論文の内容の要旨

INTERACTIVE DESIGN EXPLORATION OF PHYSICALLY VALID SHAPES
（物理的な要求を満たす形状のインタラクティブな設計手法）

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Physical simulation makes it possible to validate geometric designs in a computer without tedious and costly physical prototyping. However, since geometric modeling and physical simulation are typically separated, simulations are mainly used for rejecting bad design, and, unfortunately, not for assisting creative exploration towards better designs. In this dissertation, we propose to integrate physical simulation into geometric modeling to actively support creative design process. More specifically, we demonstrate the importance of (i) presenting the simulation results in real-time during user's interactive shape editing so that the user immediately sees the validity of current design, and to (ii) providing a guide to the user so that he or she can efficiently explore the valid deign space. To achieve these requirements, we present three algorithms each demonstrated by solid implementation of design systems with different underlying physics.

The first algorithm, “reuse of redundant intermediate data”, provides the real-time response of FEM simulation with respect to the inputs of design changes. The real-time response is achieved by amortizing recompilation cost of FEM. We implemented various applications running on the system including static and dynamic solid deformation problems, fluid problems, a thermal fluid problem, and a sound wave problem. The second algorithm “first order approximation” further accelerates FEM simulation in static setting by using sensitivity analysis. It quickly predicts simulation results with respect to design changes, enabling interaction with high-resolution simulation. We demonstrate its effectiveness with a clothing design system. The third algorithm “force space analysis” is for generating useful information quickly that guide user toward better design. Using the analysis in the domain of force the design system can compute suggestions and annotation which tell the user how to make the model valid. We present a plank-based furniture design with nail-joint and frictional constraints as a demonstration.

These applications shows the concurrent feedback and guidance from the physical simulation allow novice the user to intuitively design objects with physical constraints. Proposed algorithms have generality and can be applied to similar design support systems based on physical simulation in other domains.