Time-parallel Methods for Transient Diffusion and Topology Optimisation

PhD Student: Magnus Appel
Principal supervisor: Joe Alexandersen

Duration: 01-09-2024 - 31-08-2027

Introduction

Topology optimisation is a computational method which can generate novel designs for a wide variety of applications, including structural mechanics, heat conduction, fluid flow, and photonics. Relative to stationary problems, topology optimisation for time-dependent (transient) problems is very computationally expensive due to the demand for computing the state of the system at many time steps.

As an example: a fluidic oscillator is a type of fluidic device which creates an oscillating jet due to instabilities in the fluid flow, as shown in Figure 1. These have applications in aerodynamics and cooling of electronics. Due to the instability, it does not make sense to make stationary simulations of fluidic oscillators. To date, no large-scale, high-freedom computational design tools have been applied to fluidic oscillators due to the high cost. It would be convenient to be able to parallelise the time steps. This is where parallel-in-time methods come in.

Parallel-in-time Methods

Parallel-in-time (PinT) methods have been researched since the 1960s. They come in multiple varieties, each with their own advantages and disadvantages. Among the fastest PinT methods are space-time multigrid methods, where time is treated as being just another dimension of the domain, as shown in Figure 2. Classical multigrid methods are then applied to the space-time domain, and domain decomposition can be used to parallelise the computation with respect to both space and time.

