LookAhead – A New Approach for Event Handling in Co-Simulation by Predicting State Events

Authors:

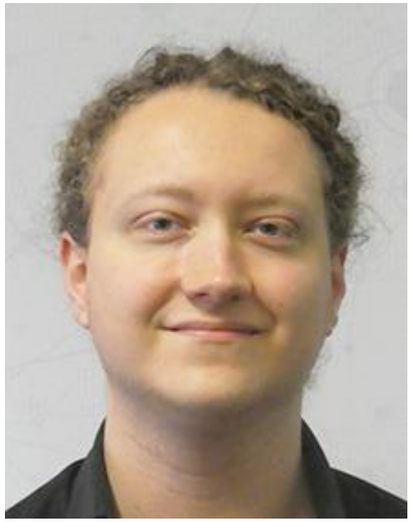
Felix Tischer, Simon Genser, Daniel Watzenig, Martin Benedikt

www.v2c2.at

Presenter:
Felix Tischer
Virtual Vehicle Research Center
felix.tischer@v2c2.at

About Me

- **Felix Tischer MSc, 29**
- **Industrial Engineering, Technical College Bulme, Graz**
  - Graduated 2014
- **Astrophysics (MSc) Karl Franzens University, Graz**
  - Graduated 2021
- **Researcher, Virtual Vehicle Research as of 2022**
- **Doctorand, TU Graz from March 2023 onwards**
  - In cooperation with Virtual Vehicle



Work & Research

Co-Simulation & Software Group

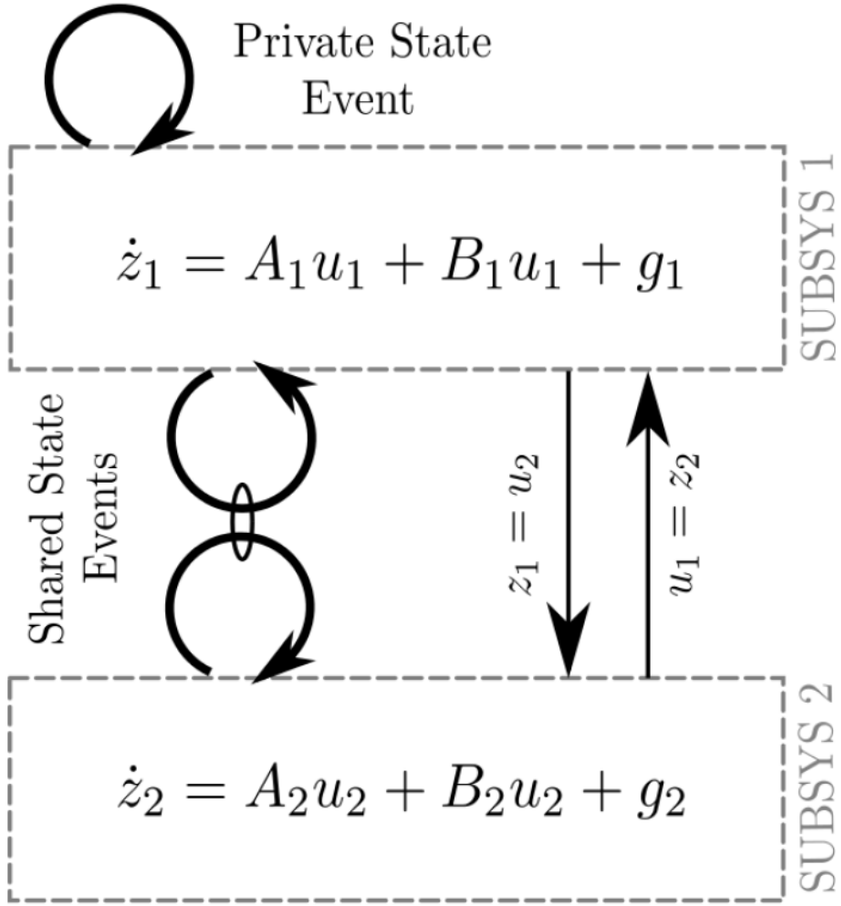
- Developing solutions for co-simulation problems
- Development of digital twins with focus on predictive maintenance for project partners
- Implementation of features on our own co-simulation platform ICOS

