Monte Carlo based CT Simulation of Virtual Patient Geometries

Simon Kirchhof, Kristina Giske, Lucas N. Burigo
Division of Medical Physics in Radiation Oncology, DKFZ

dkfz.
GERMAN CANCER RESEARCH CENTER
IN THE HELMHOLTZ ASSOCIATION
Research for a Life without Cancer

Monte Carlo User Application of Triangular- and Tetrahedral-Mesh Virtual Patient Geometries

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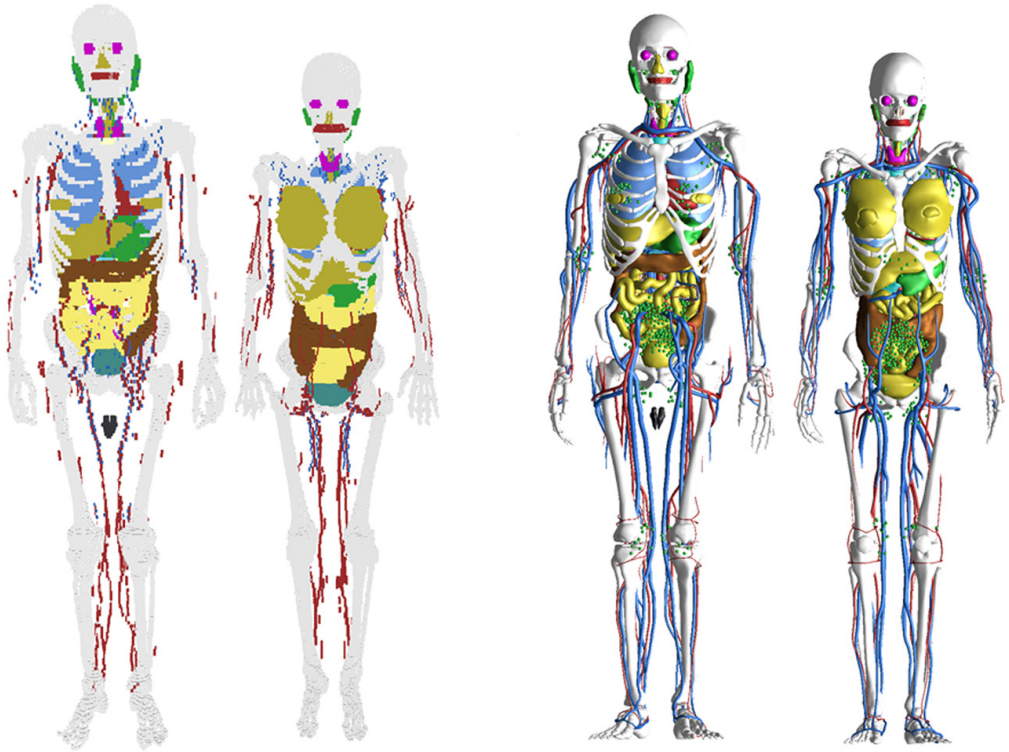
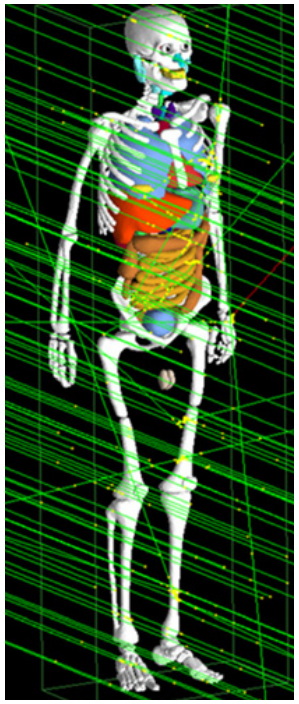
Trend: Surface-Mesh Phantoms



Conversion of ICRP reference phantom [1]

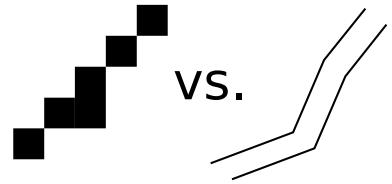


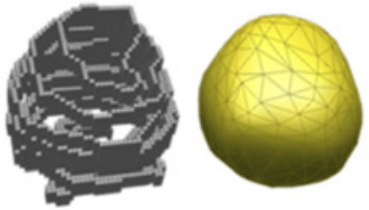
Radiation worker organ dosimetry [2]

[1] Kim et al. 2017, [2] Yeom et al. 2013

Advantages to Exploit

- Representation of thin organs





Urinary bladder wall [2]

[2] Yeom et al. 2013

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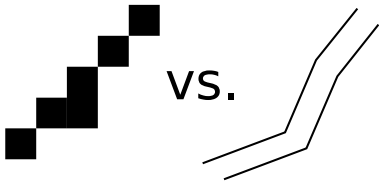
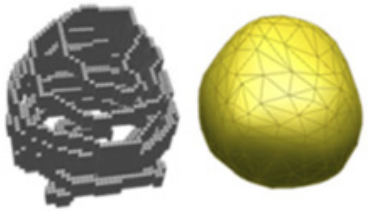
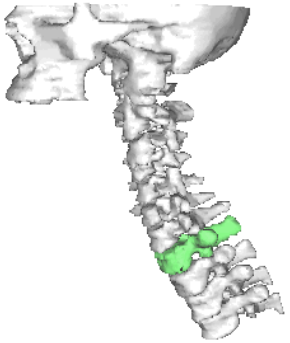




Urinary bladder wall [2]

