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A framework for data exchange and benchmarking of frictional contact solvers in multibody dynamics.

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Abstract

There is currently no entirely satisfactory or robust solver for the computation of contact forces for multibody systems subject to dry friction laws. There are also multiple formulations of the mathematical problem [2], as Nonlinear or Linear Complementarity Problems, (NCP)s or (LCP), respectively, Variational Inequalities (VI)s, and many more. Such problems are difficult computationally as they are NP hard. Benchmarking is necessary as in other aspects of multibody dynamics simulation [3, 4]. Datasets and statistical performance and quality metrics are needed to develop better solvers and understand and compare existing ones. The data specification should allow different re-formulations, and be usable for any type of solver, e.g., iterative, direct, etc. Existing formats like FCLIB [1] store only the matrices corresponding to a specific formulation. This motivates our work.

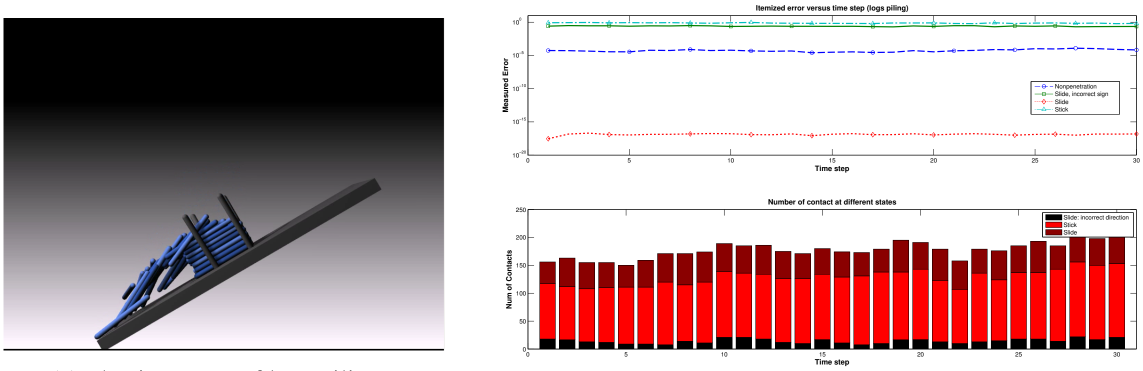
We previously introduced a format specification for the descriptor form kinematic data [4] using the Hierarchical Data Format 5 (HDF5) `www.hdfgroup.org` and collected problem sets on our Webpage: `tinyurl.com/rpih5`. This information sufficient for, and is to be used as initial conditions for taking a step for any single stage, single step integration methods, assuming locally linear constraints. Instrumented simulations write "frames" at each or selected steps in one single file. These are loaded in a any environment supporting HDF5 and, after manipulation, a step is computed with a method of choice. The data allows any choice of friction law, problem formulation and solver. We wrote a set scripts in MATLAB and OCTAVE to support the most common formulations and formats. A user can focus on solely on writing a solver. We wrote interface code for existing solvers such as those in the Siconos platform `tinyurl.com/siconos`, and GAMS `www.gams.com`. We also provide scripts to compute statistics describing the quality of a solution. All our software is available on our website.

We chose HDF5 since it is a standard for scientific data and is supported by multiple standard tools used for statistical analysis and scientific visualization. HDF5 also supports parallel read and write operations, making it suitable for distributed file systems and large datasets.

An exemplar application is shown in Fig. 1a. The picture comes from the datafile itself. along with descriptive text. These should always be present. The simulation consisted of dropping long, thin logs into a confined space on an inclined plane. This involves hundreds of contacts, many of them sliding, and some ill-conditioning due to the dimensions. The frames were produced with the AgX toolkit `www.algoryx.se` first. AgX uses a split solver, where standard constraints and normal forces are computed with an LCP solver using direct numerical algebra, and friction is estimated iteratively with Projected Gauss-Seidel (PGS) iterations.

Results were loaded into our MATLAB based environment and we re-solved each problem with a prox-based PGS solver. Looping over all data in an HDF5 file is trivial in MATLAB: only one file is needed for any simulation. The same applies for other tools. Results such as those shown in Fig. 1b are easy to produce, and data easy to manage and curate.

To evaluate the solutions produced we performed a deeper analysis than simply computing the global error as shown in Fig. 1b. We checked the error on the Coulomb sitck/slip conditions shown in the red curve, and this is very good here. We counted the contacts reported as sliding or sticking and separated them into three categories shown in the bar graph. In black are the sliding contacts for which the tangent force points *along* the direction of sliding. In bright red are the sliding contacts for which friction opposes velocity, sticking contacts are in dark red. The 2-norm of the overall deviation from maximum dissipation for sliding contacts is shown in green. For sticking contacts the error is the amount of residual tangential



(a) Physics scene of logs piling

(b) Statistics analysis for 20 time steps

Figure 1: Demo using a NCP PGS solver on one of the benchmark problems

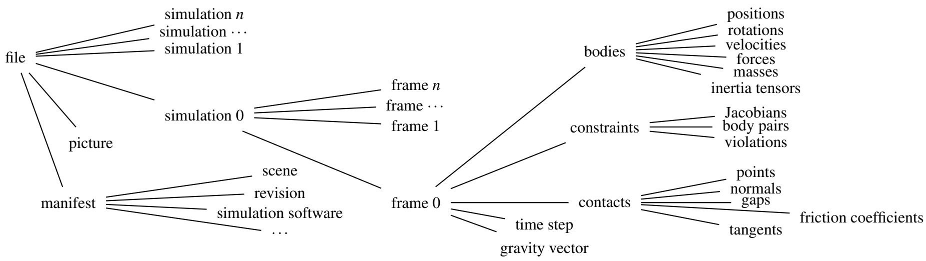


Figure 2: The layout of the HDF5 specification, excluding optional data.

velocity, shown in turquoise. The blue line is the penetration error. The global complementarity error here is of the order of 10^{-5}. Yet the overall solutions are bad.
What this shows is that it is necessary to separate these errors to make a reasonable evaluation of a solver. As for solver development, one should try to understand the reason for the different types of errors, which might help finding better numerical methods. Of course, much more information can be gained from the dataset, such as statistical information on convergence rate of relaxation solvers, for instance.
We believe that this framework and those metrics will help constructing new, better and faster solvers. It should is especially useful in early stages of development since then, one typically uses a scripting language which cannot possibly be integrated with an existing multibody dynamics simulation library. This usually leads to using trivial or random problems for testing, providing little information. If the functionality to write datasets is introduced in an existing library, one can also get deep understanding of the quality of the simulation and isolate problem cases for analysis and solver improvements.

References

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