Visualization of a FE Simulation of Capillary Pressure in a 3D Embankment Dam

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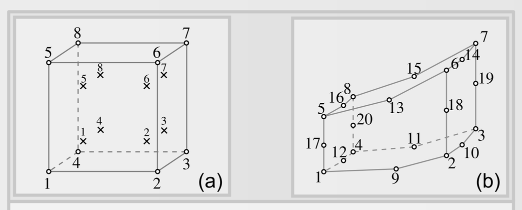
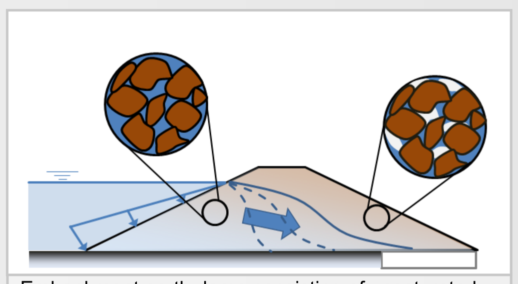
Finite Element Simulation

- FE Simulation in OpenSees
  - Open **S**ystem for **E**arthquake **E**ngineering **S**imulation
  - C++ framework for FE simulations developed at Berkeley University
  - Mixed mesh of linear and quadratic cells is used
  - Water flow simulation in a 3D embankment dam
- Three-phase model
  - Solid, water, and gas phase (soil)
  - Coupled hygral-mechanical model [1]
  - Material model operates on integration points
- Multiple solution variables
  - Displacement, gas pressure, capillary pressure
- Aim
  - Scalability to big problem sizes
  - Improve robustness and stability of the simulation code
  - More realistic simulation of material response (elasto-plasic material)



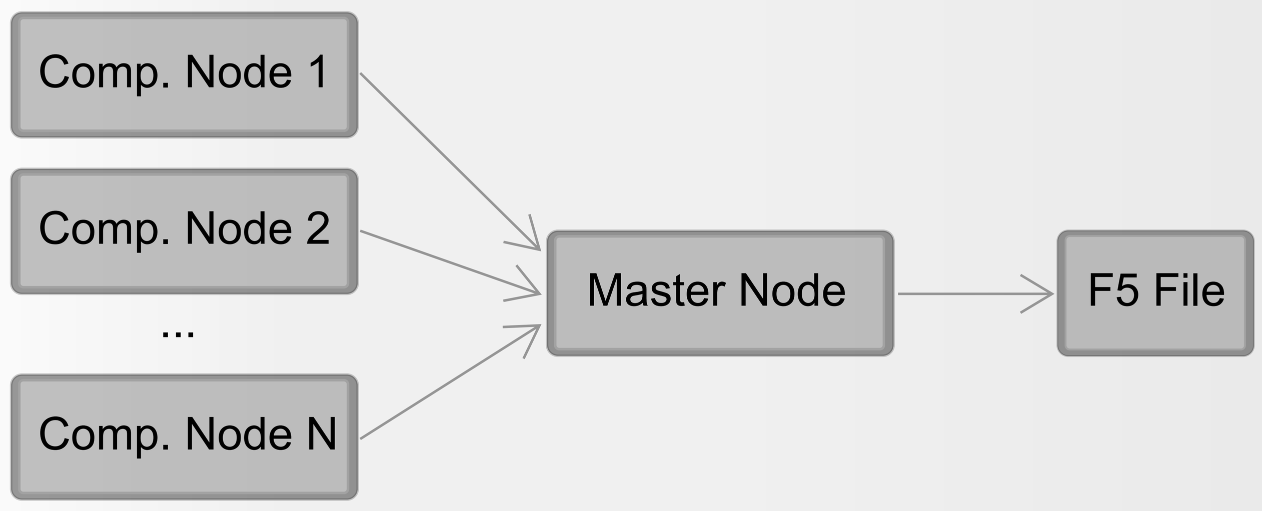
(a) Undeformed linear hexahedral element c3d8 illustrated including nodes and integration points.
(b) Deformed quadratic element c3d20, nodes only.



Embankment earth damn consisting of unsaturated (right), partially and fully saturated soil (left).