PhD Topics

- Focus on non-iterative and hybrid co-simulation
- Event handling in co-simulation
- Prediction of state events
- Effect of scheduling order on hybrid co-simulation

Terminology

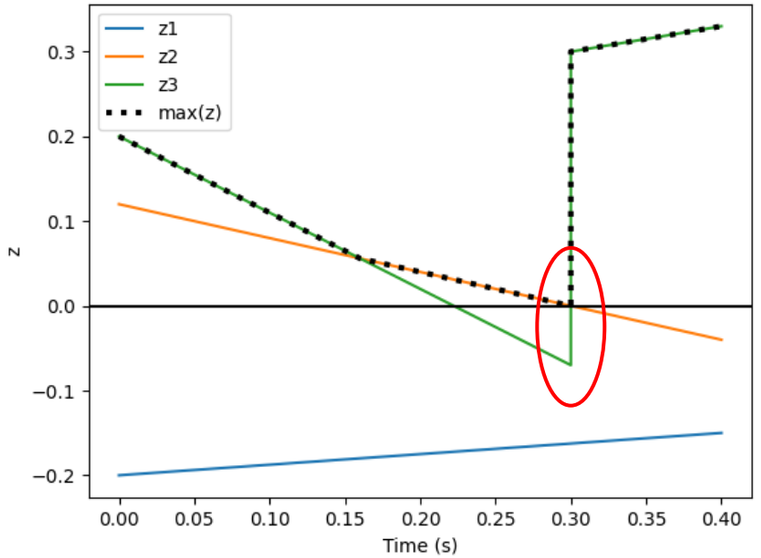
- **What is co-simulation?**
  - Coordinated execution of multiple simulations
  - Exchange of data between simulations (subsystems)
    - At communication time steps ≥ simulation time step
  - Subsystems are treated as blackboxes
    - Allows for modular, multi-domain, and IP-protected simulations
- **What is an event?**
  - Time-discrete change in a system
    - Change of values, functions, models, etc
  - Triggered by reaching a point in time (time event), or
  - Triggered by being in a certain state (state event)
- **Events in continuous state co-simulation**
  - Continuous and time-discrete systems => hybrid co-simulation
  - Events can affect one subsystem (private event), or
  - Can include two or more subsystems (shared event)



Defining Events

- **Event occurs when all its conditions are met**
- **After the event, at least one condition is not met**
  - Otherwise, event would happen again => non-discrete behaviour
- **Formulate conditions as real-valued functions z**
  - Take inputs, outputs, parameters as arguments
  - Evaluate to $z < 0$ when condition is fulfilled
  - Continuous, except at events
- **Event indicator is a set of condition functions $Z = \{z\}$**
  - Event occurs when $z \leq 0$ for all $z \in Z$:

