Large Scale Level Set Topology Optimization Using OpenVDB and PETSc

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INTRODUCTION

What is level set topology optimization?

- A **structural optimization** method that produces creative and unintuitive designs
- The design is represented by a level set function, producing **3D printer friendly geometries**

RESEARCH CHALLENGES

1. The operations involved in morphing the geometry are slow. This is addressed using a **VDB**, **a tree data structure** to represent the geometry
2. Simulating the physical characteristics, such as stress and stiffness is computationally expensive. This is addressed by performing finite element analysis using **parallel computing** software **PETSc**

VDB DATA STRUCTURE

VDB is a sparse and hierarchical tree data structure (like octrees) that efficiently represents geometries, resulting in **fast convergence characteristics**.

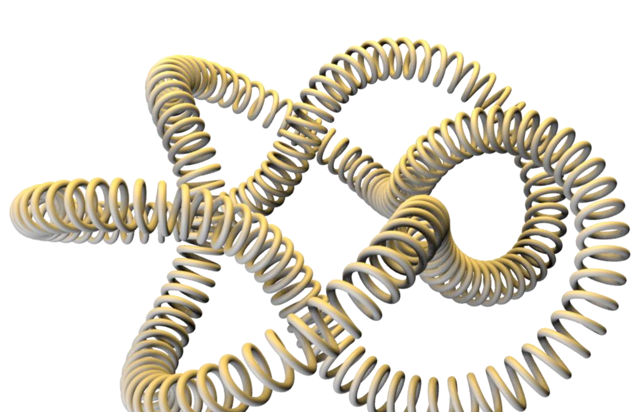

Fig. 1

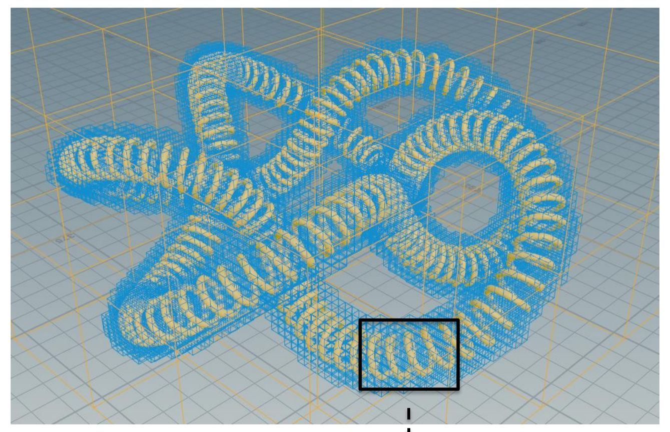

Fig. 2

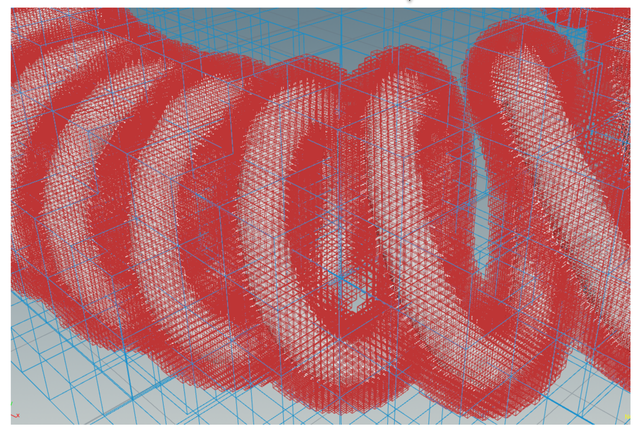

Fig. 3

Fig. 1: The geometry of a helix-torus.

Fig. 2: The helix-torus represented by the VDB data structure as a wireframe.

Fig. 3: A close-up view of the VDB data structure. The red wire frame objects contain the level set function values which store the design boundary information.

