# Application of Model Order Reduction Techniques in LS-DYNA

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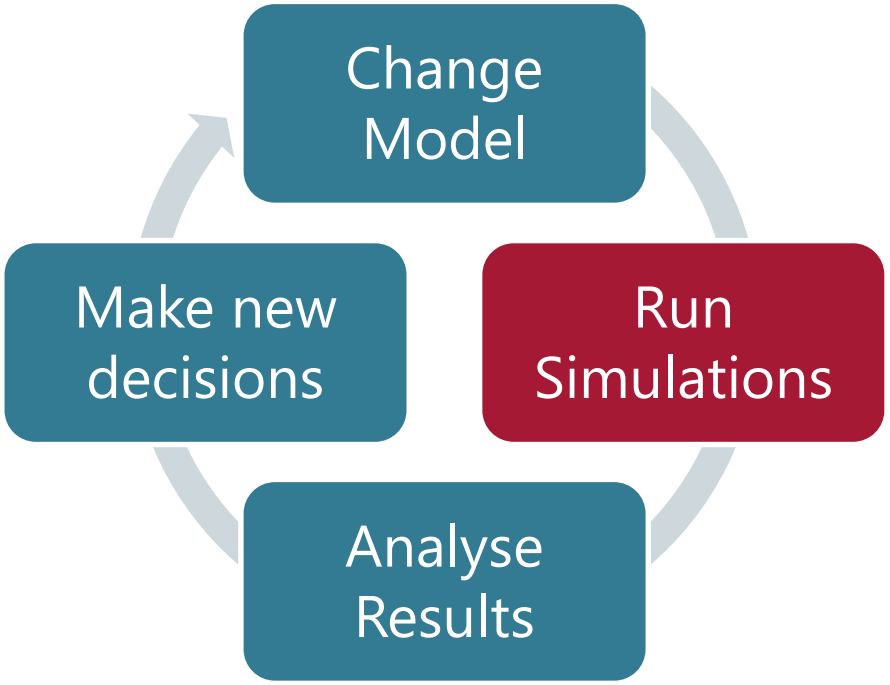
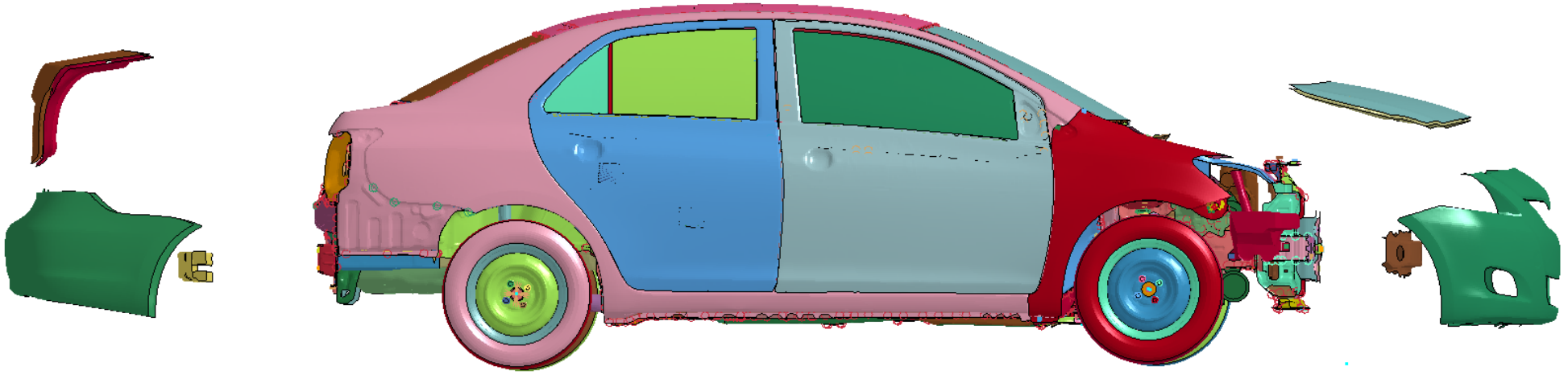
# Outline

- Motivation
- Model Order Reduction
- Reduction Process in LS-DYNA
- Integration into simulation data management
- Example
  - Approximation Quality
  - Computing Time
- Conclusion
- Ongoing work

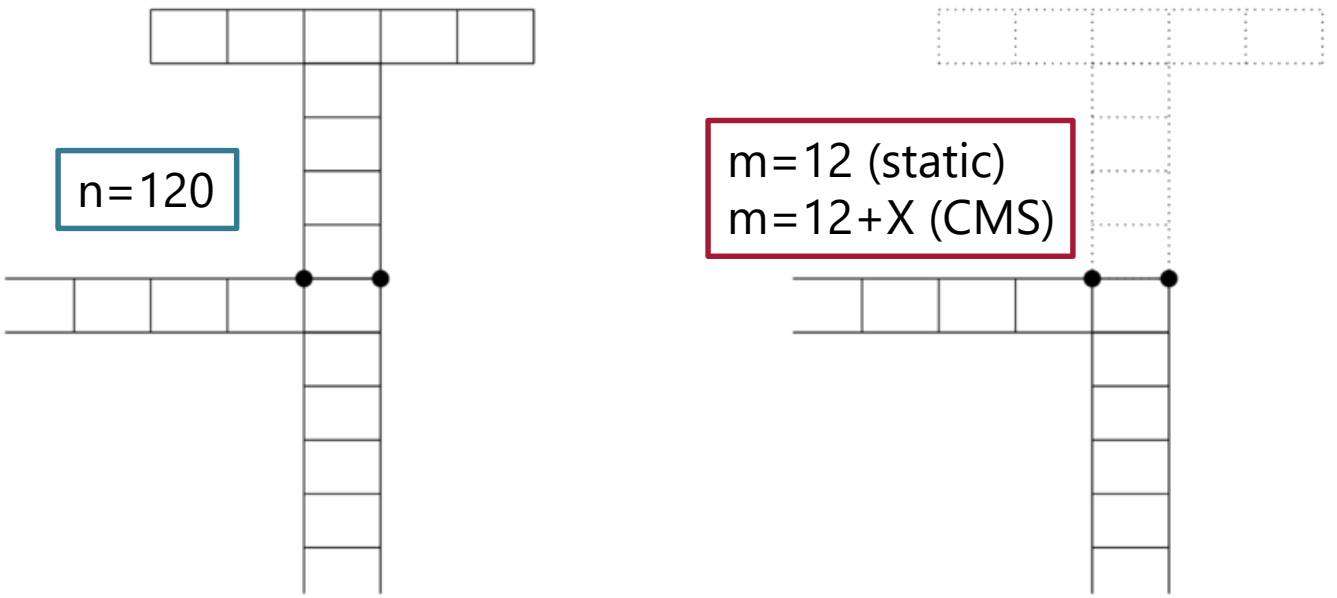
# Motivation

- Large models in automotive crash simulation (~10Mio. elements)
- Many crash simulations during development iteration cycles
- Increased accuracy might not be neccessary (different disciplines)
- Crash models already split in individual parts with clear interfaces
- Reduction of  computing time by approximating specific areas
  - Model Order Reduction



