Mapping biochemical applications onto microfluidic-based biochips

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ArtistDesign Event @ DATE, March 15, 2012

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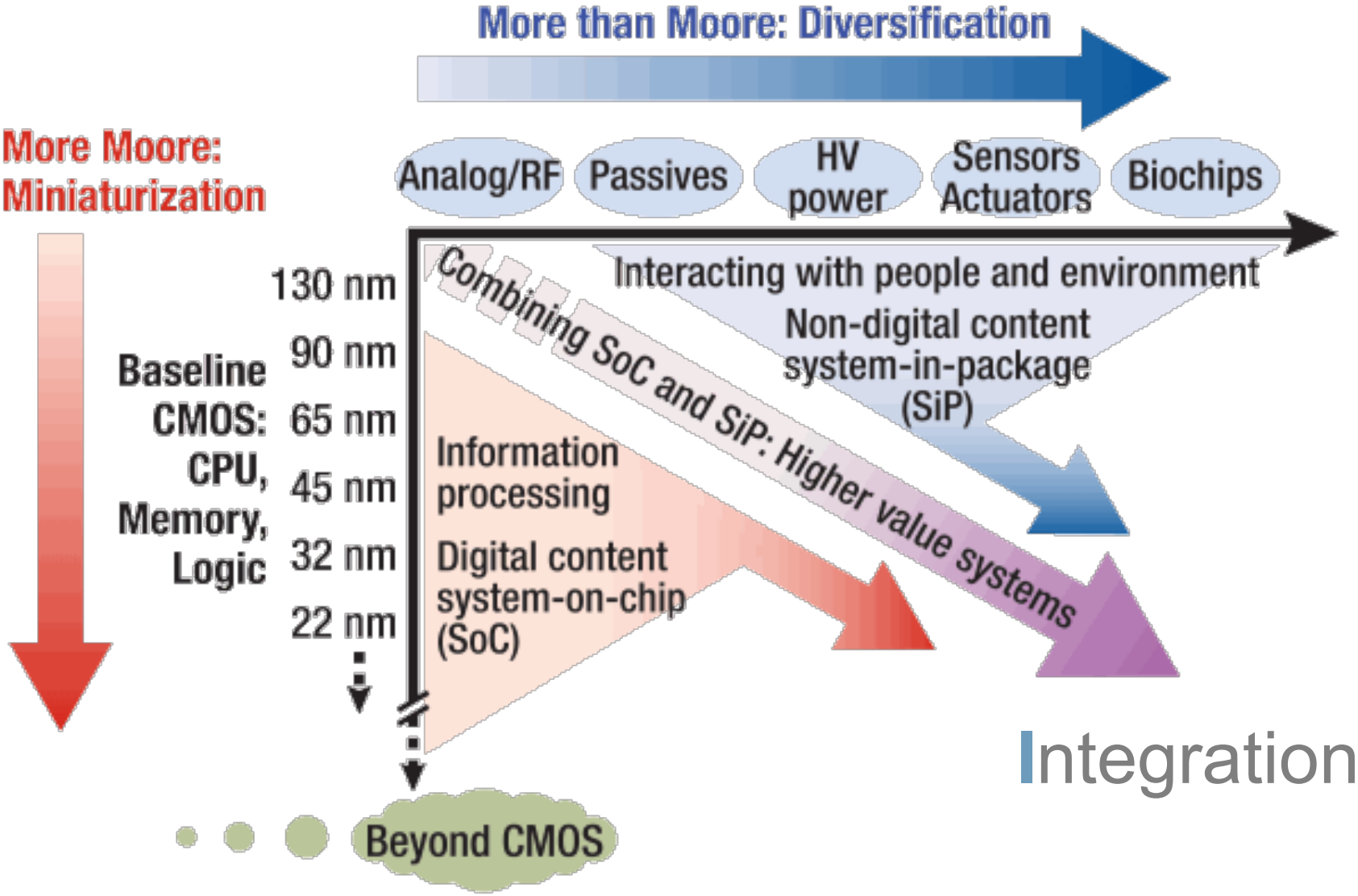
More than Moore!



Integration

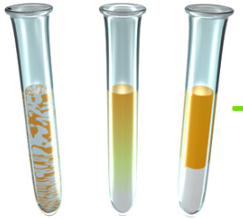
Outline

- Motivation & relation to MPSoC
- Biochip architectures
- The mapping problem

Motivation

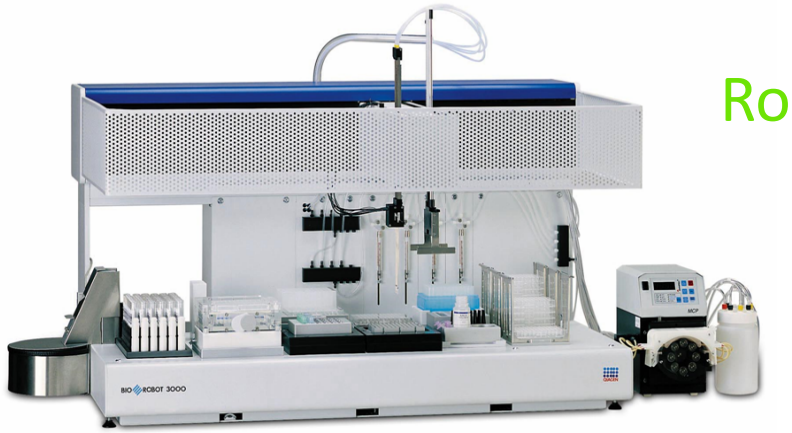
- Biotech
  - DNA analysis
- Medicine
  - Clinical diagnosis
  - Therapeutics
- Ecology
  - Monitoring the quality of air/water/food
- Pharmacy
  - Screening
  - Synthesis of new drugs