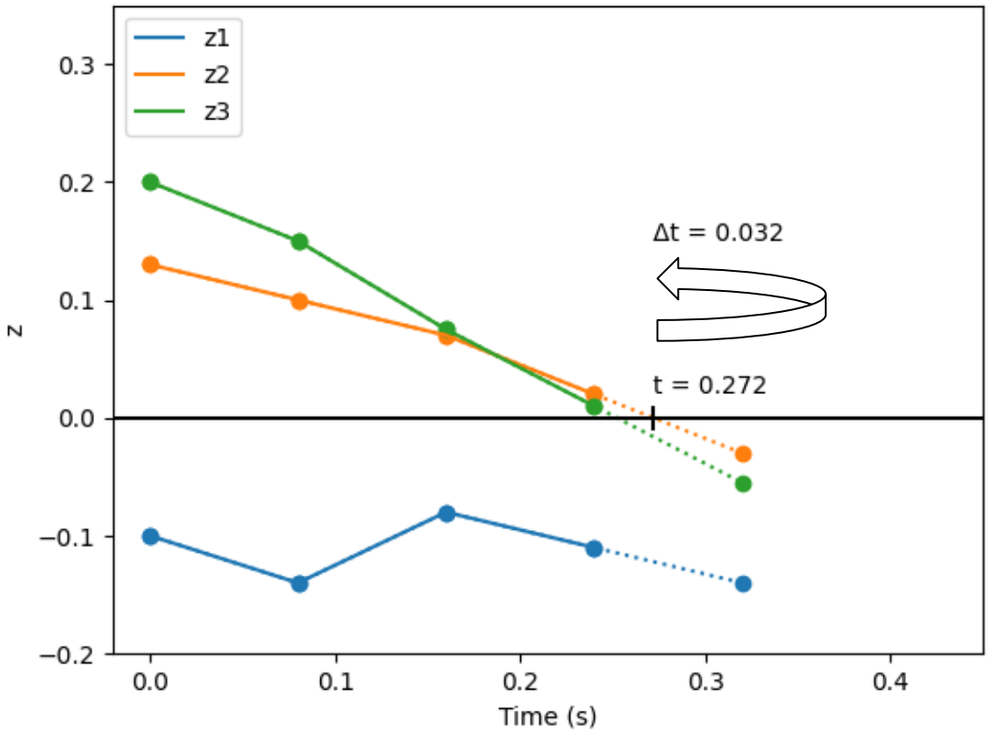
$$\max_{z \in Z} z(t) \leq 0$$



- **Examples: distance between objects, relative velocity, threshold speed**

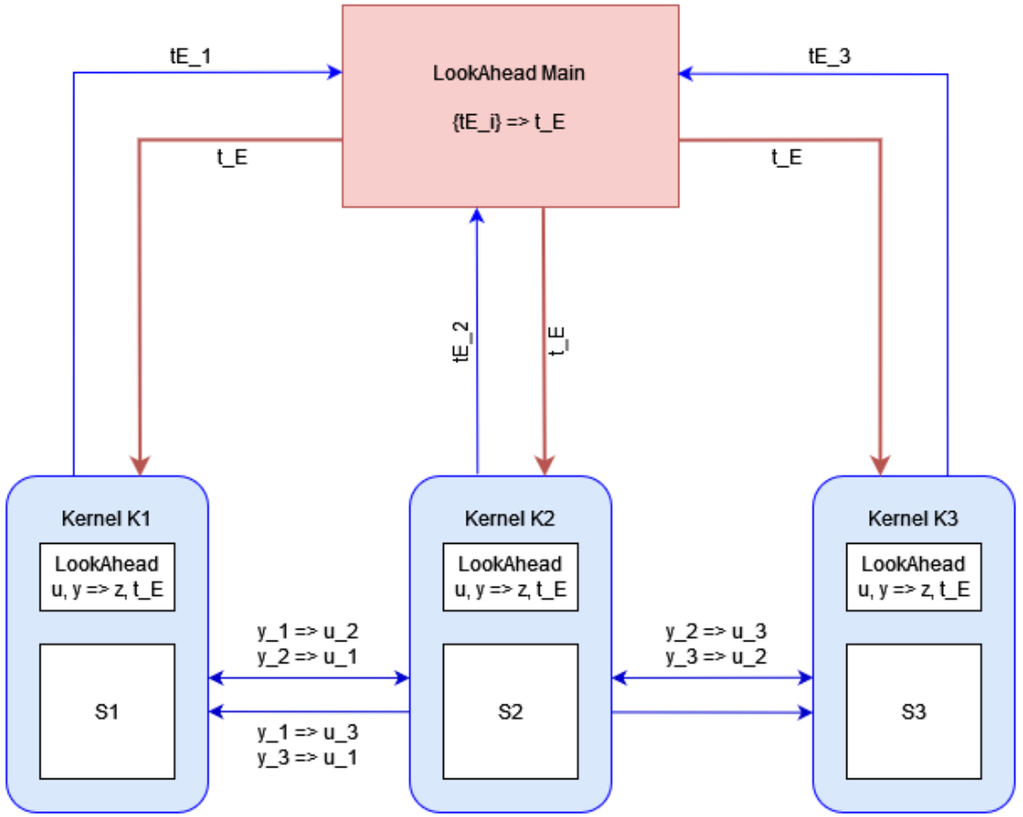
LookAhead I

- **Subsystems with events are equipped with local LookAhead instance**
  - Set up event conditions for each event
    - Have to be able to be evaluated without access to internal variables
    - Some knowledge of the subsystem is required, even if it is a blackbox
- **After each step, for each event:**
  - Calculate current values for z
  - Extrapolate into future via current and previous values
  - Predict if event occurs by checking if $z \leq 0$ for all $z \in Z$
