The Munich Microfluidics Toolkit: Design Automation and Simulation Tools for Microfluidic Devices

(Invited Paper)

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***Abstract*—Microfluidic devices have become essential in biochemical and medical research, enabling high-throughput experimentation on compact and cost-effective platforms. However, the design and realization of microfluidic devices is a manual, tedious, and error-prone task. Additionally, multiple iterations for prototyping are often needed until a physical realization works as intended. Accordingly, methods for the *automatic* design and simulation of microfluidic devices are key—something that is standard in the design of conventional circuits and systems. In this work, we present the *Munich Microfluidics Toolkit* (MMFT), an open-source toolkit that provides corresponding tools for automating the design and simulation of microfluidic systems. For selected design tasks—such as the generation of meanders, gradient generators, organs-on-chip layouts, as well as ISO-compliant routing and validation—we showcase corresponding tools and provide an overview of simulators for microfluidics. MMFT helps researchers and engineers to design microfluidic devices in an automatic fashion (often with the click of a button) and to validate them through simulation across different abstraction levels. All tools are publicly available at https://www.cda.cit.tum.de/research/microfluidics/mmft/.**

***Index Terms*—microfluidics, design automation, simulation, abstraction**

I. Introduction

Microfluidic devices, also known as *Labs-on-a-Chip* (LoCs), offer a compact and cost-effective solution for automated and high-throughput biochemical and medical experiments on miniaturized platforms [1]. Recent advancements in the field have reached a new level of sophistication, including innovative diagnostic assays driven by the COVID-19 pandemic [2], [3], *Organ-on-Chip* (OoC) systems that mimic the physiological functions of human bodies [4], new manufacturing possibilities [5], and the emergence of ISO standards [6], [7].

These developments have led to more powerful microfluidic devices but, at the same time, present significant challenges for designers: precise dimensioning, placing and routing of components and channels, accurate injection of samples and chemicals, as well as timely initiation of processes such as mixing, heating, or incubation. Overall, designing microfluidic devices involves complexities akin to those in conventional circuit and system design. Yet, designers of these devices lack access to the advanced design and simulation tools that are standard in conventional circuit and system design [8], [9], often resorting to manual, intricate, and time-consuming methods.

The *Munich Microfluidics Toolkit* (MMFT), which is developed by the Chair for Design Automation at the Technical University of Munich, aims at addressing this gap. It provides a collection of design and simulation tools supporting researchers and engineers in realizing microfluidic devices. To this end, the toolkit explicitly utilizes experiences from related fields in which similar problems have already been considered, namely:

- *Electronic Design Automation* (EDA), a field that emerged with the arrival of electronic devices and is dedicated to automating the design of electronic circuits and systems. These methods can handle the design process of devices composed of billions of components/transistors—radically changing electronic devices throughout the years. Considering this and the fact that there are analogies between electronic chip design and designing microfluidic devices, there is potential for a similar revolution in the design of microfluidic devices.
- *Computational Fluid Dynamics* (CFD, [10]–[12]), i.e., the numerical simulation of fluid flow and related physical phenomena. Used thus far in, e.g., aerospace engineering, automotive engineering, chemical engineering—initial solutions to utilize those methods for simulating microfluidic devices have been developed and proved promising [13], [14].

Based on this background, several methods and tools have been developed and added to MMFT over recent years, including solutions for placement, routing, the design of channels and networks, as well as tools that support the ISO 22916 standard. In addition to that, the toolkit is under continuous development and is constantly extended with further solutions and tools to address emerging challenges and application domains in microfluidics.

In this paper, representative solutions and tools from MMFT are showcased. More precisely:

- *Meander Designer [15]*, a tool that automatically generates meanders—a frequently occurring entity in many microfluidic devices.
- *Gradient Generator [16]*, a tool that automatically generates designs for devices that produce mixtures of various concentrations.

- *Organs-on-Chip Designer [17], [18]*, a tool that automatically generates designs for experiments with multiple organs on a single chip.
- *ISO Design Tools* that automatically
  - generate ISO-compliant routings of channels in a microfluidic component (*Routing Tool [19]*), and
  - automatically validate the ISO compliance of microfluidic chips (*ISO Validation [20]*).

In addition, we also showcase the *MMFT Simulator*, which provides simulation methods on different levels of abstraction to produce results that are fast, accurate, or a combination of both for

- continuous flow networks [14], [21], [22],
- species concentrations and mixing [23],
- droplet-based microfluidics [14], [24]–[26], and
- membrane models, e.g., for organs-on-chip [26].

