Mesh-based vs. Image-based Statistical Appearance Model of the Human Femur: A Preliminary Comparison Study for the Creation of Finite Element Meshes

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Statistical Appearance Models in Orthopaedic Biomechanics

- Statistical *shape* models have remarkable popularity
- *Intensity* has been integrated since it is related to bone mechanical properties
- Statistical *appearance* model combine variations of bone shape and mechanical properties
- The major issue are accurate anatomical correspondences

Importance of Correspondences

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- Correspondences must be accurate both on the surface and in the volume of the bone
- Two different approaches:
  - Mesh-based: output compatible with FE simulations / smoothing can penalize correspondences
  - Image-based: non constraints due to node positioning / no iso-topology, invertible DVF

Comparison of mesh-based vs. image-based pipeline for the creation of statistical appearance models for FE simulations

Mesh-based and Image-based Pipelines

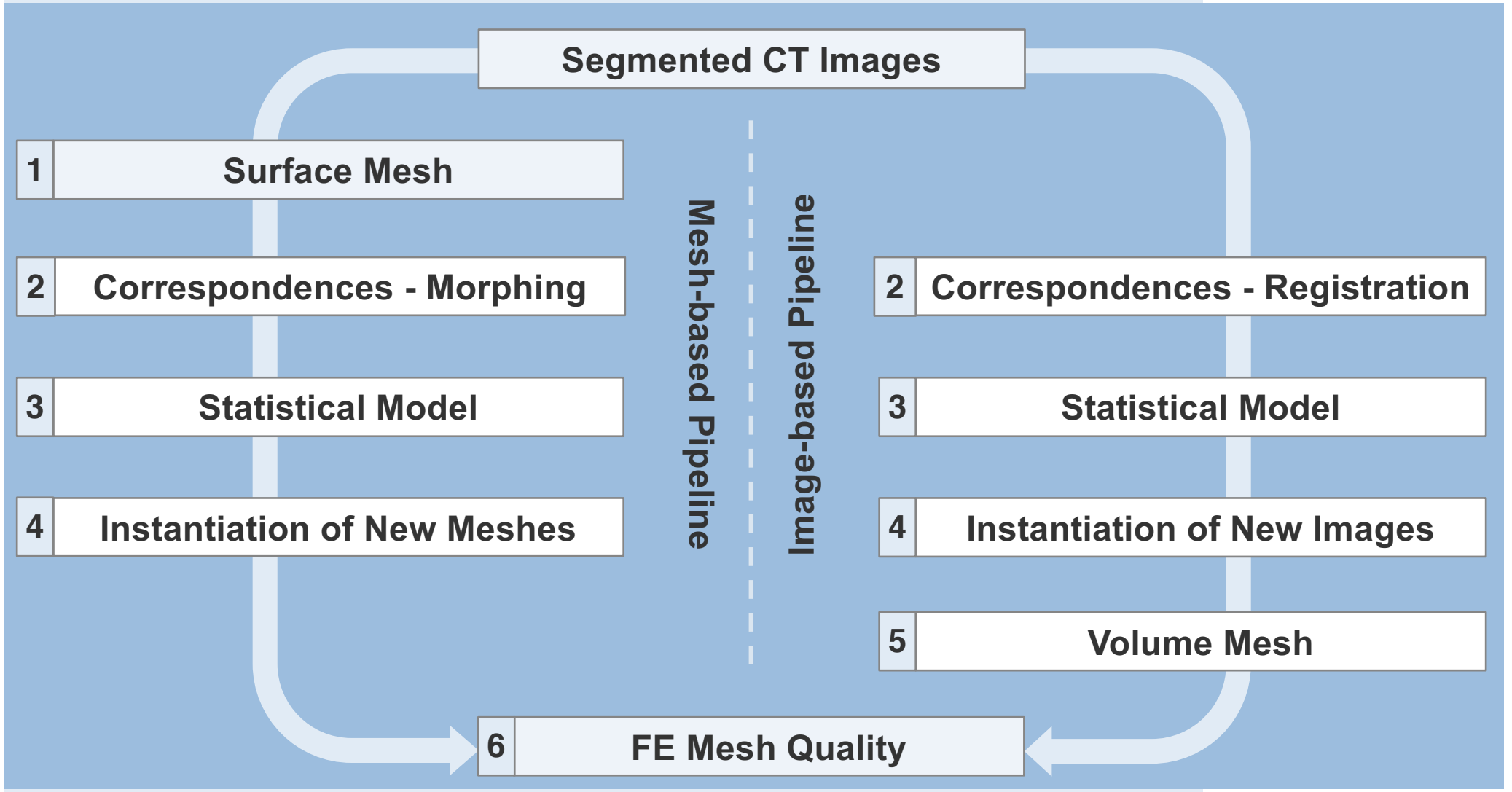
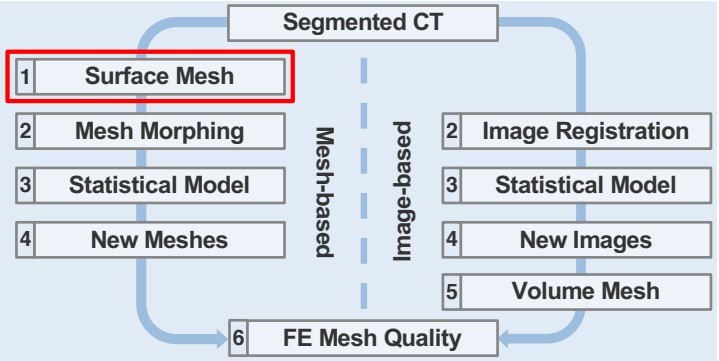


