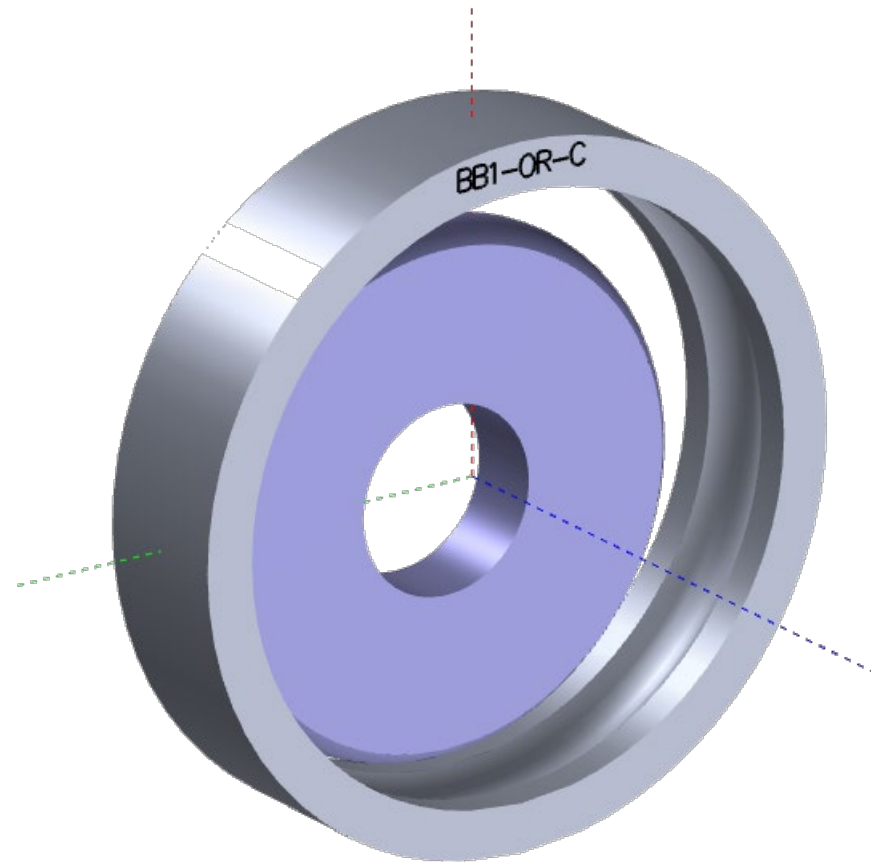# TLM, FMI & EXTRIPOL: Acronyms for Stable Co-simulation?