All of these tools and more are available online at https://www.cda.cit.tum.de/research/microfluidics/mmft/. Many feature an intuitive user interface or are distributed as packages for the Python programming language. This ensures that the implemented methods are easily accessible and usable by the broader microfluidic community. This paper provides a representative showcase of these tools, while more detailed descriptions and technical foundations are available in the corresponding references.

The remainder of this paper is structured as follows: First, we review microfluidic devices and the corresponding design process in Sec. II. In Sec. III, we present the design automation tools of MMFT. Correspondingly, Sec. IV covers the MMFT simulation tools, before the paper is concluded in Sec. V.

II. Microfluidic Devices and their Design Process

A. Microfluidic Devices

Microfluidics is a highly interdisciplinary research area focused on precisely controlling and manipulating fluids at small scales, typically ranging from micro- to picoliters [1]. At these dimensions, common fluid operations, such as mixing, heating, and incubation, etc., can be combined into a single microfluidic chip. This way, bulky laboratory equipment can be miniaturized into LoCs using microfluidics [27], [28]. Compared to traditional laboratory set-ups, LoCs have several key advantages:

- *Miniaturized Platforms:* The small scale leads to significantly reduced sample volumes, which is an important factor when it comes to costly reagents or limited samples, and requires less space (in the laboratory) for the set-up.
- *Automation and High-Throughput:* The integration of multiple operations into a single chip allows to highly automate processes, for which usually qualified and expensive staff would be required. Additionally, parallelization of these processes allows to increase the throughput and make it more time and cost effective.
- *Point-of-Care (PoC) Testing:* Certain LoCs can perform diagnostic assays directly at the patient's side, eliminating the need for a centralized lab or time-consuming transport (e.g., COVID-19 rapid self-tests and pregnancy tests).

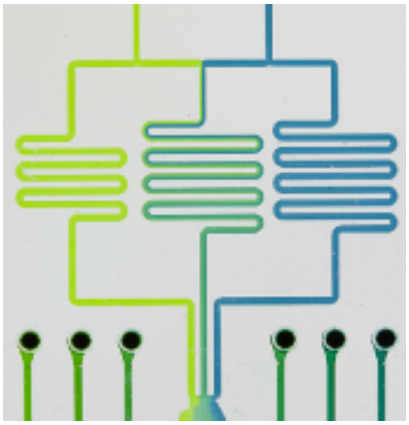

Fig. 1: Microfluidic chip creating a gradient.

In Fig. 1, an example of a microfluidic device is shown: a gradient generator that mixes two fluids, one of the aforementioned fluid operations. The device has two inlets into which yellow and blue fluids enter the chip. Due to channel splitting and merging, the fluids are moved through the chip, allowing them to mix. This way a concentration gradient is generated. By carefully designing the channel geometry, the flow rates can be precisely controlled and, thus, desired mixing ratios are realized.

Advancement in the development of LoCs and more complex channel networks paves the way for integration and realization of complex assays, which are combinations of the aforementioned fluid operations. However, the more complex the chip design gets the more complex their design process is, especially in channel-based chips where local changes to one component of the chip affect the entire flow field and subsequently the behavior of the chip [29]. Therefore, the design process of these microfluidic chips requires a considerable amount of work. In the next section, this design process is detailed, as well as possibilities to improve the current state of the art.

B. Design Process

Miniaturizing experiments and lab procedures on microfluidic chips brings many benefits, but designing these chips is no straightforward feat.

In Fig. 2, the workflow is depicted. Currently, the design of the device is based on the desired functions for the planned experiment. For this, a chip design needs to be created, specifically the required functional components need to be realized through a microfluidic channel network. Thus far, this is still mainly done by a domain expert who needs to design and calculate these required channel network geometries by hand, resulting in a manual, tedious, and error-prone design process.

Once the desired operations are realized through a chip design and the microfluidic channel network geometry is finalized, the chip can be fabricated and tested. However, if the fabricated chip does not work as intended, the process needs to go back to the drawing board to debug the design, resulting in long and costly debugging loops.

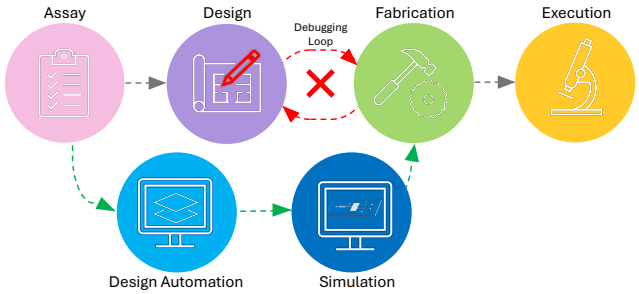

Fig. 2: Workflow of the development process of a microfluidic device.

