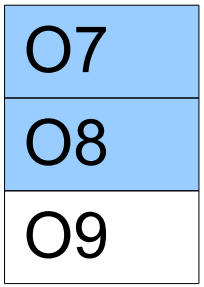
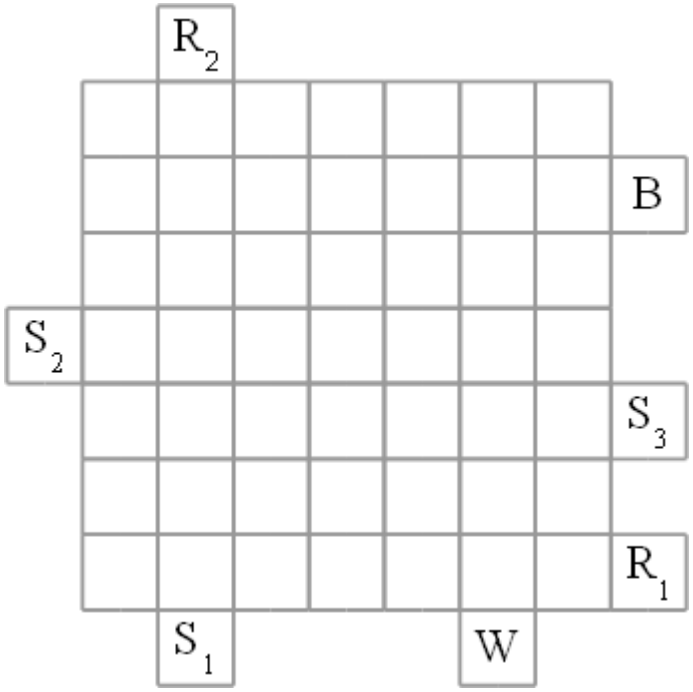
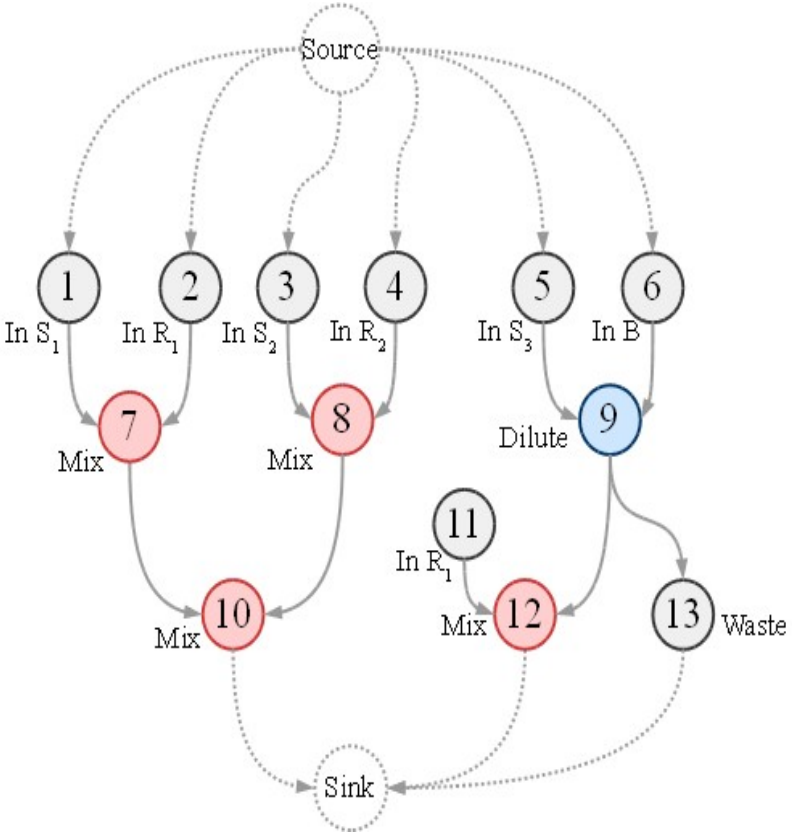
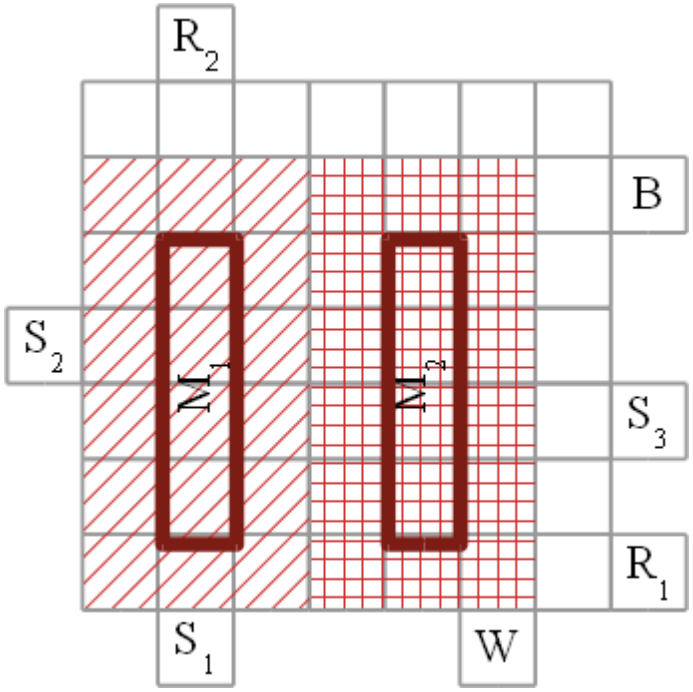


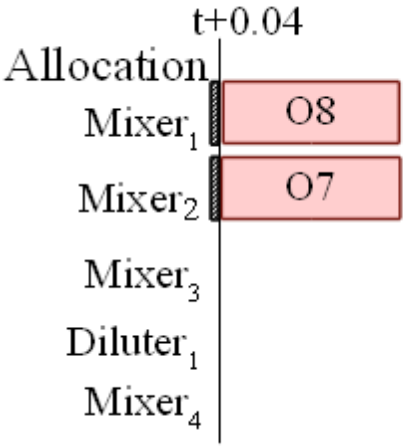




Module-Based Synthesis

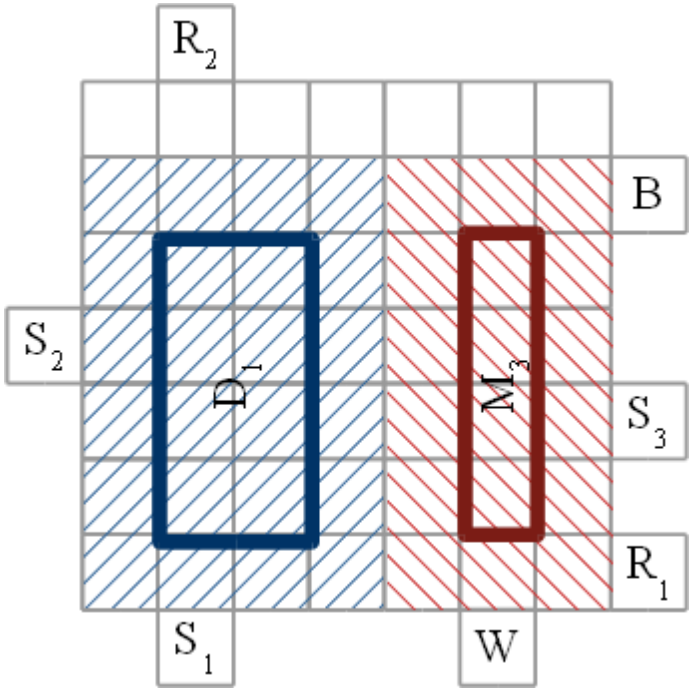
O7	1x4
O8	1x4

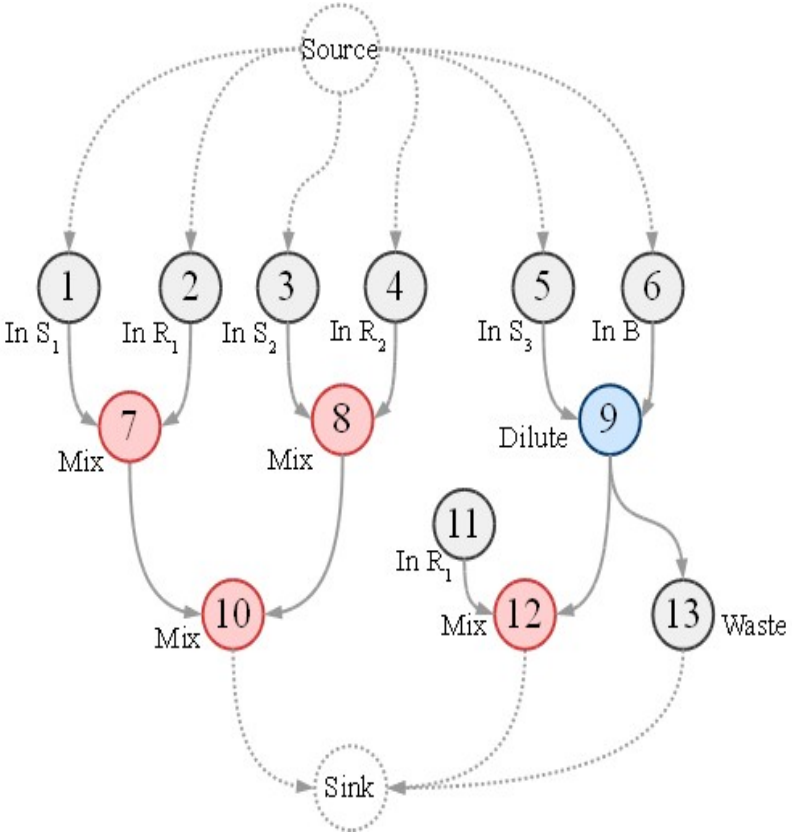




Module-Based Synthesis

O9	2x4
O10	1x4





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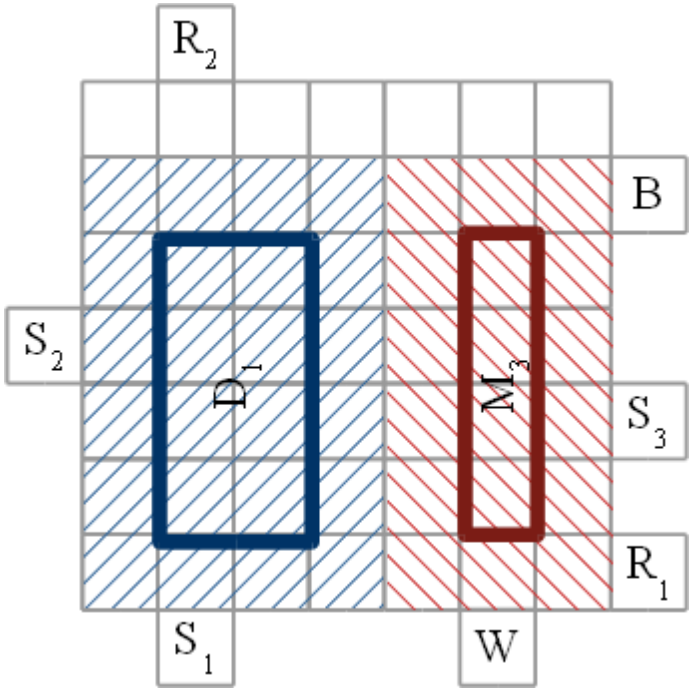

