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Center for Information Services and High Performance Computing – TU Dresden

Design Approach for a Generic and Scalable Framework for Parallel FMU Simulations

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Linkoping, 02. February 2015

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ZIH Center for Information Services & High Performance Computing

Outline

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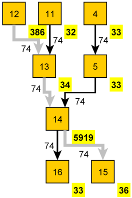
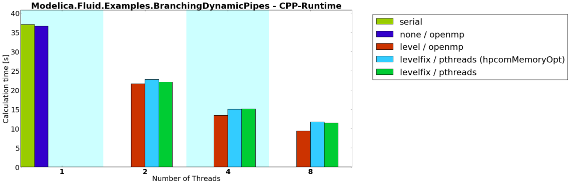
Outline

Tasks within HPC-OM

The three main tasks/goals within the HPC-OM project are:

1. Domain independent parallelization of Modelica simulations.
   - Equation based parallelization using task graph.
   - Algorithms for task merging and clustering.
   - Implementation of various schedulers.
   - Code generation for OpenMP, PThreads and Intel TBB.
   - Exploiting repeated structures and vectorization in Modelica.
2. Parallel time integration.
3. Coupling of interactive simulations and an HPC system.





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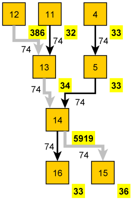
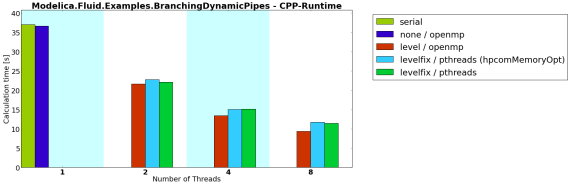
4. *High speedups.*





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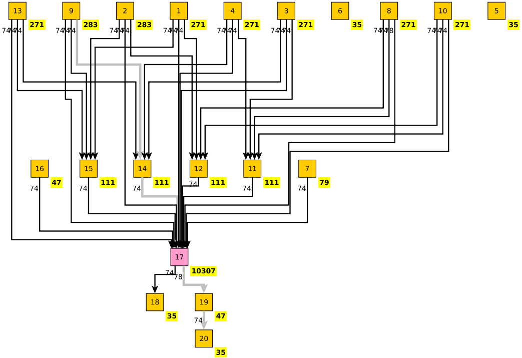
Task Graph Parallelization

...is promising, but current restrictions are:

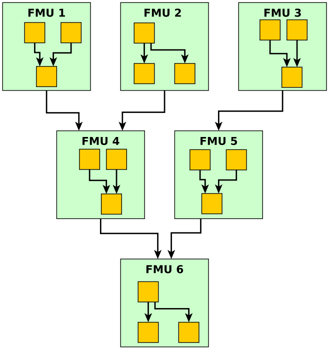
- Model dependent benefit, because
  - tasks are too lightweight,
  - one large equation system thwarts whole parallel computation.
- OpenModelica has some issues regarding large models.



How to Achieve High Speedups?

Idea: Build simulation from several FMUs to obtain multiple levels of parallelism:

- Task graph parallelization with FMUs as nodes.
- Use task graph parallelization generated by OMC in each FMU.



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FMI/FMU - Short Recap

- Can bring together sub-models from distinctive authoring tools (language, libraries, solvers, etc.).
- Models can be used in already existing production codes and frameworks.
- Protects intellectual property.

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Single-threaded simulations using coupled FMUs have limitations:

- Suitable for real time applications?
- Large and complex models have long simulation execution times and demand for high memory consumption.

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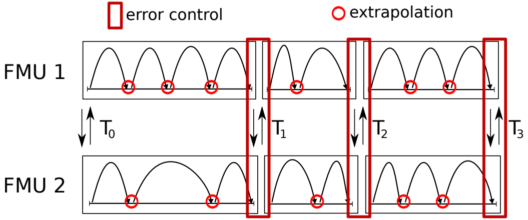
- Large and complex models have long simulation execution times and demand for high memory consumption.

Therefore, FMU simulations exploiting today's multi-core hardware are needed.

Synchronisation Step Approach

- Synchronisation of FMUs happens after predefined time intervals.
- At every synchronisation point, numerical error is calculated.
- In between inputs are extrapolated for single solver steps.



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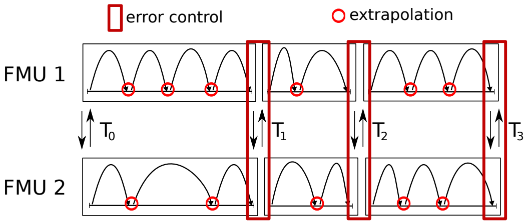
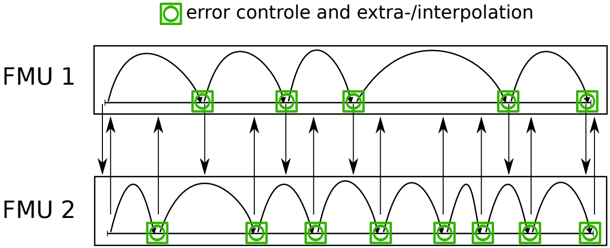


+ No communication between synchronisation steps.
+ Clear and strait forward implementation possible.
– Revert FMUs to last synchronisation point or even rerun simulation.
– Communication leads to delays during synchronisation points.

Generic Approach - Idea

- Values of every valid solver step are communicated.
- Dependent FMUs take most recent values as inputs.
- Solvers can base the error estimation on profound data.
- Less interfering in solver step size.



