# Simpleware Research

## Release Version V-2024.06

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## Import Formats

- DICOM (version 3.0 and 2D stacks) including:
  - 4D (time-resolved) DICOM with time step selection
  - Option to store DICOM tags with imported data
- DICOM encapsulated STL surface models
- ACR-NEMA (versions 1 and 2)
- DICONDE
- Interfile
- Analyze
- Meta-image
- Raw image data
- 2D image stacks:
  - BMP
  - GIF
  - JPEG
  - PCX
  - PNG
  - TIFF
  - XPM
- Natively supported pixel types:
  - 8-bit Unsigned Integer
  - 16-bit Unsigned Integer
  - 16-bit Signed Integer
  - 32-bit Floating Point
- STL
- PLY
- IGES/IGS
- STEP/STP

## Export Formats

- Background 3D image:
  - RAW image
  - MetaImage
  - Stack of images (BMP, JPG, PNG, TIF)
  - DICOM
- Background 4D image:
  - RAW image (all frames/active frame)
  - MetaImage (all frames/active frame)
  - Stack of images (active frame only)
  - DICOM (active frame only)
- Segmented 3D image:
  - RAW image
  - MetaImage
- Segmented 4D image:
  - Mask RAW (all frames/active frame)
  - Mask MetaImage (all frames/active frame)
- Surface model (triangles):
  - STL
  - IGES
  - 3MF
  - OBJ
  - PLY
  - ACIS (SAT)
  - ANSYS surface
  - ABAQUS surface
  - Open Inventor
  - Point cloud
  - MATLAB file surface
  - DICOM encapsulated STL
- Animations:
  - AVI
  - Ogg Theora
  - H.264/MPEG-4 AVC
  - Windows Media Video (WMV)
  - PNG sequence

  - Transparent PNG sequence
- 2D and 3D screenshot:
  - JPEG
  - PNG
  - Postscript (*.eps)
  - BMP
  - PNM
  - PDF
  - Generate virtual X-Ray, with object burn
- Export scene – export the current 3D view:
  - 3D PDF
  - 3MF
  - OBJ
  - PLY
  - VRML
- FE Output – the FE exports can include nodes, hexahedral, tetrahedral and shell elements, boundary layer prism elements, material properties, contact surfaces and node sets:
  - Abaqus (*.inp)
  - Adina (*.in)
  - Ansys (*.ans)
  - Ansys Workbench (*.inp, preferred)
  - Ansys Workbench (*.cdb)
  - COMSOL Multiphysics (*.nas, recommended)
  - COMSOL Multiphysics (*.mphtxt)
  - COMSOL Multiphysics (*.mph, unsupported)
  - LS-DYNA (*.key)
  - Nastran (*.nas)
  - Patran (*.out)
  - VTK (*.vtk)
  - MATLAB (*.mat)
- CFD Output – the CFD exports can include nodes, hexahedral and tetrahedral elements, boundary layer prism elements, material type and boundary conditions:
  - FLUENT (*.msh)
  - Abaqus (*.inp)
  - OpenFOAM
  - COMSOL Multiphysics (*.nas, recommended)
  - COMSOL Multiphysics (*.mphtxt)
  - COMSOL Multiphysics (*.mph, unsupported)
  - VTK (*.vtk)
  - MATLAB (*.mat)
  - Option to store a mesh for each model in the Simpleware project file
- IGES (*.igs)
- STEP (*.stp)

## General User Interface

- Modern ribbon interface
- Custom ribbon with user-selected tools (My tools)
- Quick find search feature for tools
- User-defined customization: dockable toolboxes, range of 2D/3D view options
- Undo/redo operation support
- Independent part visibility control in 2D and 3D
- Keyboard shortcuts: set user-defined shortcuts to commands or tools to customize and speed up repeated workflows
- Ability to import multiple image sets into the workspace to aid segmentation
- Histogram and profile line utilities assist in finding optimal threshold values
- Automatic logging and timestamp of filters and tools applied since the creation of a project
- Workspace tabs: toggle between the active document, mask statistics, model statistics, centerline statistics, the document log, and the scripting interface
- Integrated dynamic help tool
- Interactive tutorials
- Links to external support resources
- Visualize surface and mask objects together
- Preferences – a number of different options available for default settings:
  - General: number of undos to save, default startup layout, max permissible CPUs for parallelized operations
  - Slice views: display orientation labels, choose whether to use a dark background, specify model contour and mask voxel outline colors
  - PACS: two-way PACS communication, configure access (servers, ports, keys etc.)
  - Segmentation: options to adjust behavior of some segmentation tools and set Hounsfield presets for the Threshold tool
  - 3D view: save last camera position before exiting the document, stereo rendering settings, options to further divide higher-order mesh elements (for FE meshes and NURBS patches)
  - Volume rendering: GPU rendering supported, Background volume rendering visibility on startup
  - Folders: options to change locations of temporary files