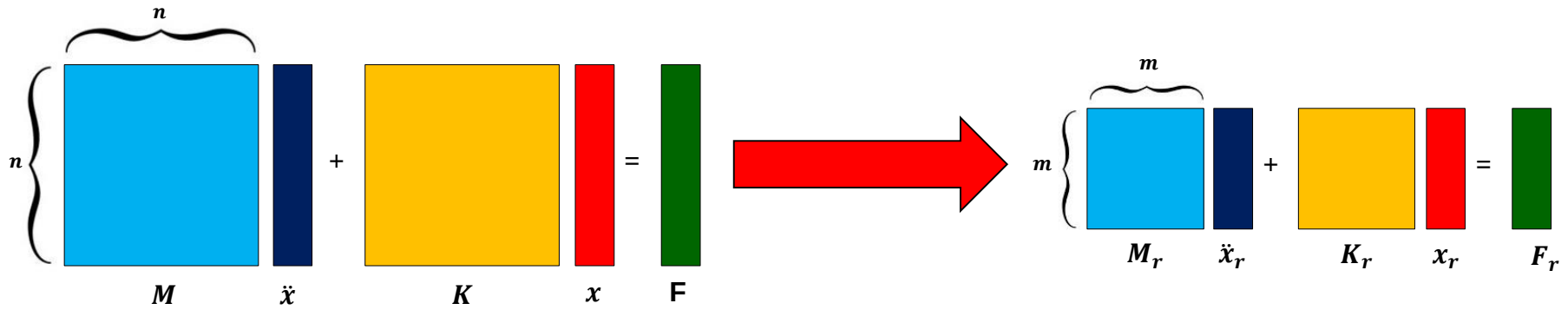
# Model order reduction




Static Condensation:
- No acceleration term
- Only accurate for low frequencies
- Simple to compute

Component Mode Synthesis (CMS):
- Dynamic reduction
- Adds features of arbitrary eigenmodes to static condensation

Simplified Equation for Reduced Part



# Reduction Process

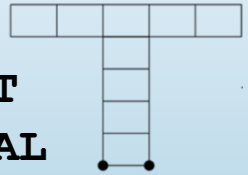
Offline Step

Reduction Master

*INCLUDE

Part

*NODE
*ELEMENT
*MATERIAL
...
*SET_NODE



*IMPLICIT_MODES
<<Options>>

Reduced Matrices

Online Step

Master

*INCLUDE

Reduced Part

*NODE
*ELEMENT
...

Interface only!

*DIRECT_MATRIX_INPUT

Reduced Matrices

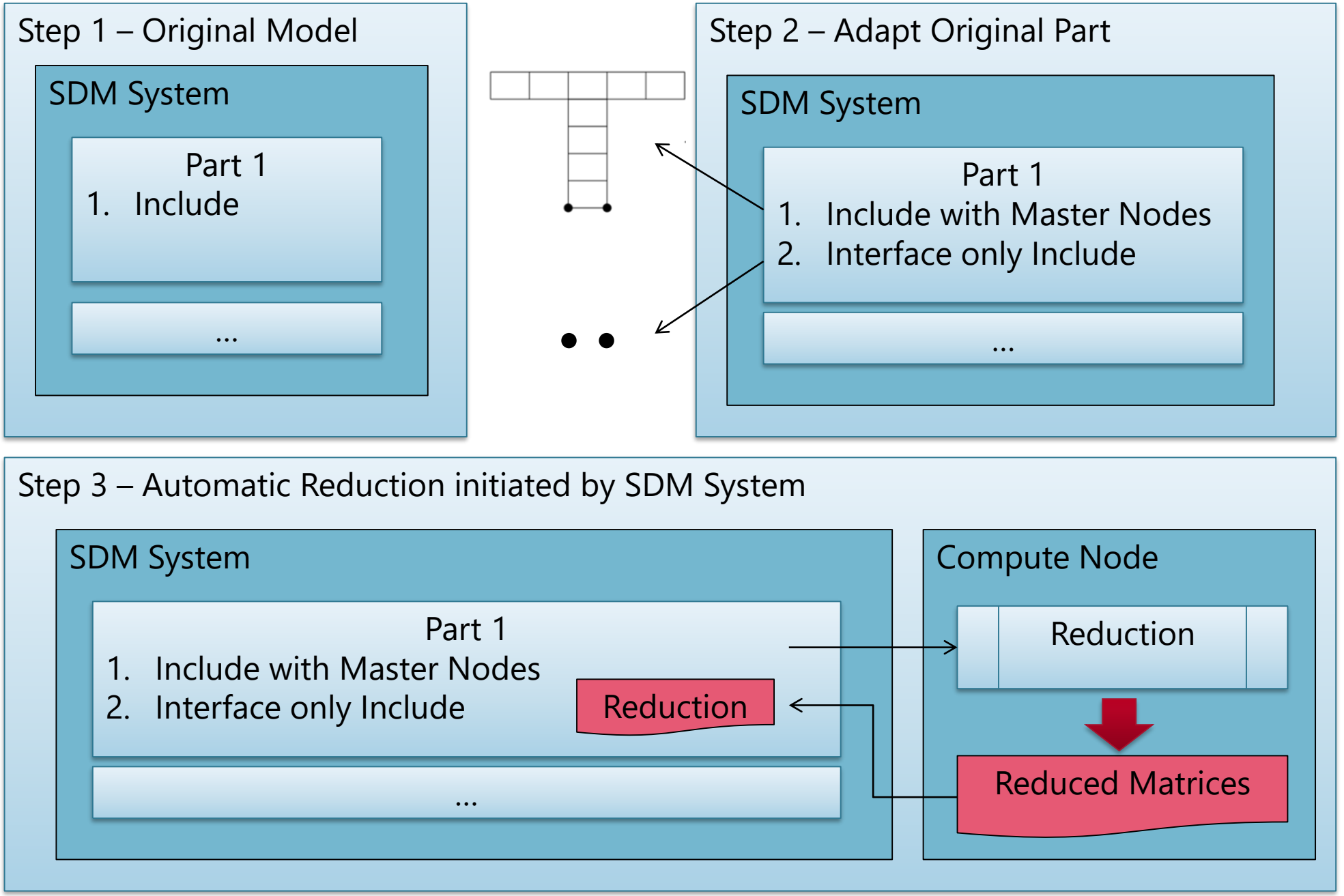
Other Part 1

Other Part 2

...

*CONTROL_TERMINATION
...

