ParchMint: A Microfluidics Benchmark Suite

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***Abstract*—Continuous-flow based microfluidic laboratory-on-a-chip (LoC) devices have gained traction in recent years for their ability to automate biological experiments at micro and nano-liter scales. While the design automation algorithms for these devices have been maturing, there has yet to be any work to create a benchmark suite to enable the analysis of algorithmic quality or the exchange of device designs between researchers. We propose ParchMint, a new standard interchange format for continuous-flow based microfluidic LoCs and an associated set of benchmarks.**

I. The State of Microfluidic Benchmarks

Research into continuous-flow microfluidic LoC design automation currently relies on a small number of architectural netlists without a common set being used across all research groups. These benchmarks were first generated by converting bioassay specifications for electrowetting-based digital microfluidics, released by DTU Compute in Denmark [1] and by Duke University in the United States [2]. These require a conversion process to generate architectural netlists, with each process generating a different outcome [3, 4]. There is a wealth of literature describing microfluidic LoCs fabricated for performing biology which provides enough visual information for design automation researchers to convert by hand into architectural netlists [5, 6]; however, to the best of our knowledge these formats have not been widely disseminated. The process of hand conversion leads to high variance in component sizes, port locations, and abstraction level.

II. Contribution

A standard notation for describing a continuous-flow microfluidic LoC architecture is necessary to allow for multiple groups to be able to describe new benchmarks in a replicable manner and effectively evaluate new algorithms against existing ones. To this end, the ParchMint standard interchange format is introduced as an architectural netlist description standard. These netlists take the form of a JavaScript Object Notation (JSON) file. The architecture netlist is primarily described through three top-level object collections: *Components*, *Connections*, and *Layers* Every object within the system has a name and id field, which represent a human-readable label and a unique id that can be referenced by other objects, respectively. The component objects contain the x- and y-span fields which collectively describe the bounding box associated with the component, a list of ports and the corresponding id of the layer to which it belongs. Each port contains a (x, y) location where that point lies on the edge of the component. The connection objects contain a single source and a list of sinks reference ids.

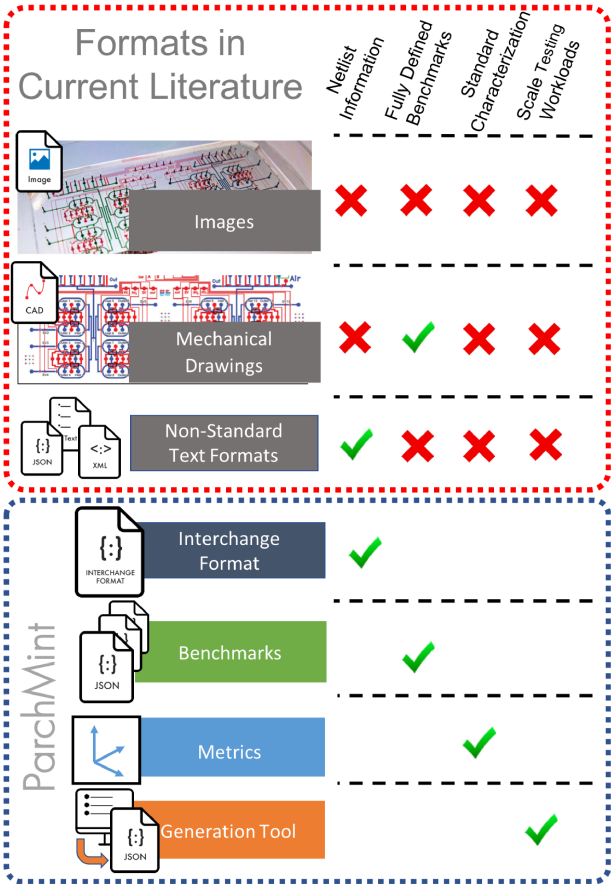

Fig. 1: Currently, individual research teams create benchmarks by analyzing device images or layout files (such as computer-aided design (CAD) files) manually, as represented in the figure with device from Wu et al. [7], ParchMint solves this problem by providing a standard method for specifying benchmarks and a publicly available set to test against. The individual components of ParchMint address the various issues faced by the researchers when developing algorithms for physical design automation of microfluidic devices.

The *Features* collection at the top level is used to describe the concrete placement and routing information of the abstract components and connections, and can contain *Component Features* and *Connection Features*. The component features contain location information for a component, and only one component feature can exist for each component object in the component list. The connection feature contains a beginning and ending point for a straight line segment of a connection and allows multiple straight line segments that constitute a single connection object in the connection list.