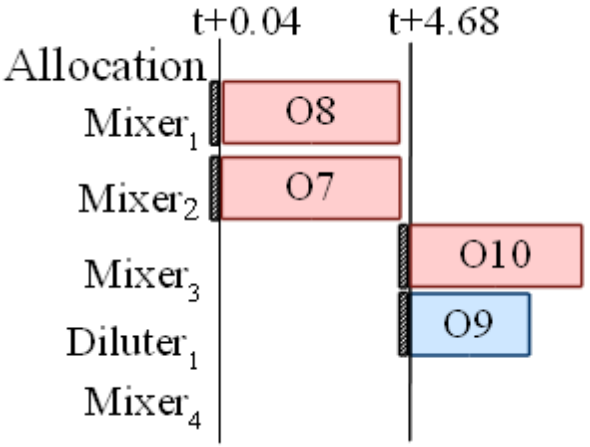

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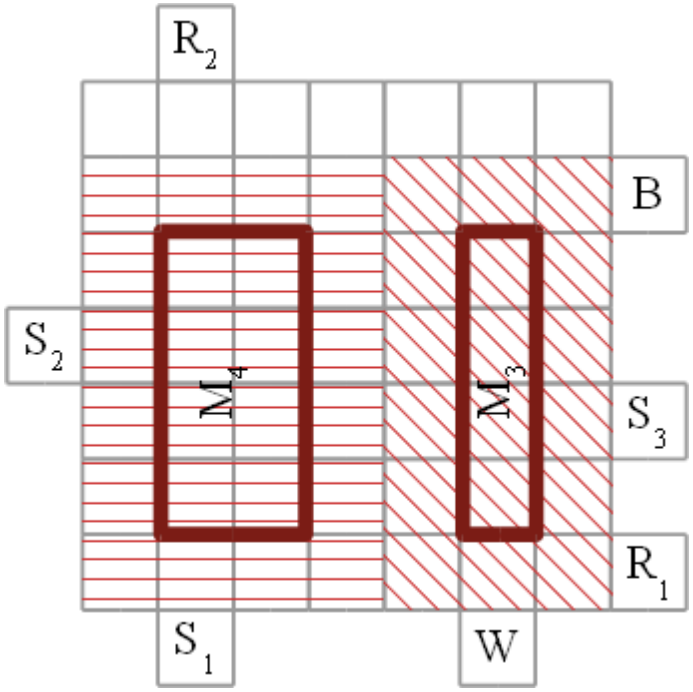
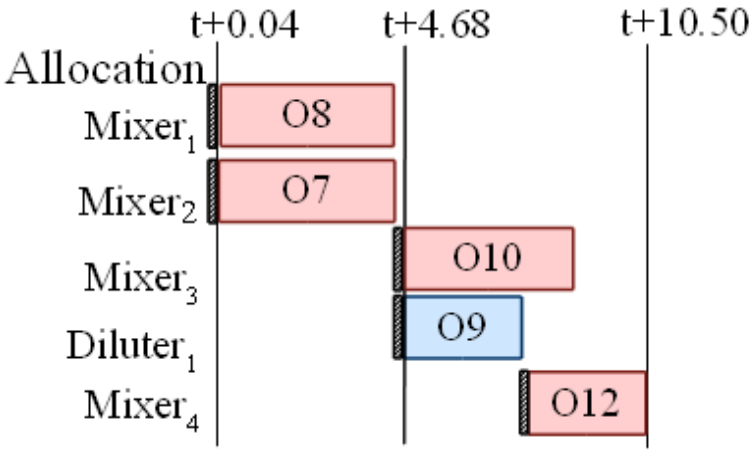
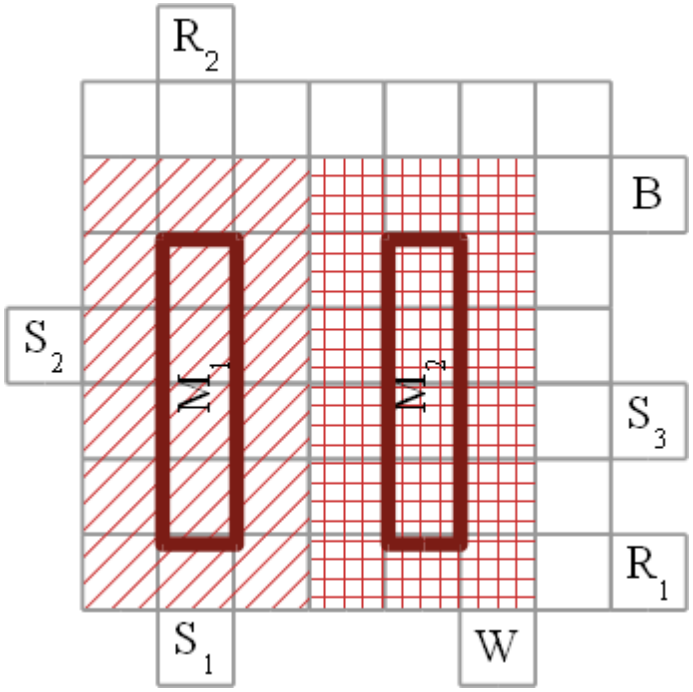
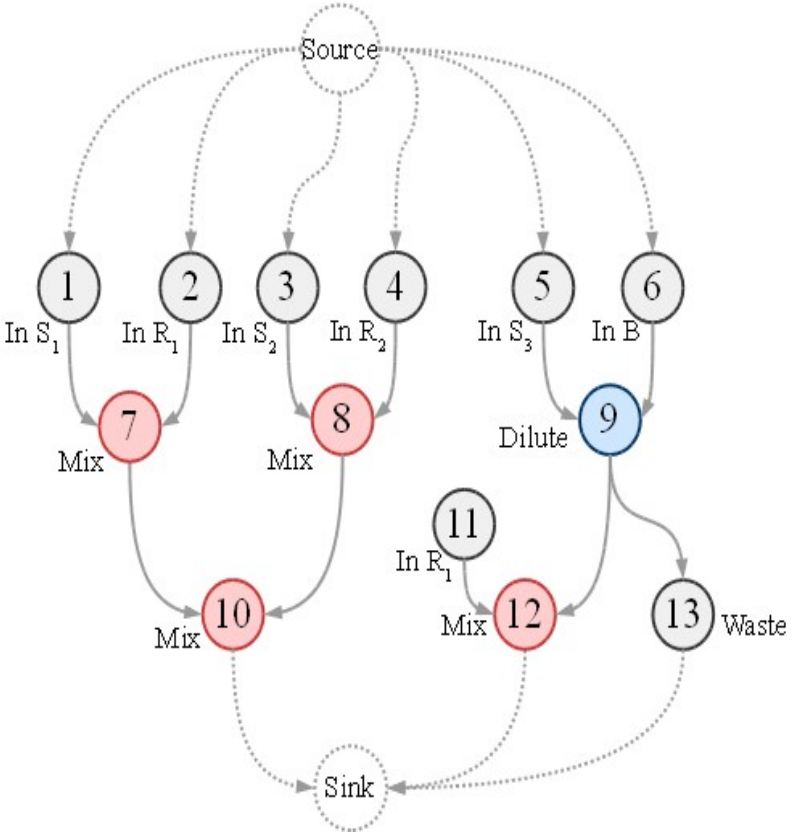




Reconfigurability





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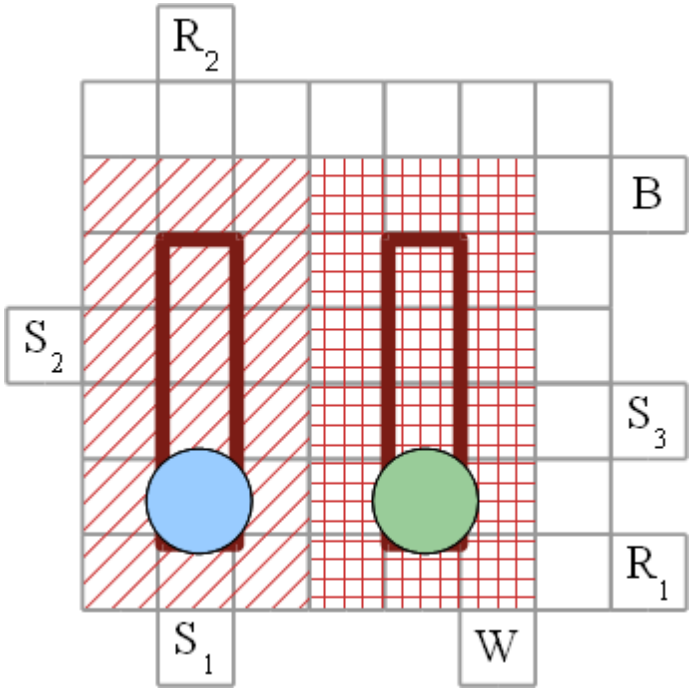

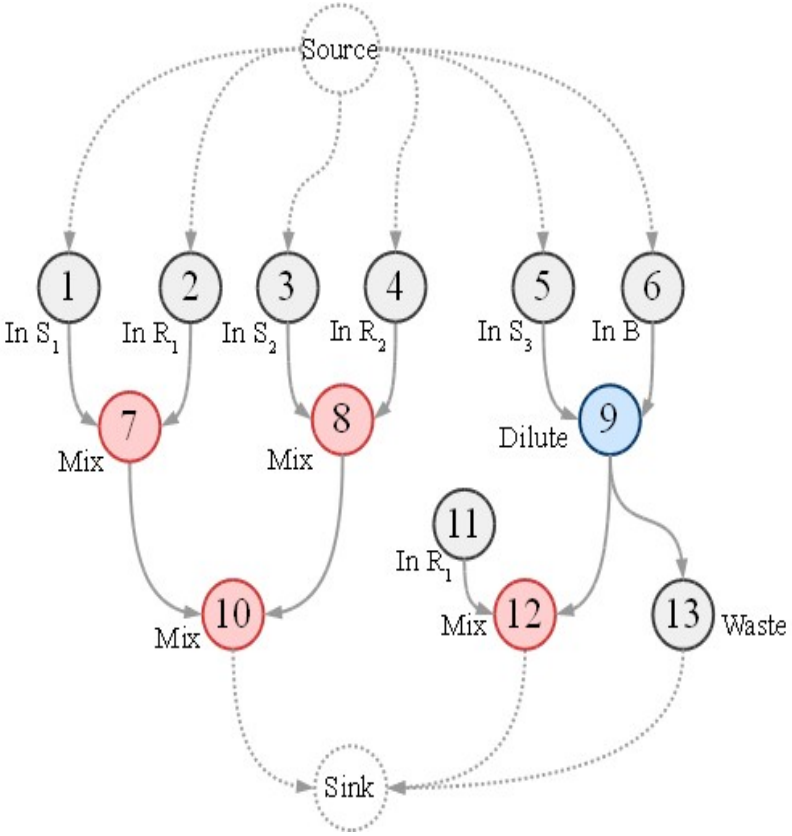

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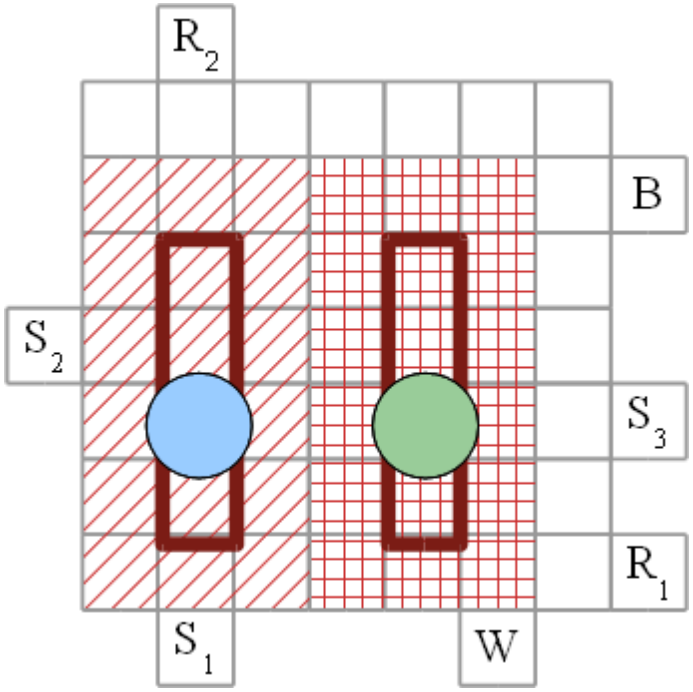

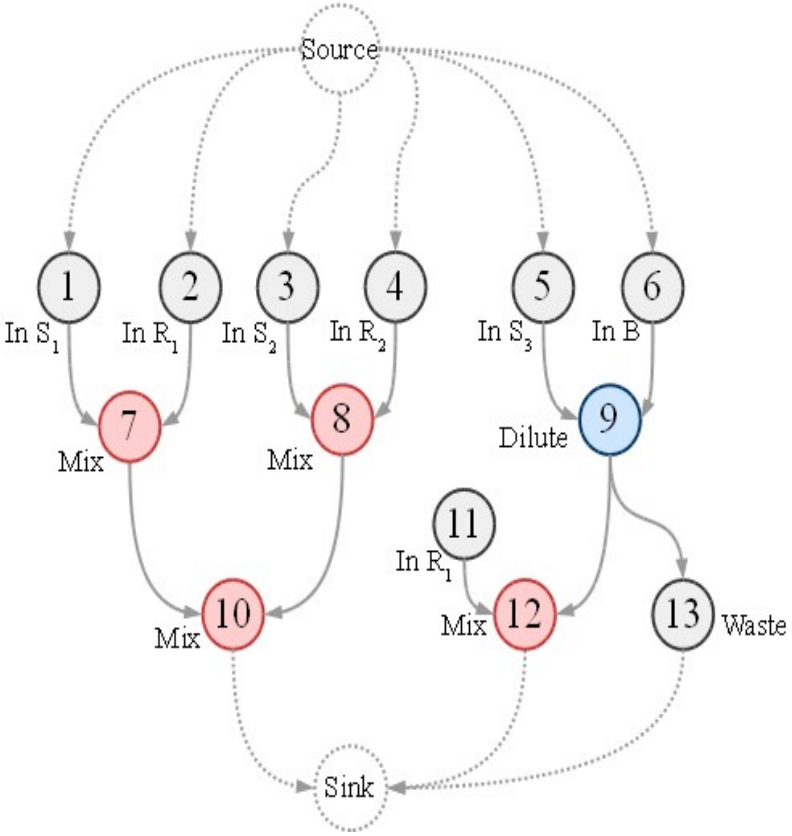

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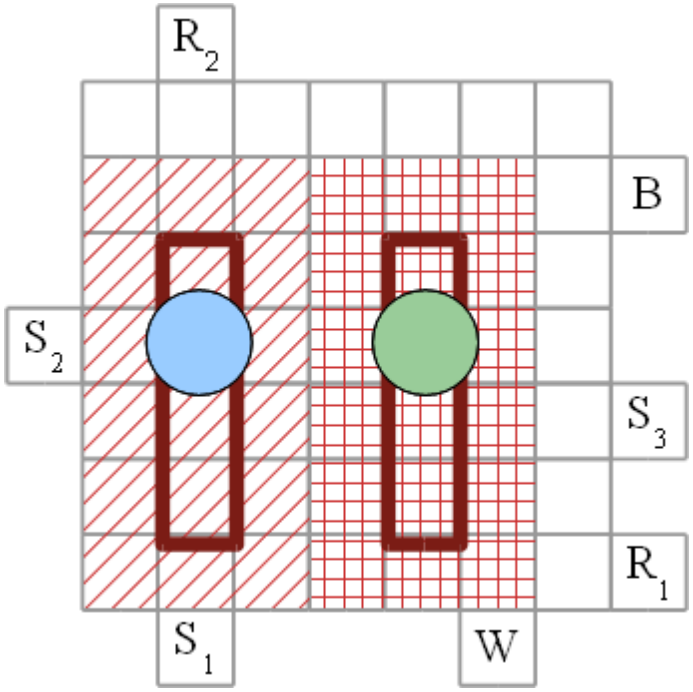