# Integration into simulation data management



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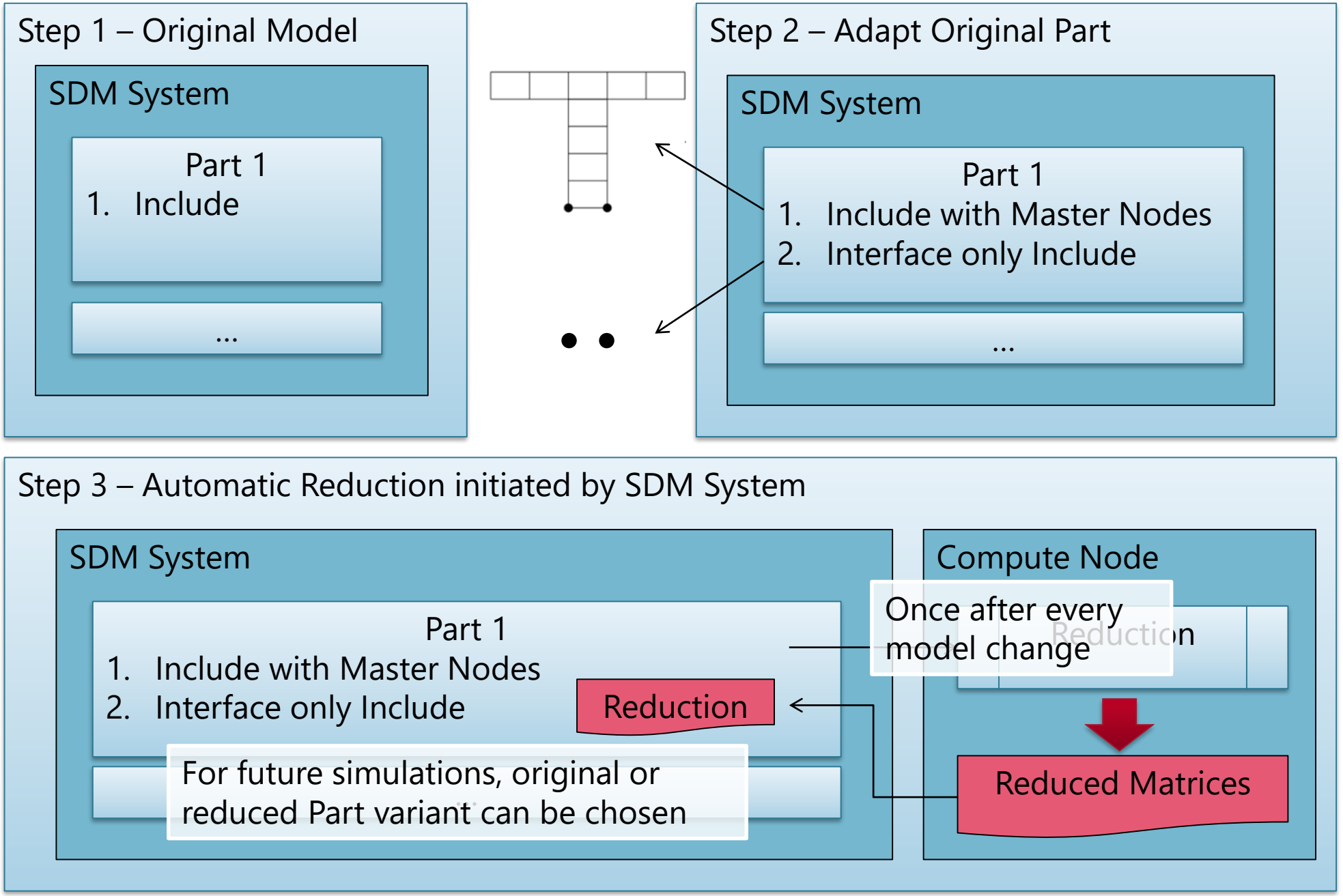
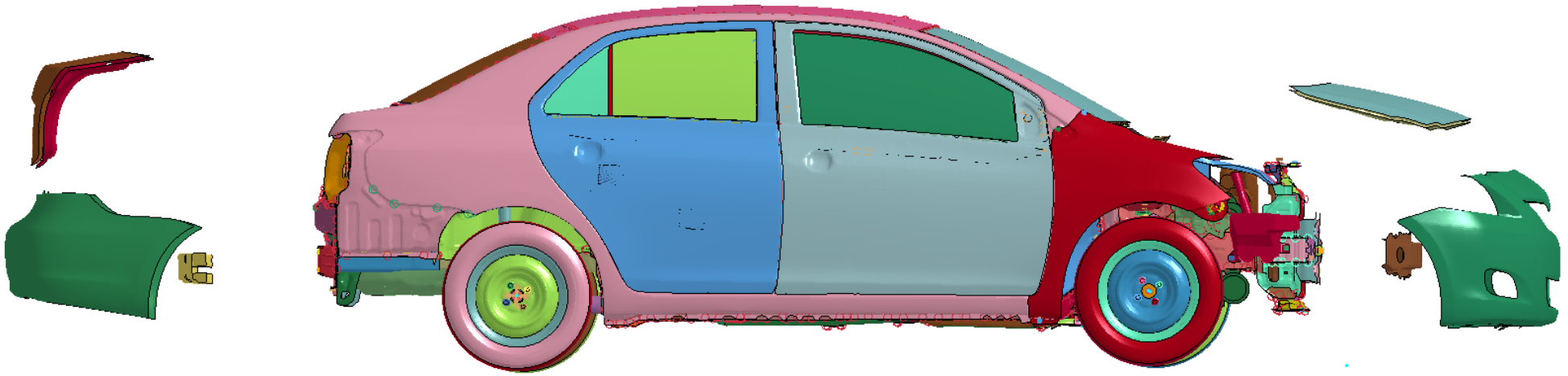


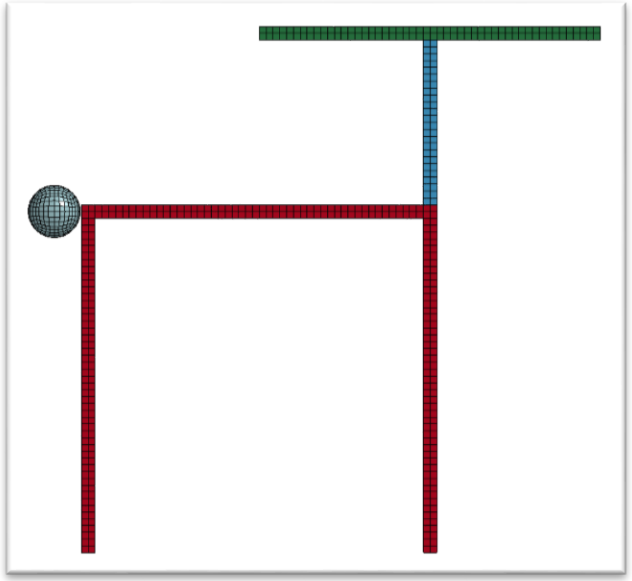
# Integration into simulation data management

- Hold Original and Reduced model for several parts of the crash model
- Depending on the discipline (front-crash, rear-crash,...) choosing a combination of original and reduced variants
  - Possible because of modularity and interface modelling