Image to Surface Mesh



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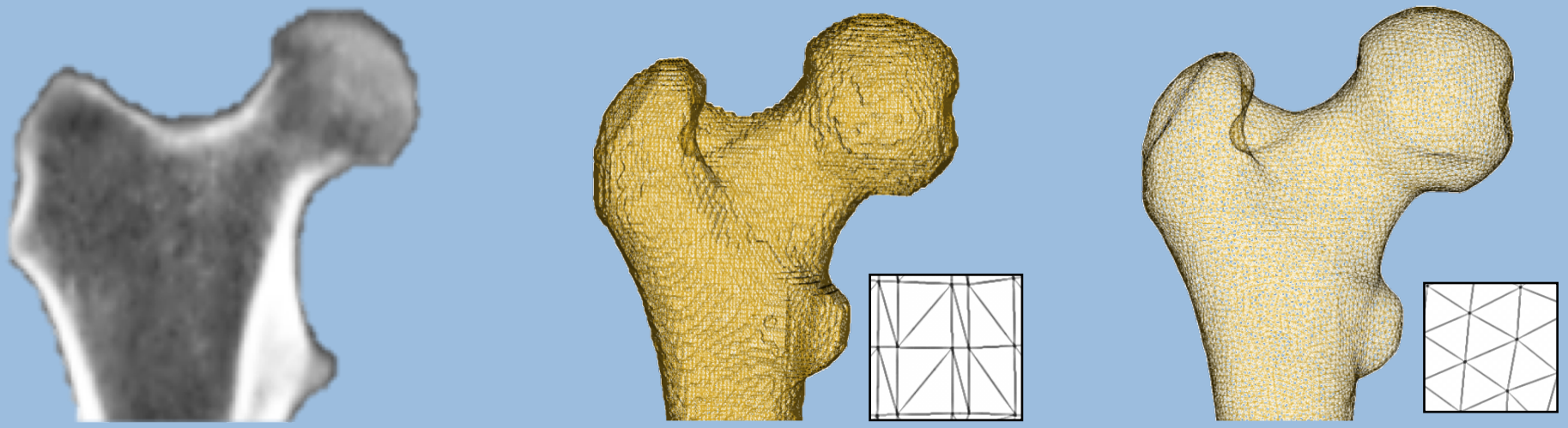
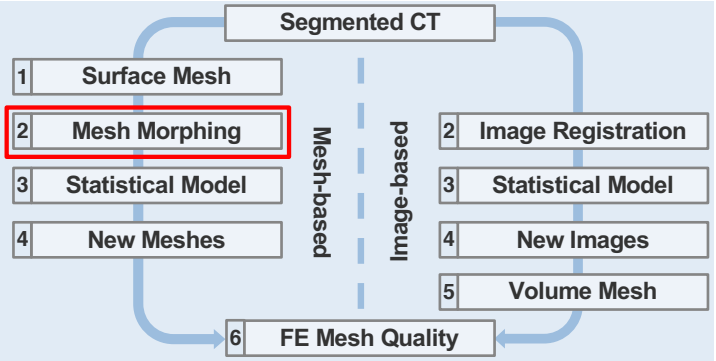
COMPUTER AIDED AND IMAGE GUIDED MEDICAL INTERVENTIONS