Here, introducing design automation methods supports non-experts in designing the desired microfluidic chip and facilitates redesigns. Additionally, methods for simulation and validation can be introduced. The simulation verifies functionality and identifies potential errors or problems in the design, like uneven flows, false pressure drops, or inconsistencies. Then, corresponding design choices can be revisited even before the chip is fabricated, subsequently reducing the length and effects of the debugging loops. Once the simulation results in the desired outcome, the device can be fabricated and the desired experiment can be executed.

By integrating automated design algorithms and efficient simulation engines, the previously long and iterative design workflow of microfluidic chips can be streamlined by generating desired and verified designs at the push of a button. This allows to collapse these loops into a straight forward workflow and substantially reduces development time, ensures designs follow consistent principles, and minimizes human error. Sec. III and Sec. IV present a collection of such automated design tools and simulation approaches, respectively.

III. Design of Microfluidic Devices

The design of microfluidic devices frequently includes repetitive and labor-intensive tasks. Currently, those tasks are still mostly done manually. MMFT aims to assist microfluidic designers by automating such tasks. To this end, various design tools have been developed as part of MMFT, many of which offer interactive and user-friendly graphical interfaces or easy-to-use Python interfaces. In the following, we showcase representative design automation solutions and tools from MMFT.

A. Meander Designer

When creating the design of a microfluidic device, designers frequently have to handle reoccurring entities. *Meander channels* (an example is depicted at the bottom of Fig. 3) are one example, which are used in different platforms but always have to fit the respective application and design rules. Due to the frequency of their occurrence, a substantial amount of design time has to be used for designing meanders.

1) Design Task: The goal of generating meander channels is to realize a channel design that precisely implements a desired hydrodynamic resistance or total volume, ensuring that a larger network of channels behaves as intended. The hydrodynamic resistance, however, depends on the channel

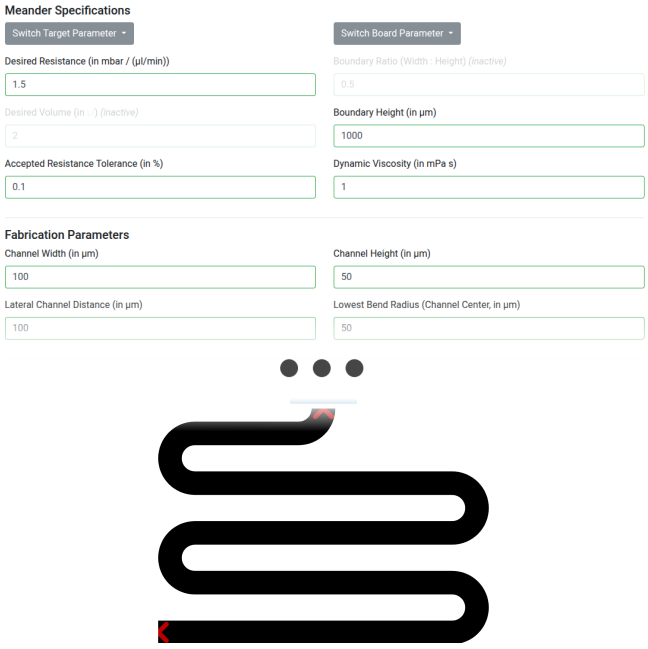

Fig. 3: Meander Designer.

width, height, and length, and on the viscosity of the fluid phase. Additionally, practical considerations such as precise inlet/outlet positions, lateral distance between channels, total channel volume, and width/height ratio of the entire meander play a role in the resulting design. Furthermore, non-ideal fabrication results have to be accounted for in the form of a correction factor. For example, in the process of soft lithography, the fabrication results, e.g., the actual channel width, depends on a variety of parameters such as the photo mask, the exposure step, the development step, and various tempering steps. Therefore, an (optional) correction factor in form of a constant or first order function is introduced in order to factor in such fabrication defects.