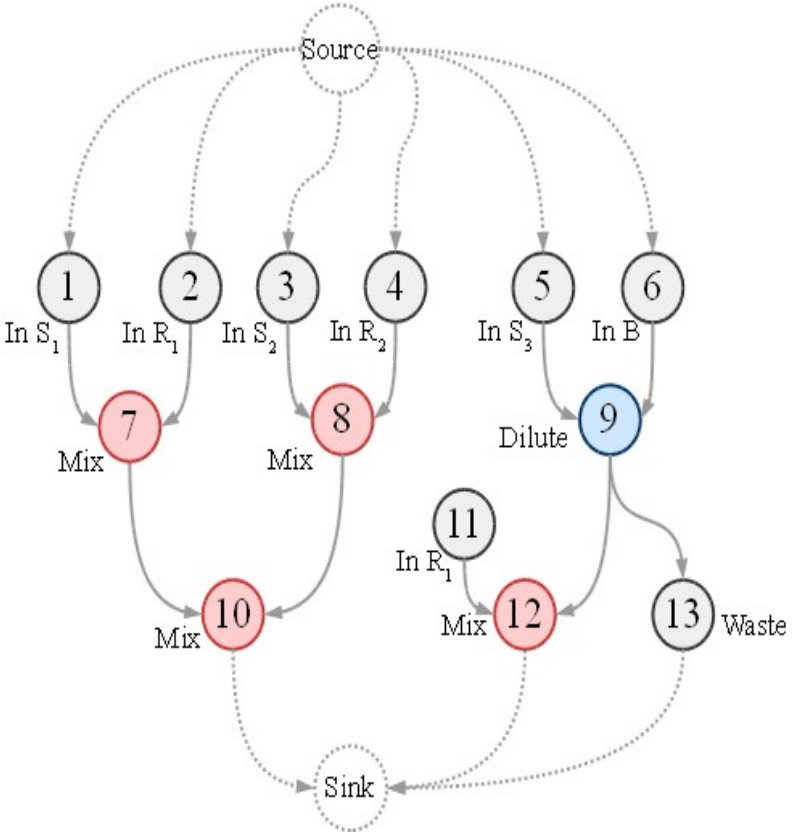

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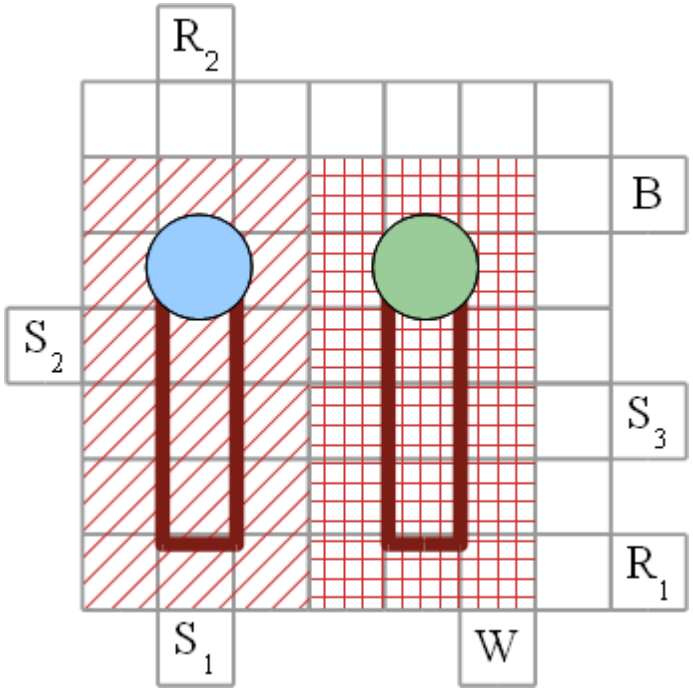

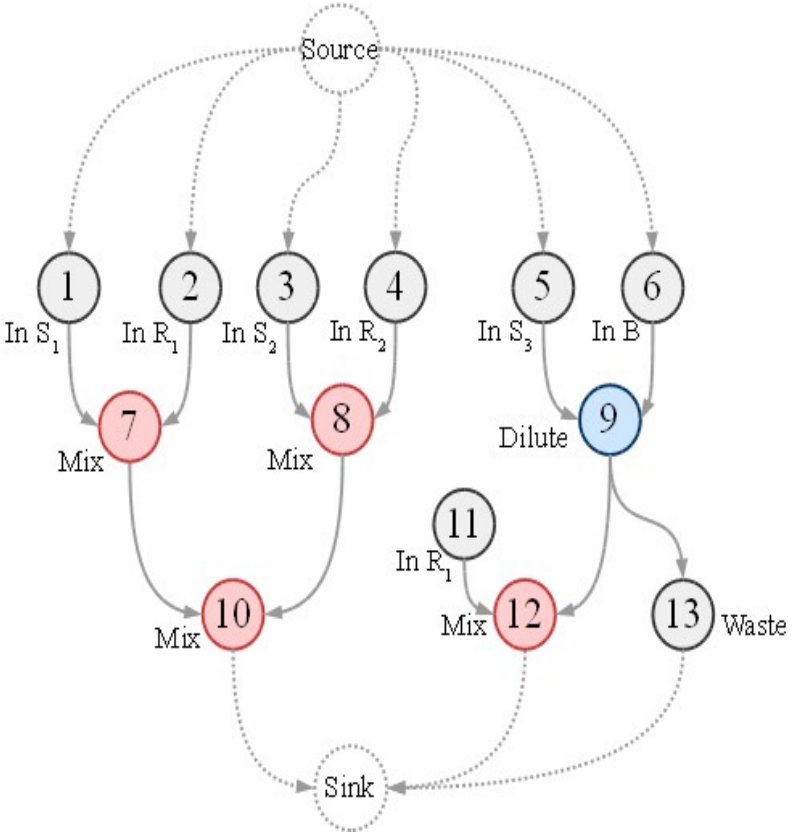

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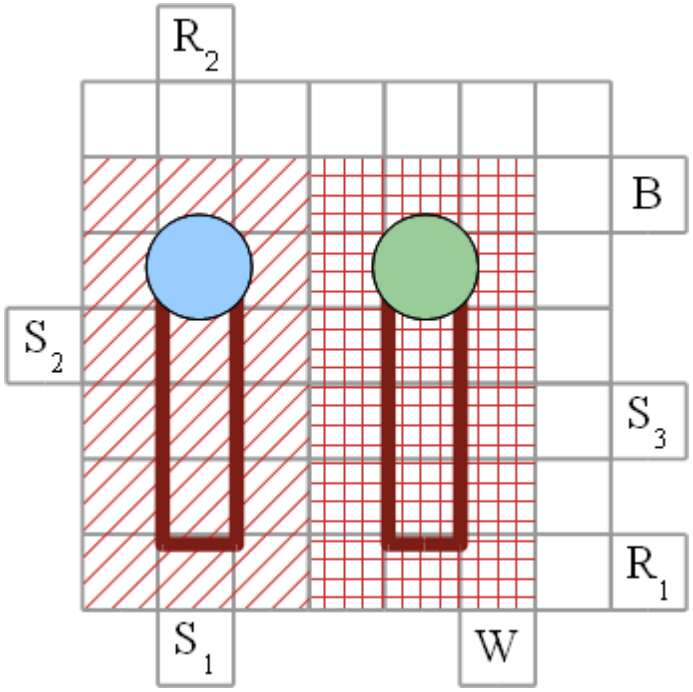

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  - Pessimistic segregation area
  - Routing performed post-synthesis

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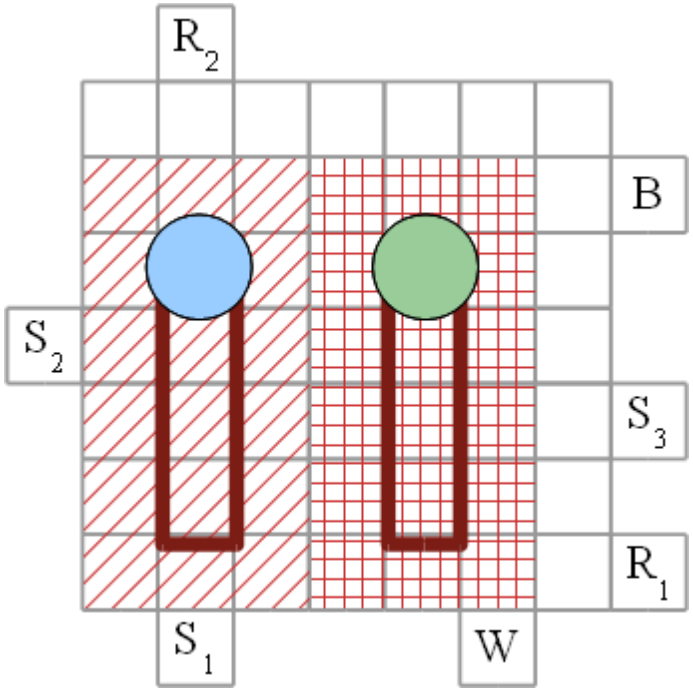

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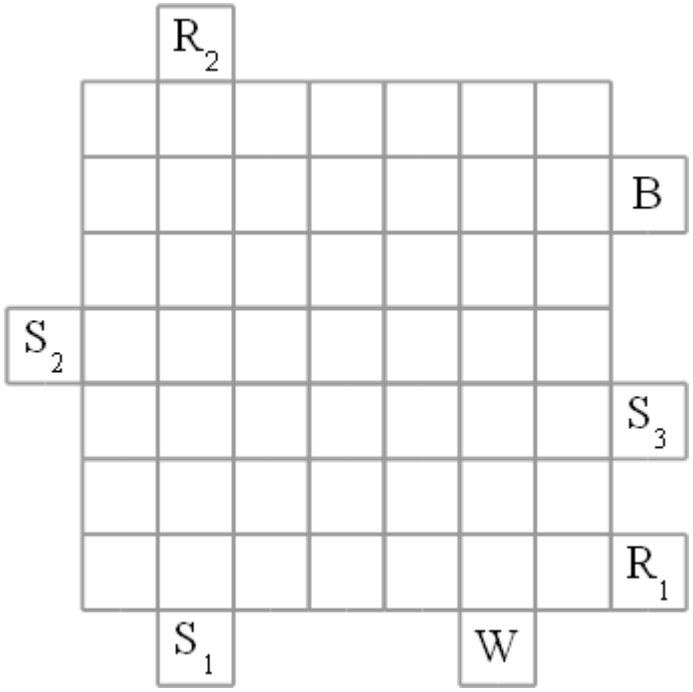
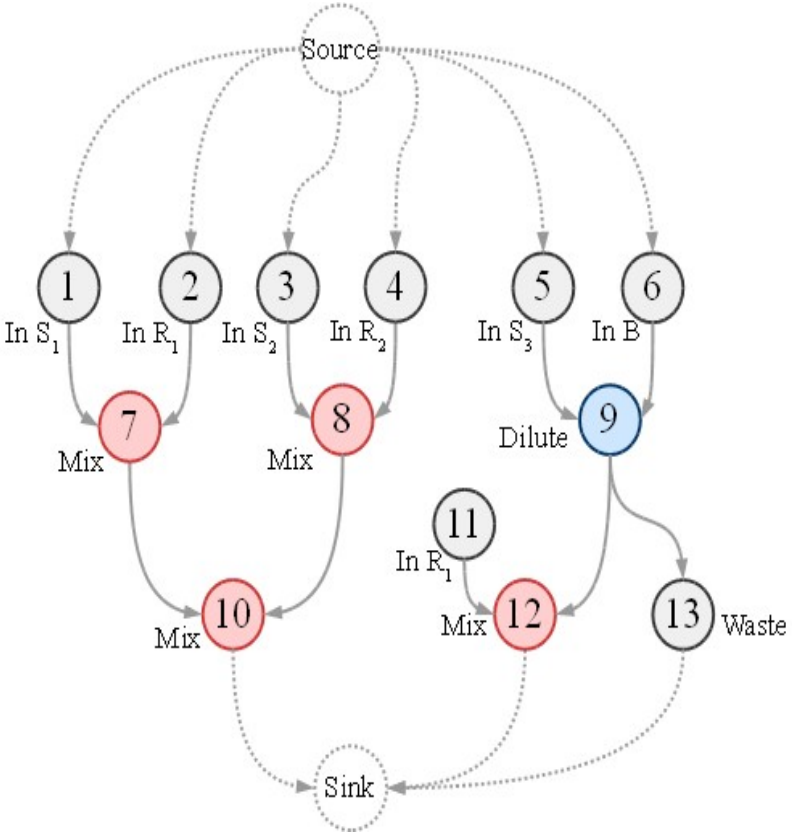
Eliminate the concept of modules: Routing-based synthesis

Droplet-Based Synthesis





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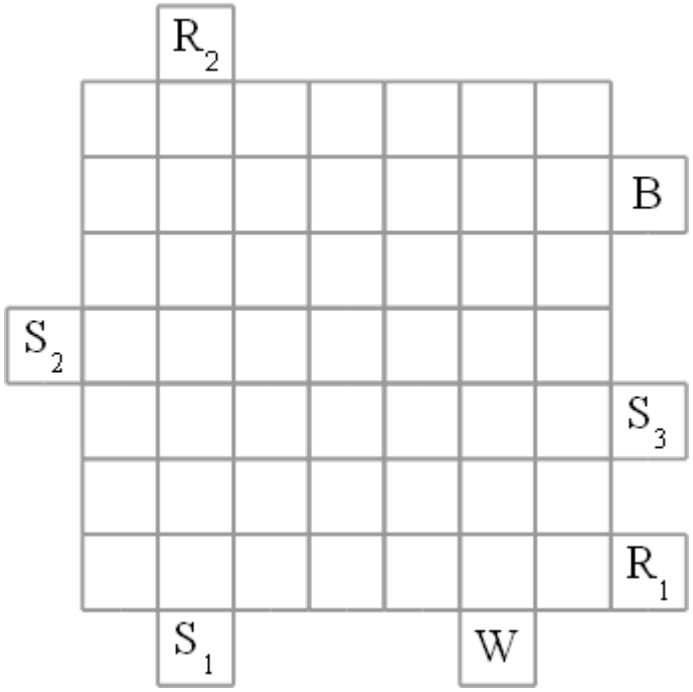
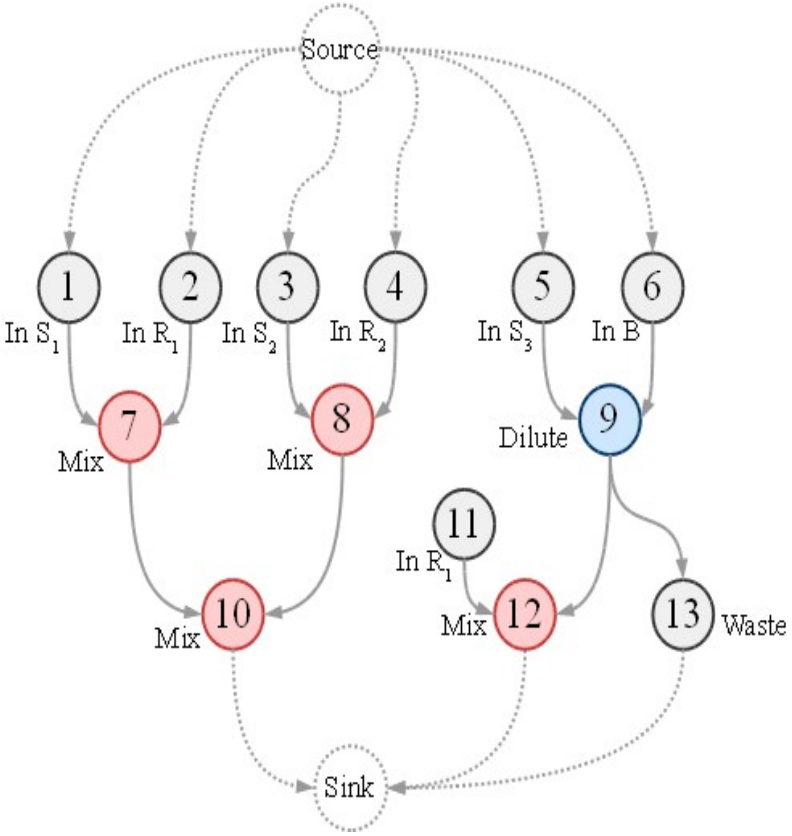
O7
O8
O9