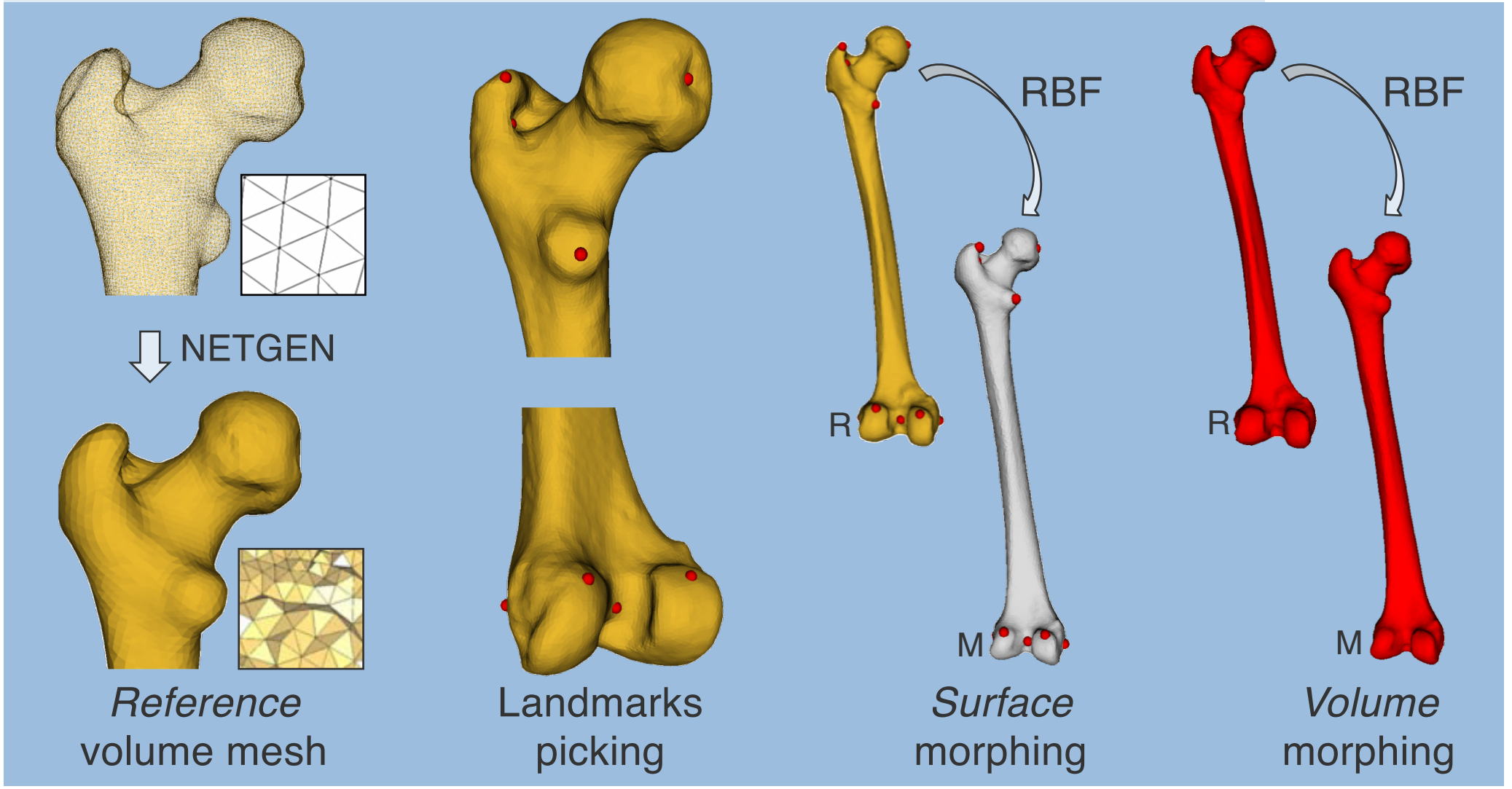


VTK marching cubes

VTK decimation
VTK smoothing
MRFSurface

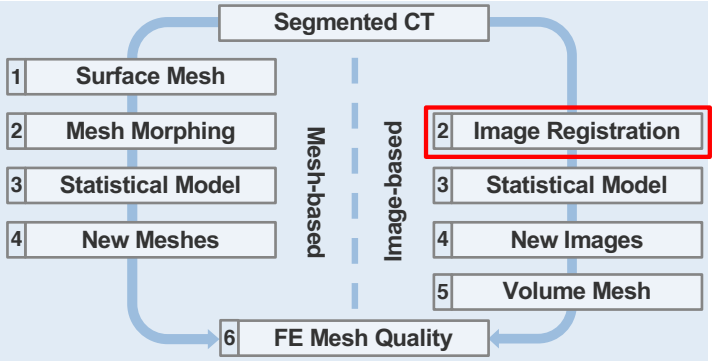
RBF Morphing
Correspondence Detection





Boichon, C. et al. *Shape Indexing of Human Femora Using Morphing and Principal Component Analysis*. 