Simpleware: Converting 3D Images into Numerical Models
Company Overview
Simpleware Ltd.

Developers of world-leading image processing environment for the conversion of 3D images into numerical models.

- Image-based meshing software and services for your research in:
  - Biomechanics
  - Materials
  - Natural Sciences
- Headquartered in Exeter, UK
- US sales office and world-wide reseller network
- Global customer base
Simpleware Software

Automatic conversion of 3D images into high quality CAD models and meshes, which can be directly used for:

- Computer Aided Design (CAD)
- Rapid Prototyping (RP)
- Finite Element Analysis (FEA)
- Computational Fluid Dynamics (CFD)
Target Markets & Applications

Medical & Dental
- Biomechanics & Orthopaedics
- Implant Design
- Physiological Flows
- Consumer Products
- Cell Mechanics

Materials & Geology
- Oil & Gas
- Non-destructive Evaluation
- Composite Analysis
- Material Characterisation
- Pore Scale Fluid Flow

Natural Sciences
- Palaeontology
- Archaeology
- Functional Morphology
- Food Sciences
- Pollination
Software Solutions
Image-Based Meshing

1. Import volume image data
2. Voxel grid formed
3. Segmentation of regions of interest
4. Extract segmented voxels
5. Create volume/surface mesh
Image-Based Meshing

Stack of 2D Images

Identify Voxels of Region of Interest - Segmentation

Volume & topology preserving smoothing to generate 3D object
Introduce & position CAD objects to combine CAD and image based models
Image-Based Meshing

Perform Booleans on Image-based models

Robust, high quality surface and volume meshing of multipart objects with conforming interfaces
Direct approach - from scan to model

Scanning
Volume image data e.g. MRI, CT, μCT etc

ScanIP
Image processing

+CAD
CAD import & positioning

+FE
Volume mesh generation

CAD & FE/CFD
Model
ScanIP software
Image Processing/Segmentation
ScanIP – Base Module

Complete image processing environment for importing, filtering, segmentation and visualisation of volume images.

- Import wide range of data formats
  - Dicom, stacks of images, Raw images, volume images etc.
- Filters: can be applied both on image and segmented mask data
  - Noise reduction, smoothing, morphological, metal artefact reduction...
- Manual and automated segmentation tools
  - Paint, paint with threshold, threshold, region growing, floodfill
- 3D editing tools for interactive segmentation in 3D view
  - Apply filters (smooth/dilate/delete) on local regions in 3D view
ScanIP – Base Module

Complete image processing environment for importing, filtering, segmentation and visualisation of volume images.

- Robust and high quality multipart surface mesh generation
  One click required to generate STL for RP/CAD or surface meshes for FE packages
- 2D and 3D measurement and statistics
  Volume fractions, porosity, surface areas, centre of mass, moments of inertia, av/sd greyscale values, point-to-point distances (2D/3D), mask connectivity
- Wide range of visualisation options
  Full screen view, backgrounds, lighting, 3D stereo, clipping
- Full 64bit support and automatically parallelises
- Intuitive and user friendly interface
  Quick to learn, tooltips, fully documented, log history
+CAD – Bolt on module
Import and positioning of CAD data
+CAD – Bolt on Module

- Direct import of most common CAD formats
  STL, IGES, STEP, 3DS

- Interactive 3D positioning widget or constrained motion
  Rotate and translate using mouse or type in values

- Superimpose image data for improved positioning
  Volume rendering and clipping to help position implants

- CAD primitives for surgical template generation
  Create cylinders, tubes, spheres, cuboids within application

- Internal micro-architecture generation
  Import STL file to shell out and replace with internal structure,
  Reduce material usage and weight for RP applications

- Import and repair dirty CAD data
  Import poor quality STL and use image processing techniques to fix -> mesh
+FE – Plugin Module
FE/CFD mesh generation
+FE – Plugin Module

Bolt on module based on proprietary meshing algorithms

- Fully automated and robust multipart volume meshing
  One click required to generate FE/CFD meshes consisting of multiple regions
  Fully integrated within the ScanIP environment

- Choice of meshing algorithms:
  +FE-Grid –
  Traditional image-based meshing creating mixture of hex and tet elements
  Very fast and high quality meshes even for the most complex segmentation
  +FE-Free –
  New algorithms which allow for mesh adaptation based on features
  Can significantly reduce mesh size whilst still preserving small features
  Specify target edge lengths – min/max and element change rates