Generic Approach - Aspects and Challenges

Aspects

+ Just single solver steps need to be rerun.
+ Replaces unsafe extrapolation with interpolation.
+ Direct error handling, i.e.,
  - change of numerical behaviour is treated on occurrence,
  - solver step size depends only on input values, not on synch. points.

– Increasing communication effort.

– Sophisticated implementation with complex data structures.

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- Asynchronous communication is needed.
- FMUs need to be smartly distributed on system for high efficiency.
- Adoptable to different simulation setups.

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- Asynchronous communication is needed.
  $\rightarrow$ Field of parallel computing provides several solutions.
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  $\rightarrow$ Knowledge transfer from task scheduling.
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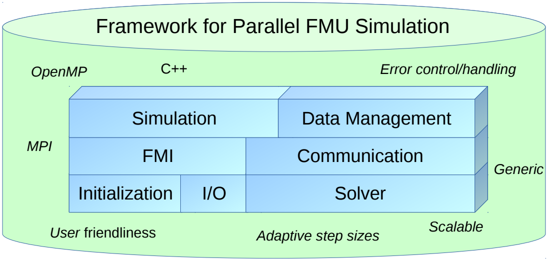
- Asynchronous communication is needed.
  → Field of parallel computing provides several solutions.
- FMUs need to be smartly distributed on system for high efficiency.
  → Knowledge transfer from task scheduling.
- Adoptable to different simulation setups.
  ! Requires interchangeable modular structure of the system and components.

FMU Simulation Framework

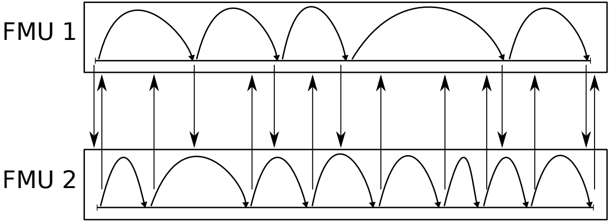
Final goal is a generic and scalable framework for coupled FMU simulations.



Outline

DataHistory

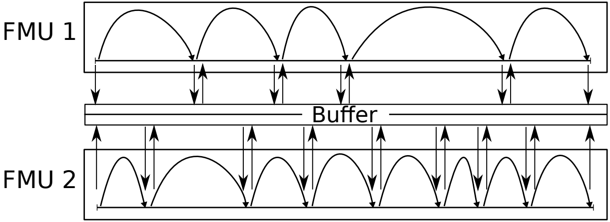
Challenge: How to provide input/output data for asynchronous simulation?



DataHistory

Challenge: How to provide input/output data for asynchronous simulation?
Answer: Use buffers!

- Saves relevant state values of FMUs.
- Input values are written remotely.
- Interface for accessing input values on local storage.



DataManager

Challenge: How to achieve efficient communication and handling of parallel FMU simulation?

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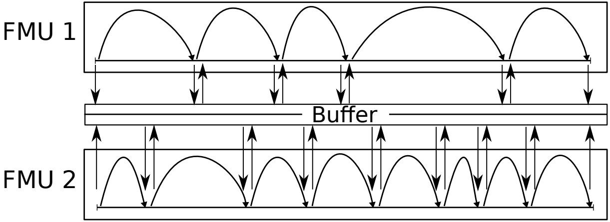
Answer: Use a manager!

- Initiates shared and distributed memory writes for input values.
- Writes result data to file.
- Controls DataHistory, e.g., flushes unnecessary data.
- Interpolation/extrapolation of input data.

→ **Hides communication and data flow from solvers.**



Outline

Summary

- Presented approach for efficient asynchronous parallel simulation of coupled FMUs.
- Key features and main challenges have been identified:
  - Use task graph parallelized FMUs generated from OpenModelica.
  - Use model exchange FMUs in order to obtain asynchronous simulation.
  - ! Need scalable data structures and communication.
  - ! Need localized buffers to provide input values for FMUs.

Outlook

What has to be done?

- Finish implementation.
- Show scalability by performing large simulation with numerous FMUs.
- Find a fancy name for this piece of software - suggestions are welcome.
- Make a release available.

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Thank you for your attention.

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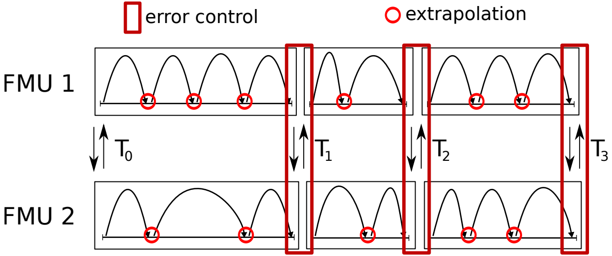
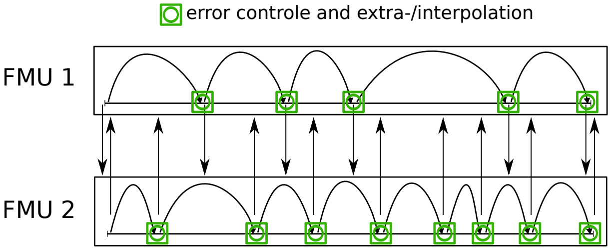
FMU Input Extrapolation



- error control of input values only at synchronization points
- in between extrapolated inputs only based on previous interval
- in several cases FMUs need to be set back to last synchronization point

FMU Input Extrapolation



- error control of input values based on most recent values
- solver can directly check error after every step
- leading to higher numerical stability
- less interfering in solver step size
- more dynamical error handling possible

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