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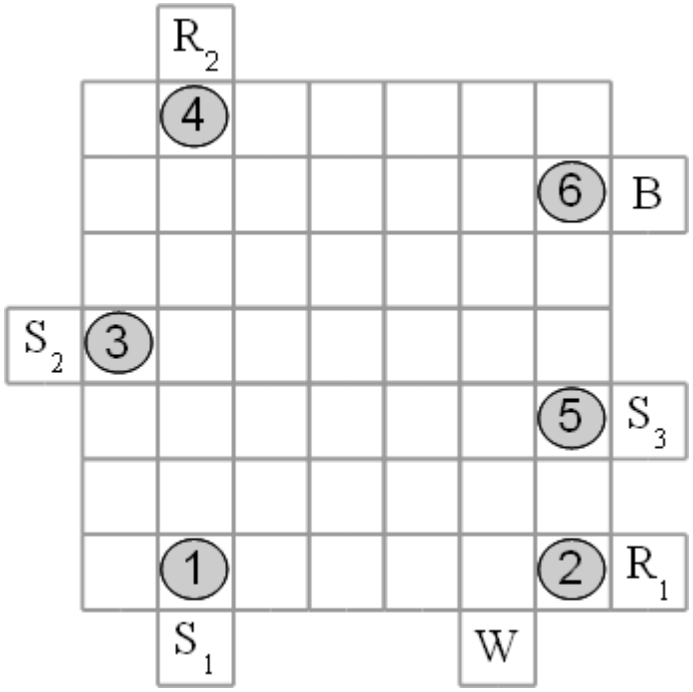

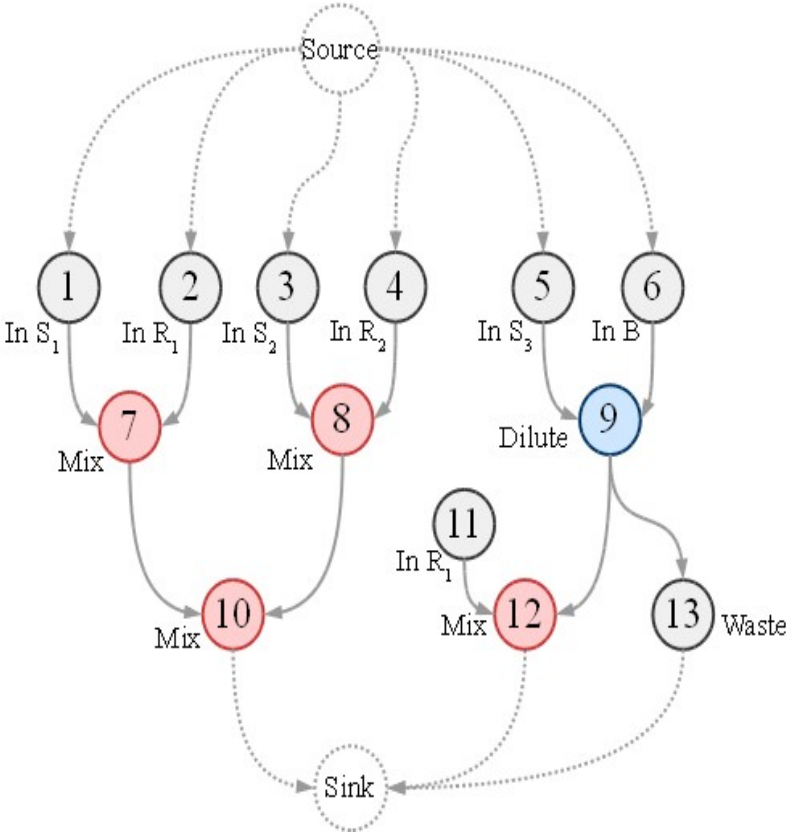

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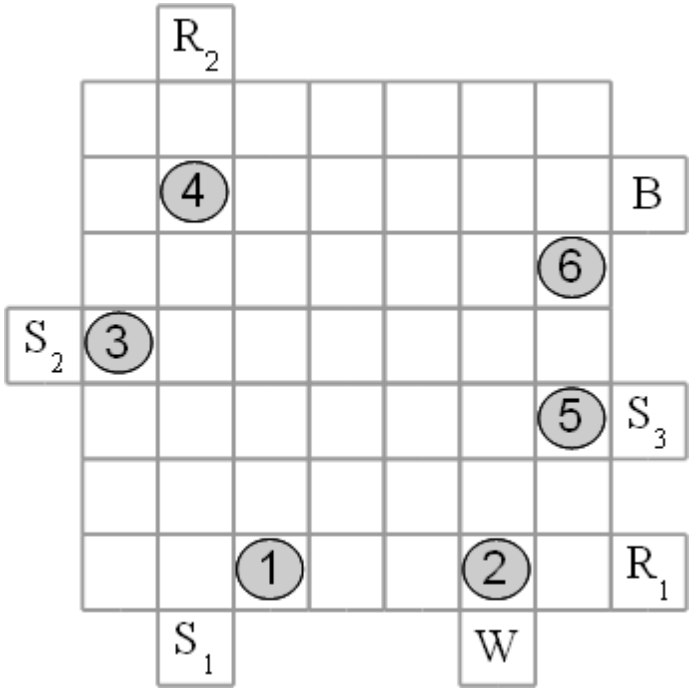

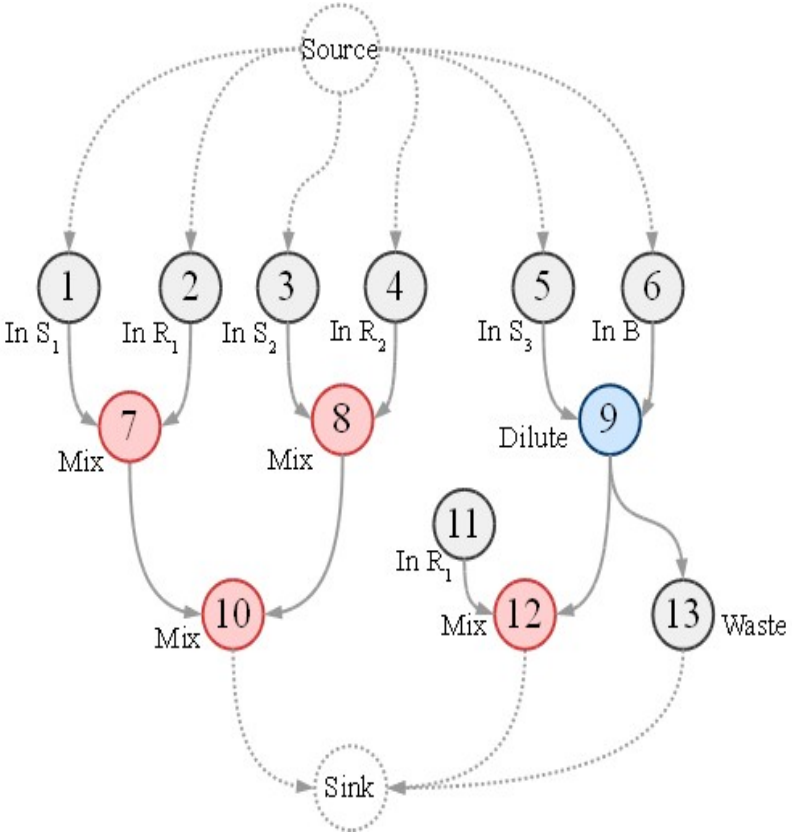

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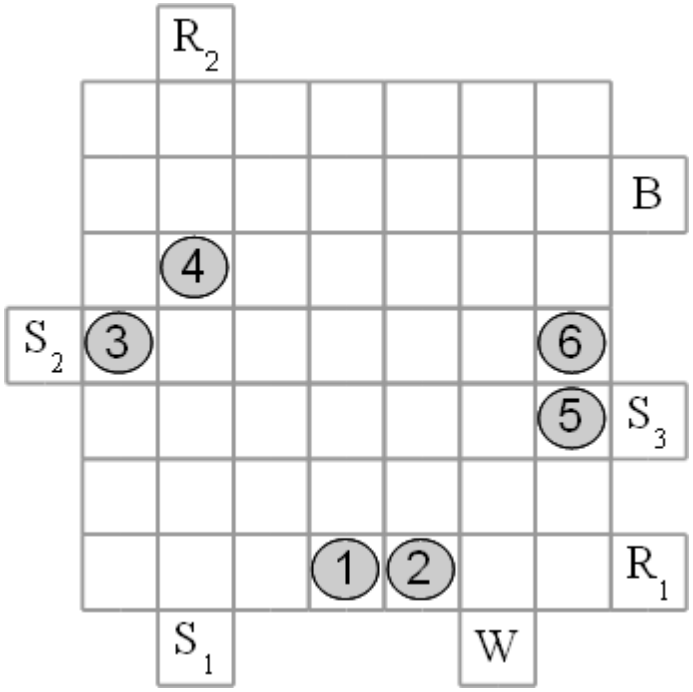

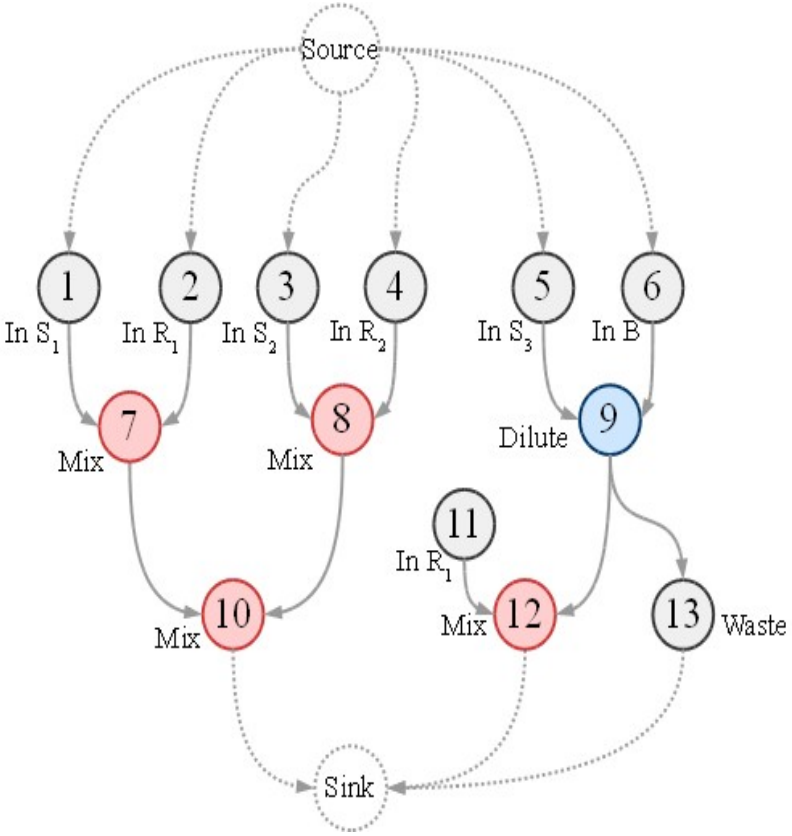

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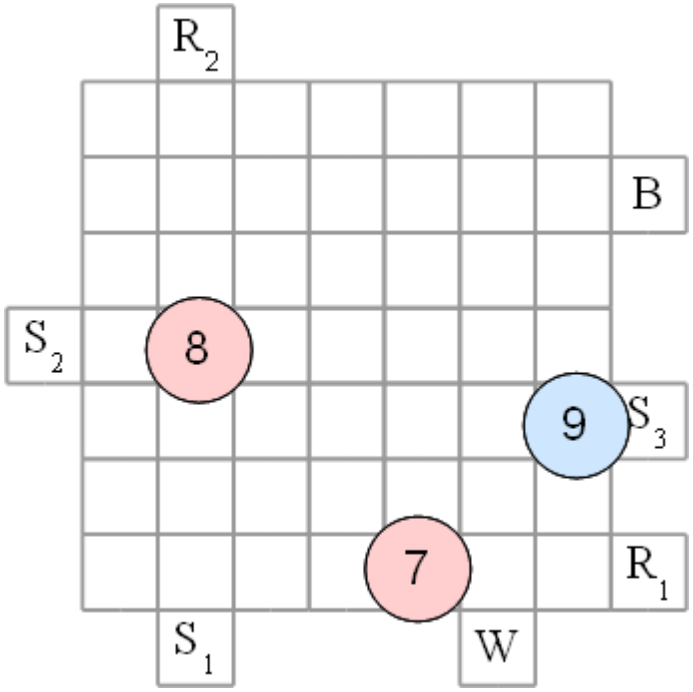

