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GPU-accelerated vector-form particle-element method for 3D elastoplastic contact of structures

Key words:

Graphics processing unit (GPU); Parallel acceleration; Elastoplastic contact; Contact search; Finite particle method (FPM)

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Motivation

□ Research background

- The **strong nonlinearities** involved in **elastoplastic contact of structures** make it difficult to get accurate solutions.
- The contact calculation processes are usually very **time-consuming** for **large-scale contacts**.
- An **effective** and **efficient method** is urgently needed to solve the elastoplastic contact of structures.

□ Contact algorithms for elastoplastic contact

- Finite element method (FEM):
***effective, not efficient** for large-scale contacts*
- Finite particle method (**FPM**):
***effective, efficient** for large-scale contacts*

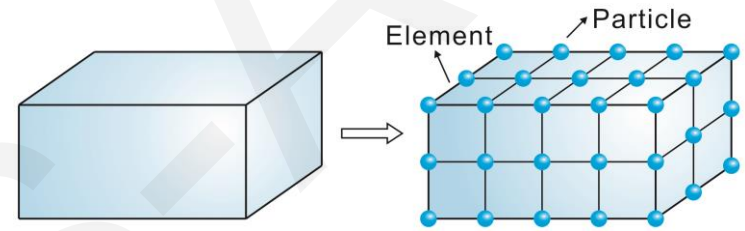
Method

Hexahedral elements in the FPM

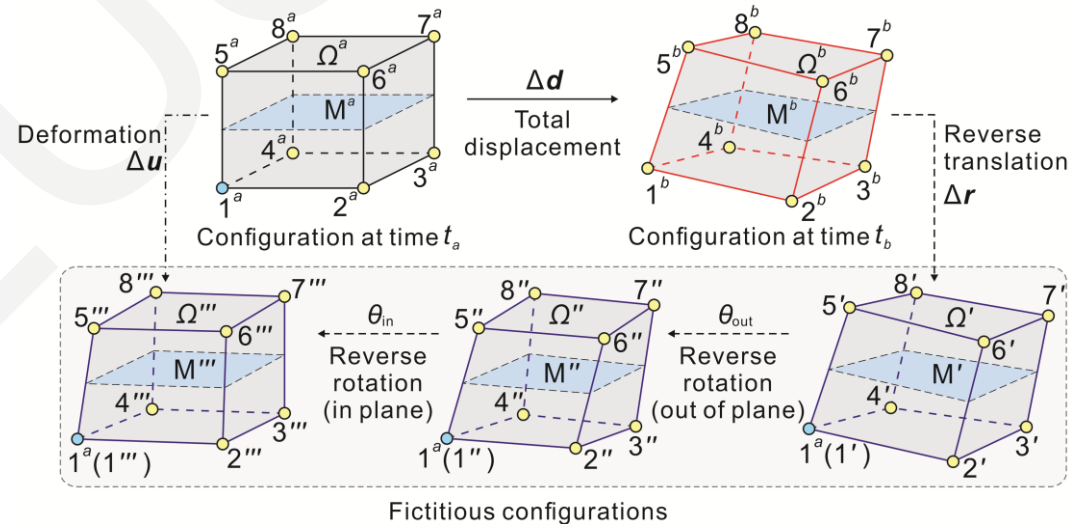
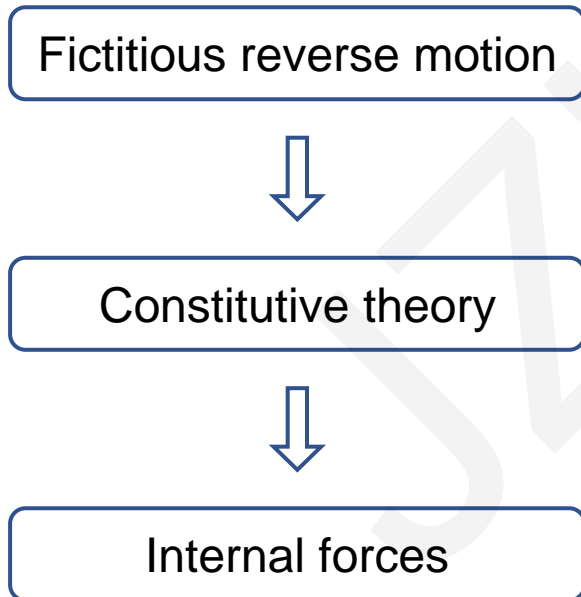
- Motion equations of particles

$$m\ddot{\mathbf{d}} = \mathbf{F}_{\text{ext}} - \mathbf{F}_{\text{int}} - \mathbf{F}_{\text{dmp}} + \mathbf{F}_c$$

