SimTech
Cluster of Excellence

Dynamore
Informationstag
Juni 02, 2016

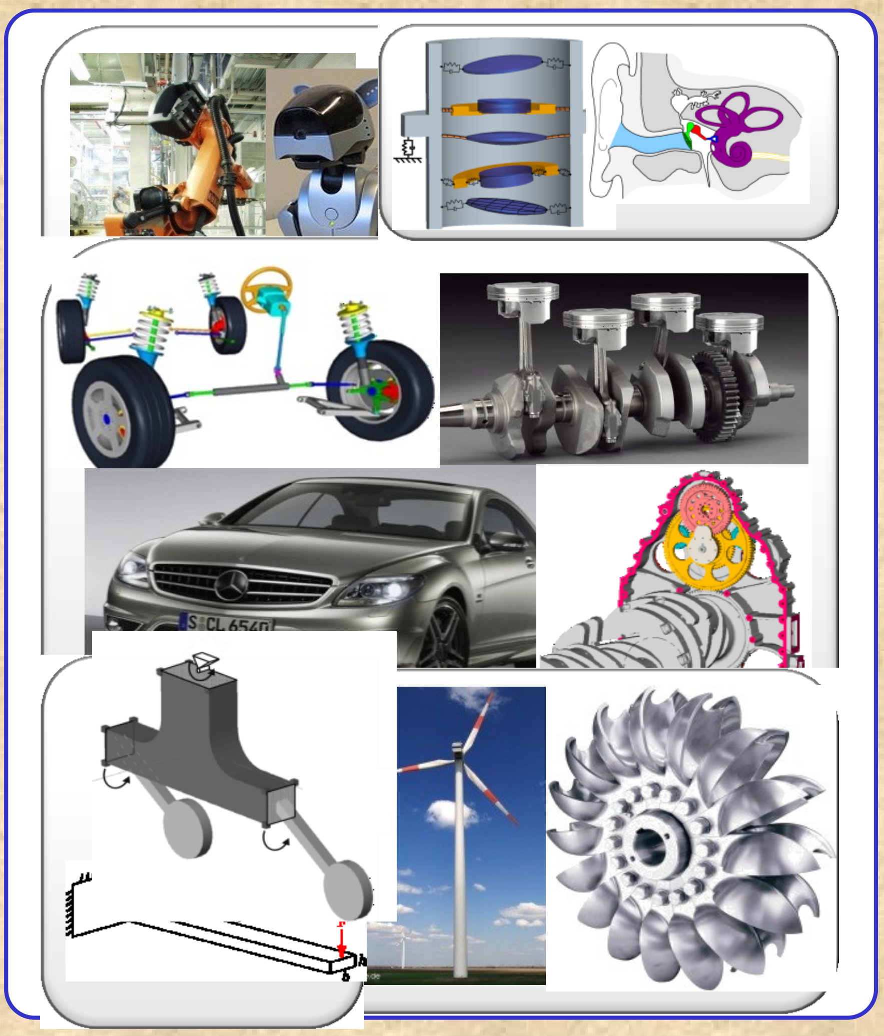
Das menschliche Verhalten bei seitlichen Fahrzeugmanövern – "Fare-Side“ Crash, Spurwechsel und Seitenkollision

Christian Kleinbach, Lacie Feller, Jörg Fehr

Institute of Engineering
and Computational Mechanics
University of Stuttgart, Germany
Profs. Eberhard / Hanss / Fehr

Simulation of Dynamical System

- simulation and analysis of dynamical systems
- simulation is essential in the development process of new products
- third discipline besides theory and experiment
- research
  - multibody dynamics
  - mechatronics and optimization
  - uncertainties
  - contact mechanics
  - **bio mechanics**
  - **driving safety**



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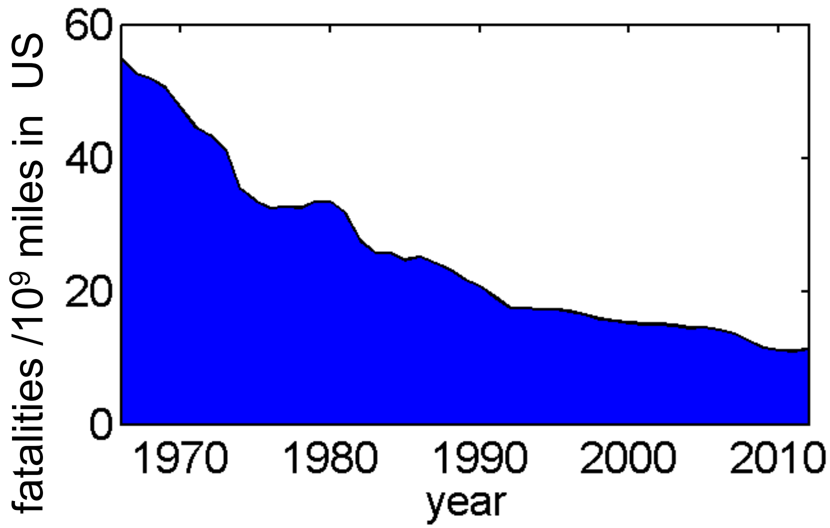
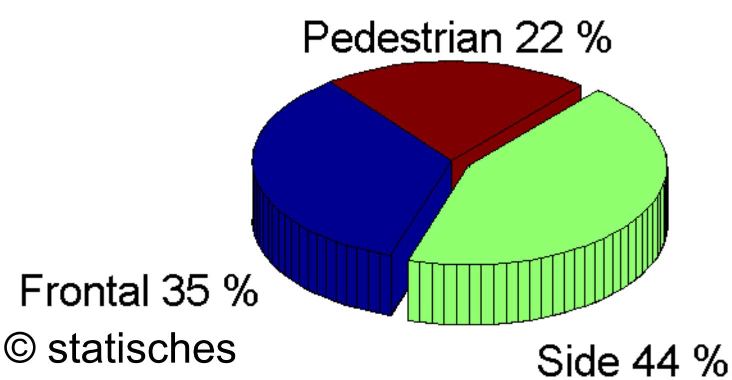
Driving Safety
Why?

- vehicle safety
  - 3.8 Mio. car to car crashes in 2012 in the US [NHTSA12]



- side crashes are most deathly



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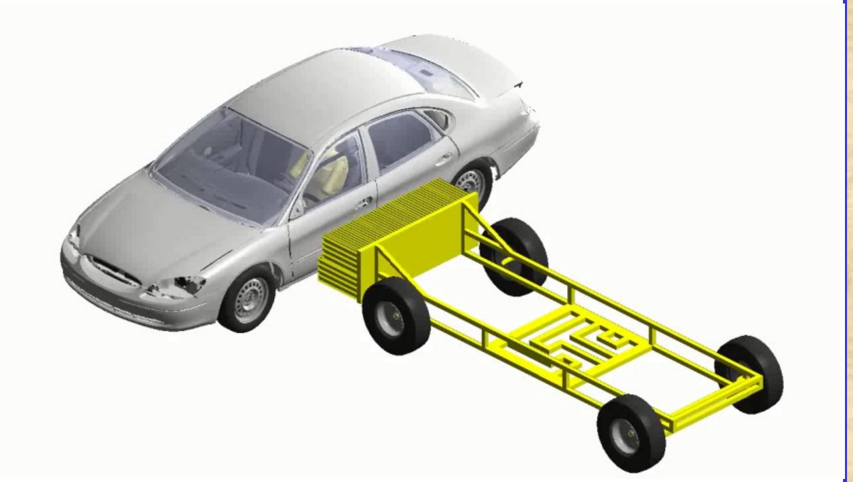
standardized European crash test

- moving deformable barrier 950 kg, 50 km/h
- 2001 Ford Taurus car model with a seatbelt, no airbag

