Anatomy of Finite Element Analysis *in* Biomechanics

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Satellite Meeting on
Overview and Use of Standards and Formats Relevant to MSM
2015 MSM Consortium Meeting

PRESENTATION GOALS

- To provide an overview of a **common workflow** for finite element analysis (FEA) in biomechanics

- To establish an understanding of the **components** of the FEA workflow

  raw/derivative data – submodels - ...

- To illustrate **technologies** to assist the FEA workflow

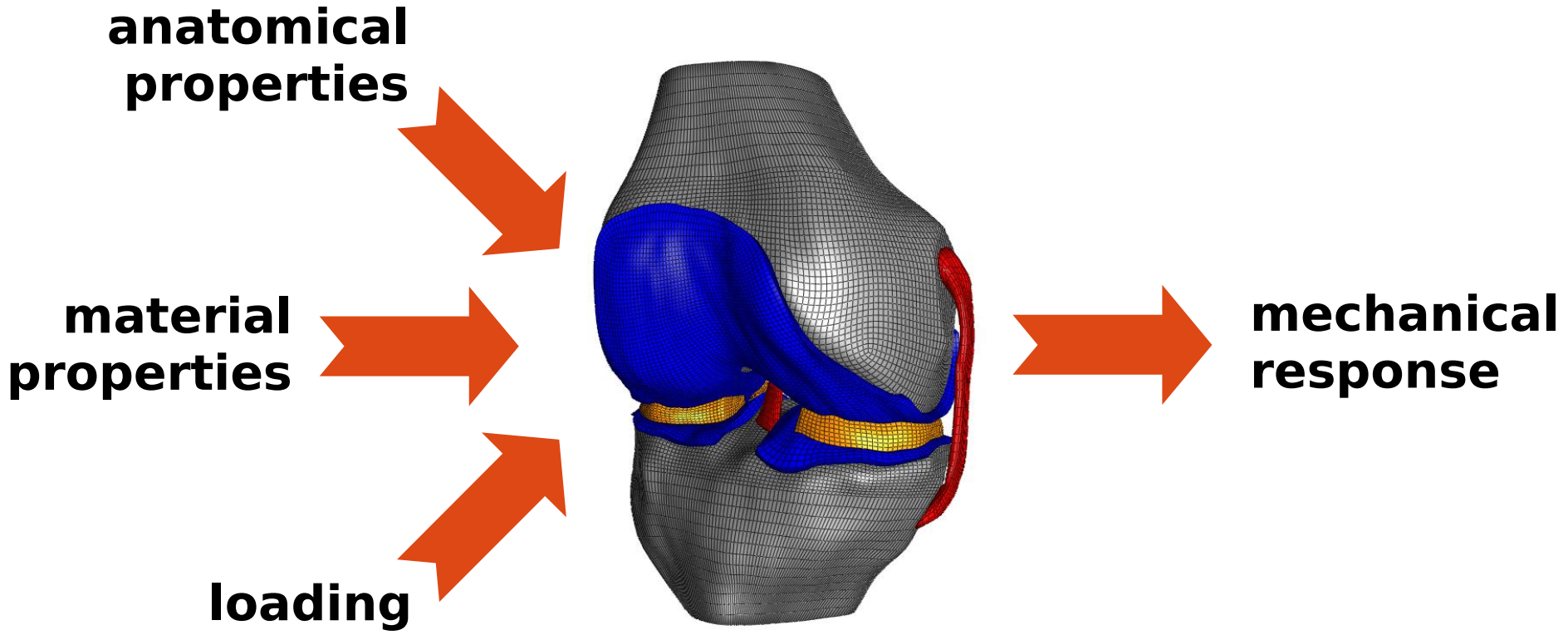
  formats/standards - markup languages

  simulation software – auxiliary software

  computing strategies – repositories

  ...

PREMISE OF FEA



POPULARITY OF FEA

PubMed | "finite element" | Search

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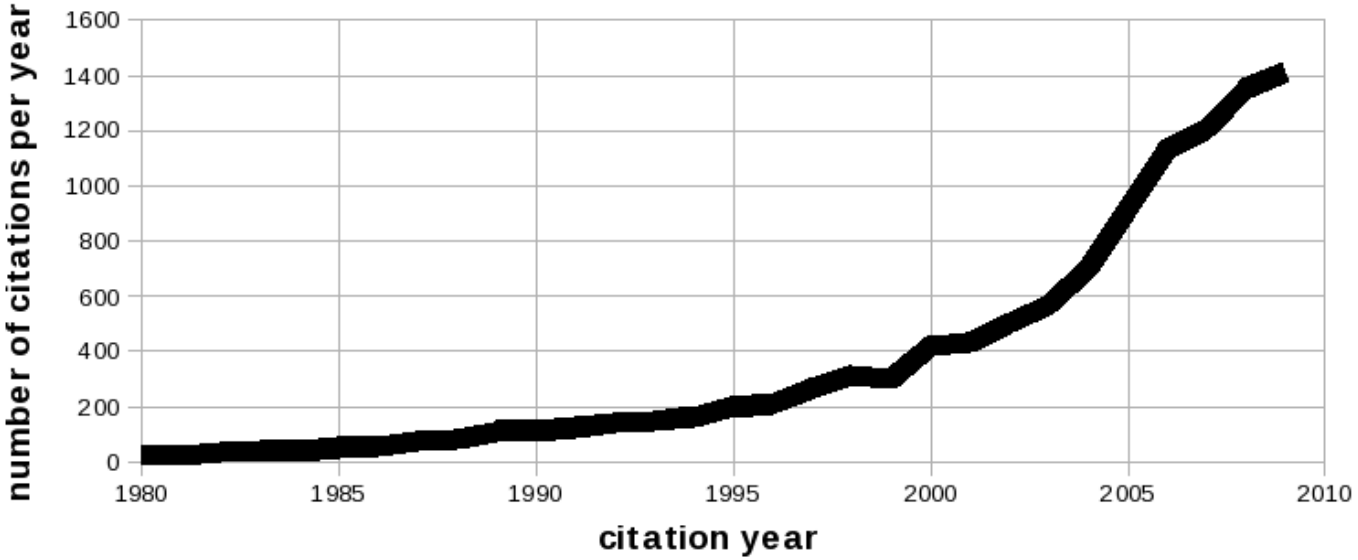
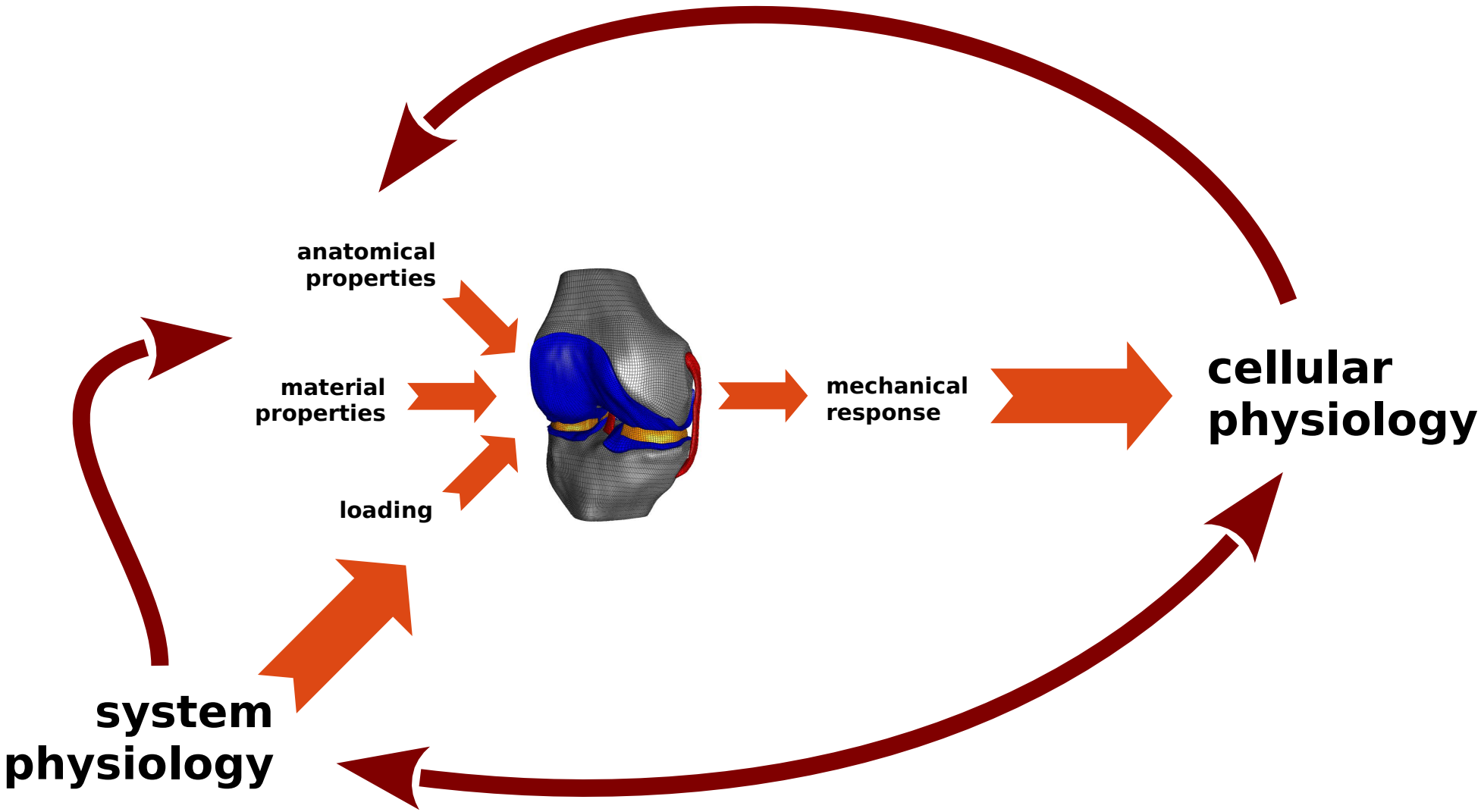
(as of Sep 7, 2015)