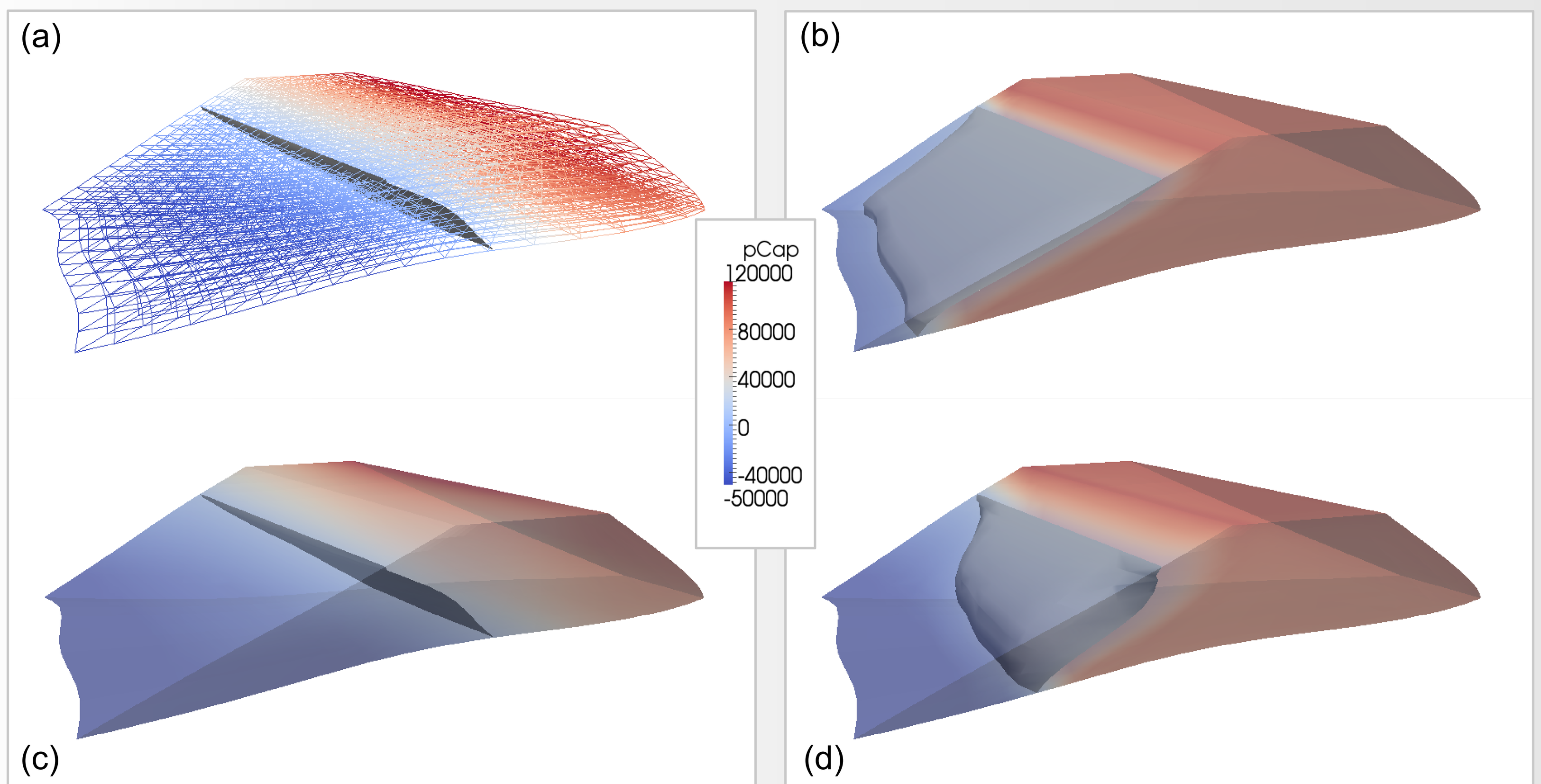
OpenSees to F5 file

- F5 File Creation
  - Extended the OpenSees framework to export FE data to F5 [3]
  - Data is pulled to the master node (MPI)
  - Data is written after each simulation step
  - Ouput file type is specified in the FE solver input file
  - One file per time step or all time steps in one file is supported