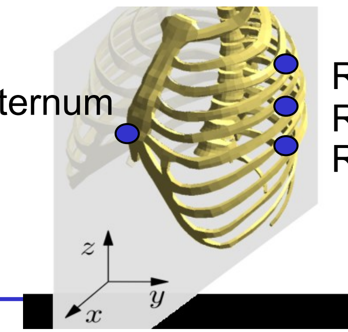


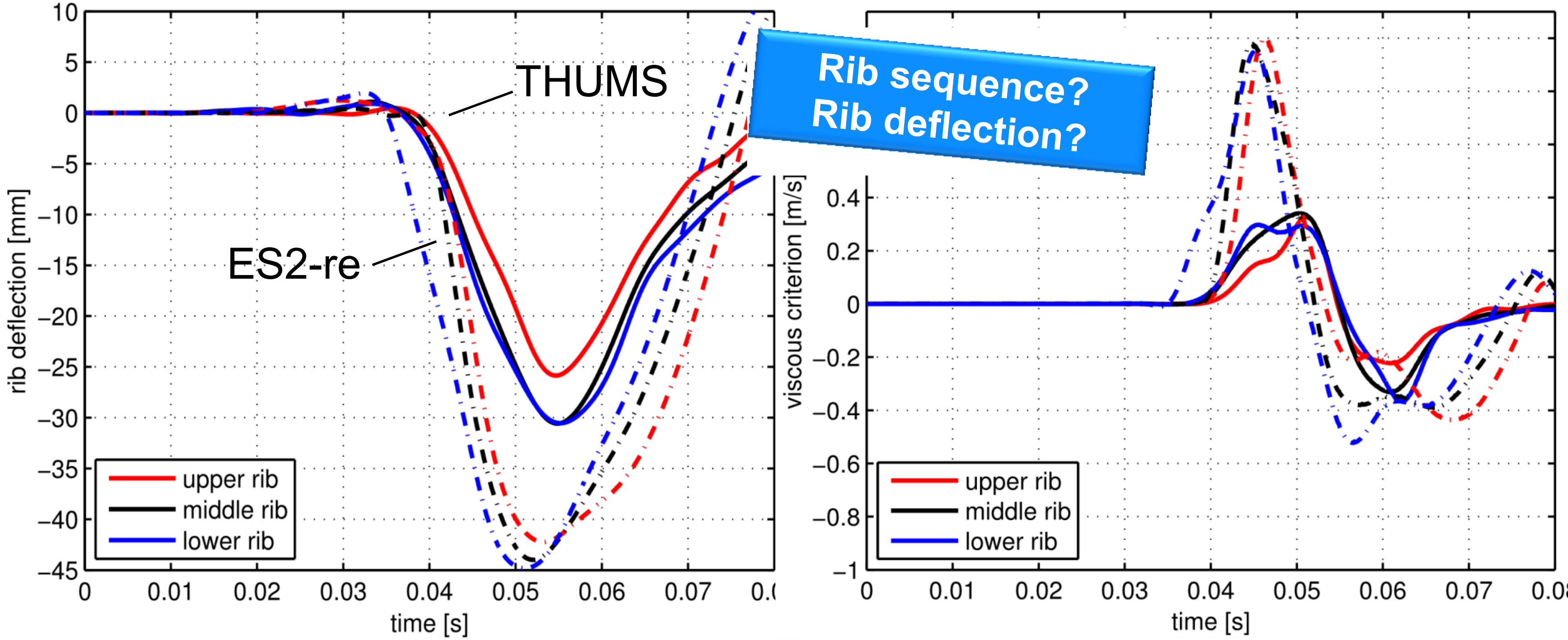
- comparison between Dummy and HBM (THUMS) behavior

Driving Safety What

- comparison between Dummy and HBM (THUMS) behavior

- ribcage kinematics

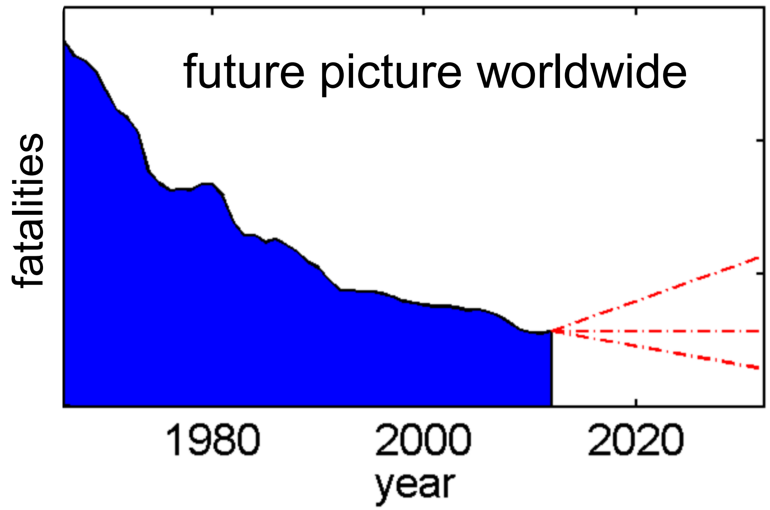


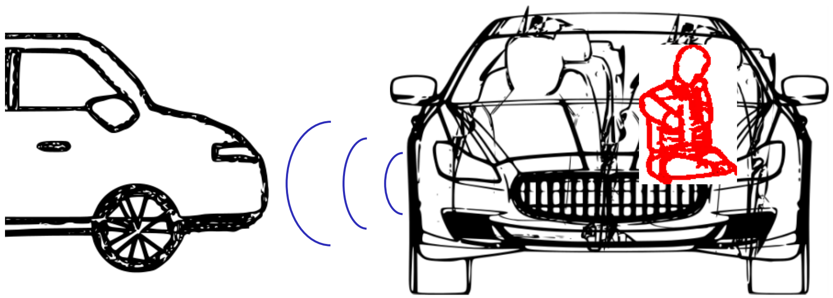


Rib sequence?
Rib deflection?

Driving Safety Future?

- highly autonomous driving / active safety





	Pre-Crash	In-Crash
time duration	+	-
acceleration/forces	+	-
dummy behavior	-	+

- driver changes his position by muscle movement
- current status of safety modeling does not include these effects
- ? optimal human body model ?
  - FE vs. MBS
  - activated not activated
- **optimal safety design based on optimal human body model**

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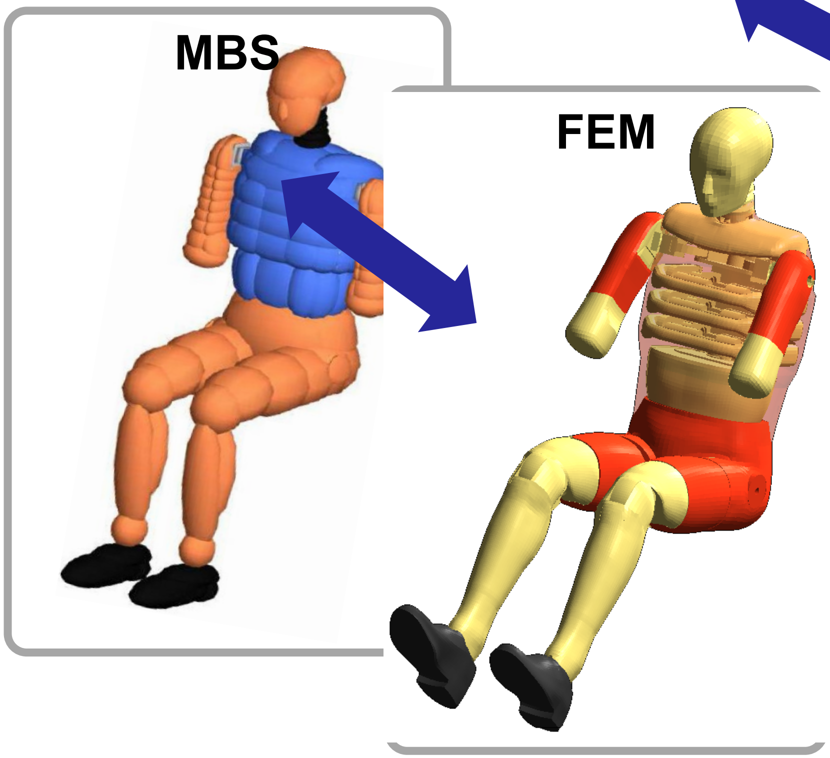
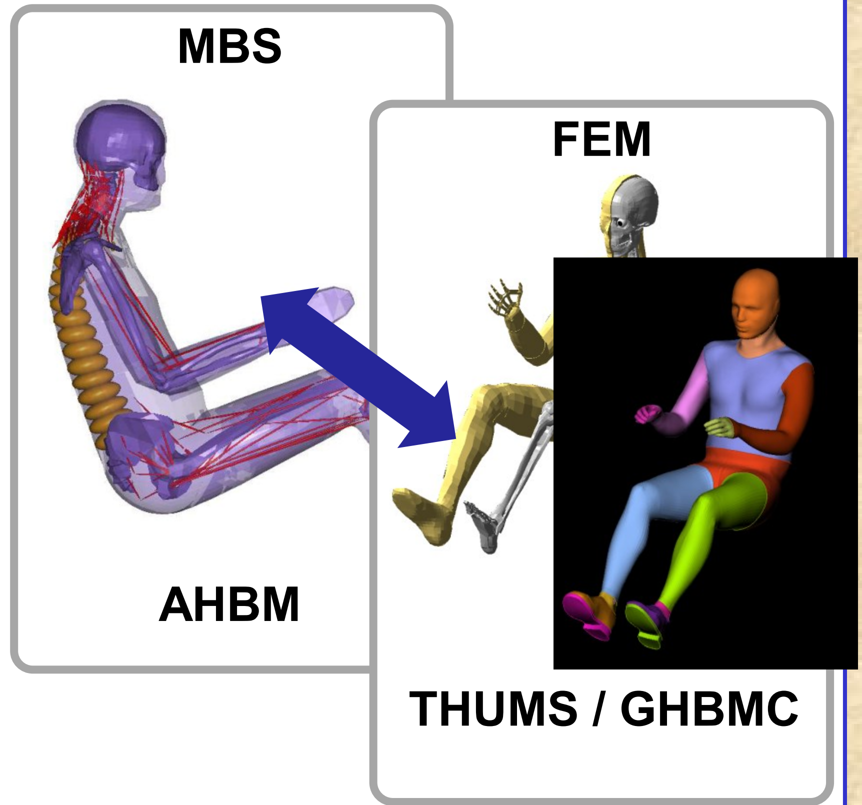
What?