2) Design Tool: In order to facilitate the design of such meander channels, a tedious manual task thus far, we developed the *Meander Designer* [15], a tool that generates meander channels automatically while still considering all of the aforementioned parameters and constraints. Using the web-based GUI as shown in Fig. 3, the designer only has to provide the desired parameters. Then, by the click of a button, the tool fully automatically generates the desired meander design as a *Scalable Vector Graphics* (SVG) file. Using this file, further steps (such as fabricating the design) can be conducted. The tool is available online at https://www.cda.cit.tum.de/research/microfluidics/meander_designer/.

B. Gradient Generator

Concentration gradient generators are common components of microfluidic devices when specified mixing ratios have to be acquired for biological and chemical research [30], [31]. Especially tree-shaped gradient generators, comprised of branching and mixing via meander channels, are commonly used due to their flexibility in concentration values and their ability to maintain the gradient profile indefinitely.

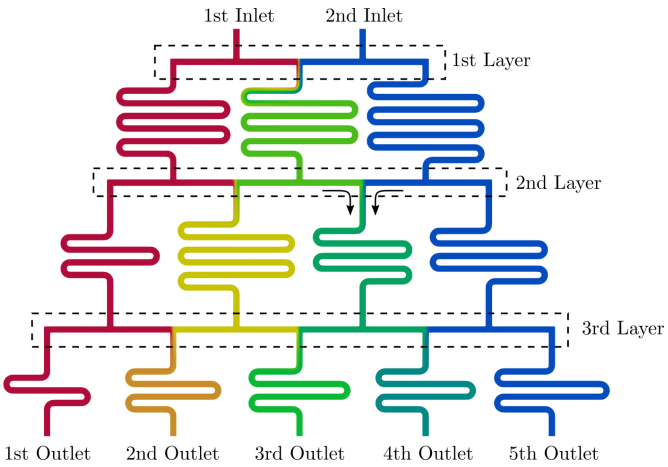

Fig. 4: Gradient Generator design.

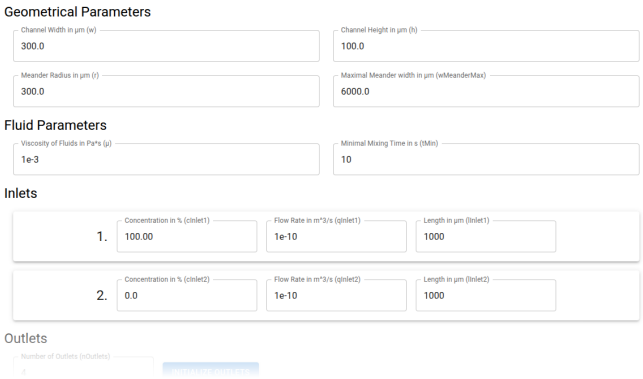

Fig. 5: Gradient Generator tool.

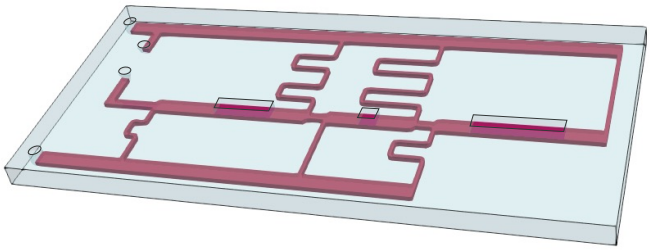

Fig. 6: Geometry output of the MMFT OoC Designer with three modules.

1) Design Task: An example of a gradient generator is shown in Fig. 4. Considering two inlets with given fluid concentrations (red and blue), the goal is to create the design of a gradient generator such that each outlet provides a different mixture with a desired concentration (e.g., Fig. 4 depicts 5 outlets: red, orange, green, teal, and blue). Whenever two fluids arrive at a channel branch, they mix according to their respective concentrations, flow rates, and the subsequent channel length, which can be moderated by introducing meander channels. Additionally, various microfluidic and geometric features and parameters have to be considered, e.g., channel width and height, radius of arcs, fluid viscosity, and minimum mixing time. All of these parameters affect each other and, hence, make determining a design realizing the desired concentration ratios a highly non-trivial task.

2) Design Tool: In order to simplify this time-consuming design task, we developed the *Gradient Generator* [16], which automatically creates designs of tree-shaped concentration gradient generators with the desired parameters. The tool provides an easy-to-use web-based interface (depicted in Fig. 5) where all desired input parameters can be specified. A design of a gradient generator can then be created by a simple click on a button. The resulting design can be exported as a SVG file. Again, this file can be used for further steps such as fabricating the design. Overall, this completely turns a tedious and error-prone manual design step into a fully automatic process in which only basic parameters have to be provided. The gradient generator tool is available online at https://www.cda.cit.tum.de/research/microfluidics/gradient_generator/.

