Pin-count reduction for continuous flow microfluidic biochips

Microfluidic biochips are replacing the conventional biochemical analyzers integrating the necessary functions on-chip. We are interested in flow-based biochips, where a continuous flow of liquid is manipulated using integrated microvalves, controlled from external pressure sources via off-chip control pins. Recent research has addressed the physical design of such biochips. However, such research has so far ignored the pin-count, which rises with the increase in the number of microvalves. Given a biochip architecture and a biochemical application, we propose an algorithm for reducing the number of control pins required to run the application. The proposed algorithm has been evaluated on several biochips, including the AquaFlux biochip from Microfluidic Innovations LLC.
Synthesis of on-chip control circuits for mVLSI biochips

Microfluidic VLSI (mVLSI) biochips help perform biochemistry at miniaturized scales, thus enabling cost, performance and other benefits. Although biochips are expected to replace biochemical labs, including point-of-care devices, the off-chip pressure actuators and pumps are bulky, thereby limiting them to laboratory environments. To address this issue, researchers have proposed methods to reduce the number of off-chip pressure sources, through integration of on-chip pneumatic control logic circuits fabricated using three-layer monolithic membrane valve technology. Traditionally, mVLSI biochip physical design was performed assuming that all of the control logic is off-chip. However, the problem of mVLSI biochip physical design changes significantly, with introduction of on-chip control, since along with physical synthesis, we also need to (i) perform on/off-chip control partitioning, (ii) on-chip control circuit design and (iii) the integration of on-chip control in the placement and routing design tasks. In this paper we present a design methodology for logic synthesis and physical synthesis of mVLSI biochips that use on-chip control. We show how the proposed methodology can be successfully applied to generate biochip layouts with integrated on-chip pneumatic control.

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Volume management for fault-tolerant continuous-flow microfluidics

Recent advancements in microfluidic biochips allow for easier and faster design and fabrication of increasingly complex biochips to replace conventional laboratories. A roadblock in the deployment of biochips however is their low reliability. Physical defects can be introduced during the fabrication process, and may lead to failure of the biochemical application. This can be costly because of the reduced manufacturing yield, the need to redo lengthy experiments, using expensive reagents, and can be safety-critical, e.g., in case of a cancer misdiagnosis. Researchers have started to propose fault models and test techniques for continuous flow biochips. Six typical defects: Block, leak, misalignment, faulty pumps, degradation of valves and dimensional errors have been identified. The resulting faults can be abstracted into blocks and leaks for simplicity. Both fault types can occur in the control as well as the flow channel, some common causes being environmental particles, imperfections in molds or bubbles in the PDMS gel. While some faults may be detected before the execution of an application by introducing a test run, other faults occur only during runtime as a result of deterioration or caused by the applied pressure. If such a fault is detected during runtime, e.g. with a CCD camera, we propose a just in time solution that calculates and assigns fluid volumes to alternate components and routes allowing for the completion of the application despite the occurring fault.

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Waste-aware fluid volume assignment for flow-based microfluidic biochips

Microfluidic biochips are replacing the conventional biochemical analysers integrating the necessary functions on chip. We are interested in Flow-Based Microfluidic Biochips (FBMB), where a continuous flow of liquid is manipulated using integrated microvalves. Using microvalves and channels, more complex Fluidic Units (FUs) such as switches, micropumps, mixers and separators can be constructed. When running a biochemical application on a FBMB, fluid volumes are dispensed from input reservoirs and used by the FUs. Given a biochemical application and a biochip, we are interested in determining the fluid volume assignment for each operation of the application, such that the FUs volume requirements are satisfied, while over- and underflow are avoided and the total volume of fluid used is minimized. We propose an algorithm for this fluid assignment problem. Compared to previous work, our method is able to minimize the fluid consumption through optimal fluid assignment and reuse of fluid waste. Due to the algorithm’s low complexity, fluid requirements can also be calculated during runtime for error recovery or statically unknown cases.

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A Pin-Count Reduction Algorithm for Flow-Based Microfluidic Biochips

Microfluidic biochips are replacing the conventional biochemical analyzers integrating the necessary functions on-chip. We are interested in flow-based biochips, where a continuous flow of liquid is manipulated using integrated microvalves, controlled from external pressure sources via off-chip control pins. Recent research has addressed the physical design of such biochips. However, such research has so far ignored the pin-count, which rises with the increase in the number of microvalves. Given a biochip architecture and a biochemical application, we propose an algorithm for reducing the number of control pins required to run the application. The proposed algorithm has been evaluated using several benchmarks.

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