Introduction to Simulink, Stateflow, and Simscape

By Paul Peeling
MathWorks
Key Technologies for Embracing Complexity

- Model-Based Design
- Multi-Domain Modelling
- Code Generation
Two Engineering Challenges

Shift schedule optimisation of an automatic transmission controller

Modelling and control of an inverted double pendulum
Modelling Automatic Transmission
Modelling Automatic Transmission in Simulink
Blocks in Simulink

- Fundamental blocks
- Subsystems
- Other Simulink Models
- MATLAB Code
- DLLs
- Stateflow Charts
- Simscape Components
- …
Simulation of dynamic systems

\[ I_e \dot{N}_e = T_e - T_i \]

\( N_e = \) engine speed (RPM)

\( I_{ei} = \) moment of inertia of the engine and the impeller

\( T_e, T_i = \) engine and impeller torque

\[ T_i = \frac{N_e^2}{K^2} \]

\( K = f_2 \frac{N_{in}}{N_e} = \) K-factor (capacity)

\( N_{in} = \) speed of turbine (torque converter output) = transmission input speed (RPM)

\( R_{TQ} = f_3 \frac{N_{in}}{N_e} = \) torque ratio
Simulink: Key Features

- Visual, block-diagram, environment
- Hierarchical, component-based modelling
- Extensive and expandable libraries of pre-defined blocks
- Open Application Program Interface (API)
- Full MATLAB® integration
- Multi-domain
Stateflow for Complex Logic

- When to use Stateflow?
- Model **instantaneous** changes in dynamic systems
  - Changes in state
  - Events
- Finite state machines
- Flow diagrams
Stateflow Overview

- Extend Simulink with a design environment for developing state machines and flow charts
- Design systems containing control, supervisory, and mode logic
- Describe logic in a natural and understandable form with deterministic execution semantics
Stateflow: Key Features

- Defines functions
  - Procedurally, using MATLAB
  - Graphically, using flow diagrams
  - In tabular form, with truth tables
- Provides language elements, hierarchy, and parallelism
- Animates Stateflow® charts
- Incorporates custom and legacy C code
- Performs static and run-time checks
Conclusions

Simulink and Stateflow provide:

- A powerful environment for modelling real processes...
- in a modular fashion...
- and are fully integrated with the MATLAB environment for extensive design & analysis capability
Physical Modelling

Inputs and outputs, state charts, algorithms, ...

Physical devices
What does this model represent?
Modelling an electrical circuit in Simulink

Step 1: figure out the equations

Step 2: build the model

\[ U_0 = f(t) \]

\[ U_R = R \cdot i_0 \]

\[ i_1 = C_1 \cdot \frac{dU_1}{dt} \]

\[ i_2 = C_2 \cdot \frac{dU_2}{dt} \]

\[ U_0 = U_R + U_1 \]

\[ U_2 = U_1 \]

\[ i_0 = i_1 + i_2 \]
Differential Algebraic Equation

\[ U_0 = f(t) \]

\[ U_R = R \cdot i_0 \]

\[ i_1 = C_1 \cdot \frac{dU_1}{dt} \]

\[ i_2 = C_2 \cdot \frac{dU_2}{dt} \]

\[ U_0 = U_R + U_1 \]

\[ U_2 = U_1 \]

\[ i_0 = i_1 + i_2 \]
Modeling an electrical circuit in Simscape

\[ U_0 = f(t) \]
\[ U_R = R \cdot i_0 \]
\[ i_1 = C_1 \cdot \frac{dU_1}{dt} \]
\[ i_2 = C_2 \cdot \frac{dU_2}{dt} \]
\[ U_0 = U_R + U_1 \]
\[ U_2 = U_1 \]
\[ i_0 = i_1 + i_2 \]

Component equations

Constructed by the Simscape solver
Mathematical Modelling of Mechanical Systems

Derivation of the equations of motion requires extensive knowledge and great effort.

\[ \dot{\alpha} = \int \left( -L_2 \sin(\alpha) + n \omega \left( -\sin(\alpha - \gamma) \right) \sin(\gamma) - n \varepsilon \left( -\sin(\alpha - \gamma) \right) \cos(\alpha - \gamma) \alpha^2 - n \cos(\alpha - \gamma) \gamma^2 \right) \frac{d\gamma}{1 - n \varepsilon \sin^2(\alpha - \gamma)} \]
With SimMechanics

Bodies
- Fixture
- Link1
- Link2

Joints
- Revolute Joint1
- Revolute Joint2

SimMechanics Model
Physical Systems in Simulink®

Electrical power systems

Mechanical dynamics (3-D)

Drivetrain systems (1-D)

Multidomain physical systems

Fluid power and control

Electromechanical and electronic systems
Simscape Key Features

- Library of foundation physical modelling building blocks
  - Mechanical, electrical, hydraulic,…
- Simscape language source provided
- Signals and parameters with units, and automatic unit conversion
- Physical network solver technology designed for physical systems
- Integrated with Simulink to support complete system modelling (physical system plus algorithms)
- Convert to C code for deployment