- Dummy Models



- based on mechanical substitutes
- designed for one specific scenario

- Human Body Models



- based directly on the human body
- universal models

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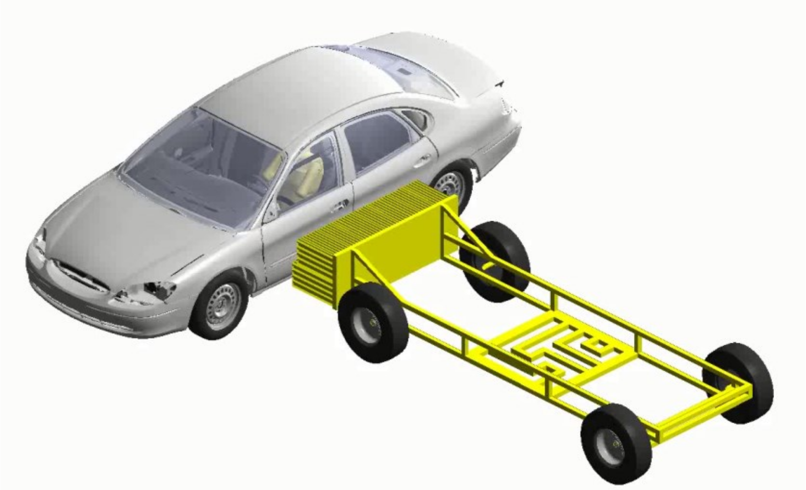
How? [FehrKleinbach15]

comparability needs to be ensured

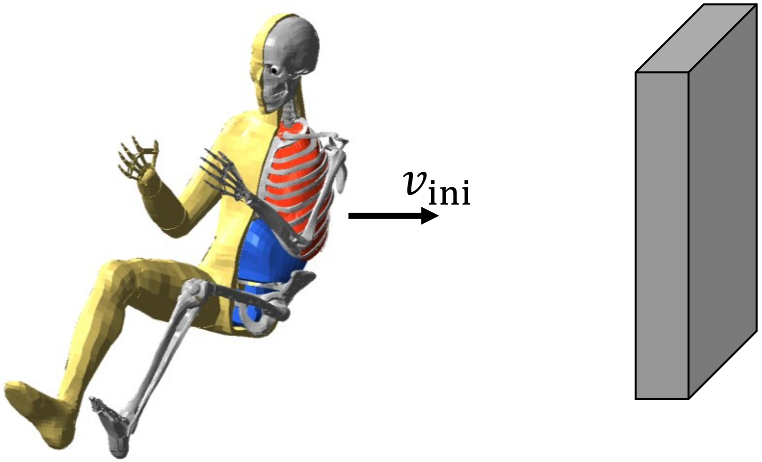
- full car crash is very complex



- usually not available in MBS
- too many parameters
  - seating position
  - door intrusion
  - contact definitions
- 14 hours calculation time

simple setup for comparison [FehrKleinbach15]

- active controlled deceleration
  - passenger:
    initial velocity v_{ini}
    initial energy J_{ini}



- t_{final} passenger at rest
- J_{ini} absorbed by safety system and passenger

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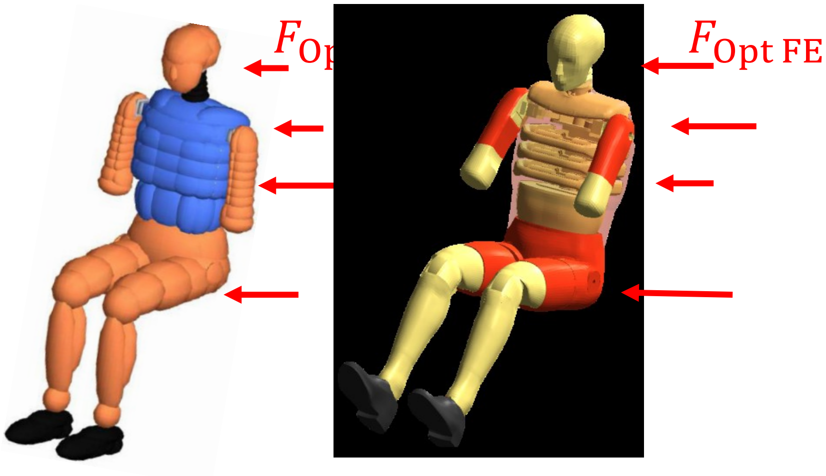
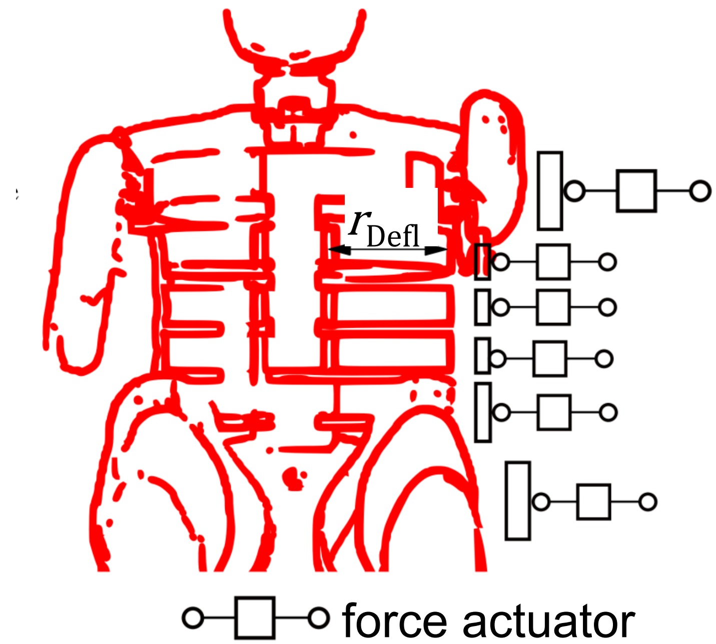
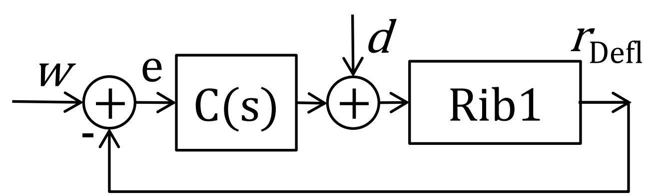
Design of Optimal Safety Systems

- design optimal safety system
  - for different models



- active approach
- online measurement of injury value
- e.g. injury value r_{Defl} below/ above desired value $w \rightarrow e$ controller $C(s)$ increase/ decrease forces on thorax plate
- use control to find optimal energy distribution





- ***DEFINE_CURVE_FUNCTION** with **PIDCTL**
- **User Defined Function**

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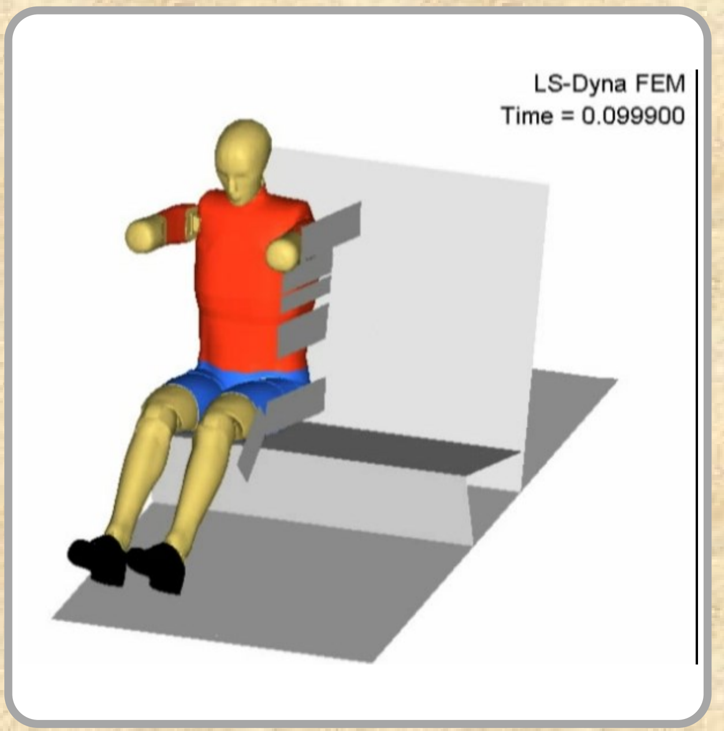
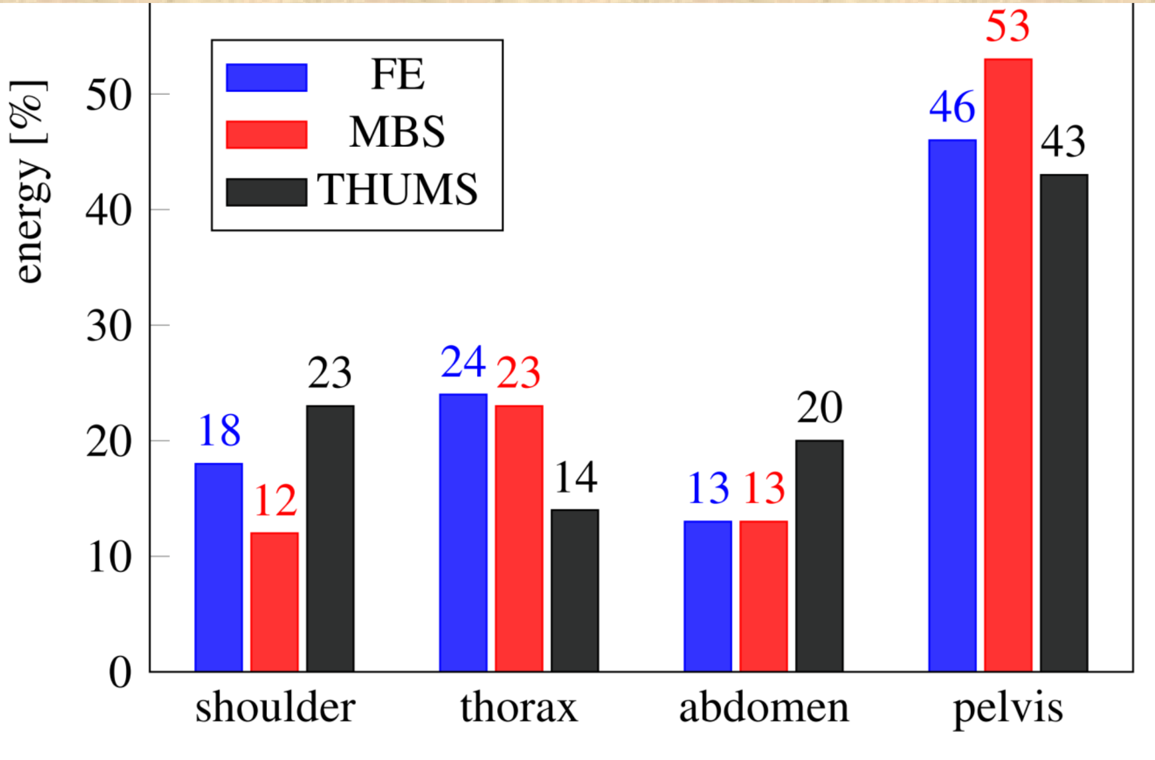
Comparison FE / MBS / THUMS