1st Virtual Physiological Human Conference - VPH2010. No. 1 (2011)

Polyaffine Log-Demons
Correspondence Detection



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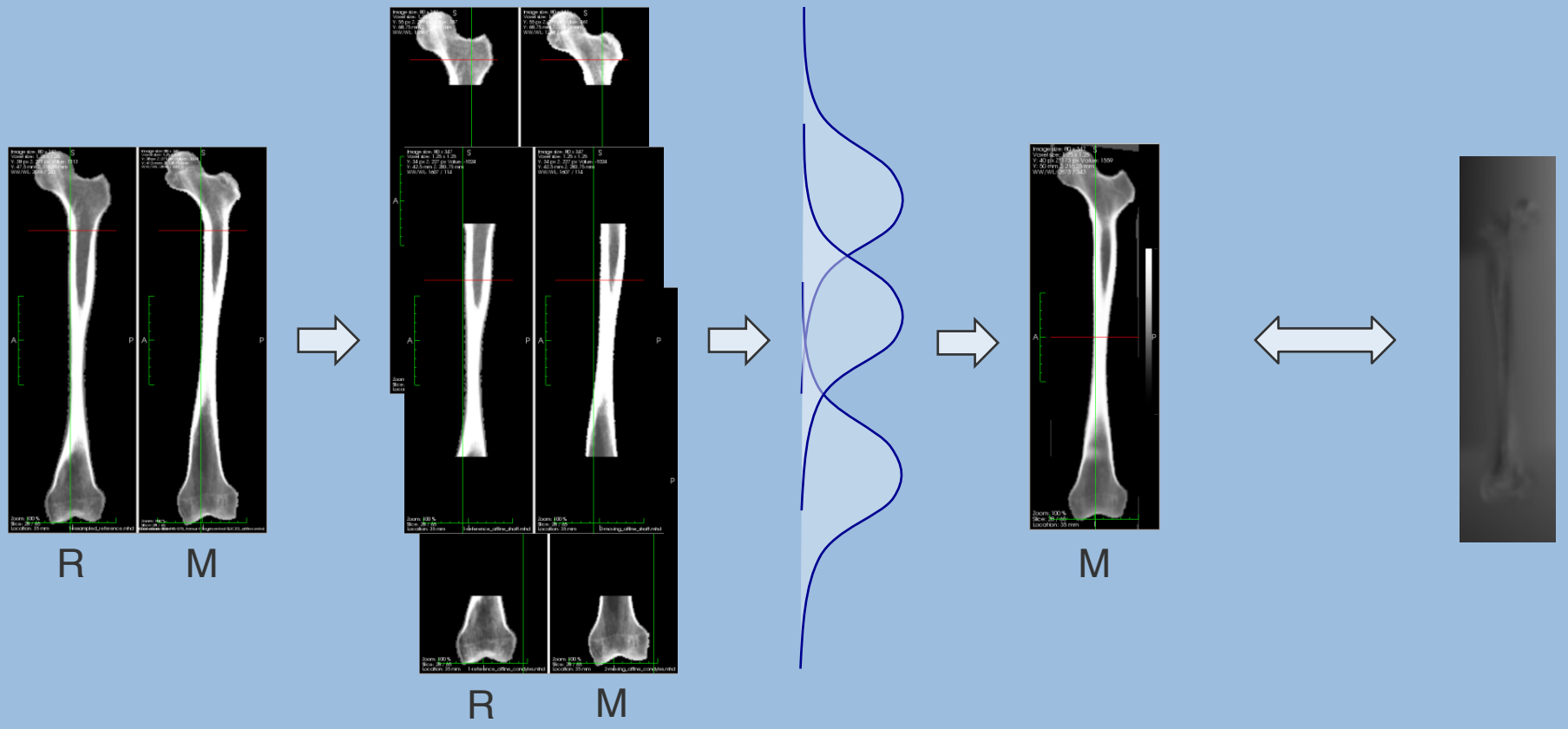
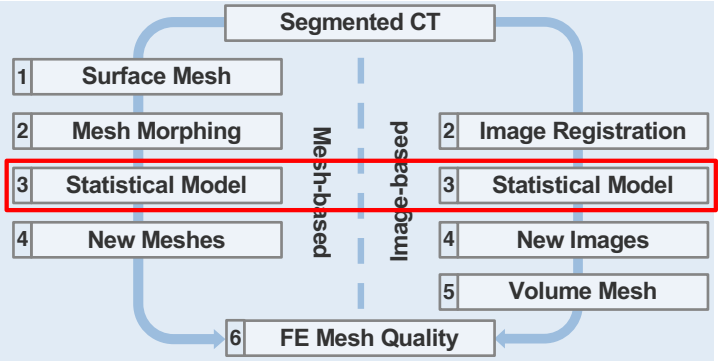
CO-ME COMPUTER AIDED AND IMAGE GUIDED MEDICAL INTERVENTIONS