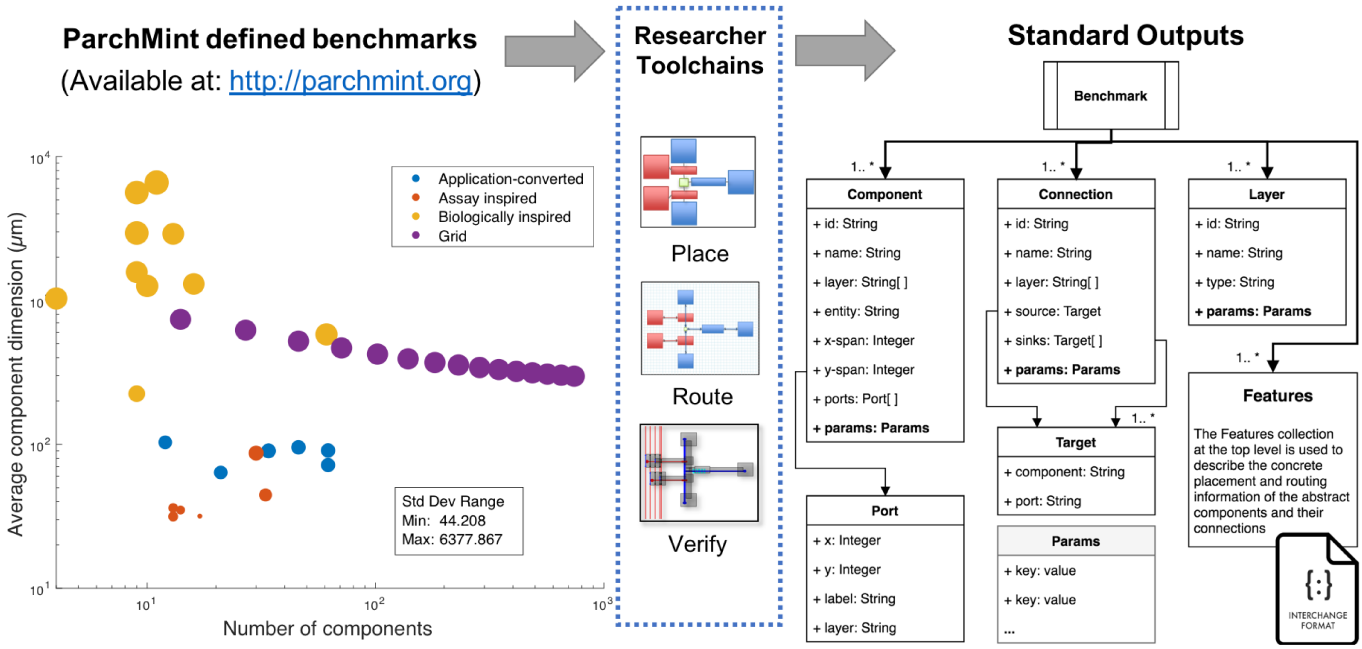

Fig. 2: ParchMint proves researchers with a set of curated benchmarks available in the standard interchange format. Researchers then can then use their algorithms/design tool-chains against these benchmarks. The interchange format allows researchers to store all the placement and routing information in the standard interchange format. Additionally they can store any additional physical design artifact they generate as Features in the JSON file. ParchMint provides researchers with benchmark characterization metrics that help them to understand the topologies for which the algorithms fail to generate designs.

We have attempted to create a representative set of benchmarks that exhibit the attributes that are commonly seen in biological experiments and shown in existing real-world designs.

- **Assay Inspired Benchmarks**: Netlists created by generalizing images from previous device publications.
- **Application-converted Benchmarks**: Generated architectures based on DTU Compute's electrowetting-based digital microfluidic bioassays [8].
- **Biologically Inspired Benchmarks**: Benchmarks taken from Ref [9] and inspired by devices used in synthetic biology experiments.
- **Grid Benchmarks**: Generic $N \times N$ grids of cell-traps with valves that allow for row or column selection.

All these benchmarks have been made available at https://parchmint.org

III. Conclusion

We present here the first comprehensive benchmark suite for continuous-flow based microfluidic devices. The suite contains scaled designs inspired by real devices and applications, designs those approximate real-world devices in both scale and complexity, and designs that utilize dense sub-structures. This suite will enable researchers to run their algorithms on a set of publicly available benchmarks and compare against other publications to accurately evaluate and compare their work.

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