- Conforming segmented regions automatically handled
  Algorithms preserve conformity creating shared nodes/elements

- Material properties can be assigned based on greyscale values
  Mapping equations to go from HU to density, density to Young’s Modulus etc

- Add contacts, node sets, shells and CFD boundary types to mesh

- Wide range of dedicated export formats
  ABAQUS, ANSYS Classic/Workbench, Adina, COMSOL,
  LS-DYNA, Nastran, Fluent

Bolt on module based on proprietary meshing algorithms
Simpleware Software Structure

CT, MRI, Micro-CT

ScanIP
image processing tools
+FE
volumetric meshing

FE, CFD
IGES, STL

CAD, STL

+CAD
integrating CAD into image

STL internal structures
Unique Features
Unique features of Simpleware

*Simpleware’s technology has several key advantages:*

- **Image Filters**: wide range and flexible
- **Multi-part meshing**: robust automated mesh generation for topologies of arbitrary complexity and with any number of constituent materials/phases
- **Image-based accuracy**: the geometric accuracy of mesh domains is only dependent on image accuracy
- **Surface/Volume mesh quality**: automatic high qualities and user definable
Wide range of image filters

Extensive list of basic and advanced filters to help reduce noise in the image or clean up the segmentation

- Noise
- Metal artefact
- Closing
- Cavity Fill
3D Editing Tools for Interactive Segmentation
Unique features of Simpleware

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- **Image-based accuracy**: the geometric accuracy of mesh domains is only dependent on image accuracy
- **CAD/Surface mesh quality**: high quality triangulation of the surfaces
- **Volume mesh quality**: high quality tet or hex/tet volume discretisation of the domains
Automatic handling of multipart

- Smoothing and meshing multiple segmented regions, important to maintain interfaces from segmentation to model
Automatic handling of multipart

- Smoothing and meshing multiple segmented regions...
  Traditional part-by-part approaches risk poor meshing, gaps/overlaps, non conforming interfaces.

Traditional approach
Build parts one by one

Simpleware algorithms
Unique features of Simpleware

*Simpleware’s technology has several key advantages:*

- **Multi-part meshing**: robust automated mesh generation for topologies of arbitrary complexity (such as foams) and with any number of constituent materials/phases
- **Image-based accuracy**: the geometric accuracy of mesh domains is only dependent on image accuracy
- **CAD/Surface mesh quality**: high quality triangulation of the surfaces
- **Volume mesh quality**: high quality tet or hex/tet volume discretisation of the domains
Smoothing – Topology Preservation

- Accuracy of 3D model from segmentation to smooth 3D surface/volume mesh

Unsmoothed voxel model

Traditional non-topology preserving smoothing

Simpleware topology preserving smoothing

Mesh
Smoothing – Volume Preservation

- Accuracy of 3D model from segmentation to smooth 3D surface/volume mesh

Unsmoothed voxel model: 204 mm³

Traditional smoothing: 193.9 mm³
  ~5% loss

Simpleware smoothing: 203.5 mm³
  ~<0.5% loss
Image-based accuracy: Partial Volume

No loss of accuracy during smoothing

a. Binary interpolation

b. Greyscale based interpolation
Image-based accuracy: Partial volume

Binary interpolation  Greyscale interpolation
Unique features of Simpleware

*Simpleware’s technology has several key advantages:*

- **Multi-part meshing:** robust automated mesh generation for topologies of arbitrary complexity (such as foams) and with any number of constituent materials/phases
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+FE-Grid mesh

Extracts +FE-Grid surface mesh

+FE-Free remeshes surface according to features

+FE-Free fills remeshed volumes with tet elements
Meshing Options

- Surface meshes – single and multipart
- Volume meshes – single and multipart
- Additional mesh features – node sets, surfaces, shells and CFD boundary conditions
Choose +FE-Free Algorithm

Set Your Coarseness Level

Edit Advanced Parameters – Optional
+FE Free mesh controls

Число элементов = 49 000
Число узлов = 11 000
AS = 1.7 / 4.9

Число элементов = 170 000
Число узлов = 39 000
AS = 1.7 / 5.6

Число элементов = 542 000
Число узлов = 117 000
AS = 1.6 / 5.8

Число элементов = 973 000
Число узлов = 190 000
AS = 1.5/5.8
Multipart Mesh Decimation (+FE Free)