- Modeling of movement



[2] Yeom et al. 2013

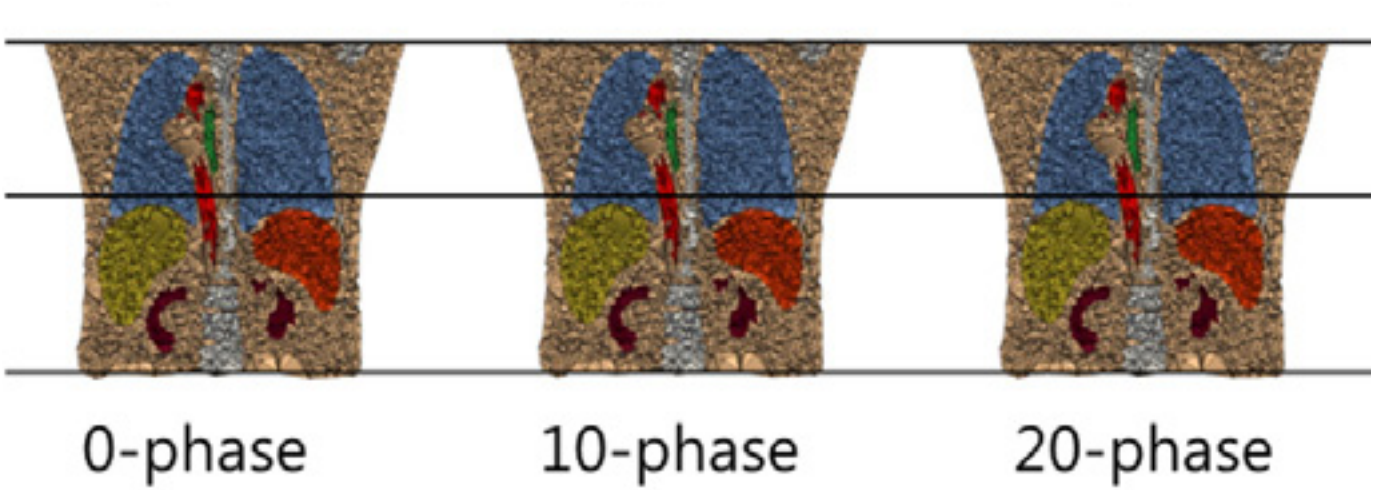
RT Example: 4D Mesh Phantom

CT images of breathing cycle

segmentation + modeling

Surface-(mesh) phantom

tetrahedralisation



Patient-specific 4D tetrahedral mesh phantom [3]

[3] Han et al. 2015

RT Example: 4D Mesh Phantom

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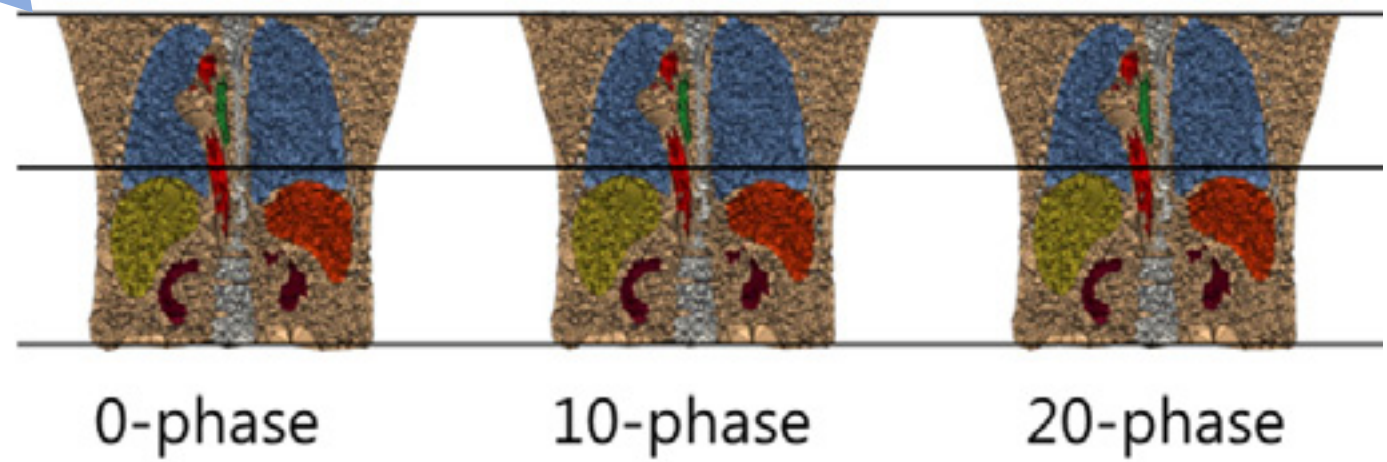
segmentation + modeling

Surface-(mesh) phantom

tetrahedralisation

interpolate material calibration (from HU)



