

Programmable Microfluidics

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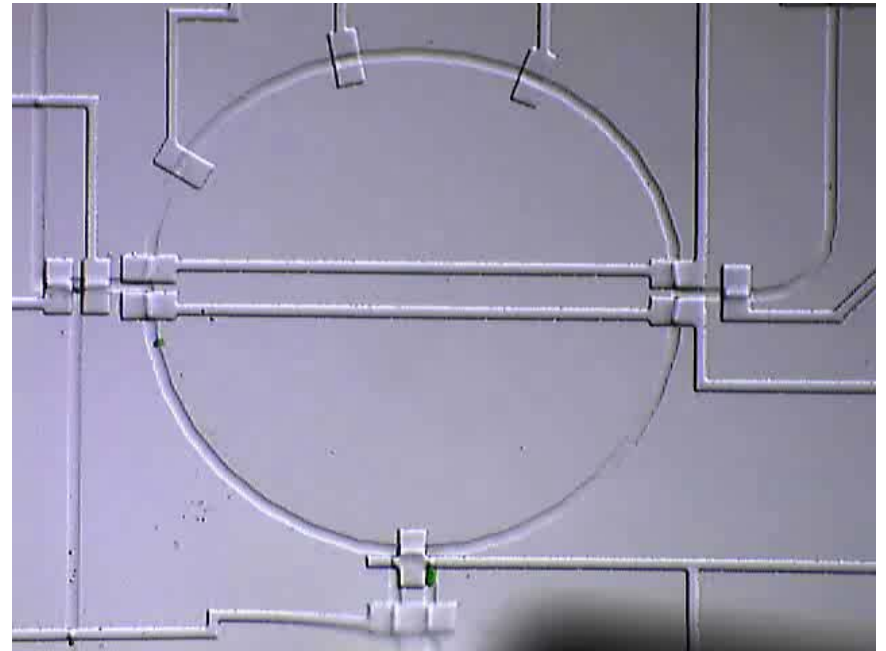
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Microfluidic Chips

- Idea: a whole biological lab on a single chip
 - Input/output
 - **Actuators:** temperature, light/dark, cell lysis, etc.
 - **Sensors:** luminescence, pH, glucose, etc.
- **Benefits:**
 - Small sample volumes
 - High throughput
 - Geometrical manipulation

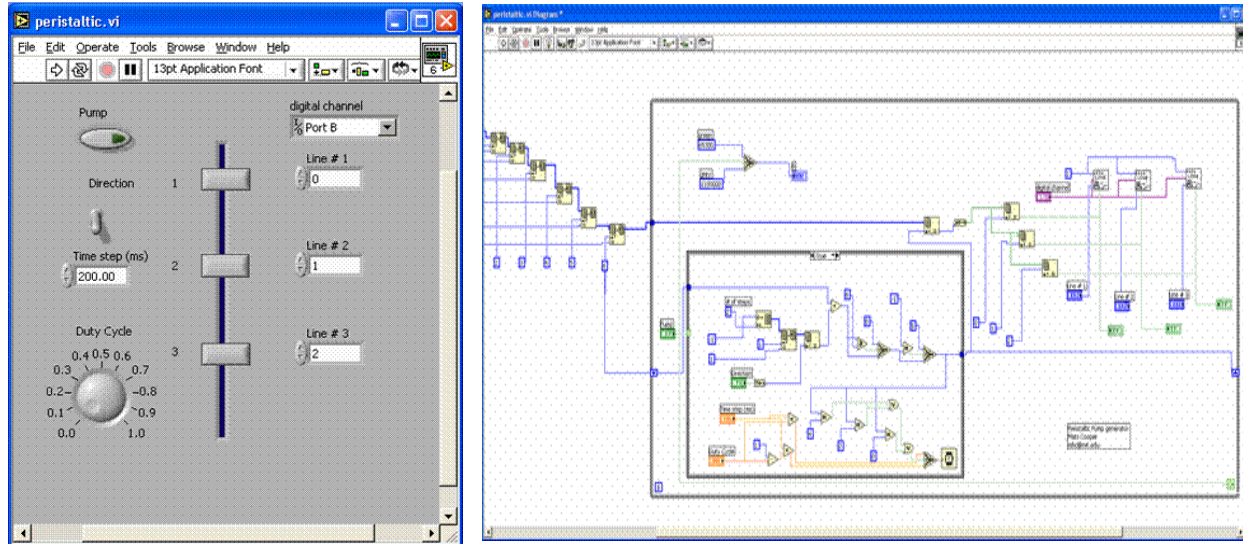


1 mm

Our Goal:

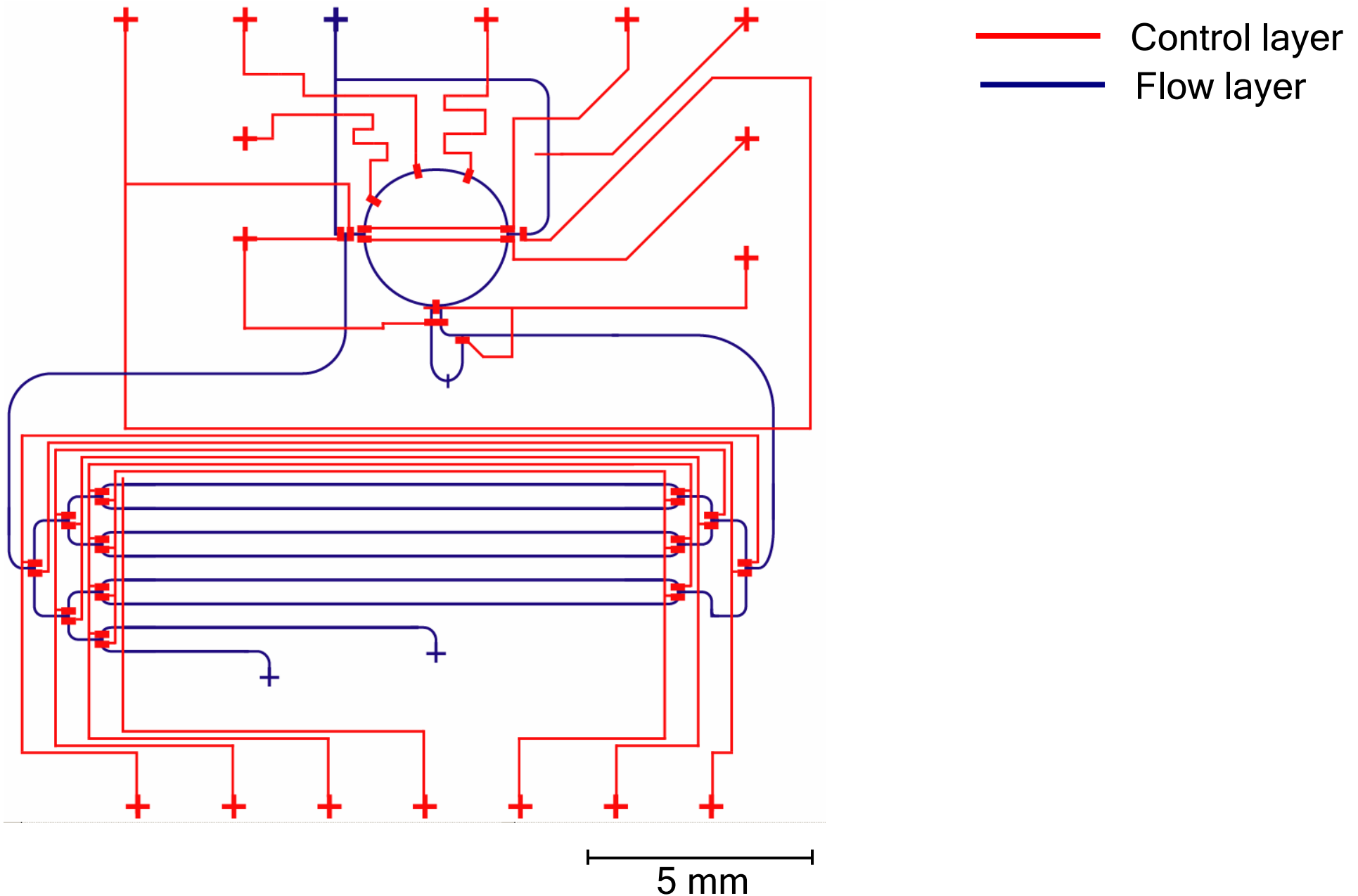
Provide Abstraction Layers for this Domain

- Current interface: gate-level control (Labview)