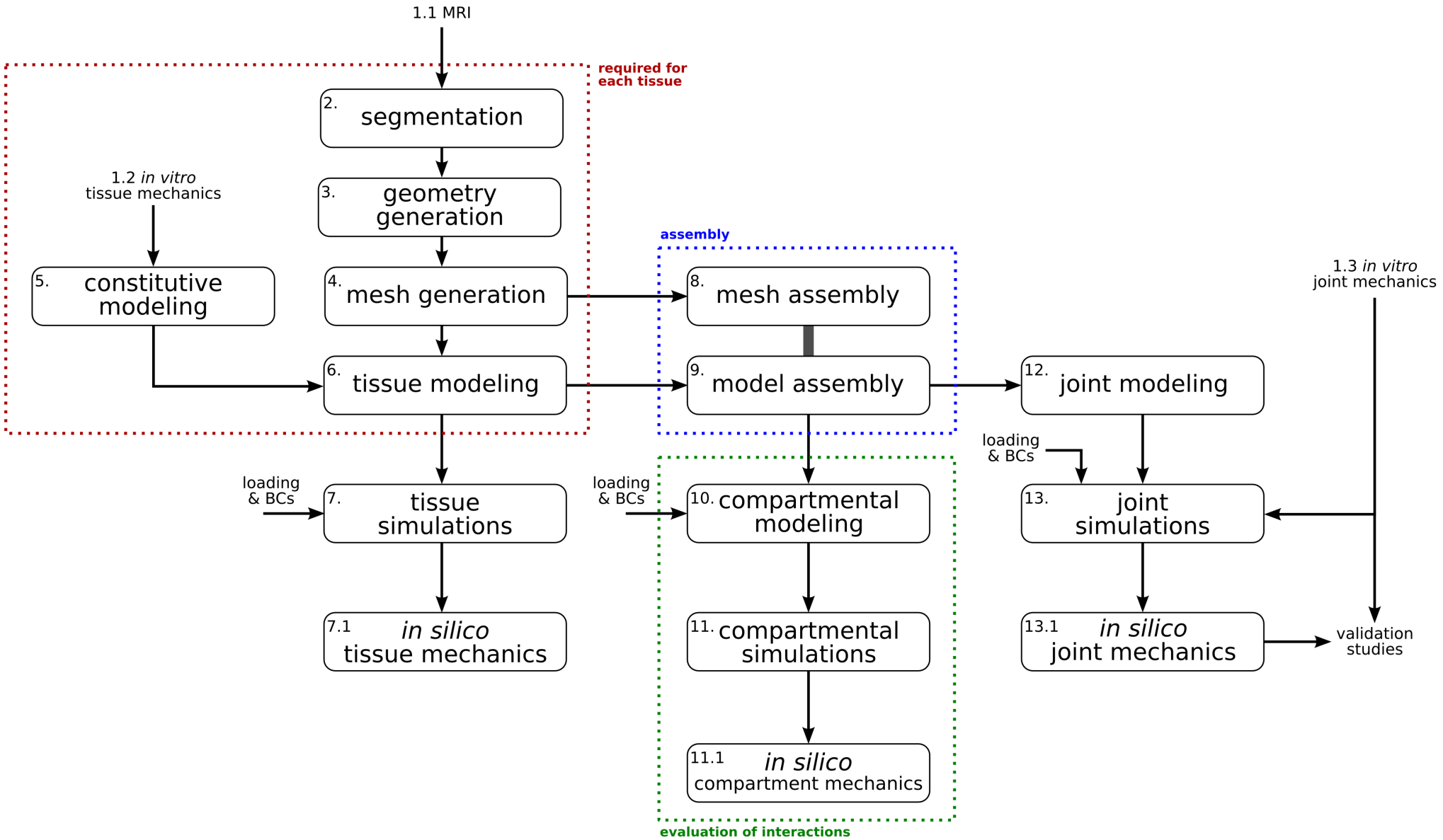
FINITE ELEMENT ANALYSIS IN MEDICINE

adapted from Erdemir et al. (2012)