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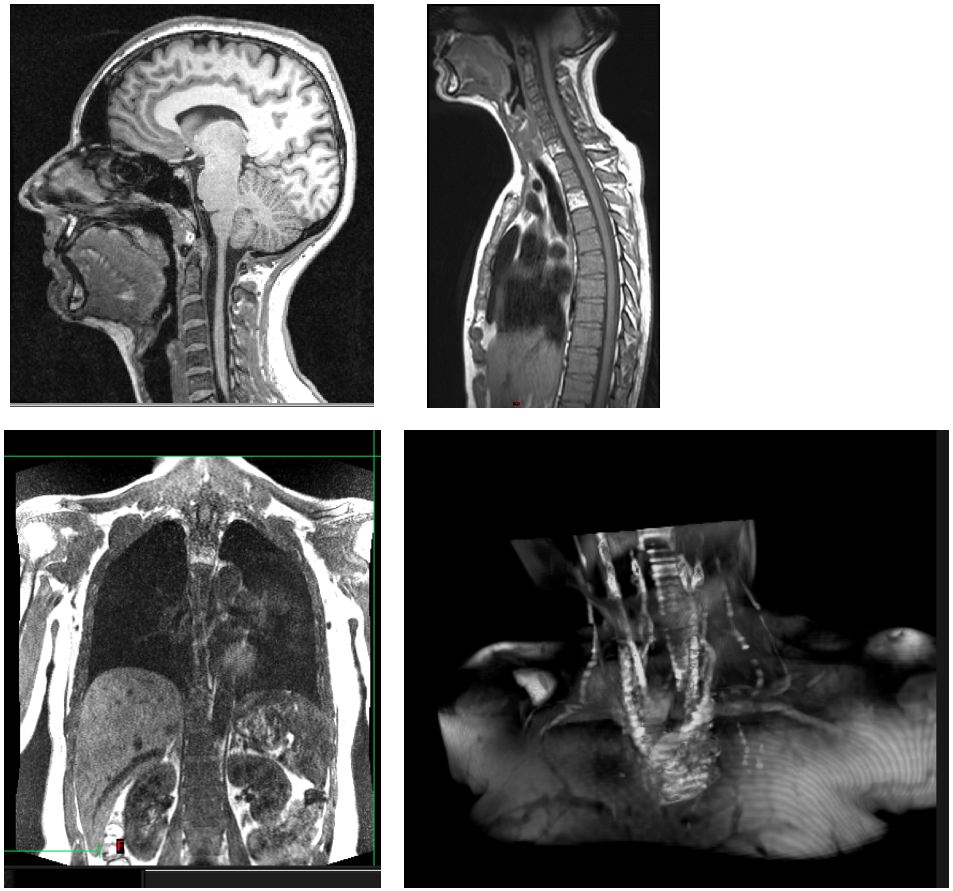
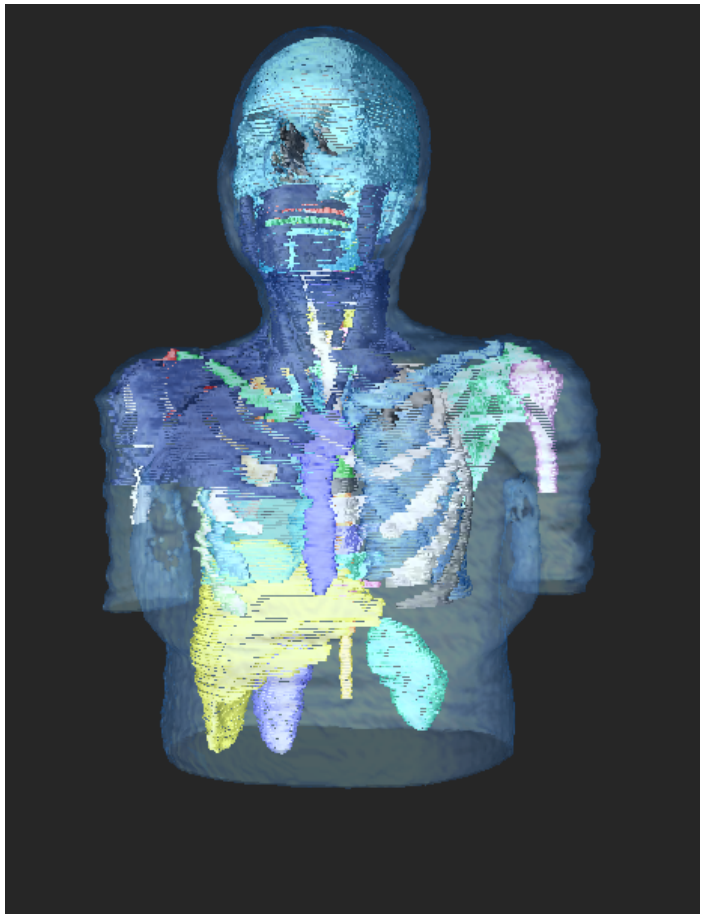
Our Work

Our Patient-Specific Modeling



Diagnostic images of a patient (MR, CT, etc.)

Segmentation



Virtual patient (K. Giske):

- Surface-mesh phantom
- Patient specific organ sizes

Unstructured Meshes in GPMC

	Mesh-Support		Solutions	
	Polygon	**Polyhedra**	**Library**	**Application**
MCNP6	yes	yes	native	native
PENELOPE	yes	no	PenMesh	-
Geant4	yes	no	-	GATE
	yes	no	-	TOPAS
	yes	yes (via tetgen)	CADMesh	-
	yes	no	DAGSolid	

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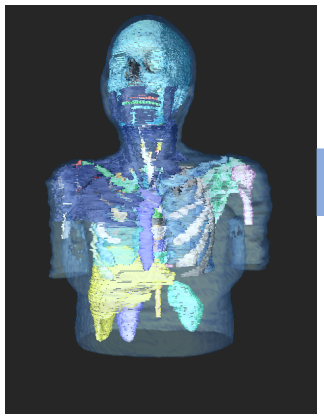
GOAL: Integrate proxy library and user application

