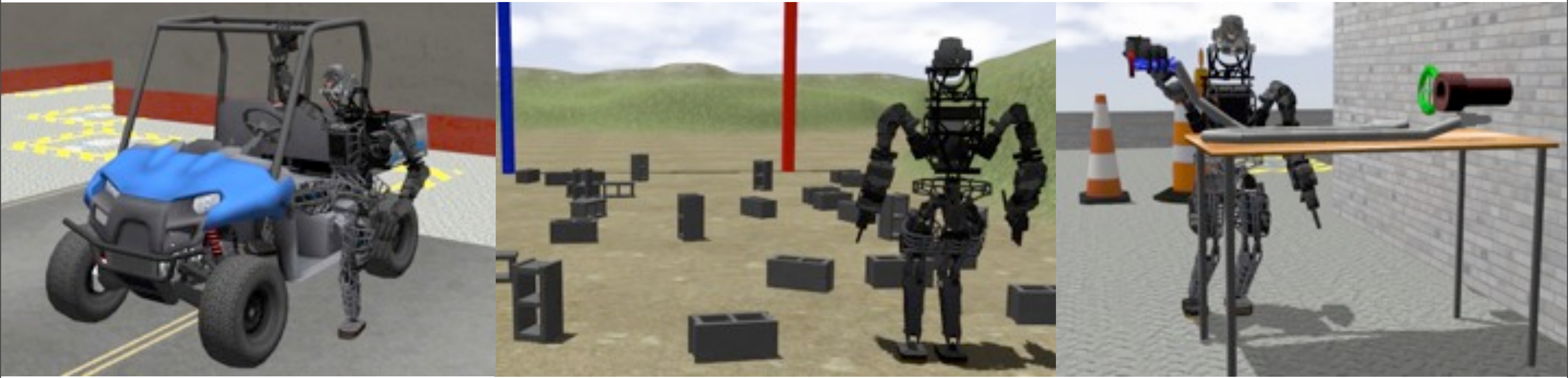
Comparison of Rigid Body Dynamic Simulators for Robotic Simulation in Gazebo

Steven Peters (scpeters), John Hsu (hsu)