C. Organs-on-Chip

Organs-on-chips (OoCs) represent parts of human or other animal physiology on a chip and, by this, are able to mimic the physiological functions of the body and provide in vitro testing platforms for the pharmaceutical, cosmetic, and chemical industries [4]. They are composed of miniaturized organ tissues (so-called organ modules). The connection between those organ modules is achieved via a *microfluidic channel network* and, by this, represents organ functionalities and their interactions on-chip, with the hope to ultimately replace animal testing.

1) Design Task: Designing microfluidic channel networks that connect multi-OoC geometries is a complex task that requires sophisticated orchestration of numerous aspects. To accurately represent the desired physiology on chip, the defined modules are scaled in proportion to each other. Additionally, a target shear stress is defined and implemented via the flow rate. Finally, the channel dimensions, more specifically the width and lengths of the channels at constant channel heights as well as the pump pressures are calculated to generate the desired design.

2) Design Tool: The *MMFT OoC Designer* automatically generates and exports the complete chip design for multi-OoCs [17], [18]. For this, the tool

1) computes the formal design specifications,
2) iteratively
   - corrects pressures,
   - adapts channel lengths, and
   - corrects offsets,
3) generates a 2D layout of the device, as well as
4) translates it into 3D, and exports it, ready for subsequent simulations and fabrication.

The generated 2D and 3D designs can be exported as SVG and *Standard Triangle Language* (or *STereoLithography*, STL) files, respectively. Fig. 6, showcases a colored in version of the resulting 3D geometry. The open-source tool and a step-by-step tutorial are available at https://github.com/cda-tum/mmft-ooc-designer.

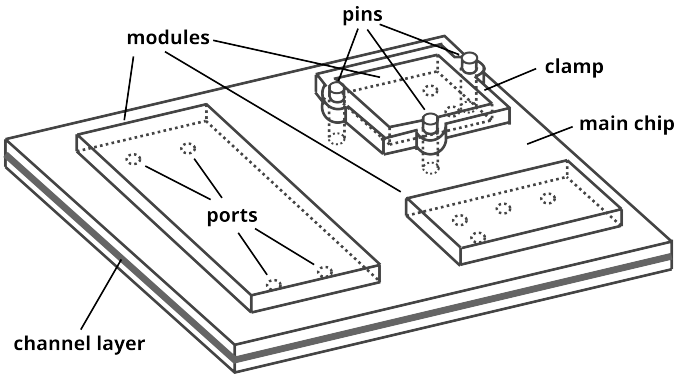

Fig. 7: ISO-22916-compliant architecture.

D. Design of ISO-22916-Compliant Microfluidic Chips

Until recently, microfluidics in general, and the organs-on-chip subfield in particular, suffered from a lack of standardization, leading to a limited interoperability of different devices. Fortunately, this is beginning to change with the introduction of *ISO 22916:2022* [6], an international standard that aims to improve this and, therefore, enable more complex and interconnected microfluidic devices consisting of multiple components. A representation of the general device architecture based on this ISO standard is illustrated in Fig. 7. On such a device, different modules can be mounted on a main chip and connected via ports, i.e., openings that allow for the transfer of fluids between different components. The design tasks that naturally arise here are the placement of modules and routing of microfluidic channels (for which initial non-ISO-compliant solutions have been proposed, e.g., in [32], [33]). To this end, we developed two tools that aim to facilitate the design of microfluidic devices that adhere to this standard. The first one, the *MMFT Routing Tool*, is able to automatically route channels on a single component with certain design constraints. The second one, the *MMFT ISO Validation Tool*, examines placement and routing validity of the main chip, including interconnection of modules. Both of these tools are introduced in the following sections.

1) MMFT Routing Tool: As an example for component design, we considered the *Stand-Alone Reconfigurable and Translational* (STARTER) platform [7], which builds on the *ISO 22916* standard and increases device interoperability and design freedom for the user due to its modularity, reconfigurability, and material-agnostic interfacing. The platform's architecture allows for experiment flexibility through a central component, the so-called *routing block*, which dictates fluidic connections between the interfaced components such as pumps, sensors, and Organs-on-Chips. Such connections are established by microfluidic channels that carry the fluid between different ports (i.e., interfaces to other components) of the routing block.

a) Design Task: Depending on the complexity of the experiment setup, and, therefore, on the number and characteristics of desired connections to be implemented, designing these routing blocks constitutes a complex task where many parameters such as channel width and spacing, port diameter, pitch, etc, have to be considered. Thus far, this design task was handled manually in CAD software starting from a routing block template, a process that is tedious and prone to human error.