FEA IN MULTISCALE M&S

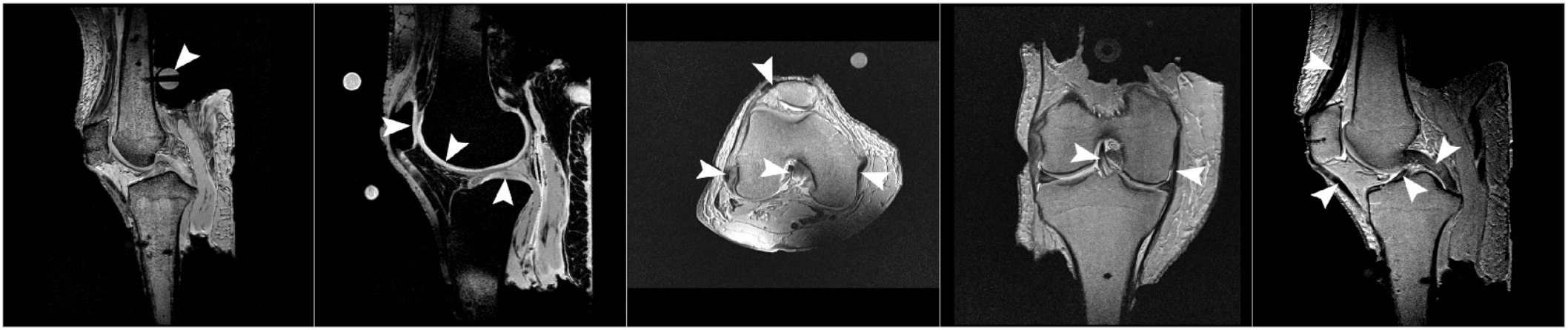


COMMON FEA WORKFLOW



Adapted from Open Knee(s), refer to ***http://wiki.simtk.org/openknee/Specifications*****.**

DATA: ANATOMY



Modalities

magnetic resonance imaging
computed tomography
various microscopy

Formats/Standards

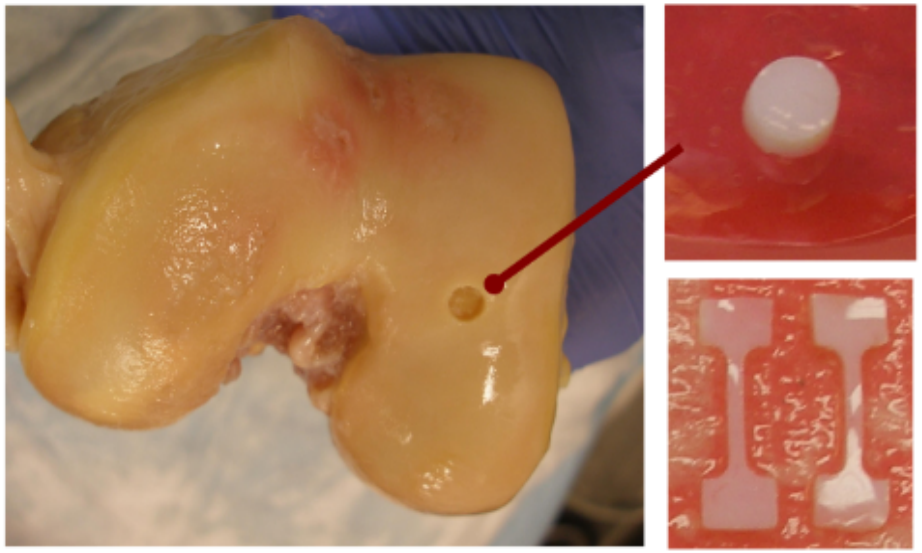
DICOM
Digital Imaging and Communications in Medicine

NIfTI
Neuroimaging Informatics Technology Initiative

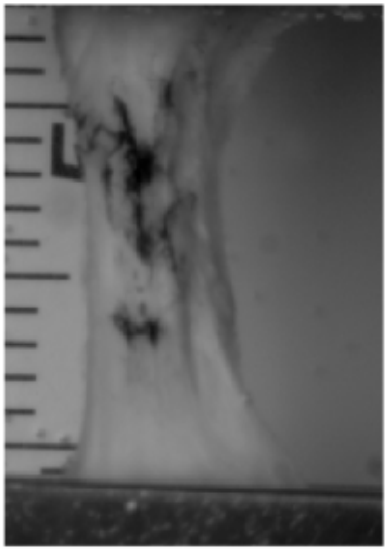
various image formats

DATA: PHYSIOLOGY

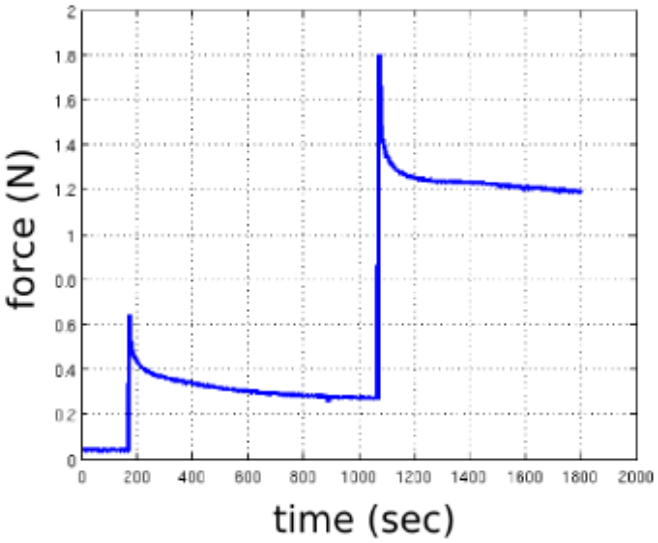
Tissue Sampling



Uniaxial Testing



Stress Relaxation



Modalities testing of isolated tissue samples
in situ testing + inverse analysis
imaging based estimation