ROSCon 2014

Open Source Robotics Foundation

Outline

DARPA Virtual Robotics Challenge

Overview of the Open Source Gazebo Simulator

Physics Engines in Gazebo

Benchmark Physics Tests

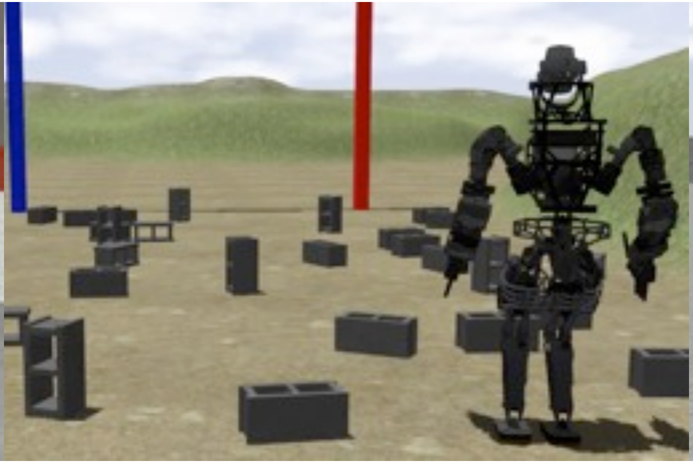
Robotic Walking Task

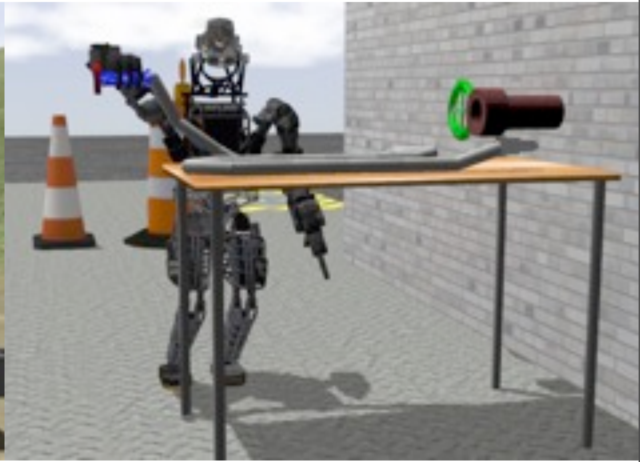
Conclusion

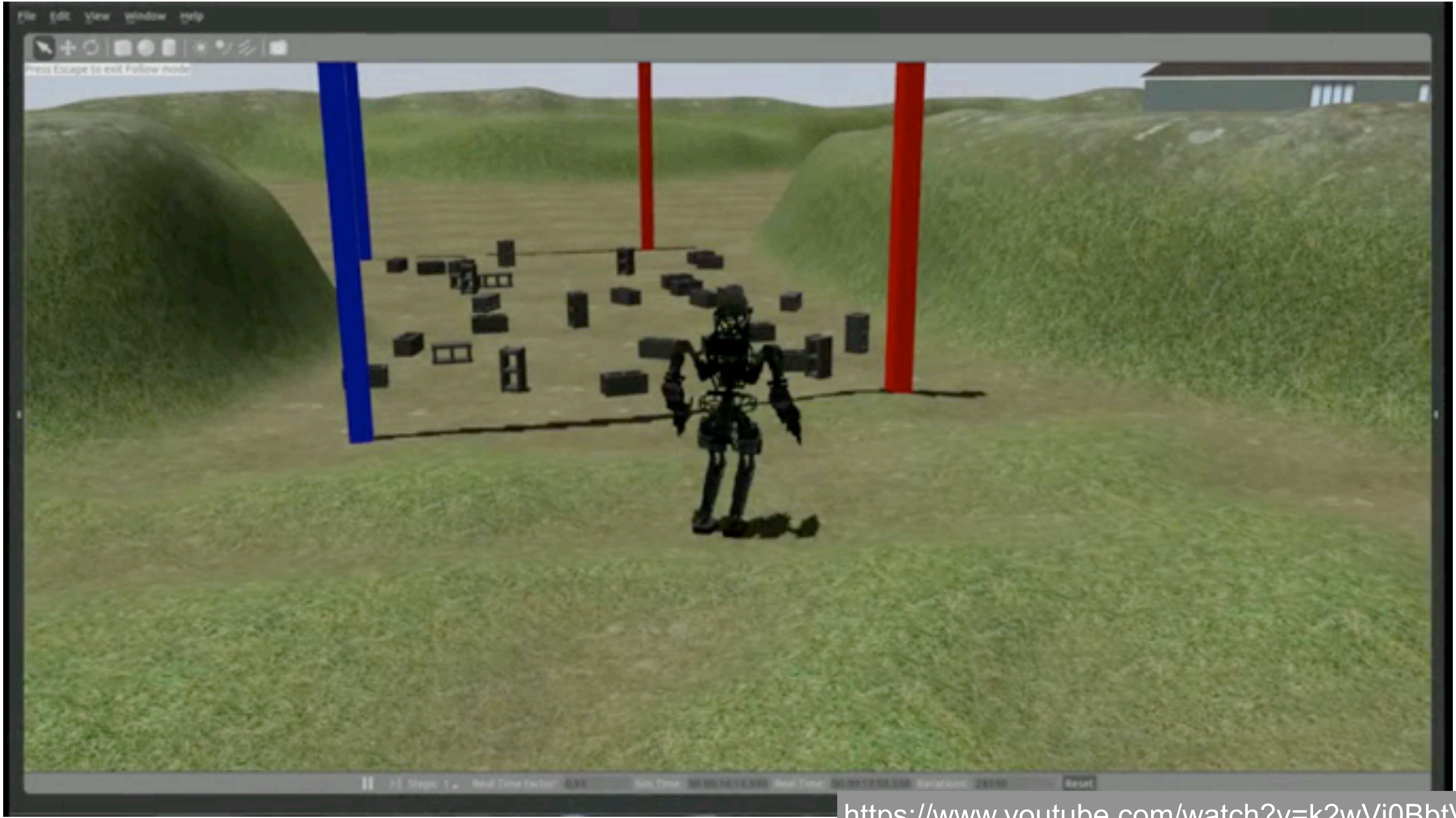
DARPA Virtual Robotics Challenge

Disaster first responder scenario: what is needed to fight fires?

Drive a utility vehicle (ie. water truck).
Walk across various terrains.
Thread a fire hose into standpipe.





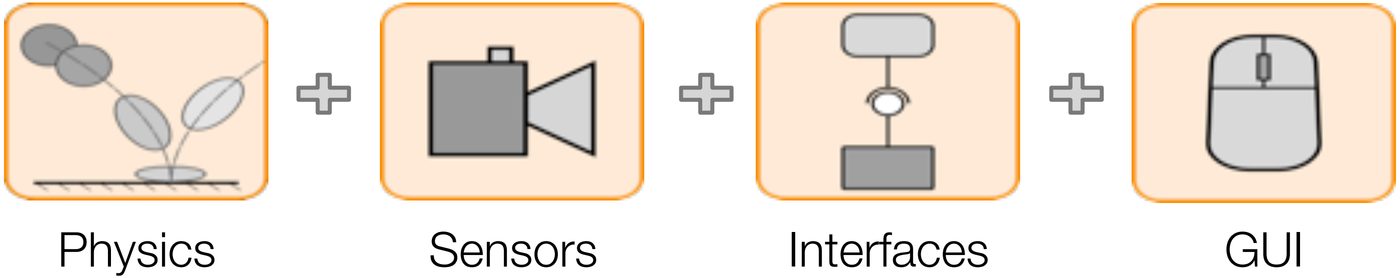


https://www.youtube.com/watch?v=k2wVj0BbtVk

Gazebo Simulator: Overview and Purpose

Goal: Best possible substitute for physical robot

Architecture:



Use cases:

- Design and testing of robot components and control
- Software testing and verification
- Competitions

gazebosim.org

Open Source Robotics Foundation

Open Source Physics Engines in Gazebo

Open Dynamics Engine	bitbucket.org/odedevs/ode Robotics, gaming
Bullet	github.com/bulletphysics/bullet3 Gaming, animation, Sony, AMD, Google
Simbody	github.com/simbody/simbody Biomechanics, Stanford
DART	github.com/dartsim/dart Robotics, animation, Georgia Tech

Open Source Physics Engines in Gazebo

Easy to switch between physics engines (gazebo 3.0+)

Command line option:

```
gazebo -e {bullet|dart|ode|simbody}
```

Attribute in sdf world file:

```
<world><physics type=”simbody” />...
```

gazebo4 package includes support for Bullet, ODE, and Simbody

(Dart requires building from source)

from packages.osrfoundation.org:

```
sudo apt-get install ros-indigo-gazebo4-ros-pkgs
```

Physics engine differences: coordinate representation

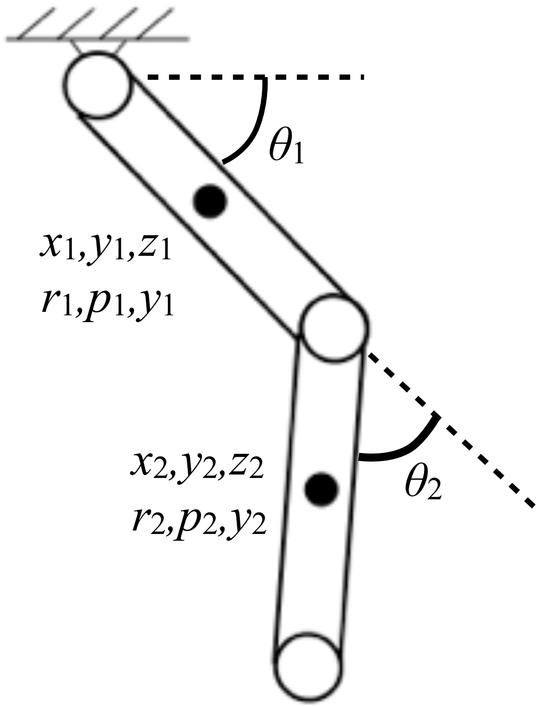
Consider double pendulum:

Maximal coordinates (ODE, Bullet):

- 12 degrees of freedom, 10 constraints
- Sparse 12x12 mass matrix
- Accuracy depends on constraint solver

Generalized coordinates (Simbody, DART):

- 2 degrees of freedom, no constraints
- Dense 2x2 mass matrix
- Kinematics implicit in formulation



Physics engine differences: spring / damper numerics

Explicit spring damper

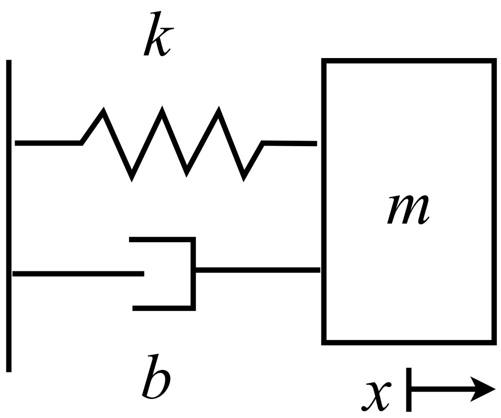
Velocity (i+1) depends on states (i)

$$\dot{x}_{i+1} = \dot{x}_i + 1/m\,(-kx_i - b\dot{x}_i)$$

Implicit spring damper

Velocity (i+1) depends on states (i+1)

$$\dot{x}_{i+1} = \dot{x}_i + 1/m\,(-kx_{i+1} - b\dot{x}_{i+1})$$



Explicit: easier to compute

Implicit: numerically stable

Physics engine differences: summary

Features:	DART	ODE	Bullet	Simbody
Contact	Rigid / Impulse	Rigid / Impulse	Rigid / Impulse	Rigid / Force variable step size
Joint Damping	Implicit	Explicit or Implicit* * in our fork of ODE	Explicit	Implicit
Coordinates	Generalized	Maximal	Maximal Generalized not yet supported by Gazebo	Generalized

Comparing physics engines: benchmark tests

- Scenario to simulate
  - Model, initial conditions, disturbances, control inputs
  - Expected behavior
- Choose parameters to vary
  - Time step size, number of objects, solver iterations
- Performance metrics
  - Accuracy, computational speed

Complexity

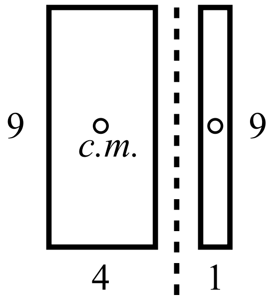
Simple models
Known solutions

Robot walking
???

