Lecture 8

Forward Dynamic Simulations

EML 5595

Mechanics of the Human Locomotor System

Outline

- Numerical Integration
- Simulation Problems
- Journal Article Reviews

  Gilchrist and Winter (1997)

  Panne and Lamouret (1995)

Outline

- Numerical Integration

Forward Dynamics Process

- Measure kinematics and ground reactions
- Perform inverse dynamics analysis to estimate joint torques
- Perform optimization analysis to estimate muscle forces
- Define initial positions and velocities and estimated joint torque or muscle force inputs
- Numerically integrate equations of motion to predict new motion

Forward Dynamics Equations

$$\mathbf{M}(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}} = \mathbf{N}(\boldsymbol{\theta})\mathbf{T} + \mathbf{G}(\boldsymbol{\theta}) + \mathbf{V}(\boldsymbol{\theta}, \dot{\boldsymbol{\theta}})$$

$$\downarrow$$

$$\mathbf{q} = \boldsymbol{\theta}, \mathbf{u} = \dot{\boldsymbol{\theta}}$$

$$\downarrow$$

$$\mathbf{M}(\mathbf{q})\dot{\mathbf{u}} = \mathbf{N}(\mathbf{q})\mathbf{T} + \mathbf{G}(\mathbf{q}) + \mathbf{V}(\mathbf{q}, \mathbf{u})$$

$$\downarrow$$

$$\begin{bmatrix} \dot{\mathbf{u}} \\ \dot{\mathbf{q}} \end{bmatrix} = \begin{bmatrix} \mathbf{M}(\mathbf{q})^{-1}\left(\mathbf{N}(\mathbf{q})\mathbf{T} + \mathbf{G}(\mathbf{q}) + \mathbf{V}(\mathbf{q}, \mathbf{u})\right) \\ \mathbf{u} \end{bmatrix}$$

$$\downarrow$$

$$\mathbf{y} = \begin{bmatrix} \mathbf{u} \\ \mathbf{q} \end{bmatrix}, \dot{\mathbf{y}} = \begin{bmatrix} \dot{\mathbf{u}} \\ \dot{\mathbf{q}} \end{bmatrix}$$