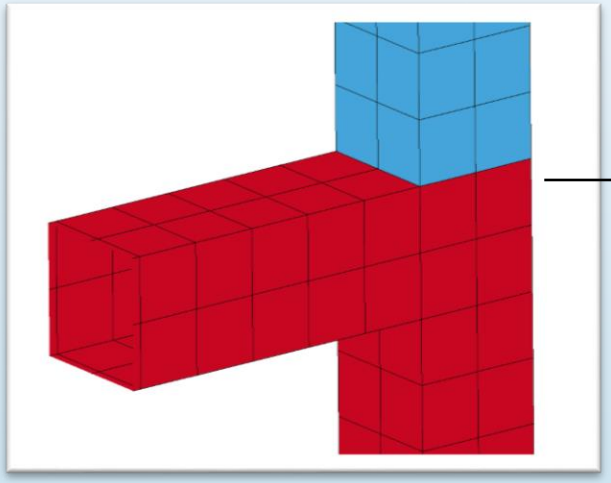
- Offline step already done automatically
- Reduced part can be used multple times (in the same model or in different simulations)
  → More expensive Reduction method becomes viable

# Examples: Model

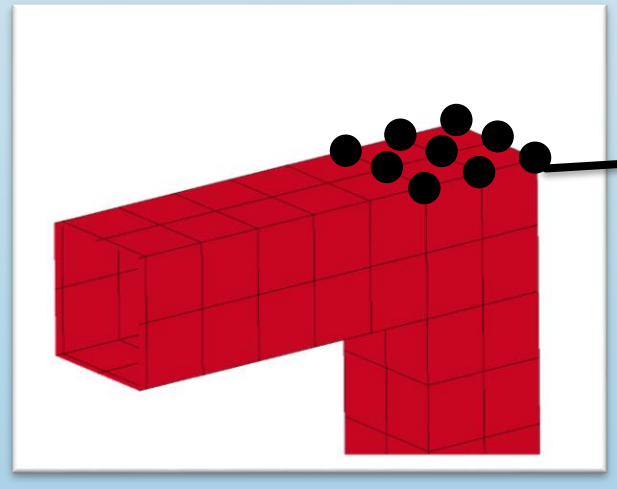


- Clamped Frame: 1212 nodes, 1224 shell elements
- „T“: 603 nodes, 608 shell elements
- Linear elastic material model
- Impactor sphere with initial velocity
- Reduction with static condensation and CMS with different numbers of modes

Detail: Interface Frame <-> „T“



9 shared nodes Between Parts



Connection Nodes = Master Nodes for Reduction

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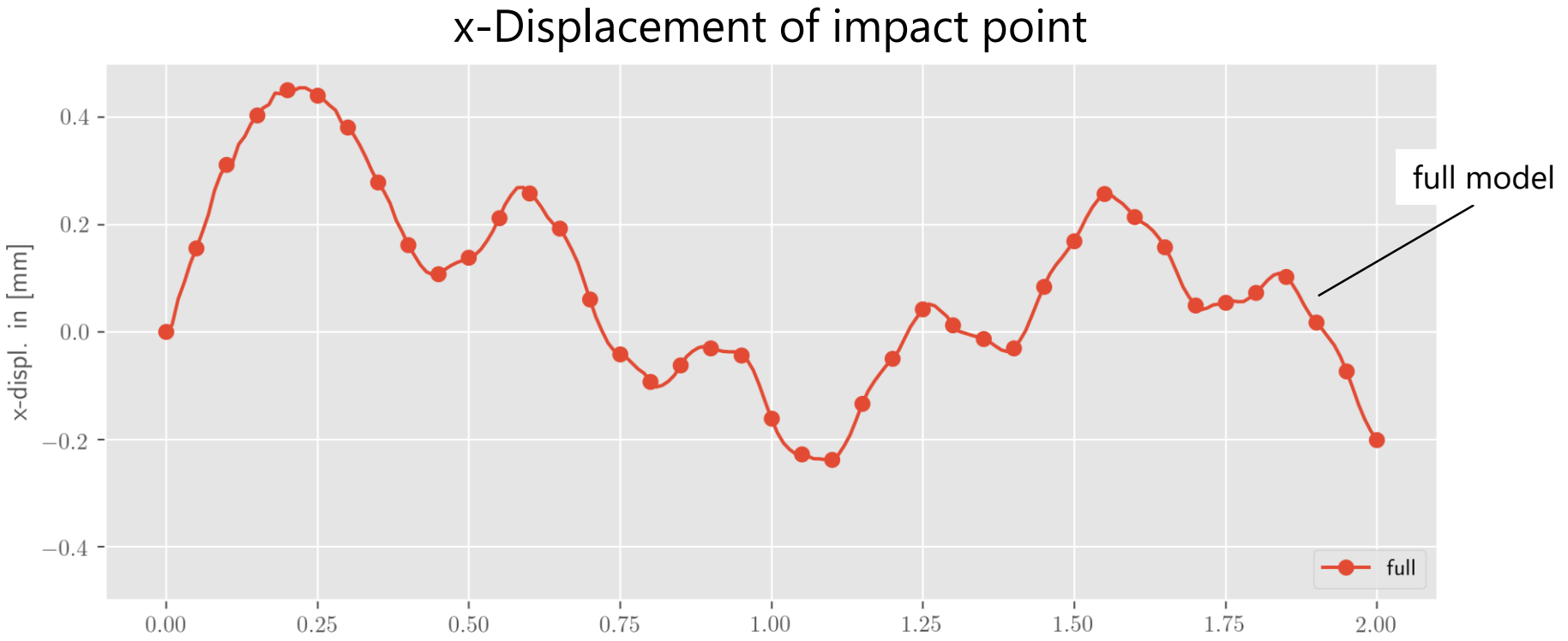
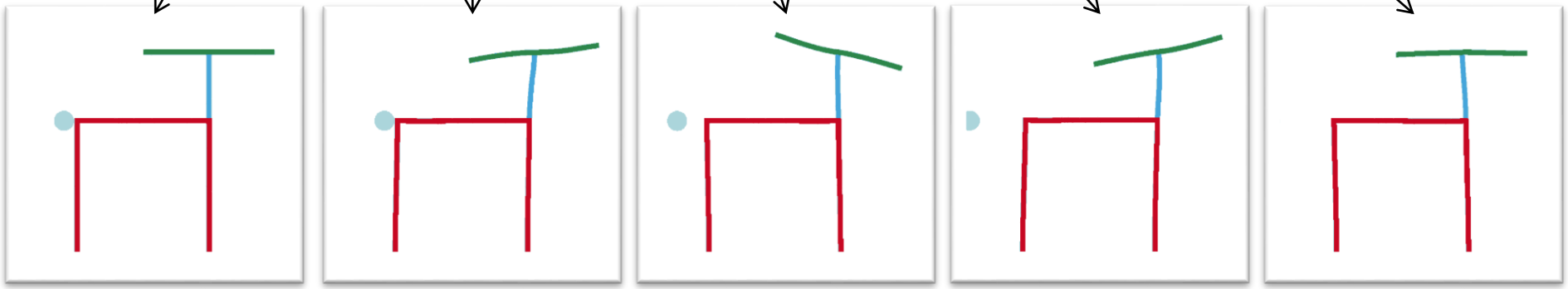
# Examples: Approximation Quality




Stages:



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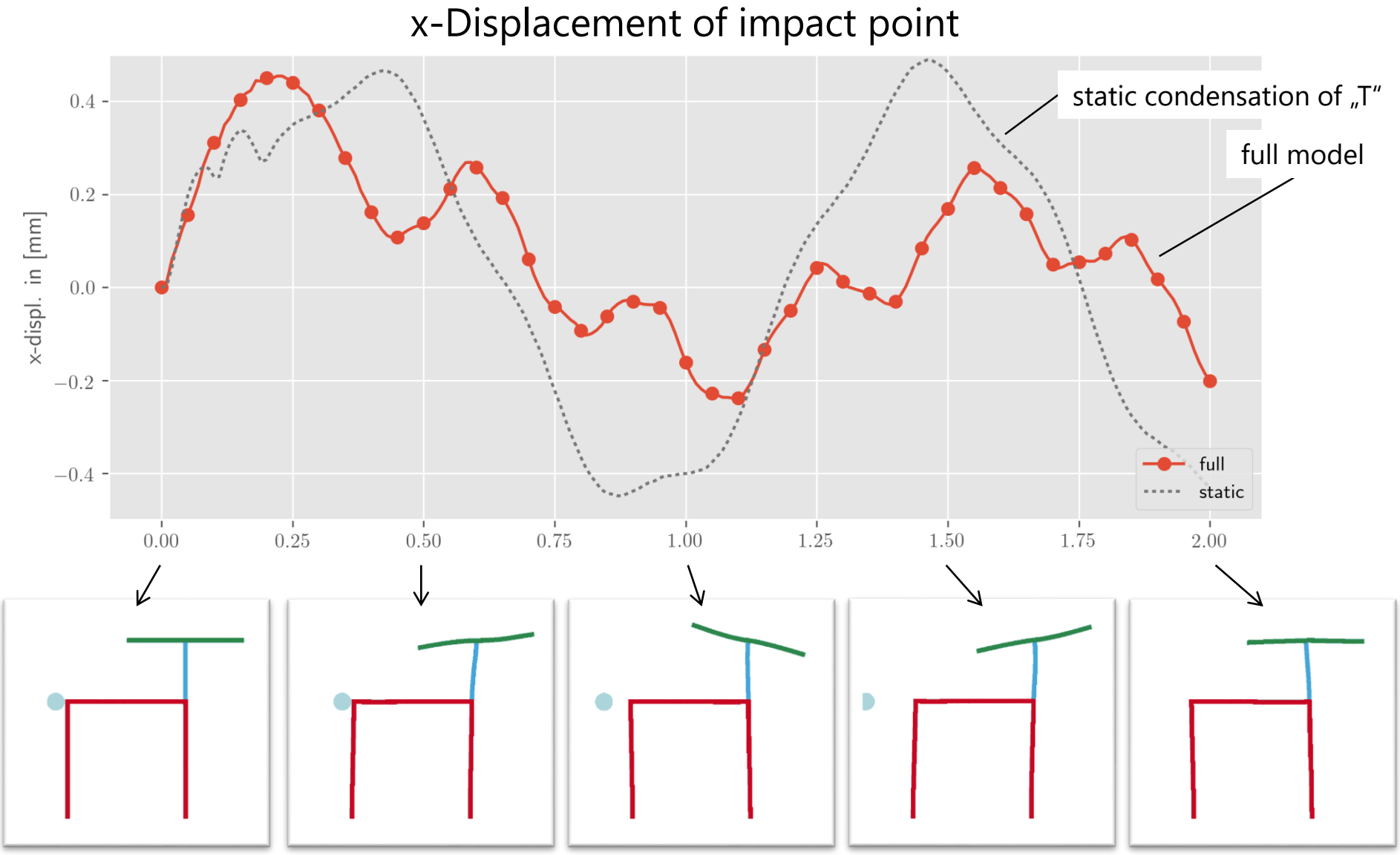

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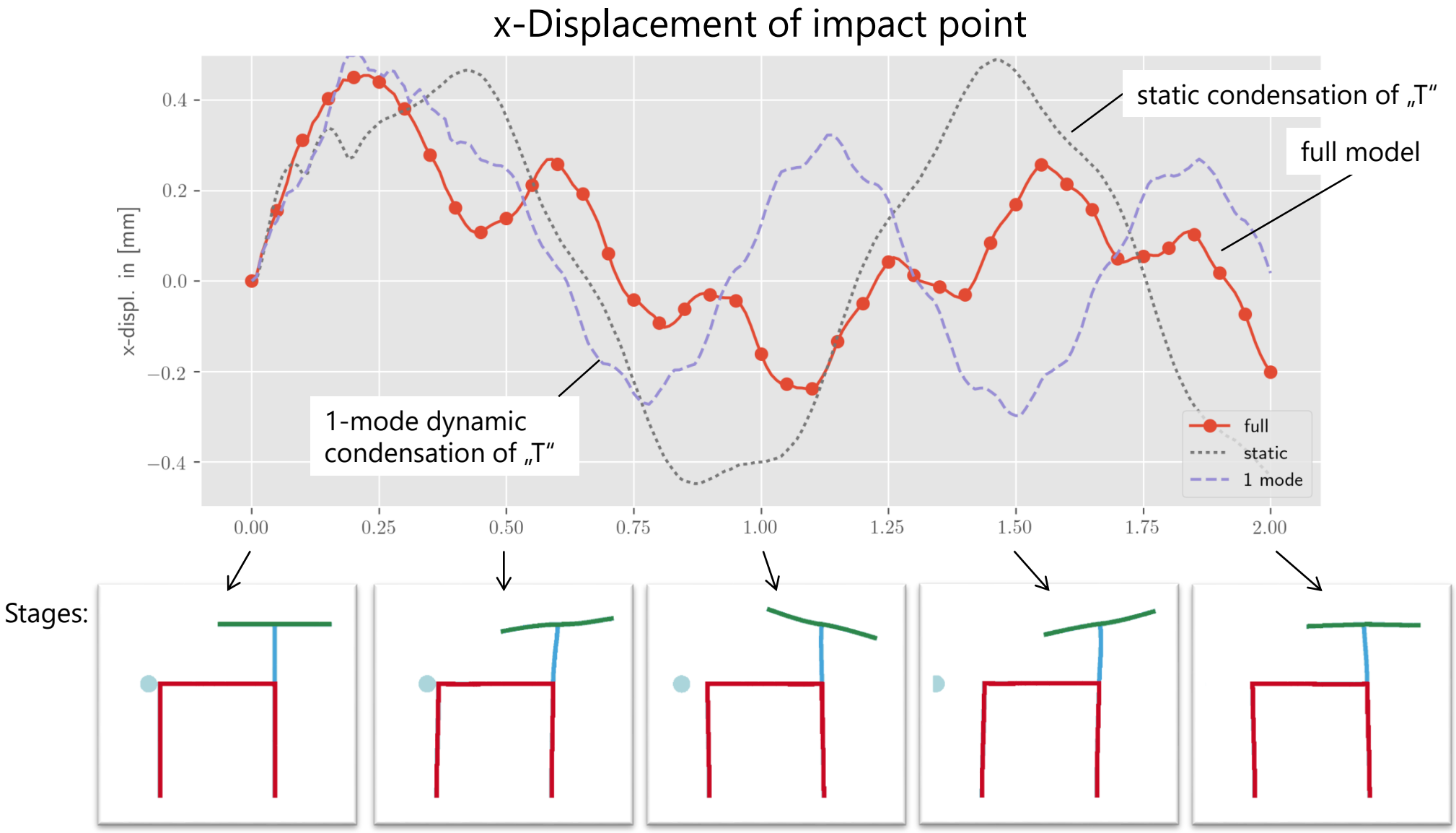