- Elemental internal forces



Discretization of a structure

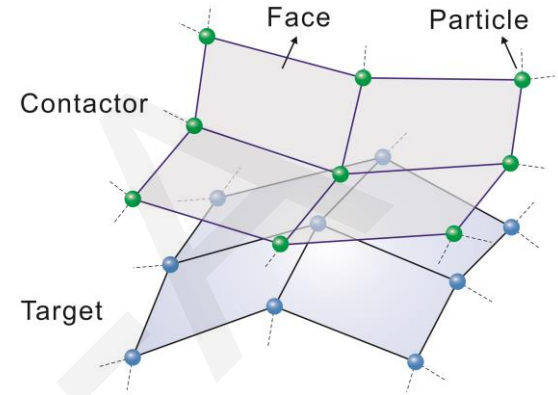


Fictitious reverse motion

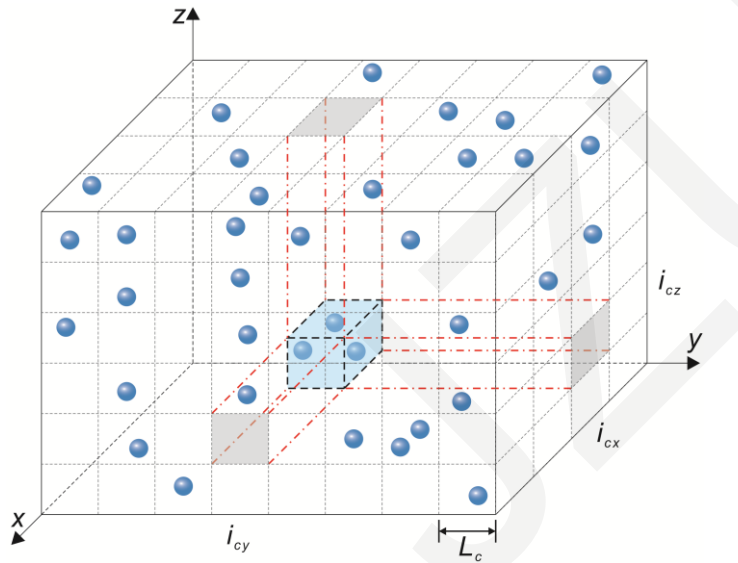
Method

□ Parallel contact algorithm

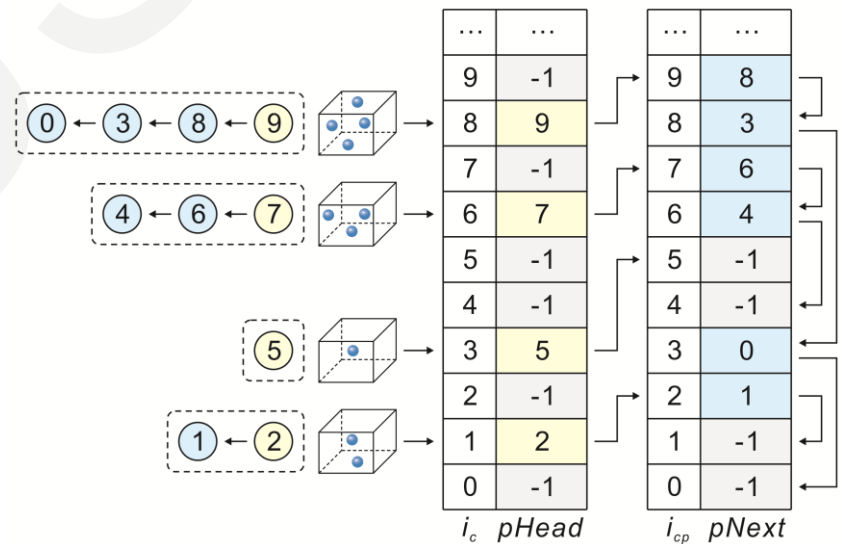
- Discretization of contact surfaces
- Parallel contact search
- Enforcement of contact constraints