  - Statistics: default template for Mask, Model and Centerline statistics
  - Number formatting: customize how numbers are formatted within Simpleware software
  - Annotations: set default styles for annotations
  - Scripting: enable/disable supported scripting languages
  - Licensing: change license location
  - Miscellaneous: reset suppressible dialogs, clear the undo/redo stack, mask name/color creation options
- Interactive anatomy diagrams indicate the expected output, if anatomies are present and identifiable in the input data
- Toggle segmentation of each available anatomy
- Toggle the generation of landmarks
- Landmarks accessible via the Measurements tool
- Reduce region of interest to a sub-volume of a larger extent scan, either automatically or manually

## 2D User Interface

- 3x 2D views
- Orientation labels
- Scale bars
- DICOM information overlay
- Interactive cropping using 2D view
- Window/Level values and control options
- Ability to work on single slice, selection of slices or whole volume
- Slice cursors to identify the position of 2D slices
- Mask visualization options: solid, translucent, voxel outline
- View 3D model contours from model/3D view, surface objects and volume meshes on 2D slices
- Multi-planar reconstruction through translation and rotation of reslicing axes

## 3D User Interface

- Background volume rendering: using standard presets or greyscale mapping
- Single mask volume rendering
- Interactive cropping using 3D view
- Clipping box: unconstrained, interactive sectioning of 3D rendering
- Fast 3D preview mode for rapid visualization of segmentation: ability to change preview quality to speed up rendering and reduce memory consumption
- Live 3D: automatic 3D volume rendering refresh of masks
- Mask transparency
- Wireframe mode
- Vertex lines superimposed over surfaces mode
- Lighting and 3D rendering adjustments
- Background adjustments:
  - Single color
  - Two color gradient
  - Skybox
- View surface entities: CFD boundary conditions, node sets, contacts, shells
- View contours of greyscale-based material properties
- Model shading options: none, flat, Gouraud, hardware shader
- Fullscreen mode
- Camera control tool
- Load and save 3D view camera positions
- View slice planes
- Slice intersection position widget
- Show image dimensions on scale axes
- 3D stereoscopic visualization with selected hardware modes available:
  - Crystal eyes
  - Red/blue
  - Interlaced
  - Left
  - Right
  - Dresden
  - Anaglyph
  - Checkerboard

## Image Processing Tools

- Data processing:
  - Crop
  - Pad
  - Rescale
  - Shrink wrap
  - Resample using various interpolation techniques: nearest neighbor, linear, majority wins and partial volume effects
  - Flip
  - Shear
  - Align
  - Register datasets: align background images to other background images or any other dataset type based on sets of landmark points and/or automatic greyscale-based registration

- Basic filters (most commonly used):
  - Smoothing: recursive Gaussian, smart mask smoothing, de-stepping
  - Noise filtering: mean filter, median filter
  - Cavity fill
  - Island removal filter
  - Fill gaps tool (using largest contact surface or mask priority)
  - Bone filling
- Advanced filters (more specialist applications):
  - Binarization
  - Combine backgrounds
  - Connected component
  - Gradient magnitude
  - Lattice factory
  - Local maxima
  - MRI bias field correction (N4)
  - Masking filter
  - Morphological by reconstruction
  - Sigmoid
  - Simplify partial volume
  - Slice propagate
  - Distance maps:
    - Danielsson
    - Signed Maurer
  - CT correction:
    - CT image stabilizer
    - Histogram cylindrical equalization
    - Histogram slice equalization
    - Metal artefact reduction
  - Smoothing and noise removal:
    - Bilateral
    - Curvature anisotropic diffusion
    - Curvature flow
    - Discrete Gaussian
    - Gradient anisotropic diffusion
    - Min/max curvature flow
    - Patch-based denoising
  - Level sets:
    - Canny segmentation
    - Fast marching
    - Geodesic active contours
    - Laplacian level set
    - Shape detection
    - Threshold level set
  - Skeletonization:
    - Pruning
    - Thinning
- Morphological filters:
  - Erode
  - Dilate
  - Open
  - Close
  - 3D Wrap
- Segmentation tools:
  - Paint/unpaint
  - Paint with threshold
  - Smart paint
  - Interpolation toolbox – contains the following options:
    - Slice interpolation: smooth or linear
    - Slice propagation: adapts to image or uses direct copy
  - Confidence connect region growing
  - Background flood fill
  - Mask flood fill
  - Threshold
  - 3D editing tools for application of filters to local regions: option to apply in multiple regions and on camera facing surface only in advanced tool version
  - Mask ungroup tool
  - Automated generation of masks for pre- segmented images
  - Magnetic lasso
  - Multilevel Otsu segmentation
  - Split regions tool, with the ability to mark regions in the 3D view
  - Merge regions tool
  - Direct copy: background to mask or mask to background
  - Watershed segmentation tool
- Boolean operations – applied to/between masks. General and Venn diagram UI options:
  - Union
  - Intersect
  - Subtract
  - Invert
- Local surface correction: local, greyscale-informed correction of mask surface, including the ability to apply on a region of interest only