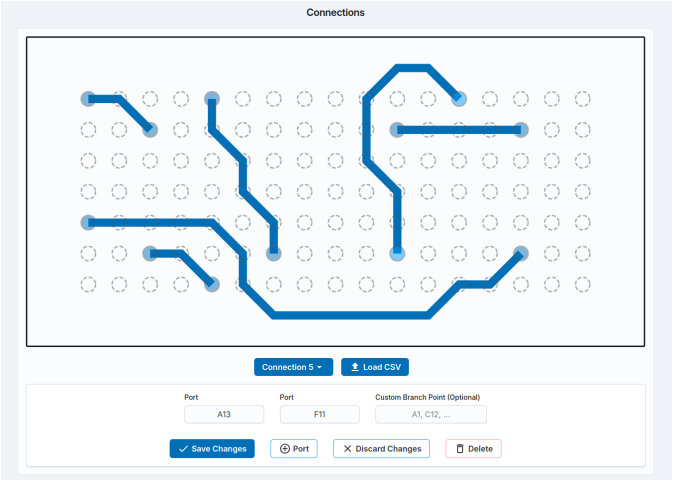

Fig. 8: Routing Tool.

b) Design Tool: In an effort to automate this, we developed the *MMFT Routing Tool* [19], parts of which are depicted in Fig. 8. Connections can be created in a *click-and-point* fashion or by typing the corresponding port identifiers. Additionally, connections can also be imported from a CSV file. Finally, the tool offers the option to export the generated design of the routing block as DXF, a popular CAD format that can be used for fabrication. By using this tool, a reduction in design time from originally $\sim 2\,\mathrm{h}$ to merely $\sim 30\,\mathrm{min}$ was observed during the design and fabrication of the examples. Errors were reduced as well, as designers could focus on simply checking that the correct connections were selected, rather than needing to extensively check the full channel geometry. Last but not least, this shift in focus encourages collaborations with those who may have less design experience. The MMFT Routing Tool is available at https://www.cda.cit.tum.de/app/mmft-routing-block-channel-router/.

2) MMFT ISO Validation Tool: As opposed to single component design, ISO-compliant microfluidic system typically consist of several components. Such components are placed on a main chip board where they are interconnected with microfluidic channels. The design of such systems quickly becomes a complex and time-consuming task.

a) Design Task: Here, we again consider the ISO-based architecture as previously introduced (depicted in Fig. 7). This time, the focus is on geometric constraints that stem from the interconnection of modules. As illustrated in Fig. 9, geometric features such as module size and spacing, occupied ports, clamps, pins, etc., have to be considered. When routing comes into play, additional constraints come into play, e.g., channel width, distance between channels, routing exclusion zones, etc. Last but not least, placement and routing heavily depend on each other, as a change in module placement induces a change in routing and vice-versa. Thus, even for moderately sized devices placement and routing constitutes a complex task with a large scope of possible errors.

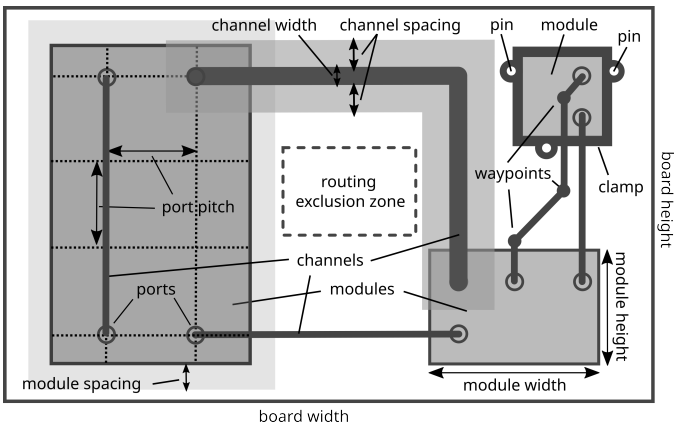

Fig. 9: Chip geometry.

