Paper Review 2

Jingchuan Zhou 01656348

Computer Graphic

Paper Review: Efficient Solver for Spacetime Control of Smoke

In modern society, physically-based fluid animations are increasingly popular in some computer graphics areas, such as movies and desktop systems. In this article, it mainly presents the special problem of the keyframe-based spacetime control of smoke. The method is to compute a dense sequence of control force fields with a set of given keyframe smoke shapes that can drive the smoke shape to match several keyframes at certain time instances. However, the computation of keyframe-based control of fluids is time-consuming because of its high dimensional space and iterative computation. There are two different techniques for studying fluid control problems, proportional-derivative(PD) controllers and optimal controllers. The latter controllers are better than the former ones.

Compared with Treuille's and McNamara's simple but inefficient method, this article presents an approach that maintained the additional dual variables and exploits the special structure of the Navier-Stokes equations discretized on a regular staggered grid and solves the optimization problem by finding the stationary point of the first order optimality conditions. This approach could iteratively update our solution without requiring it to satisfy the Navier-Stokes equations exactly in each iteration, it only need to ensure the final computed solution at the end of the algorithm is feasible. Therefore, it alternatively updated the velocity fields and controlled force fields using the alternating direction method of multiplier (ADMM), which did not take considerable running time as prior methods. It used ADMM method to decompose the problem into two sub-problems: Advection Optimization (AO), which only considers passive advection as hard constraints; and Navier-Stokes Optimization (NSO), which only considers fluid dynamics as hard constraints. The ADMM algorithm always converged in less than fifty iterations. And after testing on several 2D and 3D benchmarks and a wide range of parameter choices, they found the best performance happened with only 2 iterations.

The approach in this article also has some disadvantages. It strongly depended on the spatial structure and the staggered grid discretization of the Navier-Stokes equations. And it is much slower than a simple PD controller who considers one time-step at a time in that its optimal controller solved the space time optimization with all the time-steps. While they solved this problem by using a much larger time-step size with a novel advection operator. What is more, they should lower the spatial resolution in the control phase and then use smoke up sampling approach to generate a better animation.

In conclusion, this was an extremely informative paper that clearly described a new algorithm for the optimal control of smoke animation. The benefit of this method is that the locally optimal control forces can be found as realizing an order of magnitude improvement over the gradient based optimizer.

Paper Review: Two-Scale Topology Optimization with Microstructures

Nowadays, there are many problems in designing complex structures, which required many high-level technology. A common approach to solve these problems is using topology optimization. The idea of the topology optimization is to divide a high-level object into small elements and optimize their material distribution, which will make the object satisfied their goal function. In the past, topology optimization are mainly applied in the field of homogeneous materials and focused on the macroscopic changes in object geometry. With the arrival of multi-material three dimensional printing techniques, people would like to use materials at a much higher resolution, which allows us to approach much better designs and improve functional performance. However, for the current standard techniques for topology optimization cannot work well in the new technology because of the increase of the number of cells in the object. There are many work related for handling this issue now. Most recent method is to separate the issue to macro structural and micro material design. But, these approaches remain computationally expensive and, in most cases, limited to the well-known minimal compliance problem. Some researchers reduce the problem complexity by temporarily ignoring the geometry of the microstructures and consider only their macroscopic physical behavior. But, this leads to new difficulties as the space of material properties covered by all printable microstructures is much wider than the properties of the base materials. From these two direction, we found the range and number of physical parameters are required in micro structures increase. Therefore, two challenging problems need to be solved to work with the microstructures of material properties: one computing the gamut and efficiently optimizing the distribution. To solve these problems, this paper present a novel computational framework for topology optimization. New approach computing the gamut of the material properties of the microstructures by alternating stochastic sampling and continuous optimization, which gives us a discrete representation of the set of achievable material properties. By this way, the topology optimization problem can be reformed in the continuous space of material properties and present an efficient optimization scheme inside the gamut. Eventually, mapping the optimal material properties back to discrete microstructures.

This new version formulation can be applied to a large kinds of problems. The formulation are test in many different material spaces using isotropic, cubic, and orthotropic materials. And the algorithm are improved to dealing with diverse functional objectives such as minimal compliance and target strain distribution. Moreover, new approach utilizes 3D printers with high resolution by supporting designs with trillions of voxels.

After reading this paper, I realized a fully automatic method for computing the space of material properties achievable by microstructures made of a given set of base materials. In this method, paper present a generic and efficient topology optimization algorithm capable of handling objects with a trillion voxels. To evaluate the method, a variety of test is applied to it and it proved to be validate on various design problems of practical interest. There are two progress in the method, one is to use a pre-computation process to efficiently sample the space of microstructures and their corresponding material properties to define a continuous material property gamut.

Second is to use this gamut as a constraint in a generalized topology optimization framework to assign spatially varying material properties throughout the optimized object. And the method proved to be an improvement over traditional binary topology optimization schemes.

Above all there are still three drawbacks in this method. First, current method do not provide any theoretical guarantees that the gamut space cannot be further expanded. Second, the method do not prove to support microstructures with additional properties, for example, electrical or magnetic properties and their combined property gamut. Third one is that the new framework builds on linear elasticity and optimizes the material distribution of objects subject to small deformations only. So, the improvement should be focus on extending the algorithm to the nonlinear regime.

Conclusion: These two paper are both present an improved method of current technology. First one present an efficient solver for spacetime control smoke in computer graphic. Second one present a generalized topology optimization framework for microstructures. For most current technology, time consuming is an important direction for improvement. So in both two novel approach, they consider this part improve from the traditional method. However, they still have some limitation on the current result, and have some extending space to become excellent.