Robert Braun
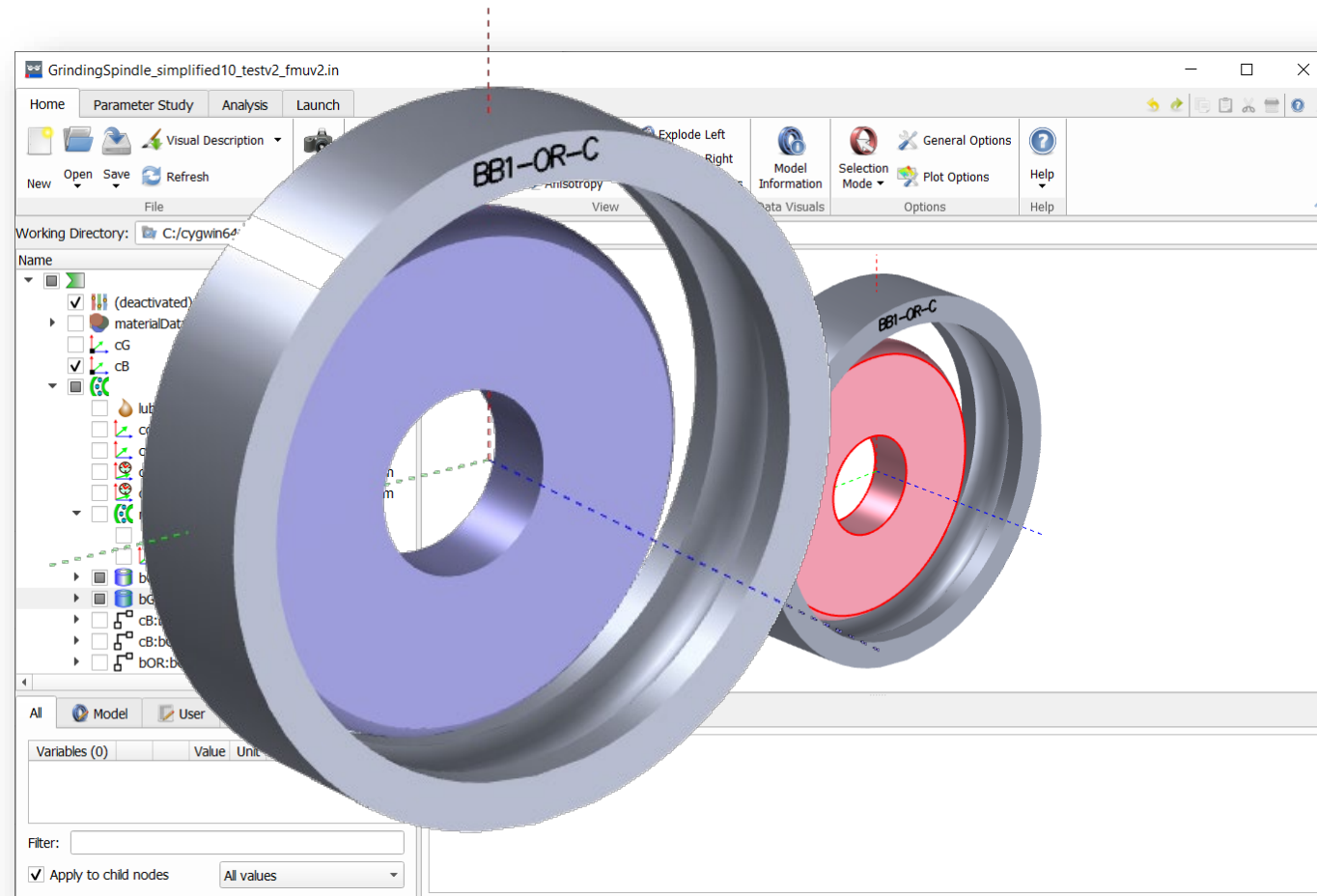
Acronyms?

- FMI – <u>F</u>unctional <u>M</u>ockup <u>I</u>nterface
- TLM – <u>T</u>ransmission <u>L</u>ine <u>M</u>odelling
- EXTRIPOL – <u>Extr</u>apolated <u>Interpol</u>ation
- BEAST – <u>Be</u>aring <u>S</u>imulation <u>T</u>ool