Interactive mesh refinement zones

- Draw and position a refinement volume
Multipart Mesh Decimation (+FE Free)

Interactive mesh refinement zones

- Draw and position a refinement volume
- Define degree of refinement and mesh
Multipart Mesh Decimation (+FE Free)
Interactive mesh refinement zones

- Draw and position a refinement volume on 3D rendering
- Define degree of refinement and mesh
- Control surface and internal mesh densities
- Can work on multiple parts....
Multipart Mesh Decimation (+FE Free)

Interactive mesh refinement zones

Volume

Surface Only
New Features – v5.0
Released Jan 2012 ....
Summary of new features – v5.0

General
• Initial scripting implementation
• Linux version of v4.3

ScanIP
• Improved threshold segmentation
• New Preferences dialog
• 2D and 3D view usability enhancements

+FE Module
• Boundary layer meshing for CFD
• Improved Greyscale materials assignment
• Materials library
• +FE-Free meshing performance improvements
• New Improved COMSOL export
• New OpenFOAM export

Beta version for customer testing will be available very soon
Please contact us at support@simpleware.com to register your inte
Initial scripting implementation

- Will allow the automation of repeatable tasks
- Scripts can be interpreted in several languages incl. Python
- Scripts can be executed from the user interface or from the command line

Application Programming Interface (API)
- Is an object-oriented programming library that allows access to most of the features of ScanIP that can be found in the ScanIP user interface
- Will also allow the user to write plugins for ScanIP
  - e.g. to create new menu options for repeatable tasks
  - e.g. to write new filters or segmentation tools
- Macro recording available in the release after v5.0
Initial scripting implementation

- Scripting user interface in ScanIP
Initial scripting implementation

- Simpleware API

```python
Model.SetCompoundCoarseness

SetCompoundCoarseness(val) [Python]

void SetCompoundCoarseness(int val) [C#]

Taking a value between -50 and 50, this function may modify the values of: Use adaptive surface remeshing Allow densification Target minimum edge length Target maximum error Maximum edge length Target number of elements across layers Internal change rate (volume models only) Quality optimization cycles (volume models only)

Parameter(s):
- A
  - value from -50 to 50 specifying how coarse the mesh should be.

Model.SetEditAdvancedParametersManually

SetEditAdvancedParametersManually(b) [Python]

void SetEditAdvancedParametersManually(bool b) [C#]

Sets whether advanced meshing parameters are being edited manually.

Parameter(s):
- b
  - True to edit advanced parameters manually, false otherwise.
```
Linux version

- Previous customer release (v4.3) will be available for Linux
- v5.0 for Linux will be available shortly after the release
- Floating license support for Linux even for Windows users
- Will support most Linux distributions (e.g. Redhat, Ubuntu, Debian, Fedora etc.)
- Allow use of images greater than 2 GB
ScanIP - General

- Improved threshold segmentation
  - Calibrate using histogram or profile line
  - Volume fraction feedback

- New Preferences dialog
  - Set up commonly used options
  - User interface layout, no. of CPUs to use, no. of undo/redo and scripting

- 2D and 3D view usability enhancements
  - Smooth 2D slice zooming
  - New mouse operations to pan slices
  - Pre-set 3D views – XY / XZ / YZ
Boundary Layer Meshing

- Adds layer of boundary layer elements to volume mesh
- Works on any image based model for CFD applications
- For adding to patient-specific blood flow models or pore-scale fluid flow in materials applications
- Compatible with multiple masks for FSI
- User can set number of layers and layer thickness as well as many other advanced controls
- Compatible with Fluent, OpenFOAM, COMSOL and VTK mesh exports
Improved Greyscale materials assignment

- Improvements in the way material properties are assigned to individual elements based on the greyscale intensity.
- Easier to use, more interactive and 3D visualisation for better feedback on created values.

