

# FMI Tutorial - Connecting tightly coupled FMUs

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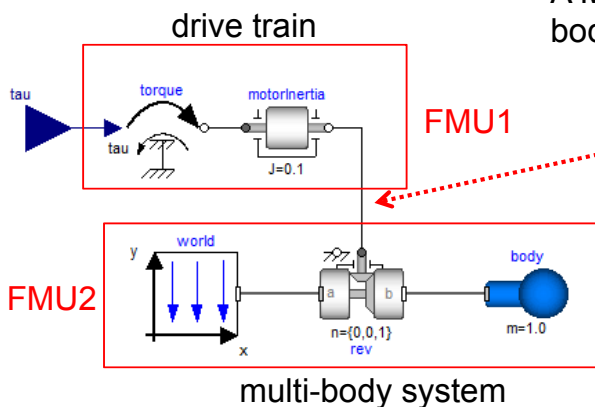
Modelica'2014 Conference, Lund, Mar. 10-12, 2014



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## Issues when connecting FMUs originating from physical models

Typical example:



### Source of the problem:

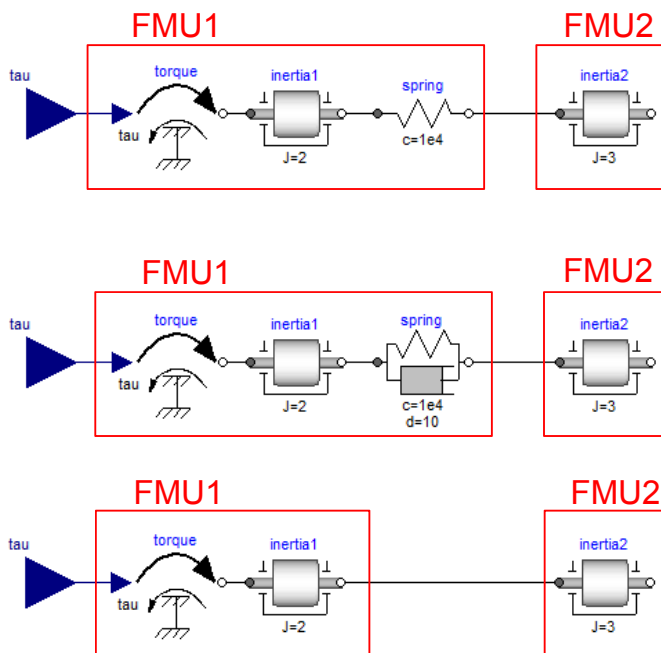
- An FMU is a **causal input-output** block (ODE)
- A Modelica model (or electrical circuit or multi-body program) is an **acausal DAE**

- **Causality of connector variables?** (which connector variable is an input which is an output?)
- **Are connector variables differentiated?** If yes, the differentiated variables must be passed as inputs/outputs as well!!!!

Current tools do not (yet) provide much help, therefore easy to make mistakes



## Analysis at hand of 3 very simple systems



Questions to answer:

1. **Planned target configuration?**  
(in which way shall the FMUs be connected)
2. **Where are the states?**  
(in the target configuration)
3. **Which connector variables are computed from the states?** (these variables are outputs of the FMU)
4. **Are derivatives of connector variables needed?**



## Utility components in MSL 3.2.1 for FMU import/export

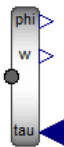
### Modelica.Mechanics.Rotational.Components

torqueToAngleAdaptor



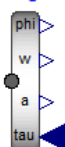
use\_w = false, use\_a = false

torqueToAngleAdaptor



use\_a = false

torqueToAngleAdaptor



simple implementation

```
flange_a.tau = tau
flange_a.phi = phi
der(flange_a.phi) = w
der(der(flange_a.phi)) = a
```

angleToTorqueAdaptor



angleToTorqueAdaptor



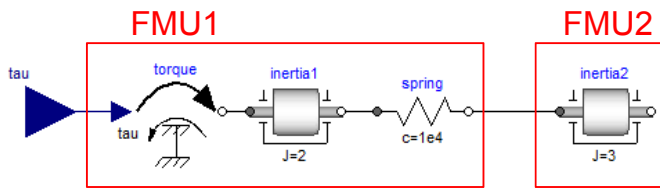
angleToTorqueAdaptor



nontrivial implementation  
(need to state that w is derivative of phi and a is derivative of w!!!)



## Inertia – spring – inertia (1)



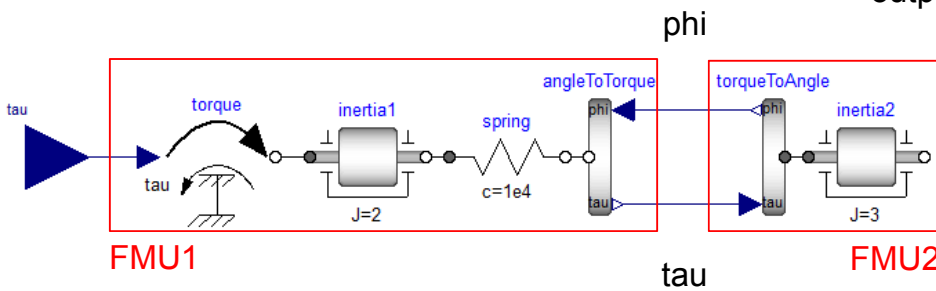
States in target configuration:

**inertia1.phi, inertia1.w**  
**inertia2.phi, inertia2.w**

**spring needs only angles**

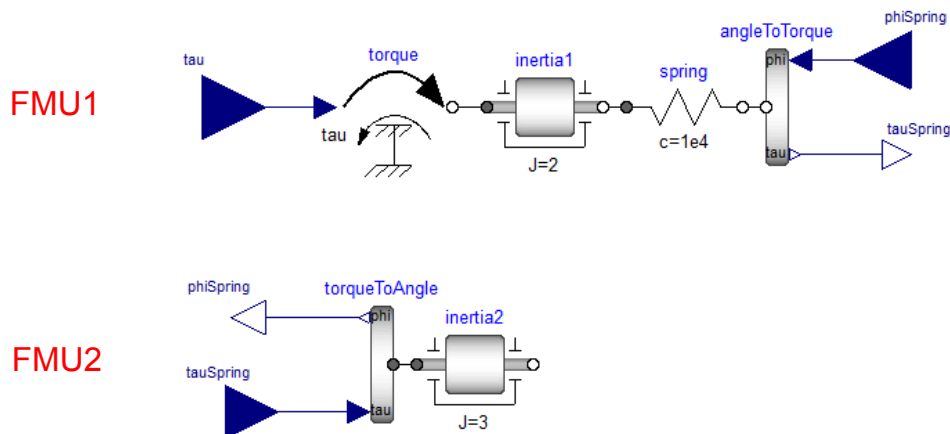
→ no differentiated connector variables

→ inertia2.flange\_a.phi is output of inertia2

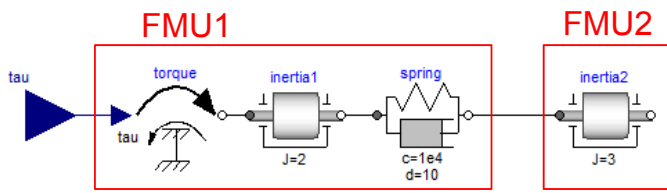


## Inertia – spring – inertia (2)

Generate FMUs for the following models:



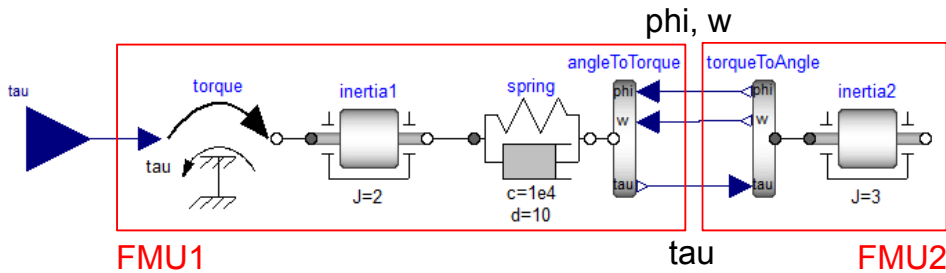
## Inertia – spring/damper – inertia



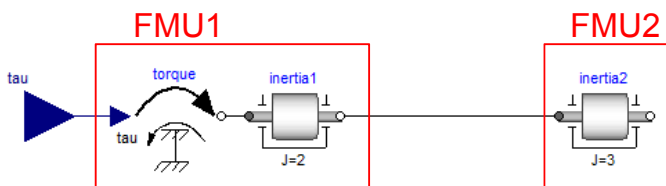
States in target configuration:

**inertia1.phi, inertia1.w**  
**inertia2.phi, inertia2.w**

**spring/damper needs angles and angular velocities!!!**  
 → differentiated connector angle needed!!!



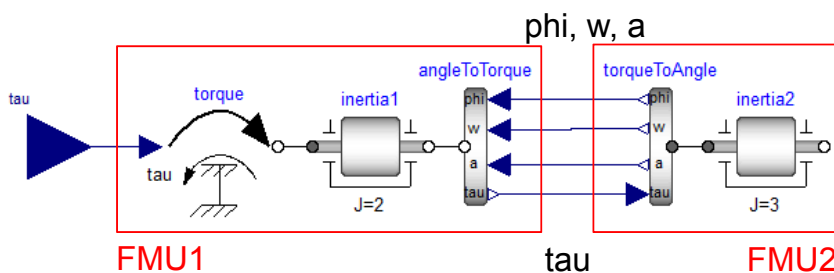
## Inertia – inertia



Index reduction in Modelica  
 (constraints between the states of inertia1 and of inertia2)

States in target application?  
**inertia2.phi, inertia2.w**

**inertia1 needs angle, angular velocity, angular acceleration**  
 → connector angle differentiated twice!!!



## Conclusion

- Exporting Modelica models with physical connectors as FMUs is difficult in FMI 2.0 because FMU is causal ODE.
- This requires to understand for the **desired target connection structure**
  - which connector variables are **inputs** and **outputs**
  - whether connector variables need to be **differentiated**
- This issue is known in the FMI group. A better solution will be introduced in the backwards compatible, next version (FMI 2.1):
  - **Define physical connectors** in the interface (not only inputs/outputs)
  - **Define causality and derivatives** of the connector variables
  - When exporting an FMU, **tool support** is needed to define in which way the exported model shall be **connected** in the **target application**