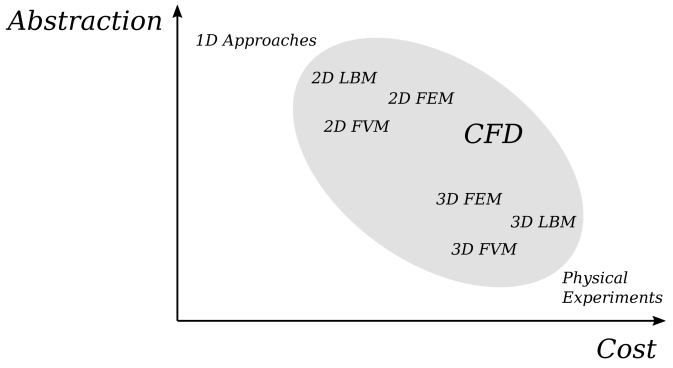

Fig. 10: Abstraction levels of microfluidic models with respect to their cost [14].

b) Design Tool: We developed an approach [20] based on *Satisfiability Modulo Theories* (SMT) that allows for easy implementation of the various aspects of the ISO standard (using inspiration from similar SMT-based approaches as proposed, e.g., in [34]–[38]). All relevant geometric constraints are encoded as equations and fed to a state-of-the-art SMT solver, which then verifies whether any of the parameters is in violation with the ISO standard. Furthermore, this approach can be used to complete a partially given design. For example, while some modules could already have a predetermined placement, other modules and their connecting channels could then be designed by the solver. Thus, the proposed method can assist with the design of ISO-compliant microfluidic devices. The corresponding implementations of the MMFT ISO Validation Tool are available at https://github.com/cda-tum/mmft-iso-designer/.

IV. Simulation

Simulation methods facilitate and speed up the design process. They allow to test and review the validity of a given design, without the need to fabricate, e.g., a microfluidic chip, beforehand [39], [40]. Simulation methods for microfluidic chips depend on the device platform, physics and can be conducted on different levels of abstraction. In this section, we describe the *MMFT Simulator*—a tool for simulation of channel-based microfluidic devices. First, the relevant physics are reviewed. Afterwards, the abstraction levels are described. Based on that, the *MMFT Simulator* is introduced as a tool for simulation of channel-based microfluidic devices on different levels of abstraction.

A. Simulation Task – Different Physical Phenomena

There exist a plethora of types of microfluidic devices, each of which involving different physical phenomena. Considering channel-based devices, we review some fluid dynamics that are relevant for the simulation task:

- *Continuous*: The continuous, single-phase flow is governed by the incompressible Navier-Stokes equations and is considered the default state. This is the basic flow type for channel-based pressure-driven microfluidic flow, which is built upon to extend for other flow physics [41].
- *Concentration*: Solutes play an important role in bio-chemical [42] or electrochemical [43] operations. The continuous fluid acts as a carrier fluid (solvent) and solutes are transported by means of advection or diffusion to a target and are, hence, governed by the advection-diffusion equation [23].
- *Droplets*: An immiscible fluid immersed into a carrier fluid forms droplets. Depending on surface tension and channel geometry, a droplet's cross-sectional area can be close to that of the channel (and, hence, can be "squeezed" in the channel) [24], [44].
- *Membranes*: Membranes play an important role in Organs-on-Chip and are sheets of porous material suspended in fluids to allow for selective cross-over [26].

All of these can be modeled using sets of governing equations. These equations, in turn, can be considered on different levels of abstraction, which are discussed next.

B. Levels of Abstraction

There are several types of simulation methods—the level of abstraction can be leveraged against the computational expense, potentially requiring advanced hardware and long simulation times. This cost of simulation heavily depends on the degree of abstraction, resulting in a trade-off between accuracy and computational cost [14].

Specifically, the abstractions can be categorized as illustrated in Fig. 10. More precisely,

- *Abstract Simulation* (1D Approaches), a high-abstraction model that simplifies the microfluidic network into an analytical solution by translating it into an electric circuit [14], [26].
- *Computational Fluid Dynamics* (CFD), solves the underlying governing equations of fluid dynamics on a computational domain which can be 2-dimensional or 3-dimensional. Methods from CFD include the Finite Volume Method (FVM, [10]), Finite Element Method (FEM, [11]), or Lattice-Boltzmann Method (LBM, [12]). Generally, these provide high accuracy, but are computationally expensive [45] and non-trivial to set up [46].
- *Actual Physical Device* (Physical Experiments), the most accurate "representation"; but prototype fabrication is error-prone, costly, and time consuming.