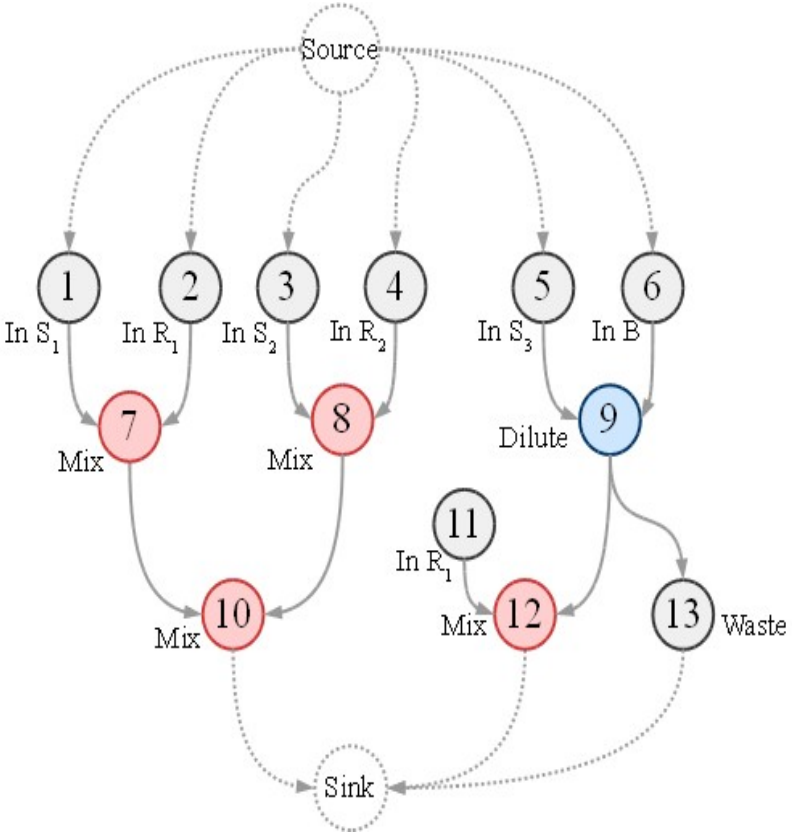

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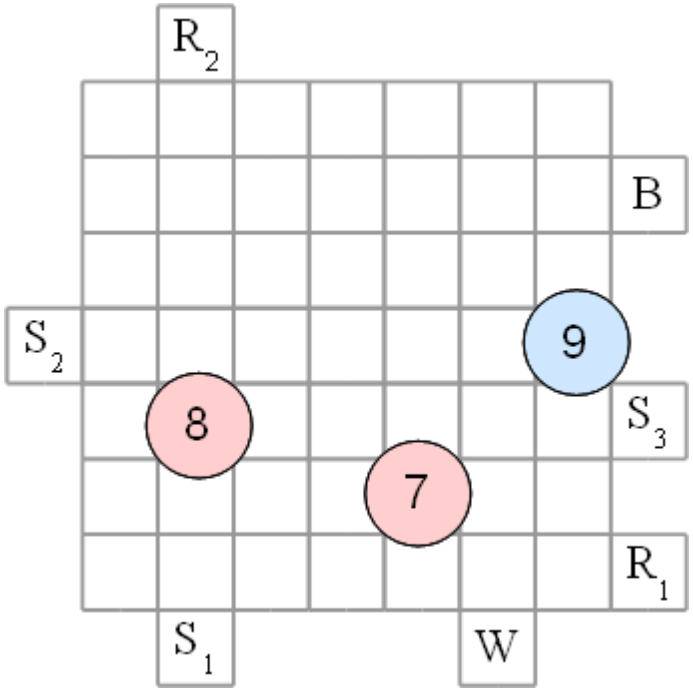

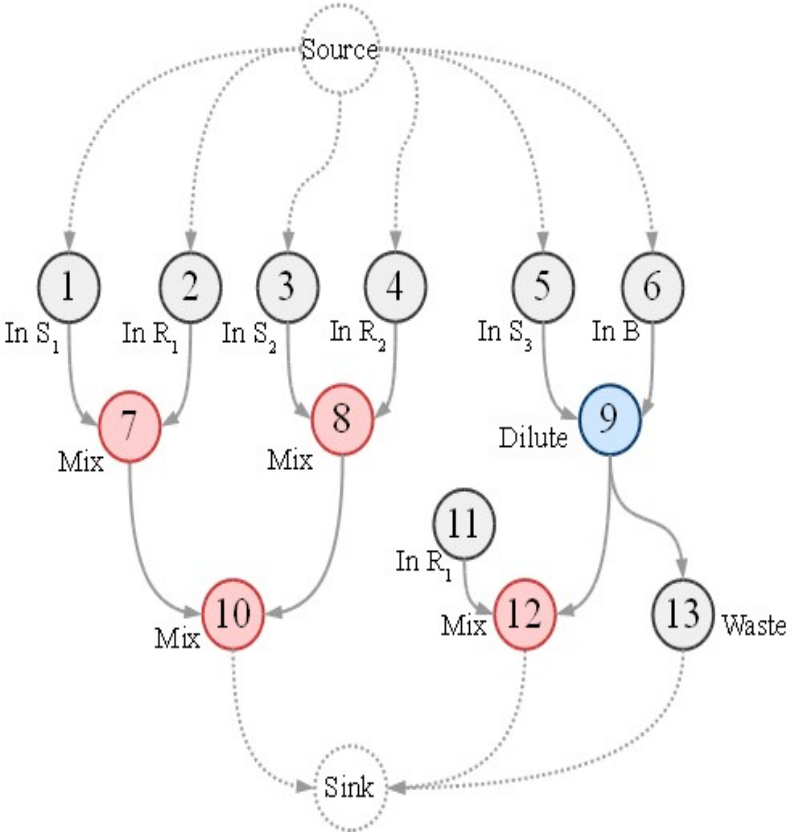

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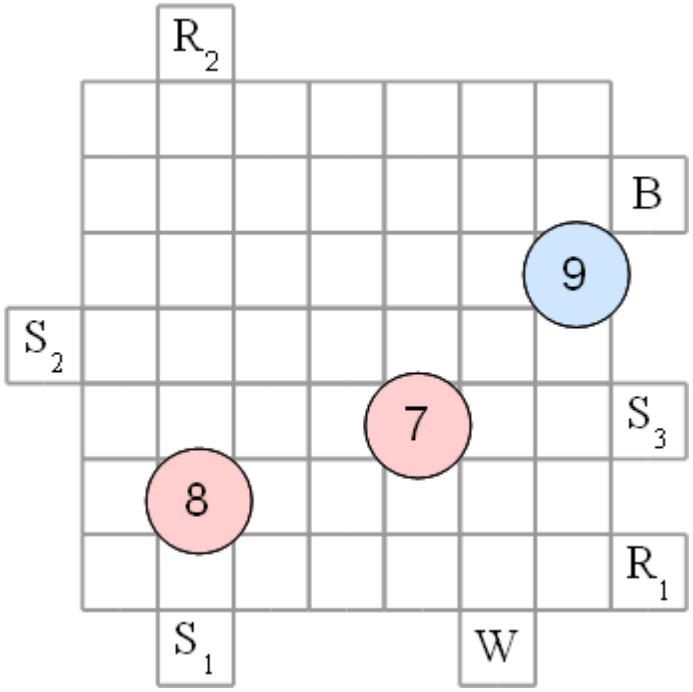

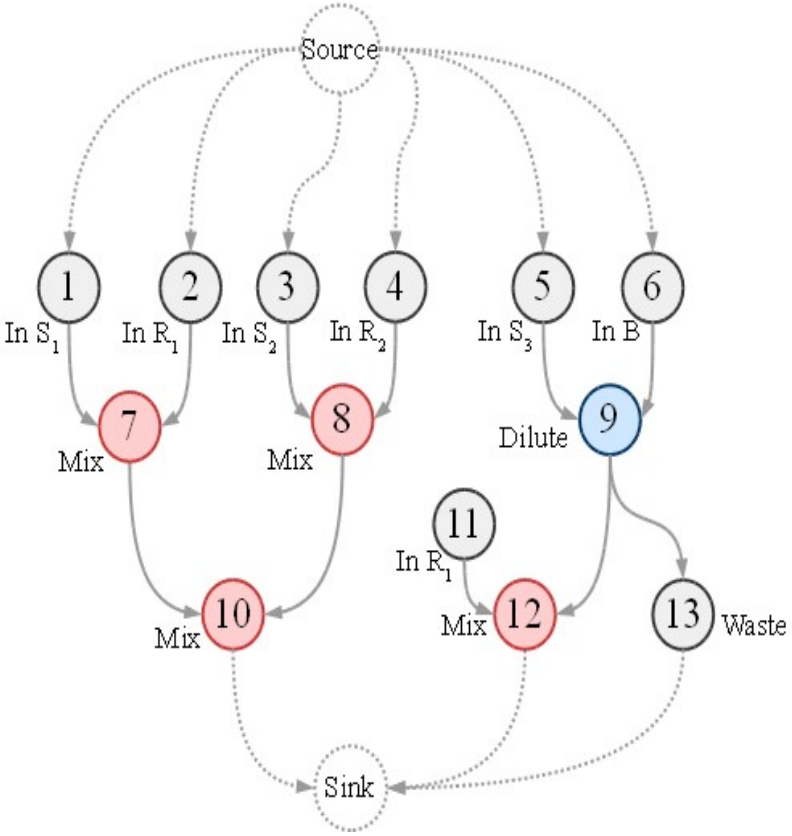

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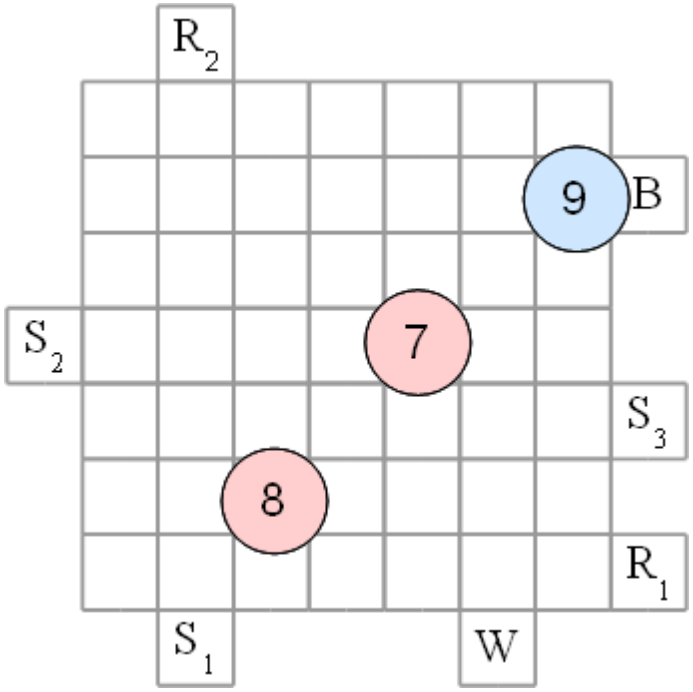