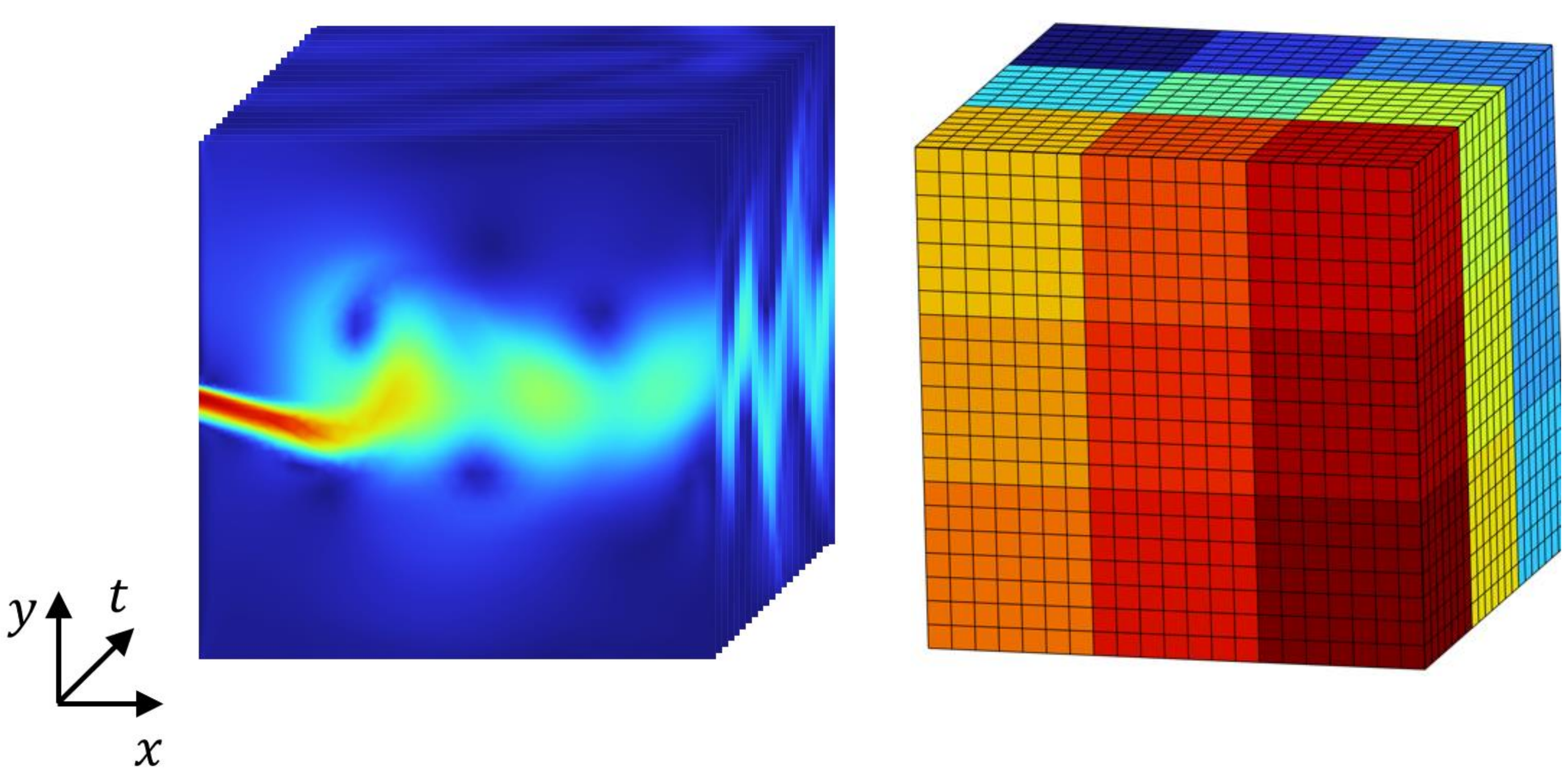


Figure 2: A space-time domain (left) along with a corresponding domain decomposition (right).

Objectives

In this Ph.D. project, we aim to develop space-time multigrid methods which are suitable for being applied to topology optimisation problems involving transient diffusion, such as heat conduction. We will do this in multiple steps:

1) Develop space-time Galerkin methods for transient diffusion.
2) Apply multigrid methods to the developed space-time Galerkin methods along with specialized smoothers.
3) Implement the developed multigrid method in the form of parallel code.
4) Test its performance on large scales using high performance computing resources.

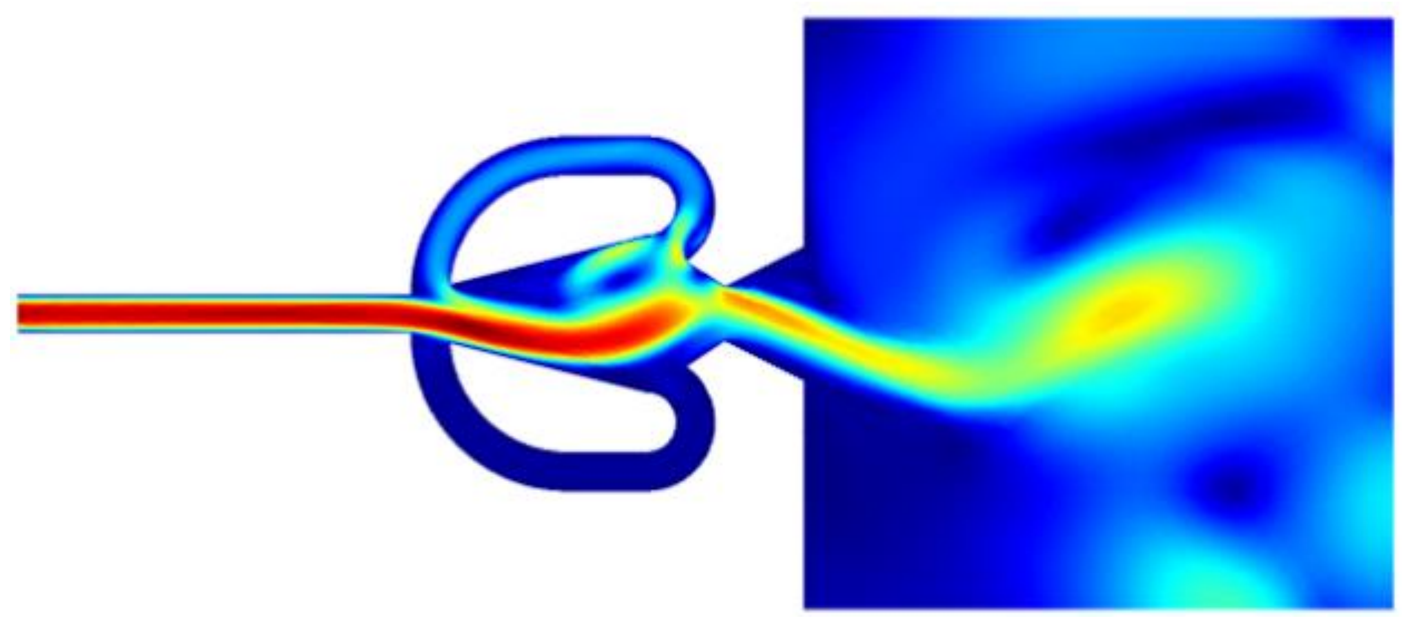


Figure 1: Simulation of flow inside a fluidic oscillator.