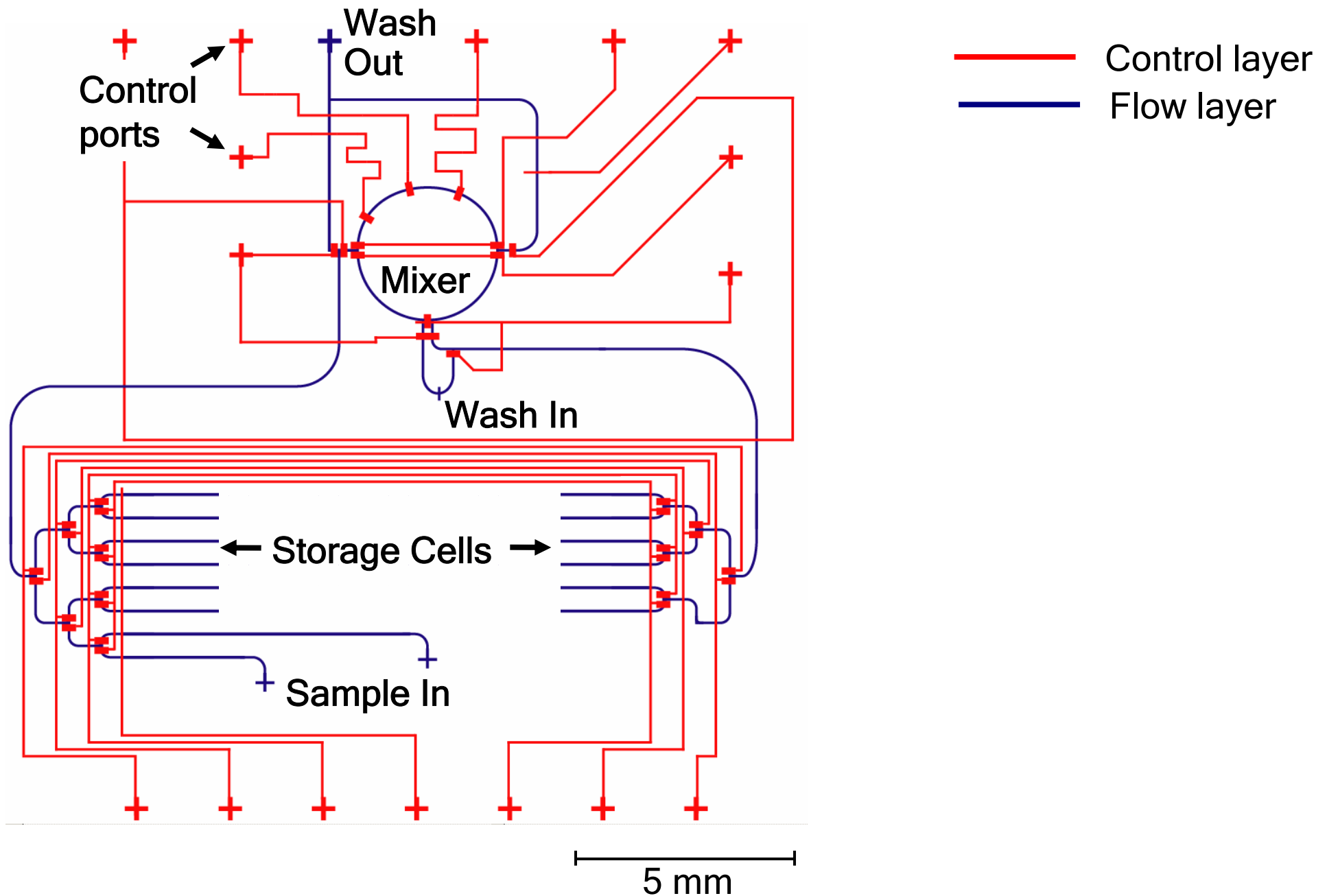


- New abstraction layers will enable:
 - Scalability
 - Portability
 - Adaptivity
 - Optimization
- NOT our goal: replace silicon computation

