Oak Ridge National Laboratory

Training Session 2: Introduction to TRANSFORM

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Introduction to TRANSFORM (60 Minutes)

- TRANSFORM Library Overview (15 min)
- Discussion of fluid and heat connectors (5 min)
- Hands-On Example 1: Heat Transfer (20 min)
- Hands-On Example 2: Fluid System (20 min)

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TRANSFORM Introduction

- 15 min – what is it, where does it fit, what can you do with it

The Future of Nuclear Covers a Large Array of Applications

What will be required of modeling and simulation tools?

Flexible and Adaptable

- Tools must be able to be used for a variety of applications
- Tools must be modifiable for new uses

- Advanced Reactor Technologies
  - HTGRs, LMRs, MSRs
- Integrated Energy Systems
  - Desalination, Hydrogen, Oil-recovery

Rapid Development

- Users need the ability to "fail fast" and mature analysis
- Modeler has control over level of fidelity

- Deployable on a range of machines
  - PCs, clusters
- Advanced languages and features
  - Python, Modelica
  - Acausal, object-oriented

Collaborative

- Domain expertise shareable to leverage skill sets
- Models able to communicate with other tools and frameworks

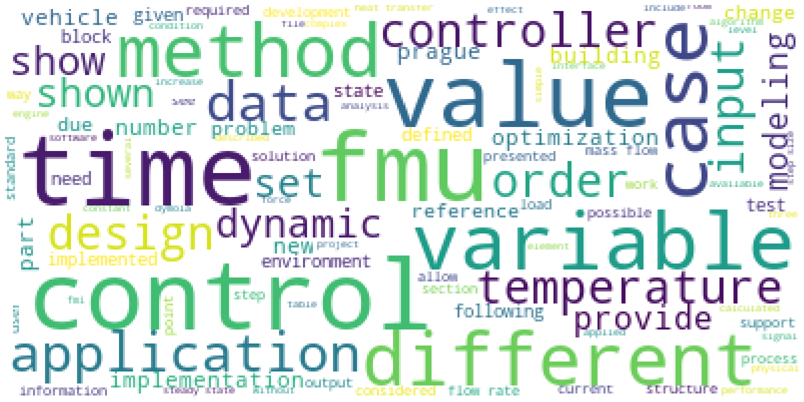
- Models should be shareable/exportable
  - Open-source or "black-box" capable
- Ability to integrate at different "scales"
  - System, CFD

So what is TRANSFORM???

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

TRANSFORM Library

Transient Simulation Framework of Reconfigurable Models



- Current TRANSFORM capabilities include:
  - Nuclear energy and auxiliary systems
  - Thermal-hydraulics, heat transfer, and control systems
- Built using the [Modelica] programming language
  - A powerful and modern dynamic system modeling language
  - Time-dependent system modeling
  - Ideal for rapid, flexible, and collaborative system modeling
- Part of an “economy” of modeling
  - Leverage other Modelica libraries
  - A growing number of tools directly support Modelica and FMI

https://github.com/ORNL-Modelica/TRANSFORM-Library

TRANSFORM – Transient Simulation Framework of Reconfigurable Models

- 2013–2015 – Originally conceived as a high-level interface approach for modeling of advanced reactors. Including exploration of deployment and collaboration methods.
  - For example: web-apps, Excel, FMU
  - The general flexibility and capability of the language was a draw to continue growing expertise in Modelica
  - However, at that time there was no standard fluid or heat transfer libraries
  - Led to difficulty/limited usefulness in developing a high-level interface which had no components with which to model
- 2015–Present – Scott Greenwood took over the Modelica development and re-imagined TRANSFORM to be a general library of components for modeling a variety of thermal-hydraulic and other multi-physics systems.

AdvSMR
High-level interface to allow a plug-and-play type approach for modeling of advanced reactors.

2013

NHES
Template based approach for modeling hybrid or integrated energy systems (IES).

2015

TRANSFORM
TRANSFORM released as a Modelica library with a large selection of TH components. Including the ability to model tritium and its diffusion through solids.

2017

MSR Models & SMR-GAIN
TRANSFORM expanded capability for source term accountancy for salt-fueled MSRs. TRANSFORM also used in support of stability analysis in GAIN award and nuclear thermal propulsion system modeling.