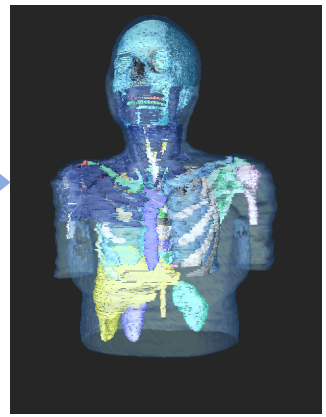
Implementation Architecture

Triangular mesh



tetgen

Tetrahedral mesh



.stl, .ply, .vtk, .smesh

.ele/.node, .vtk

C++ library

File reader

CADMesh [4] + extensions

User application

Set of pre-defined simulation tools:

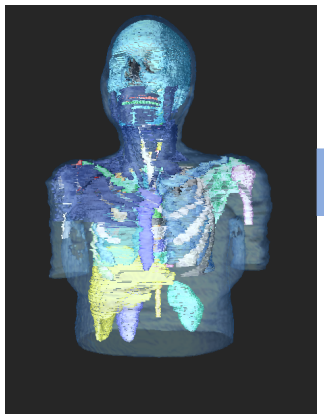
- PET/SPECT/CT
- Dosimetry

GATE [5] + extensions

[4] Poole et al. 2012, [5] Jan et al. 2011

Implementation Architecture

Triangular mesh



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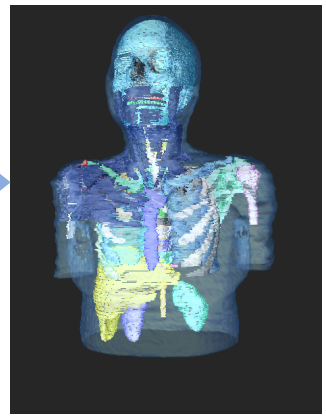

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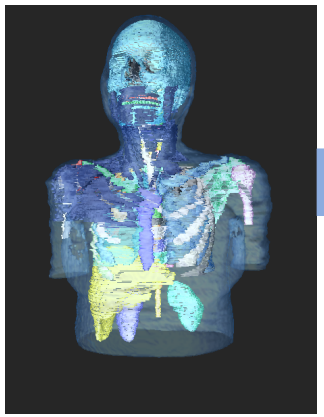

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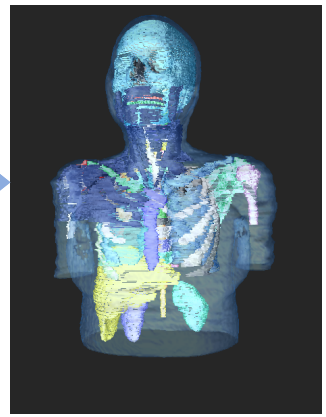

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Geant4 user actions

Geometry wrapper

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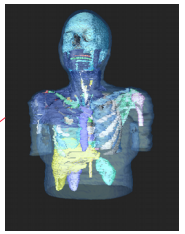
Example: Cone-Beam CT

HIGH-LEVEL USER SCRIPT (GATE)

```
1  # 1. PRIMITIVE GEOMETRY-----------------------------------------------------
2  # ...
3
4  # 2. PATIENT GEOMETRY -------------------------------------------------------
5  /gate/phantom/reader/setPathToMeshFile     polygonMeshPhantom.smesh
6  # /gate/phantom/reader/setPathToMeshFile     tetrahedralMeshPhantom.ele
7
```



Standardized geometry

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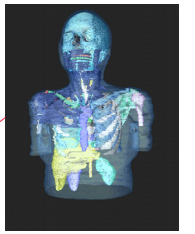
# ...

# 2. PATIENT GEOMETRY ---------------------------------------------------------
/gate/phantom/reader/setPathToMeshFile     polygonMeshPhantom.smesh
# /gate/phantom/reader/setPathToMeshFile     tetrahedralMeshPhantom.ele

# 3. USER ACTIONS -------------------------------------------------------------
/gate/actor/addActor                       EnergyFluenceActor  detectorArray
/gate/actor/detectorArray/attachTo         detectorPanel
/gate/actor/detectorArray/setSize          1.0 409.6 409.6 mm
/gate/actor/detectorArray/setResolution    1   512   512
/gate/actor/detectorArray/setEnergyResponse response.dat

# /gate/actor/addActor                       TetMeshDoseActor doseSensor
# /gate/actor/doseSensor/attachTo            phantom
# /gate/actor/doseSensor/saveCSV             dose.csv
# /gate/actor/doseSensor/saveVTK             dose.vtk
```



Standardized geometry

Non-MC detector modeling

Dose tally in tetrahedral mesh

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10 /gate/actor/detectorArray/attachTo         detectorPanel
11 /gate/actor/detectorArray/setSize          1.0 409.6 409.6 mm
12 /gate/actor/detectorArray/setResolution    1   512   512
13 /gate/actor/detectorArray/setEnergyResponse response.dat
14
15 # /gate/actor/addActor                       TetMeshDoseActor doseSensor
16 # /gate/actor/doseSensor/attachTo            phantom
17 # /gate/actor/doseSensor/saveCSV             dose.csv
18 # /gate/actor/doseSensor/saveVTK             dose.vtk
19
20 # 3. SOURCE -------------------------------------------------------------------
21 #...
22
23 # 4. PHYSICS / VRT ------------------------------------------------------------
24 # ...
```