  - If yes, determine time of latest zero-crossing
    - Otherwise, proceed to next event
  - If an event is predicted, return next time step

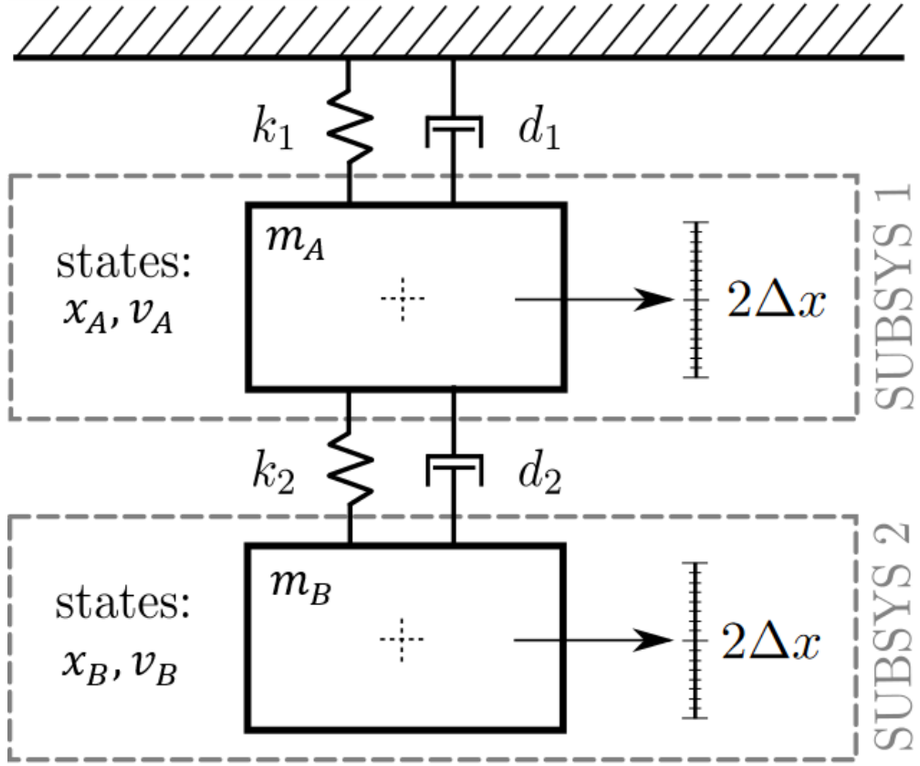


LookAhead I – Concept

- **Each subsystem with LookAhead returns next time step**
- **Main LookAhead**
  - Part of master algorithm
  - Takes smallest time step if events are predicted
    - Otherwise, the default time step
- **To avoid missing events, the algorithm:**
  - Extrapolates further than one time step into the future (forecasting factor)
  - Returns a smaller event time than calculated (safety factor)
  - Both factors can be tuned depending on the predictability of the system