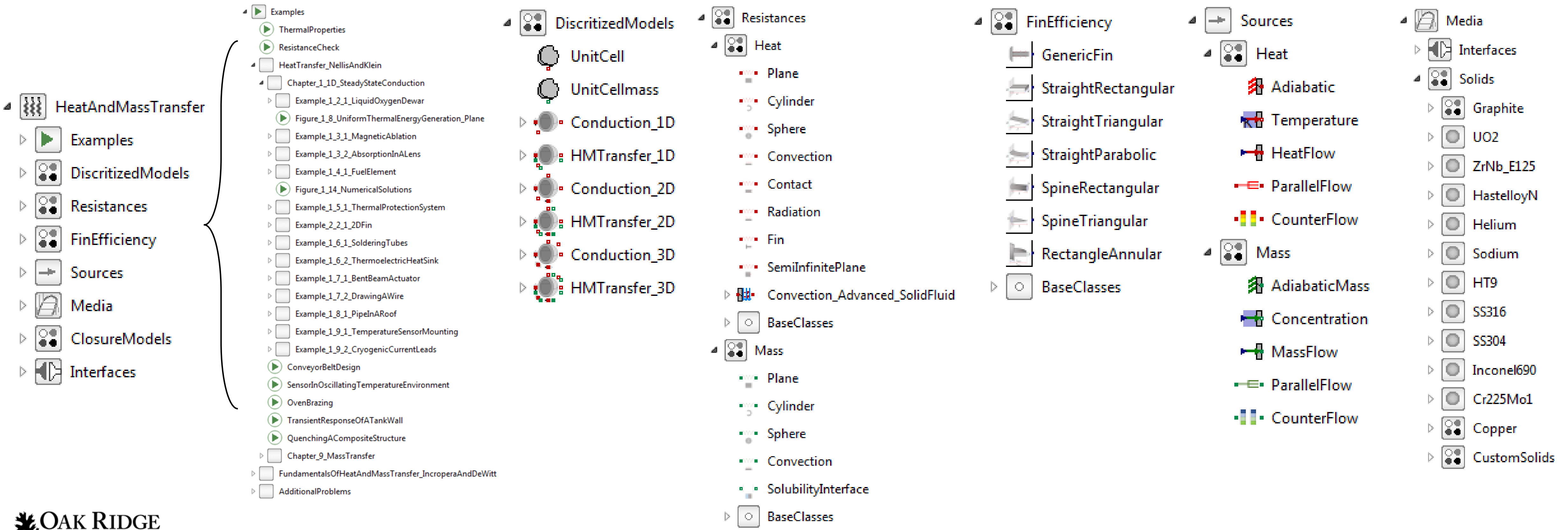
2018

NTP & More
TRANSFORM leveraged to model system behavior of nuclear thermal propulsion systems, benchmark CIET experimental data, and design molten salt experiments for the Versatile Test Reactor.