Seiler, C. et al. *Femur Specific Polyaffine Model to Regularize the Log-Domain Demons Registration.* SPIE Medical Imaging. vol. 7962 (2011)

Statistical Models



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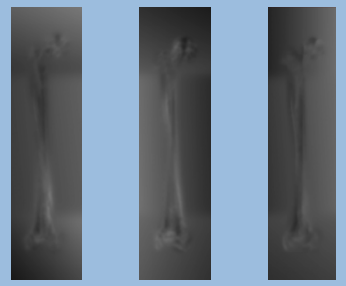
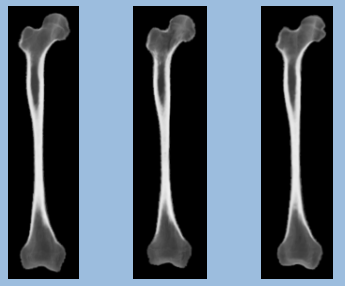
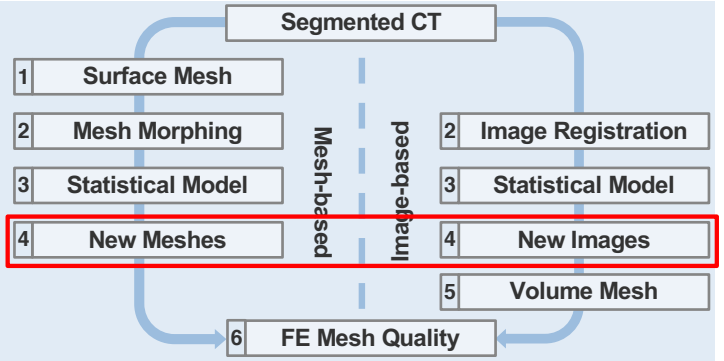
	Mesh-based pipeline	Image-based pipeline
Statistical *shape* model		
Statistical *intensity* model		

Statistical *appearance* model

$$b = \begin{pmatrix} W_s\, b_s \\ b_g \end{pmatrix} = \begin{pmatrix} W_s\, \Phi_s^T (x - \bar{x}) \\ \Phi_g^T (g - \bar{g}) \end{pmatrix} \Rightarrow b = \Phi_c c,\ \Phi_c = \begin{pmatrix} \Phi_{c,s} \\ \Phi_{c,g} \end{pmatrix}$$

Cootes, T.F., Taylor, C.J.: *Statistical Models of Appearance for Medical Image Analysis and Computer Vision*. SPIE Medical Imaging. pp. 236-248. (2001)

