University of Stuttgart

Institute for Nonlinear Mechanics

Bachelor's thesis
Term paper
Master's thesis

Large-scale simulation of frictional contact dynamics on distributed memory machines

Topic Areas:	nonsmooth dynamics, parallel numerics
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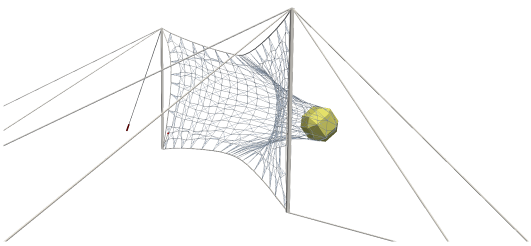
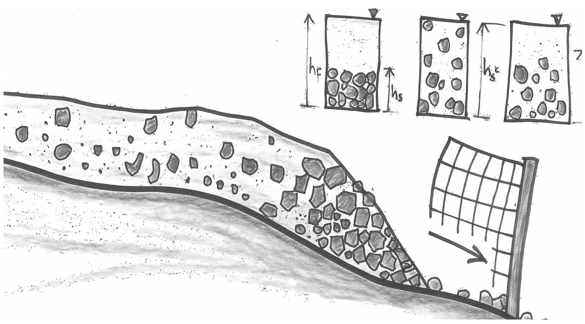
Prerequisites/Prior Knowledge:	Nonsmooth Dynamics, Parallel Numerics

The protection of human infrastructure against natural hazards has become one of the paramount objectives of modern engineering, especially in light of the increasing consequences of climate change. Natural phenomena such as rockfall and debris flows pose serious risks to settlements, transport routes, and critical facilities. Mitigation strategies often rely on protection systems such as flexible rockfall nets or debris flow barriers, which must be designed to withstand extreme impact scenarios.



To accurately design and evaluate such protection systems, large-scale numerical models are required. These models must capture the complex interaction between rigid bodies (rocks, soil, debris) and flexible, often elasto-plastic, protective structures. The resulting simulations involve thousands to millions of particles in contact with large deformable structures and therefore demand efficient high-performance computing methods.



A key challenge in these models is the accurate representation of Coulomb friction, which governs the interaction forces at contact points. Concepts from convex analysis and nonsmooth dynamics provide powerful tools for discretizing these interactions. Among them, Moreau's mid-point rule has become a standard choice. Each time step requires the solution of an affine normal cone inclusion of the form

$$\mathbf{G}\boldsymbol{\Lambda} + \mathbf{b} \in \mathcal{N}_C(-\boldsymbol{\Lambda}),$$

which can equivalently be expressed as the fixed-point problem

$$\boldsymbol{\Lambda} = -\operatorname{prox}_C\left(\rho(\mathbf{G}\boldsymbol{\Lambda} + \mathbf{b}) - \boldsymbol{\Lambda}\right).$$

This formulation naturally gives rise to iterative solution techniques such as projected Jacobi and Gauss–Seidel methods.

The focus of this thesis is the investigation of distributed memory implementations of these methods for large-scale contact dynamics problems. Specifically, the goal is to design, implement, and compare parallel variants of projected Jacobi and Gauss–Seidel schemes. To this end, different software frameworks will be explored, including:

- `Eigen3`: as dense matrix backend,
- `PETSc`: as sparse matrix backend,
- `Coal`: as contact detection library.

Beyond the mathematical and numerical challenges of nonsmooth dynamics, the thesis will address fundamental aspects of parallel simulation, such as spatial partitioning of the computational domain, load balancing, and efficient communication on distributed memory architectures.

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