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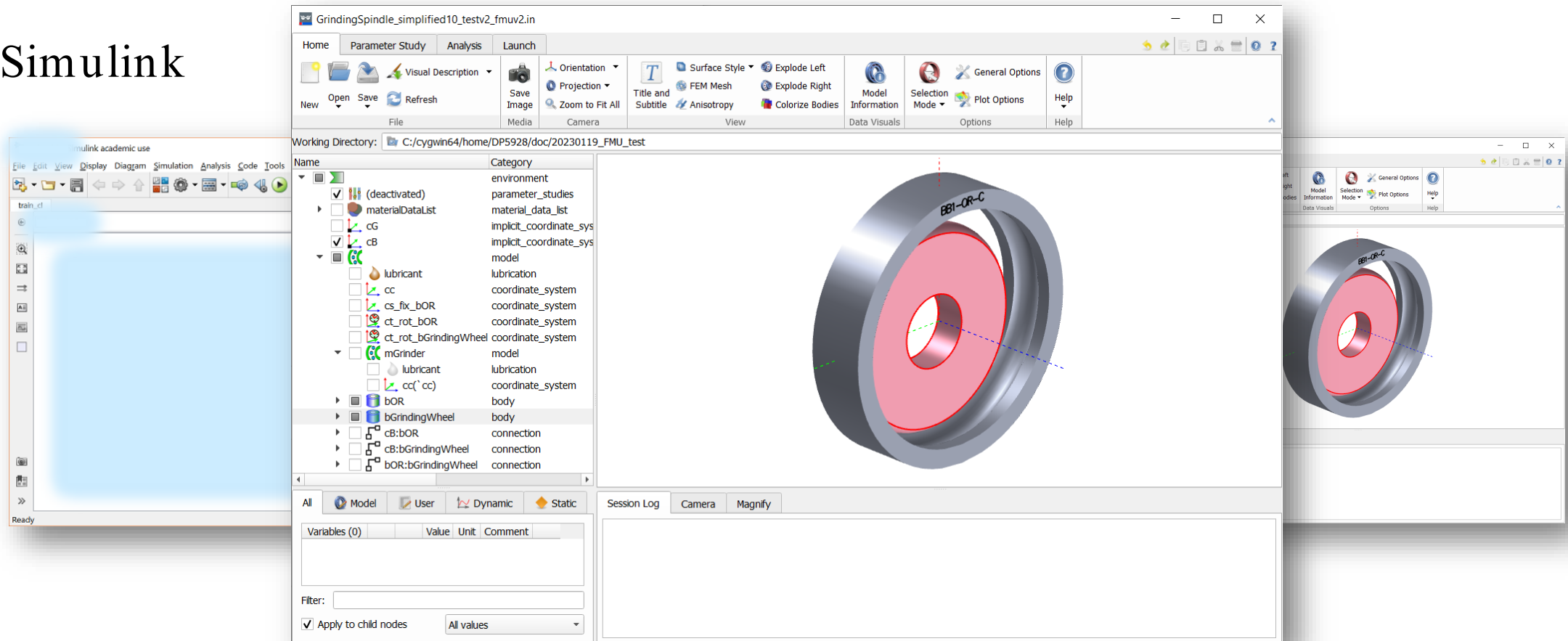
Grinding Co-simulation
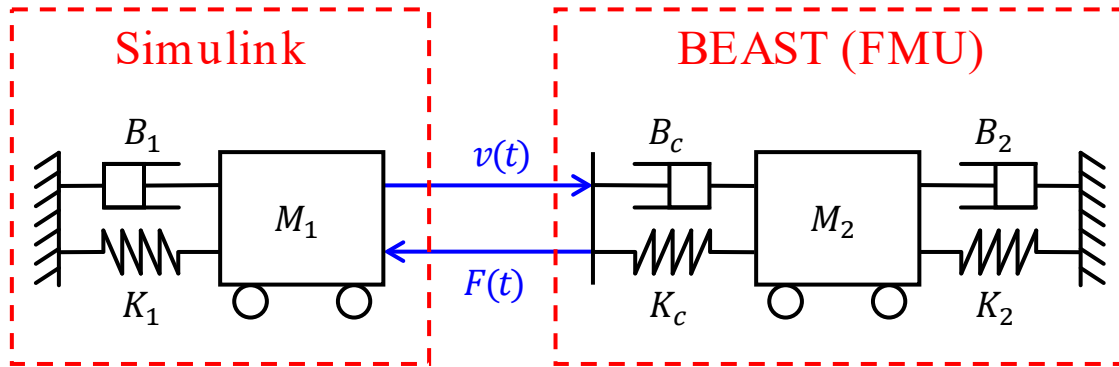
BEAST – BEAring Simulation Tool
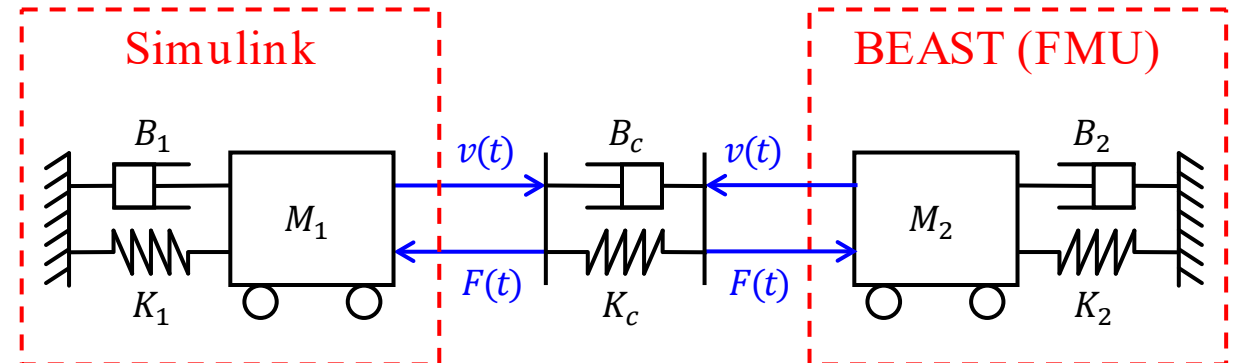
Functional Mockup Interface

