Parallelization of Multibody Systems Incorporating Co-Simulation Techniques

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Motivation

- Reduction of the computation time of large multibody systems [1]
- Execution of multibody simulations on high performance computers
- Efficient simulation of models including different time scales

Monodisciplinary models:
- multibody systems
- FE-models
- …

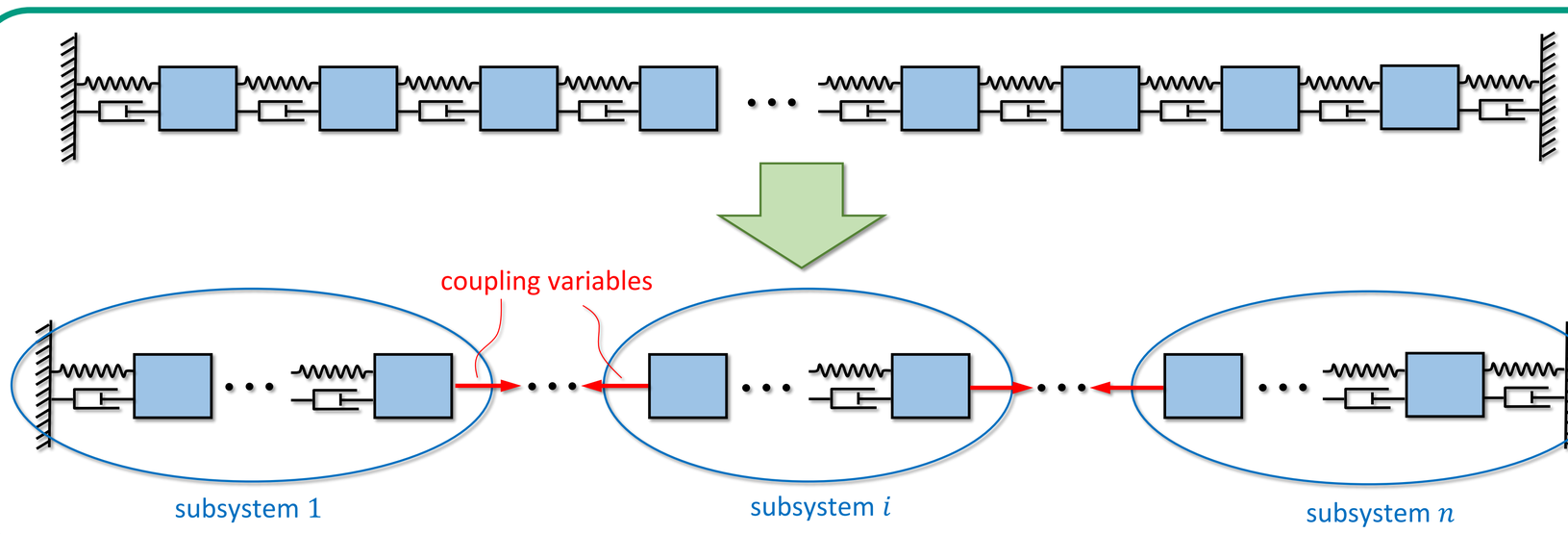
⇒ **parallelization**

Co-Simulation

Multiphysical models:
- fluid-structure interaction
- coupled electromechanical systems
- …

⇒ **solver coupling**

Basic Concept



Co-Simulation Procedure:

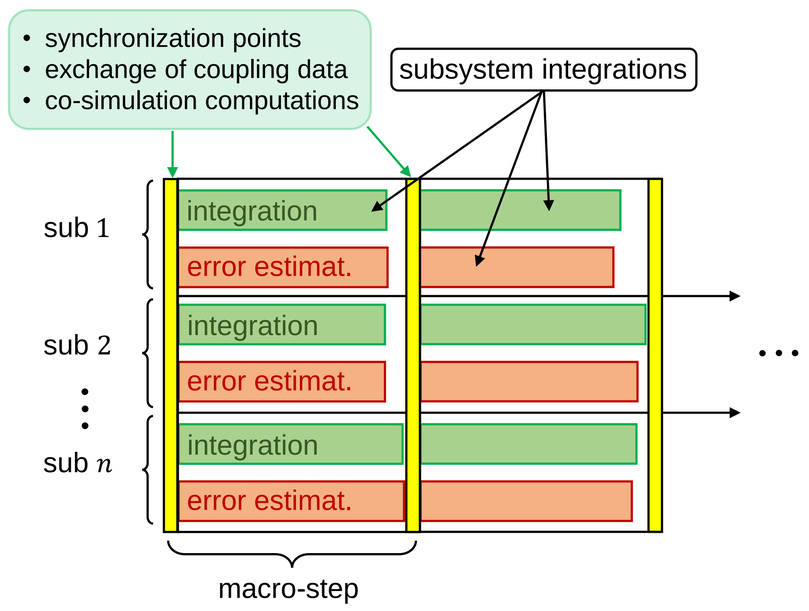
- Split the overall system into **subsystems**
- Introduce **coupling variables**
- Formulate **coupling conditions**
- Define a **macro-time grid**
- Solve the coupled problem in parallel by a **co-simulation approach**

Implementation Scheme

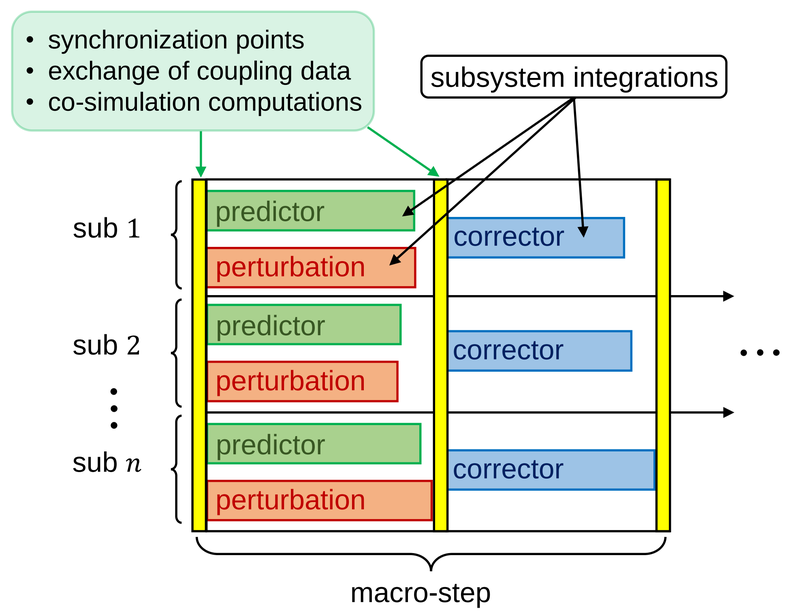
Co-Simulation Interface:

- Hybrid MPI/OpenMP parallelization:
  - ⇒ Each subsystem is executed by one MPI rank
  - ⇒ Multiple integrations of the same sub-system (for error estimation or integration with perturbed coupling variables) are parallelized with OpenMP
- Explicit and implicit co-simulation methods
- Macro-step size controller [2]
- Variable approximation order of the coupling variables
- Simulations are carried out on the *Lichtenberg High Performance Computer of TU Darmstadt*