Motivation



Test tubes

- ☐ Automation
- ☐ Integration
- ☐ Miniaturization

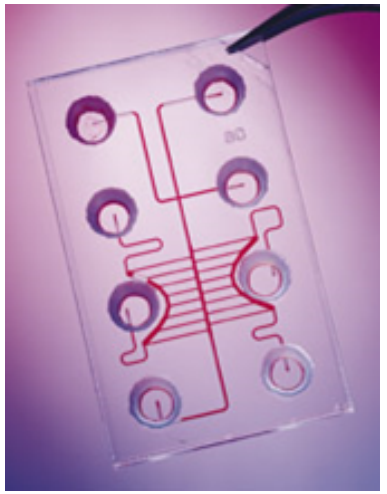


Robotics

- ☑ Automation
- ☑ Integration
- ☐ Miniaturization

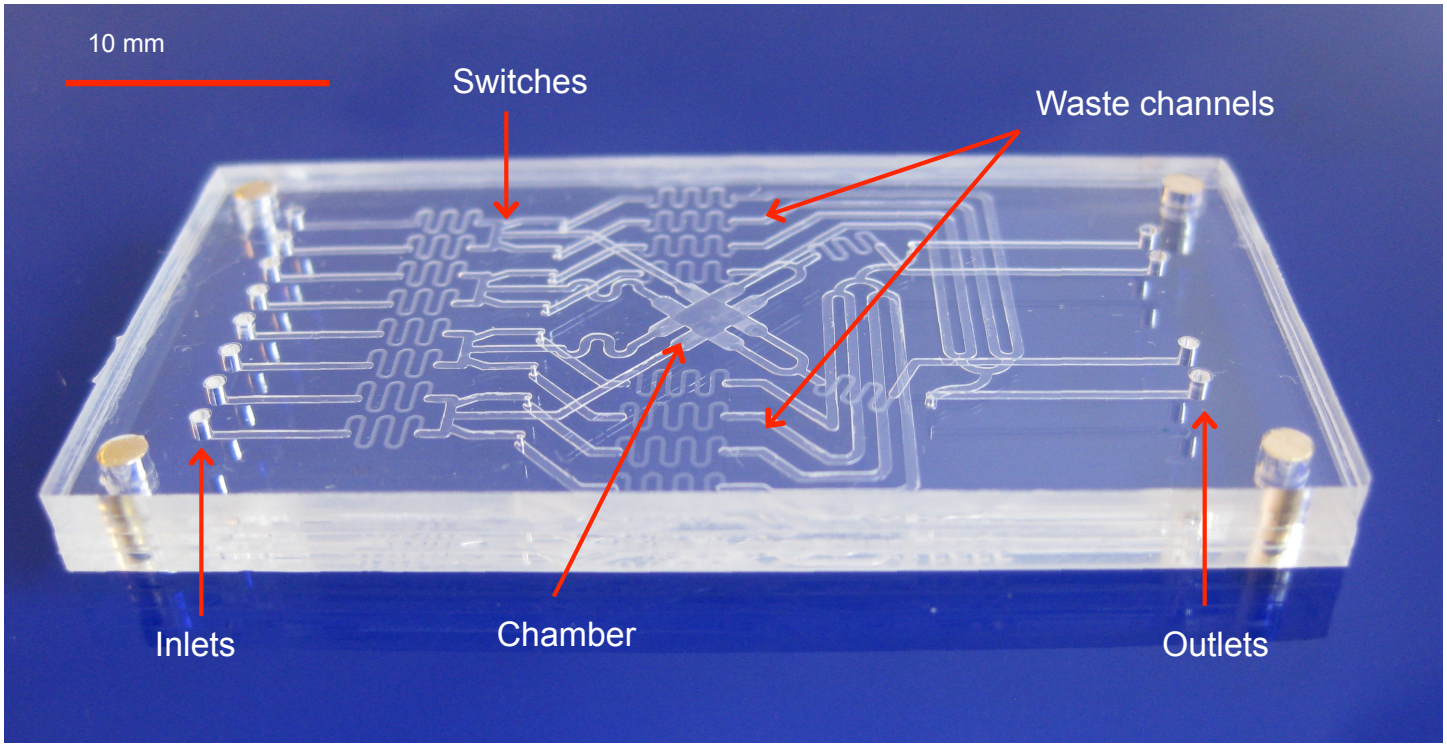
Microfluidics

- ☑ Automation
- ☑ Integration
- ☑ Miniaturization

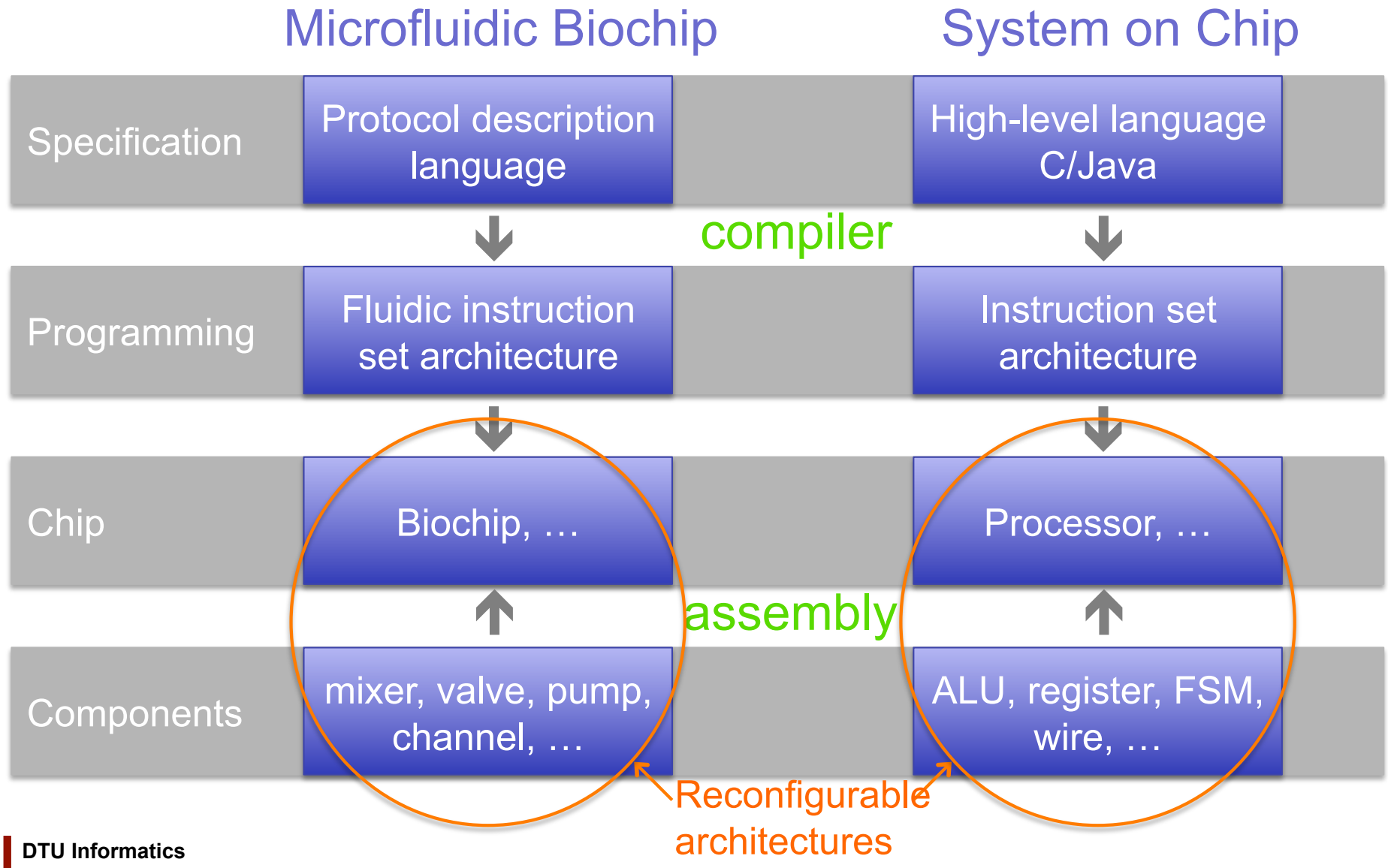


Microfluidic biochip?

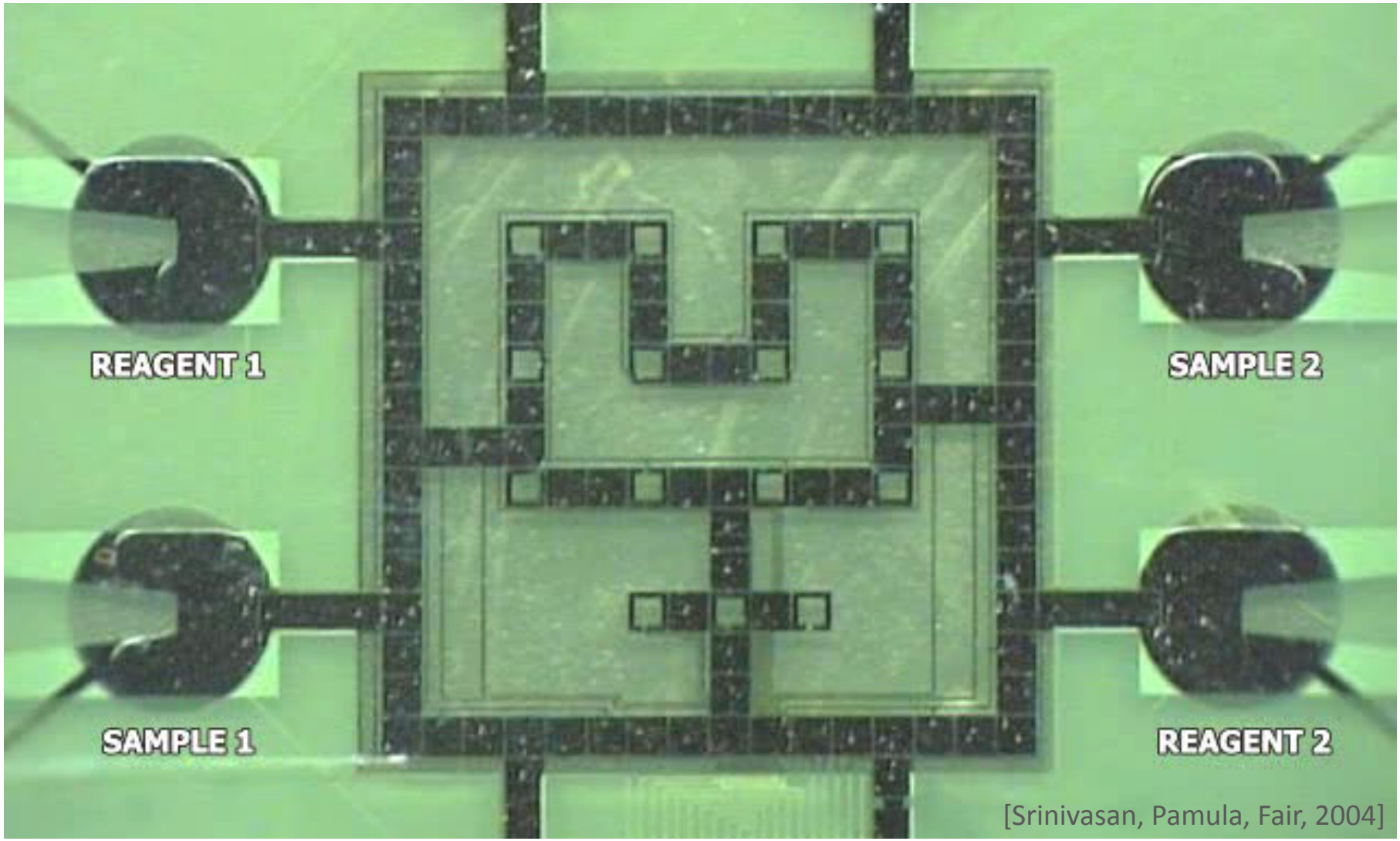
- Manipulations of continuous liquid through fabricated micro-channels