- Materials library – import/export from file
Other +FE module

- **+FE-Free meshing improvements**
  - Surface remeshing step can now use multiple CPUs
    - Can be at least twice as fast – depending on CPUs
  - Significant memory usage reductions
    - E.g. 65% reduction

- **Improved COMSOL export**
  - Project file (*.mph) rather than a mesh file (*.mphtxt)
  - Material properties can now be exported to COMSOL with mesh
  - Also can export contact pairs and shell elements

- **Dedicated OpenFOAM export**
  - Popular open source CFD solver
Case Studies
Case Studies
- Biomechanics/Biomedical -
Head Model for Realistic Simulation

- In vivo MRI scan of 26 year old male
- Segmentation
  - Threshold, floodfill and filters
  - Segmentation of 12 structures

In collaboration with: Naval Research Laboratory and ARUP
Head Model for Realistic Simulation

- **Multi-part mesh generation**
  - 12 structures meshed simultaneously
  - Multipart smoothing with conforming interfaces

- **FE analysis Abaqus and LS-Dyna**
  - Boundary conditions and loads
  - Response to blast wave and to dynamic loading conditions
Head Model for Realistic Simulation
Head Model for Realistic Simulation

- *In vivo* MRI scan of 26 year old male
- **Segmentation**
  - Threshold, floodfill and filters
  - Segmentation of 12 structures
- **Multi-part mesh generation**
  - 12 structures meshed simultaneously
  - Multipart smoothing with conforming interfaces
- **FE analysis Abaqus and LS-Dyna**
  - Boundary conditions and loads
  - Response to blast wave and to dynamic loading conditions
- **Extended to Include a Helmet**

*In collaboration with: Naval Research Laboratory and ARUP*

Dental Model

- **In vivo CT scan**
- **Segmentation**
  - Threshold, floodfill and filters
  - Teeth and mandible
- **+CAD**
  - Introduce template
  - Use template to position implant

*In collaboration with: COMSOL Italy*
Dental Model

- **Multi-part mesh generation**
  - Teeth, mandible and implants
  - Multipart smoothing with conforming interfaces

- **FE analysis in COMSOL**
  - All boundaries and domains available for selection in COMSOL
Investigating Vascular Complications using Computational Fluid Dynamics

- **Abdominal Aortic Aneurysms**
  - Balloon like distensions which are prone to rupture causing life threatening complications
  - Endovascular repair (EVAR) – treatment

- **Patient specific models**
  - Segmented in ScanIP
  - Adaptive surface mesh - ScanFE

- **Boundary conditions**
  - Inlets and superior/inferior outlets

- **Outcome**
  - Analyses may prove useful in determining dangerous hemodynamic factors, allowing for improved risk assessment, assisting the choice between treatments/surgeries

*Thanks to:* Dr. Samuel Thrysøe
MR-Center, Aarhus University Hospital Skejby
Investigating Vascular Complications using Computational Fluid Dynamics

Blood flows into aneurysm
Transcranial Current Stimulation Focality: FEM

- *In vivo* MRI scan
- Segmentation
  - Brain, CSF, skull and scalp
  - +ScanCAD to introduce electrodes

In collaboration with:
City College of New York
Transcranial Current Stimulation Focality: FEM

- **Multi-part mesh generation**
  - 4 structures meshed simultaneously
  - CAD electrodes introduced to the image data

- **FEM analysis**
  - COMSOL Multiphysics
  - Comparison of electrode configurations

*In collaboration with: City College of New York*
Designing and Manufacturing Patient-Specific

**Workflow**
- Using ScanIP to process the patient CT data to provide an accurate STL to the bone geometry
- Then use the Delcam software tools to design and manufacture an implant

**ScanIP**
- Segmented in ScanIP
- Volume and topology preserving

**Delcam**
- CopyCAD – design – trbrid modelling
- Partmaker – production CAM
- Powermill – tool paths for CNC machine

**Outcome**
- From image to implant in 1 week

*Thanks to:
Chris Lawire, Delcam
Chirs Whittington, Camplex*
Subject Specific Humerus Analysis

- Creating the model from medical images
  - Import MRI data
  - Threshold to extract the bone
  - Create surface mesh for export

- Creating landmarks
  - Pick points, record, label and export directly to AnyBody

- Use landmarks to morph bone to AnyBody

- AnyBody analysis run:
  - Average male
  - Scaled to subject body size
  - Scaled to subject body size w/morphed humerus

In collaboration with: AnyBody Technology
Subject Specific Humerus Analysis

Analysis run with load conditions for lifting a dumbbell
Subject Specific Humerus Analysis

- Creating the model from medical images
  - Import MRI data
  - Threshold to extract the bone
  - Create surface mesh for export

- Creating landmarks
  - Pick points, record, label and export directly to AnyBody

- Use landmarks to morph bone to AnyBody
- AnyBody analysis run
- Computed load cases in Ansys

In collaboration with: AnyBody Technology
Case Studies
- Materials, Geology, NDE -
Material Characterisation of Composite