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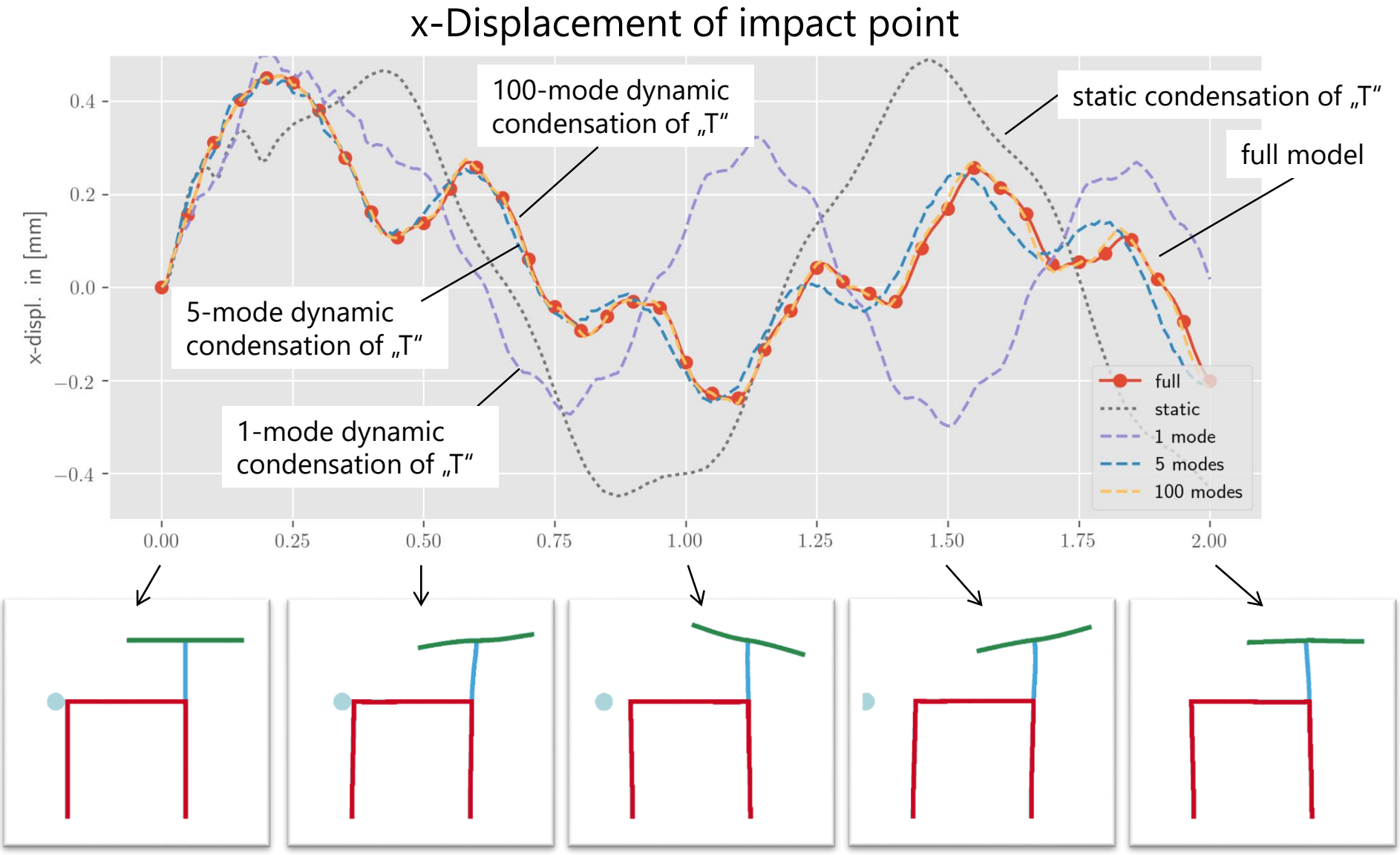
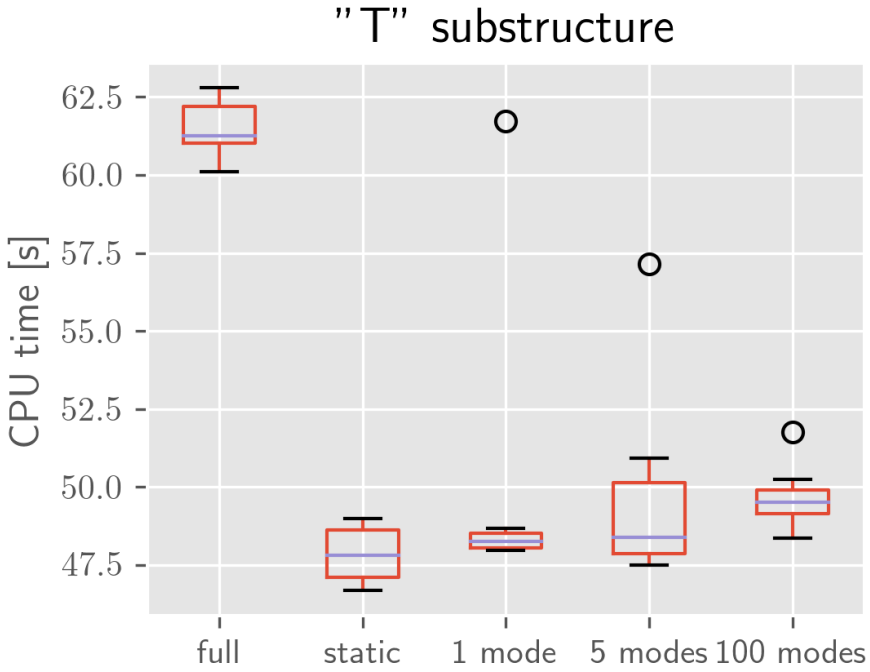
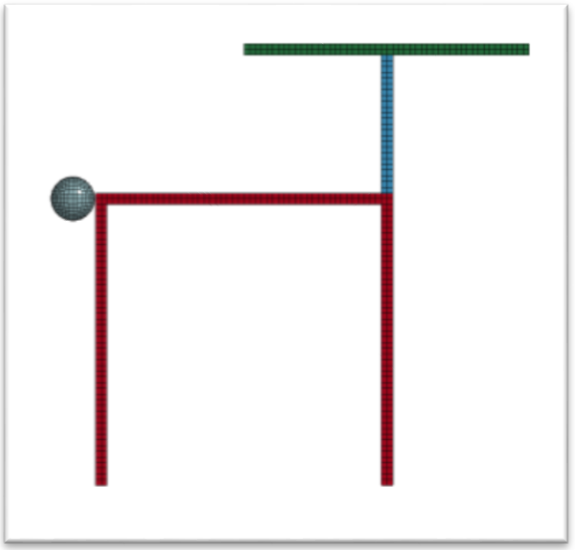