Biochip design

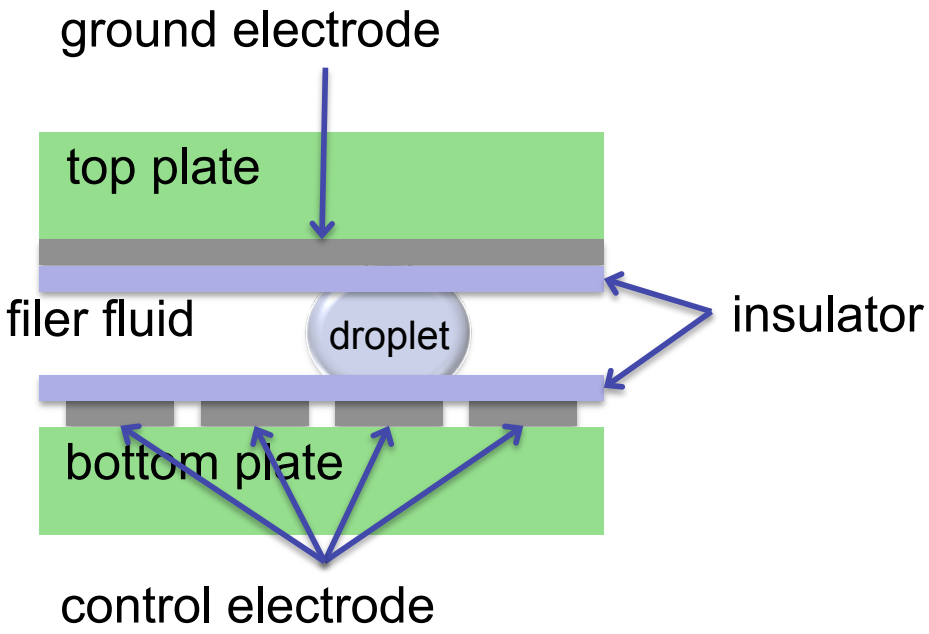


Digital microfluidic biochip



[Srinivasan, Pamula, Fair, 2004]

Digital microfluidic biochip

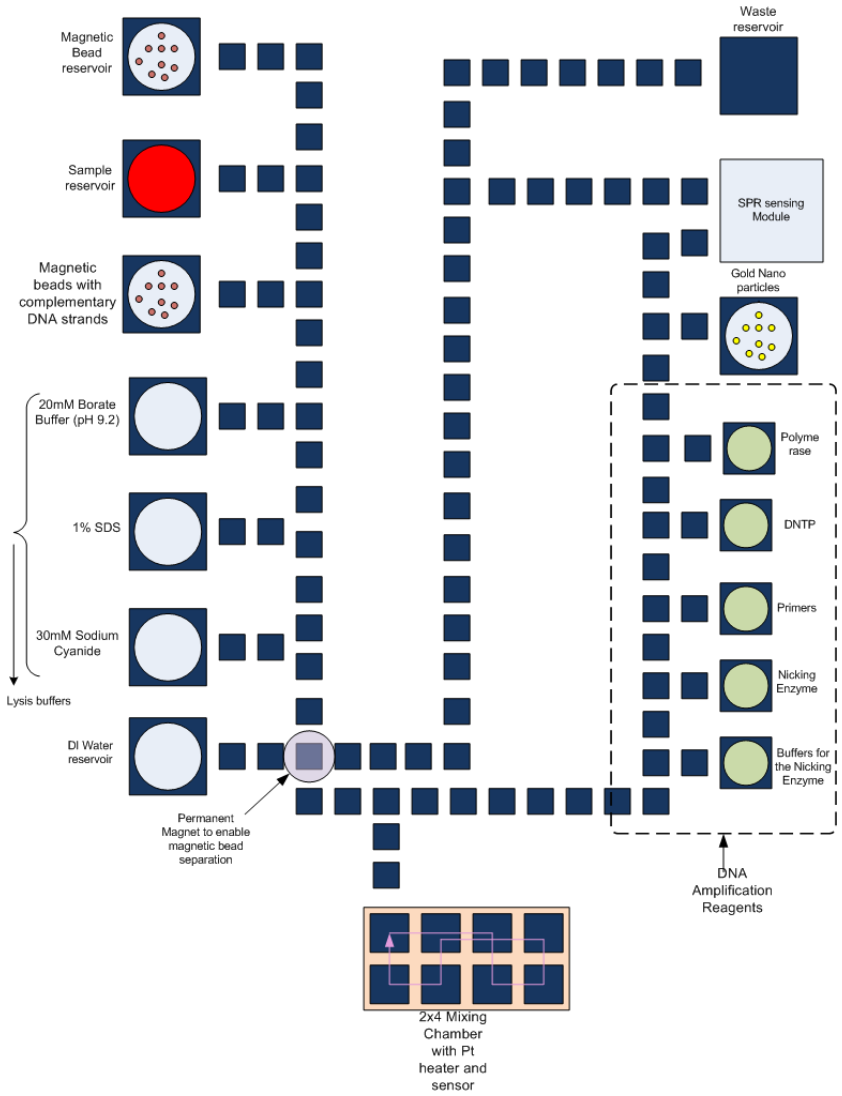


Speed: 12-25 cm/s
Size of electrode: 0.15 cm
Cell-to-cell transport: ~0.01 s

Biochip architecture?

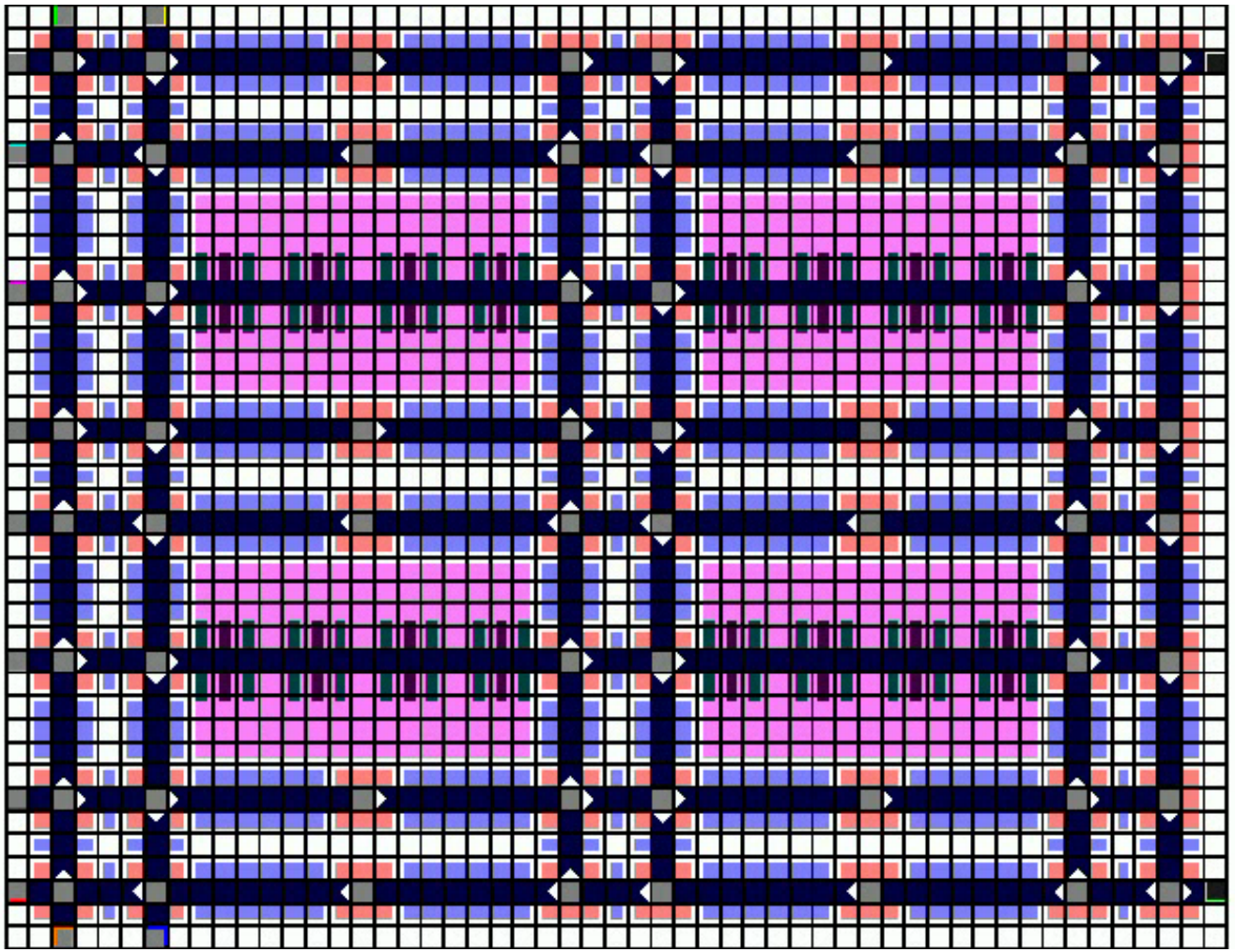
- Application specific architecture
  - Spatial and temporal assignment done at design-time
- General purpose architecture
  - Spatial assignment done at design-time
  - Temporal assignment done at run-time
- Reconfigurable architecture
  - Spatial and temporal assignment done at run-time