FINITE ELEMENT SIMULATIONS IN PETSc

- **PETSc** is a parallel computing friendly software that is useful in scientific applications
- The finite element method (**FEM**) is used to simulate the physical characteristics such as stress and stiffness, by solving systems ~ **100 million DOFs**

RESULTS: TORSION BALL

The torsion ball problem is to design a **lightweight** structure which is **stiff under a torsion load**. The structure is clamped as shown in **Fig 4a** under torsion load as shown in **Fig 4b.**

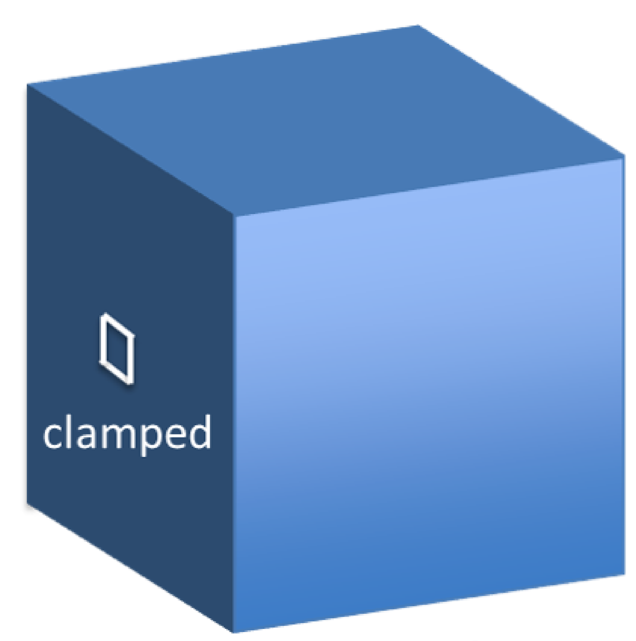

Fig. 4a

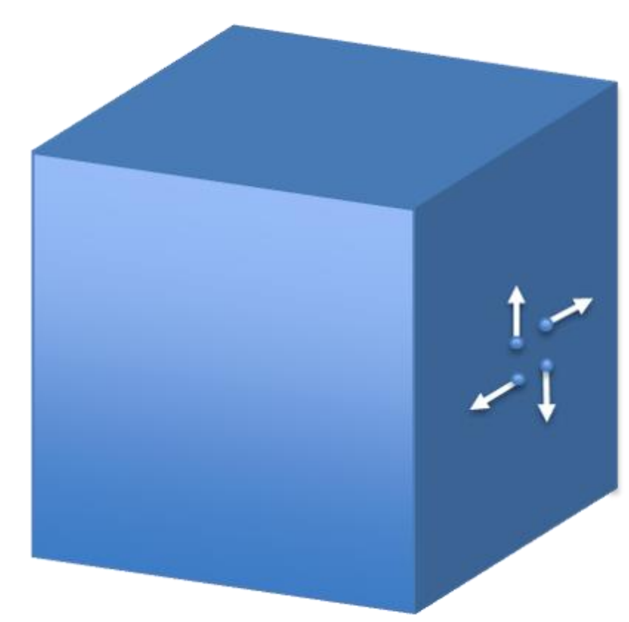

Fig. 4b

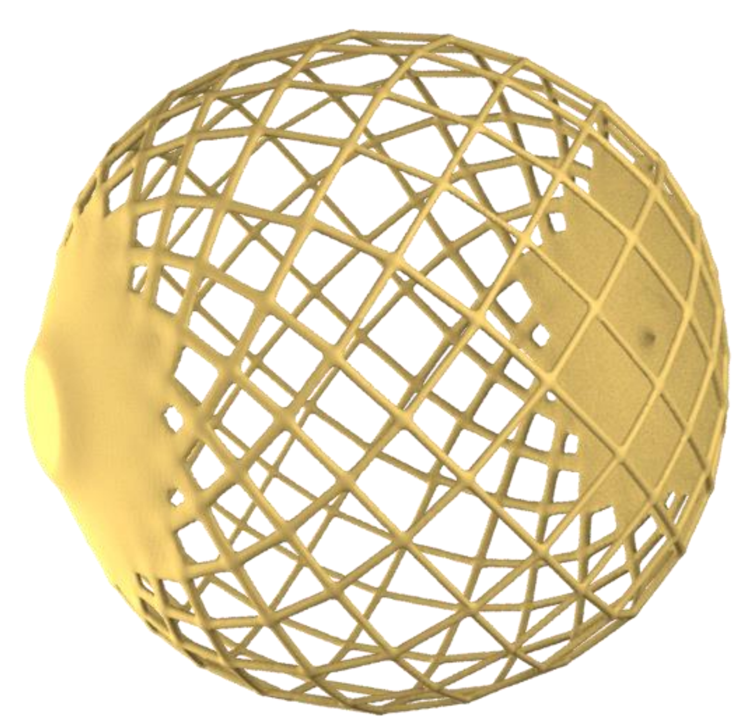

Fig. 5

Optimized lightweight torsion (**Fig 5**) ball that is stiff under torsion. The structure has criss cross trusses forming on the surface of a sphere.