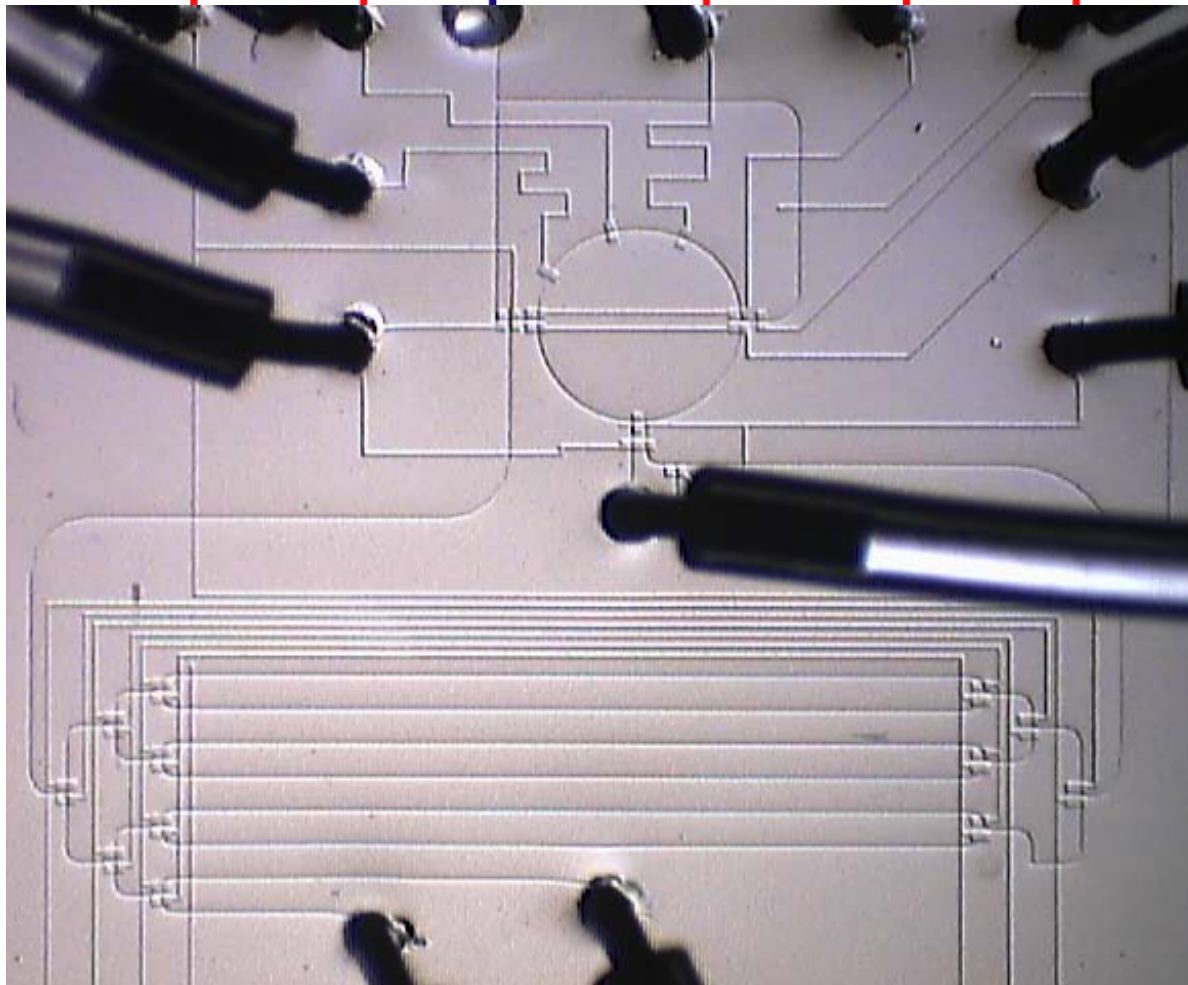
A General-Purpose Microfluidic Chip



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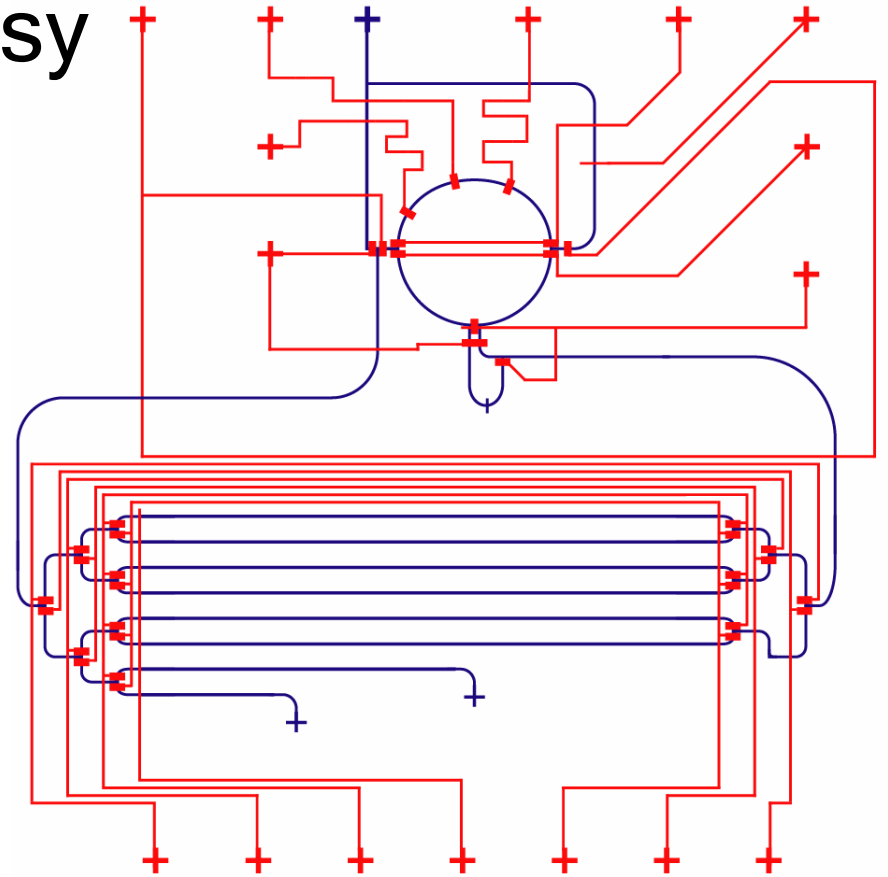