Discretization of contact surfaces



Decomposition of three-dimensional space

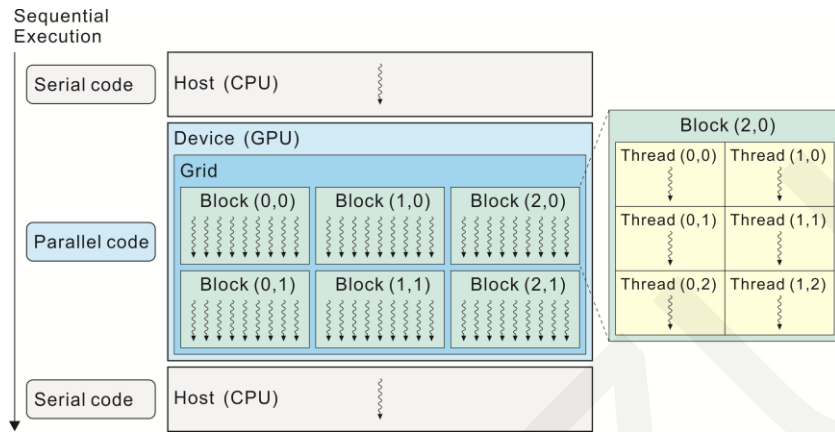


Connected list data structure

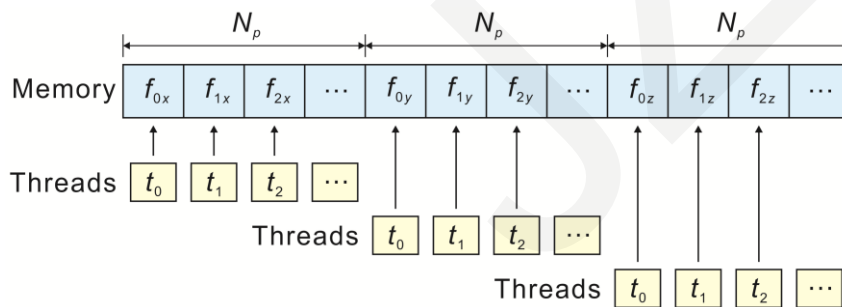
Method

Parallel implementation

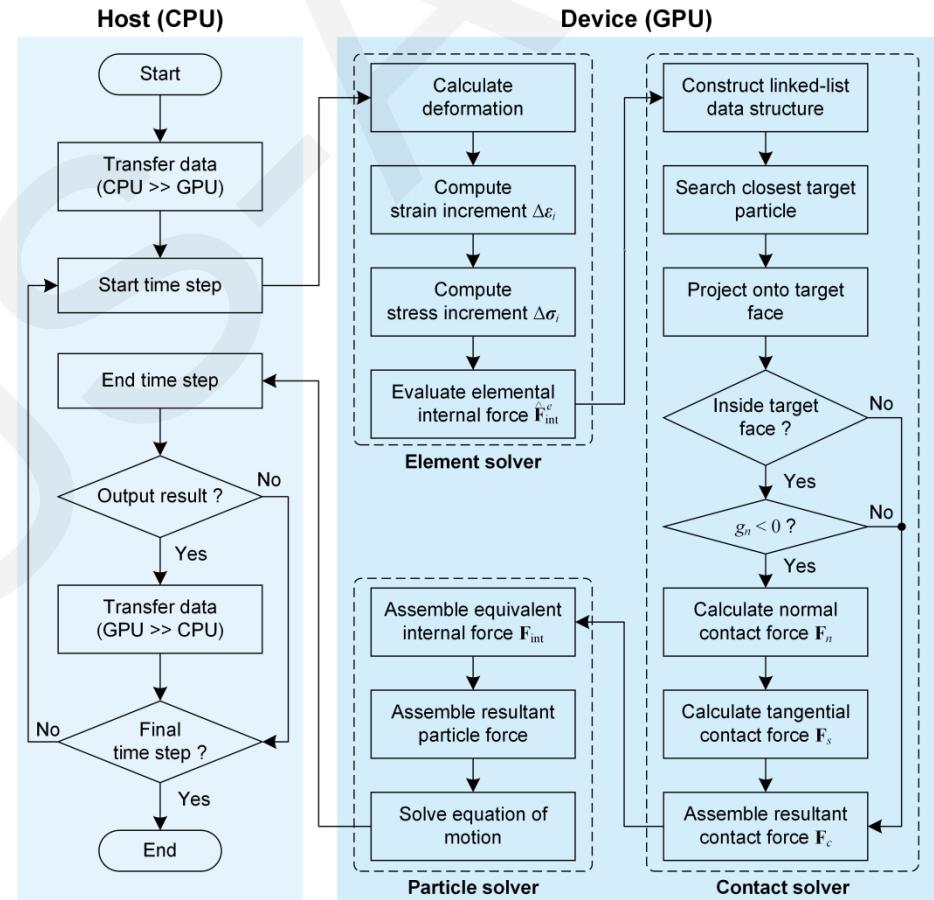
- Parallel FPM solvers
- GPU memory optimization