2019

Library Package Example: Heat & Mass Transfer

- Standard implementation of diffusive heat and (trace) mass transfer



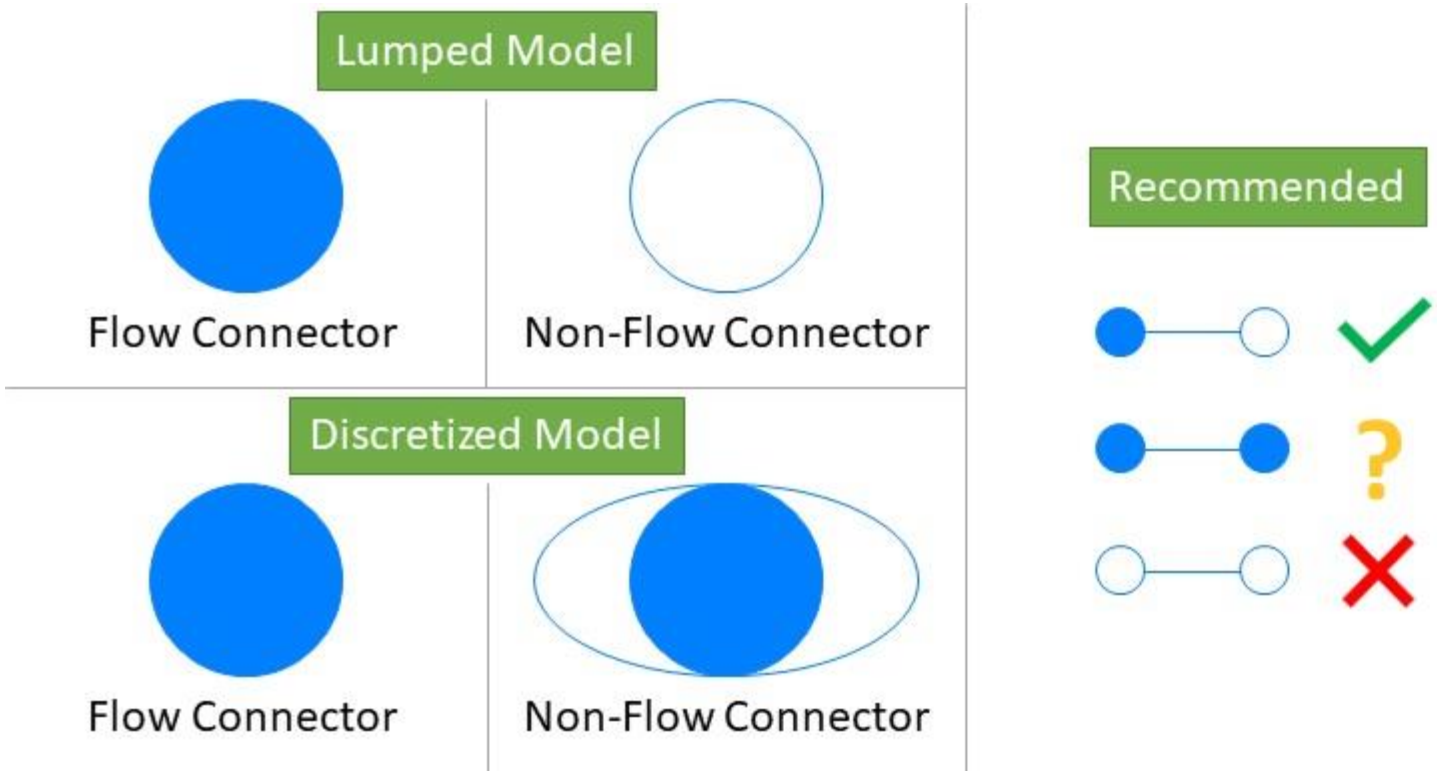
A Brief Demo of the Heat and Mass Library

Real Quick: Connectors!

- 5 min - stream, flow, non-flow, actual stream, instream

How to connect connectors?

- Pay attention to the connector visual cue!



Connectors: Fluid

- FluidPort
- FluidPort_Flow
- FluidPort_State
- FluidPorts_Flow
- FluidPorts_State

```
connector FluidPort
  "Interface for quasi one-dimensional fluid flow in a piping network
  (incompressible or compressible, one or more phases, one or more substances)"

  replaceable package Medium = Modelica.Media.Interfaces.PartialMedium
    "Medium model" a ;

  flow Medium.MassFlowRate m_flow
    "Mass flow rate from the connection point into the component";
  Medium.AbsolutePressure p "Thermodynamic pressure in the connection point";
  stream Medium.SpecificEnthalpy h_outflow
    "Specific thermodynamic enthalpy close to the connection point if m_flow < 0";
  stream Medium.MassFraction Xi_outflow[Medium.nXi]
    "Independent mixture mass fractions m_i/m close to the connection point if m_flow < 0";
  stream Medium.ExtraProperty C_outflow[Medium.nC]
    "Properties c_i/m close to the connection point if m_flow < 0";
end FluidPort;
```

- Note: The connector graphic used in TRANSFORM helps guide the user on what the port defines.