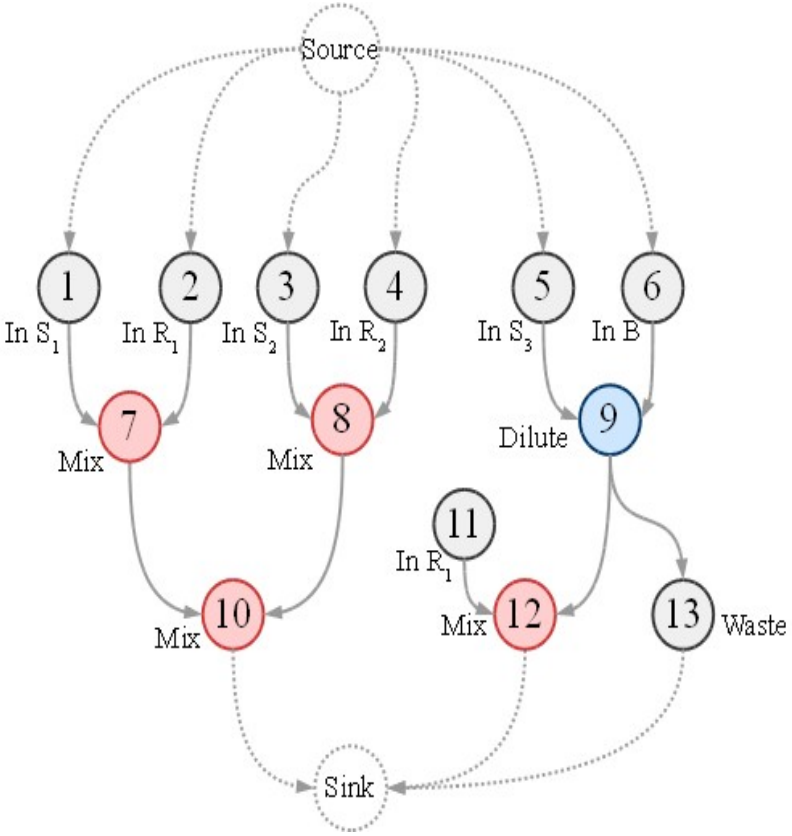

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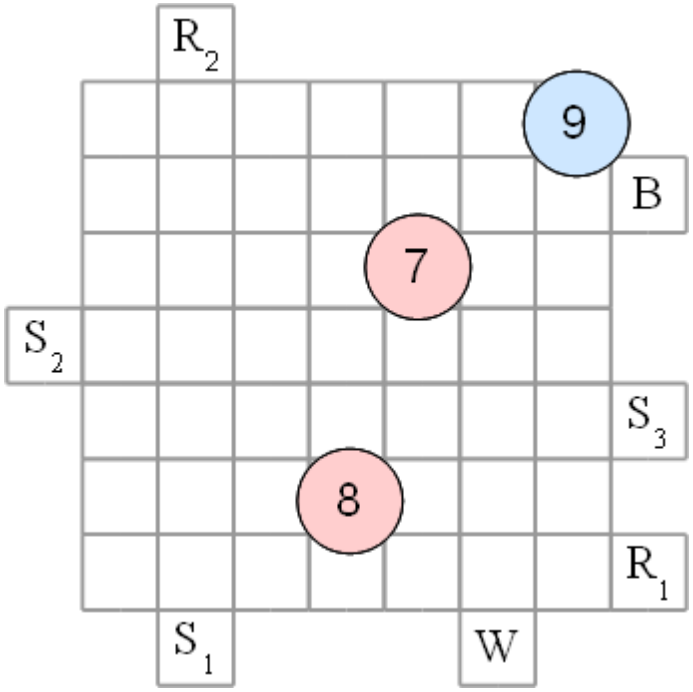
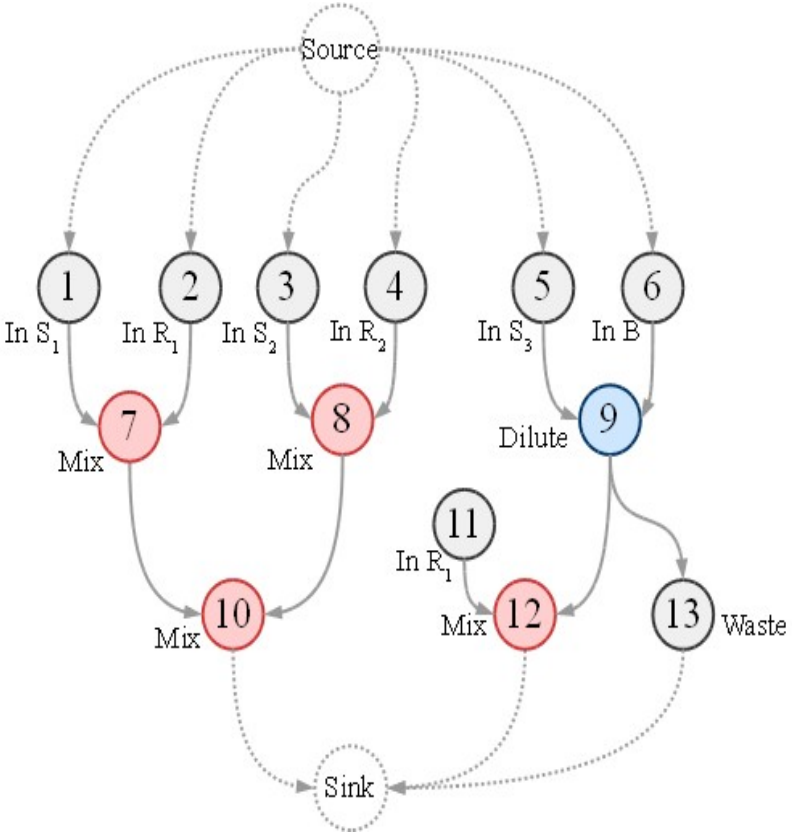
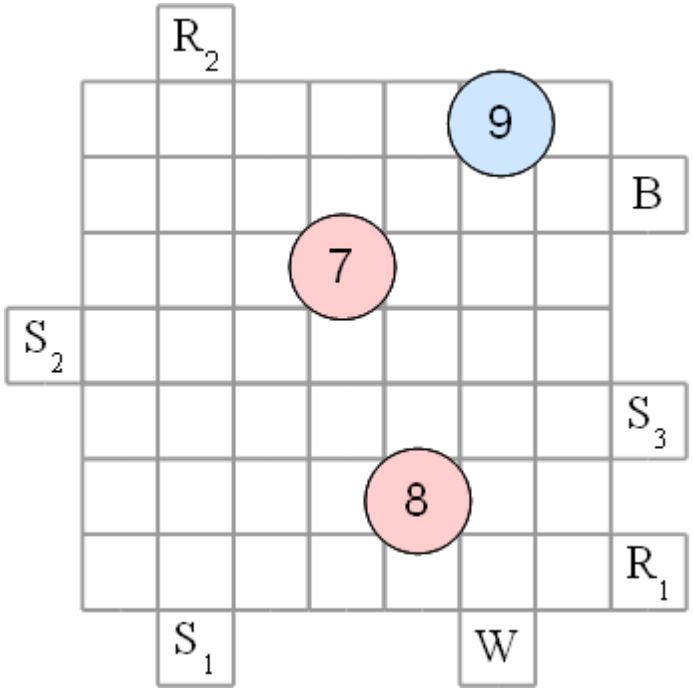
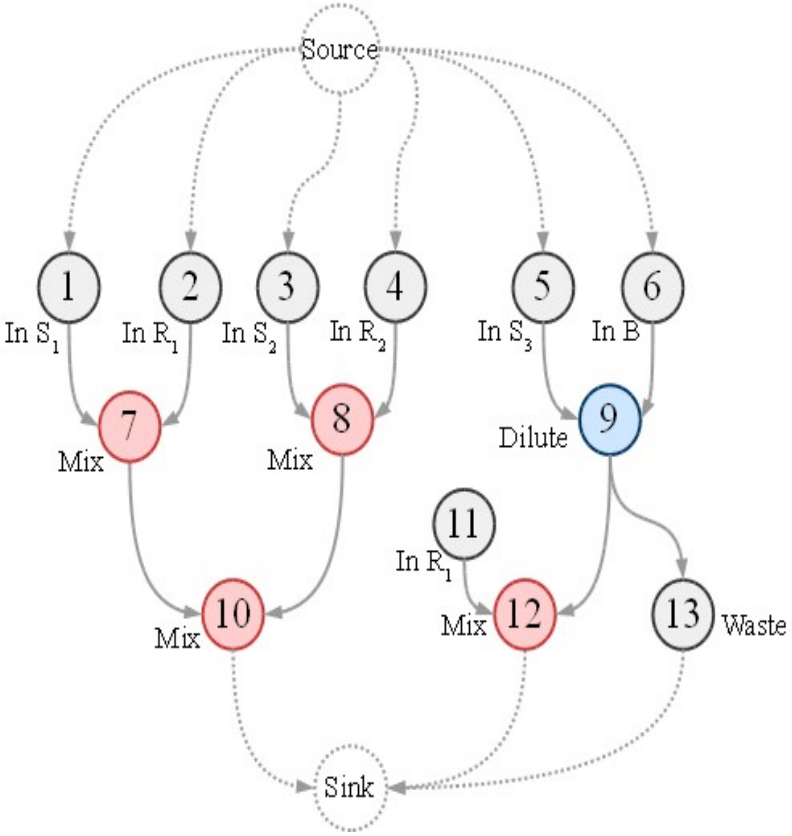




Droplet-Based Synthesis





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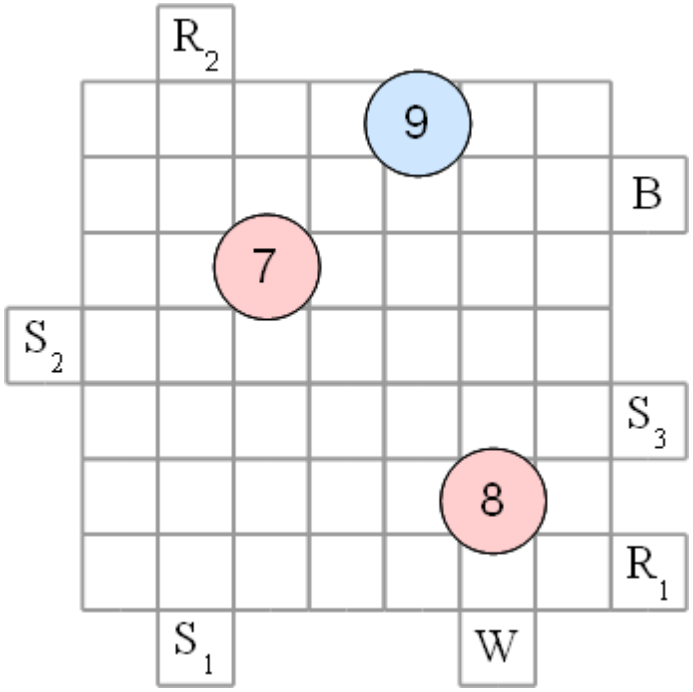
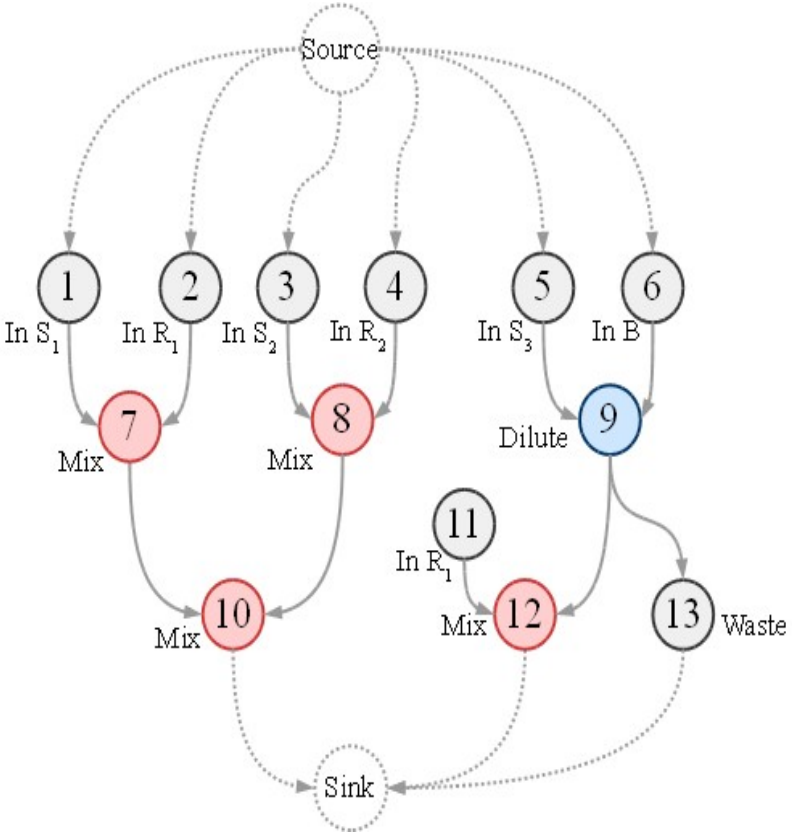
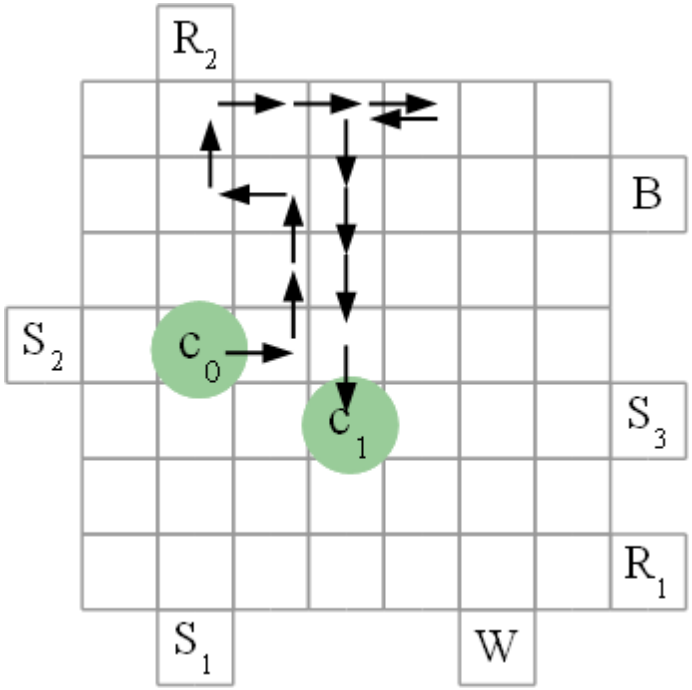
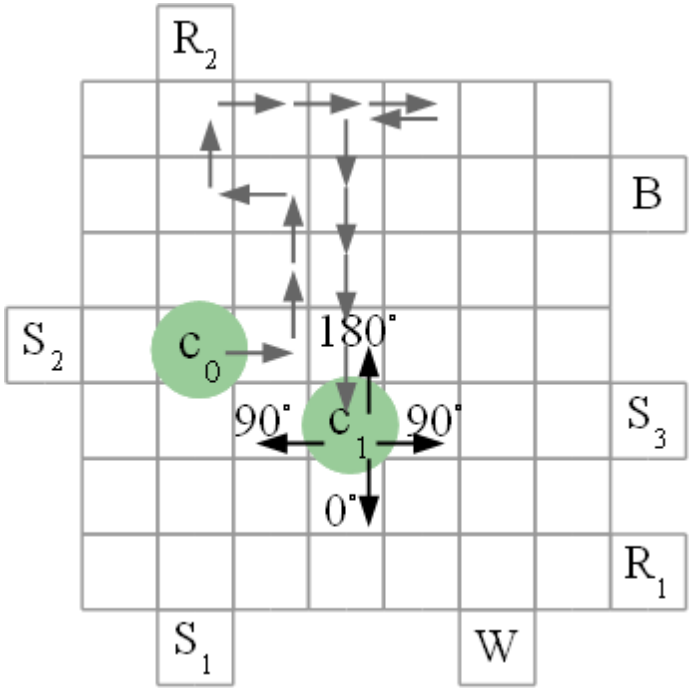




Characterize Droplet Movement



Characterize Droplet Movement



p^{90}, p^{180}, p^{0} ?