CUDA Programming model



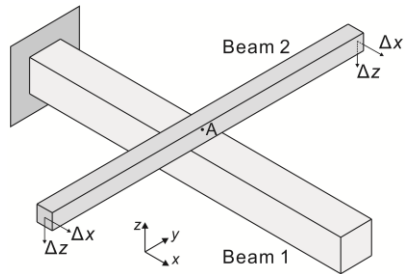
SoA memory layout



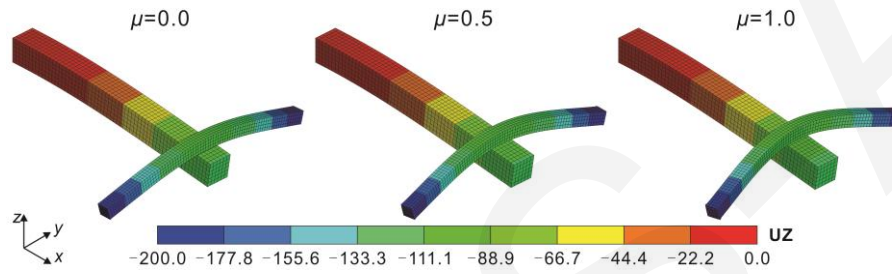
Flowchart of parallel FPM solvers

Verification

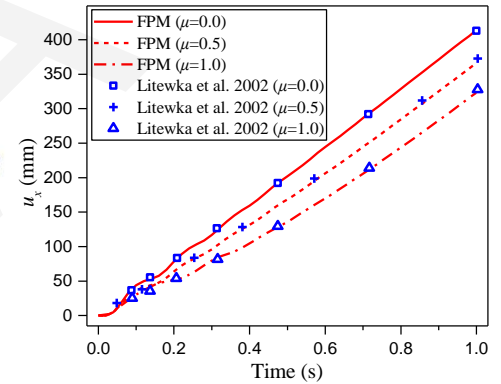
□ Elastic contact



Geometry

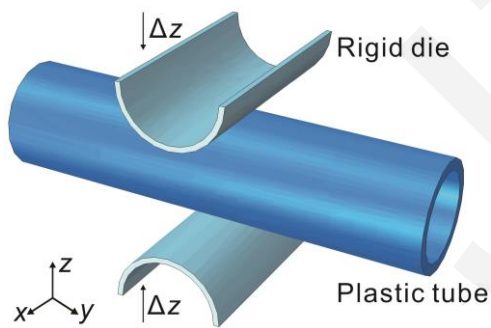


Displacement contour

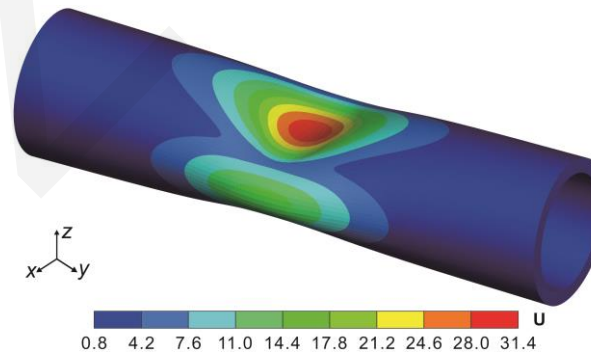


Displacement

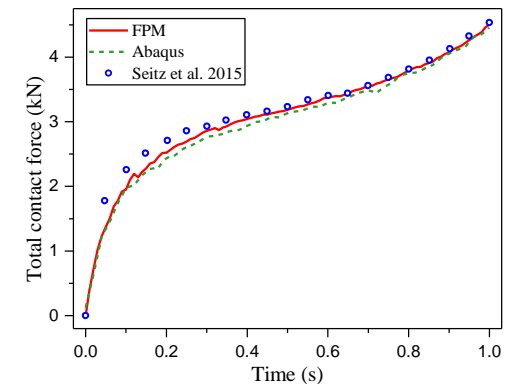
□ Elastoplastic contact



Geometry



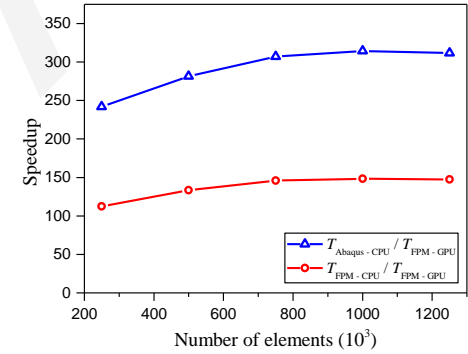
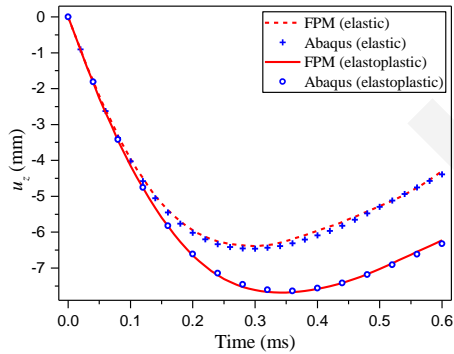
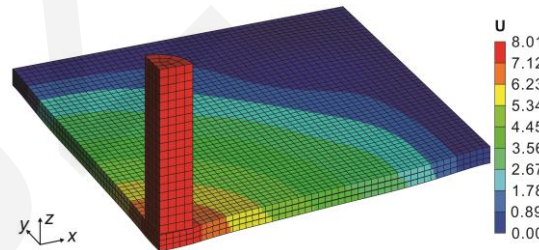
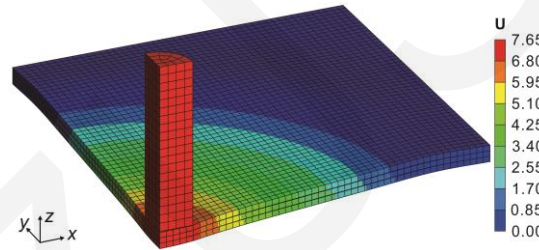
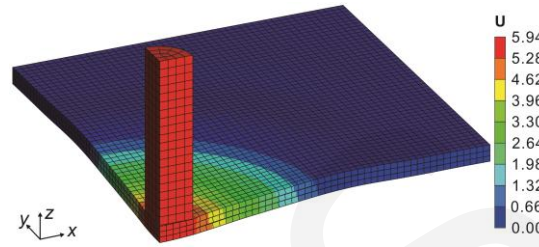
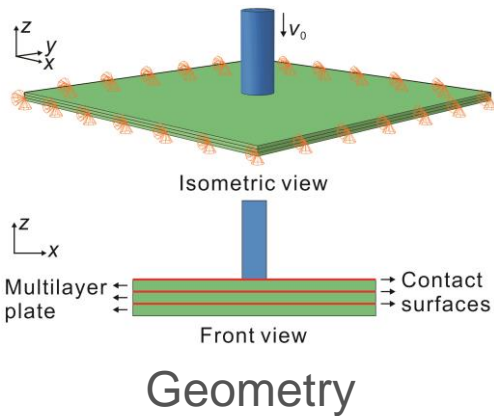
Displacement contour



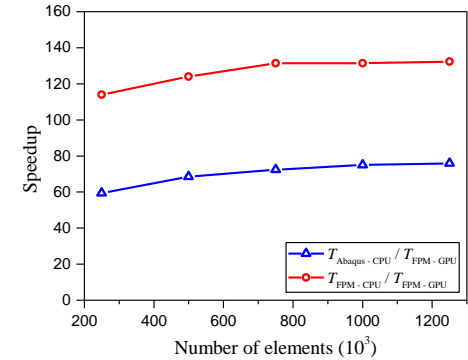
Contact force

Efficiency test

□ Elastoplastic contact



Speedup of contact calculation



Speedup of overall computation

Displacement contour

Conclusions

- Two verification examples that involve elastic and elastoplastic frictional contacts are investigated. The proposed method is shown to be **effective** in both **elastic** and **elastoplastic contacts**.
- The efficiency of the GPU-accelerated FPM is investigated. It is shown that the proposed method is **efficient** in both **elastic** and **elastoplastic large-scale contacts**.
- The GPU-accelerated FPM is approximately **130~140** times faster than the serial one, and **70~80** times faster than Abaqus. Specifically, the GPU-accelerated FPM contact solver is approximately **110~140** times faster than the serial FPM contact solver, and **310~340** times faster than the Abaqus contact solver.