- Multi-label tools – use mask labels to label different regions within a mask. Use for statistics and visualization:
  - Label disconnected regions
  - Split mask into pores
  - Combine masks to multi-label mask
  - Mask label editor
  - Reports (automatically generate pre-formatted reports of common metrics using a multi-label mask or full model's mesh):
    - Particles report
    - Pores and throats report
- Window/level tool
- Overlap check: display/generate mask to check overlap volume in active masks

## Ankle CT Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for the ankle
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Calcaneus
  - Fibula
  - Talus
  - Tibia
- Landmarks placed on identified anatomy:
  - Ankle center
  - Fibular notch
  - Malleolus (lateral, medial)
- Automatic ROI detection within larger extent scans
- Option to retain all bone fragments

## Craniomaxillofacial (CMF) CT Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for the CMF region
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Cranium
  - Cranium (filled orbitals)
  - Mandible
  - Cervical spine
  - Upper/lower canines
  - Upper/lower incisors
  - Upper/lower molars
  - Ear canals
  - Airways
  - Eyeballs
  - Optic nerves
  - Mandibular nerves
  - Cranial cavity
  - Skin
- Landmarks placed on identified anatomy:
  - Mandibular foramen (left/right)
  - Mandibular angle (left/right)
  - Mandibular symphysis
  - Coronoid process (left/right)
  - Condylar process (left/right)
  - Orbitale (left/right)
  - Porion (left/right)
  - Nasion
  - Foramen magnum center (FMC)
- Automatic ROI detection within larger extent scans
- Option to retain all bone fragments
- Option to split teeth into canines, incisors and molars

## Heart Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for heart blood pool and muscle
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Aorta
  - Left Atrium
  - Left Coronary Artery
  - Left Ventricle
  - Myocardium
  - Pulmonary Artery
  - Right Atrium
  - Right Coronary Artery
  - Right Ventricle
- Landmarks placed on identified anatomy:
  - Aortic Commissure (1, 2 and 3)
  - Aortic Coronary Cusp (left, right, and posterior)
  - Aortic Coronary Ostium (left, right)
  - Atrial Appendage (left, right)
  - Coronary Sinus Ostium Centroid
  - Left Ventricle Apex
  - Left Ventricle Base
  - Right Ventricle Apex

  - Tricuspid Valve Centroid
  - Vena Cava Ostium Centroid (inferior, superior)
- Segmentation and landmarking available for 3D and 4D frames
- Automatic ROI detection within larger extent scans

## Heart Valve Analysis

- Analysis tool streamlining the workflow for computing characteristics of Aortic Valve, Mitral Valve, Tricuspid Valve or Pulmonary Valve. Tools include:
  - Fit planes through Cusps (Aortic Valve only)
  - Measure distance to Ostia (Aortic Valve only)
  - Fit plane through Annulus (all)
  - Centerline analysis (Aortic and Pulmonary Valves):
    - Aortic Valve: centerlines created for the Ascending Aorta, and shapes generated representing best fit circles for the Sinotabular Junction, Sinuses of Valsalva and Tubular Ascending Aorta
    - Pulmonary Valve: the outputs include centerlines created for the Pulmonary Trunk and left/right Artery

## Hip CT Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for hip or pelvis region
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Hip (left and right)
  - Sacrum
  - Proximal Femurs
- Landmarks placed on identified anatomy:
  - Anterior Superior Iliac Spine (left and right)
  - Posterior Superior iliac Spine (left and right)
  - Greater Trochanter (left and right)
  - Lesser Trochanter (left and right)
  - Pubic Tubercle (left and right)
  - Femur Head (left and right)
  - Coccyx
- Automatic ROI detection within larger extent scans
- Option to retain all bone fragments

## Hip Revision CT Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for hip or pelvis region when metal artefacts are present
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Hip (left and right)
  - Sacrum
  - Proximal Femurs
  - Implants - If selected, the tool will output four masks: Cups, Stems, Other metal and All metal.
- Landmarks placed on identified anatomy:
  - Anterior Superior Iliac Spine (left and right)
  - Posterior Superior iliac Spine (left and right)
  - Greater Trochanter (left and right)
  - Lesser Trochanter (left and right)
  - Pubic Tubercle (left and right)
  - Femur Head (left and right)
  - Coccyx
- Automatic ROI detection within larger extent scans
- Option to retain all bone fragments

## Knee MRI Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for the knee
- Automatic segmentation suitable for use on MRI scans (PD weighted Sagittal/Coronal and T1 Coronal and T2 Sagittal)
- Produces masks for:
  - Femur and associated cartilage
  - Tibia and associated cartilage
  - Patella
  - Fibula
- Landmarks placed on identified anatomy:
  - Femur Condyles (lateral and medial)
  - Femur Epicondyles (lateral and medial)
  - Tibia Condyles (lateral and medial)
  - Tibia Intercondylar Eminence
- Automatic ROI detection within larger extent scans

## Knee CT Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for the knee
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Femur
  - Tibia
  - Fibula
  - Patella
  - Fabella (where present)