Application specific biochip



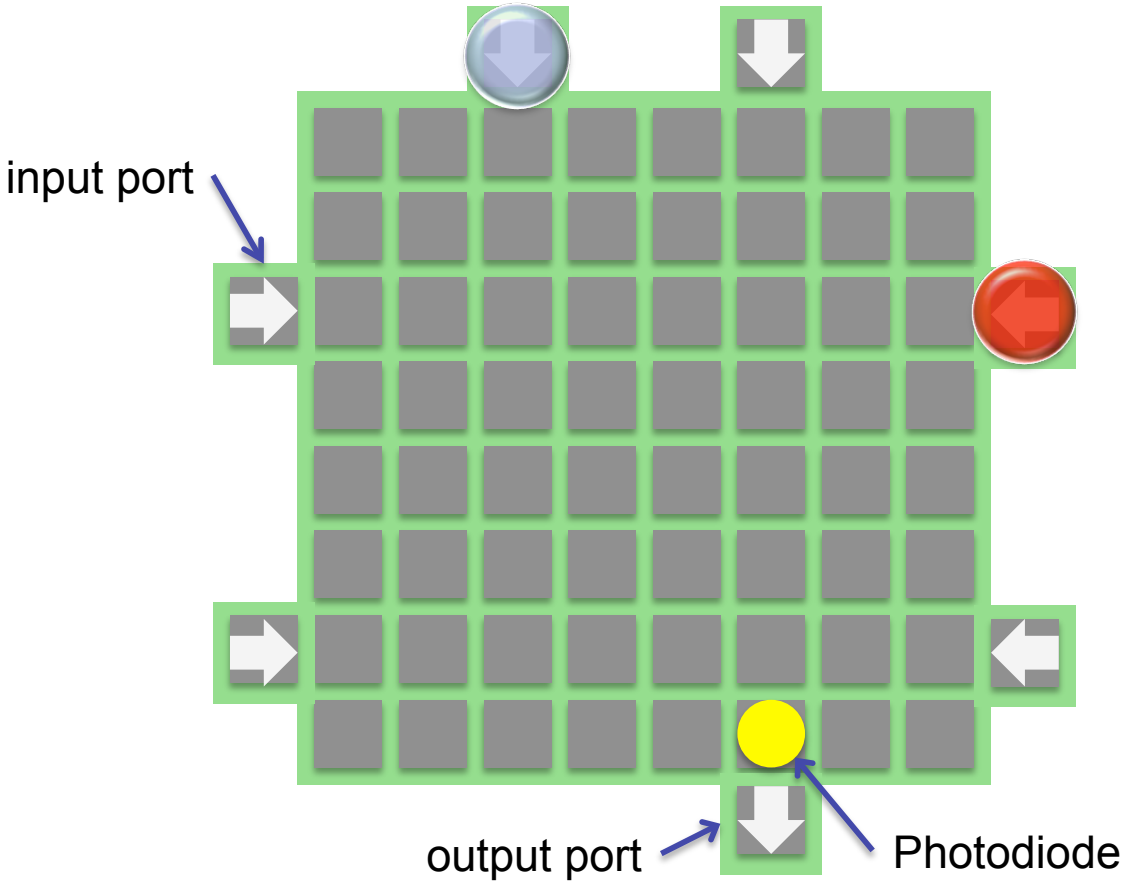
- Biochip for malaria detection
- Operation:
  - Infected cell isolation
  - Cell Lysis
  - DNA extraction
  - DNA amplification using PCR
  - Optical detection using SPR

General purpose biochip

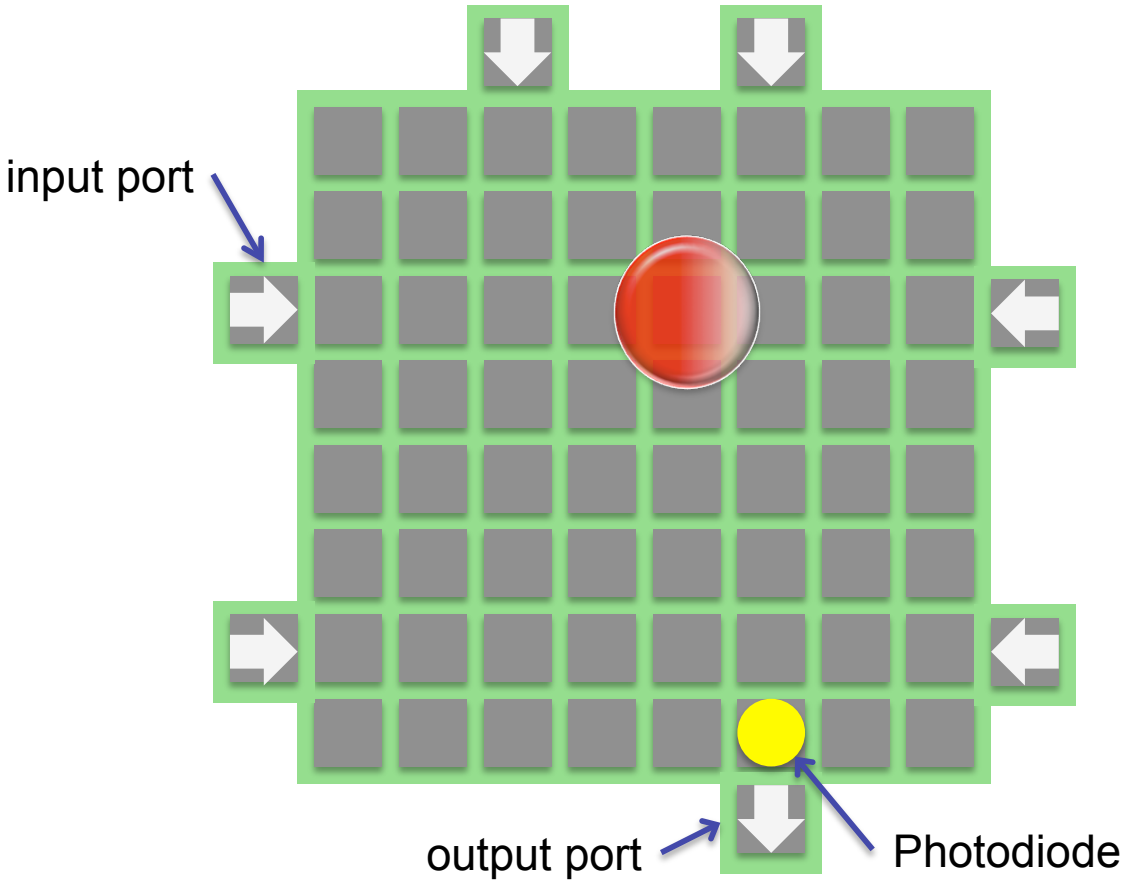


[Griffith, Akella, 2005]