- Control layer
- Flow layer

5 mm

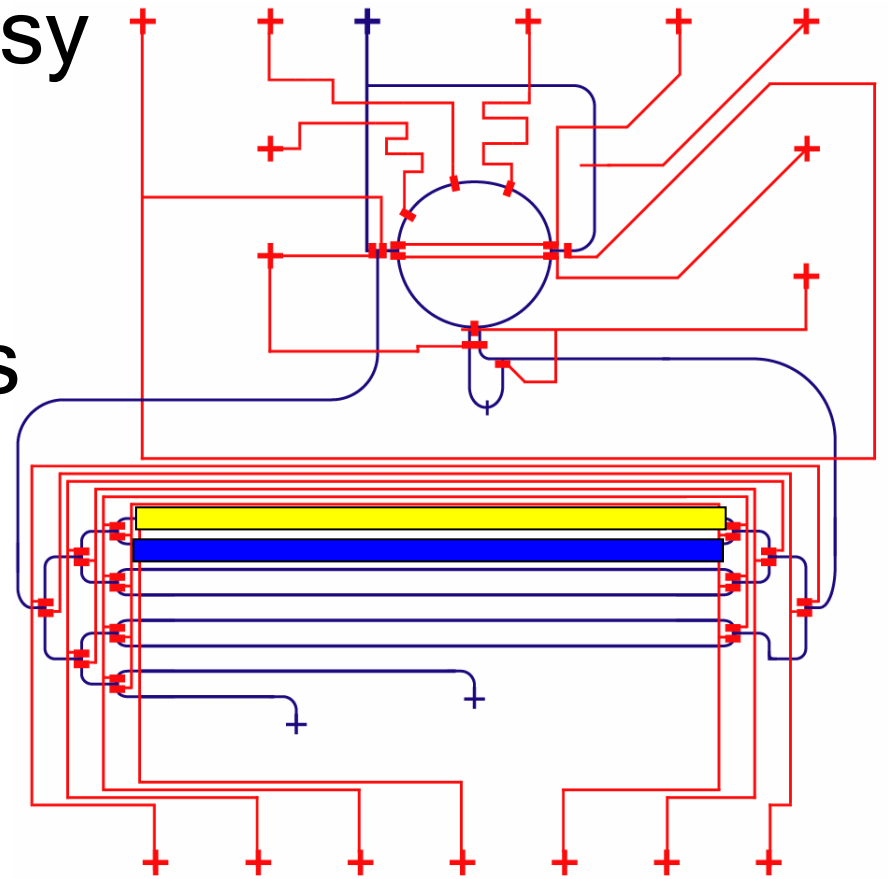
Providing a Digital Abstraction

- All fluid operations are lossy
- How to control the error?



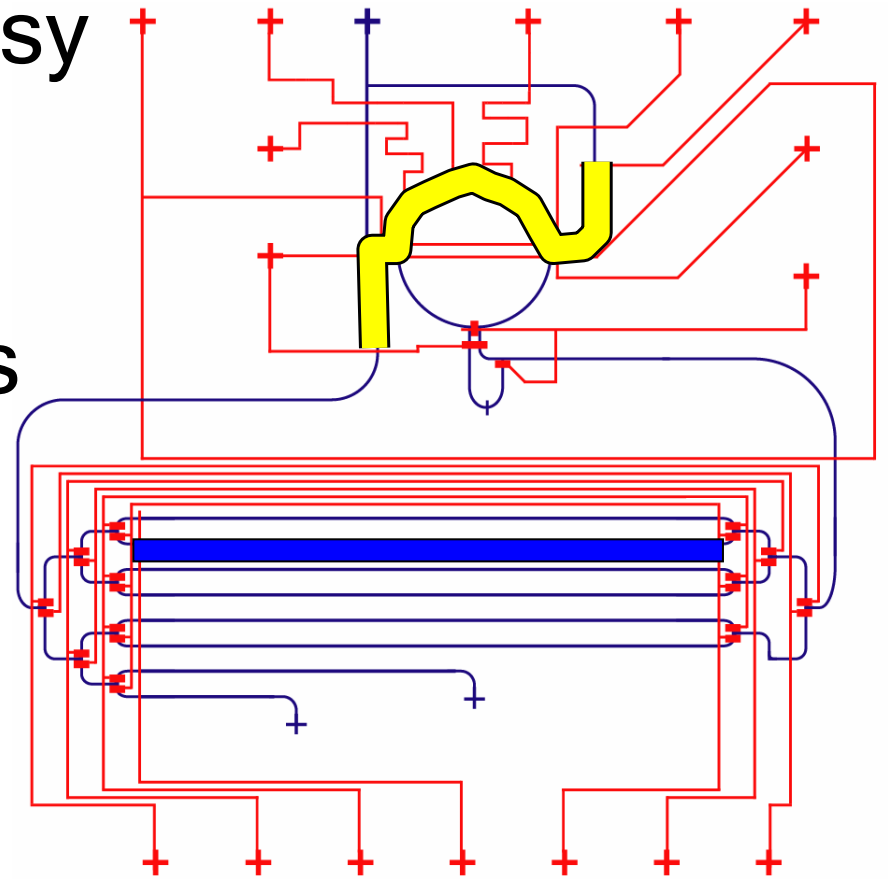
Providing a Digital Abstraction

- All fluid operations are lossy
- How to control the error?
- Solution: discrete samples
 - throw out half of sample on each mix