- Landmarks placed on identified anatomy (for left and right knees):
  - Femur posterior condyles (lateral, medial)
  - Femur epicondyles (lateral, medial)
  - Femur distal condyles (lateral, medial)
  - Femur proximal shaft centre
  - Tibia condyles (lateral, medial)
  - Tibia intercondylar tubercles (lateral, medial)
  - Tibia posterior condyles (lateral, medial)
  - Tibial tuberosities
  - Tibia distal shaft centre
  - Patella poles (distal, proximal)
  - Patella borders (lateral, medial)
  - Fibula apices
- Automatic ROI detection within larger extent scans
- Option to retain all bone fragments

## Shoulder CT Segmentation and Landmarking

- Anatomy-specific automated segmentation tool for the shoulder
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Humerus
  - Scapula
  - Clavicle
- Landmarks placed on identified anatomy:
  - Clavicle lateral end
  - Clavicle medial end
  - Malleolus (lateral, medial)
  - Humerus bicepital groove
  - Humerus bicipital groove
  - Humerus greater tuberosity
  - Humerus head centre
  - Humerus lesser tuberosity
  - Scapula acromion
  - Scapula coracoid
  - Scapula glenoid cavity
  - Scapula inferior angle
  - Scapula medial border
  - Scapula notch
  - Scapula spine
  - Scapula superior angle
- Automatic ROI detection within larger extent scans
- Option to retain all bone fragments

## Spine CT Segmentation

- Anatomy-specific automated segmentation tool for the spine
- Automatic segmentation suitable for use on CT scans
- Produces masks for:
  - Vertebrae: the vertebrae are selected as a single part using the selector diagram, but the output is split into individual vertebrae where possible
  - Sacrum
- Automatic ROI detection within larger extent scans
- Option to retain all bone fragments
- Option to output additional spine joined mask
- An additional mask will be outputted which contains all the vertebrae merged together. This option is useful for applications where individual vertebrae are not required

## Statistical Analysis

- Quick statistics: quickly compute commonly required quantities (volume, surface area, average greyscale, etc.)
- Mask statistics (based on voxel information):
  - Built-in templates: general statistics, contact statistics, material statistics, orientation, pore sizes, surface statistics
  - Ability to generate user-defined templates
  - Variety of statistical information pertaining to:
    - Voxels: count, volume, surface area, etc.
    - Greyscales: mean, standard deviation, minimum, maximum, etc.
  - Surface estimation: area, area fraction, volume, volume fraction, etc.
  - Material properties: mass, mass density, Young's modulus, Poisson's ratio, moment of inertia, etc.
  - Axis-aligned bounding boxes
  - Axis-aligned bounding ellipsoids
  - Object-oriented bounding boxes
  - Object-oriented bounding ellipsoids
  - Create a user-defined statistic
- Model statistics (based on polygon information):
  - Ability to generate user-defined templates
  - Built-in templates: general statistics (perimeters, surfaces, volumes and NURBS surfaces), mesh quality (CFD, FE-linear elements and FE-quadratic elements), orientation (perimeters, surfaces, volumes), pore sizes, surface quality (linear, quadratic), volume mesh statistics

  - Variety of statistical information pertaining to:
    - Surface parameters: element count, node count, edge count, etc.
    - Perimeters: length, mean edge length, mean dihedral angle, etc.
    - Surface triangle and quadrilateral primitives: edge- length, in-out ratio, distortion, etc.
    - Tetrahedral, hexahedral, pyramid and prismatic volume element primitives: angular skew, volume skew, shape factor, Jacobian, etc.
    - Axis-aligned bounding boxes
    - Axis-aligned bounding ellipsoids
    - Object-oriented bounding boxes
    - Object-oriented bounding ellipsoids
    - Create a user-defined statistic
- Centerline statistics:
  - Built-in templates: line orientation, lines by network, lines by node, constriction, shape, twist, nodes by network.
  - Ability to generate user-defined templates
  - Variety of statistical information pertaining to:
    - Lines: count, network, length, Euclidean length, curvature, torsion, closed, looped, positions, orientation, connection count, cross-sectional area and perimeter, incircle radius, twist, control points, object-oriented bounding boxes, mean orientation vector, best fit circle, inscribed radius, circumscribed radius, bounding ellipse radius
    - Nodes: name, mask, network, position, line count, connection count.
    - Create a user-defined statistic
  - Probe centerlines to get measurements at specific locations
- Save and import user-defined templates and statistics
- Compute statistics within user-defined regions of interest (ROIs)