- most energy absorbed in pelvis
  - accordance to the human body
- large loads can be transmitted through the pelvis



- standard setup to compare different models
  - human body models
  - FE vs. MBS
  - **muscled vs. unmuscled**



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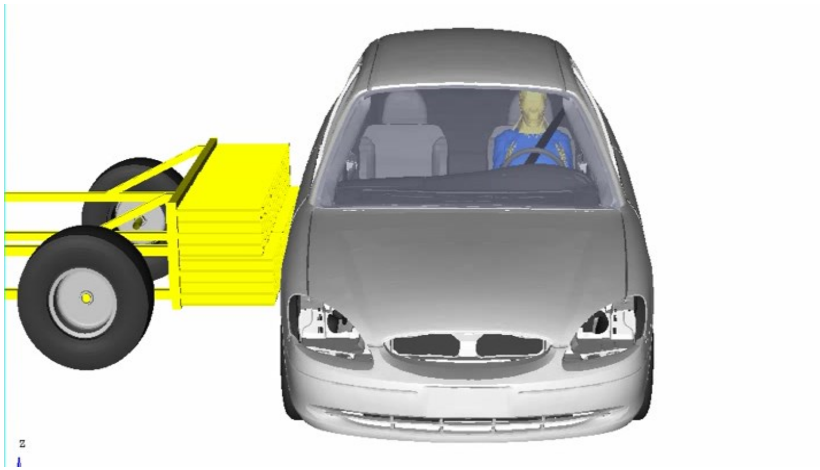
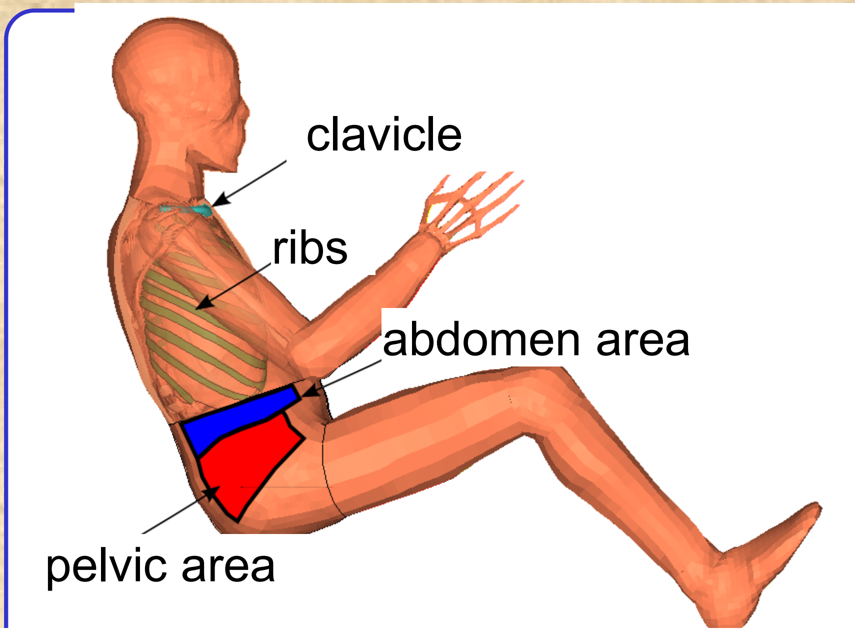
Lateral Safety Scenarios Student Projects

- Far-Side crash [Mack16]



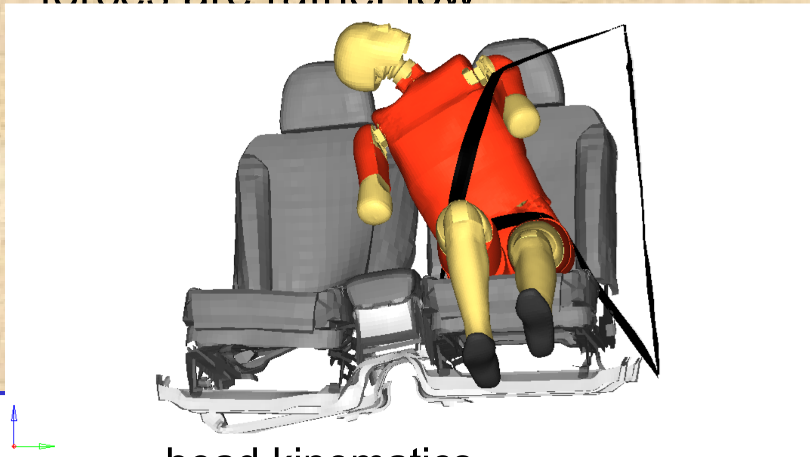
  - current safety devices have nearly no effect
- injury criteria for THUMS
  - head: acceleration
  - neck: tension and shear
  - shoulder: clavicle force
  - chest: deflection and VC
  - abdomen: outer force on abdominal area
  - pelvis: outer force on pelvic area

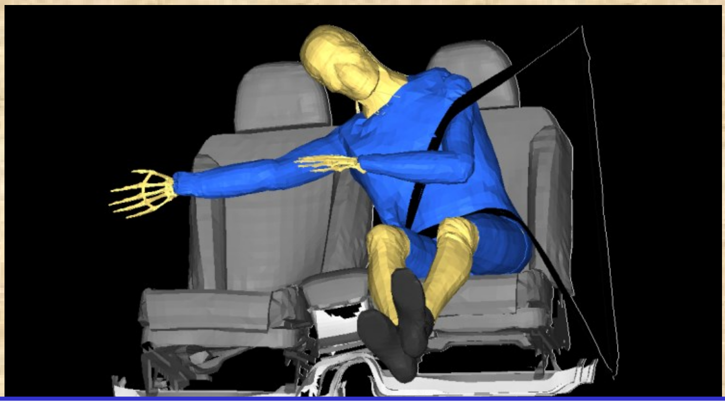


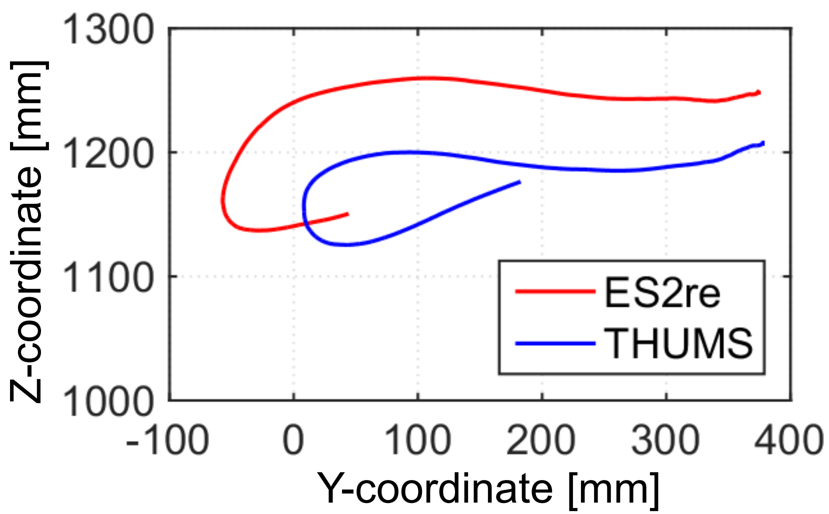
	Grenzwert		THUMS		2 THUMS	
	Oben	Unten	Mit	Ohne Gurt	Mit	Ohne Gurt
HIC15	700	500	5	3,1	41	3,5
a3ms [g]	80	72	10	10	18,1	8
Nackenscherkraft [kN]	1,1	-	0,22	0,11	0,14	0,22
Nackenzugkraft [kN]	1,1	-	-0,09	0,1	-0,063	-0,14
Schlüsselbeinkraft [kN]	1,48	-	0,44	-0,64	-0,33	-0,054
Rippeneindrückung [mm]	50	28	14	22	19,1	21
VC-Kriterium [$\frac{m}{s}$]	1	-	0,13	0,17	0,27	0,20
Abdomenkraft [kN]	3	-	0,9	0,69	0,93	0,62
Hüftkraft [kN]	2,8	1,7	1,4	0,8	1,11	0,58