Creation of New Instances



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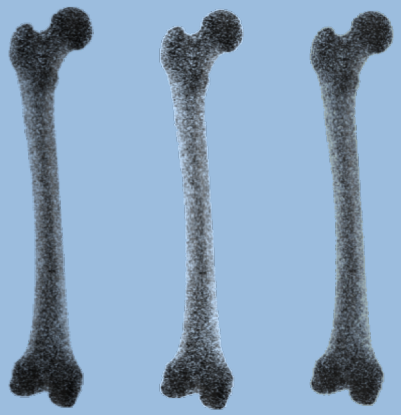
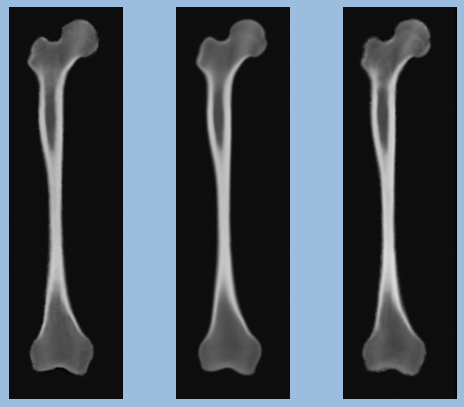
Mesh-based pipeline

Image-based pipeline

Intensity

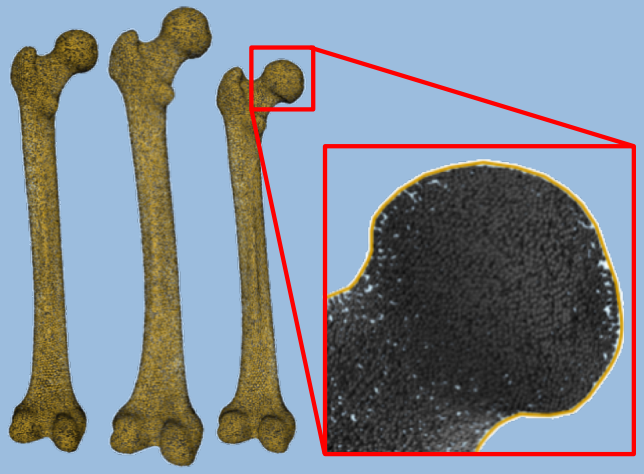
$$\tilde{g} = \bar{g} + \Phi_g \Phi_{c,g} c$$

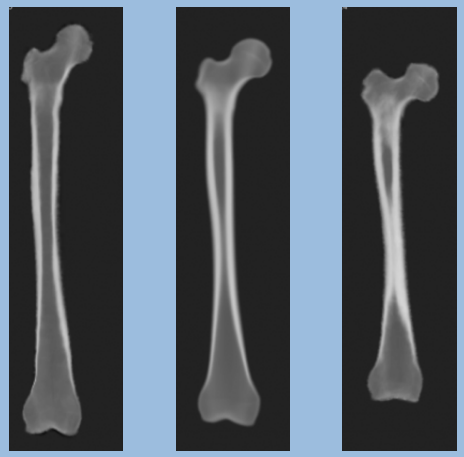




Shape

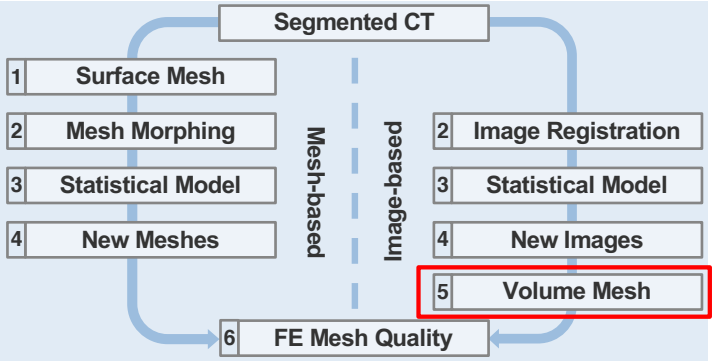
$$\tilde{x} = \bar{x} + \Phi_s W_s^{-1} \Phi_{c,s} c$$