Export to and Visualization in Paraview

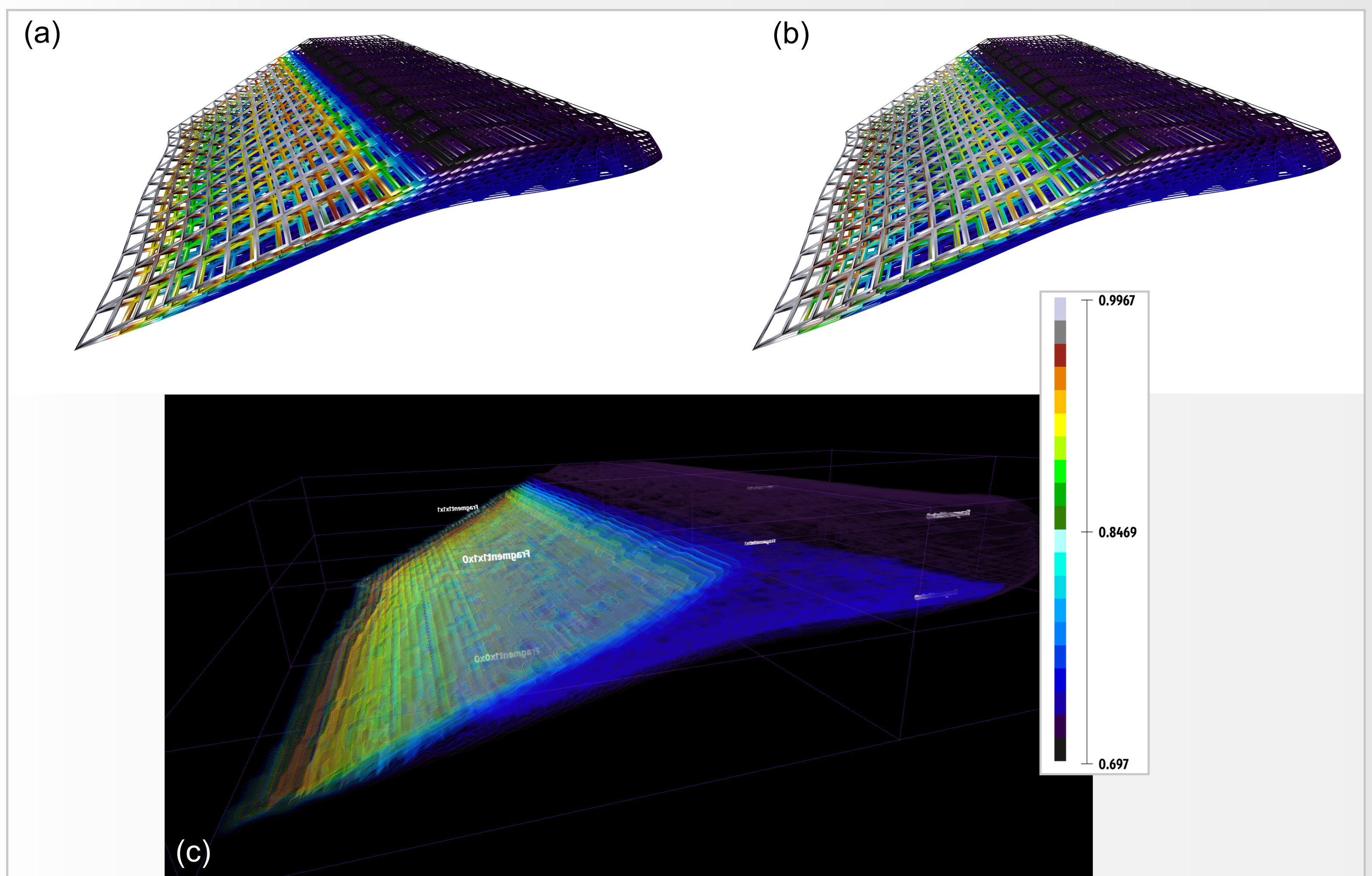
- Paraview Export
  - Extended the OpenSees framwork for Paraview export
  - ASCII format is written per time step
- Paraview Visualization
  - Wireframe of FE Mesh via Lines
  - Iso-surface of capillary pressure (phreatic surface)
  - Surface boundary of FE Mesh color coded by scalar field
  - Visualization on deformed and undeformed FE Mesh
- Limitations
  - Data on Integration Points can only be investigated by index and value (no spacial information available)
  - Cell based data allows only one data value per cell (but there are up to 8 data values at integration points per cell)



Simulation results after 1 day (b), 5 months (d) and 10 months (a,c). The iso-surface illustrates the phreatic surface of the water flow. Capillarily pressure is shown via color-map on the wireframe (a) and the surface boundary (b,c,d).