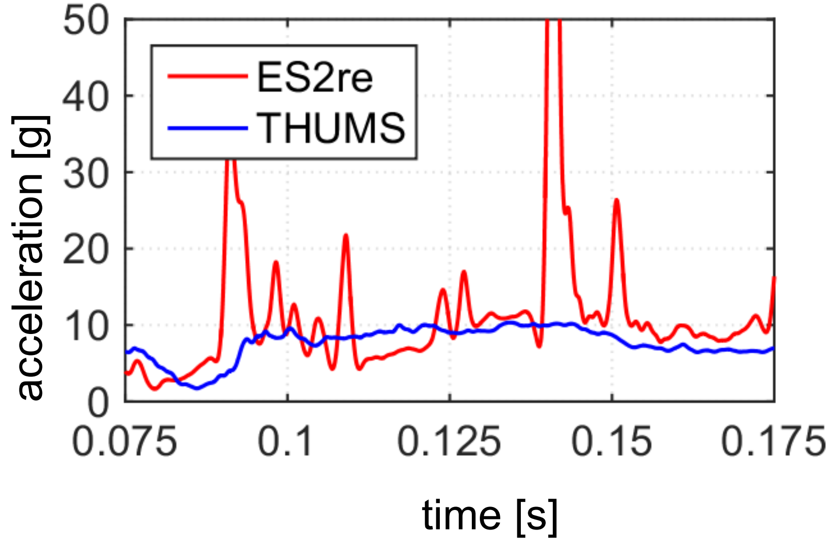
Comparison with Dummy

- kinematic comparison ES2re vs. THUMS
- forces are rather low



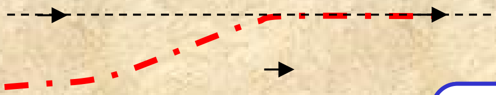




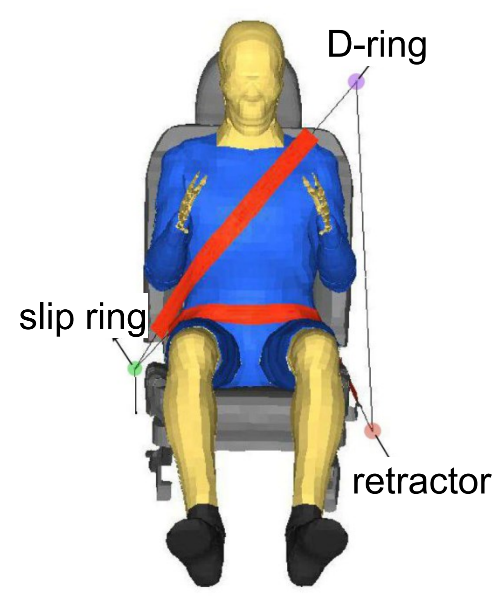


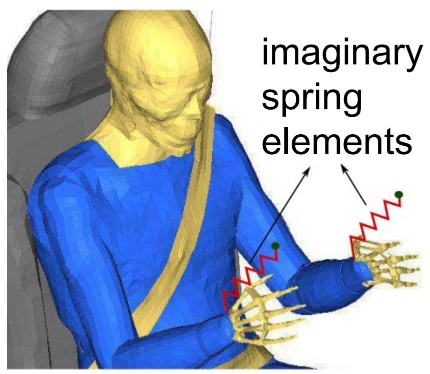
Lateral Safety Scenarios
Student Projects

- Far-Side crash [Mack16]
- single lane change [Rangarajan16]

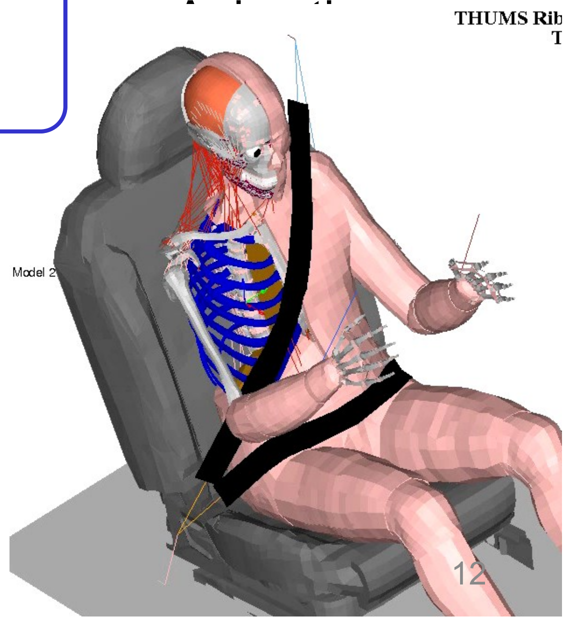


  - simplified model
  - seat + belt + HBM (THUMS)
  - **BOUNDARY_PRESCRIBED_MOTION_RIGID** seat rails
  - imaginary springs to prevent hands falling down





THUMS (Toyota)



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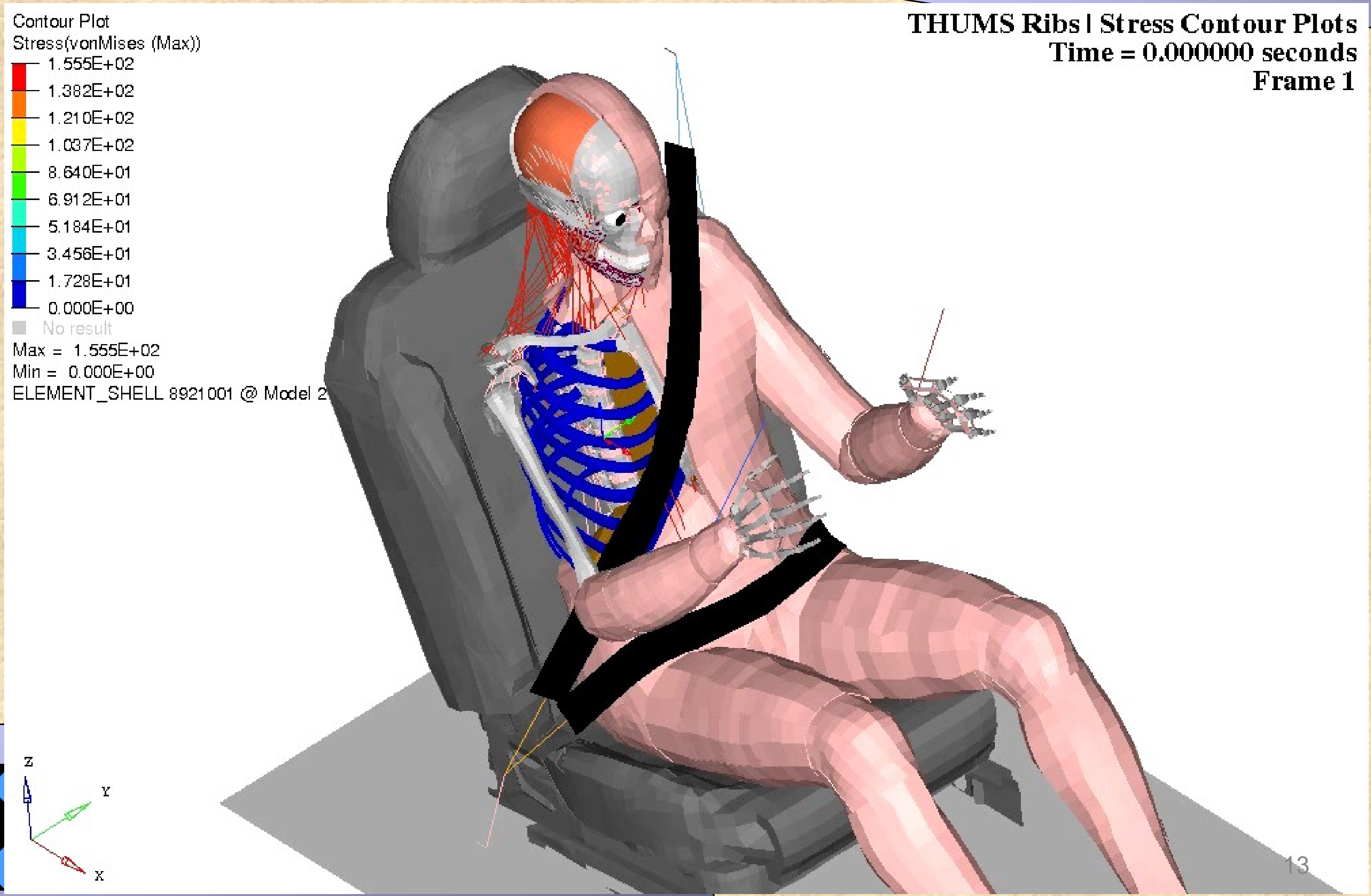
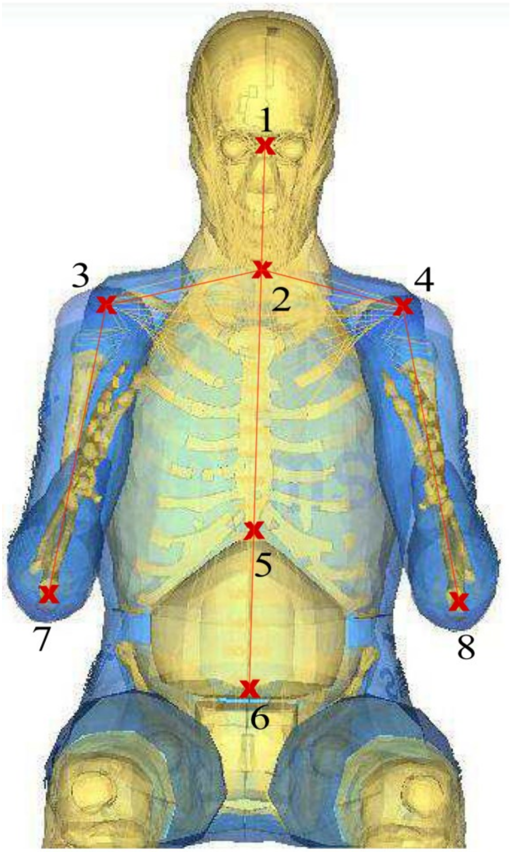
Single Lane Change Video

