Programmable Microfluidics

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1 Introduction

Recent years have seen tremendous miniaturization of chemical and biological instrumentation that is culminating in the advent of fully integrated "lab-on-a-chip" systems. Such systems out-perform their laboratory counterparts by providing high throughput, reduced reagent consumption, low cost and automatic control. The enabler of these advances is microfluidics: an integrating technology for manipulating fluids at the picoliter scale. Microfluidic chips have demonstrated basic functionality for single applications, but they have been lacking the abstraction layers needed to perform varied and complex experiments on a single platform.

2 Our Approach

We are developing a general-purpose platform for programmable microfluidics. Our vision is to apply the core principles of the computer science community to provide scalability, portability, and high-level programming abstractions for the microfluidic domain. Using novel abstractions, scientists will be able to orchestrate large, adaptive, and reusable procedures that are beyond the grasp of today's hardware-oriented user interface.

Programmable microfluidic chip. We have completed a prototype implementation of a general-purpose microfluidic chip. As depicted in Figure 1, the prototype contains a mixer, a 6-cell storage array, I/O, and a general interconnection network. The mixer is a rotary pump [1] that combines two fluid samples via continuous flow in a circular direction.

High-level programming abstractions. We have developed BioStream: a high-level language for describing microfluidic operations. One of the benefits offered by BioStream is a "digital abstraction" that allows the programmer to manipulate first-class fluid variables. A digital abstraction is needed because fluidic operations are lossy: once a fluid is used (for example, as the input to a mixer) it is consumed and is no longer available for future operations. Unlike with silicon computation, there is no hardware-based notion of "gain" to regenerate fluids after they have been used. To address this issue, the BioStream runtime system provides gain at the software level. BioStream tracks the sequence of mixes that were used to generate each fluid, such that if the programmer uses a fluid more than once, the sequence is repeated to regenerate the fluid of interest.

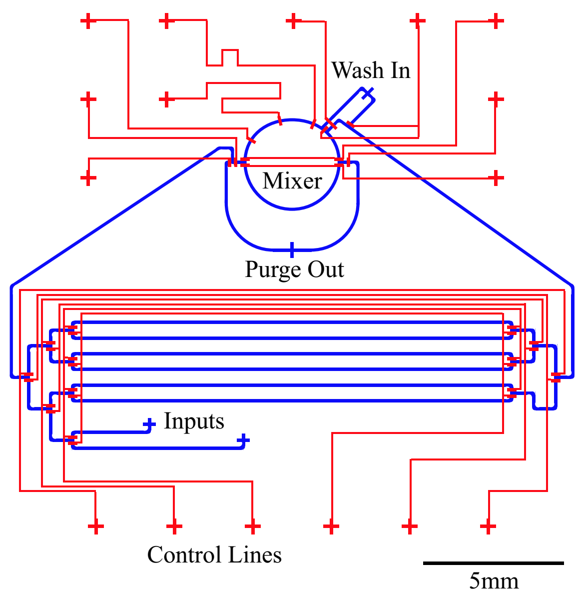

Figure 1: Programmable microfluidic chip.

3 Rationale

Just as programmability was the key to harnessing the power of silicon-based computers over the course of the last 50 years, we believe that a novel set of abstraction layers will be essential to harness the full power of microfluidic devices. Applications that can utilize programmability include adaptive enzymatic assays, fixed-pH reactions, automatic optimization of PCR conditions, feedback-driven directed evolution, and complex protocol sequences.

In the long run, we believe that the language used to describe experiments will even become a standard in the scientific community, appearing in the literature as a precise account of the methods employed. Multiple researchers will be able to replicate a procedure (or use it as a subroutine) by running the high-level description on their own microfluidic chip.

References

[1] H. Chou, M. Unger, and S. Quake. A microfabricated rotary pump. *Biomedical Microdevices*, 3:323–330, 2001.