The stiffness of the ball is characterized using **20 million finite elements.** The optimization converges in 3 hours.

RESULTS: BRIDGE

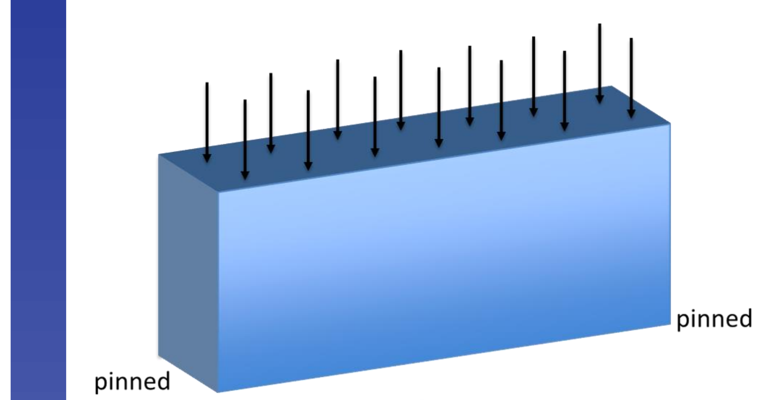

Fig. 6

The bridge problem is to design a **lightweight** structure that is **stiff under a pressure load** on top with its corners pinned as shown in **Fig. 6**.

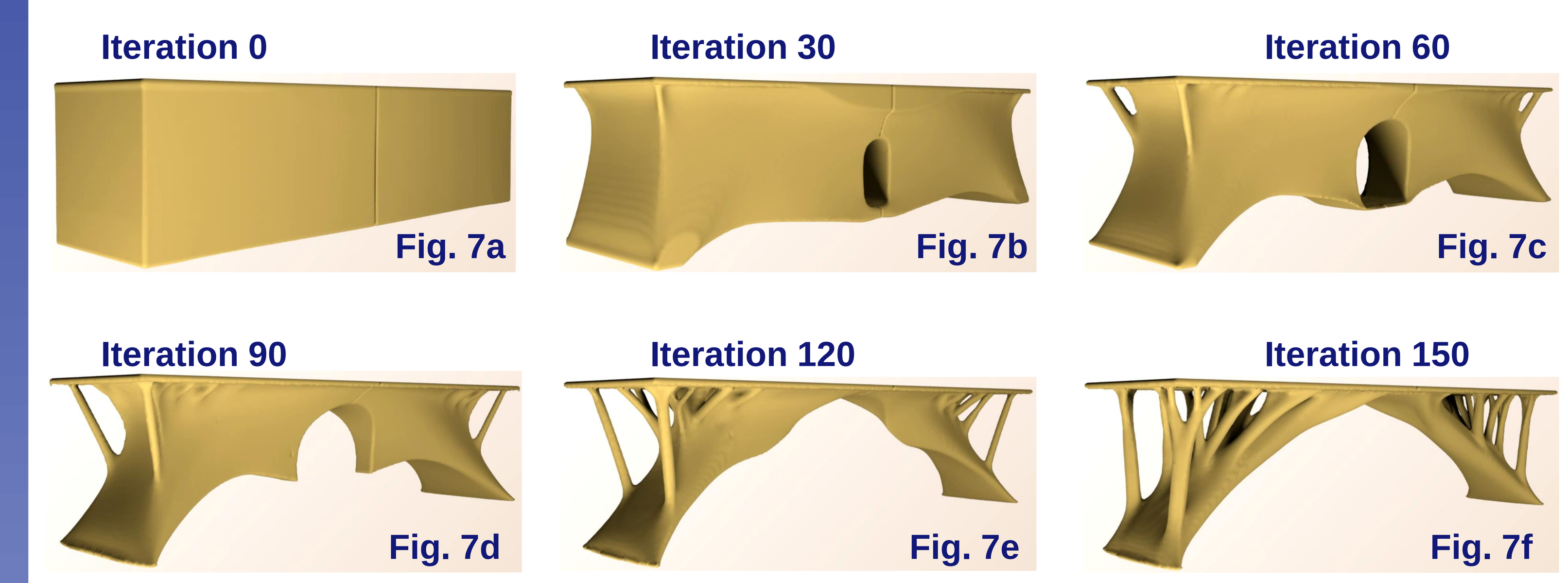

Fig. 7a Fig. 7b Fig. 7c Fig. 7d Fig. 7e Fig. 7f

The design evolution of the bridge is shown in **Fig 7**. The starting design of the optimization is a complete solid covering the entire domain (**Fig 7a**). The design evolves in towards the stiff and lightweight bridge in **Fig 7f.**

RESULTS: HEAT DISSIPATION STRUCTURE

- The heat dissipation structure is a **lightweight design that dissipates heat** being produced everywhere.
- The optimized structure shown in **Fig. 8** shows **branches emanating from the heat sink** and drawing heat from everywhere in the domain.