Benchmark 1: Free-floating rigid bodies

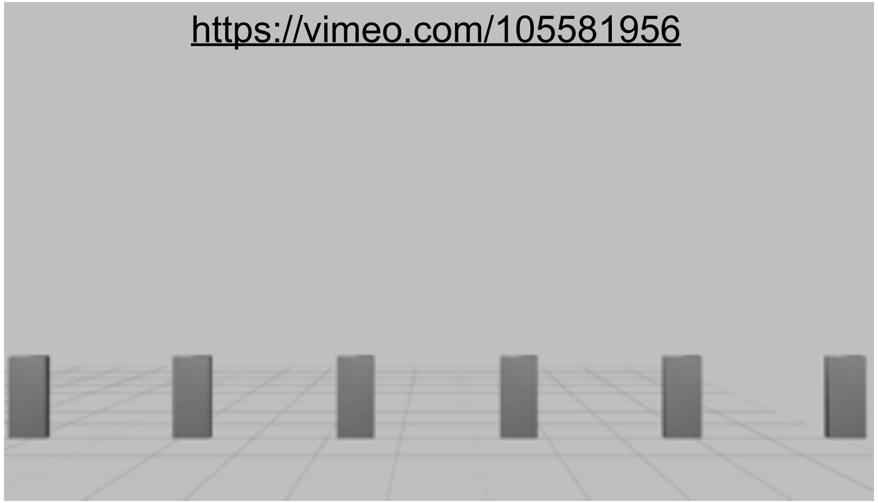
Model: boxes 1x4x9

- Free-floating
- Constant gravity field



Initial conditions:

- Largest angular velocity about axis of size 4 (leads to tumbling)



Expected behavior:

- Parabolic trajectory of center of mass (*c.m.*)
- Angular momentum conserved in world frame

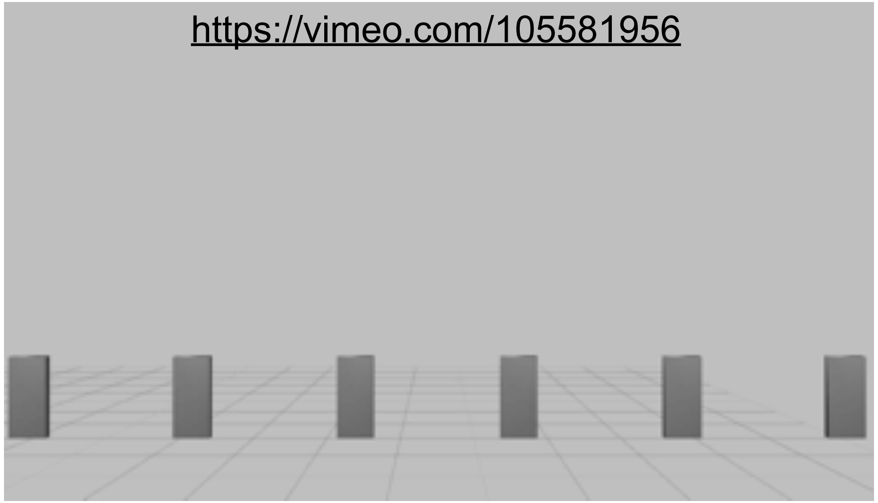
Benchmark 1: Free-floating rigid bodies

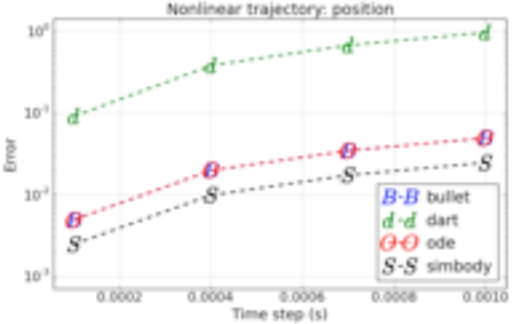
Parameters:

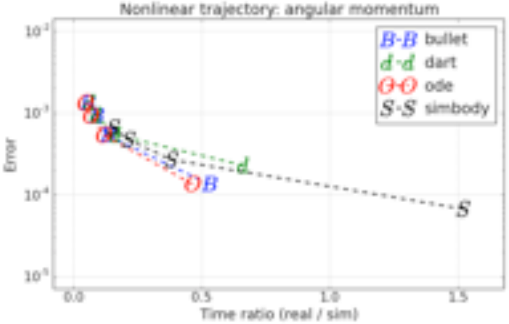
- Solver time step size (*s*)
- Number of boxes

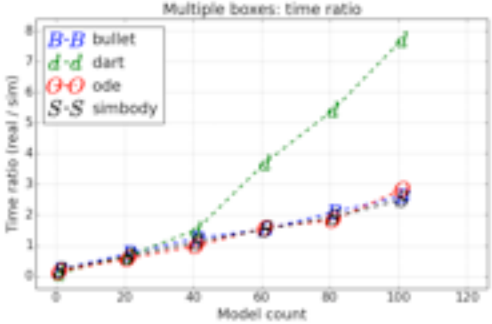
Performance metrics:

- Center of mass position error (max)
- Angular momentum error (max)
- Computational time per box





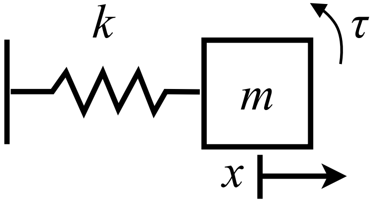


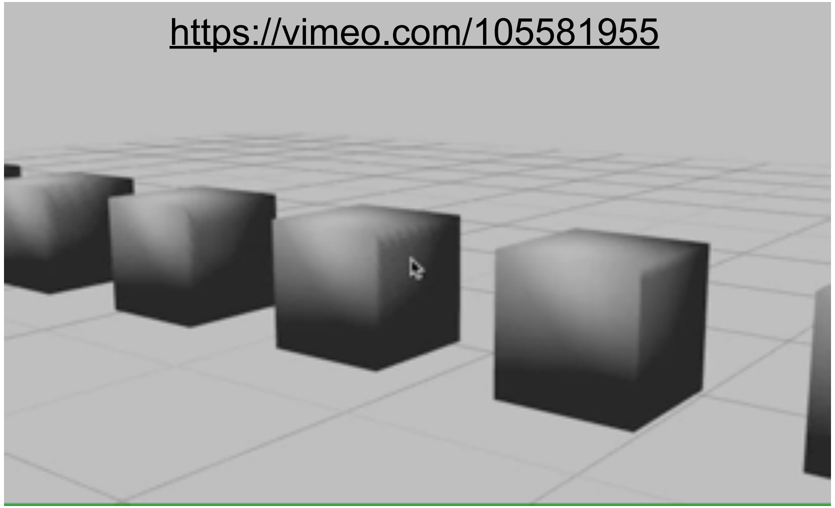


Benchmark 2: mass-spring oscillators

Model:

- Rigid bodies connected to world with prismatic joints
- Spring force acting on rigid bodies
- Disturbance torque $\boldsymbol{\tau}$ applied





Expected behavior:

- Sinusoidal trajectory
- No angular deviation

Benchmark 2: mass-spring oscillators

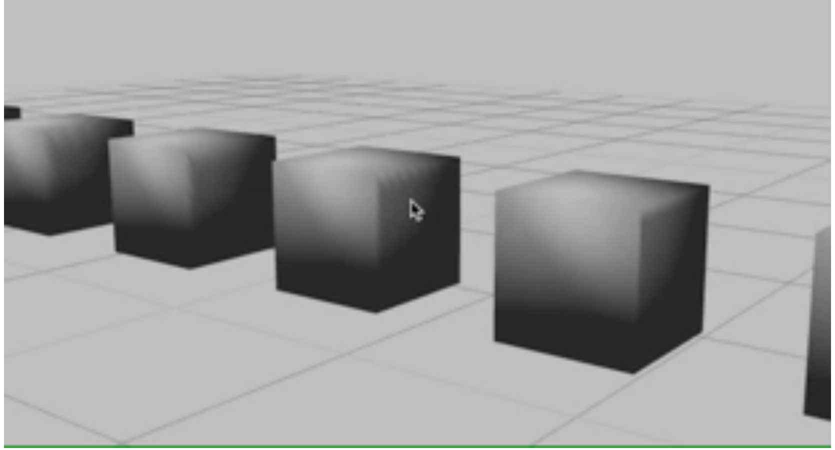
Parameters:

- Solver time step size (*s*)
- ODE constraint solver iterations

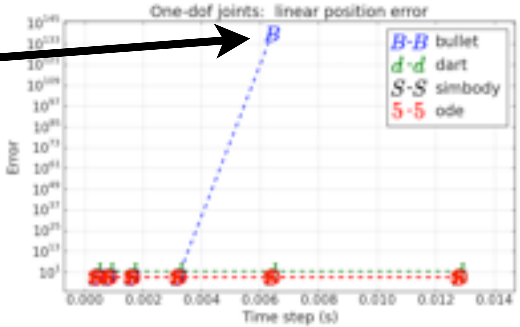
Performance metrics:

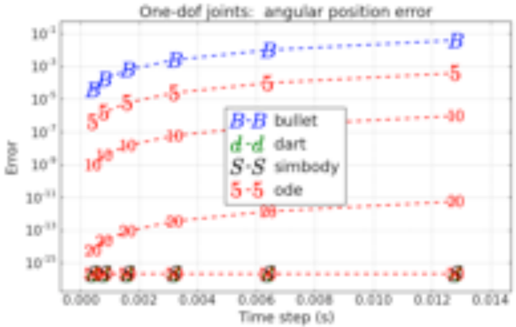
- Position error
- Angular constraint satisfaction

https://vimeo.com/105581955



Explicit spring unstable for large time steps





Open Source Robotics Foundation

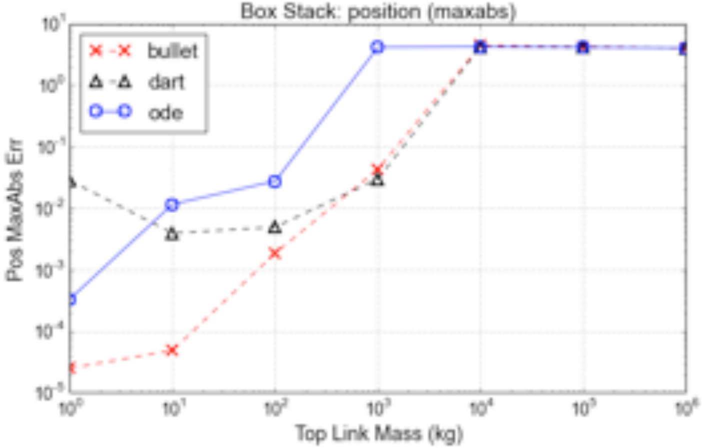
Benchmark 3: object stacking

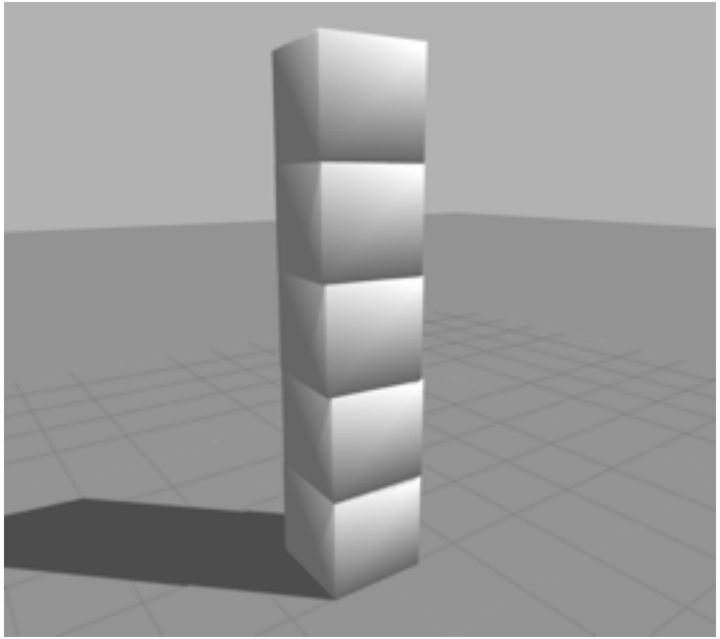
Boxes stacked with large inertia ratio

- Static equilibrium
- Variable inertia ratio

Metrics

- Position / velocity error
- Computational speed





ODE	Bullet	DART	Simbody
0.4	0.5	1.1	>100

Time ratio (real / sim)

Benchmark 4: robot walking

Model:

- Atlas humanoid robot from Boston Dynamics
- Walking on flat ground using black-box controller

