Overview: Solvers for Simscape Models

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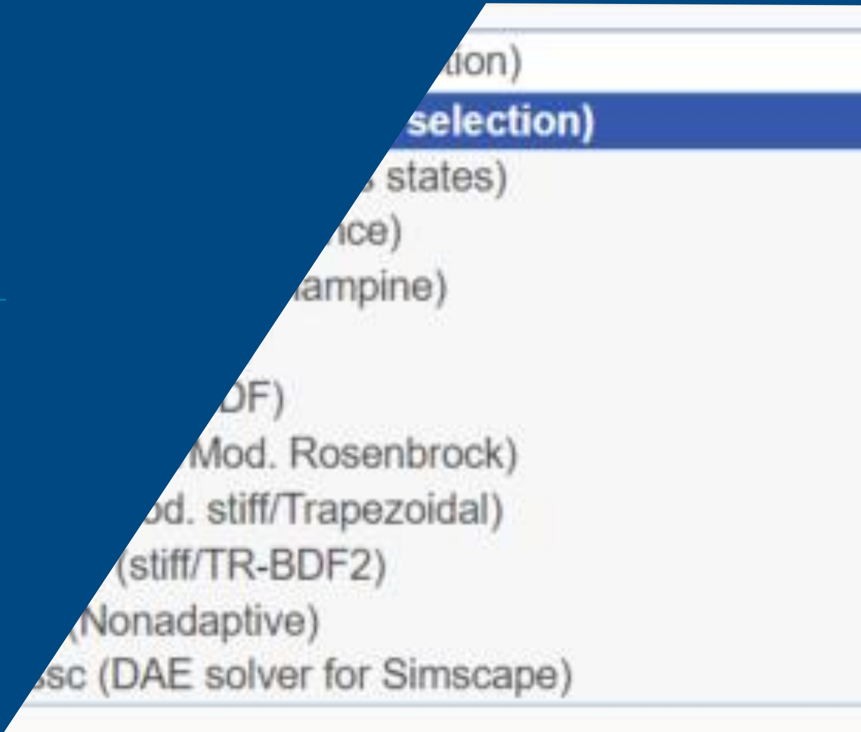


Solver and Model Considerations

- A model might:
  - Include discrete and/or continuous states
  - Be stiff/non-stiff

- A solver can be categorized by:
  - **Step size type:** Fixed-step vs. variable-step
  - **State updates:** Discrete vs. continuous
  - **Integration:** Explicit vs. implicit
  - **Order:** Fixed vs. variable

Name provides some info:

ode3

Fixed step/continuous/explicit/third order

ode15s

Variable step/continuous/implicit/variable order

Explicit vs. Implicit Solvers

- Explicit Solvers:
  - Use past information to compute next step
  - Less computational effort
  - Less robust
  - Well-suited for *non-stiff* systems

$$y_{k+1} = y_k + h \cdot f(t_k, y_k)$$

- Implicit Solvers:
  - Compute next step self-consistently
  - More computational effort
  - More stable
  - Better suited for *stiff* systems/Typically better suited for Simscape models