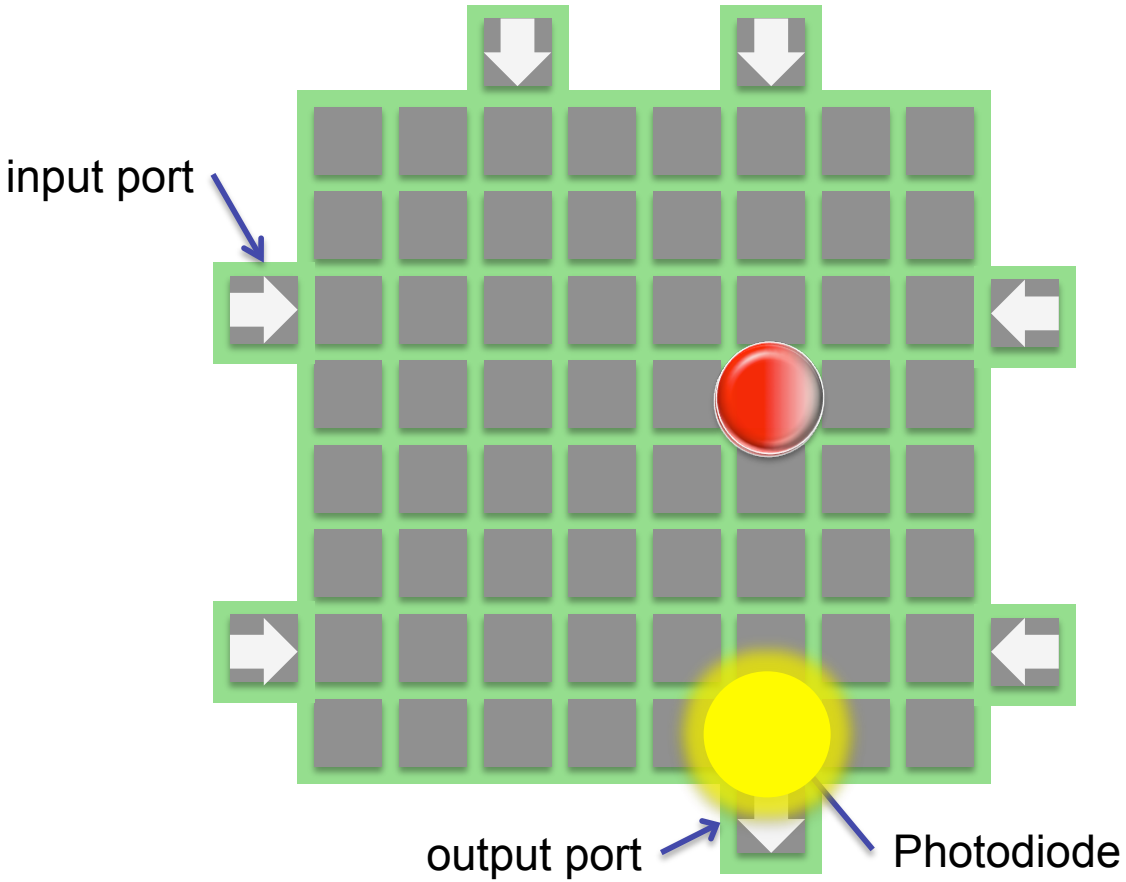
Reconfigurable biochip



Reconfigurable biochip

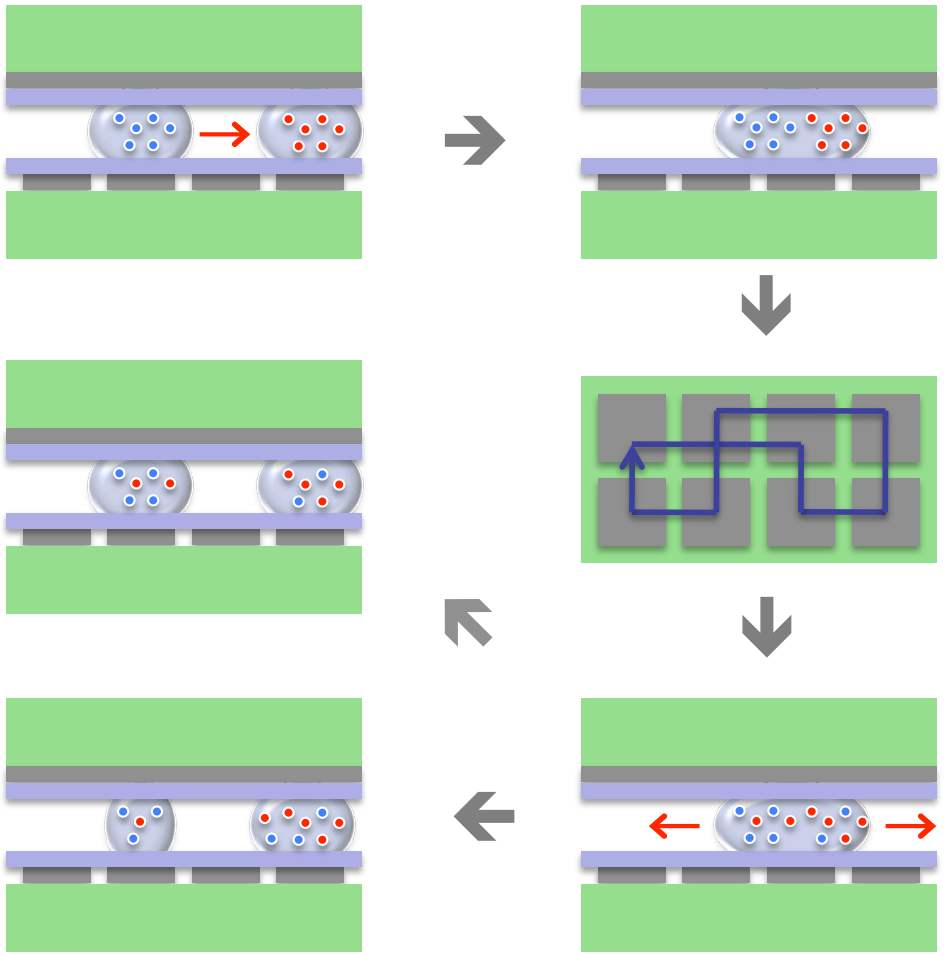


Reconfigurable biochip

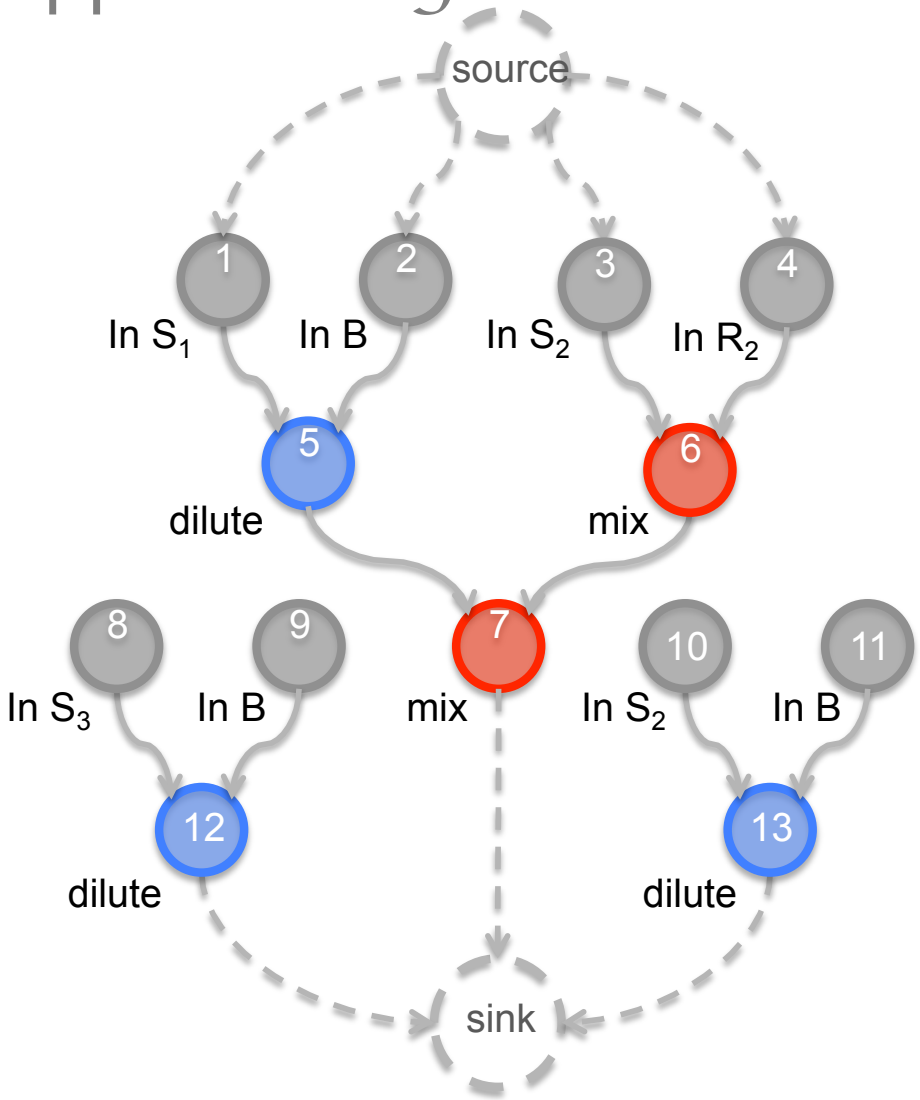


Biochemical operations

- Transport
- Merging
- Mixing
- Splitting
- Diluting
- Detection
- …



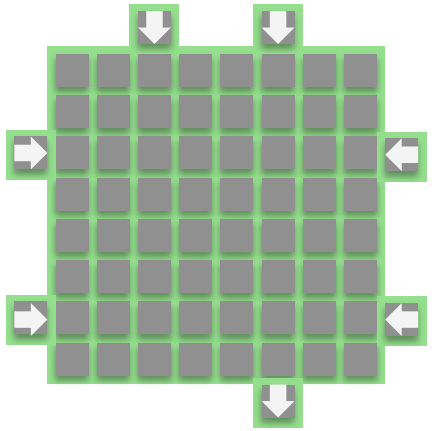
application $\mathcal{G}$ Biochemical application



library $\mathcal{L}$

module	Operation	Area (cells)	Time (sec)
M1	Mixing	2x4	3
M2	Mixing	2x2	4
D1	Dilution	2x4	4
D2	Dilution	2x2	5