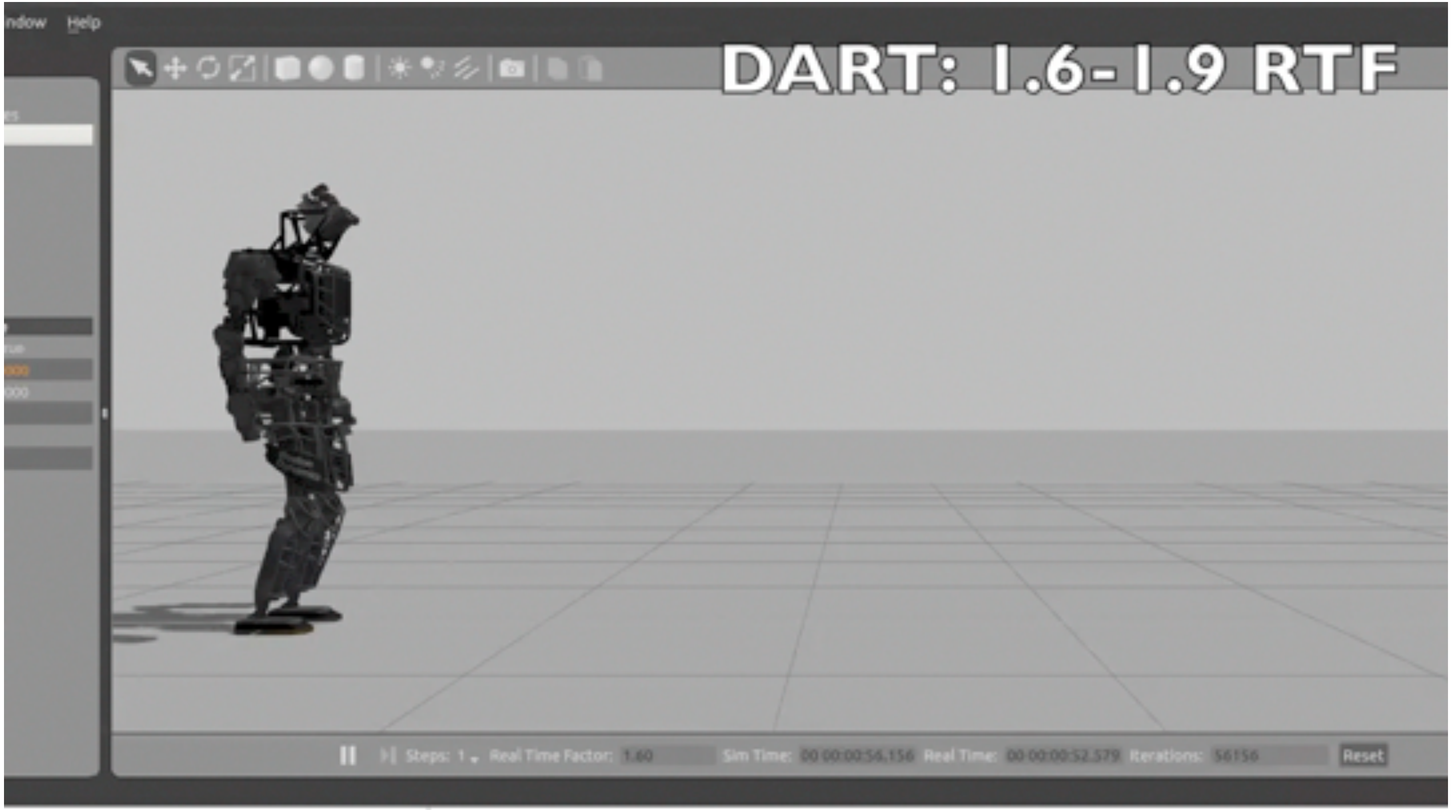
Parameters:

- Solver time step size (*s*)
- ODE constraint solver iterations

Expected behavior:

- Expect walking without falling over
- Complex scenario, no exact solution

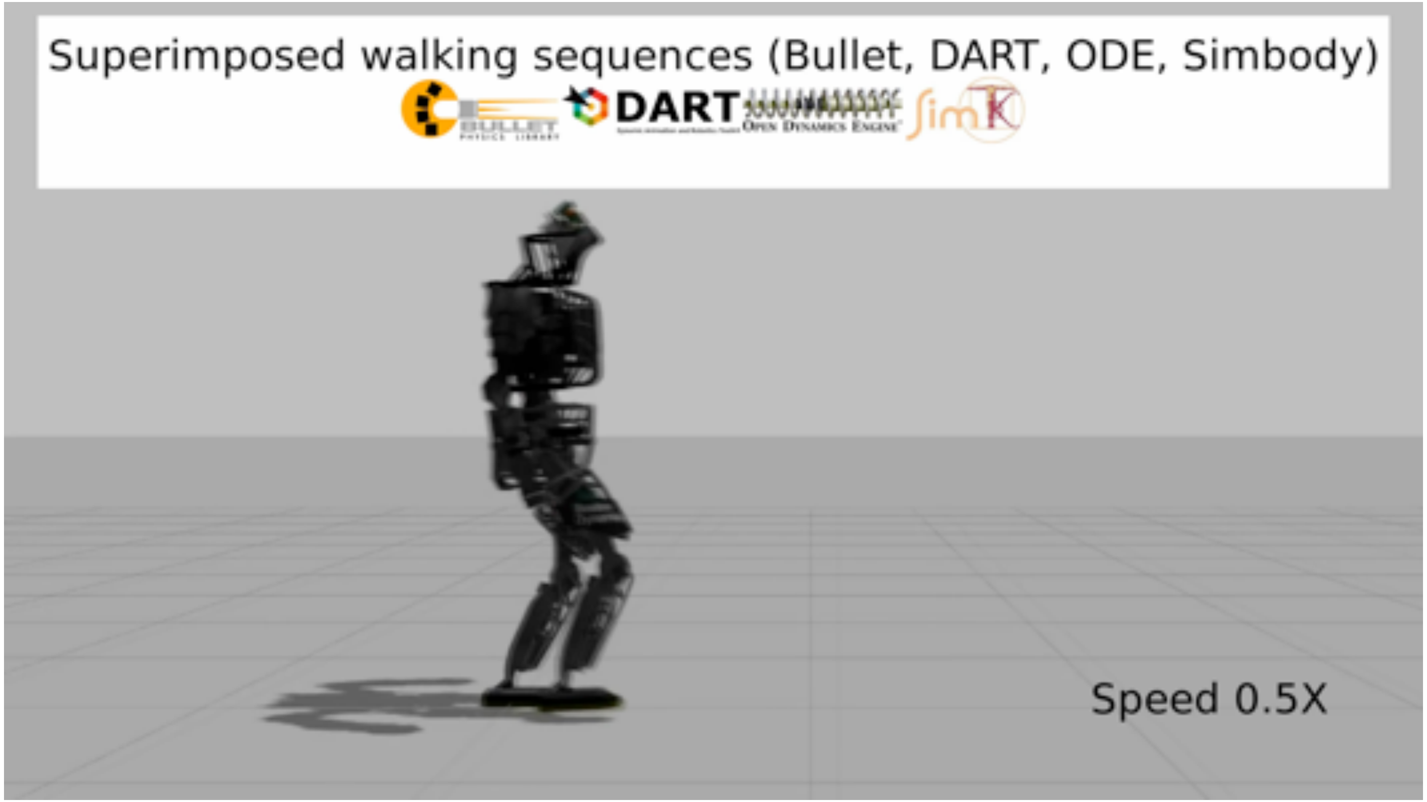
Robotic walking task: speed comparison



Open Source Robotics Foundation

https://vimeo.com/105584932

Robotic walking task: superimposed



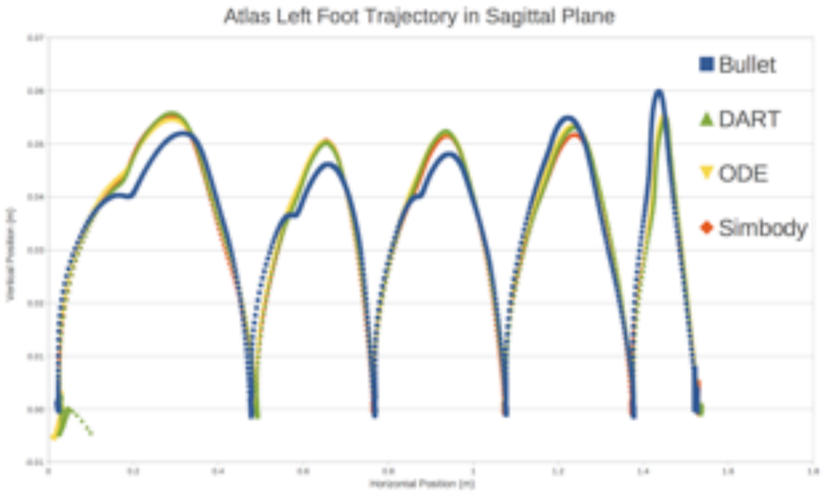
Open Source Robotics Foundation

http://vimeo.com/84443645

Robotic walking task: analysis

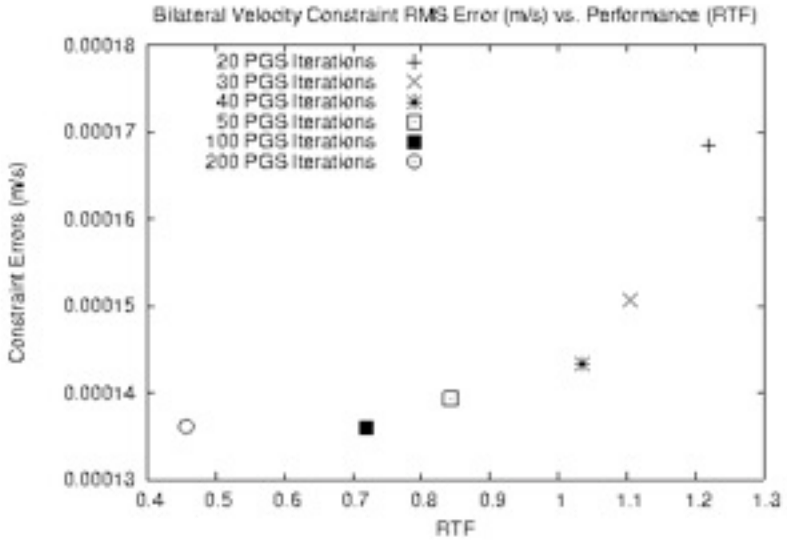
Trajectories look similar

Hard to say more without validation



ODE parameter study

Iterations vs error vs speed



Physics engine differences: summary

Features:	DART	ODE	Bullet	Simbody
Contact	Rigid / Impulse	Rigid / Impulse	Rigid / Impulse	Rigid / Force variable step size
Joint Damping	Implicit	Explicit or Implicit* * in our fork of ODE	Explicit	Implicit
Coordinates	Generalized	Maximal	Maximal Generalized not yet supported by Gazebo	Generalized

Future Work

Test more solver parameters (factorial!)

Benchmark problems of intermediate complexity

Common data formats to reproduce benchmarks outside Gazebo

Plugin architecture for Gazebo physics

Validation

gazebosim.org

OSRF Sponsors

DARPA

NASA

NSF

Sandia National Laboratories

YUJIN ROBOT

BOSCH Invented for life

rethink robotics

ROS Industrial consortium