Formats/Standards various text formats

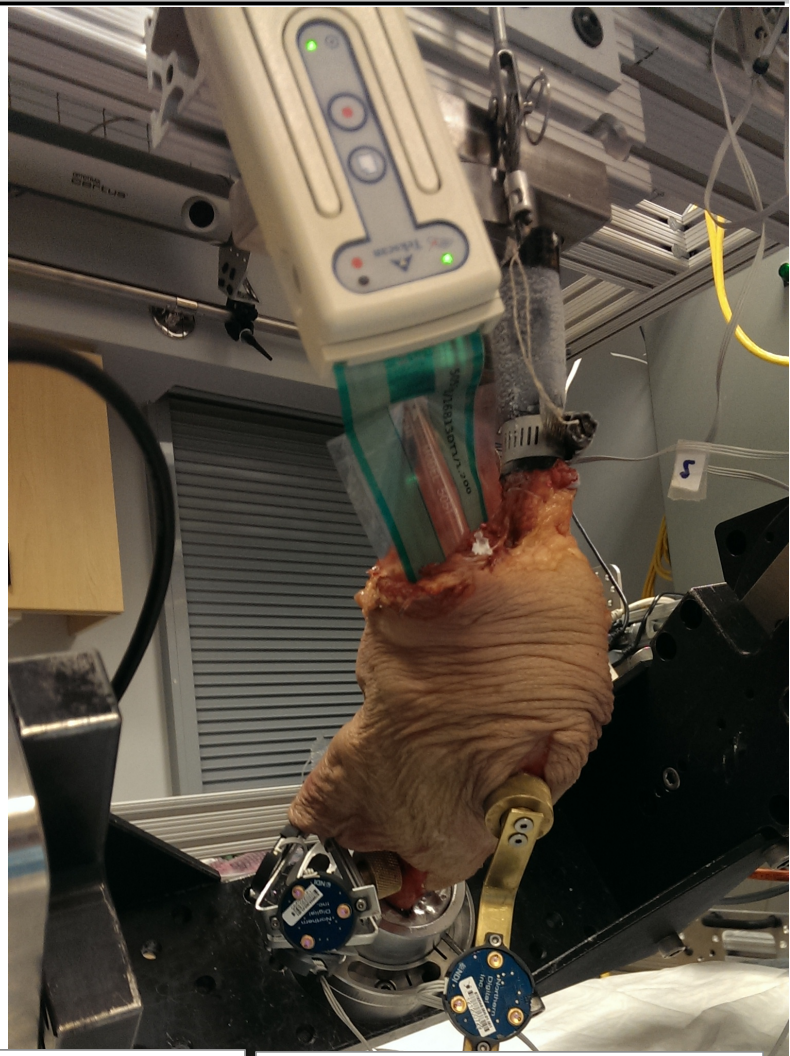
DATA: LOADING

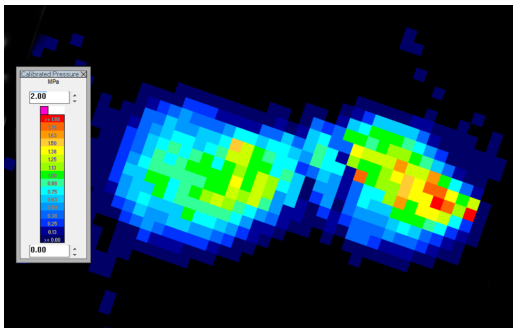
Modalities

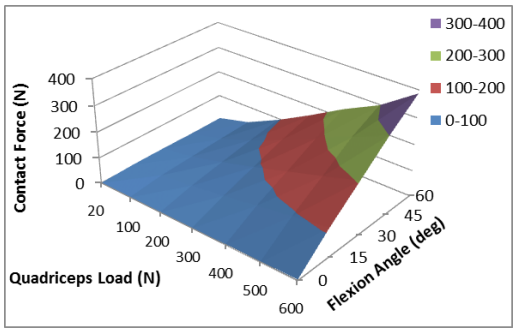
in vitro testing
in vivo testing
model based estimation

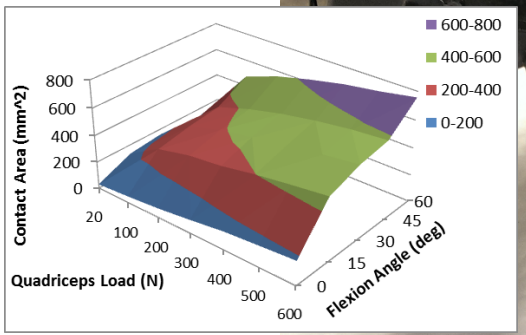
Formats/Standards

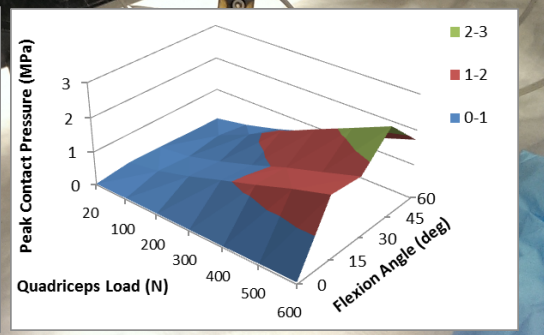
various binary formats
various text formats



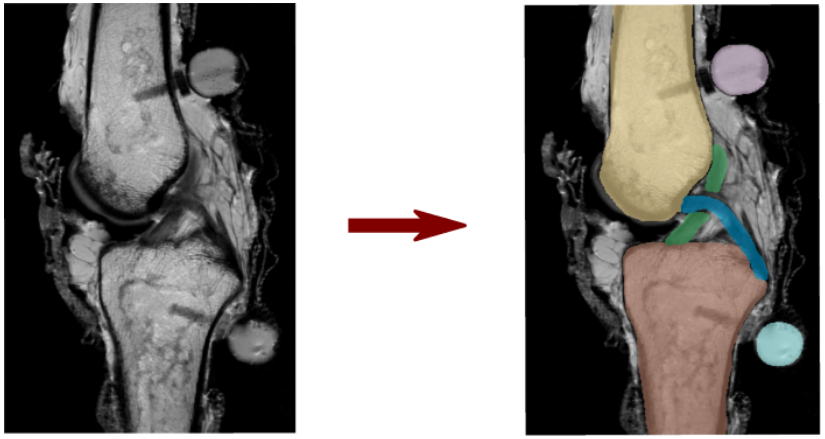
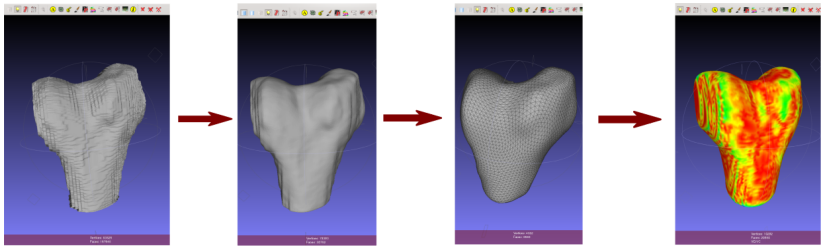
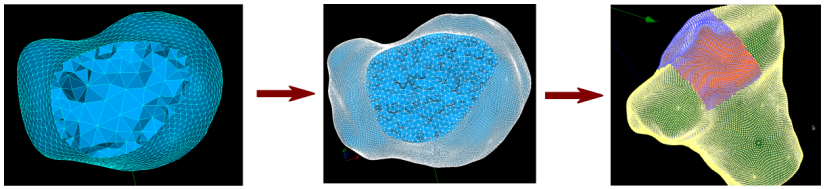




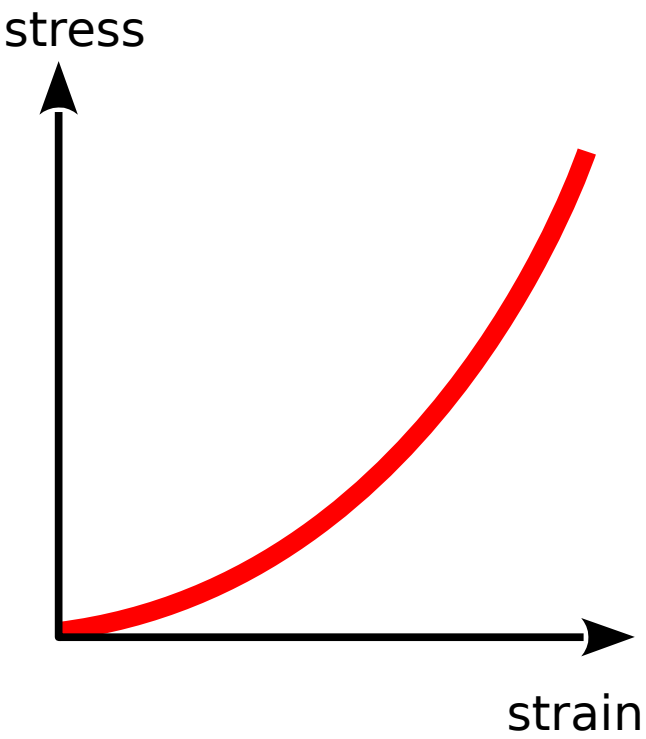




PRE-PROCESSING: GEOMETRY

	DERIVATIVE DATA	FORMATS & STANDARDS	SOFTWARE
SEGMENTATION 	tissue volume *voxel-based*	DICOM NifTI various IMG	FOSS *3D Slicer* *ITK-SNAP* commercial *Mimics* *Simpleware*
GEOMETRY GENERATION 	surface geometry *parametric or explicit*	STL IGES STEP	FOSS *MeshLab* *SALOME* commercial *various CAD*
MESH GENERATION 	volume mesh *nodes* *elements* *sets*	various TXT various XML various HDF	FOSS *Netgen* *IA-FEMesh* commercial *various FEA* *TrueGrid*