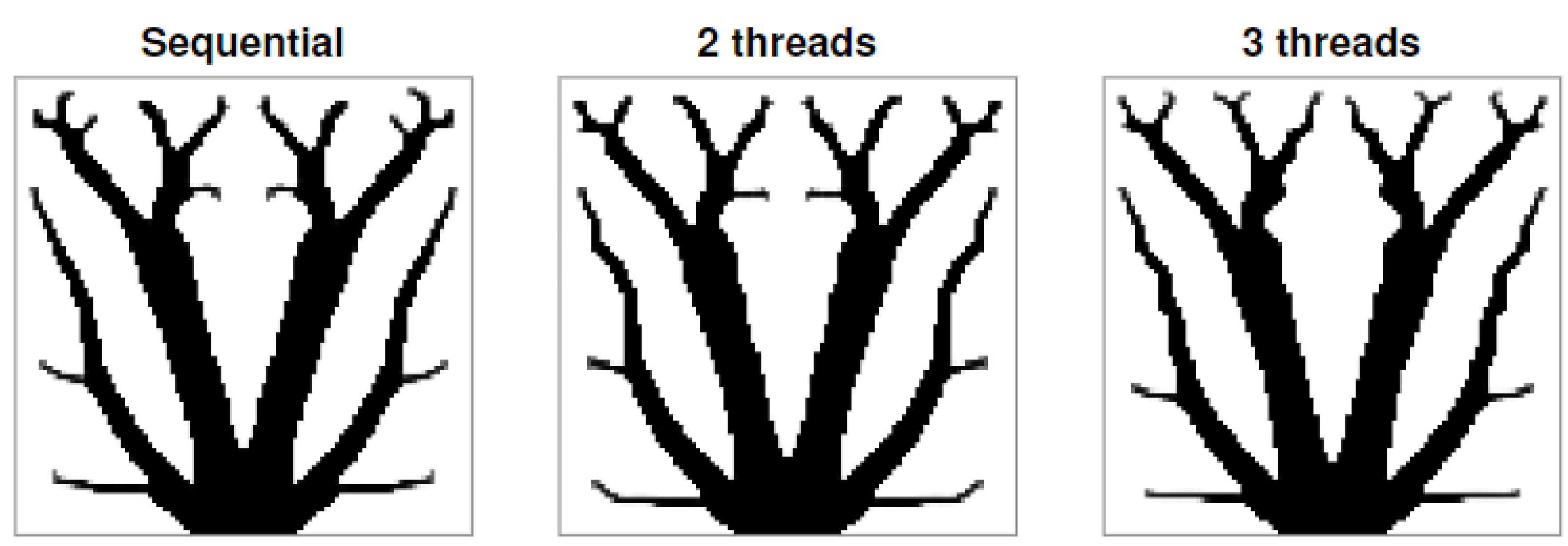
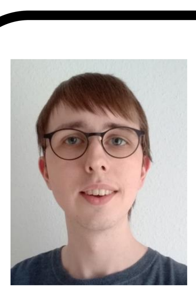


Figure 3: Topology-optimised heat sink designs obtained using a parallel-in-time method named Parareal.

Challenges

- Time-dependent problems obey causality, meaning that information only flows in one direction along the time axis. For this reason, time-dependent problems do not really ``want´´ to be parallelised with respect to the time axis, and parallel-in-time methods are usually less accurate than sequential methods.
- Multigrid methods work less well if the system contains small or thin structures. This is frequently the case when performing topology optimisation of diffusion problems, as shown in Figure 3 where there are multiple thin branches.



Magnus Appel
Ph.D. student
University of Southern Denmark
magap@sdu.dk

SDU

SDU Mechanical Engineering
Department of Mechanical and Electrical Engineering