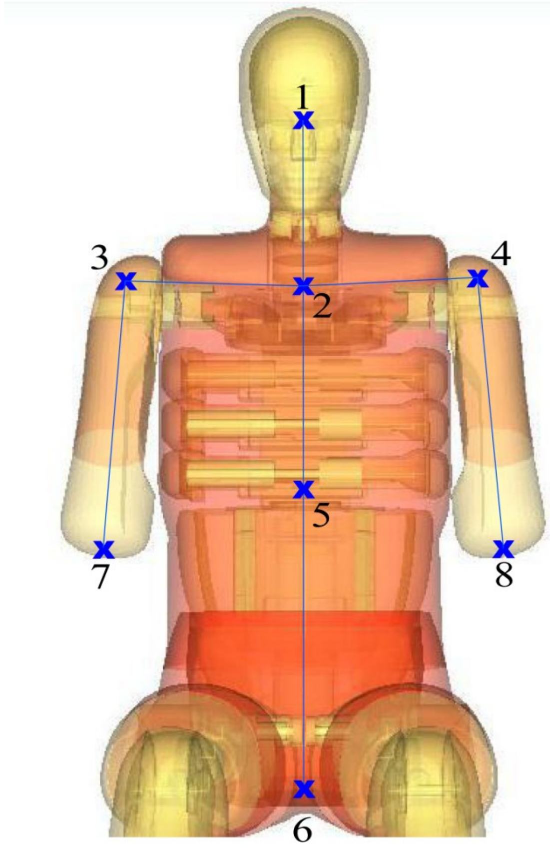


Kinematic Comparison

- THUMS



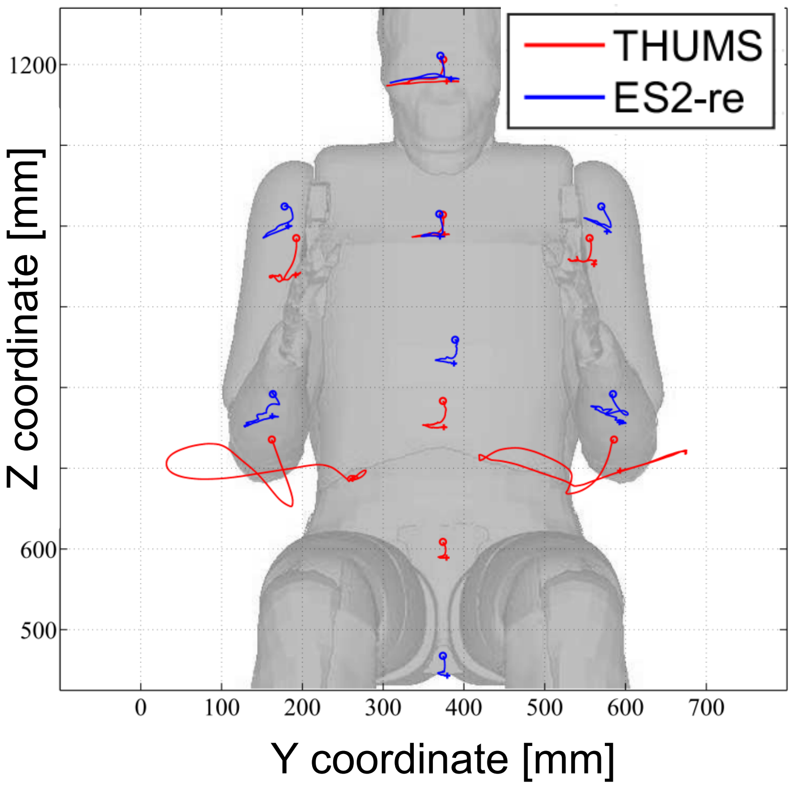
- ES2



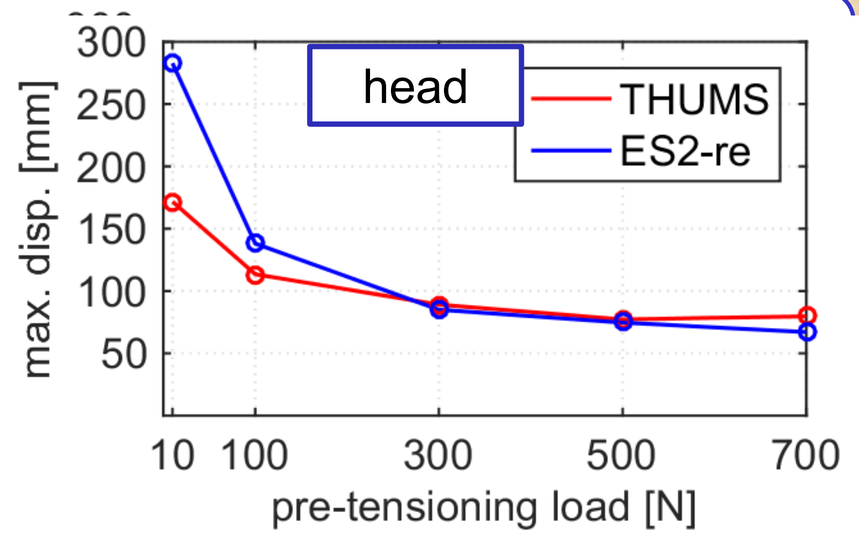
Results

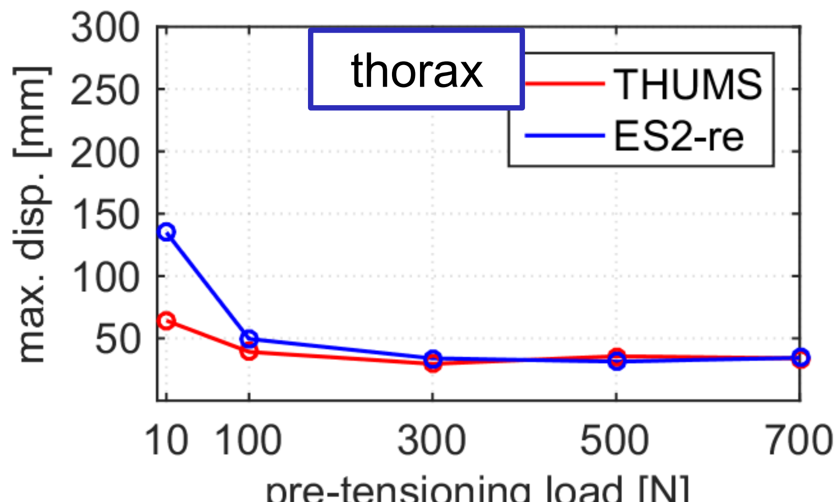
kinematic comparison

- pretensioner with 300 N



- without pretensioner difference between THUMS and ES2-re
- no muscle activation THUMS v3.0
  - comparison with AHBM
- low forces

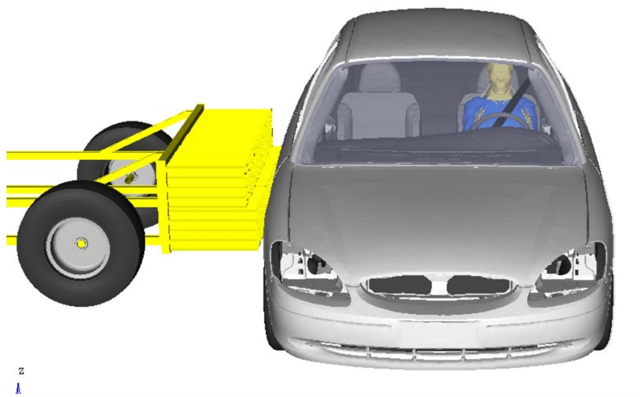




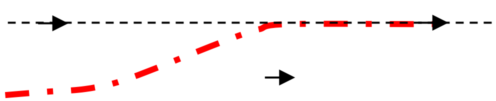
Inclusion of Muscle Activity

lateral safety scenarios
student projects

- Far-Side crash [Mack16]



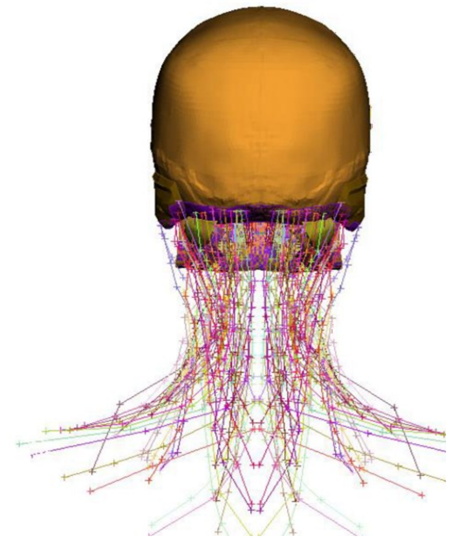
- lane change [Rangarajan16]



- pre-activation of safety devices
  - larger time horizon
  - lower forces

GHBMC model

- 54 neck muscles are modeled as 1D MAT156 elements
- effects of mu length and c raction veloc included