## Fiber Orientation Analysis

- Allows fiber orientation to be analyzed directly from the image data (without the need for segmentation)
- Option to include a mask representing the fiber region for fiber volume and diameter information
- Specify the fiber diameter and the sampling size to be analyzed for the whole image or a region of interest
- Copy the centerlines generated during the analysis to the centerlines editor for further editing or analysis
- Statistics for analyzed region or region of interest:
  - Analyzed volume, fiber volume, fiber density, principal orientation
  - Eigen analysis (major, medial, minor vectors and value)
  - Orientation tensor
  - Fiber length and cross-section information
- Plot statistics, export as *.png or *.csv:
  - Angle to principal orientation histogram
  - Angle to image axis histogram
  - Orientation tensor components vs image axis
  - Fiber density vs image axis (requires segmentation)
  - Principal orientation hedgehog diagram
  - Length of whole fibers histogram
  - Diameter of all segments histogram (incircle/best fit circle) (requires segmentation)
- Visualize vectors:
  - Orientation vectors, Eigen vectors, Eigen ellipsoids in 3D view
  - Orientation vectors in 2D slices
  - Change color scheme, and glyph density/scale/width
  - Export as *.csv or *.txt files
- Map to mesh:
  - Export (or assign using Simpleware Elite or Apex) fiber orientation information per mesh cell
  - Average orientation tensor, eigenvector and eigenvalue data calculated for each mesh cell
  - Export volume fraction information per mesh cell (requires segmentation)

## Particle Analysis

- Allows particles (either isolated or touching) to be analyzed from a mask or multi-label mask
- Two types of pore analysis available:
  - Touching: for particles that are in contact with each other
  - Isolated: for particles that are separated from each other
- Statistics for analyzed region or region of interest:
  - Particle volume (Total, Mean, SD, Min, Max)
  - Particle area (Mean, SD, Min, Max)
  - Particle volume fraction
  - Particle equivalent volume sphere diameter (Mean, SD, Min, Max)
  - Particle bounding box extent (Mean, SD, Min, Max)
  - Particle ellipsoid diameter (Mean, SD, Min, Max)
  - Particle flatness
  - Particle elongation
  - Particle shape factor
  - Particle sphericity

- Plot statistics, export as *.png or *.csv:
  - Volume histogram
  - Area histogram
  - Flatness histogram
  - Elongation histogram
  - Shape factor histogram
  - Sphericity histogram
- Particle visualization:
  - Contact count
  - Voxel count
  - Surface area
  - Boundary contact area
  - Label contact area
  - Volume
  - Max greyscale
  - Mean greyscale
  - Major length
  - Flatness
  - Elongation
  - Shape factor
  - Sphericity
  - Orientation angle to x/y/z axis
  - Orientation to mean
  - Export as *.csv or *.txt files
- Map to mesh:
  - Export (or assign using Simpleware Elite or Apex) particle volume fraction information per mesh cell

## Pore Analysis

- Allows pores (either open or closed) to be analyzed from a mask or multi-label mask
- Two types of pore analysis available:
  - Open: for connected pore networks
  - Closed: for pores that are separated from each other
- Statistics for analyzed region or region of interest:
  - Total pores count
  - Total throat count volume
  - Volume fraction
  - Internal pore volume (Mean, SD, Min, Max)
  - Internal pore surface area (Mean, SD, Min, Max)
  - Pore equivalent volume sphere diameter (Mean, SD, Min, Max)
  - Pore flatness (Mean, SD, Min, Max)
  - Pore elongation (Mean, SD, Min, Max)
  - Pore shape factor (Mean, SD, Min, Max)
  - Pore sphericity (Mean, SD, Min, Max)
  - Pore coordination number (Mean, SD, Min, Max)
  - Throat contact count
  - Throat contact area
  - Throat radius (Mean, SD, Min, Max)
  - Throat flatness (Mean, SD, Min, Max)
  - Throat elongation (Mean, SD, Min, Max)
  - Throat eccentricity (Mean, SD, Min, Max)
  - Throat shape factor (Mean, SD, Min, Max)
- Plot statistics, export as *.png or *.csv:
  - Volume histogram
  - Area histogram
  - Flatness histogram
  - Elongation histogram
  - Shape factor histogram
  - Sphericity histogram
- Particle visualization:
  - Contact count
  - Voxel count
  - Surface area
  - Boundary contact area
  - Label contact area
  - Volume
  - Max greyscale
  - Mean greyscale
  - Major length
  - Flatness
  - Elongation
  - Shape factor
  - Sphericity
  - Orientation angle to x/y/z axis
  - Orientation to mean
  - Export as *.csv or *.txt files
- Map to mesh:
  - Export (or assign using Simpleware Elite or Apex) pore volume fraction information per mesh cell

## Surface Mesh Generation

- Topology and volume preserving smoothing
- Triangle smoothing
- Decimation

- Multipart surface creation
- Surface element quality control (for volume meshing in third party software)
- So-called 'sub-pixel accuracy' through the use of partial volume effects data

## Surface Mesh Quality Inspection Tool

- Inspect surface triangles or clusters of triangles
- Option to show mesh errors (e.g. surface holes, surface intersections) and warnings
- Show distorted elements above a user-defined threshold
- Display quality metric histograms
- Zoom into the pathological element to inspect it more closely