$$\downarrow$$

$$\dot{\mathbf{y}} = f(\mathbf{y})$$

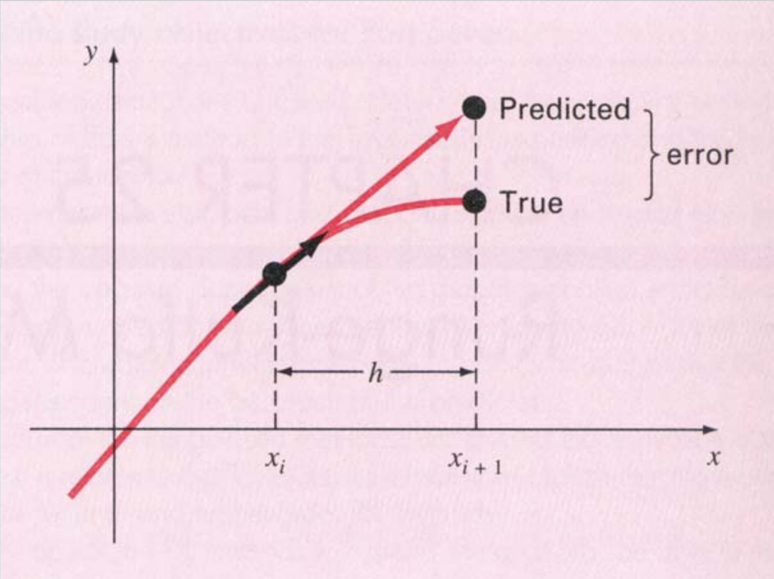
Types of Integrators

Let $\dot{\mathbf{y}} = f(t, \mathbf{y}), \Delta t = h$

Explicit Euler Integrator

$$\mathbf{y}_{i+1} = \mathbf{y}_i + f(t_i, \mathbf{y}_i)h$$

Explicit equation for $\mathbf{y}_{i+1}$



Implicit Euler Integrator

$$\mathbf{y}_{i+1} = \mathbf{y}_i + f(t_{i+1}, \mathbf{y}_{i+1})h$$

Implicit equation for $\mathbf{y}_{i+1}$

Re-write as nonlinear root-finding problem

$$\mathbf{y}_{i+1} - \mathbf{y}_i + f(t_{i+1}, \mathbf{y}_{i+1})h = 0$$

Iterate guess of $\mathbf{y}_{i+1}$ until the equation = 0 to within some tol

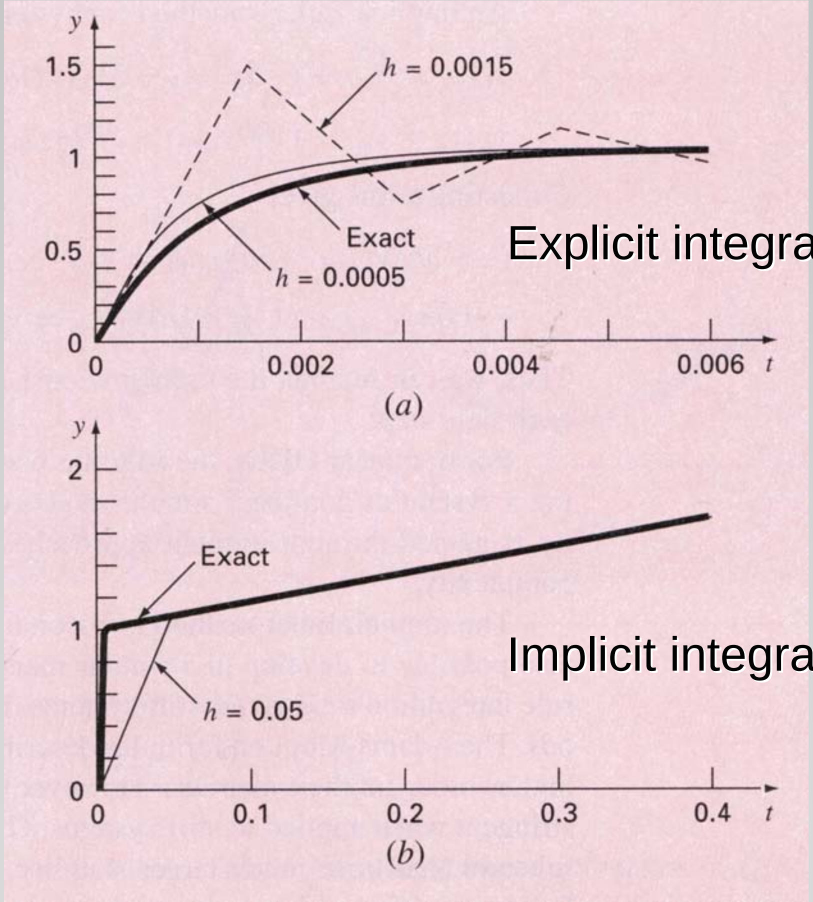
When to Use Each Type

- Try an explicit integrator first – classic example is 4th Order Runge-Kutta integrator
- Try an implicit integrator only if the explicit integrator is slow
- Integration speed is related to number of equations solved and the numerical “stiffness” of the equations

Stiff Systems

- Stiff systems typically exhibit motions on different time scales (e.g., a rigid body system possessing stiff springs)
- Numerical stiffness is an issue of accuracy and stability
- A stiff system is one that requires an extremely small step size to meet accuracy requirements and remain stable
- Can you think of some examples of stiff systems?