- physiological activation dynamics are not present in any commercial model
- collaboration Syn Schmitts group

Inclusion Muscles Activation via Reflex

- muscle reflex activation

WHEN

sense changes in length

HOW

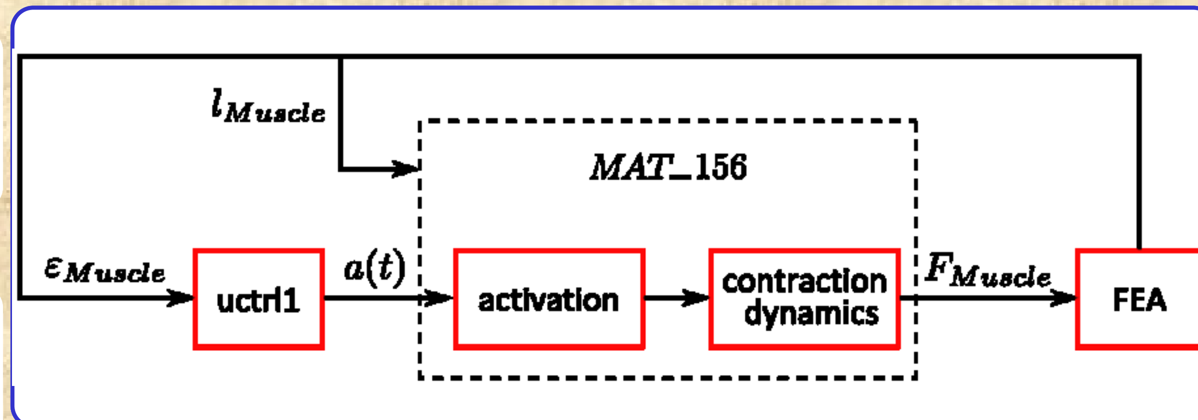
signal to activate the muscle

WHAT

muscle Contraction

observe changes in head motion

- implementation via uctrl- subrotine



- compute muscle activation after strain threshold & initial time delay have been surpassed

$$\frac{da}{dt} = \frac{u-a}{\tau(a,u)}$$

$$\tau(a,u) = \begin{cases} t_{act}(0.5+1.5a) & u > a \\ \frac{t_{deact}}{0.5+1.5a} & u \leq a \end{cases}$$

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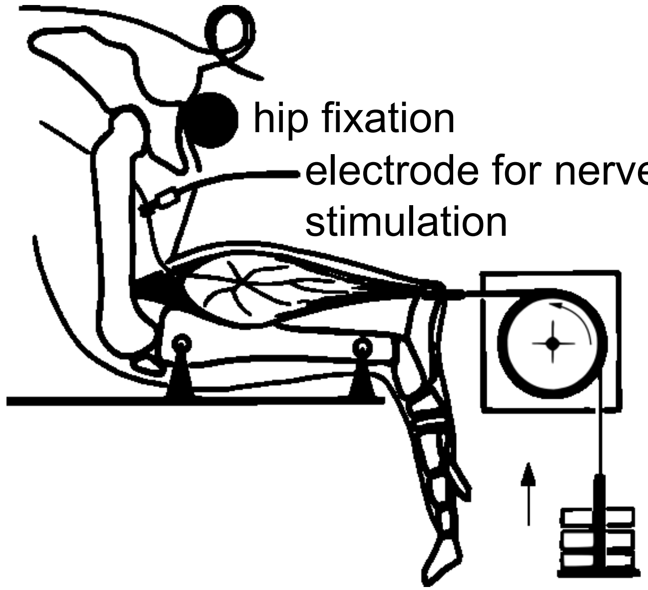
Inclusion of Muscles

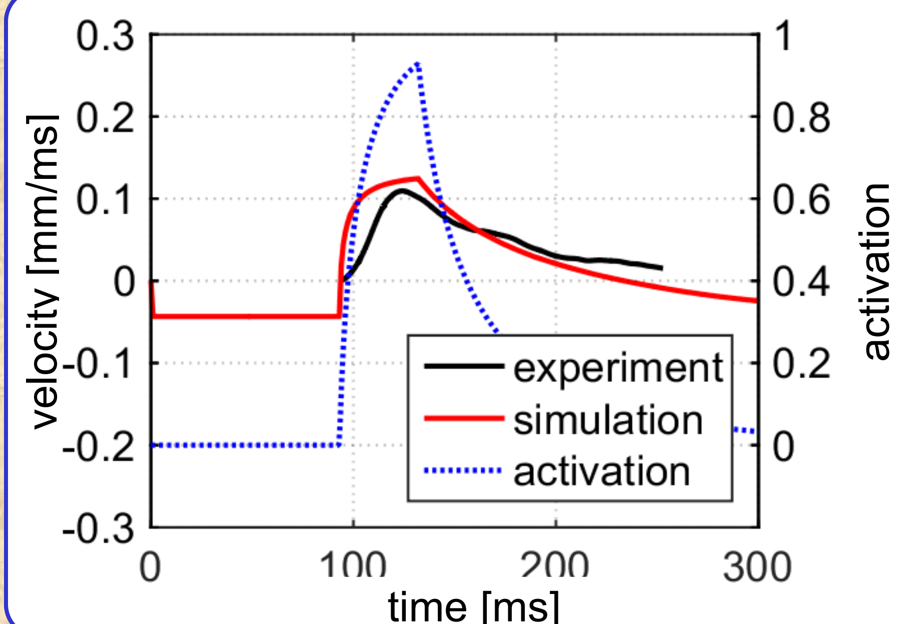
component level validation

- concentric contraction of a piglet muscle



- experimental results from [GüntherSchmittWank07]

- 100 gram lift off
- activation based on strain rate



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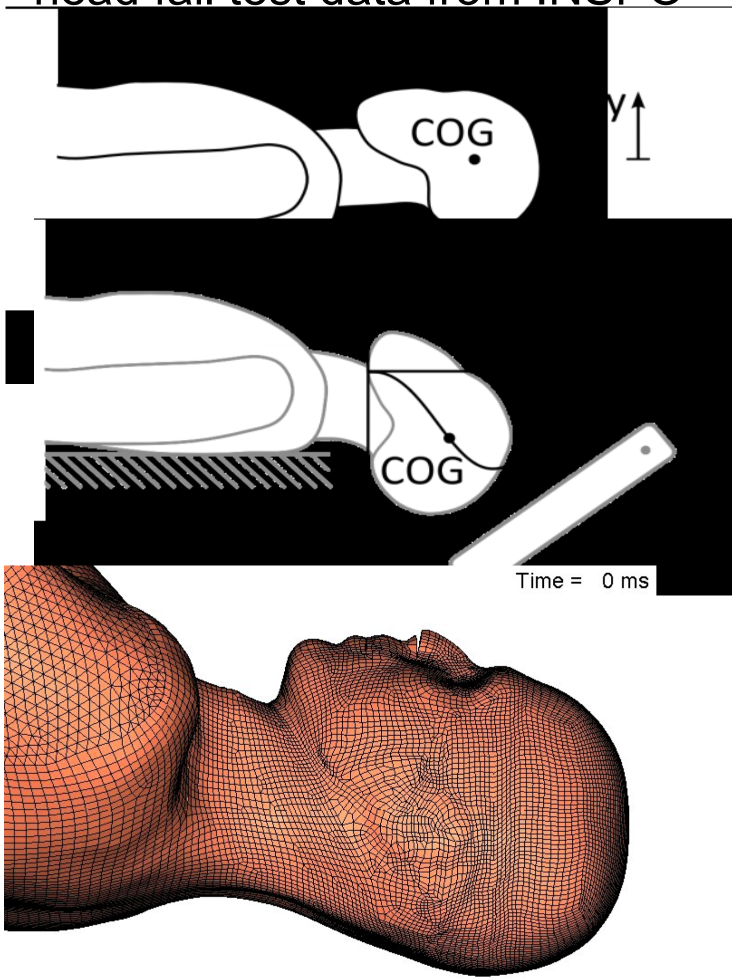
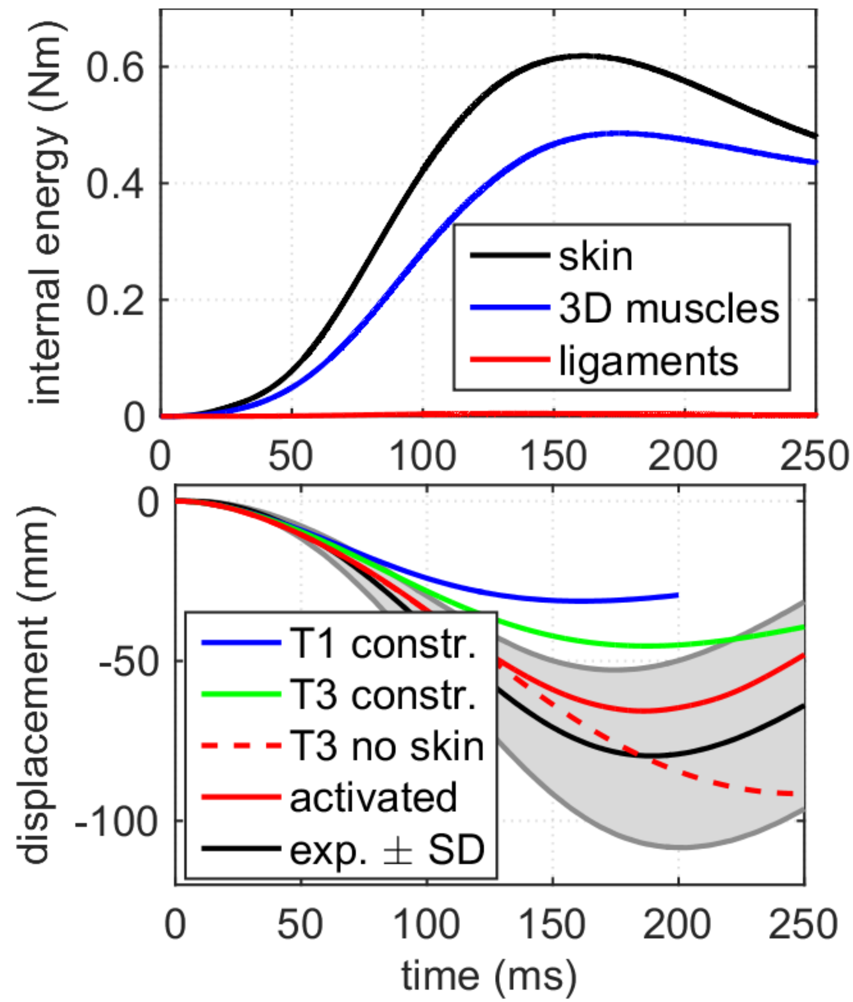
Inclusion of Muscles [FellerEtAl16]