## Measurement Tools

- Create and save points, distances and angles in 2D/3D
- Visualization options to display all at once or selected
- Snap to 3D surface option
- Profile line
- Histogram
- Export as comma-separated values
- Centerline creation toolkit:
  - Centerline creation (general)
  - Centerline creation for fibers
  - Junction editing
- 2D contour measurements:
  - Creation mode
  - Area
  - Total perimeter
  - In-circle diameter
  - Out-circle diameter
  - Trigone-Trigone (TT) distance
  - Septal to Lateral (SL) distance
  - Intercommissural (IC) distance
  - Posterior perimeter
- Wall thickness analysis tool for masks or surface objects, using a raycasting or sphere fitting algorithm
- Mask similarity calculator:
  - Dice score
- Shape-based measurement tools:
  - Shape editor: create, edit, visualize, export and measure shapes
  - Shape fitting: fit shapes to geometry
  - Shape-to-shape measurements: obtain measurements between shape objects
- X-ray image import, with alignment and object registration

## 3D Printing Toolkit

- Set of tools for editing, analyzing and visualizing surfaces before sending them to a 3D printer which includes:
  - Preparation tools:
    - Model preview
    - Mask to surface
    - Emboss text
    - Hollow
    - Cut
    - Create connectors (inc. manual and automatic options)
    - Pins and sockets connectors
  - Design tools:
    - Create cutting guide
  - Analysis tools:
    - Greyscale visualization
  - Inspection tools:
    - Color proofing
    - Check printability
  - Export a variety of file formats including:
    - 3MF
    - STL
    - OBJ
    - PLY
    - 3D PDF
    - VRML

## Animations

- Create and export animations in the 3D view
- Built-in-quick animations:
  - Rotations
  - Slice reveals
  - Volume rendering
- User-defined animations cues:
  - Background colors
  - Camera (orbits, follow path and key frame-based),
  - Clipping
  - Opacity
  - 2D slice planes
  - Volume rendering

- Export formats:
  - AVI
  - Ogg Theora
  - H.264/MPEG-4 AVC
  - Windows Media Video (WMV)
  - PNG sequence
- Variety of export sizes: From 480p to 2160p (4K)

## 4D Frame Toolbox

- Active frame slider to manually control frame displayed in the 2D slice views and 3D view
- Cine mode for active slice view and 3D view
- Compare frames: compare two 2D slice views to examine differences
- Options to set the time between frames and delete unwanted frames

## Working with Surface Data

- Surface to mask tool – conversion of surface objects to image masks by voxelization. Three available methods:
  - Accurate for manifold objects: when converting watertight surface object
  - Accurate for non-manifold objects: when converting non-watertight surface object
  - Robust: Less accurate but failsafe option for poor quality surface objects
- Mask to surface tool: use the current 3D visualization of a mask to create a surface object
- Create shape – generate surface object primitives:
  - Cuboid
  - Cylinder
  - Sphere
  - Cone
  - Tube
- Sweep centerlines: create surface objects from centerlines or centerline networks
- Manipulate surface objects both interactively and by absolute position and orientation:
  - Transform
  - Rotate
  - Scale: aspect ratio preserving or along specified axis
  - Zero position: move surface object to the image space origin
- Use global, local or user-defined axis for object manipulation
- 2D nudge tool to fine tune position of surface object in 2D views
- Snap registration tool: automatic registration of two surfaces with no additional inputs
- Register datasets tool – register surfaces to other surfaces or any other dataset types:
  - Register to datasets in the current project or a foreign project (a separate Simpleware project file)
  - Best fit algorithm to align surface objects together with 3 methods: landmark, automatic, landmark and automatic
  - Landmark: uses picked landmark points on the moving and fixed surface objects
  - Automatic: uses all points on the moving and fixed surface objects
  - Landmark and automatic: uses landmark registration initially, then automatic registration for fine tuning
  - Root mean square error (RMSE) reported
- Check and fix tool: check for surface errors and attempt to fix them
- Group surfaces: group surface objects into one single object
- Ungroup surfaces: create new surfaces by separating a surface object into its connected components
- Surface to surface Boolean operations – general and Venn diagram interface options:
  - Union
  - Intersect
  - Subtract
- Smooth – surface triangle smoothing:
  - Option to preserve volume
  - Option to preserve edges above a user-defined angle threshold
- Subdivide – increase triangle count, e.g. to better capture surface curvature, with the following methods:
  - Adaptive linear
  - Linear
  - Butterfly
  - Loop
- Flatten: project triangles to a plane
- Decimate: reduce triangle count by percentage reduction or maximum number of triangles
- Remesh: regenerate surface triangulation based on target edge length
- Remove triangles: delete unwanted triangles
- Fill holes – in a surface's triangulation:
  - Displays number of holes and smallest/largest hole diameter
  - Fill all holes or fill holes up to a user-defined maximum hole size

