Issues that continue to hinder Modeling & Simulation in Robotics

(the reality check)

Arunkumar Byravan
University of Washington

M&S in Robotics

- Modeling and Simulations provide a way to:
  - Prototype/design algorithms cheaply & safely
  - Generate large scale data for learning
  - Benchmark, compare and test algorithms across multiple platforms

- We expect our simulators to be:
  - Close to reality – high fidelity, photo-realistic etc.
  - General purpose – work well across environments, robots, tasks etc.
  - Easy to use – work with low effort, limited domain knowledge etc.

Issue: Model mismatch

- Non-smooth dynamics, Hybrid/Switching dynamics (friction/contact/collisions)
- Soft/Non-rigid robots/objects
- Liquids, Fluids
- Terra-mechanics, Granular media
- Sensors/Actuators
- Communication/Networking
- Human interaction, Human-Robot Interaction

Issue: Generality

- Few simulators work “out of the box” across different domains:
  - Choice of multiple models – requires expensive system ID
  - Customized representations for environment, robot and task specs

- Existing simulators try to accurately model the real-world deterministically:
  - Hard problem due to partial observability, model error etc.
  - Can work with stochastic predictions of multiple possible futures

Issue: Ease of use

- Many existing simulators are opaque and hard to use:
  - Significant learning curve for end-users; Low-level API (C/C++)
  - Hard to interface to other packages; Non-interactive (unlike game engines)

- Lack of composability, abstractions and hierarchies:
  - Abstractions delimit “levels” of appropriate modeling detail & accuracy
  - Abstractions govern model/controller/behavior composition

General issues

- Lack of (physical/simulated) **benchmarks** & shared repositories
- Lack of a "port" to **combine real-world data and human-in-the-loop** systems with analytical models and simulators
- **Poor scaling/non-determinism** of computation time
- Lack of approaches to **simulate and verify failure/edge** cases

Policy/Admin issues

- Lack of **strong collaborations** between simulation/modeling researchers and roboticists
- Lack of **established standards**: for describing robots, simulator capabilities, control/sensory interfaces etc.
- Lack of **focus on M&S** in the research community and funding agencies
  - Lack of incentive in industry/academia to work on M&S
- Lack of an established curriculum to train personnel

Issue: Reality gap

- Non-smooth dynamics (friction/contact/collisions):
  - Models are either over simplified or computation heavy; Poor models of hybrid, switching dynamics
- Soft/Non-rigid robots/objects:
  - Lack of proper representations/models of deformations, dynamics and contact
- Liquids, Fluids:
  - Lack of proper representations, computational pipelines and physical models
- Terra-mechanics, Granular media:
  - Lack of well understood models of contact, collision between solid/granular media

Issue: Reality gap

- Sensors/Actuators:
  - Poor models for touch sensors, photo-realistic rendering, cable/tendon-driven, hydraulic/pneumatic actuators, friction models etc.
  - Lack of realistic noise models
- Communication/Networking:
  - Lack of simulated models of latency, degraded/lost communications, sensor denied environments etc.
- Human interaction, Human-Robot Interaction:
  - No general mathematical formulation, lack of real-world data for learning
  - Lack of models for shared autonomy, crowd behavior, trust etc.

Issue: Generality

- Few simulators work “out of the box” across different domains:
  - Choice of models for contact, friction, collision etc.
  - Expensive & time-consuming system ID of physical parameters
  - Customized representations for environment, robot and task specifications

- Existing simulators try to accurately model the real-world deterministically:
  - Hard problem due to partial observability, model error etc.
  - Can work with stochastic predictions of multiple possible futures – principled noise addition

Issue: Ease of use

- Many existing simulators are opaque and hard to use:
  - Significant learning curve for an end-user for setting up new scenarios
  - API in low-level languages like C/C++
  - Hard to interface to other packages
  - Non-interactive (unlike game engines)

- Lack of composability, abstractions and hierarchies:
  - Abstractions delimit “levels” of appropriate modeling detail & accuracy
  - Abstractions govern model/controller/behavior composition

General issues

- Lack of **benchmarks** (simulated tasks and physical testbeds), shared repositories of models/tasks/environments
- Lack of a "port" to **combine real-world data and human-in-the-loop** systems with analytical models and simulators (VR/AR?)
- **Poor scaling/non-determinism** of computation time with increase in fidelity/environment complexity (GPU/Cloud?)
- Lack of principled approaches to **simulate and verify performance** under edge/failure cases and catastrophic situations

Policy/Admin issues

- Lack of strong collaborations between simulation/modeling researchers and roboticists
- Lack of established standards: for describing robots, simulator capabilities, control/sensory interfaces etc.
- Lack of focus on modeling and simulation in the research community and funding agencies. Lack of incentive in industry/academia to work on M&S
- Lack of an established curriculum to train personnel