PRE-PROCESSING: MATERIAL PROPERTIES



CONSTITUTIVE MODELING

$$W = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i} \left(\overline{\lambda_1^{\alpha_i}} + \overline{\lambda_2^{\alpha_i}} + \overline{\lambda_3^{\alpha_i}} - 3 \right) \rightarrow \mu_i , \alpha_i$$

DERIVATIVE DATA

stress-strain data
constitutive coefficients

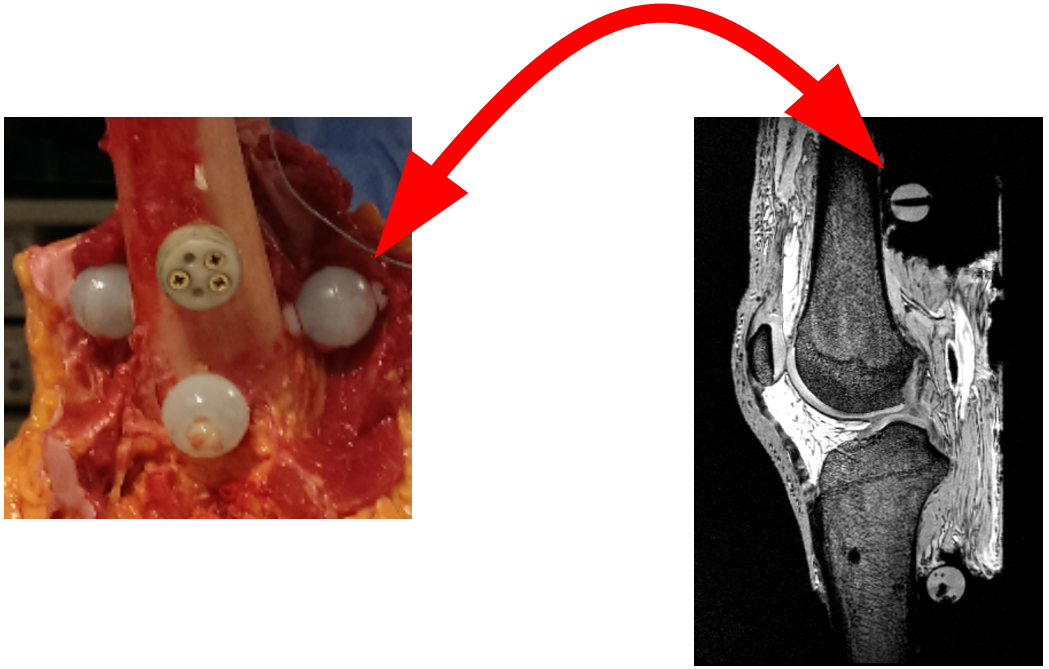
FORMATS & STANDARDS

various TXT
coefficients in publications

SOFTWARE

various for data fitting
scripting languages

PRE-PROCESSING: LOADING & BCS



- Representation of loading time history in a usable manner
- Spatial registration of anatomy and loading
- Establishment of reference states
- May require other modeling strategies