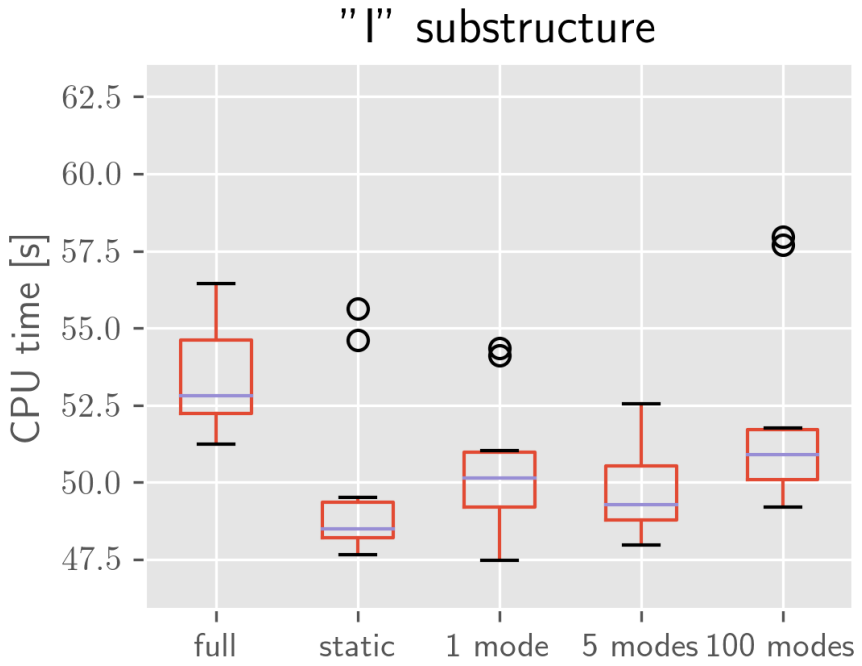
# Example: Computing Time

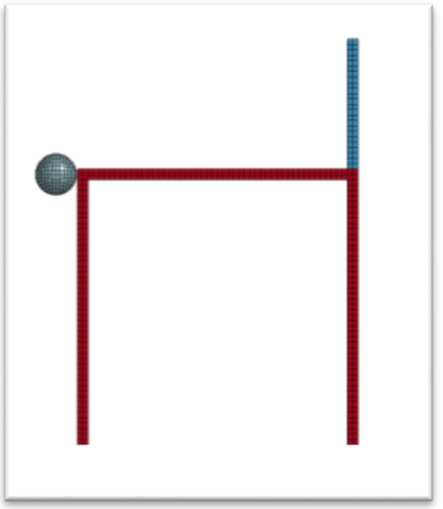


| T | DOF | CPU time [s] | DOF change [%] | CPU time change [%] |
|---|---|---|---|---|
| **full** | 10890 | 61.26 | | |
| **static** | 7326 | 47.80 | -32.7 | -21.9 |
| **1 mode** | 7327 | 48.25 | -32.7 | -21.2 |
| **5 modes** | 7331 | 48.39 | -32.6 | -21.0 |
| **100 modes** | 7426 | 49.50 | -31.8 | -19.1 |

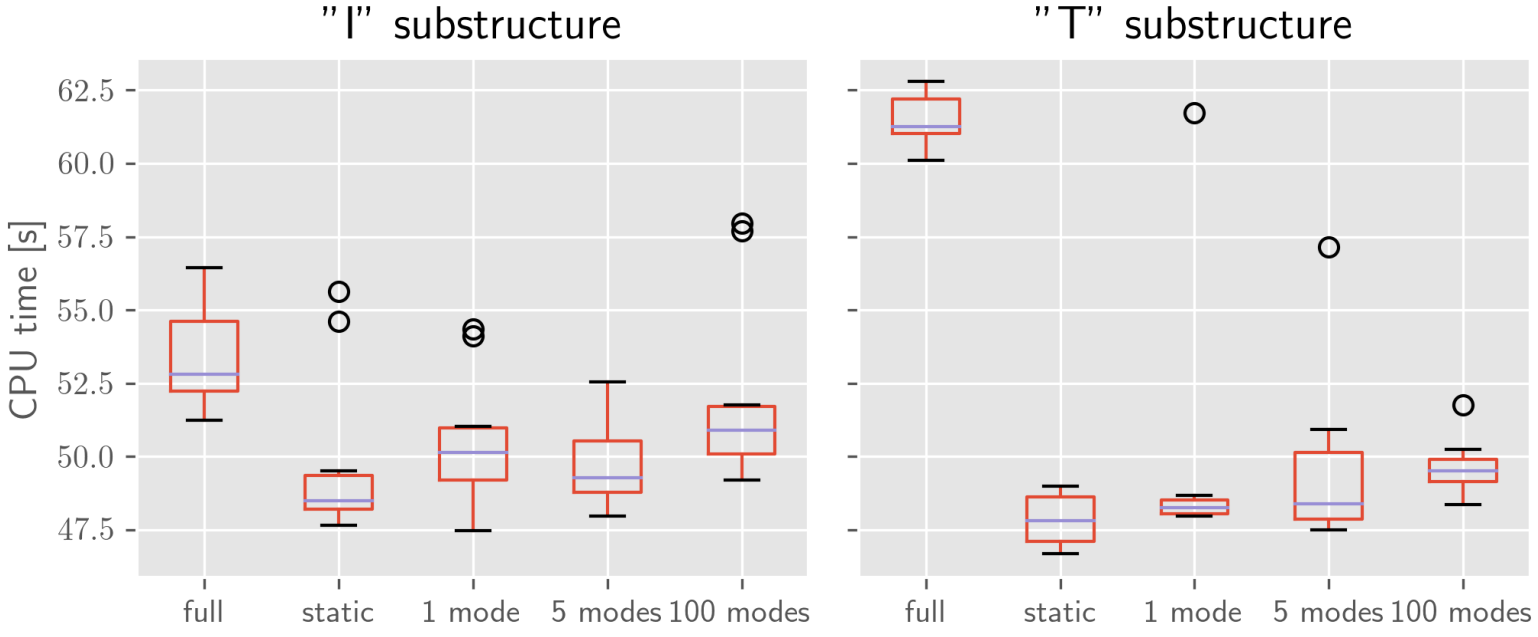
# Example: Computing Time

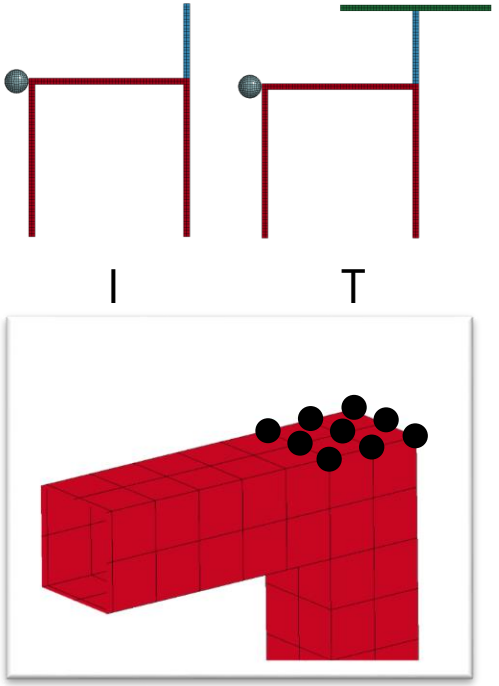


| I | DOF | CPU time [s] | DOF change [%] | CPU time change [%] |
|---|---|---|---|---|
| **full** | 8484 | 52.81 | | |
| **static** | 7326 | 48.48 | -13.6 | -8.1 |
| **1 mode** | 7327 | 50.12 | -13.6 | -5.0 |
| **5 modes** | 7331 | 49.28 | -13.5 | -6.6 |
| **100 modes** | 7426 | 50.90 | -12.4 | -3.6 |