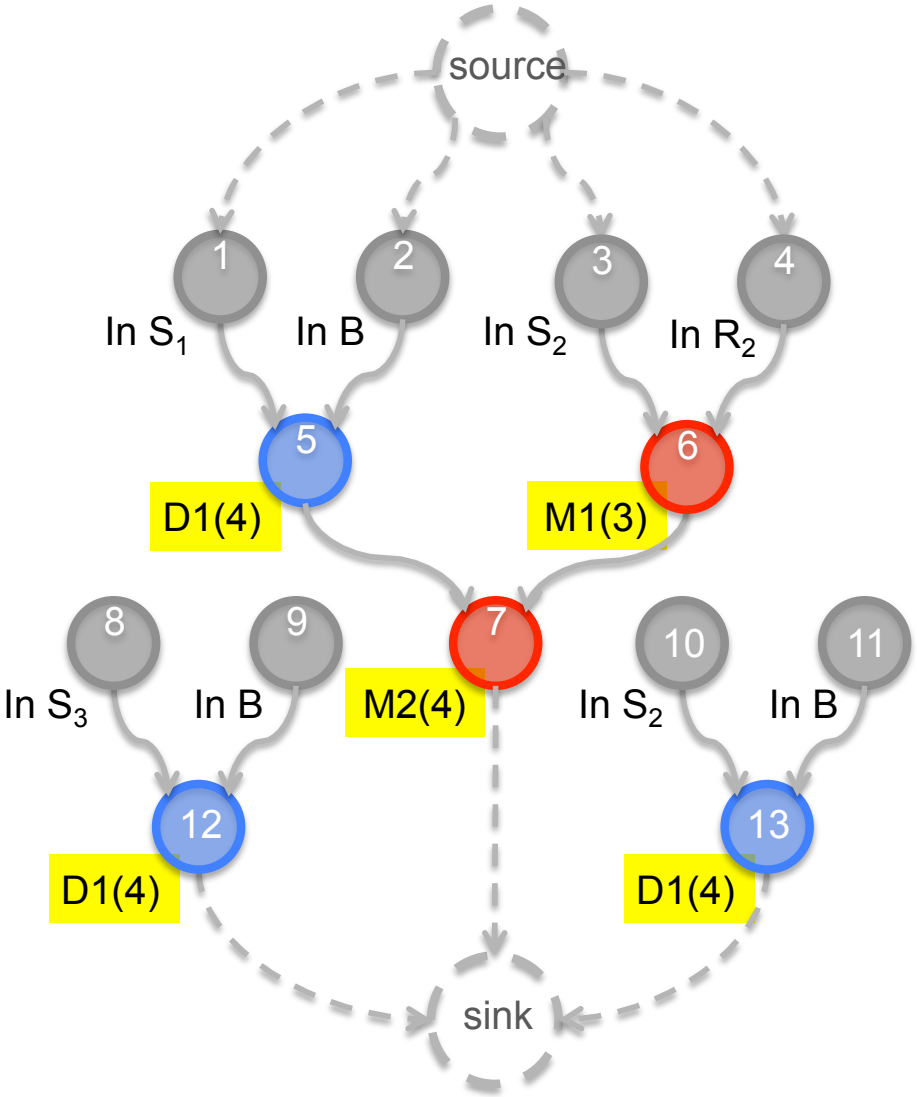
array $\mathcal{C}$

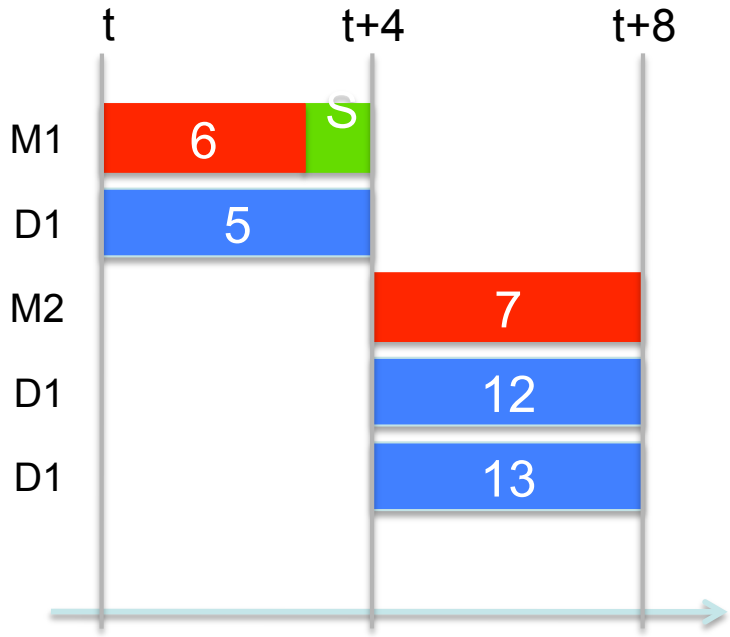


Mapping biochemical applications onto microfluidic biochips

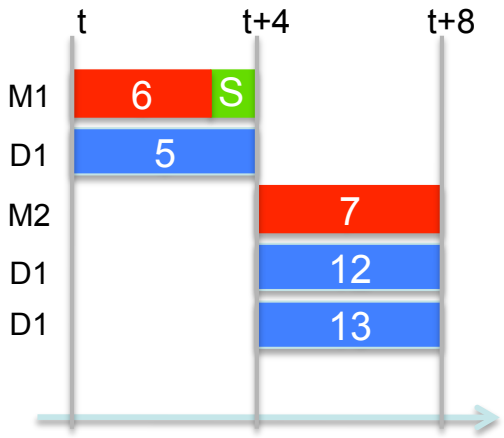
- Allocation $\mathcal{A}$
  - Determine modules $\mathcal{M}_k$ from library $\mathcal{L}$
- Binding $\mathcal{B}$
  - Assign each operation O_i to a module $\mathcal{M}_k$
- Schedule $\mathcal{S}$
  - Determine start time t_i^{start} of each operation O_i
- Placement $\mathcal{P}$
  - Place modules on the $m \times n$ array
- Synthesis Ψ
  - Given $<\mathcal{G}, \mathcal{C}, \mathcal{L}>$, find $\Psi = <\mathcal{A},\mathcal{B},\mathcal{S},\mathcal{P}>$ which minimize the schedule length $\delta_{\mathcal{G}}$

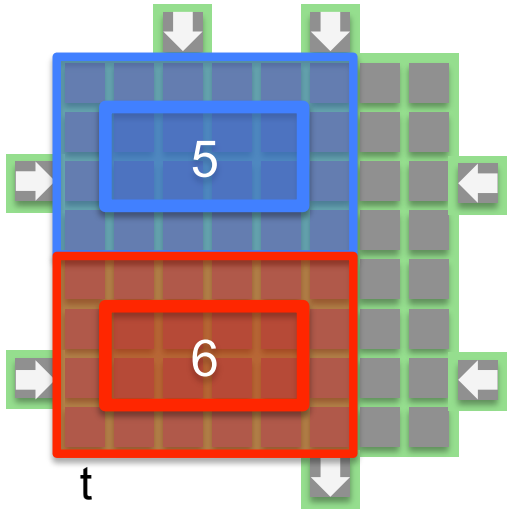
Scheduling

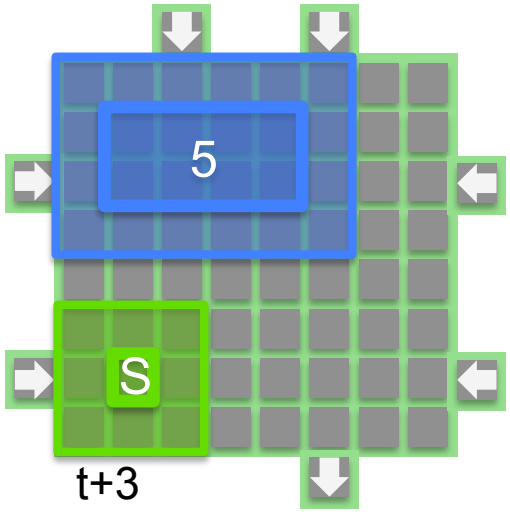

source
1
2
3
4
In S_1
In B
In S_2
In R_2
5
6
D1(4)
M1(3)
8
9
7
10
11
In S_3
In B
M2(4)
In S_2
In B
12
13
D1(4)
D1(4)
sink