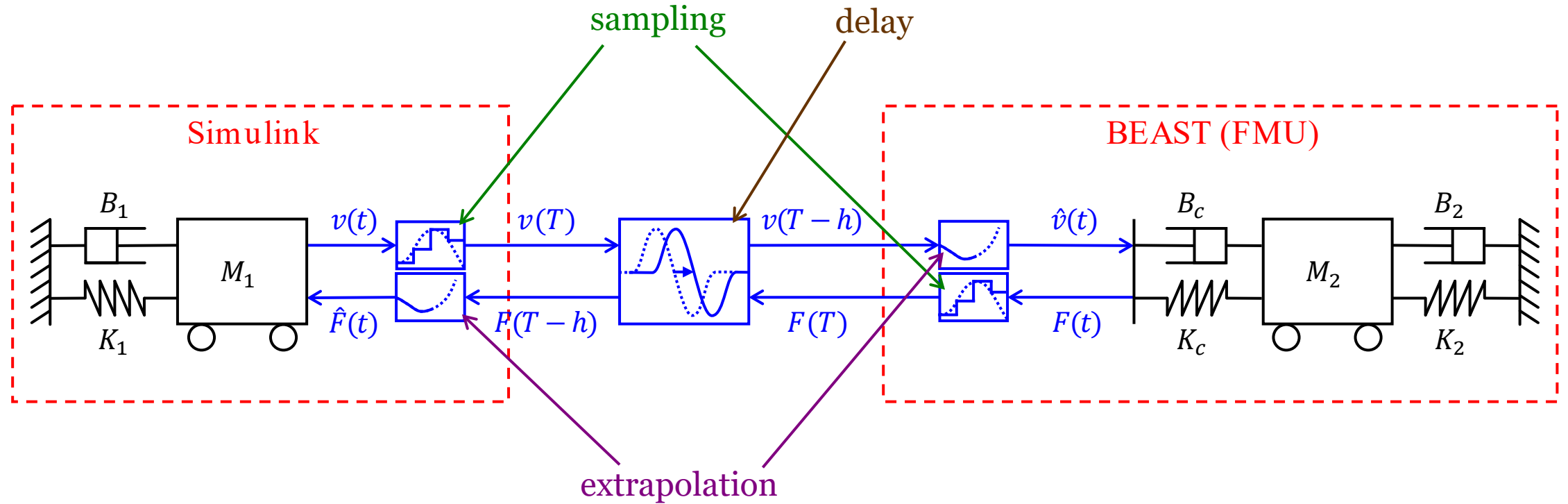Simulink

Approaches

Force-discplacement coupling
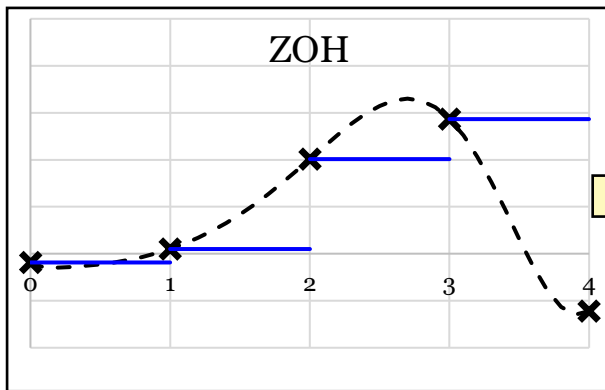
Force-force coupling
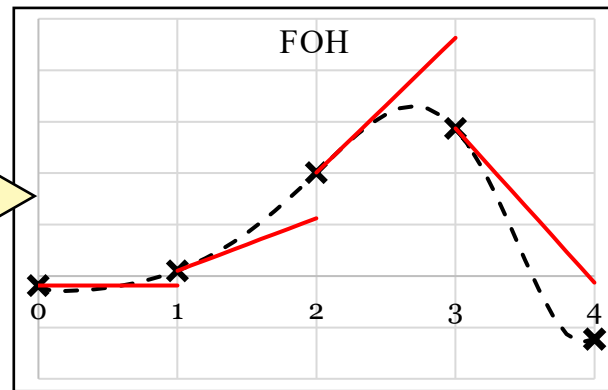(using TLM)

Force-Displacement Coupling

Extrapolation

Before project:

Zero-order hold

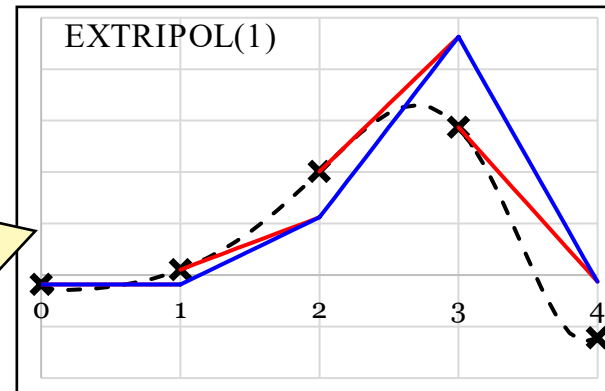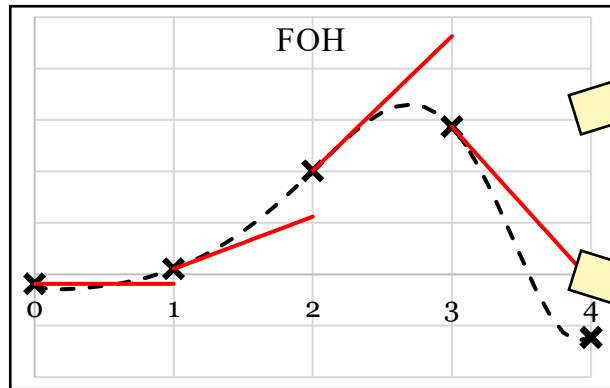First improvement:

First-order hold

Problem: Input still discontinuous ⇒ solver restarts

Extrapolated Interpolation (EXTRIPOL)

Co-Simulation Results
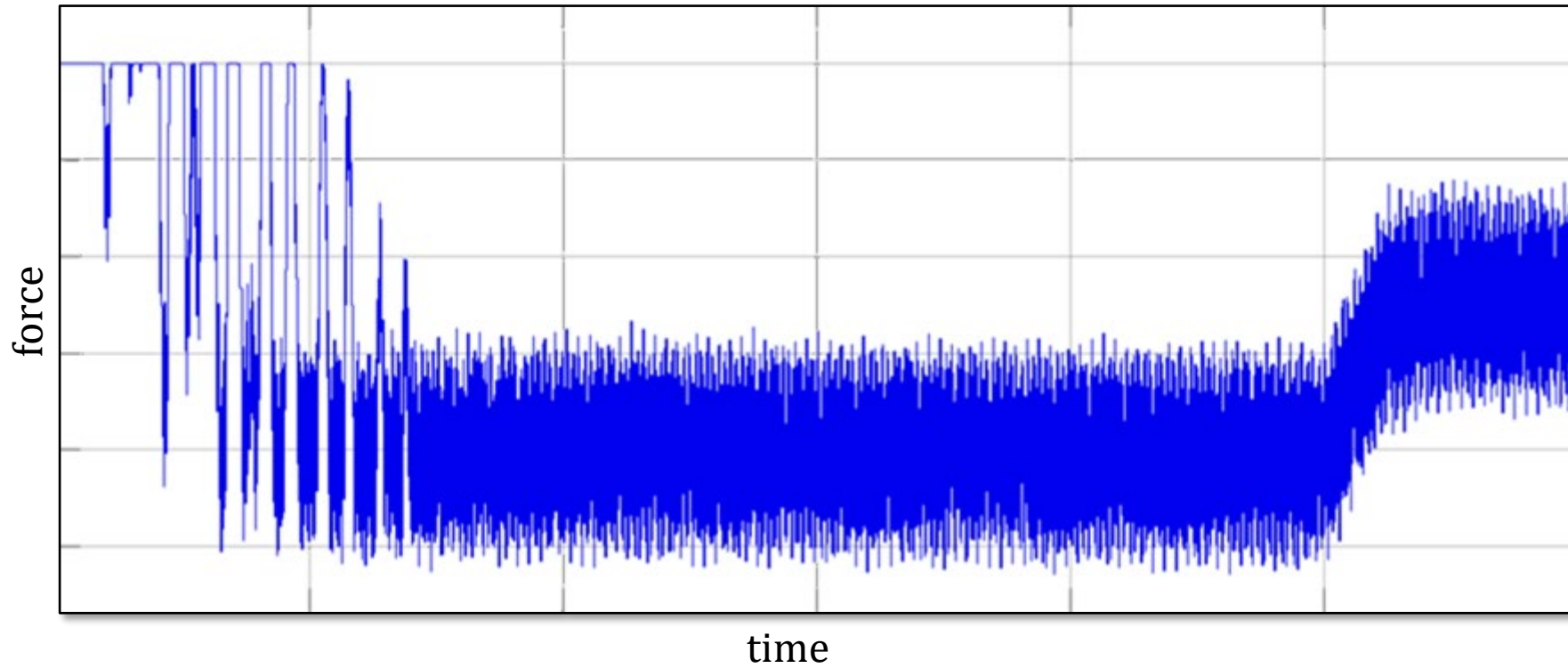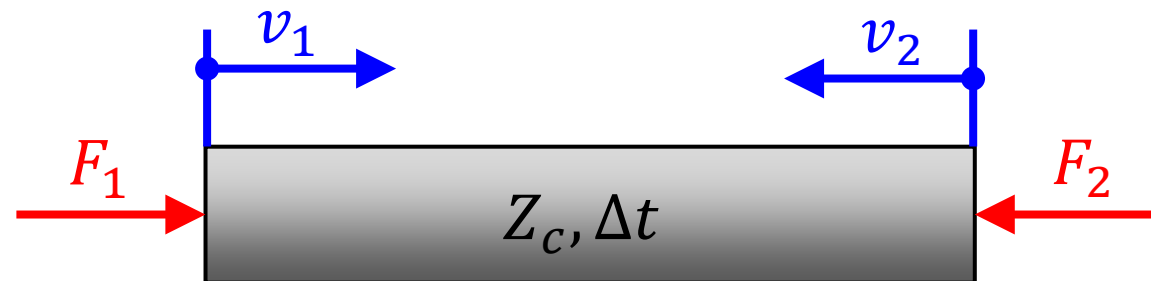

