4bf Automatic Design of Biofluidic Microcircuits

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Real-world design problems are inevitably highly complex and multidisciplinary in nature. My work [1,2,3,4,5,6], which focuses on the automatic design of biofluidic microchips, is an example of such a real-world design problem. The goal in biofluidic microcircuit design is essentially to miniaturize an entire analytical chemistry laboratory onto a glass or plastic microchip about the size of a microscope slide. These chips, often called Labs-on-a-Chip (LoC), have been used throughout the life science and biomedical industries for applications in genomics, proteomics, drug discovery, and forensics [7]. Specifically, my work focuses on developing efficient algorithms to automatically generate and optimize designs for channel-based, electrokinetically driven microfluidic circuits.

LoC design is difficult because it combines complex physiochemical phenomena with challenging chip layout and channel interconnectivity issues. The chemistry that takes place during chip operation, as well as the chip layout and manufacturing process must be understood so that the appropriate design trade-offs and constraints are considered. Channel geometry, and the system's channel topology have been shown to contribute a great deal to the overall performance of the final LoC design [1]. These issues result in a design problem that is both highly nonlinear and highly combinatorial, especially when design automation is involved, which can result in the need to handle a large number of discrete decisions procedurally.

The bulk of the current work concerning LoC design involves time consuming laboratory experimentation or iterative simulation using computational fluid dynamics (CFD) or finite element modeling (FEM) packages [7]. While these approaches are excellent for analysis, they are inefficient for design optimization. More efficient system simulation approaches have been presented [8,9], however these tools generally require a great deal of user-interaction and are therefore not readily embeddable within an optimization framework. Some simple shortcut methods for specific LoC unit operations have been presented (eg. [10]), however, they lack the generality required for complete system level LoC design. The goal of my work has been to create the tools necessary to perform complete system level LoC design and optimization.

My work involves four major components: (1) The physical analysis and conceptualization of chip-based unit operations. (2) The development of an efficient system simulation framework [2] that implements accurate reduced-order models developed by colleagues [9]. (3) The formulation of the LoC design optimization problem. (4) The creation of efficient tailored solution algorithms that enable the design of complex LoC's. Since microscale processes often do not have macroscale counterparts, my first task was to conceptually decompose LoC's into a set of canonical microscale unit operations. A key component of my work was the identification of a single, compact set of independent physical parameters that allow efficient information passing between all models in a general way. The simulation framework that I developed is based on concepts taken from process flowsheet and electrical circuit simulation and is capable of handling a variety of chip-based unit operations such as mixing, reaction, injection and separation. I used mixed integer (MINLP) and general disjunctive math programming (GDP) languages to rigorously formalize the LoC optimization problem. Since the resulting problems can not be solved using traditional methods, I developed efficient customized heuristics, and adapted concepts from a range of fields including Very-Large-Scale-Integration (VLSI) circuit design, computational geometry and operations research.

My work allows complex microfluidic circuits to be simulated in only seconds. I developed high-speed heuristics and a rigorous optimal design approach for chip-based capillary electrophoresis systems [3]. This work was extended to the multi-objective problem where device size was minimized and device

performance was maximized which required a distributed computing approach [4]. In my most recent work, I created a multilevel design algorithm that is capable of simultaneously designing, interconnecting and laying out compact chips containing up to 30 capillary electrophoresis subsystems in only minutes to hours [5,6]. The current focus of my work involves extending my current formulations and solution strategies to the design of LoC's that incorporate mixing, reaction, injection and separation.

My complete **list of publications** can be found HERE

My Work:

[1] Pfeiffer, A.J., Mukherjee, T., and Hauan, S., "Topology Trade-offs in the Synthesis of Chip-Based Electrophoretic Separation Systems", in Proc. of NanoTech 2003 (MSM '03), 2003, pp. 250 - 253.

[2] Pfeiffer, A.J., Mukherjee, T., and Hauan, S., "Computer-Aided Synthesis of Microscale Electrophoretic Separation Systems in Confined Areas", in Proc. of International Mechanical Engineering Congress and Expo (IMECE 2003), 2003, MEMS-Vol. 5, pp. 15 - 24.

[3] Pfeiffer, A.J., Mukherjee, T., and Hauan, S., "Design and Optimization of Compact Microscale Electrophoretic Separation Systems", Ind. Eng. Chem. Res., 2004, pp. 3539 - 3553.

[4] Pfeiffer, A.J., Siirola, J.D., and Hauan, S., Optimal design of microscale separation systems using distributed agents, in Proc. of Foundations of Computer-Aided Process Design (FOCAPD 2004), 2004, pp. 381 - 384.

[5] Pfeiffer, A.J., Mukherjee, T., and Hauan, S., "Simultaneous Design and Placement of Multiplexed Chemical Processing Systems on Microchips", in Proc. of International Conference on Computer-Aided Design (ICCAD 2004), 2004, pp. 229 - 236.

[6] Pfeiffer, A.J., Mukherjee, T. and Hauan, S., "Automatic Design of Biofluidic Microchips", presented at Design Automation Conference Ph.D. Forum (DAC/SIGDA 2005) Anaheim CA, July 2005.

References:

[7] Geschke, O., Klank, H., and Tellemann, P., "Microsystem Engineering of Lab-on-a-Chip Devices", Wiley-VCH, 2004.

[8] Korsmeyer, T., Zeng, J., and Geiner, K., "Design Tools for BioMEMS", Design Automation Conference (DAC 2004), 2004, pp. 622 - 627.

[9] Wang, Y., Magargle, R., Lin, Q., Hoburg, J.F. and Mukherjee, T., "System-Oriented Modeling and Simulation of Biofluidic Lab-on-a-Chip", Transducers 2005.

[10] Griffiths, S.K. and Nilson, R.H., "Design and Analysis of Folded Channels for Chip-Based Separations", Anal. Chem., 2002, pp. 2960 - 2967.