Connectors: Heat and Mass

- Heat

```
connector HeatPort
  "Interface for one-dimensional heat transfer"

  flow Modelica.SIunits.HeatFlowRate Q_flow
    "Heat flow rate. Flow from the connection point into the component is positive.";
  Modelica.SIunits.Temperature T "Temperature at the connection point";

end HeatPort;
```

- Mass (trace)

```
connector MolePort "Interface for one-dimensional mole/mass transfer"

  parameter Integer nC = 1 "Number of substances";

  flow SI.MolarFlowRate n_flow[nC]
    "Molar flow rate. Flow from the connection point into the component is positive.";
  Modelica.SIunits.Concentration C[nC] "Concentration at the connection point";

end MolePort;
```

- HeatPort
- HeatPort_Flow
- HeatPort_State
- HeatPorts_Flow
- HeatPorts_State
- MolePort
- MolePort_Flow
- MolePort_State
- MolePorts_Flow
- MolePorts_State

Model Creation: Connectors

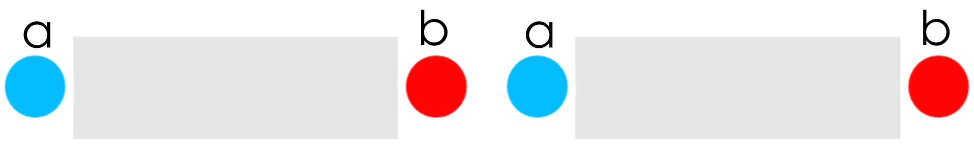
- Connectors provide a method of passing a collection or related data

- Simplest connector
  - Real input
  - Real output
- Connectors
  - Can hold any number of variables
  - Types are:
    - flow | a + b = 0
    - "non-flow" | a = b
    - stream | a = inStream(b); b = inStream(a)
- Common naming convention is "port"
  - e.g., port_a, port_b …. Not inlet/outlet

```
connector FluidPort

  flow SI.MassFlowRate m_flow;
  SI.AbsolutePressure p;
  stream SI.SpecificEnthalpy h_outflow;

end FluidPort;
```



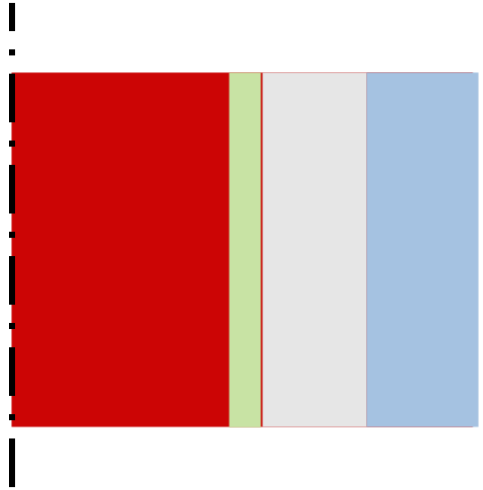
Hands-On Examples:

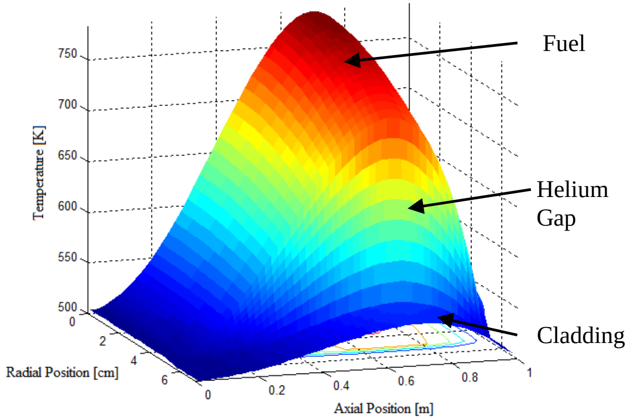
Heat Transfer

- 20 min – examples demonstration use of TRANSFORM heat transfer components

Hands-On Example 1: Heat Transfer Network

- Using the HeatAndMassTransfer components, create a heat transfer network of a fuel pin
  - Adiabatic centerline, radial conduction (fuel), gap conductance, radial conduction (cladding), convection heat transfer, temperature boundary
- Once the network is created, duplicate the model and add in discretized models for dynamics in the fuel
- Try making a boundary condition time dependent