force

time

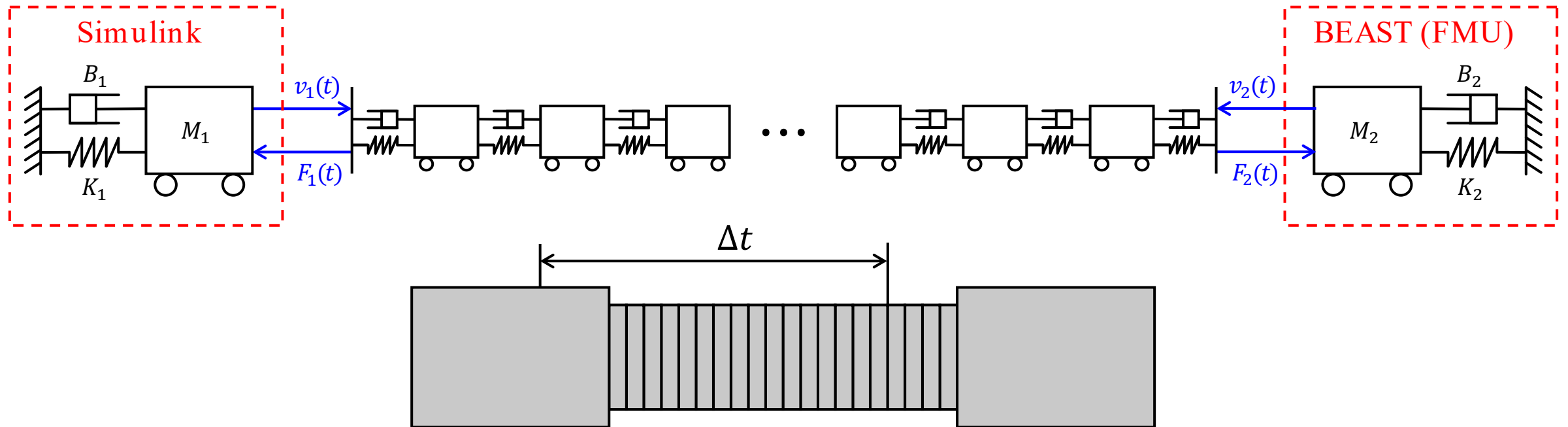LINKÖPING UNIVERSITY

What about stability?

Transmission Line Modelling

- Extrapolation seems to work, but cannot guarantee stability

- Articifial time delay between velocity and force

- Potential solution: TLM?

Transmission Line Modelling (TLM)

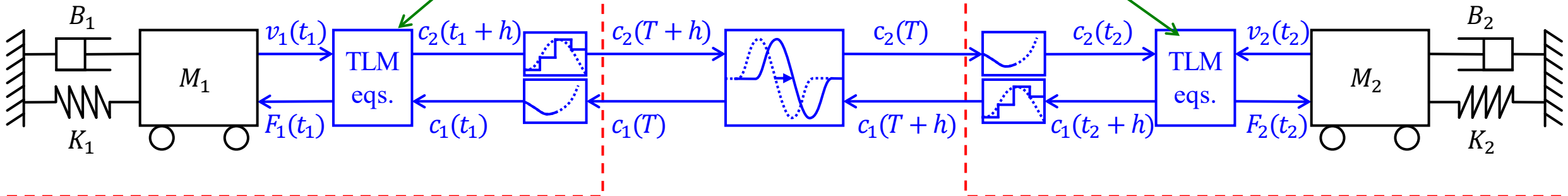Imagine force-force coupling with distributed inertia:

Enables <u>communication delay without numerical instability</u>!
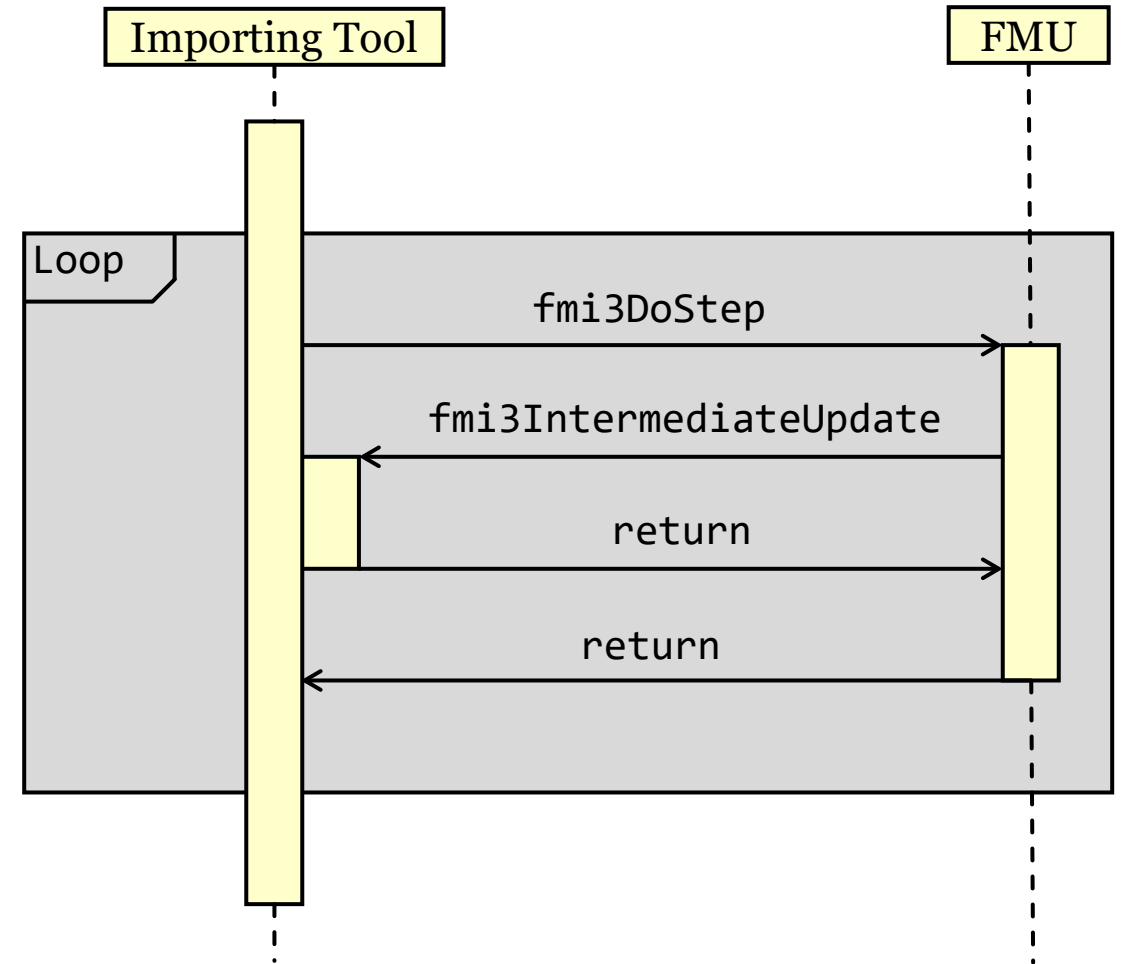
TLM with FMI 1.0 and 2.0