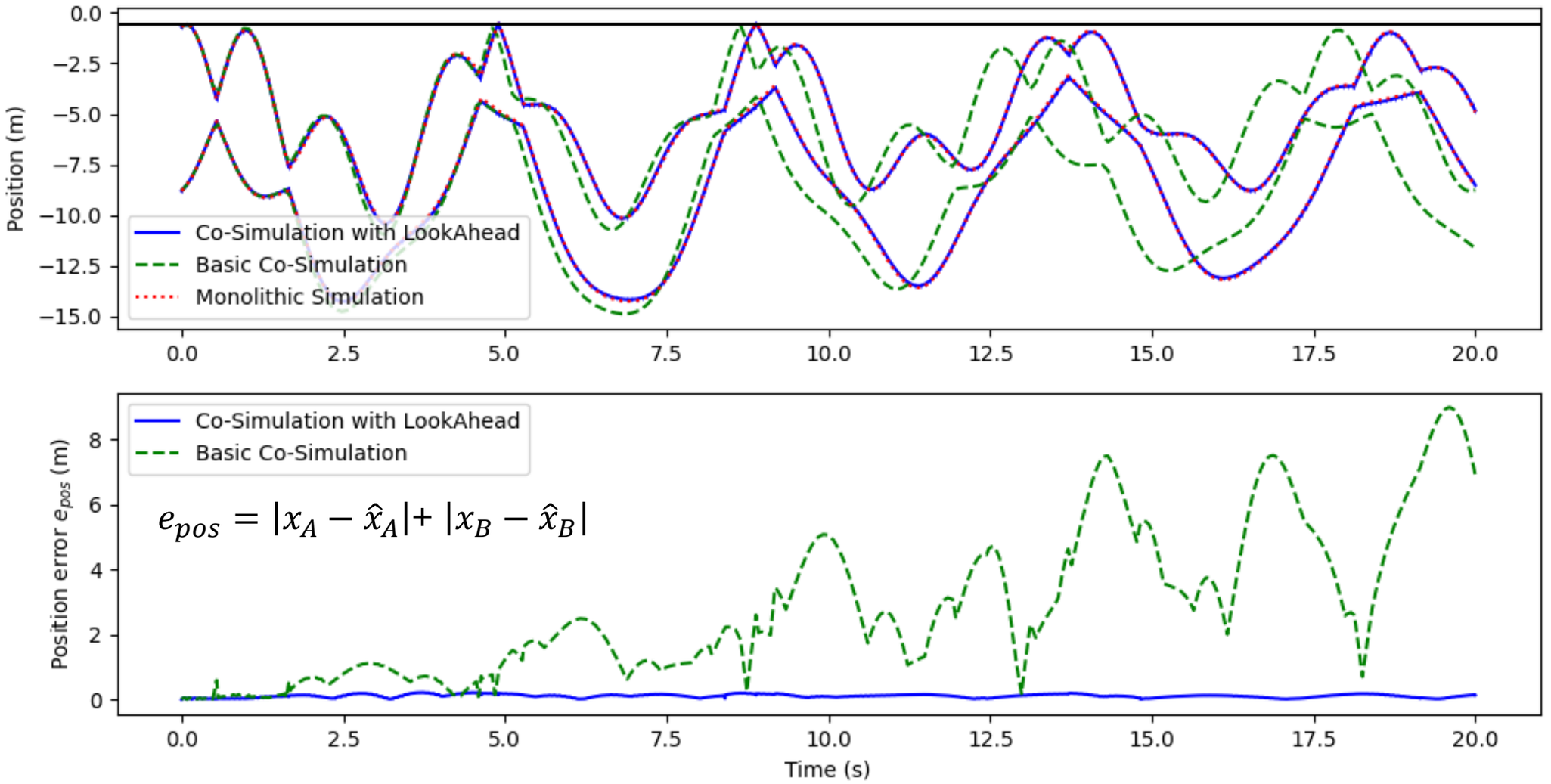


Example



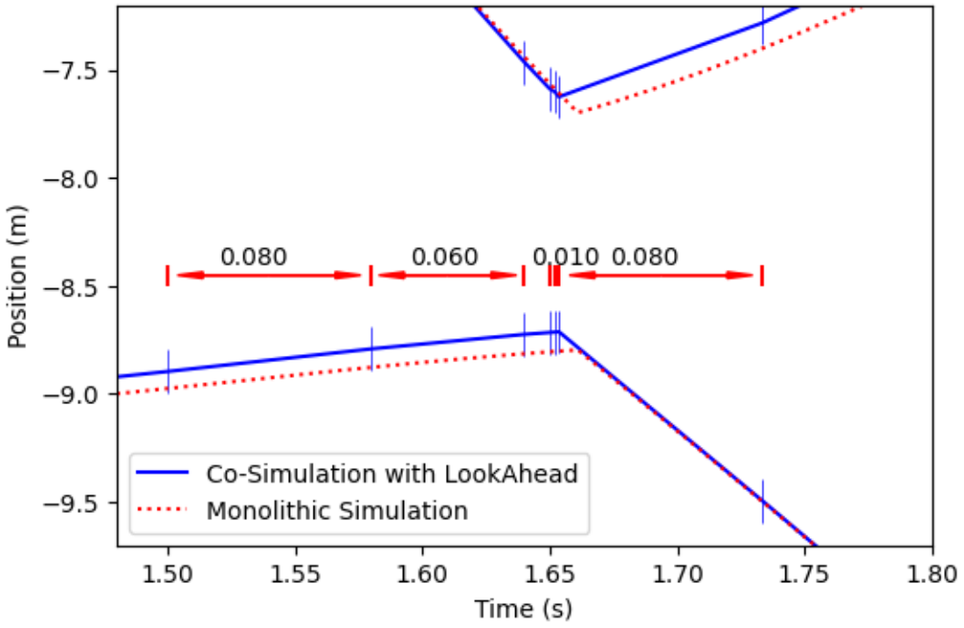
- **Simple spring-damper-mass system**
  - Two masses connected with dampened springs
  - Connected to ceiling at the top
  - Described by system of 4 ODEs, can be solved monolithically
  - Simulation time step of 0.001 s, simulation time 20 s
- **As basic Co-simulation**
  - Realised as two subsystems each with 2 ODEs
  - Parallel execution of simulation steps
  - Fixed communication time step of 0.08 s (250 time steps)
- **With LookAhead algorithm**
  - Base communication time step of 0.08 s, adaptable by LookAhead
- **Two possible events**
  - Upper mass collides with ceiling (private event) => velocity gets reflected downwards
  - Both masses collide (shared event) => elastic collision

Results I


Position (m)
0.0
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
Co-Simulation with LookAhead
Basic Co-Simulation
Monolithic Simulation
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Position error e_{pos} (m)
Co-Simulation with LookAhead
Basic Co-Simulation
$e_{pos} = |x_A - \hat{x}_A| + |x_B - \hat{x}_B|$
0
2
4
6
8
Time (s)

Results II

- **11 events (2 private, 9 shared) encountered during simulation time (20s)**
- **Reference solution:**
  - Monolithic simulation of both masses as a system of 4 ODEs
  - Event check after each time step (0.001 s)
- **Basic co-simulation:**
  - Deviates from reference solution quickly
  - RMS error of 3.65 m
- **Co-simulation with LookAhead:**
  - Takes 32 additonal steps
  - LookAhead reduces RMS error to 0.12 m
    => 30 times less!
- **To get the same error without LookAhead:**
  - Basic co-simulation with smaller time step
  - Communication time step of 0.01 s needed
    - 2000 instead of 250 steps



Conclusion

Summary

- **Significant error improvement (factor 30 in this example)**
- **Almost no additional computation cost**
- **Independent of underlying model complexity**
  - Only dependent on number and complexity of events
- **Events have to be entered manually**

Future Work

- **Improve extrapolation routine for less predictable systems**
- **Compare with other event handling algorithms**

LOOKAHEAD – A NEW APPROACH FOR EVENT HANDLING IN CO-SIMULATION BY PREDICTING STATE EVENTS

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virtual vehicle

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THANK YOU

Presenter:
Felix Tischer
Virtual Vehicle Research Center
felix.tischer@v2c2.at

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