DERIVATIVE DATA

load time history
boundary condition descriptions

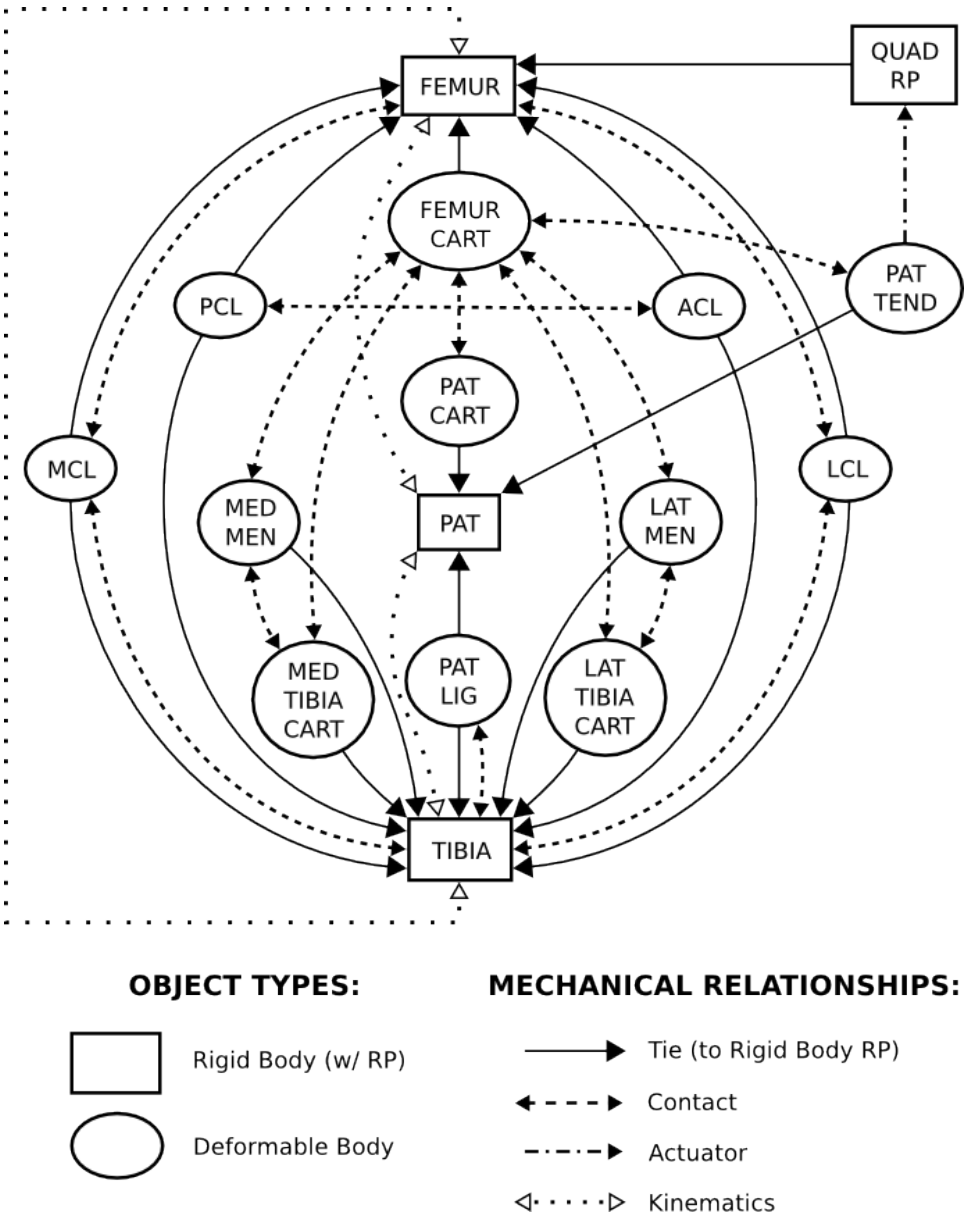
FORMATS & STANDARDS

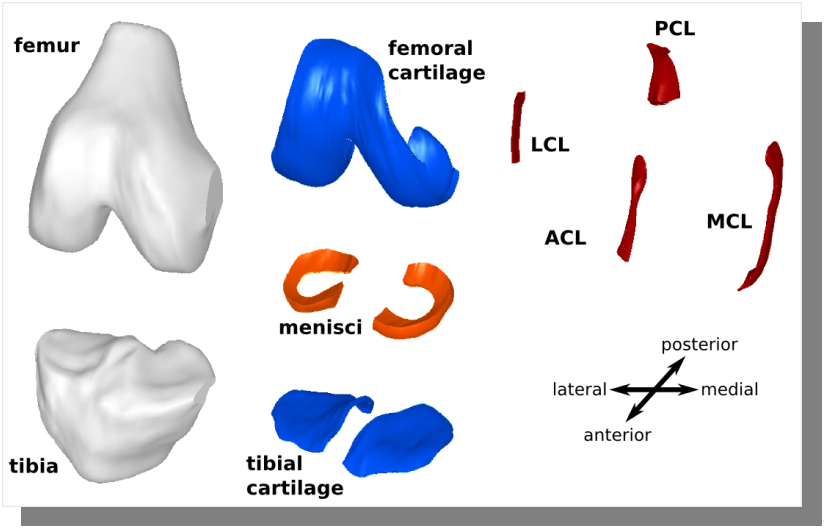
various TXT
publications

SOFTWARE

scripting languages
other M&S musculoskeletal systems models

PRE-PROCESSING: ASSEMBLY





- Representation of whole model
- Customization to swap components
- Compartmental modeling

MODEL FORMAT

Specific to simulation software

Model definition → mesh
material properties
loading & BCs

TEXT FORMATS

Abaqus (.inp)
etc.

XML FORMATS

FEBio (.feb)
FieldML (.fml)
etc.

BINARY FORMATS

Abaqus (.cae)
etc.

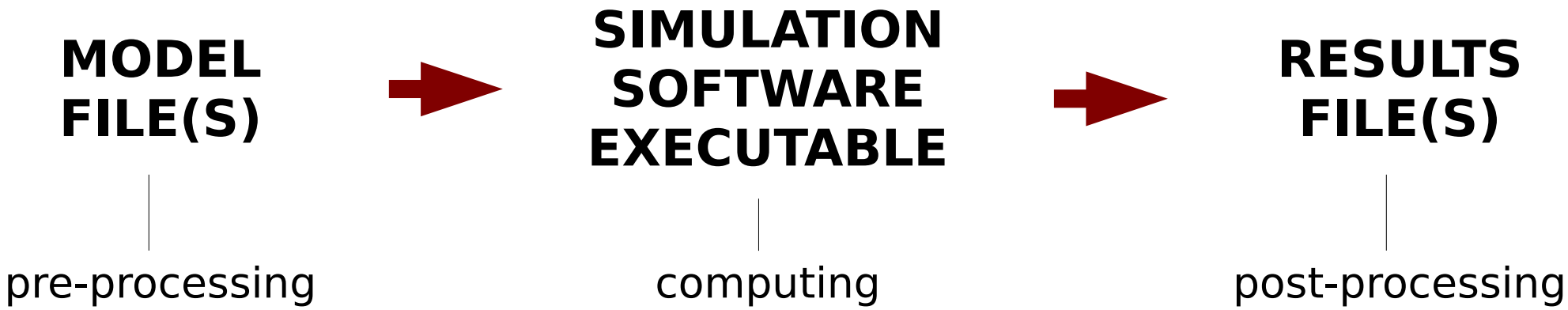
MIXED FORMATS

COMSOL
FieldML
Code Aster
(mesh as binary)

SCRIPT FORMATS

Code Aster
(Python)

SIMULATION PROCESS




```
erdemir@ae-ultrabook:~$ febio2.lnx64 -i tf_joint_FEBio_v2.feb
```

SIMULATION SOFTWARE

- Commonly imported from manufacturing industry
- Commonly designed for the analysis of man made structures with a handful of recent exceptions
- Choice of simulation software highly depends on software capabilities, features, and cost

COMMERCIAL	ACADEMIC FREE	FREE & OPEN SOURCE
Abaqus COMSOL etc.	FEBio Continuity 6 etc.	Code Aster OpenCMISS etc.

For a comprehensive list of FEA software, refer to ***https://en.wikipedia.org/wiki/List_of_finite_element_software_packages***.