Visualization in Vish

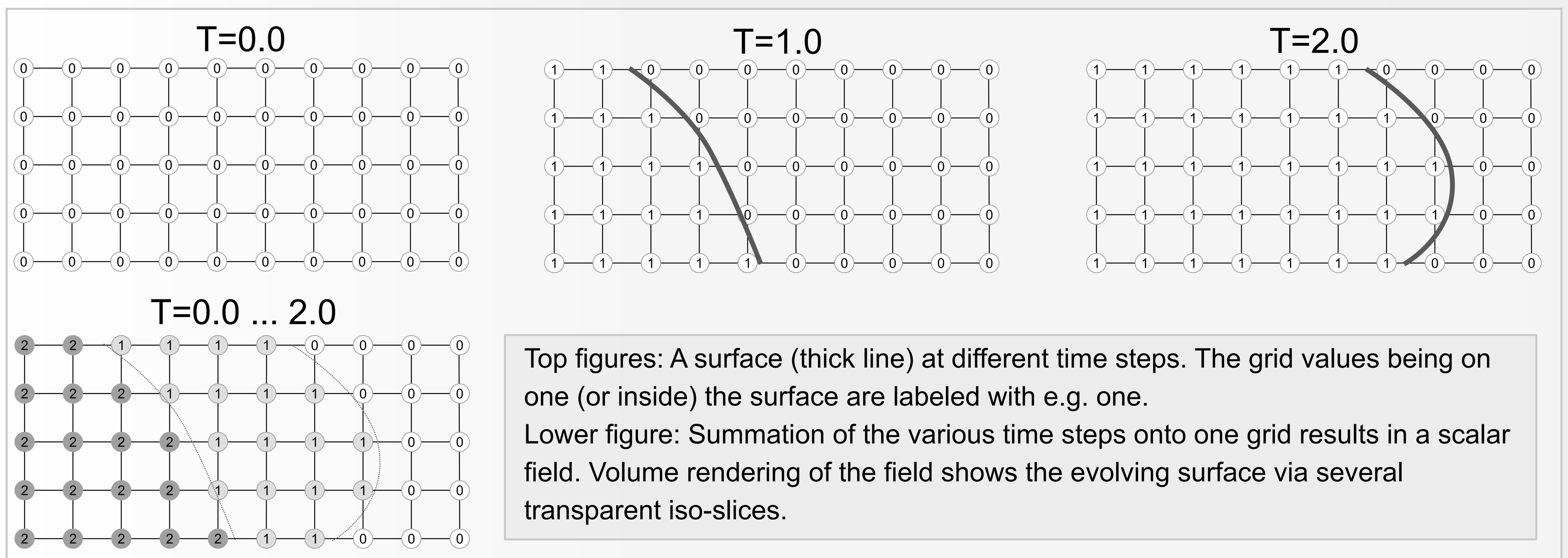
- FE Visualization in Vish
  - Open academic flexible visualization framework (C++/OpenGL) [2]
  - Based on earlier developed FE data model in [4]
- Methods
  - Sample on Uniform Grid
  - Introduce fragmentation to support blocks of different grid resolutions
    - + Extended F5 model for regular fragments
  - Volume rendering to illustrate scalar fields (e.g. capillary pressure)
  - Colored grid to illustrate geometry, vector-, and scalar fields,
    - + e.g. FE-grid, displacement, and capillary pressure



Simulation results after 1 day. The color-map illustrates the water saturation. Colored cages show averaged (a) and element-wise (b) data on the nodes of the quadratic FE mesh. A volume rendering of water saturation sampled on 8 uniform grid fragments with adaptive size control is shown in (c).

Aim and Future Work

- Visualization of an Evolving Phreatic Surface via one Volume Rendering
  - Add a value to each grid point of an zero-initialized grid on one side (inside) of the surface
  - Use volume rendering to form iso-surfaces representing the evolving surface



Top figures: A surface (thick line) at different time steps. The grid values being on one (or inside) the surface are labeled with e.g. one.
Lower figure: Summation of the various time steps onto one grid results in a scalar field. Volume rendering of the field shows the evolving surface via several transparent iso-slices.

- Aim
  - Visualize data stored on integration points
  - Localize integration points
  - Better volume visualization
- Future Work
  - Improve inside-cell interpolation
  - Compute scalar surface evolution field and visualize the evolution of the phreatic surface in one image
  - Sample on AMR structure instead of uniform grid
  - Enable AMR volume rendering

[1] Gamnitzer, P.; Hofstetter, G. (2013): An improved cap model for partially saturated soils. In: 5th BIOT Conference on Poromechanics, Wien, 10.07.2013 - 12.07.2013. Reston: ASCE, American Society of Civil Engineering, ISBN 978-0-7844-1299-2, Bd. CD ROM, S. 569 - 578.
[2] Benger, W., Ritter, G., and Heinzl, R. (2007). "The Concepts of VISH.", Proc. 4th High End Visualization Workshop Obergurgl, Lehmanns Media, p. 26-39.
[3] Ritter, M. (2009). "Introduction to HDF5 and F5", CCT Technical Report Series, Lousiana State University, CCT-TR-2009-13.
[4] Ritter, M.; Aschaber, M.; Benger, W.; Hofstetter, G. (2013): Visualization of Finite Element Data of a Multi-Phase Concrete Model. In: 5th BIOT Conference on Poromechanics, Wien, 10.07.2013 - 12.07.2013. Reston: ASCE, American Society of Civil Engineering, ISBN 978-0-7844-1299-2.