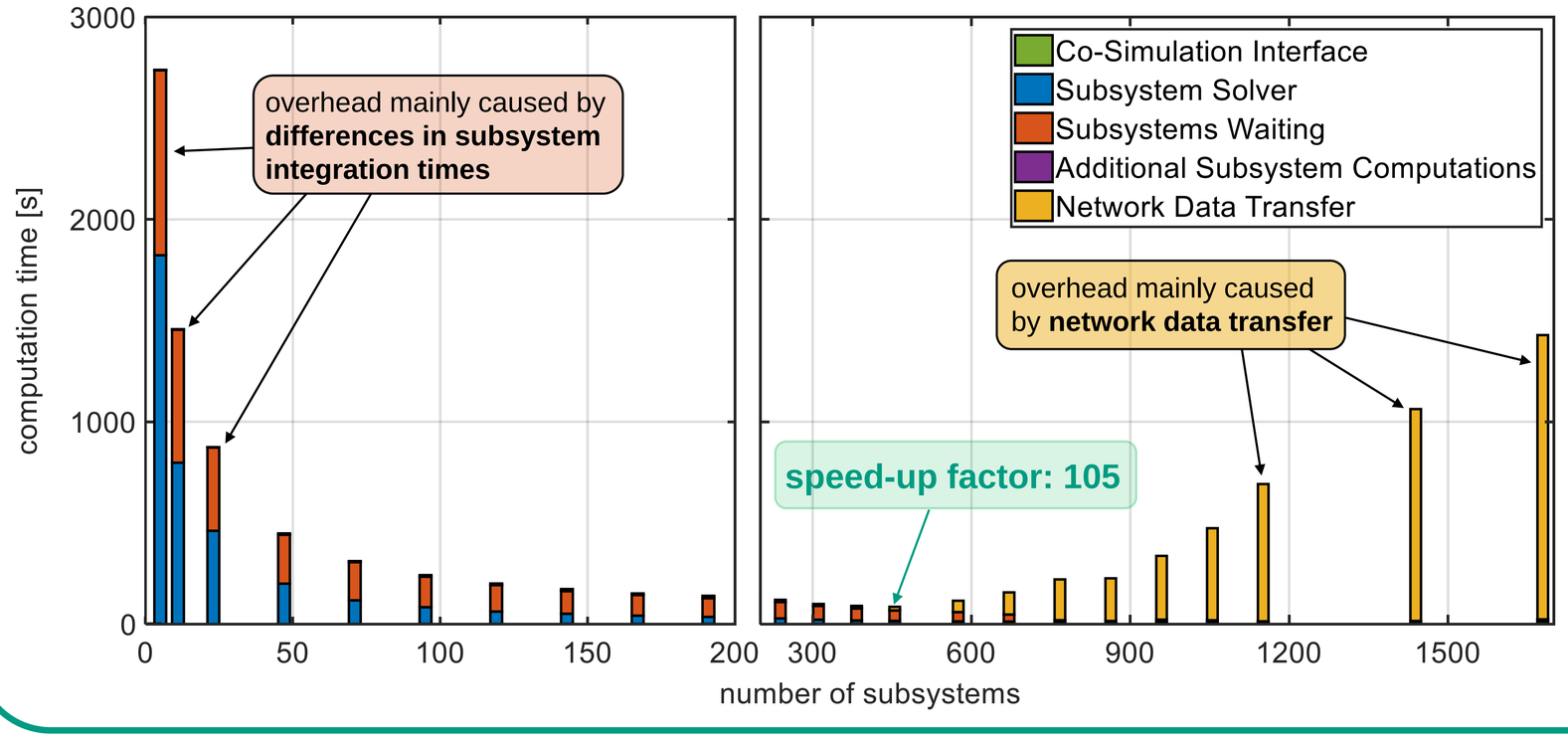
***Explicit* Co-Simulation Method:**



***Implicit* Co-Simulation Method:**



Results



Simulation Parameters:

- Nonlinear test model
- One million degrees of freedom
- Explicit co-simulation method
- Quadratic approximation polynomials for the coupling variables
- Constant macro-step size: $h_{mac} = 2.5e-6$ s
- Subsystem solver: variable-order, variable-coefficient BDF method (sundials/IDA [3])
- Computation time of the monolithic simulation: 8982 seconds

⇒ **Speed-up factor: 105** (455 subsystems)

[1] Kraft, J., Schweizer, B.: "Reduction of Computation Time by Parallelization Incorporating Co-Simulation Techniques", *Proceedings of The VII International Conference on Computational Methods for Coupled Problems in Science and Engineering*, 2017, Rhodes Island, Greece.
[2] Meyer, T.; Kraft, J.; Li, P.; Lu, D.; Schweizer, B.: “Error estimation approach for controlling the macro step-size for explicit co-simulation methods”, *Proceedings of the 7th GACM Colloquium on Computational Mechanics for Young Scientists from Academia and Industry*, Stuttgart, Germany, 2017.
[3] Hindmarsh, Alan C and Brown, Peter N and Grant, Keith E and Lee, Steven L and Serban, Radu and Shumaker, Dan E and Woodward, Carol S, and A. Collier: “SUNDIALS: Suite of nonlinear and differential/algebraic equation solvers”, *ACM Transactions on Mathematical Software (TOMS),* Vol. 31, No. 3, 2005.