- MicroCT scan of Al-TiB2-Fe alloy
- Segmentation
  - Iso-surface constrained to run through segmented masks

In collaboration with:
Imperial College London
Material Characterisation of Composite

- **Multi-part mesh generation**
  - Merged/contact surfaces at part interfaces
  - Each part based on signal strength
  - Morphological accuracy image limited (Sub Voxel accuracy)

- **Scan to mesh in < 10 minutes**
Auxetic Foam

- **Auxetic Material**
  - Negative Poisson’s ratio
  - Contracts compression/expands tension
  - Example application: filters

- **Synchrotron XMT**
  - 0.003 mm resolution

- **Mesh generation in 10 min**

- **CFD analysis in Fluent**
  - Flow through dual of mesh
  - Fluid-structure interaction

- **Impact simulation in LS-Dyna**

In collaboration with: ARUP, NASA, University of Exeter

Impact on foam sample in LS-DYNA

Courtesy of ARUP
Simulation of Pore Scale Fluid Flow

- XMT scan of sand sample
  - Coarse sand with a mean diameter of 0.55 mm
  - Resolution of 4.3 µm
  - Extracted area in white box

- Segmentation and of particles and airspace – resample to 0.81 x 0.81 x 0.81 mm

- Mesh of complex network of air voids

- FE Simulation in COMSOL
  - Fluid flow velocity in the z direction
  - Particle trace plot

Case study courtesy of:
University of Alaska Fairbanks
Non Destructive Evaluation (NDE)

- **MicroCT scan of ceramic matrix composite (CMC)**
  - Holes clearly visible in the scan

- **Segmentation and mesh generation**
  - Details of holes

- **FE analysis in ABAQUS and Ansys**
  - Stress risers in the composite are located at expected sites such as porosities and voids locations

Совместно с:
NASA Glenn Research Center
Reverse Engineering of Manifold

- Original part
- CT scan
- Mesh generation
  - Threshold and floodfill
  - Scan to mesh in minutes
- Surface model exported into CAD software
- Volume module exported for CFD in Fluent
  - Contours of static pressure

In collaboration with:
University of Exeter
Case Studies
- Natural Science -
Investigating how sharks smell
- CT scan specimen
- Reconstruct internal nasal regions for 3D printing (RP)

Segmentation
- Threshold, floodfill and filters
- Preserving internal regions

STL generation for RP
- Whole head
- Nasal region printed in transparent plastic

Flow tank experiments
- Dye used to help visualise flow

In collaboration with: [Natural History Museum] [Bath University]

Design and Evaluation of a Virtual Rig for Performing Mechanical Tests on Fossilised Bones

- **Tyrannosaurus Rex humerus**
  - Damaged by tendon avulsion
  - Evidence to suggest this was repaired through bone remodelling

- **Segmentation**
  - CT scan of fossilised bone
  - Cortical, trabecular, canal

- **FE mesh generation: +ScanFE**
  - Multipart model
  - Used +ScanCAD to add rig parts

- **Results**
  - Max stress in the mid shaft region
  - Damage to the tendon does not affect functionality
  - Supports evidence that T. Rex arms were not very weak

Thanks to: Lee Margetts, Zartasha Mustansar, Mark Johnson, Paul Mummery, Phil Manning
Case Studies
- Microscopy -
Examples from Microscopy

- Unstretched elastin fibres and collagen
Examples from Microscopy

- Stretched elastin fibres
Examples from Microscopy

- Section of Artery Wall
Conclusions
Summary

- Using Simpleware you can ...
- ...generate **accurate models** easily and **rapidly** simulation/analysis - allows image processing to move beyond descriptive/statistical analysis of data
- ...mesh **any number of structures** simultaneously (handles multi-part junctions) and **define contact surfaces** between them - interfaces are without gaps or overlaps.
- ...generate coupled finite element and finite volume meshes for **multi-physics** applications
- ...**incorporate designs** in the image data – predict and compare the performance of different designs

=> Development based on customer needs
Simpleware Forum

www.simpleware.com/forum

- Post questions, suggestions or share knowledge with other users
- Download archived webinars and training videos
- Access download links for the latest software version
Contact information

Computational Mechanics Laboratory, LLC (CompMechLab® Ltd.)
is official distributor of Simpleware software in Russia, CIS, Baltic States, Finland and Poland.

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