Introduction to Programming with SimTK

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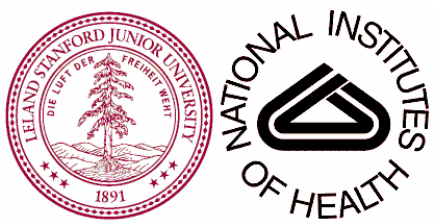


(ExamplePendulum.cpp)

```
#include "SimTKsimbody.h"
#include "SimTKsimbody_aux.h"
using namespace SimTK;

int main() {

    // Create the system.

    MultibodySystem system;
    SimbodyMatterSubsystem matter(system);
    GeneralForceSubsystem forces(system);
    Force::UniformGravity gravity(forces, matter, Vec3(0, -9.8, 0));
    Body::Rigid pendulumBody(MassProperties(1.0, Vec3(0), Inertia(1)));
    pendulumBody.addDecoration(Transform(), DecorativeSphere(0.1));
    MobilizedBody::Pin pendulum(matter.updGround(), Transform(Vec3(0)), pendulumBody,
        Transform(Vec3(0, 1, 0)));
    system.updDefaultSubsystem().addEventReporter(new VTKEventReporter(system, 0.01));

    // Initialize the system and state.

    system.realizeTopology();
    State state = system.getDefaultState();
    pendulum.setOneU(state, 0, 1.0);

    // Simulate it.

    RungeKuttaMersonIntegrator integ(system);
    TimeStepper ts(system, integ);
    ts.initialize(state);
    ts.stepTo(100.0);
}
```

Create the System

```
MultibodySystem system;
SimbodyMatterSubsystem matter(system);
GeneralForceSubsystem forces(system);
Force::UniformGravity gravity(forces, matter, Vec3(0, -9.8, 0));
```

- MultibodySystem is a subclass of System
  - Provides features for multibody dynamics
- SimbodyMatterSubsystem constructs an arbitrary set of bodies
- GeneralForceSubsytem applies forces to the bodies
  - Force::UniformGravity is an example of a force

Add a Body

```
Body::Rigid pendulumBody(MassProperties(1.0, Vec3(0), Inertia(1)));
pendulumBody.addDecoration(Transform(), DecorativeSphere(0.1));
MobilizedBody::Pin pendulum(matter.updGround(), Transform(Vec3(0)), pendulumBody,
    Transform(Vec3(0, 1, 0)));
```

- Body defines *physical properties* of a body
  - Mass, moment of inertia, appearance (optional)
- MobilizedBody combines *physical properties* (a Body) with *mobilities* (generalized coordinates)
  - Many subclasses for different types of motion
    - MobilizedBody::Pin allows rotation around a single axis
  - Multiple MobilizedBodies can use the same Body (if they have identical physical properties)

Display an Animation

```
system.updDefaultSubsystem().addEventReporter(new VTKEventReporter(system, 0.01));
```

- VTKEventReporter is an *event reporter*
  - Invoked at regular intervals during the simulation
  - Outputs information (in this case, draws an image of the System)
  - We'll discuss this much more later!

Initialize the System/State

```
system.realizeTopology();
State state = system.getDefaultState();
pendulum.setOneU(state, 0, 1.0);
```

- realizeTopology() performs initialization
  - Must be called after constructing the System, before creating a State for it
- Create a State by making a clone of the System's *default state*
  - All state variables set to default values
- Can modify the state variables before starting the simulation

Simulate It!