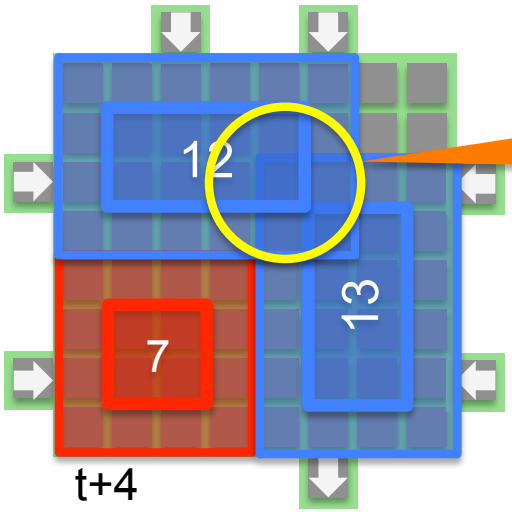

t
t+4
t+8
M1
D1
M2
D1
D1
6
S
5
7
12
13

Scheduling





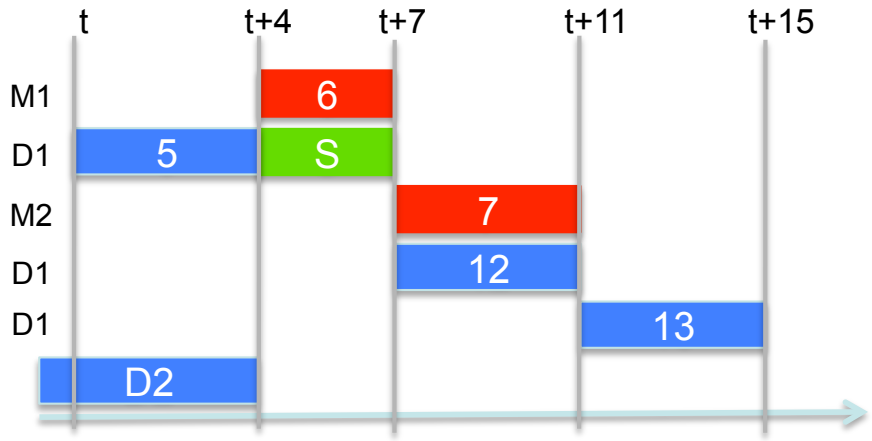


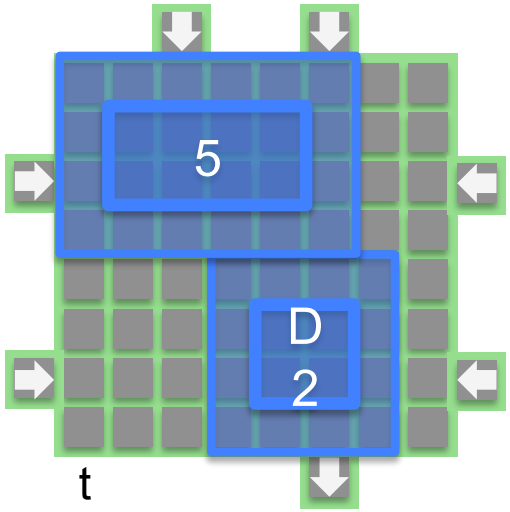


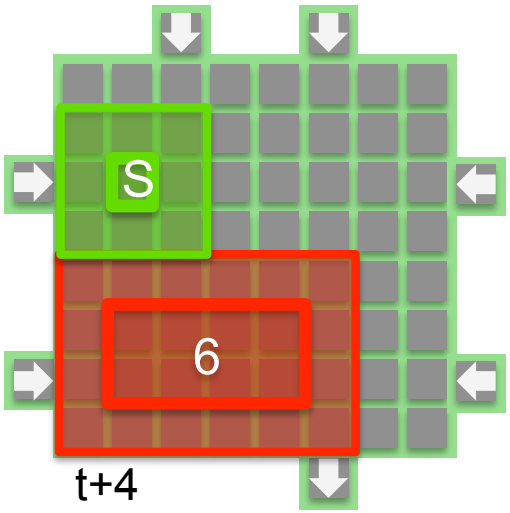
Overlapping modules

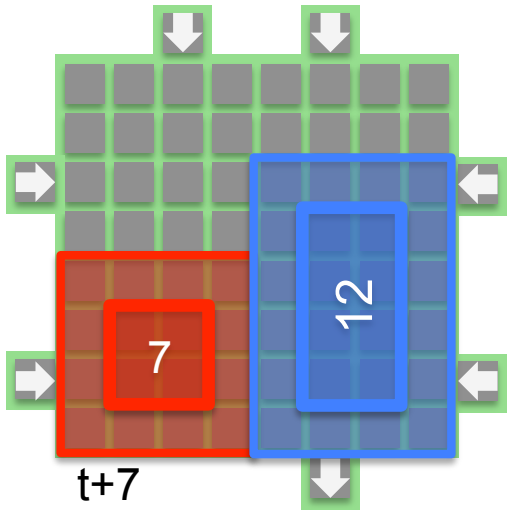
Concurrent biochemical applications

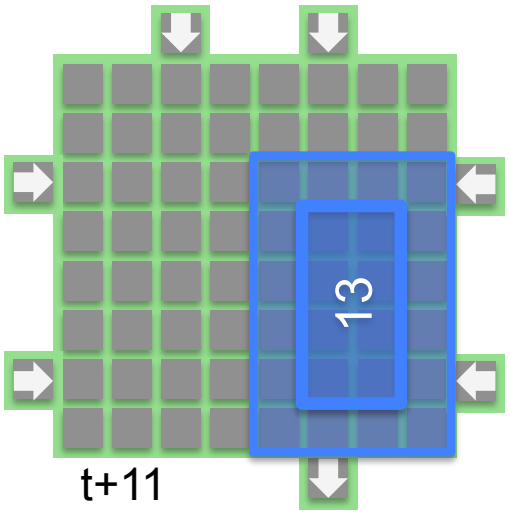
Scheduling with placement



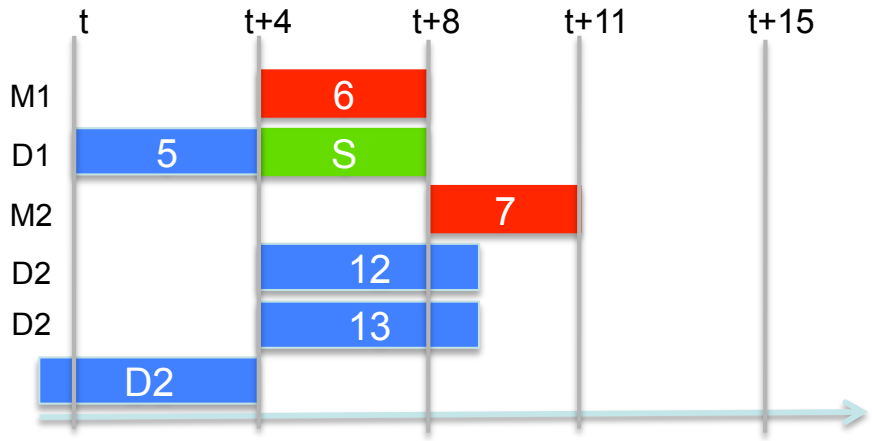


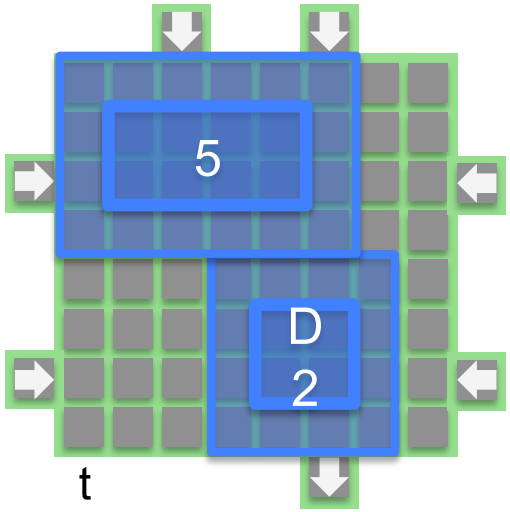


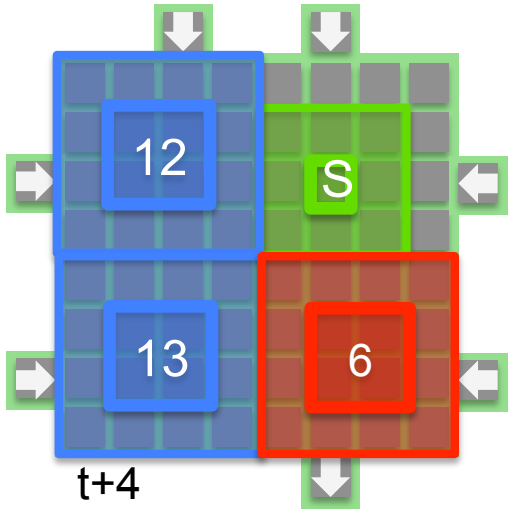


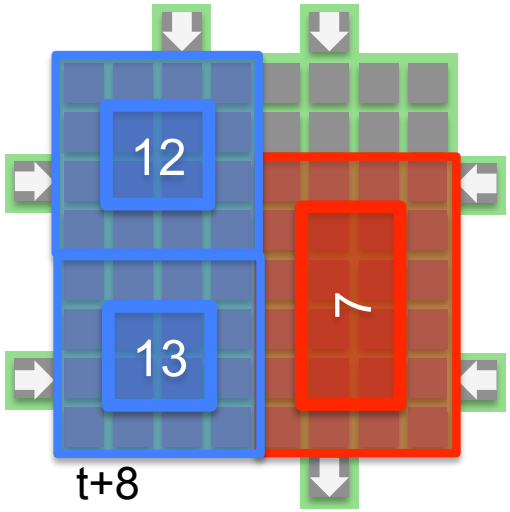


Scheduling with placement

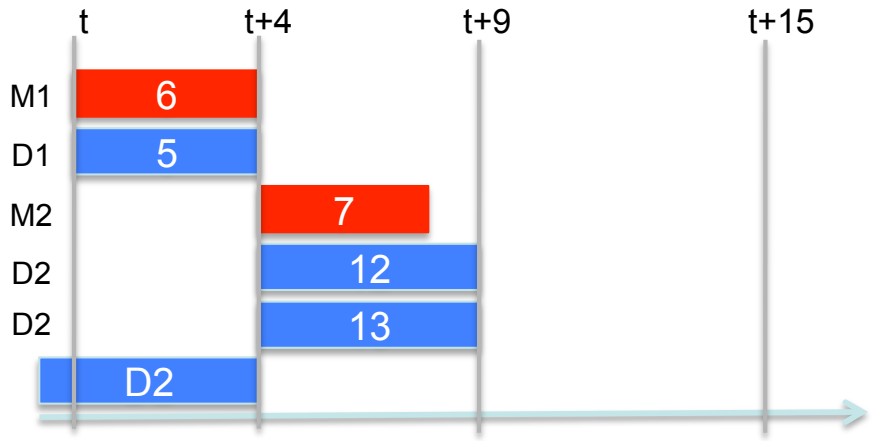