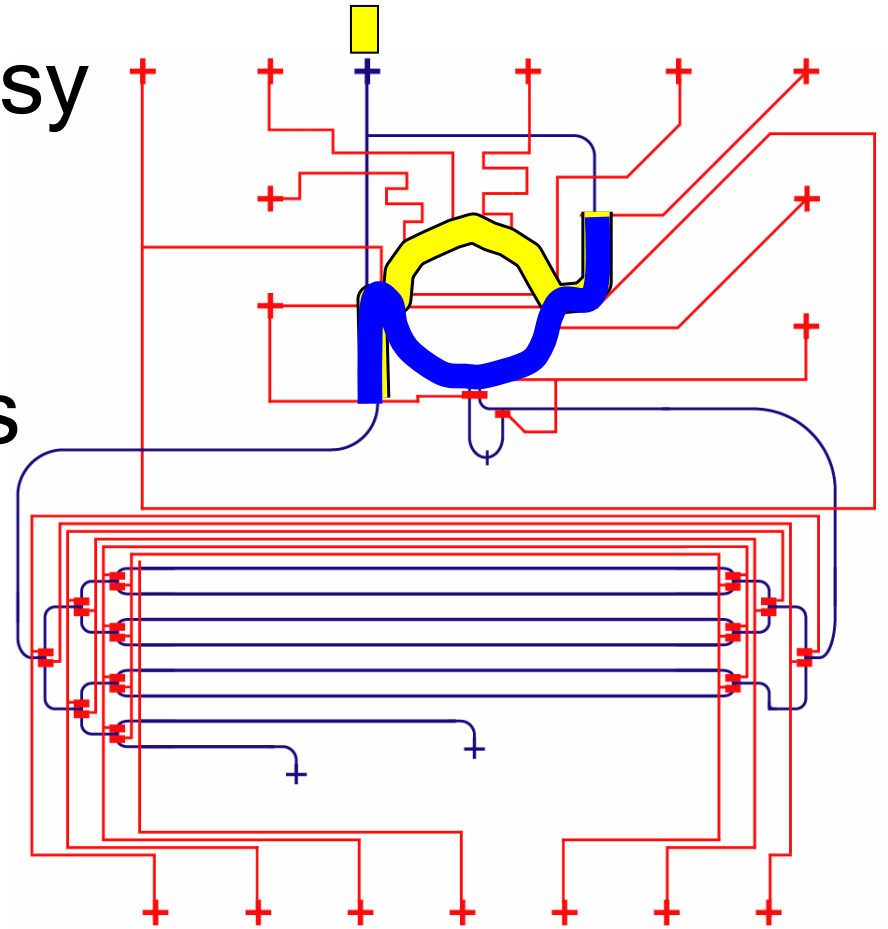
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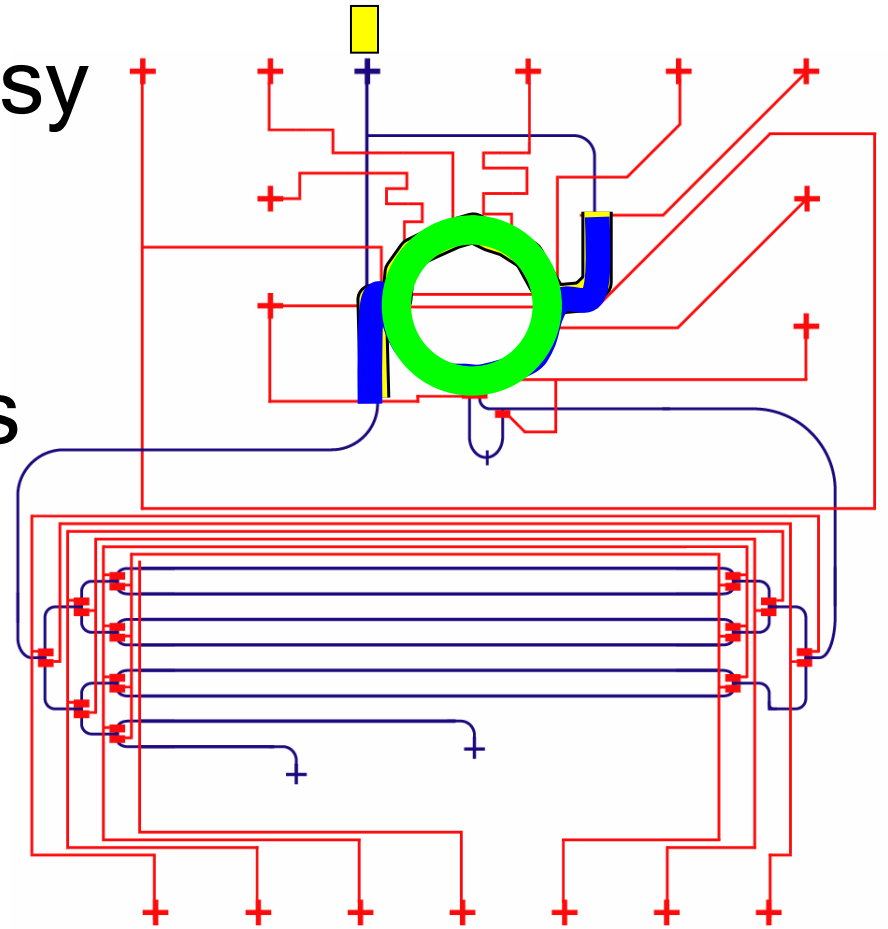
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