COMPUTING

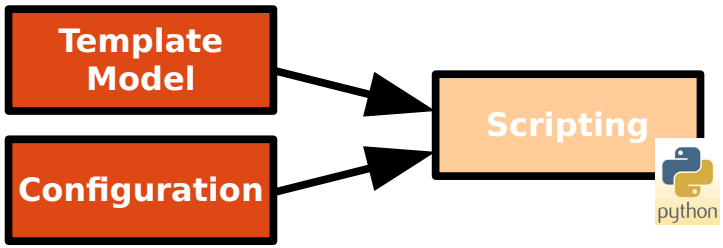
Venues

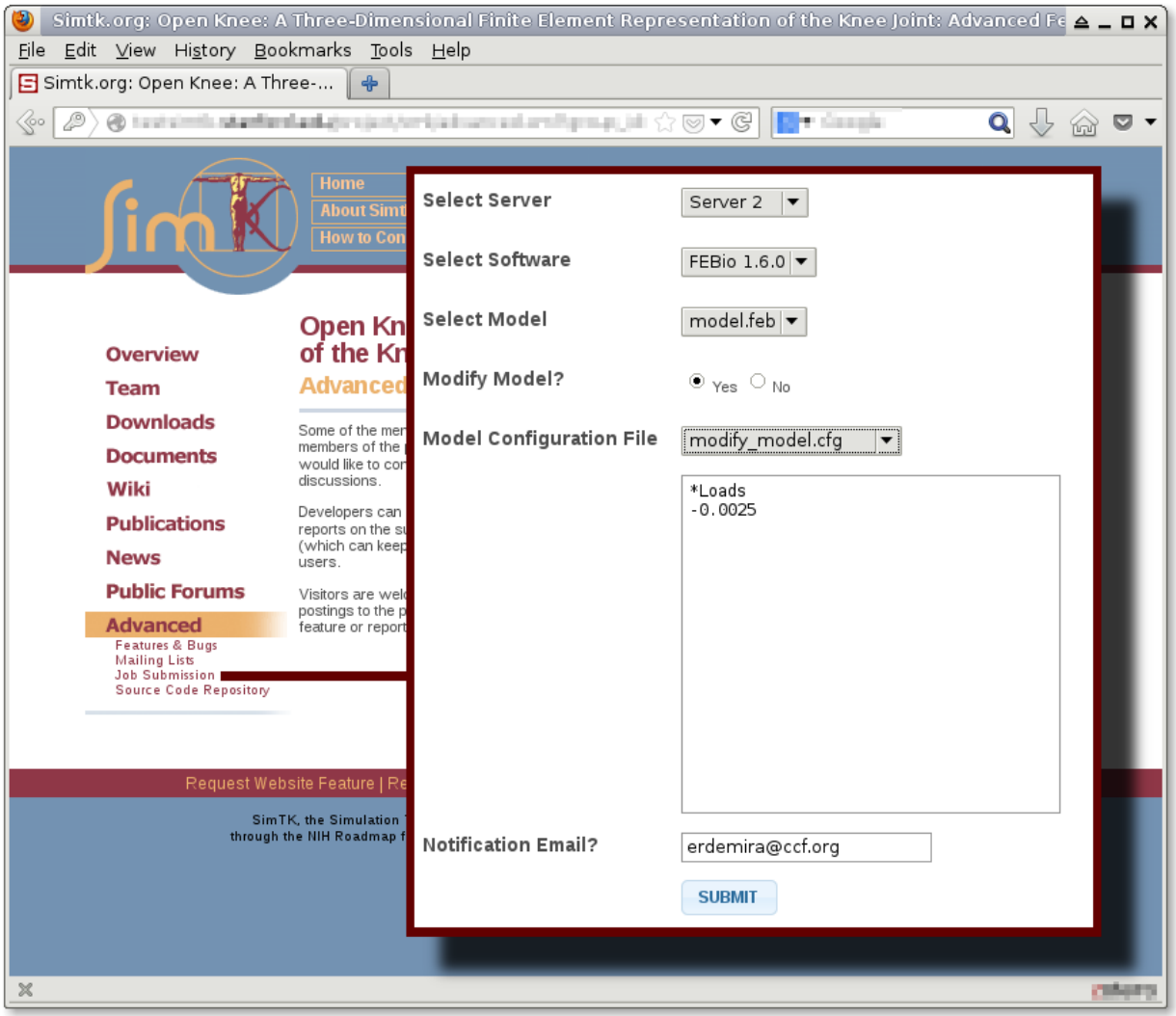
High performance computing
- XSEDE (academic)
- GPGPU

Cloud computing
- simtk.org (coming soon)
- Galaxy
- rescale (commercial)

Issues

Workflow automation
Incompatible licensing





Adapted from Open Knee(s), refer to ***https://simtk.org/home/openknee*****.**

POST-PROCESSING

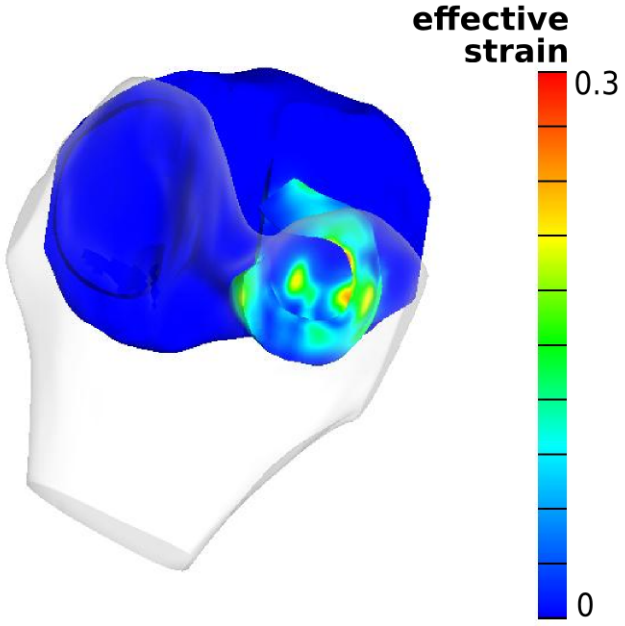
- Visualization (qualitative)
- Extraction of biomechanical markers (quantitative)
- Critical step for appropriate interpretation & evaluation

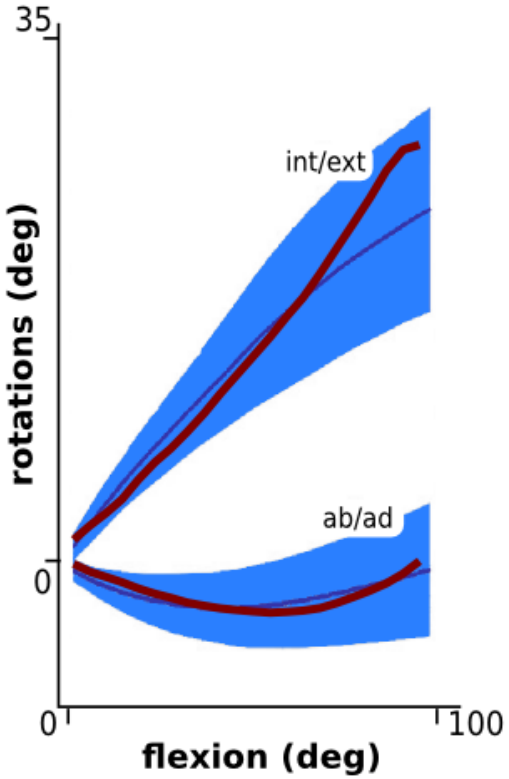
FORMATS

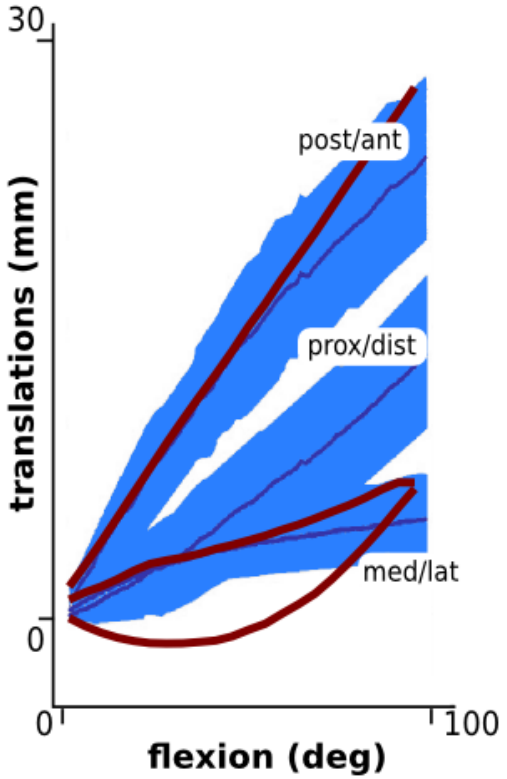
various TXT
various binary

SOFTWARE

various visualization
Python







REPORTING

Good reporting practice

clarifies uncertainty of **reproducibility**,
promotes **reusability**, and
establishes **accountability**.