- head fall test data from INSPO



- GHBMC neck to stiff
  - skin removal based energy



- influence of muscle activation can clearly been seen

Summary

human body models

- side impact scenarios
- optimal human body model
- generic side impact setup with active controlled plates
  - compare different models based on energy consumption
  - valid approach to compare models in different software
- muscle inclusion necessary for active safety questions
- GHBMC model
  - neck to stiff for low impact applications
  - muscle activation based on strain rate

challenges and current topics

- further investigations with standard setup
  - muscle vs. unmuscled
- SimTech muscle model
- combine advantage of FE and MBS via model order reduction ➔ EMBS

Compare different human models for crash analysis

hierarchical approach

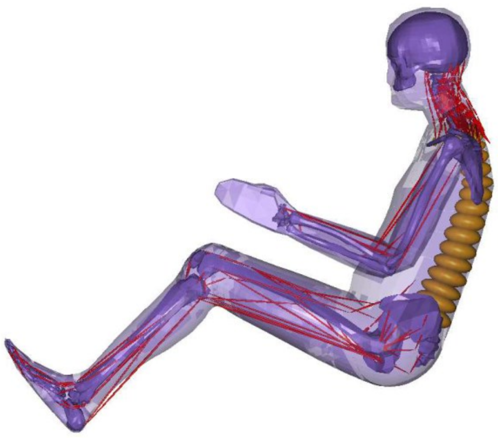
Efficient Crash Simulations

THUMS by Toyota

- detailed FE-Model of the human body
- **good biofidelity**
  - compared Thums with ES2 in side impact scenarios
  - identify body parts prone to severe injury ➔ ribcage

Human Model by TNO (Madymo)

- run-time efficient MBS-Model
- increase biofidelity by integrating **reduced elastic bodies**
- enhance applicability also for **Active Safety Systems**
- **pre crash with EMBS**



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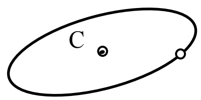
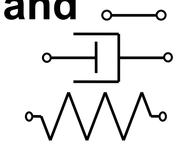
Model Order Reduction in EMBS

components of multibody system

rigid body

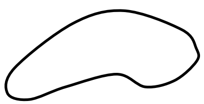


bearings and coupling elements

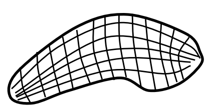


elastic body

continuum



discretization



elastic multibody system

MOREMBS

MatMorembs

Morembs++

floating frame of reference approach: linear elastic deformations

ODE with elastic degrees of freedom $\boldsymbol{q}$ is approximated via projection $\boldsymbol{q} \approx \mathrm{V} \cdot \bar{\boldsymbol{q}}$

$$\underbrace{\mathrm{V}^T \cdot \mathrm{M} \cdot \mathrm{V}}_{\bar{\mathrm{M}}} \cdot \ddot{\bar{\boldsymbol{q}}}(t) + \underbrace{\mathrm{V}^T \cdot \mathrm{D} \cdot \mathrm{V}}_{\bar{\mathrm{D}}} \cdot \dot{\bar{\boldsymbol{q}}}(t) + \underbrace{\mathrm{V}^T \cdot \mathrm{K} \cdot \mathrm{V}}_{\bar{\mathrm{K}}} \cdot \bar{\boldsymbol{q}}(t) = \underbrace{\mathrm{V}^T \cdot \mathrm{B}}_{\bar{\mathrm{B}}} \cdot \boldsymbol{u}(t) + \underbrace{\mathrm{V}^T \cdot \epsilon(t)}_{=0}$$

$$\boldsymbol{y}(t) = \underbrace{\mathrm{C} \cdot \mathrm{V}}_{\bar{\mathrm{C}}} \cdot \bar{\boldsymbol{q}}(t)$$

$\mathrm{M}, \mathrm{D}, \mathrm{K} \in \mathbb{R}^{N \times N}$

$\bar{\mathrm{M}}, \bar{\mathrm{D}}, \bar{\mathrm{K}} \in \mathbb{R}^{n \times n}$

$n \ll N$

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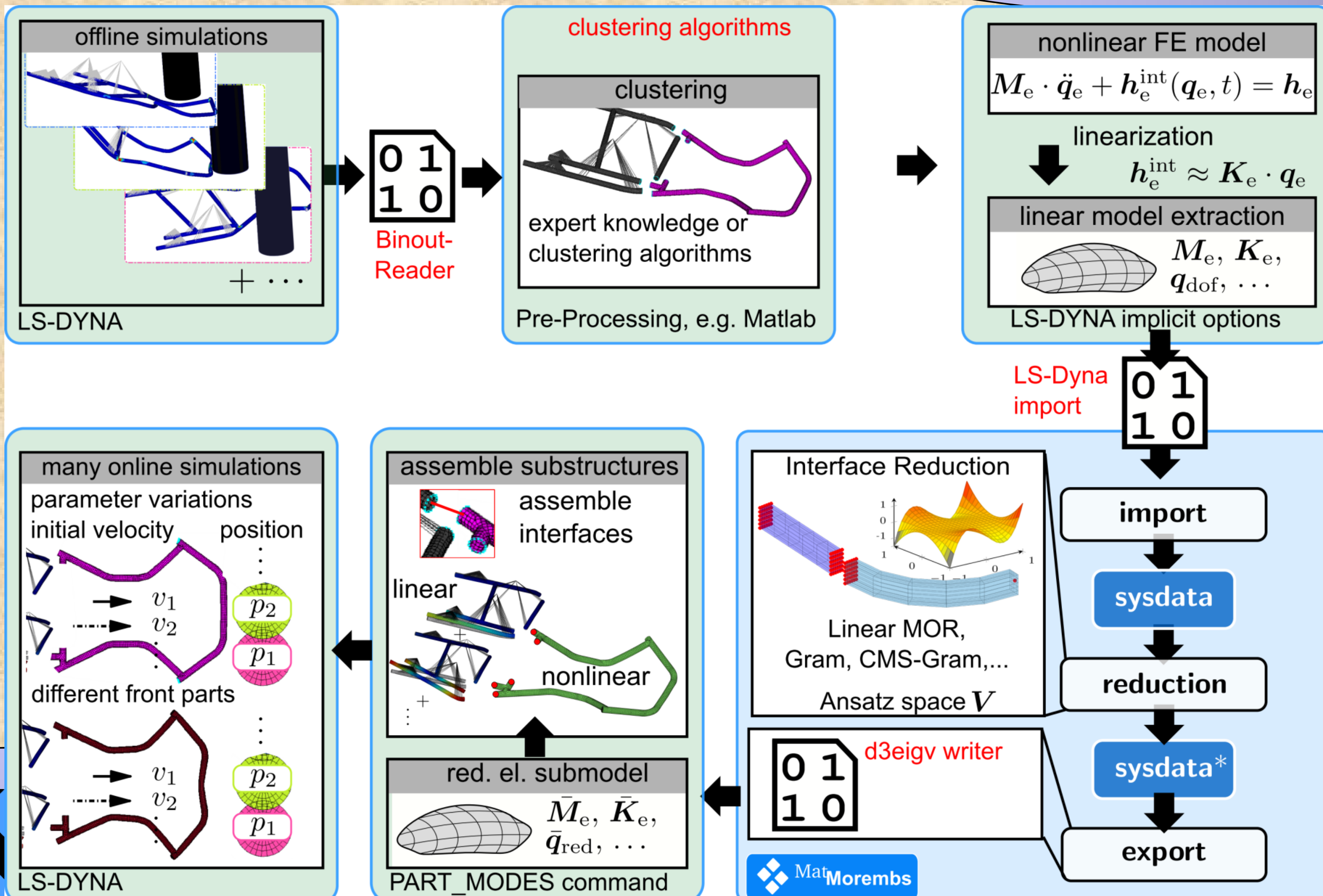
MOR Workflow



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lessons learned

- MBS and FEM both suited for safety development depending on research question
- combination of different disciplines

thank you for your attention

Literature

[FehrKleinbach15] Fehr, J.; Kleinbach, C.: A Comparison between Finite Element Models and MBS Models in Automotive Safety Applications. In Proceedings of the ECCOMAS Thematic Conference on Multibody Dynamics, Barcelona, Spain, 2015.

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