Characterize Droplet Routing

Operation	Area(cells)	Time(s)
Mix/Dlt	2x4	2.8
Mix/Dlt	1x4	4.6
Mix/Dlt	2x3	5.6
Mix/Dlt	2x2	9.96

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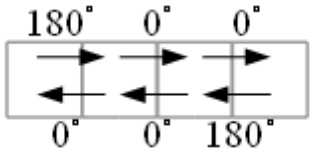
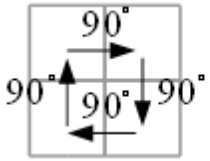
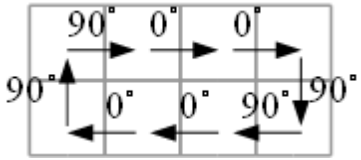
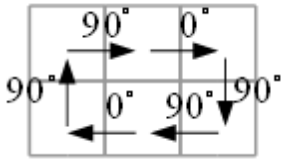
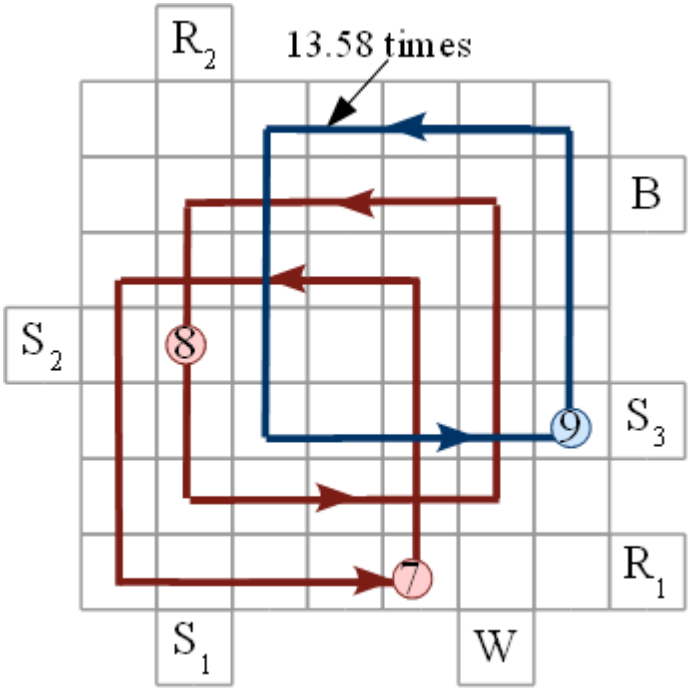


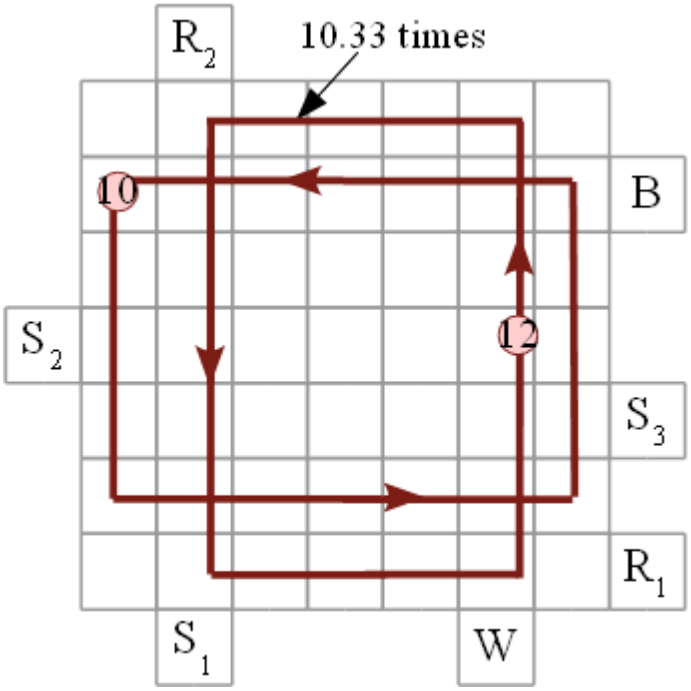






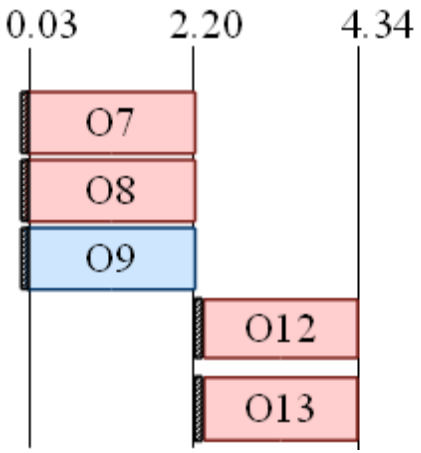
Droplet-Based Synthesis



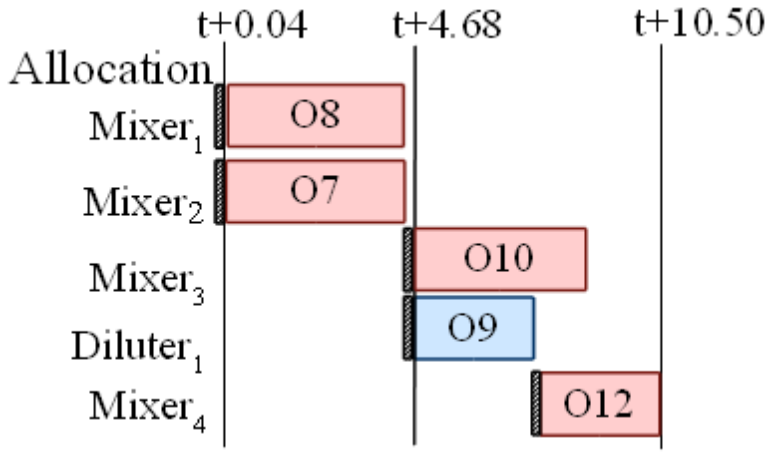


Droplet- vs. Module-Based Synthesis

Routing-Based Synthesis



Module-Based Synthesis



Problem Formulation

- Input
  - Sequencing graph
  - Library of modules
  - Area constraint

- Output
  - Implementation which minimizes application execution time
    - Allocation of modules from modules library
    - Binding of modules to operations in sequencing graph
    - Scheduling of operations
    - Routes of the droplets

Related Work

- Module-based
- Routing performed as a post-synthesis process
  - A*-based: K. F. Bohringer: Towards optimal strategies for moving droplets in digital microfluidic systems. 2004
  - Lee-based: F. Su et all.: Droplet routing in the synthesis of digital microfluidic biochips. 2006
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- **Routing done between modules: given start and end points**

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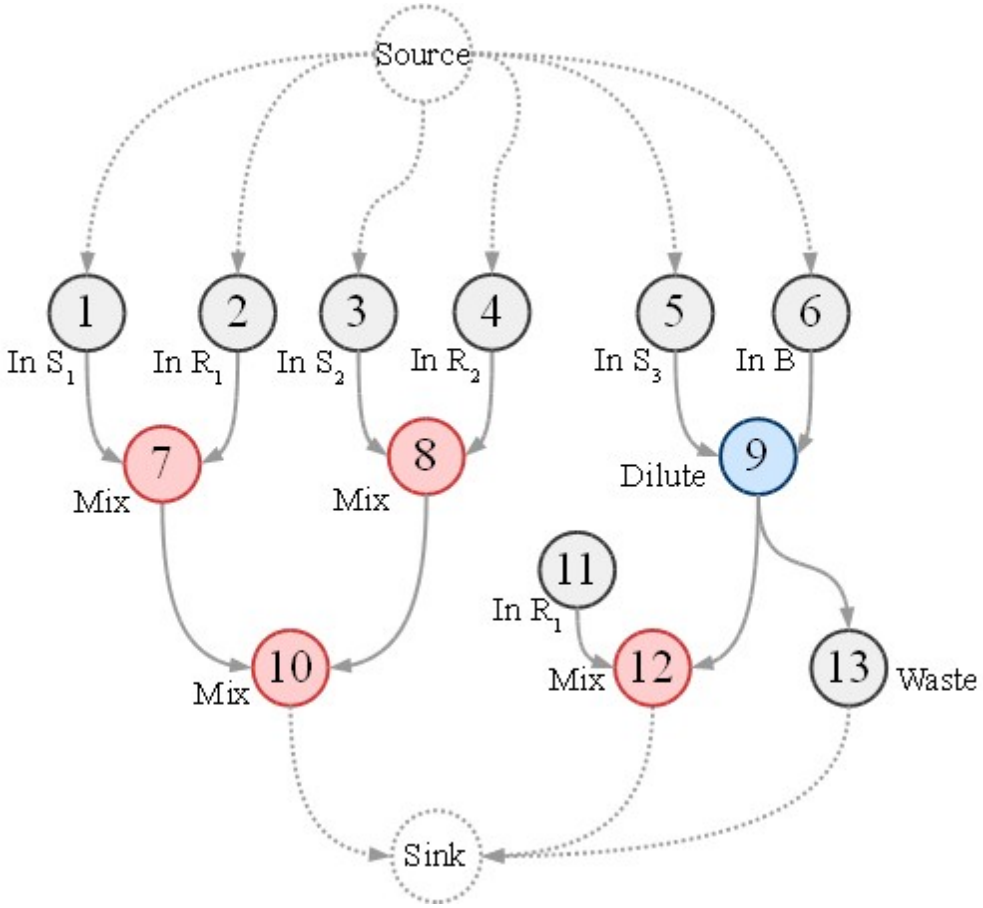
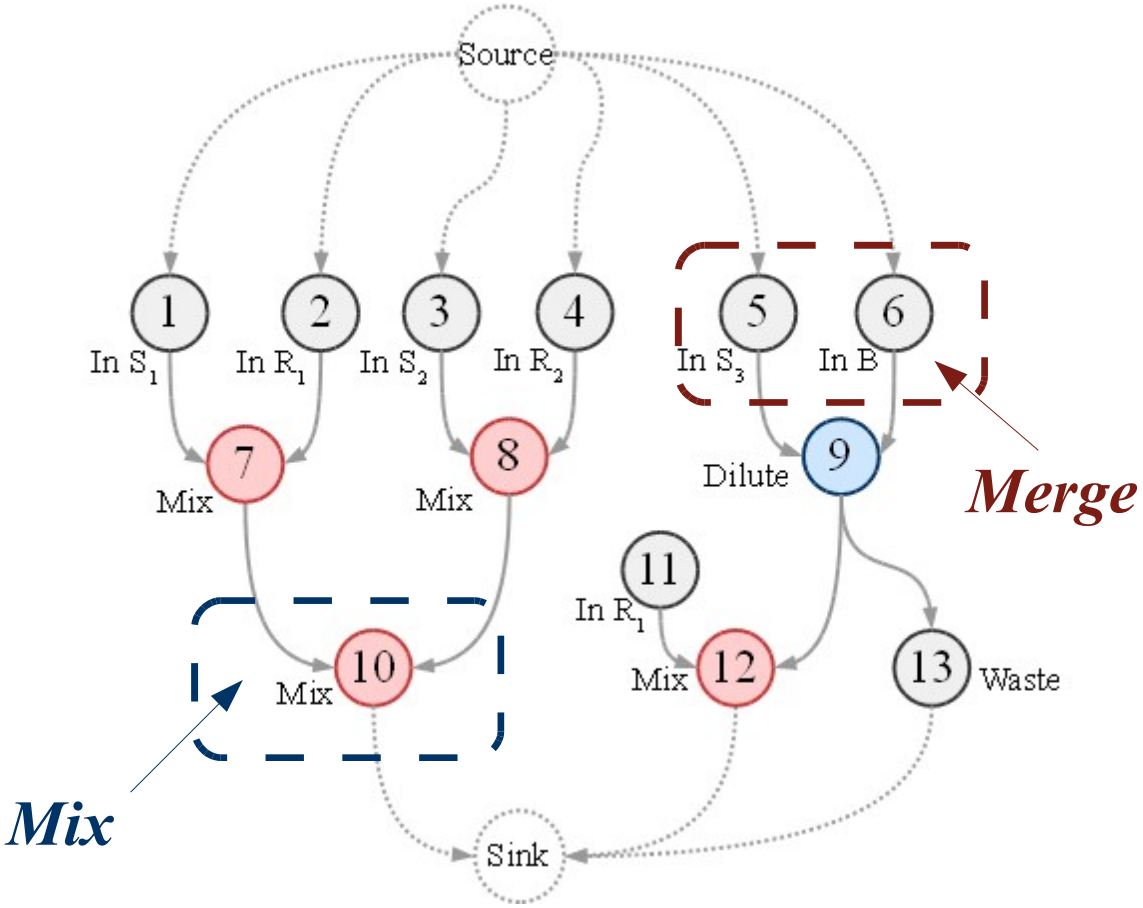
- **Routing done between modules: given start and end points**
- **Goal: minimizing the performed routing**

Proposed Solution



Proposed Solution



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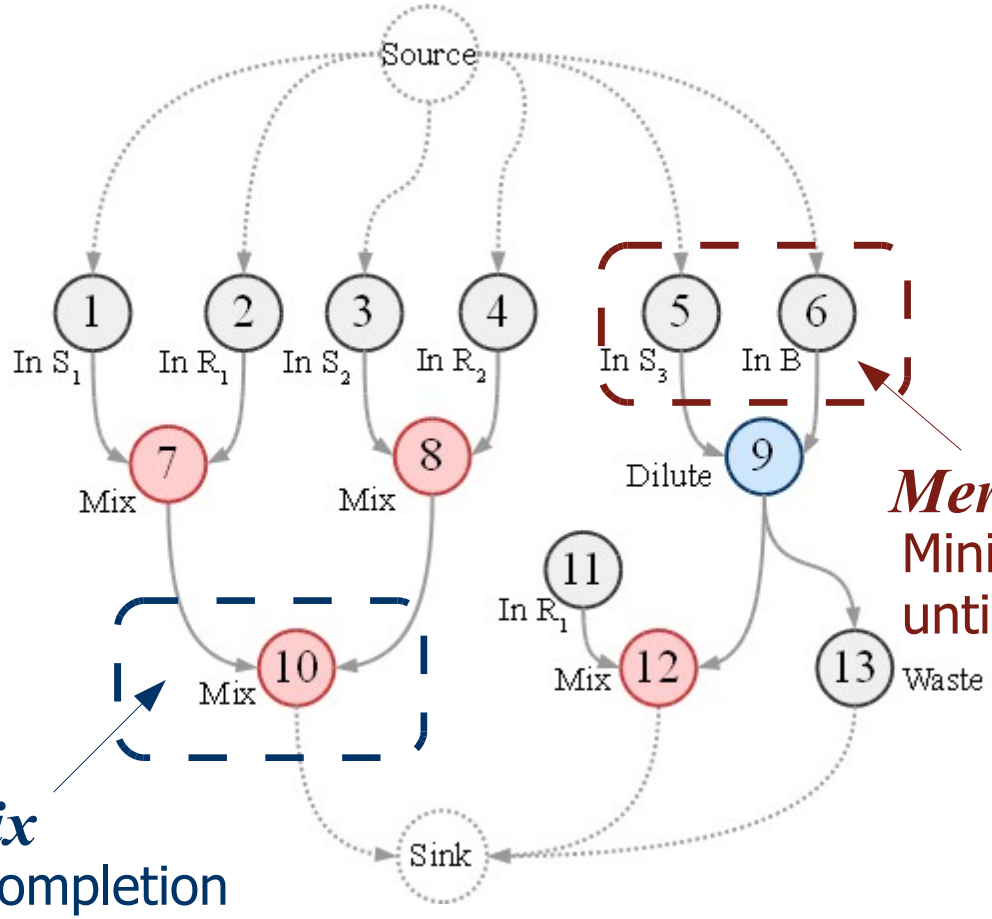