$$y_{k+1} = y_k + h \cdot f(t_{k+1}, y_{k+1})$$

Fixed-Step vs. Variable-Step Solvers

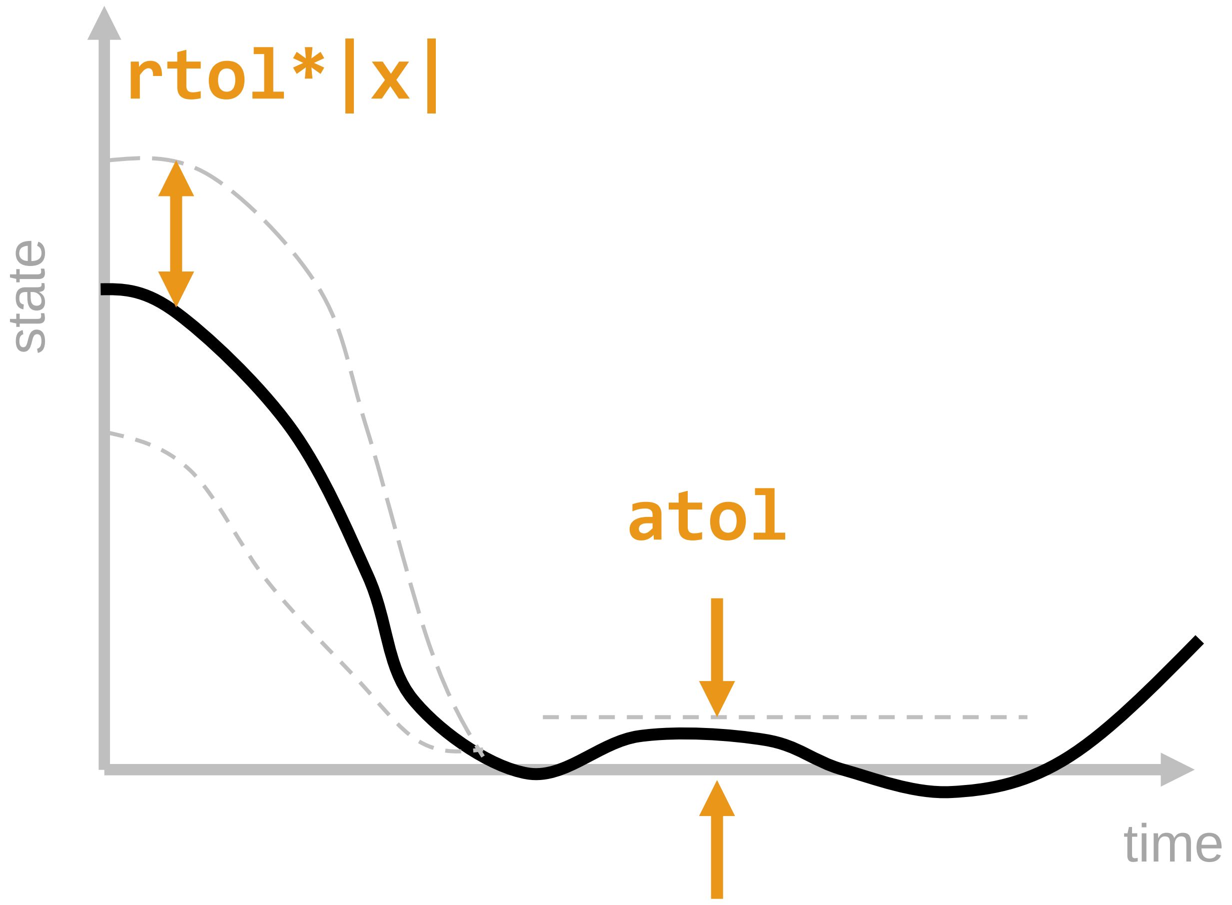
- Fixed-Step Solvers:
  - Solve model at regular time intervals (step size)
  - Decreasing step size generally increases accuracy
  - Necessary for code-generation and hardware deployment

- Variable-Step Solvers:
  - Vary step size during simulation to meet tolerance requirements
  - Can reduce the total number of steps for models with rapidly changing states

Variable-Step Solver Step Size: Error Tolerances

- Variable-step solvers allow the definition of an absolute (*atol*) and relative tolerance (*rtol*)
- During simulation step-size is chosen so that the estimated error satisfies the following equation:

$$e_k \leq \max(\mathrm{rtol}|x_k|, \mathrm{atol})$$



Continuous Solver Selection: Simulink

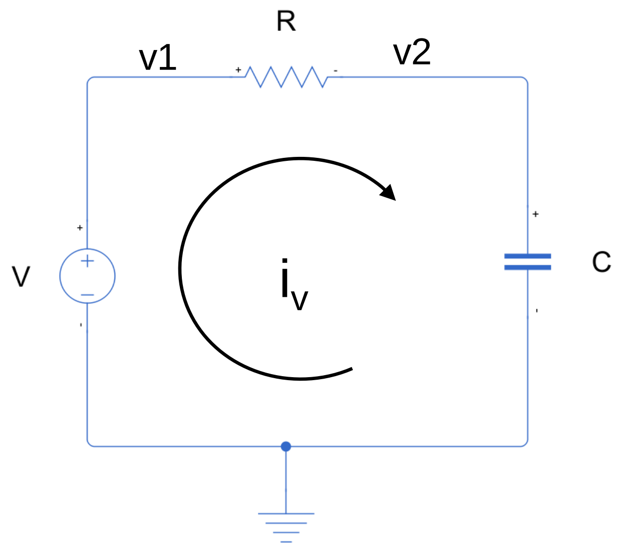
- Available Solvers in Simulink for continuous state dynamics:

	Variable-step solvers	Fixed-step solvers
Non-stiff	`ode45`	`ode8`
	`ode23`	`ode5`
	`ode113`	`ode4`
Stiff	`ode15s`	`ode3`
	`ode23s`	`ode2`
	`ode23t`	`ode1`
	`ode23tb`	`ode14x`

Solver Considerations for Simscape: DAEs

- For a Simscape network the solver will construct equations containing:
  - Ordinary differential equations (*ODEs*) that govern the rate of change of system variables
  - Algebraic equations constraints
- Typically, both are present resulting in a differential algebraic equation (DAE) system

Differential → $\dot{y} = f\big(t, y(t), z(t)\big)$
Algebraic → $0 = g\big(t, y(t), z(t)\big)$



$$\frac{dv_1}{dt} = 0$$

$$\frac{dv_2}{dt} = -\frac{v_2 - v_1}{RC}$$

Differential

$$-i_V + \frac{(v_1 - v_2)}{R} = 0$$

Algebraic

Solve for v_1, v_2, i_V

Solver Considerations for Simscape

- Variable-step solver recommended for desktop simulation:
  - Typically provides better performance and accuracy for physical system
  - Suited to uncover potential modeling issues
  - Use to create baseline results even if final model will run fixed-step