$$F_1(t) = c_1(t) + v_1(t)Z_c(t)$$
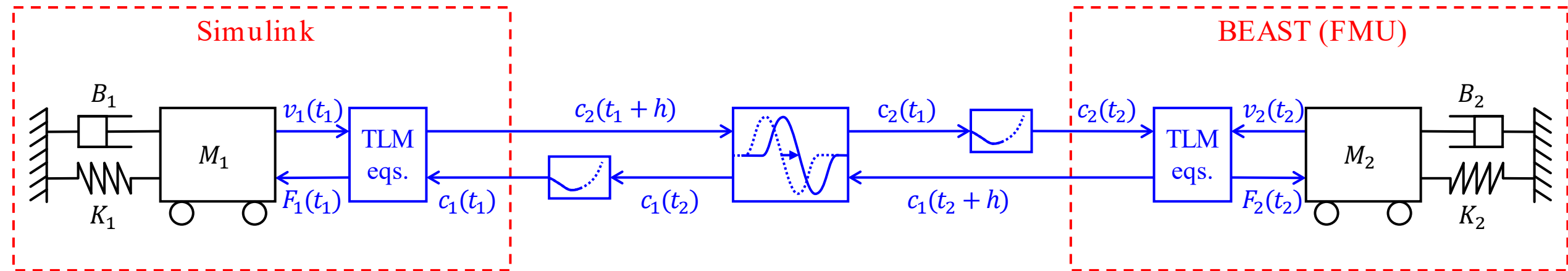$$F_2(t) = c_2(t) + v_2(t)Z_c(t)$$

TLM with FMI 3.0

- Change proposal submitted during ITEA3 OpenCPS project

- FMUs can request and provide intermeriate variables

- Released in 2022
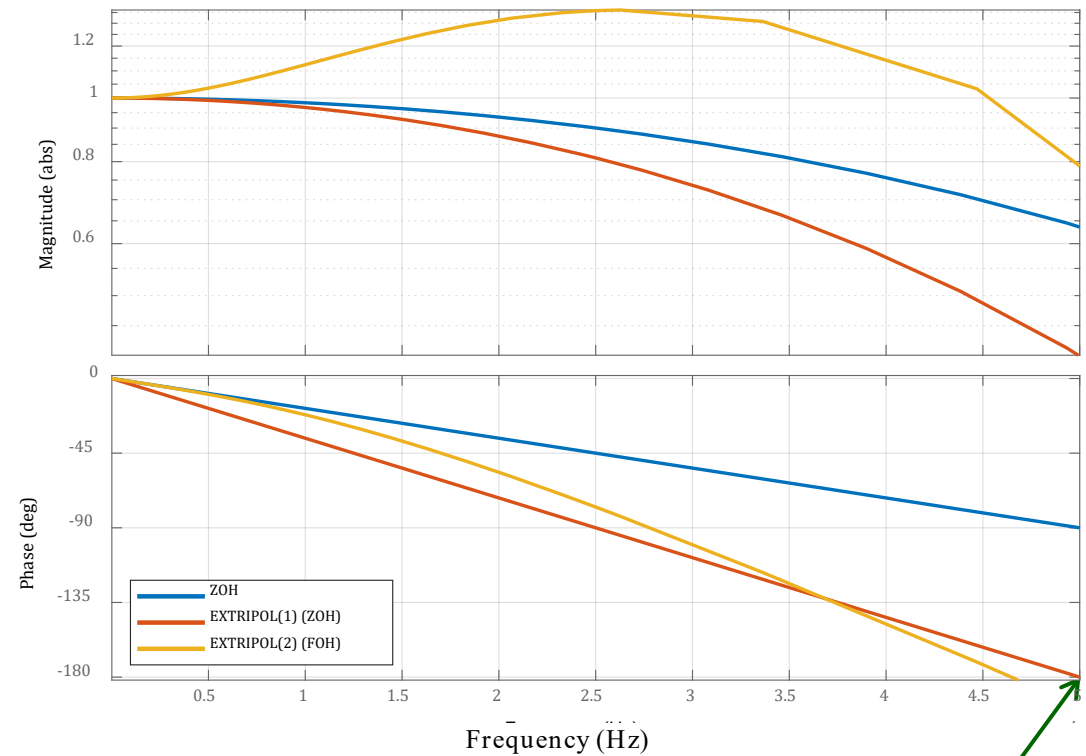
TLM with FMI 3.0

- Requires decicated master simualtion tool
- FMI 3.0 not (yet) supported by Simulink

Frequency Domain Analysis

Potential problem:

- Reduced phase stability

- Energy balance affected

Bode diagram

Nyquist frequency

Conclusions and Outlook

- EXTRIPOL
  - Recreates continuous data from sampled inputs
  - Fewer solver restarts
- TLM
  - Provides numerical stability
- FMI3
  - TLM co-simulation with conituous data exchange
  - Requires dedicated master simulation tool
  - Not yet supported by most tools
- FMI2 and TLM can be used together with EXTRIPOL

Thank you for listening!

liu.se