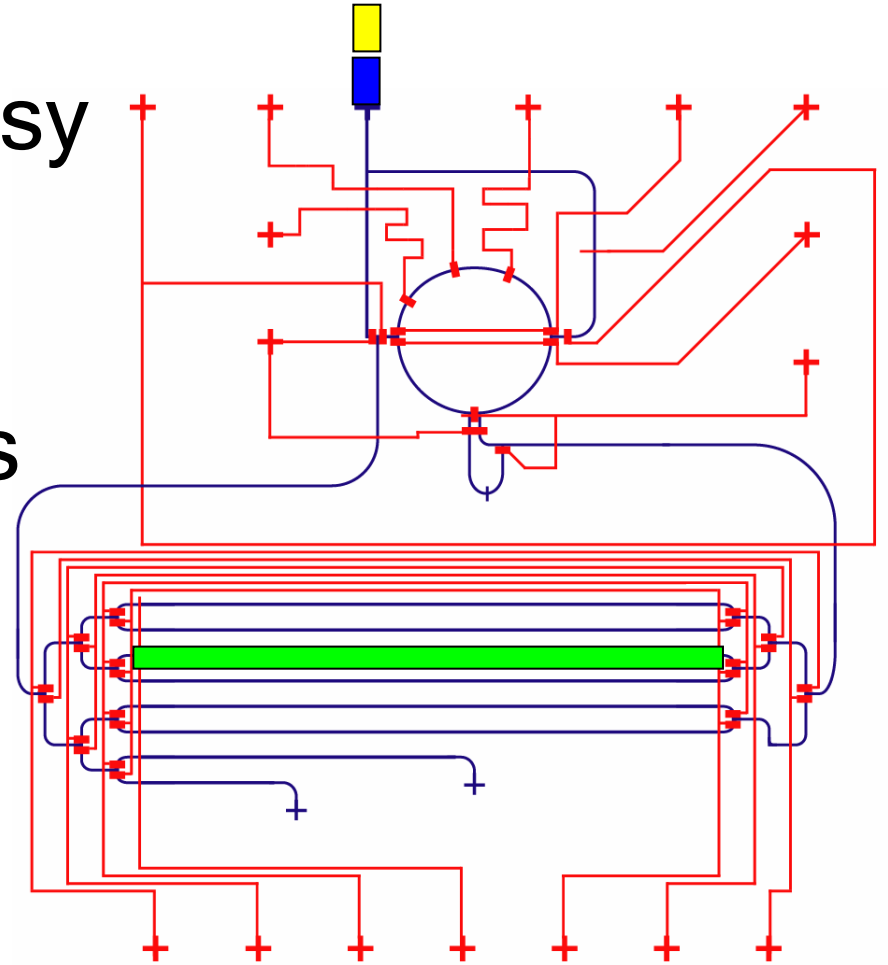
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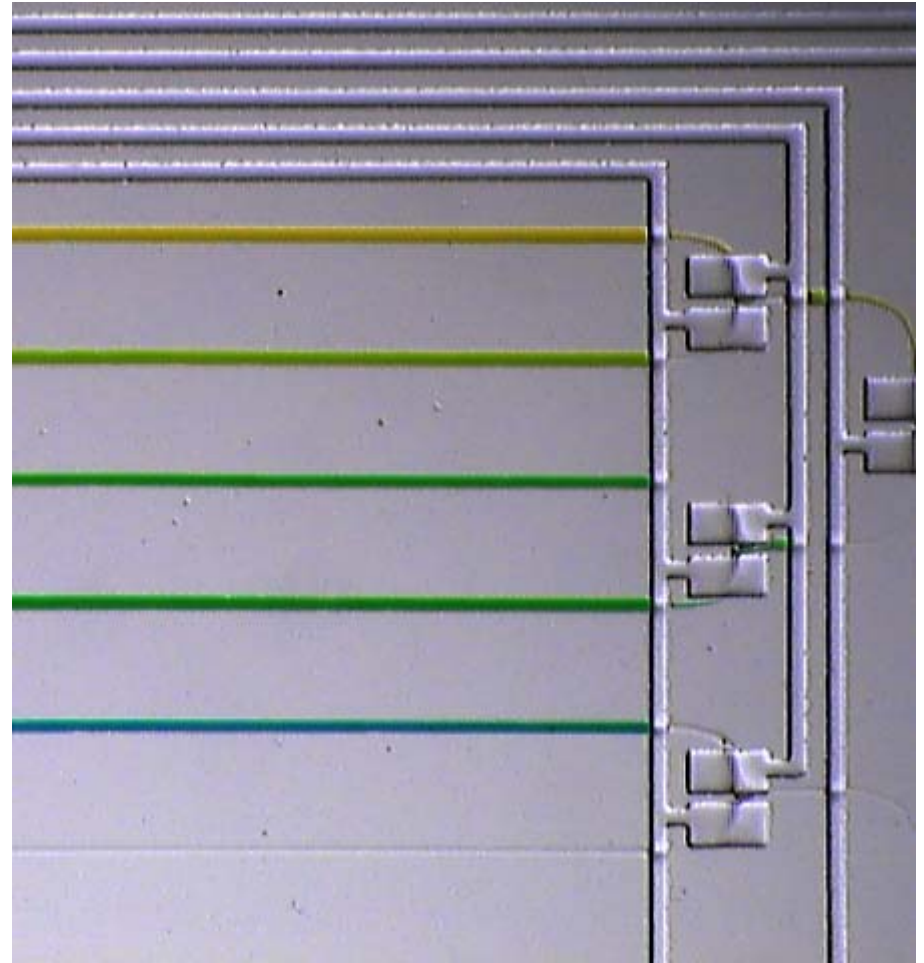