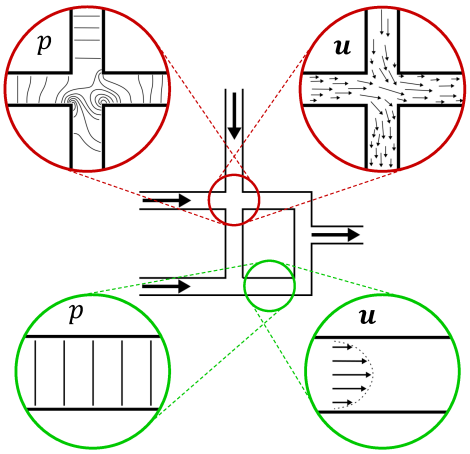

Fig. 11: Separation of the computational domain into domains that can be modeled on a high abstraction level (green) and should be modeled on a low abstraction level (red) [21].

Depending on the use case, a researcher or engineer can make a trade-off between a quick yet possibly inaccurate abstract method, or a more precise CFD method that is computationally expensive and may, in some cases, take days to finish (or, in the worst case, does not terminate at all). A natural succession of this discussion is to combine levels of abstraction to exploit the best of both worlds [22]. Such a *hybrid* simulation approach is discussed next.

C. Hybrid Simulation Approach

The *hybrid* simulation approach gives researchers and engineers more freedom in utilizing high level of abstraction where possible, yet conducting simulations on a low abstraction level where necessary [21]. To this end, the computational domain is divided into sub-domains corresponding to the required/available abstraction level. This concept is illustrated in Fig. 11. Here, the domain in green represents components for which a high abstraction domain is sufficient and, hence, which can be modeled using a high abstraction simulation method (while still obtaining relatively good accuracy). This is due to the highly laminar (i.e., strongly organized) flow, which allows it to be accurately modeled with simplifications of the Navier-Stokes equations. Consequentially, the computational simulation of flow in this domain is relatively cost-efficient. A junction, highlighted in red, however, does not have a laminar (i.e, unorganized) flow and would require a more accurate simulation method. Hence, it should be simulated with a low abstraction. An iterative coupling between the boundary conditions in the low and high abstraction domains results in an overall converged solution of the flow [21].

D. MMFT Simulator – The Simulation Matrix

To address the various physical phenomena in microfluidic devices that can be modeled on different levels of abstraction, an encompassing simulation tool for microfluidic devices can be envisioned. Overall, this leads to a matrix of simulations for various platforms on different levels of abstraction. The *MMFT Simulator* aims to achieve this using the open-source LBM library *OpenLB* [47] as CFD back end, and the approaches presented in [22], [24], [26], [48] as abstract back end. Besides that, these back ends are combined into a *hybrid* approach as described in [21]. The different simulations that are currently supported by the *MMFT Simulator* are summarized in Table I. The *MMFT Simulator* is available open-source at https://github.com/cda-tum/mmft-simulator. A python binding to the *MMFT Simulator* is available in the form of a python package at https://pypi.org/project/mmft.simulator. Besides that—in order to improve the accessibility—a *Graphical User Interface* (GUI) is being developed for the *MMFT Simulator*; a prototypical version of this GUI is available at https://www.cda.cit.tum.de/app/mmft-simulator/.

TABLE I: Functionality of the MMFT Simulator V0.3.

	Abstract	Hybrid	CFD
Continuous	✓	✓	✓
Concentration	✓	✓	✓
Droplet	✓	–	–
Membrane	✓	–	–

V. Conclusion

Microfluidic devices have evolved into highly sophisticated platforms, enabling groundbreaking applications in diagnostics, biological research, and personalized medicine. However, their growing complexity has introduced significant design and simulation challenges that are often addressed using manual, time-intensive methods. Inspired by the success of *Electronic Design Automation* (EDA) in the semiconductor domain and accomplishments in *Computational Fluid Dynamics* (CFD), this work introduced the *Munich Microfluidics Toolkit* (MMFT), an open-source collection of tools aimed at bringing similar levels of automation and accessibility to the field of microfluidics and is available at https://www.cda.cit.tum.de/research/microfluidics/mmft/.

By integrating advanced methods for placement, routing, device generation, and ISO-22916-compliant validation, MMFT supports key design tasks and reduces design efforts. Moreover, the MMFT Simulator offers a versatile suite of simulation techniques at varying levels of abstraction, enabling fast and accurate modeling of continuous flow, concentrations, droplets, and membrane interactions.

Through a unified interface and Python integration, MMFT bridges the gap between theoretical methods and practical usability, lowering the barrier to entry for researchers and engineers. As microfluidics continues to grow in complexity and impact, tools like MMFT are poised to accelerate innovation by enabling faster, more reliable, and more scalable design processes.

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