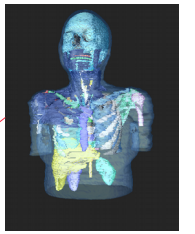

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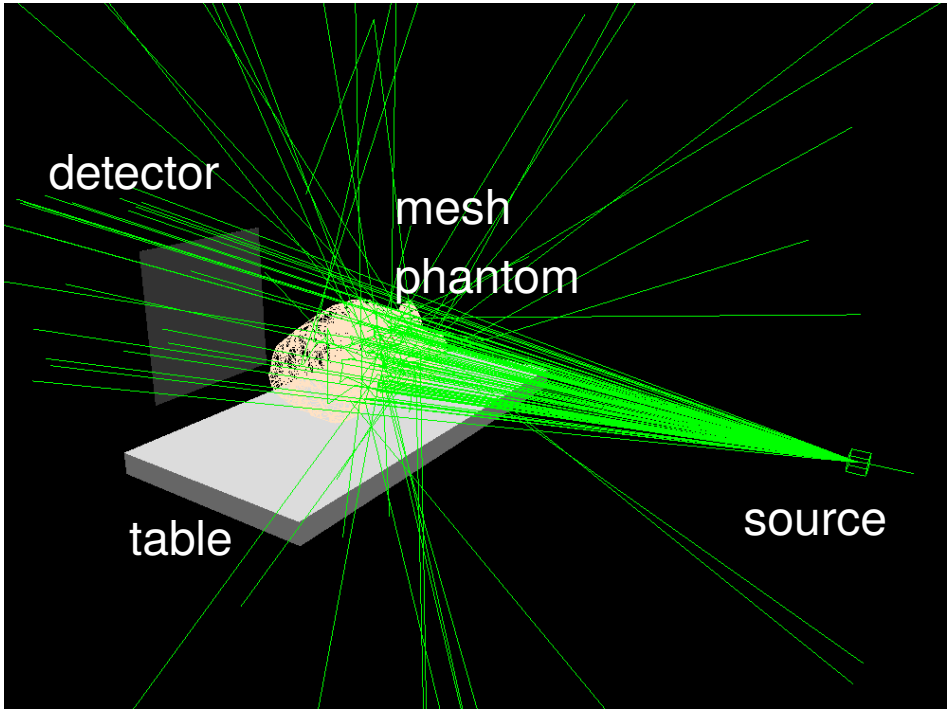
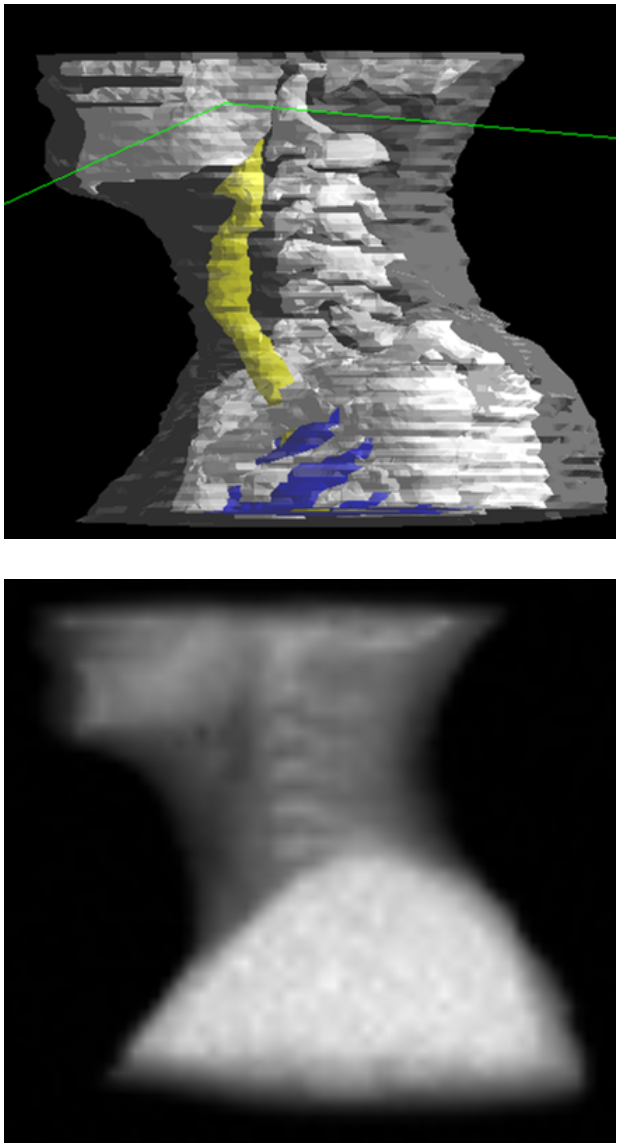


Simplified Elekta-Synergy CBCT (using GATE):

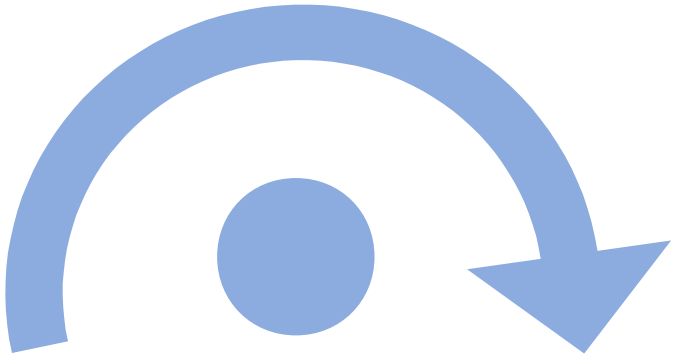
Energy:	100 kVp spectrum
Angles:	isotropic
Detector:	ideal integrator