# Examples: Computing Time




Reduction of Computing Time (with respect to reference sim.):

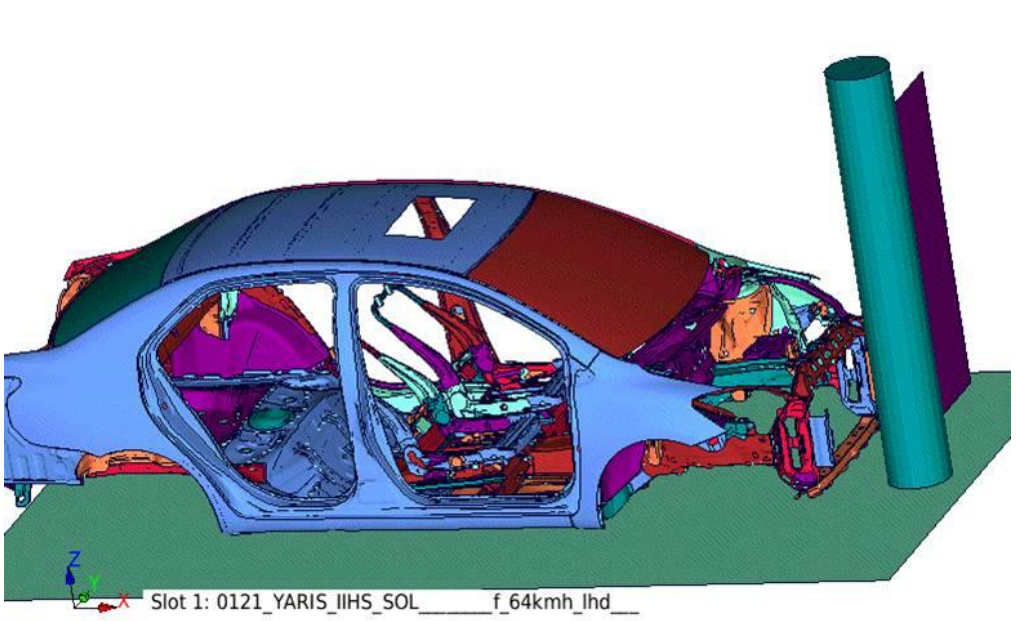
| | T (DOFs: -30%) | I (DOFs: -13%) |
|---|---|---|
| static | -22.0% | -8.2% |
| 1 mode | -21.1% | -5.1% |
| 5 modes | -21.0% | -6.6% |
| 100 modes | -19.2% | -3.6% |

# Conclusion

- General Process to use model order reduction with LS-DYNA:
  - Defining Master nodes; Reduction step; Import of reduced part as superelement
- Component mode synthesis (CMS) can be used to approximate the system response for the chosen academic example
- Approximation quality of CMS heavily depends on number of eigenmodes (also depends on the characteristics of the model)
- Significant computing time reduction can be achieved (depending on model size, with the examined models)
- Integration in existing workflows (e.g. SDM) is crucial to make MOR easily available
- By using a defined interface to connect parts, original parts and reduced parts can be interchanged

# Ongoing Work

- Solve problems that occured
- Outsource reduction step from LS-DYNA to external tools
  - Interface for system matrices is available (DMIG format)
- Improve the SDM integration (different reduction variants, scheduling of reduction run, caching,...)
- Using more complex models (more element types, failure, rigid bodies, damping,...)
  - Ultimately apply MOR to Toyota Yaris model




# Thank you!

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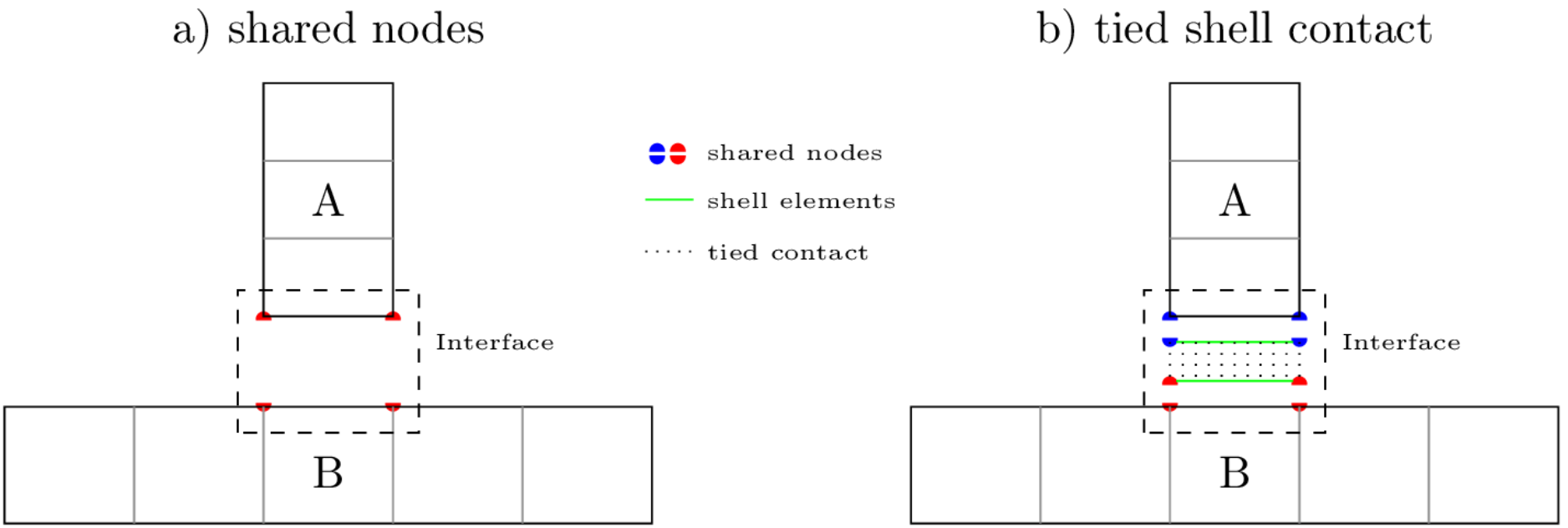
# Interface


a) shared nodes
A
B
Interface
shared nodes
shell elements
tied contact
b) tied shell contact
A
B
Interface

# Modulstrategie: Beispiel Yaris Heckklappe