Programming Model

```
Fluid blue = input (0);  
Fluid yellow = input(1);  
for (int i=0; i<=4; i++) {  
    mix(blue, i/4, yellow, 1-i/4);  
}
```

New abstractions:

- Regenerating fluids
- Efficient mixing algorithms



450 Valve Operations

Example: Fixed pH Reaction

```
Fluid sample = input (0);
Fluid acid = input(1);
Fluid base = input(2);
do {
  // test pH of sample
  Fluid pH_test = mix(sample, 0.9, indicator, 0.1);
  double pH = test_luminescence(pH_test);
  // if pH is out of range, adjust sample
  if (pH > 7.5) {
    sample = mix (sample, 0.9, acid, 0.1);
  } else if (pH < 6.5) {
    sample = mix (sample, 0.9, base, 0.1);
  }
  wait(5);
} while (detect_activity(sample));
```

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Feedback-Intensive Applications:

- Cell isolation and manipulation
- Dose-response curves
- High-throughput screening
- Long, complex protocols

Opportunities for Computer Scientists

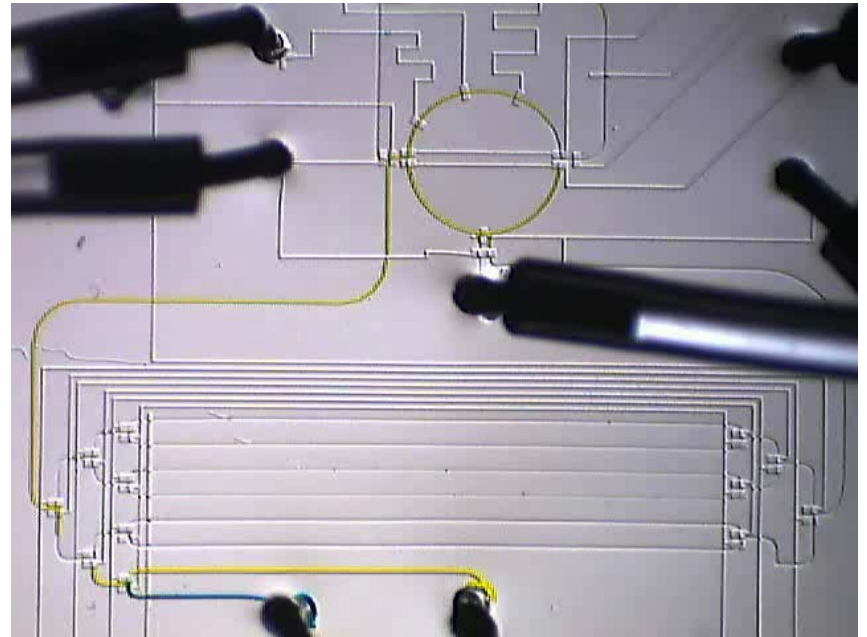
- Experimental biology is becoming a digital science
 - What are the right abstraction layers?
 - We can have a large impact

Software:

- scheduling
- programming abstractions
- verifying safety properties
- optimizing throughput, cost

Hardware:

- parallelism
- error tolerance
- reducing design complexity
- minimizing control overhead



- Vision: **A defacto language for experimental science**