- Resurface: use voxelization and iso-surface extraction to re-triangulate surface objects
- Clip: cut a surface object using finite plane
- Extrude: extrude selected triangles in a specified direction
- Hollow: hollow a surface object, creating an inner and outer surface
- Sweep: dilate the triangles of a surface object inwards and outwards to create a tube (Specialist option only)
- Auto-pad: auto pad the image boundary to contain surface object
- Feature edge editor: visualization and selection of feature edges that the meshing algorithms should try to preserve
- Interactive clipping box for section views of surface objects in 3D
- Surface deviation analysis tool – comparison of a test surface:
  - Tool allows re-meshing of surfaces (user can set edge lengths required)
  - Options to set distance limits for deviation analysis
  - Surface deviation on regions of interest or the whole part can be calculated
  - 3D color map with customizable scale, and option to set out of range color
  - 3D color map also allows the user to set nominal and critical thresholds for positive and negative values
  - Annotate visualization with minimum and maximum surface deviation
  - Probe the visualized surface deviation to show point deviation values
  - Statistical values calculated for:
    - Upper and lower deviation
    - Mean (overall), mean positive and mean negative
    - Root Mean Square Error (RMSE)
    - Percentage area above critical and nominal positive deviation
    - Percentage area below critical and nominal negative deviation
  - Export statistics as text file

## Internal Structures Wizard

- Allows shelling and adding a range of internal structures flexibly to any surface object
- Applications include reducing material usage and weight of 3D printed models
- Unit cell types available are:
  - Schwartz primitive
  - Schwartz primitive (pinched)
  - Schwartz diamond
  - Schwartz 'W'
  - Schoen gyroid
  - Neovius' surface
  - Cylinder grid
  - Schwartz primitive (2.5D)
  - Schwartz primitive (pinched) (2.5D)
  - Schwartz 'W' (2.5D)

## NURBS Model Generation

- Two-step process of creating triangulated model preview before fitting NURBS patches
- Additional remeshing algorithm
- Patch construction (auto or manual)
- Additional patch fitting options (snap to parent surface)

## Quality Inspection Tool

- Inspect NURBS model to check for errors
- Inspect individual patches or clusters of patches
- Option to show errors (e.g. surface holes and surface intersections) and warnings (e.g. patch distortions)
- Show distorted patches above a user-defined threshold
- Click on an entry in the quality inspection dialog to zoom into the specific patch
- Also pin-points location within the image data/segmentation

## Design Link with SOLIDWORKS®

- Import formats:
  - SOLIDWORKS SLDPRT
  - SOLIDWORKS SLDASM
- Launch SOLIDWORKS directly from Simpleware Elite or Apex
- Browse currently open SOLIDWORKS documents or choose additional documents to open
- Import individual parts or whole assemblies
- Visualize Design Link surface objects alongside segmented masks
- Interactively position your assembly
- Export Simpleware surface objects to SOLIDWORKS
- Export Simpleware measurements to SOLIDWORKS as reference geometries
- Part synchronization:
  - Push and pull only the geometry or position/orientation changes, or all changes at once
  - Re-link Design Link surface objects with SOLIDWORKS parts to continue working later

  - Unlink Design Link surface objects to allow editing parts in Simpleware
- Interactive positioning:
  - Position and orientation: interactively reposition the imported parts
  - Zero position: automatically place imported parts within image volume
  - Assembly transformation matrices automatically reported to the log

## Multipart Volumetric Meshing (options available for FE and CFD meshes)

- Mixed hexahedral/tetrahedral or pure tetrahedral element volume meshing
- Element types: linear, straight quadratic or curved quadratic
- Choice of meshing algorithms:
  - FE Grid: image resolution-based mesh
  - FE Free: progressively decimated (or refined) mesh from the image resolution
- Advanced FE Grid options:
  - Smooth or voxel cell (pure hexahedral with unsmoothed boundaries/interfaces) mesh
  - Surface smoothing
  - Mesh quality optimization
  - Mesh adaptation
  - Smooth masks against exterior
- Advanced FE Free options:
  - Coarseness slider to automatically adjust advanced parameters relating to mesh coarseness
  - Per-part meshing settings
  - Meshing mask and surface objects in the same model (without voxelization)
  - Adaptive surface remeshing
  - Characteristic element edge lengths (min/max)
  - Surface elements constraints: surface change rate, number of elements across a layer
  - Volume elements constraints: internal change rate, number of quality optimization cycles
  - Other options: snap to parent surface, snap surface object nodes to boundaries, smooth masks against exterior, refine near slits and cavities
- Additional mesh quality improvement – user-defined minimum target element qualities. Quality metrics include:
  - In-out aspect ratio
  - Tetrahedron volume skew
  - Tetrahedron minimum dihedral angle
  - Jacobian
  - Jacobian and in-out ratio
  - Jacobian, in-out ratio and edge length aspect ratio
  - Jacobian, in-out ratio and min weighted sine of dihedral angle
- Allow element nodes to be slightly off-surface to improve mesh quality
- Optimize mesh performance for dynamic simulations by avoiding small edge lengths
- Preserve mesh periodicity at periodic faces (if any) of the geometry
- Part-wise mesh generation with smooth, conforming interfaces at boundaries
- Adaptive meshing for reduced mesh density away from boundaries
- Automated feature-based mesh refinement (FE Free)
- Boundary layer meshing: generate triangular prism cells close to solid boundaries
- Element quality statistics provided in the log history
- Mesh refinement regions – user-defined mesh density control through the use of regions of interest (ROIs) of high density and relaxation/transition zones. Available ROI options include:
  - Rectangular frustum
  - Polygonal frustum
  - Lasso frustum
  - Sphere/spheroid
  - Cube/cuboid
  - Cylinder
  - Finite plane
  - Cone
- Support for independently meshing objects (specialist option)