Simulated projection

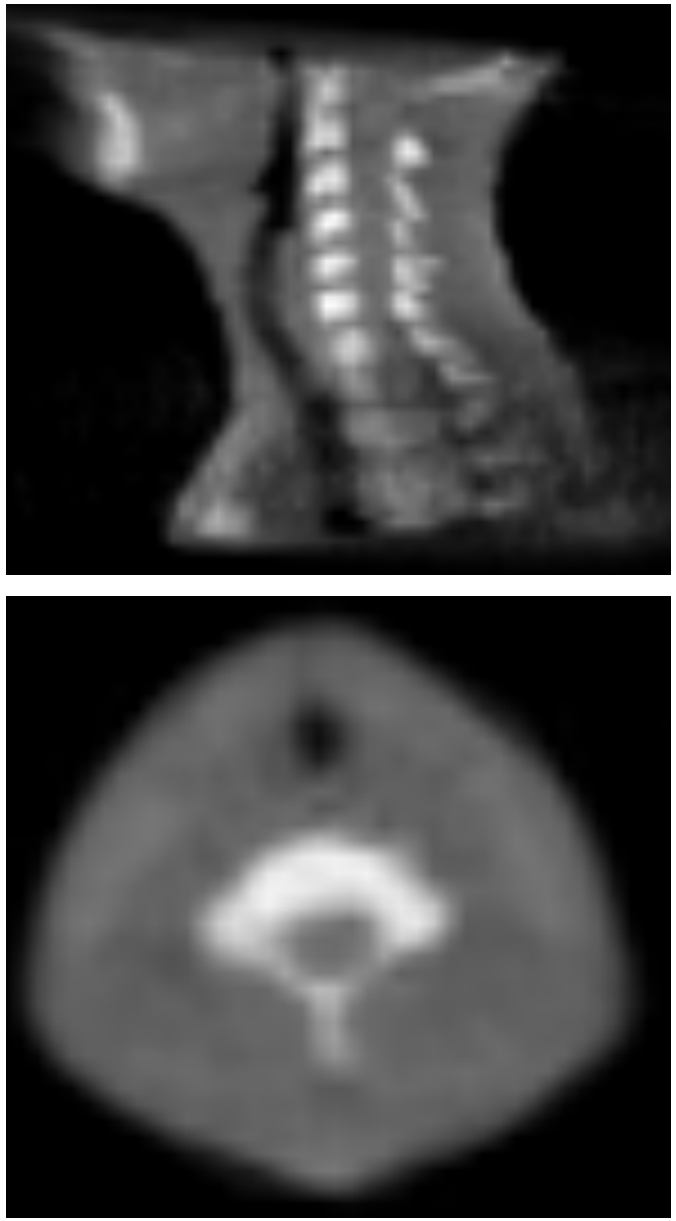
Example: Cone-Beam CT

195° short scan



200 projections

N / projection:	2e7
Concurrency:	32 cores
Computing time:	48 h
Image Resolution:	3x3x3 mm



FDK reconstruction using RTK [6]

[6] Rit et al. 2014

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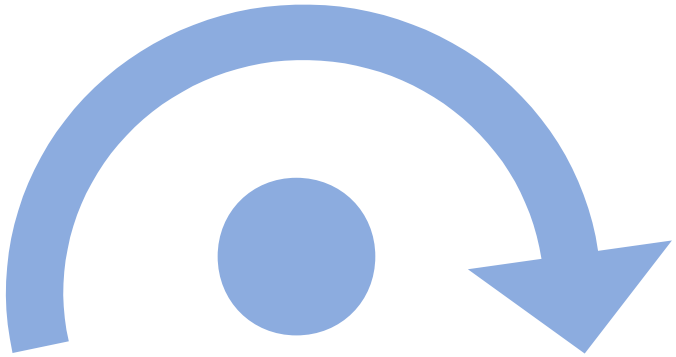
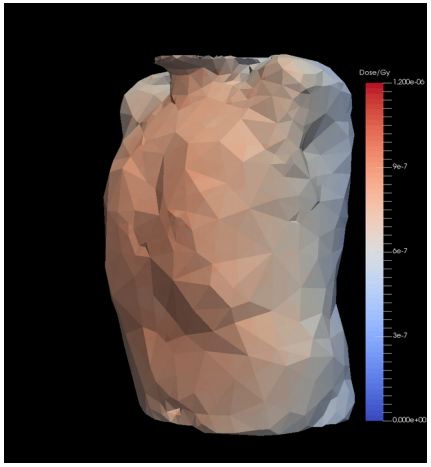
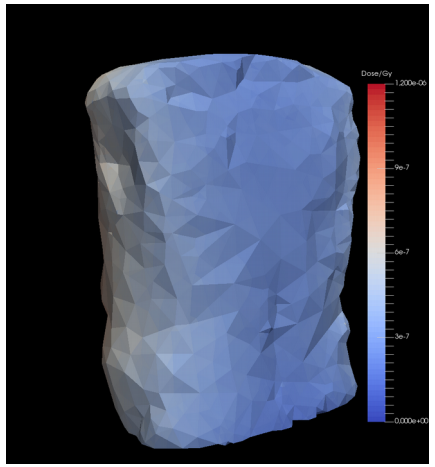
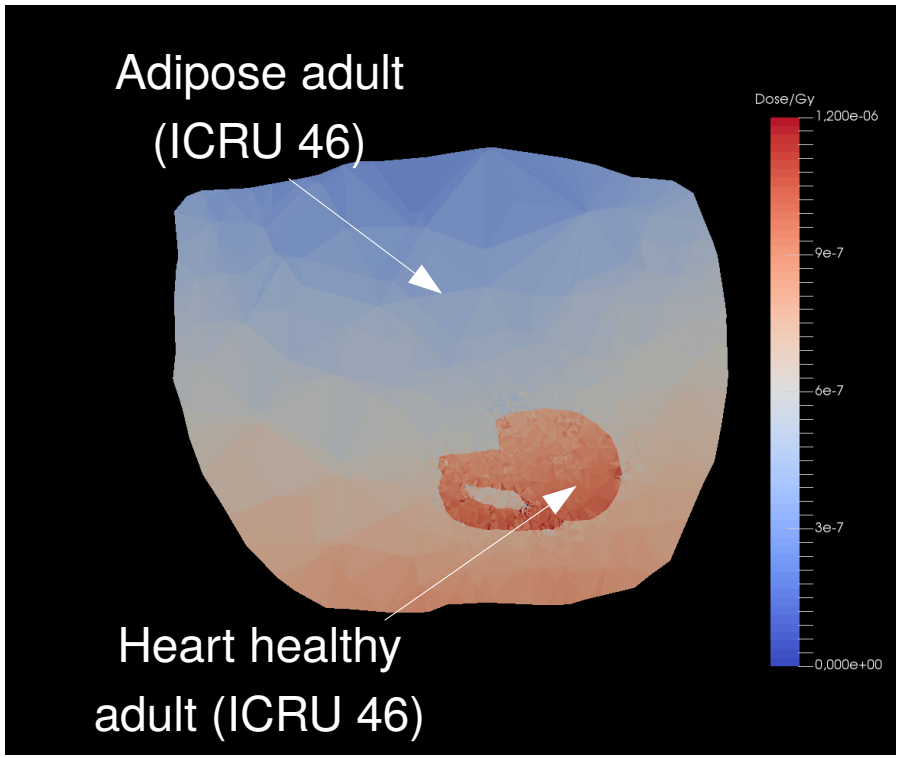