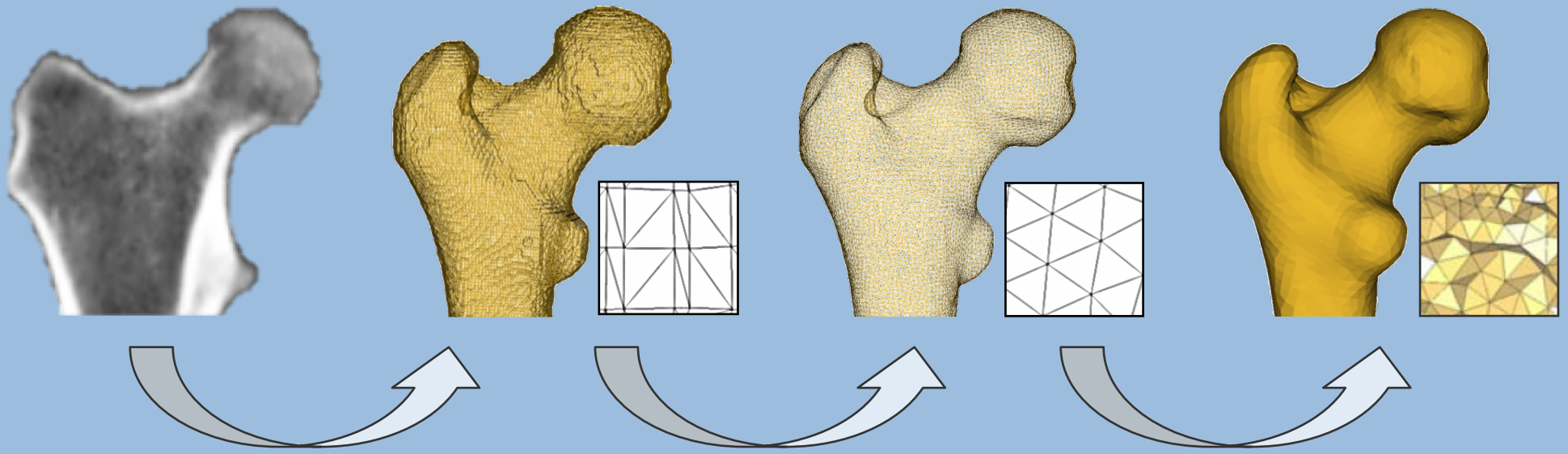




Cootes, T.F., Taylor, C.J.: *Statistical Models of Appearance for Medical Image Analysis and Computer Vision*. SPIE Medical Imaging. pp. 236-248. (2001)

Image to Volume Mesh



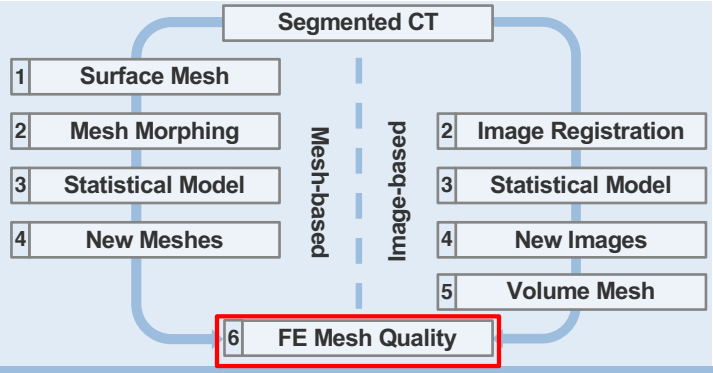


VTK marching cubes

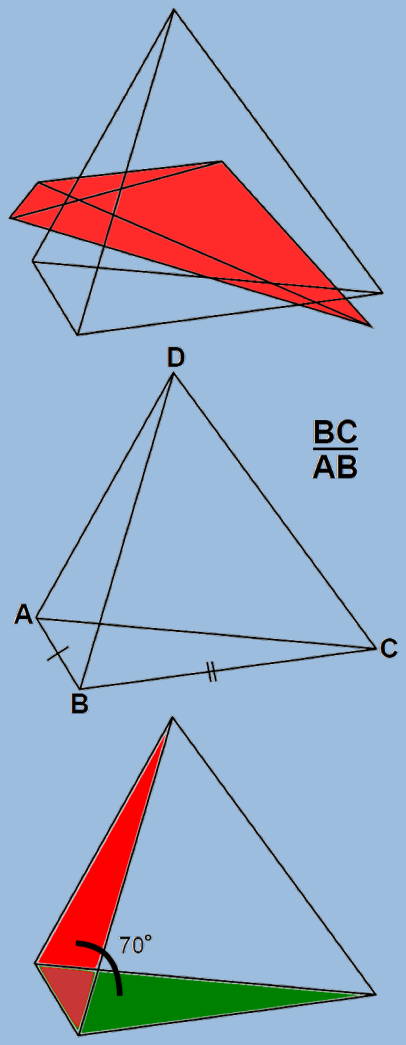
VTK decimation
VTK smoothing
MRFSurface

NETGEN

FE Mesh Quality



- Metric of *volume:* Jacobian
- Metric of *size*: Edge Ratio
- Metric of *shape*: Minimum Angle