Stiff System Example

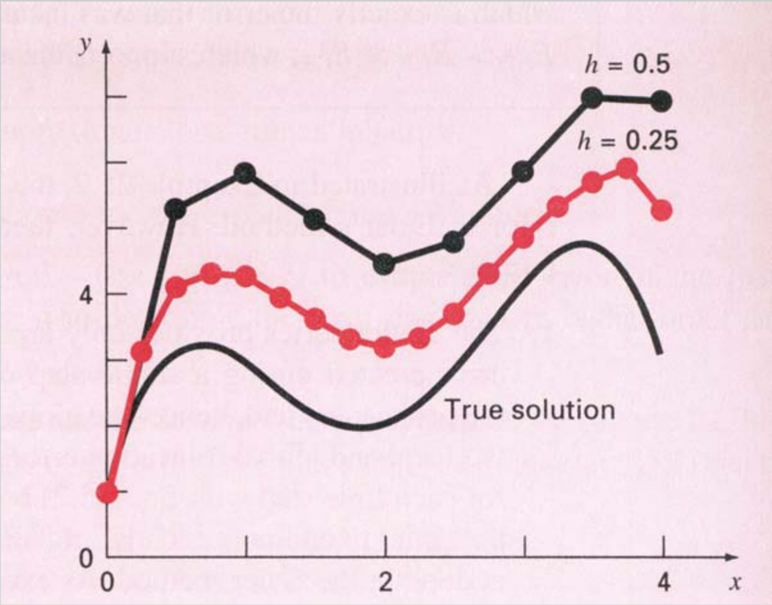


Explicit integrator

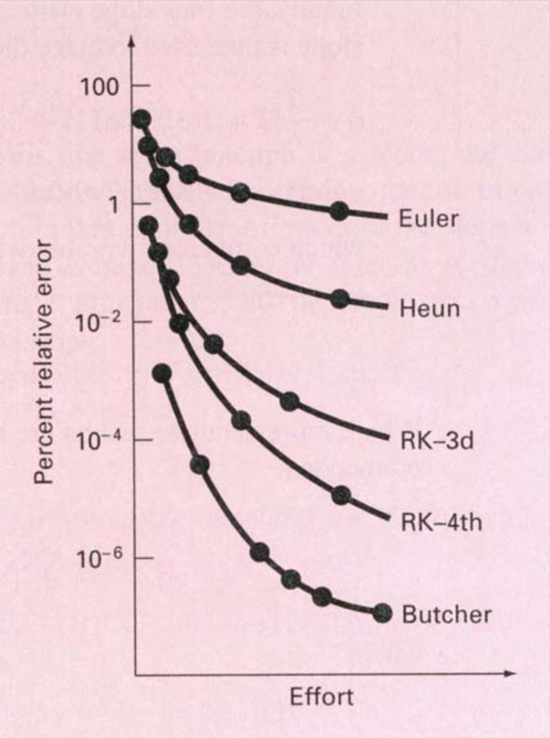
Implicit integrator

Integration Accuracy

Integration Step Size



Integrator Order



Order
1st
2nd
3rd
4th
5th

Outline

- Numerical Integration
- Simulation Problems

Problems and Solutions

Problem	Solution
• Slow integration	• Implicit integrator
• Motion drift	• Smaller time step, higher order integrator, or spline-fit controls
• Motion instability	• Feedback control
• Joint hyperextension	• Ligament torques

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Simulation Problems 1

- What was the goal of the Gilchrist and Winter paper?
- What problems did they encounter in trying to achieve it?
- What solutions did they attempt to resolve these problems?
- Can you think of additional modifications to get their forward dynamics simulation to reproduce the experimental motion and ground reactions better?

Simulation Problems 2

- What was the goal of the Panne and Lamouret paper?
- Explain the three-step optimization process that they proposed to implement their approach.
- Can you think of a simpler way to drive the HOG torque to zero using one optimization?
- If the HOG torque implementation works so well, why couldn’t Gilchrist and Winter get their simulation to work better?

For Next Time

- Download and read the Fregly and Zajac (1996) article.