200 projections

N / projection:	7.5e6
Concurrency:	36 cores
Computing time:	24 h







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	Mesh-Support		Solutions	
	Polygon	**Polyhedra**	**Library**	**Application**
Geant4	yes	yes	CADMesh-fork	GATE-fork

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- Generic Geant4 definition of unstructured mesh phantoms
- File templates

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If accepted (on github):

Available through new GATE and CADMesh release.

Acknowledgements

Thanks to Lucas N. Burigo for sharing his Geant4 expertise.

Thanks to Kristina Giske for her conceptual work on this project.

Thank you for your attention!

References

[1] Kim et al., Phys. Med. Biol. **62**, 2017.

[2] Yeom et al., Phys.Med. Biol. **58**, 2013.

[3] Han et al., Phys. Med. Biol. **60**, 2015.

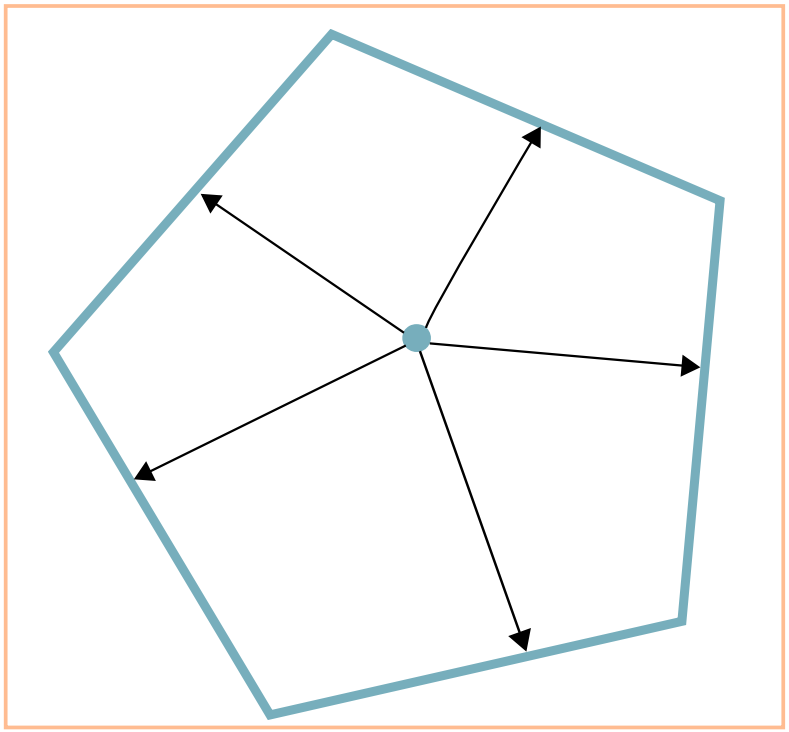
[4] Poole et al., Australas. Phys. Eng. Sci. Med. **35**, 2012.

[5] Jan et al., Phys. Med. Biol. **56**, 2011.

[6] Rit et al., J. Phys. Conf. Ser. **489**, 2014.