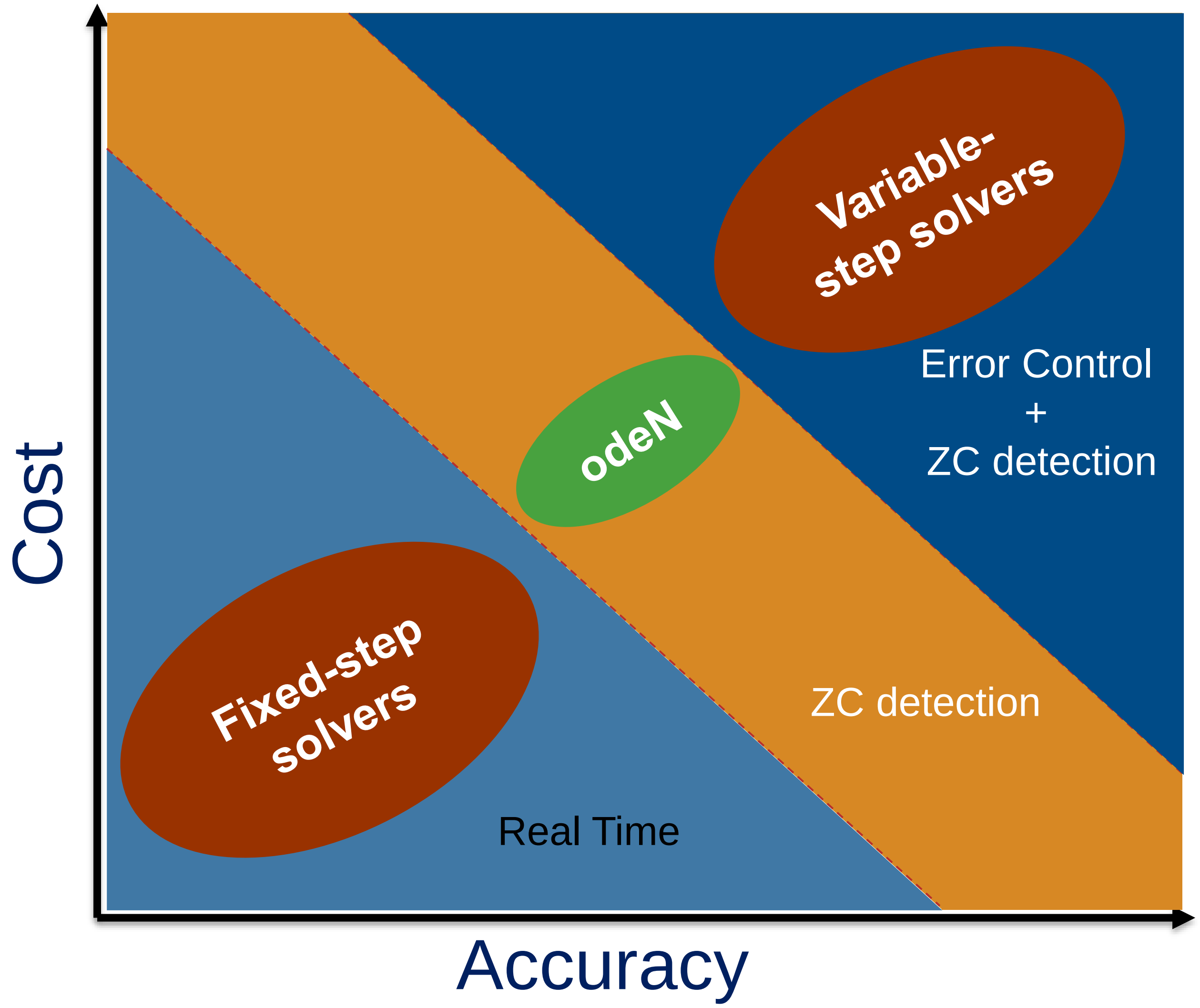
- Fixed-step simulation has two main choices:
  - Simscape local solver: No subsampling occurs, Simscape network only updated at each sample time. Simscape networks will be regarded as discrete. Choice of global solver can be independent. First choice for performance and stability
  - Simulink global solver: One sample time for whole model

Simscape Networks: Variable-Step Solver Selection

- Simscape networks typically require an implicit solver suited for stiff systems:
  - `daessc`
    - Designed specifically for DAEs
    - Exclusively available in Simscape
    - Default auto solver for DAEs from Simscape
  - `ode23t`
    - Suited for stiff systems
    - Default auto solver for stiff ODEs from Simscape
    - More stable, tends to damp out oscillations
  - `ode15s`
    - Suited for stiff systems
    - Less stable, better at capturing oscillations
  - `odeN`
    - Fixed-step integration without error control

odeN: A Fixed-Variable-Step Solver to Capture Events

- odeN fixed-step size behaviour:
  - Determined by the *Max step size*
  - Step size can reduce to capture events (i.e. zero crossings (ZC), discrete update rates, PWM signals)
  - No error-control



Simscape Networks: Fixed-Step Solver Selection

- Local Simscape solver recommended for fixed-step Simscape simulation
- Local Simscape solver:
  - `Backwards Euler` solver: Tends to damp out oscillations, more stable
  - `Trapezoidal Rule` solver: Better to capture oscillations, less stable
  - `Partitioning` solver: Converts Simscape networks into smaller sets of equations, can result in faster simulation
- Global fixed-step solvers:
  - `ode14x`: Implicit Simulink solver
  - `ode1be`: Global Backward Euler, lower cost alternative to ode14x