Merge

Minimize the time until the droplets meet

Mix

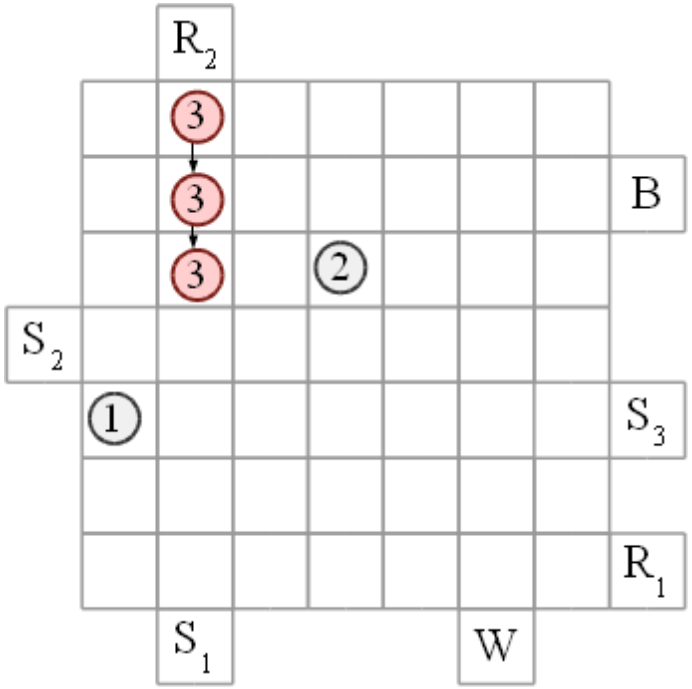
Minimize the completion time for the operation

GRASP-Based Synthesis

- Greedy Randomized Adaptive Search Procedure

GRASP-Based Synthesis

- Greedy Randomized Adaptive Search Procedure



GRASP-Based Synthesis

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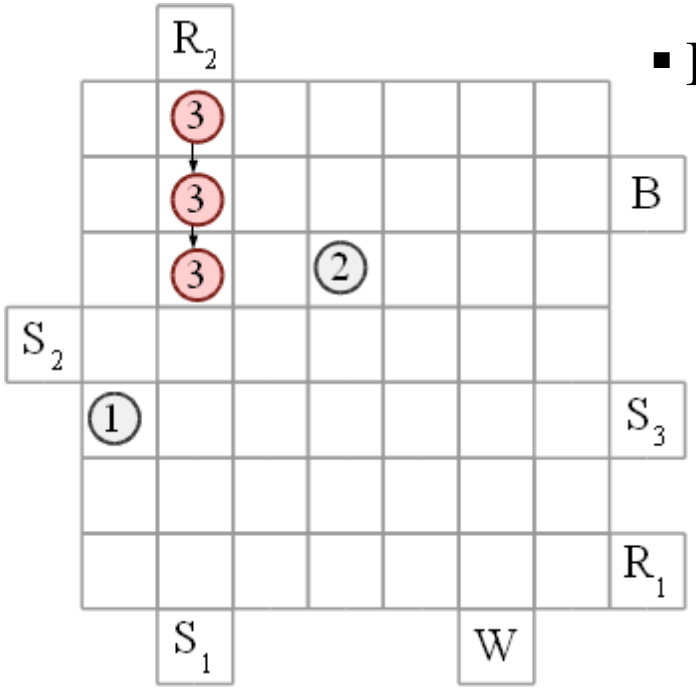
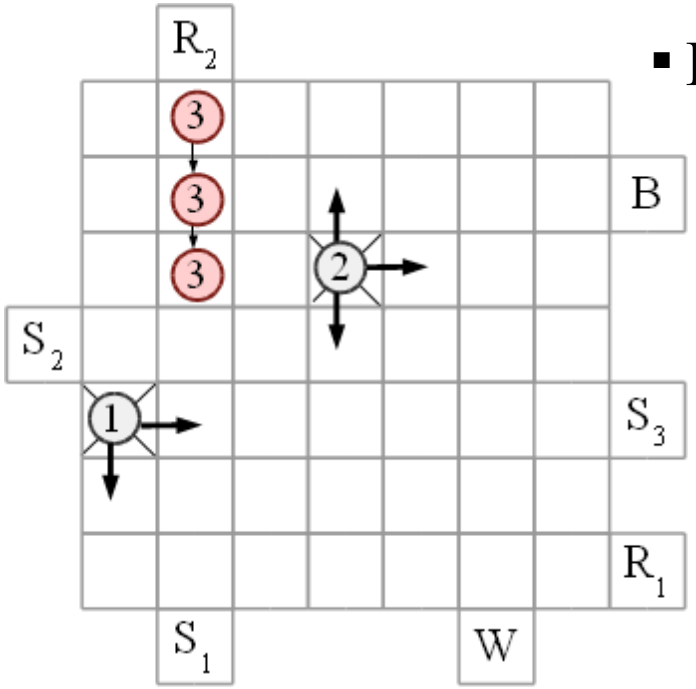


- For each droplet:
  - Determine possible moves
  - Evaluate possible moves
  - Make a list of best N possible moves
  - Perform a randomly chosen possible move

GRASP-Based Synthesis

- Greedy Randomized Adaptive Search Procedure



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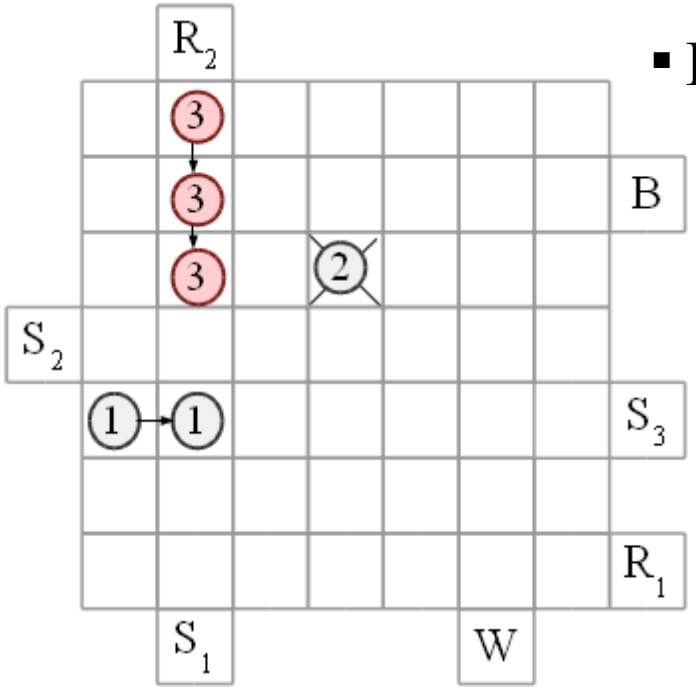

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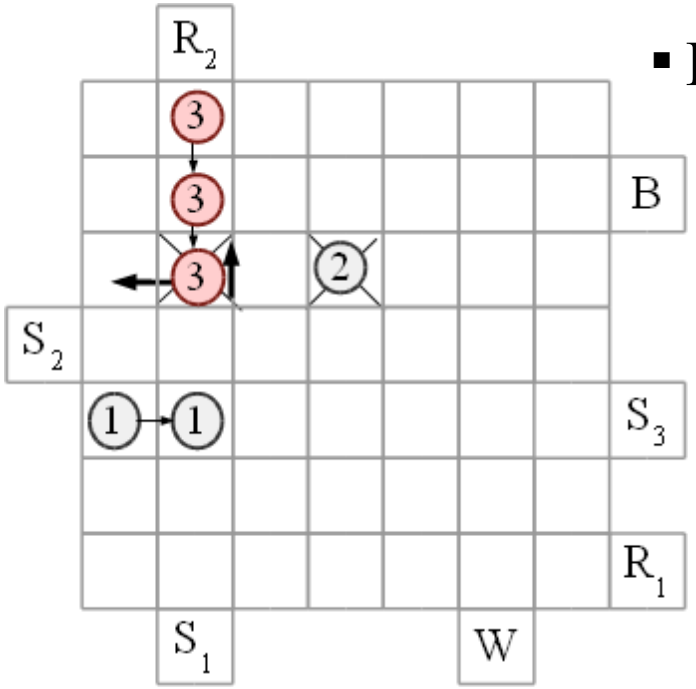

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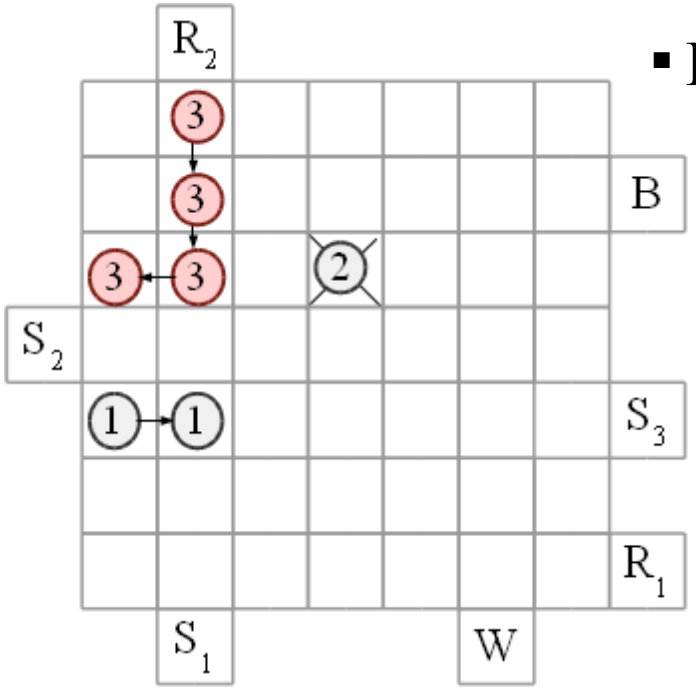

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Experimental Evaluation

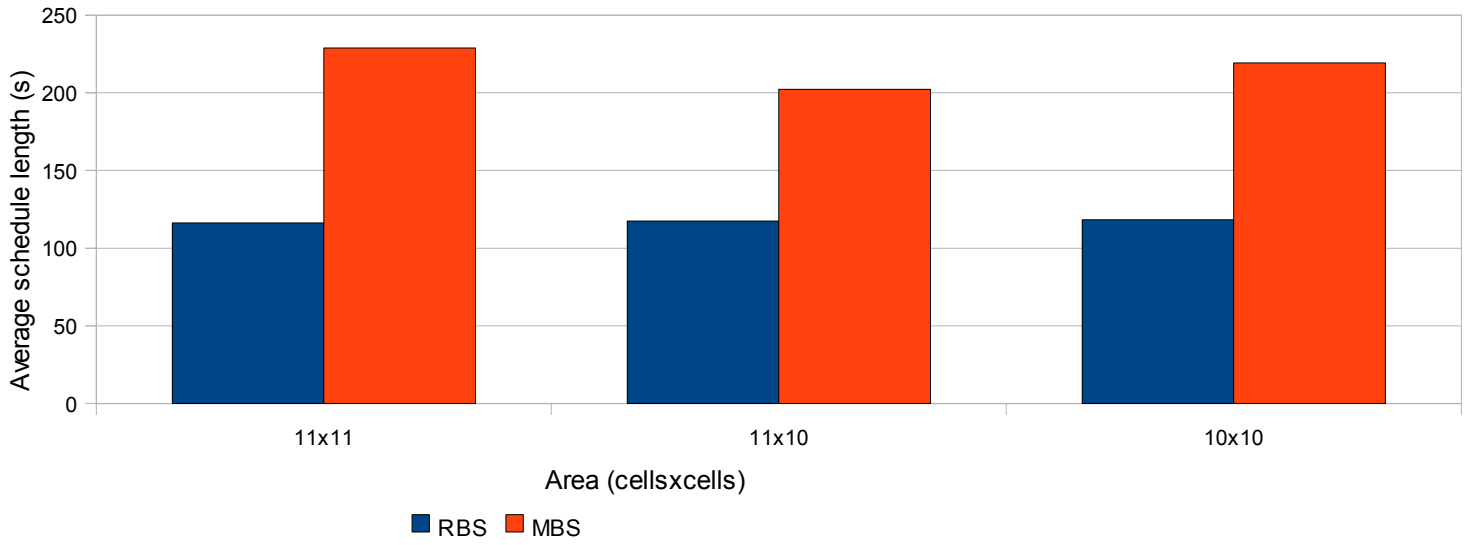
- GRASP algorithm implemented in Java
- Improvement brought by Routing-Based Synthesis (RBS) compared to Module-Based Synthesis*(MBS)
  - Two real-life applications
  - Ten synthetic bechmarks

E. Maftei at all.: *Tabu Search-Based Synthesis of Dynamically Reconfigurable Digital Microfluidic Biochips*. CASES, 2009.

Experimental Results

Improvement of RBS vs. MBS in schedule length

Colorimetric protein assay



Conclusions

- Addressed design problems characteristic to digital microfluidic biochips.
- Eliminated the concept of "virtual modules" and proposed a routing-based synthesis approach.
- Proposed a method for determining the percentage of operation completion on a given route.
- Proposed a GRASP-based algorithm for showing that routing-based synthesis leads to significant improvements compared to module-based synthesis.

…and answers