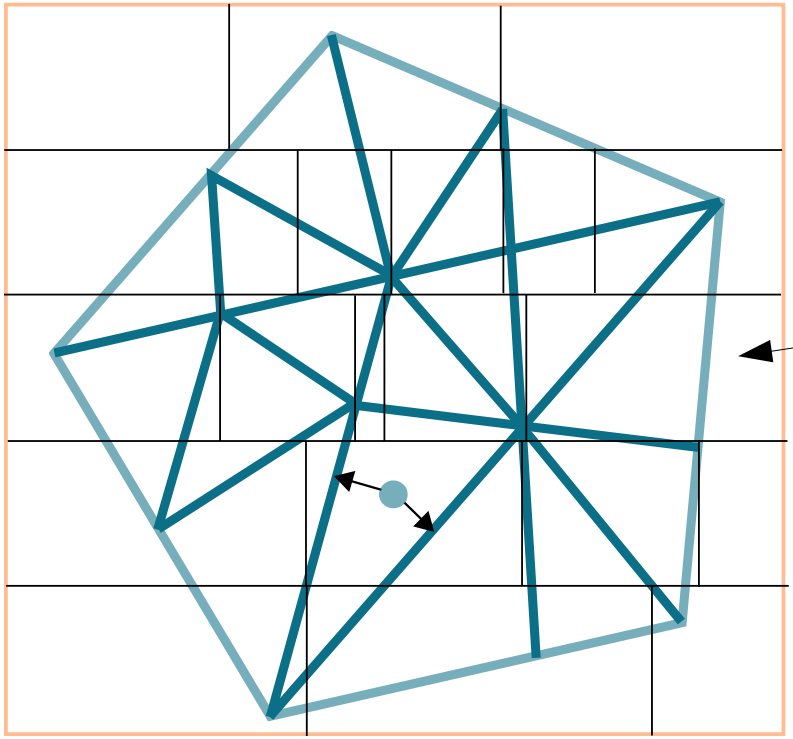
Back-up slides

Navigation (Geant4)



Polygonal geometry

Distance checks: ~ n



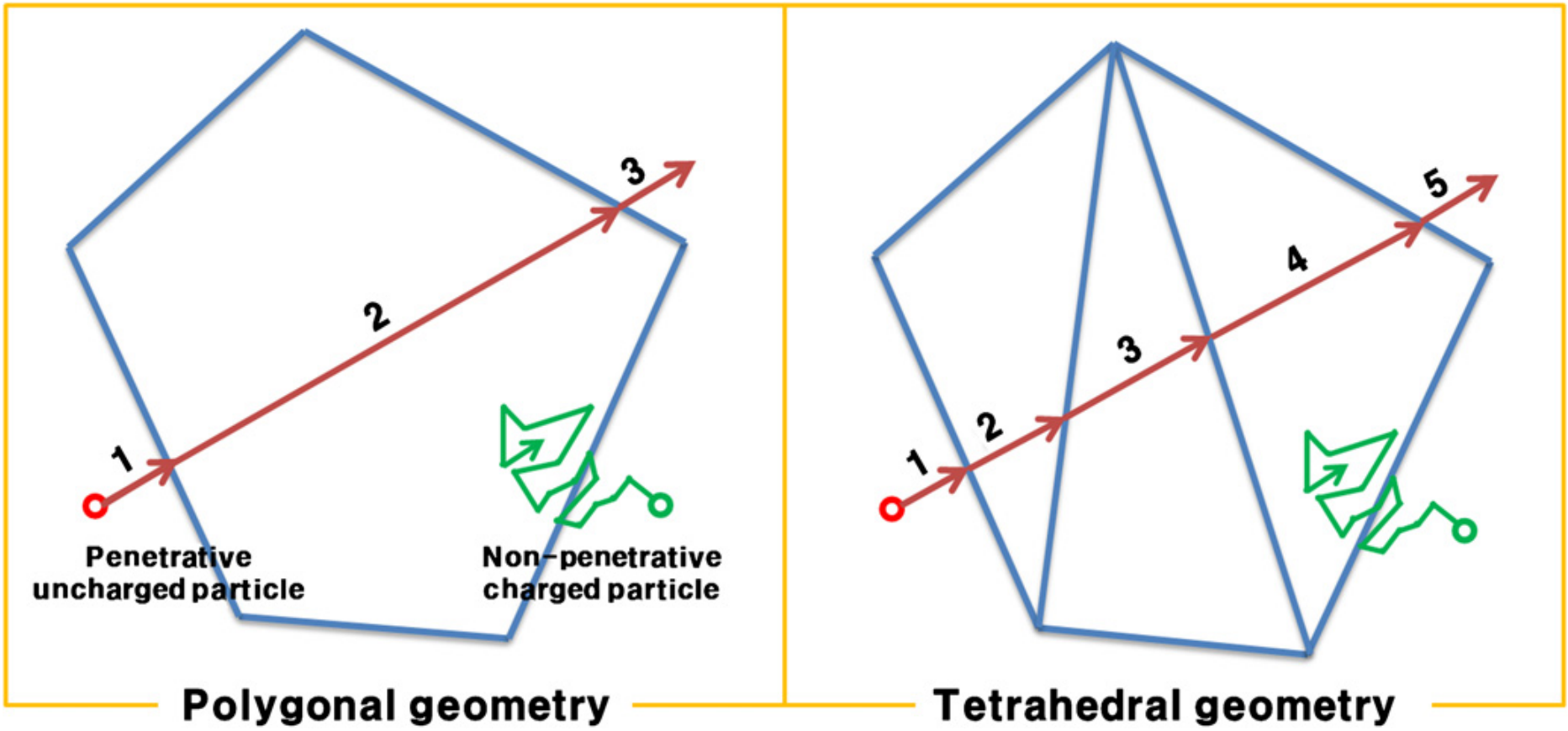
Smart voxel hierarchy

Tetrahedral geometry

Distance checks: ~ log(n)

G4TessellateSolid, 2011

Stepping (Geant4)



Graphic from Yeom et al., Phys. Med. Biol. **59**, 2014.