→ **CONFIDENCE IN MODELING & SIMULATION**

Journal of Biomechanics 45 (2012) 625–633

Contents lists available at SciVerse ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Perspective article

Considerations for reporting finite element analysis studies in biomechanics

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[e] Center for Devices and Radiological Health, Food and Drug Administration, Silver Spring, MD 20933, USA

adapted from Erdemir et al. (2012)

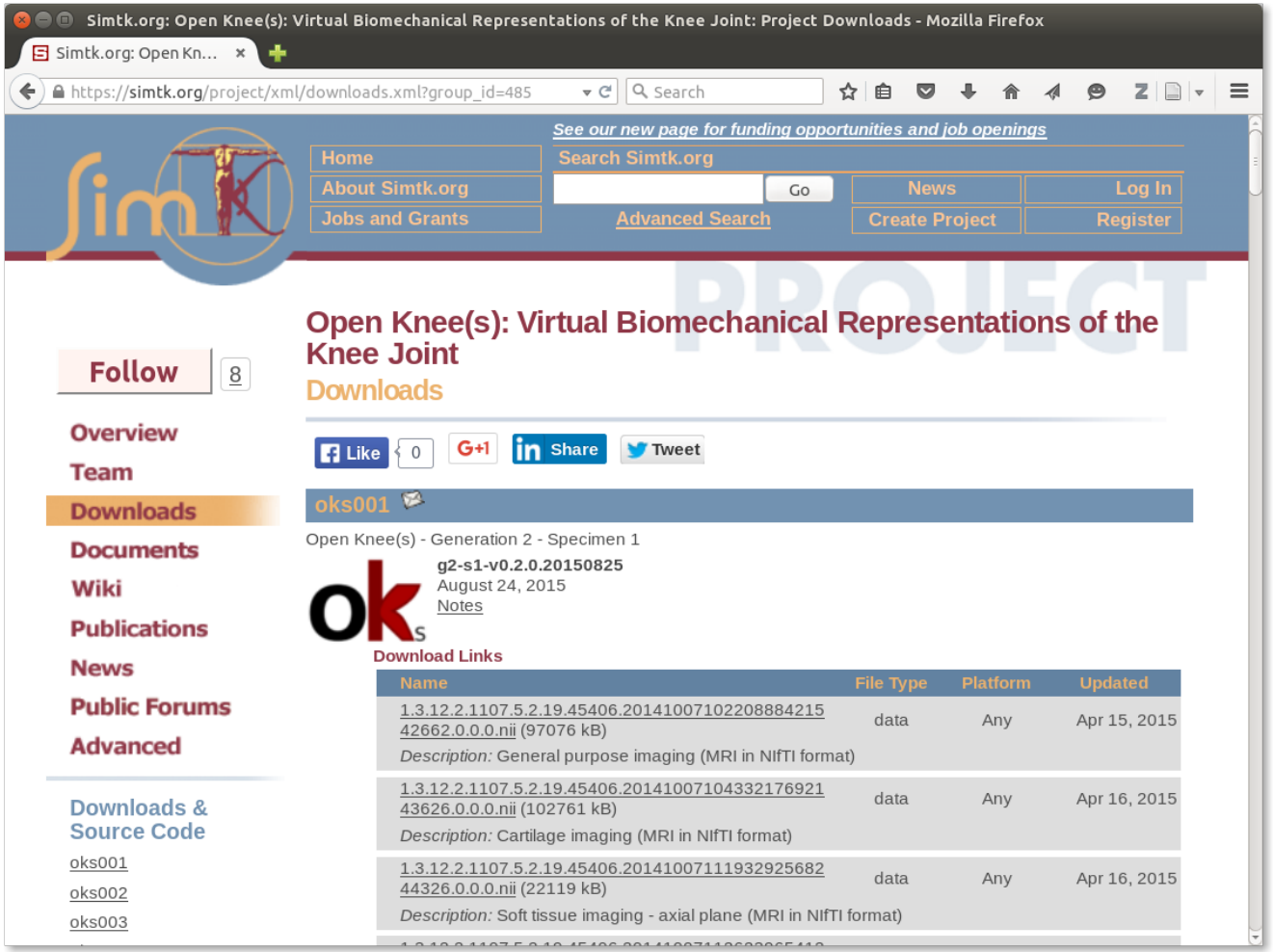
DISSEMINATION

Venues

Repositories
 simtk.org
 GitHub
Institutional repositories
Laboratory sites
Journals
 supplementary material

Issues

Scarce data
Limited sharing
Incompatible licensing



Adapted from Open Knee(s), refer to ***https://simtk.org/project/xml/downloads.xml?group_id=485*****.**

CONCLUDING REMARKS

- **Requirements** for FEA workflow in biomechanics include
  - *use of heterogeneous data*
  - *relying on various data formats*
  - *model representation specific to simulation software*
  - *software to assist model development / customization*

- **Challenges** for modularity, reusability, and reproducibility include
  - *lack of unified and generally accepted formats*
  - *lack of robust utility software for mark-up conversion*
  - *lack of large databases and comprehensive repositories*
  - *constraints for spatial association of model components*

ACKNOWLEDGMENTS

OPEN KNEE – GENERATION 1

Modeling
Craig Bennetts
Ahmet Erdemir
Randy Heydon
Scott Sibole

Data
Bhushan Borotikar
Antonie J. van den Bogert

Simulation Software
Ben Ellis
Steve Maas
David Rawlins
Jeff Weiss

NIH/NIBIB R01EB009643
NIH/NIGMS R01GM083925
NIH/NIAMS R01AR049735
Simbios

OPEN KNEE(S) – GENERATION 2

Cleveland Clinic
Dylan Beckler
Craig Bennetts
Tara Bonner
Snehal Chokhandre
Robb Colbrunn
Ahmet Erdemir
Jason Halloran

Stanford University
Scott Delp
Joy Ku
Henry Kwong

University of Utah
Ben Ellis
Steve Maas
Jeff Weiss

CWRU
Chris Flask
Shannon Donnola

Community
Elvis Danso
Katie Stemmer
Cara Sullivan

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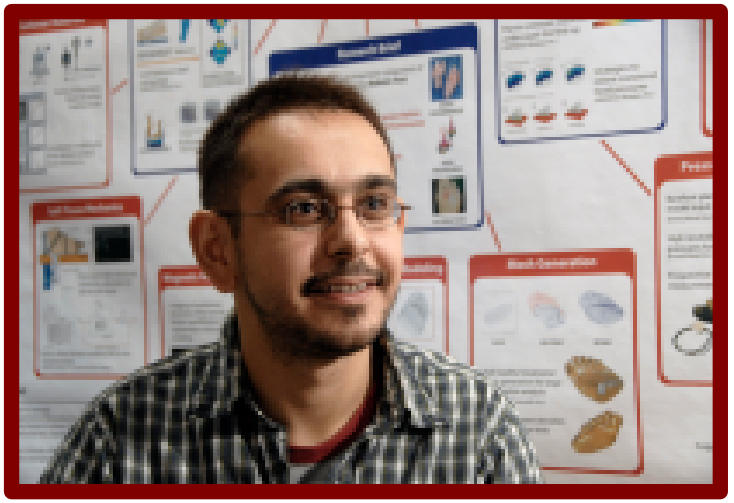
Jack Andrish
Yasin Dhaher
Trent Guess
Morgan Jones
Rami Korhonen
Paul Saluan
Carl Winalski

NIH/NIGMS
R01GM104139

https://simtk.org/home/openknee

CONTACT



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LICENSING

TRADEMARKS & OWNERSHIPS