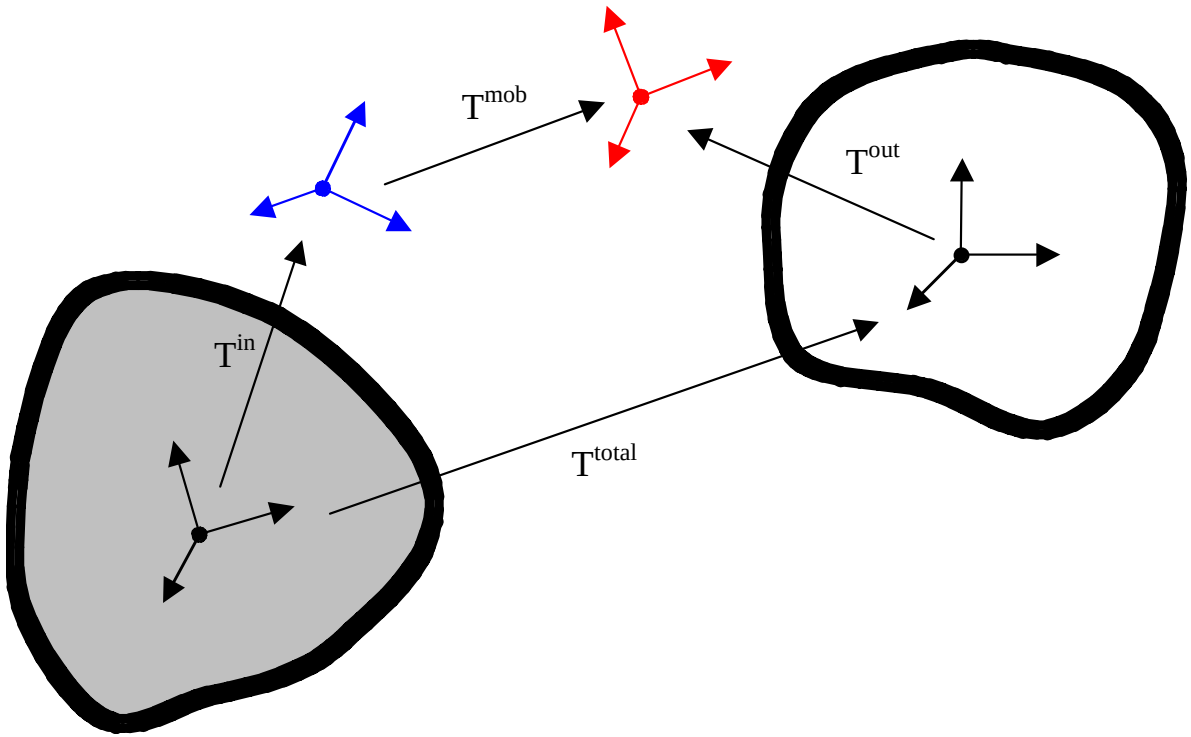
```
RungeKuttaMersonIntegrator integ(system);
TimeStepper ts(system, integ);
ts.initialize(state);
ts.stepTo(100.0);
```

- An Integrator advances the continuous equations of motion
- TimeStepper invokes the Integrator repeatedly and handles events
- We'll discuss this much more later!

Exercises

- Increase the length of the pendulum to 2 m
- Increase the duration of the simulation to 150 s
- Decrease gravity to 1.6 m/s^2 (lunar gravity)
- Change the location of the base of the pendulum
- Change the pendulum to a Ball joint
  - It now has three generalized coordinates. Initialize the speed of each one to a different value.
- Change it into a double pendulum (one pendulum attached to the end of another one)

MobilizedBody Transforms



$$T^{total} = (T^{out})^{-1}.T^{mob}.T^{in}$$

A Chain of Bodies

(ExampleChain.cpp)

```
MobilizedBodyIndex lastBody = matter.getGround().getMobilizedBodyIndex();
for (int i = 0; i < 10; ++i) {
    MobilizedBody::Ball pendulum(matter.updMobilizedBody(lastBody), Transform(Vec3(0)), pendulumBody,
        Transform(Vec3(0, 1, 0)));
    lastBody = pendulum.getMobilizedBodyIndex();
}
```

- MobilizedBodyIndex can be used to refer to a MobilizedBody in the matter subsystem
  - Basically an int, but typesafe
  - Cleaner than referencing a body with a pointer

Randomize the Chain

```
State state = system.getDefaultState();
Random::Gaussian random;
for (int i = 0; i < state.getNQ(); ++i)
    state.updQ()[i] = random.getValue();
```

- Sets every generalized coordinate to a random value
- Random is a random number generator
  - Subclasses for uniform and Gaussian distributions
  - Uses a fast, statistically robust algorithm (Mersenne Twister)

Exercises

- Instead of a chain of 10 bodies, make it into 10 independent pendulums, each with its base at a different location
- Attach each body to a randomly chosen existing body (a tree of pendulums)
- Add a spring connecting the end of the chain to ground (see Force::TwoPointLinearSpring)