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Using Lindenmayer systems for evolutionary design of static mixers

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Abstract: We describe an evolutionary design approach for the design of a static mixer vessel, using a parameterised Lindenmayer system to describe a family of designs, and using computational fluid dynamics to evaluate the effectiveness of each design.

Static mixers are vessels which allow two or more fluids to enter at one end, and produce a homogeneously mixed fluid at the other. The vessels may be square, circular or hexagonal in cross-section. Static mixers are used in a wide variety of industrial processes, and an efficient design can greatly improve efficiency of many industrial processes – such as decontamination or purification of polluted water, carbon dioxide capture from air, and catalytic reactions like extracting hydrogen from a liquid organic hydrogen carrier.

The two important attributes for a static mixer are the degree to which they can achieve bulk mixing, and transport to substrate. Transport to substrate measures, in effect, how many times a (fluid) particle collides with the structure inside the vessel as it moves down the tube. Bulk mixing measures how chaotic a fluid streamline may be as fluid moves through the vessel. This gives us multi-objective optimisation problem, with both these measures being equally important.

Lindenmayer Systems (or L-Systems) are a bio-inspired method developed by Aristid Lindenmayer in the 1960s to describe the pattern of bifurcations found in plants. They are essentially a formal grammar, whose output controls the motion of a "write head" used to create a structure. An L-System consists of an alphabet of symbols that are used to make strings. Each letter of the string is either an instruction to the write head (e.g. "turn left", or "draw one unit"), or the head of another production rule that is expanded into a given string. Thus, an initial "axiom" (string) can be expanded using the production rules in a recursive fashion.

One contribution is the addition of parameters to the L-System language, so that shapes can be parameterised: instead of the instruction *move forward one unit*, we can code *move forward* `param` *units*. This allows us to define a parameterised family of structures, which differ in the parameter values used during construction.

Evolutionary Design uses concepts from genetic evolution to search for a good solution to a design problem. We use the genetic algorithm NSGA-II to explore the space of parameters used to generate the design. NSGA-II uses the usual concepts of cross-over and mutation within a population of solutions, but improves on naive algorithms by including a number of advanced features such as elitism, and a carefully maintained Pareto Front of non-dominated solutions. It is the state of the art for multi-objective optimisation in this context.

Computational fluid dynamics allows us to test the designs produced by the L-System in a voxelised representation of the vessel. We use the single-phase Lattice Boltzmann (LB) technique to evaluate the flow field within the mixer. The LB method is based on solving the Boltzmann Transport equation rather than Navier-Stokes equation. Once this flow field is established, a multitude of massless (fictitious) tracer particles are set off from the inlet and their paths traced through the mixer. These enable the user to determine the particles' trajectories. We can construct tracer maps and from these trajectories to statistically determine the mixing and adsorption measures used in our multi-objective optimisation.

In this presentation, we will describe the workflow that allows these pieces to work together, and present results. This process has produced designs that exceed the performance of previous designs. An interesting aspect of this approach is that even though a human has designed the original individual of a (parameterised) family, the evolution process often results in shapes that no human could have imagined, and so takes us beyond the realm of designs previously possible.

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