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Parallel programming with CUDA

Sources:
- Slides: ME964 High-Performance Computing for Applications in Engineering
- Book: CUDA by Example: An Introduction to General-Purpose GPU Programming

CUDA C

Standard C Code
```c
void saxpy_serial(int n,
float a, float *x, float *y)
{
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}
// Perform SAXPY on 1M elements
saxpy_serial(4096*256, 2.0, x, y);
```

Parallel C Code
```c
_global_
void saxpy_parallel(int n,
float a, float *x, float *y)
{
  int i = blockIdx.x*blockDim.x + threadIdx.x;
  if (i < n) y[i] = a*x[i] + y[i];
}
// Perform SAXPY on 1M elements
saxpy_parallel<<<4096, 256>>>(n, 2.0, x, y);
```

From: www.nvidia.pl
Parallel programming with CUDA

Be aware of:

- hardware dependencies
- memory bandwidth
- the usefulness of tools: debuggers, profilers, ...

Many concepts:

- parallel computing
- CUDA threads synchronization
- events
- shared memory, constant memory, texture memory
- DirectX interoperability
- atomic operations
- streams
Reflections on Simultaneous Impact

Abstract

Resolving simultaneous impacts is an open and significant problem in collision response modeling. Existing algorithms in this domain fail to fulfill at least one of five physical desiderata. To address this we present a simple generalized impact model motivated by both the successes and pitfalls of two popular approaches: pair-wise propagation and linear complementarity models. Our algorithm is the first to satisfy all identified desiderata, including simultaneously guaranteeing symmetry preservation, kinetic energy conservation, and allowing break-away. Furthermore, we address the associated problem of inelastic collapse, proposing a complementary generalized restitution model that eliminates this source of nontermination. We then consider the application of our models to the synchronous time-integration of large-scale assemblies of impacting rigid bodies. To enable such simulations we formulate a consistent frictional impact model that continues to satisfy the desiderata. Finally, we validate our proposed algorithm by correctly capturing the observed characteristics of physical experiments including the phenomenon of extended patterns in vertically oscillated granular materials.

CR Categories: I.6.8 [Simulation and Modeling]: Types of Simulation—Animation

Keywords: physics, simulation, impact, mechanics, rigid bodies

Links: 🚙DL 📖PDF

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In each case, leaving pre-impact velocities unchanged leads to penetration. These velocities must therefore be altered via instantaneous impulses to avoid penetration, i.e., to become feasible. What does physics tell us about the requisite impulses and the attendant post-impact velocities?

(BRK) Break away. Bodies that were previously in contact may break away from each other as a result of impact. This might occur as an immediate consequence of the impact, as in Bernoulli’s Problem, or it may be the result of shock propagation—a sequence of ordered events occurring at an instant—as in Newton’s Cradle.

(SYM) Symmetry preserved. Spatial symmetries (e.g., about a reflection line) that exist in pre-impact configurations should also exist in post-impact configurations. After all, in an ideal system, what factor breaks such a symmetry [Bernoulli 1742]? As depicted above, both Bernoulli’s Problem and Newton’s Cradle are symmetric about the horizontal bisector.

(KIN) Energy bounded. Elastic impact ($c_r = 1$) conserves kinetic energy. Inelastic impact under a coefficient of restitution
Reflections on Simultaneous Impact

Video

http://www.cs.columbia.edu/cg/rosi/rosi.mov
Validation: Newton’s Cradle
Validation: symmetry
Validation: inelastic impact
Case study: independent collisions (default)

\[ m_1 = 2, \ m_2 = 1 \]
\[ m_3 = 1, \ m_4 = 1 \]

\[ \dot{q}_1^- = 1, \ \dot{q}_2^- = 1 \]
\[ \dot{q}_3^- = 0, \ \dot{q}_4^- = 0 \]

\[ p_- = \begin{bmatrix} 2 & 1 & 0 & 0 \end{bmatrix}^T \]
\[ p_+ = p_- + G \lambda_{min} \]

\[ \lambda_{min} = \min_{y \geq 0} \left[ 0.5 \cdot ((1 + c_r) p^- + G y)^T M^{-1} ((1 + c_r) p^- + G y) \right] \]

\[ p_+ = \begin{bmatrix} 0.8571 & -0.1429 & 1.1429 & 1.1429 \end{bmatrix}^T \]
Reflections on Simultaneous Impact

Case study: independent collisions (graph theory used)

\[ m_1 = 2, m_2 = 1 \]
\[ m_3 = 1, m_4 = 1 \]

\[ \dot{q}_1^- = 1, \dot{q}_2^- = 1 \]
\[ \dot{q}_3^- = 0, \dot{q}_4^- = 0 \]

\[ p_{1-} = \begin{bmatrix} 2 & 0 \end{bmatrix}^T \]
\[ p_{2-} = \begin{bmatrix} 1 & 0 \end{bmatrix}^T \]

Done separately:

\[ p_{1+} = \begin{bmatrix} 0.6667 & 1.3333 \end{bmatrix}^T \]
\[ p_{2+} = \begin{bmatrix} 0 & 1 \end{bmatrix}^T \]
Reflections on Simultaneous Impact

Assumption
- impact shock wave propagation velocity is assumed to be infinite (true for rigid bodies)

Pros
- it works!
- and it works for all values of restitution coefficient

Cons
- need to solve both LCP and GP problems iteratively for collisions at each time step
- complexity of the problem depends on the number of collisions
- body-thread parallelism not described in the paper

LCP - Linear Complementarity Program, GP - Generalized Reflection
Acknowledgments

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Thank you for your attention

Any questions?