## Multipart Volumetric Meshing (options available for FE meshes only)

- Shell elements: shell element sets can be defined at the outer surfaces and interfaces of parts. This shell mesh can either be exported on its own or as a layer of elements encasing the volumetric mesh
- The ROI tools can also be used to define shell element sets
- Contact Surfaces and Node Sets: contact surfaces and node sets can be automatically defined between any parts in contact as well as between a part and the surrounding medium and a part and the borders of the bounding box. The ROI tools can also be used to define surface and node sets. When ROIs are used for node and surface sets, the mesh can be aligned to these

- Multi-label mesh (and contact surfaces) export available for Abaqus (*.inp)

## Multipart Volumetric Meshing (options available for CFD meshes only)

- CFD Export Options — material definitions can be set to either fluid or solid. It is possible to define any identifiable contact surface as a specific boundary type:
  - Wall
  - Symmetry
  - Inlet (velocity, pressure, mass-flow, vent or fan intake)
  - Outlet (pressure, exhaust, vent or outflow)
  - Interior boundaries (interface, porous jump, fan or radiator)
  - Generic patch (to be assigned in CFD package)
- Define high-quality arbitrary inlets/outlets for CFD using mesh clipping planes, either automatically (using centerlines) or manually
- Boundary layer meshing: generate triangular prism cells close to solid boundaries to model high fluid gradients in the viscous regions

## Material Properties (volume element material properties can be set to)

- Placeholder: for later definition in FE package of choice
- Homogeneous: where the mass density, Young's Modulus and Poisson's ratio are constants defined by the user
- Greyscale: where material properties within parts can be automatically assigned from the image data, based on user-defined functions to relate greyscale value of the original data to density
- Density: as a function of element parent voxel greyscale (GS) is given by:

  $\rho = a + (b \times GS)$

  (where a and b are user-defined variables which may be non-integer)
- Young's Modulus: as a function of density is given by:

  $E = a + (b \times \rho c)$

  (where a, b and c, are user-defined variables)
- Poisson's ratio: as a function of density is given by:

  $\mu = a$

  (where a is user-defined)
- Map to mesh:
  - Assign fiber orientation information directly to each mesh cell in a FE model
  - Average orientation tensor, eigenvector and eigenvalue data calculated for each mesh cell

## Mesh Quality Inspection Tool

- Inspect FE/CFD mesh quality based on a variety of metrics
- Inspect elements/cells individually or in groups (violating the same quality metric)
- Show mesh errors (self-intersections) and/or warnings (distorted elements/cells)
- Visualize quality metric distributions via histogram plots
- Click on an entry in the quality inspection dialog to zoom into the specific element/cell
- Also pin-points location within the image data/segmentation
- User-defined thresholds on quality metrics
- Available mesh quality metrics:
  - Negative Jacobian
  - Volume mesh self-intersection
  - In-out aspect ratio
  - Edge length aspect ratio
  - Angular skew
  - Volume skew
  - Shape factor
  - Min/max dihedral angle
  - Jacobian
  - Minimum edge length
  - Orthogonal skew
  - Face area
  - Element volume
  - Boundary layer edge length ratio (for CFD meshes only)
  - Boundary layer wedge triangle face edge length ration (for CFD meshes only)

## Volume Mesh Statistics

- Statistics template for Model statistics
- Count information for elements, nodes, edges, faces
- Volume statistics for elements
- Length statistics for edges
- Area statistics for faces

## Volume Mesh Import and Remeshing

- Import a variety of commonly used volume mesh formats:
  - Ansys databases (*.cdb)
  - Abaqus input files (*.inp)
  - Nastran files (*.bdf, *.dat, *.nas, *.nastran)

  - VTK files (*.vtk, *.vtu)
- Adjust color and toggle visibility of individual element sets
- Position and orientate meshes using interactive tool
- Scale volume meshes
- Extract outer part surfaces of element sets for use with surface tools
- Add imported volume meshes to FE and CFD models
- Remesh imported volume meshes to different levels:
  - Leave mesh unchanged: no remeshing
  - Improve element qualities, preserve element connectivity
  - Regenerate volume mesh, preserving surface
  - Regenerate surface and volume mesh
- Add material properties: see “Material Properties: Volume element material properties can be set to” section above
- Inspect mesh quality: see “Mesh Quality Inspection Tool” section above
- Mesh export formats: see “Export Formats” section above

## Scripting

- The Simpleware Application Programming Interface (API) is an object-oriented programming library that allows access to most of the features of Simpleware
- Support for a variety of scripting languages:
  - Python 3
  - C#
- Macro recording: record, save and play macro
- Convert log entry to script
- Script editor with autocomplete functionality
- Console: a GUI-less version of Simpleware which can be run with scripted workflows

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