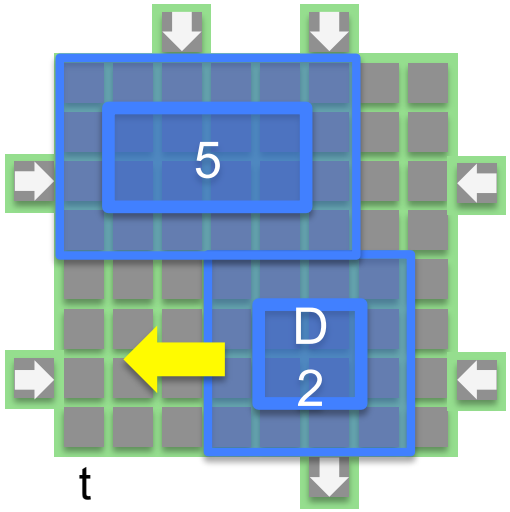


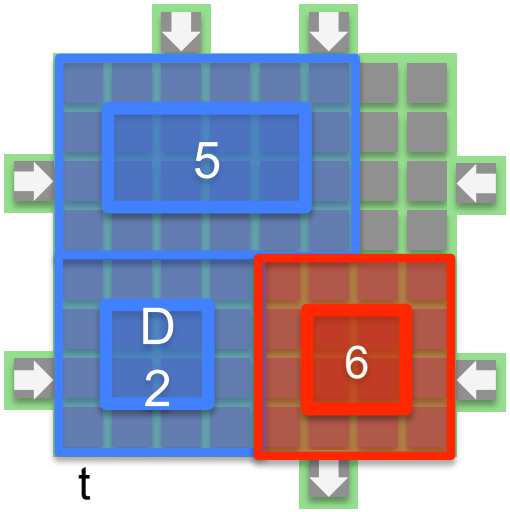


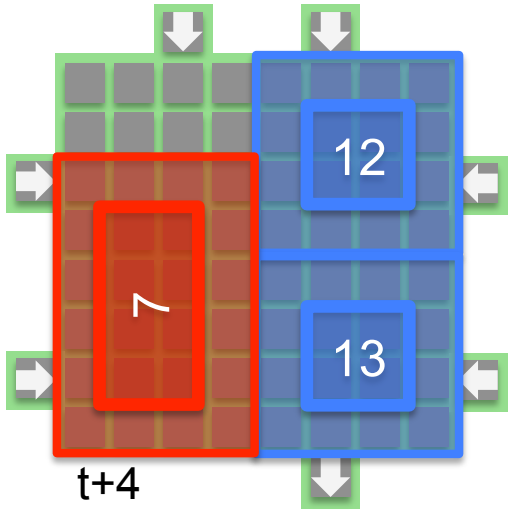


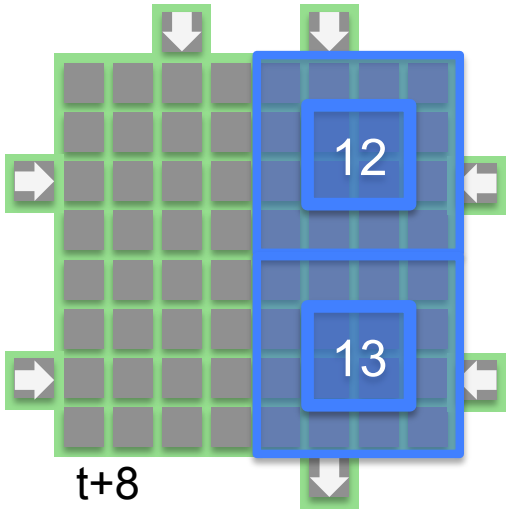
Scheduling with dynamic placement







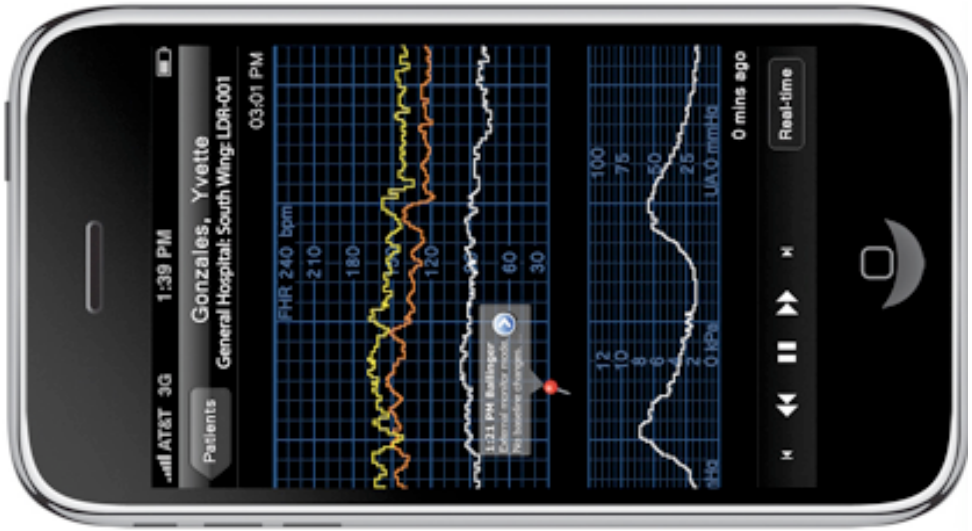


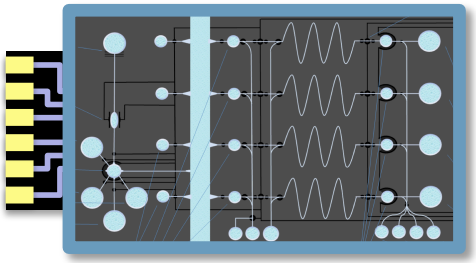


Summary

- Biochip architectures
- Synthesis of digital microfluidic biochips
- Run-time resource management leads to considerable better results
- Integration with MPSoC to allow online monitoring and feedback
- ➔ *Conditional biochemical operations*

Thank you for your attention





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