Statistical Appearance Models
Results

- 157 left femur CT images
- Compactness of the statistical appearance models

Compactness	Mesh-Based Pipeline	Image-Based Pipeline
50%	2	3
75%	6	27
90%	40	86
100%	157	157

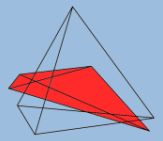
- models

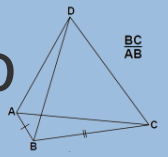
	Mesh-Based Pipeline	Image-Based Pipeline
Shape Model	5 min[1]	5 hrs[2]
Intensity Model	2 min[1]	1.5 hrs[2]
Appearance Model	9 min[1]	6.5 hrs[1]

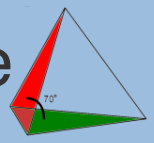
[1]Processor: Intel Core Duo, E8500 @ 3.16GHz. RAM: 8GB
[2]Processor: Intel Xeon CPU, X5550 @ 2.67GHz. RAM: 48GB

- Creation of 30 new instances for each model with 90% variation

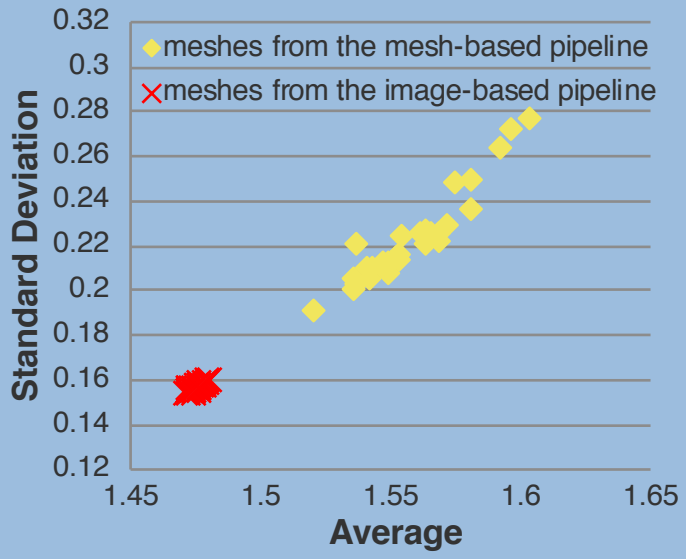
FE Mesh Quality
Results

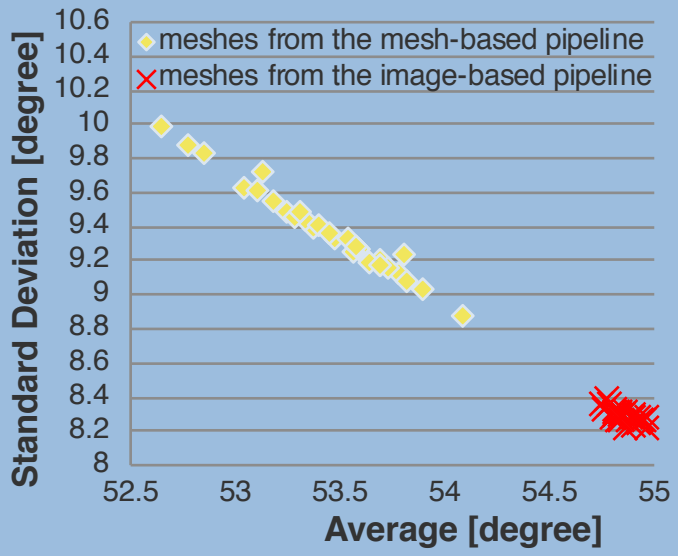
Jacobian 

Edge Ratio 

Minimum angle 

Mesh-based	Image-based
28/30	30/30





Conclusion

- Preliminary study on mesh-based vs. image-based approach
- Mesh-based pipeline:
  - Low quality of the mesh tetrahedrons
  - More compact model, iso-topological meshes
- Image-based pipeline:
  - DVF inversion issue, no iso-topological meshes, computational expensive
  - High quality of the mesh tetrahedrons

Outlook

- Validation of correspondence detection and models
- Merge strength of the two methods
- Compare the implications for FE simulations