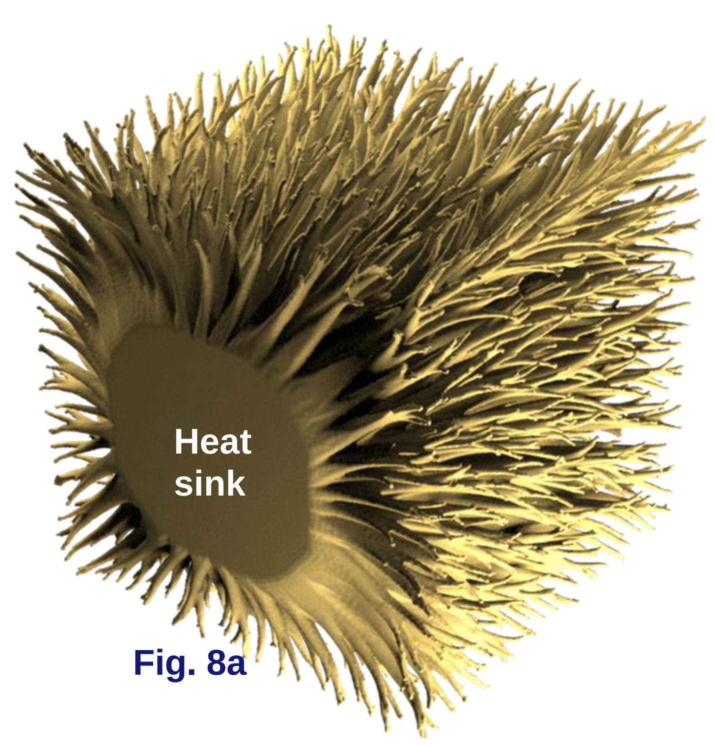

Fig. 8a

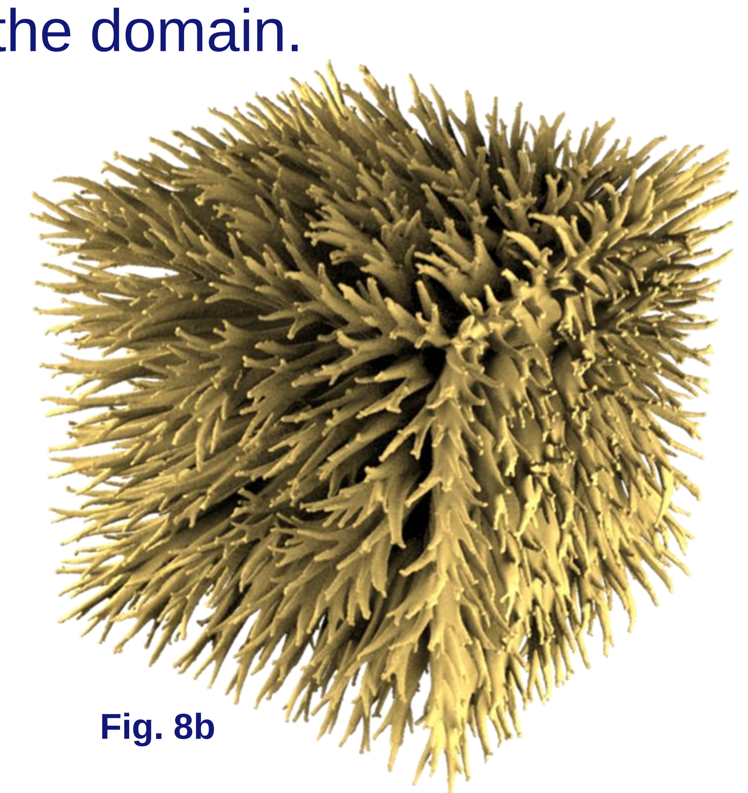

Fig. 8b