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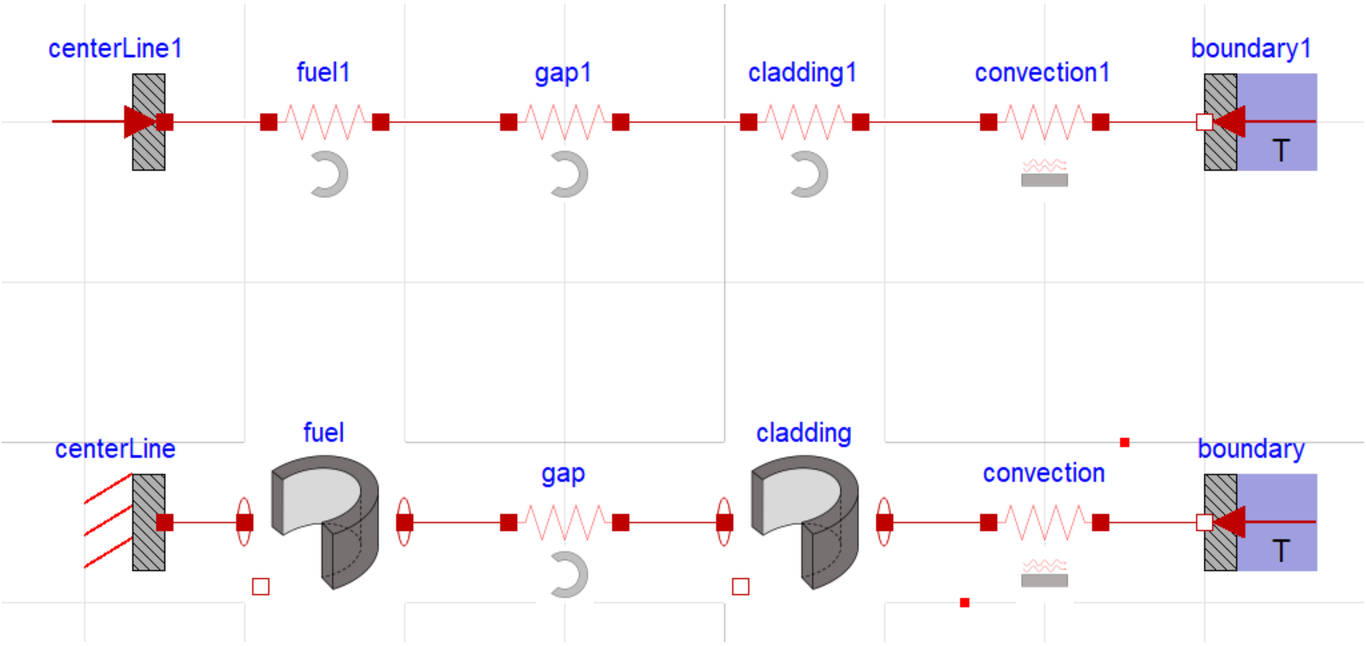
Hands-On Example 1: Heat Transfer Network

- Boundary Conditions
  - Linear heat rate: 44 kW/m
  - Convection: 240°C, 20 kW/m^2K
- Materials:
  - Fuel: UO_2
    - For steady-state model assume 2.4 W/mK
  - Cladding: Zircalloy (ZrNb_E125)
    - For steady-state model assume 17 W/mK
- Dimensions:
  - Fuel inside: 0 mm
  - Fuel outside radius: 5.17 mm
  - Gap width: 0.23 mm
  - Cladding thickness: 0.86 mm
- Other:
  - Gap conductance: 4300 W/m^2K

Steady-state model



Discretized Model

Based on Todreas and Kazimi (1990) problem 8-4

Hands-On Examples:

Fluid Systems

- 20 min – examples demonstration use of TRANSFORM fluid components

Hands-On Example 2: The Water Monster!!

- Using the Fluid components, model the Water Monster and how it might be used by a crowd
  - 125 gallons water (475 Liters)
  - 6 spigots (1 cm diameter)
  - 1 drain valve (3 cm diameter)
- How might you model the demand?
  - Stochastic?
  - Periodic?
  - Size of containers
  - How hot is it?
- Open Ended Exercise
  - Example "solution" provided in training materials

https://watermonster.us

Optional Example 3: TRANSFORM Fluids

- If time allows, check out some of the excellent fluid network examples in the TRANSFORM/Fluids/Examples
- Also, can check out Modelica Standard Library – Fluids Examples for inspiration
  - Incompressible Fluid Network
  - BranchingDynamicPipes
  - PumpingSystem
  - ThreeTanks
  - And many more!

Thank you.

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