Course objectives
Upon completion of this course you will be able to:

- Define general contact and contact pairs
- Define appropriate surfaces (rigid or deformable)
- Model frictional contact
- Model large sliding between deformable bodies
- Resolve overclosures in interference fit problems
- Understand how nonlinear problems are solved in Abaqus
- Develop Abaqus models that will converge
- Identify modeling errors that cause models to experience convergence difficulties
- Recognize when a problem is too difficult or too ill-posed to be solved effectively

Targeted audience
Simulation Analysts

Prerequisites
This course is recommended for engineers with experience using Abaqus

3 days
Day 1

- Lecture 1  Introduction to Nonlinear FEA
- Lecture 2  Nonlinear FEA with Abaqus/Standard
  - Workshop 1  Nonlinear Spring
- Lecture 3  Solution of Unstable Problems
  - Workshop 2  Reinforced Plate Under Compressive Loads
- Lecture 4  Why Abaqus Fails to Converge
  - Workshop 3  Crimp Forming Analysis
Day 2

- Lecture 5  Convergence Problems: Element Behavior
  - Workshop 4  Element Selection
- Lecture 6  Convergence Problems: Constraints and Loading
- Lecture 7  Convergence Problems: Materials
  - Workshop 5  Limit Load Analysis
  - Workshop 6  Ball Impact (optional)
- Lecture 8  Contact Workflow
  - Workshop 7  Compression of a Rubber Seal
Day 3

- Lecture 9  Surface-based Contact
  - Workshop 8  Lap Joint Analysis
- Lecture 10  Contact Properties
  - Workshop 9  Disk Forging Analysis
- Lecture 11  Interference Fits
  - Workshop 10  Interference Fit Analysis
  - Workshop 11  Syringe Analysis (optional)
- Lecture 12  Modeling Tips
  - Workshop 12  Snap Fit Analysis
  - Workshop 13  Analysis of a Radial Shaft Seal (optional)
Additional Material

- Appendix 1  Node-to-Surface Formulation
- Appendix 2  Contact Elements
- Appendix 3  Dynamic Contact using Implicit Integration
- Appendix 4  Contact Logic and Diagnostics Tools
  - Workshop 14  Bolted Flange Analysis
  - Workshop 15  Bolted Flange Analysis: Infinitesimal Sliding
  - Workshop 16  Contact: Beam Lift-Off
  - Workshop 17  Contact: Stabilization
- Appendix 5  Additional Contact Features
  - Workshop 18  Pipe Reel Analysis
SIMULIA is the Dassault Systèmes brand for Realistic Simulation solutions

Portfolio of established, best-in-class products
- Abaqus, Isight, Tosca, fe-safe, Simpack

* Included in extended licensing pool
<table>
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<tr>
<th>Portfolio</th>
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<tr>
<td><strong>Abaqus</strong></td>
<td>- Routine and Advanced Simulation</td>
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<td>- Linear and Nonlinear, Static and Dynamic</td>
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<td>- Thermal, Electrical, Acoustics</td>
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<td>- Extended Physics through Co-simulation</td>
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<td>- Model Preparation and Visualization</td>
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<td><strong>Isight</strong></td>
<td>- Process Integration</td>
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<td>- Six Sigma and Design of Experiments</td>
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<td>- Structural and Fluid Flow Optimization</td>
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<td>- Topology, Sizing, Shape, Bead Optimization</td>
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<tr>
<td><strong>fe-safe</strong></td>
<td>- Durability Simulation</td>
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<td>- Low Cycle and High Cycle Fatigue</td>
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<td>- Weld, High Temperature, Non-metallics</td>
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<td><strong>Simpack</strong></td>
<td>- 3D Multibody Dynamics Simulation</td>
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<td>- Mechanical or Mechatronic Systems</td>
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<td>- Detailed Transient Simulation (Offline and Realtime)</td>
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**Realistic Human Simulation**
- High Speed Crash & Impact
- Noise & Vibration

**Material Calibration**
- Workflow Automation
- Design Exploration

**Conceptual/Detailed Design**
- Weight, Stiffness, Stress
- Pressure Loss Reduction

**Safety Factors**
- Creep-Fatigue Interaction
- Weld Fatigue

**Complete System Analyses**
- (Quasi-)Static, Dynamics, NVH
- Flex Bodies, Advanced Contact
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Lesson 1: Introduction to Nonlinear FEA

Lesson content:

- Why Use FEA to Solve Mechanics Problems?
- What is Convergence?
- When is a Problem Nonlinear?
- Properties of Linear Problems in Mechanics
- Properties of Nonlinear Problems in Mechanics
- Numerical Techniques for Solving Nonlinear Problems
Lesson content:

- Equilibrium Revisited
- Nonlinear Solution Methods
- Abaqus/Standard Convergence Criteria: An Overview
- Automatic Time Incrementation
- Contact Convergence
- Workshop Preliminaries
- Workshop 1: Nonlinear Spring (IA)
- Workshop 1: Nonlinear Spring (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.

1.5 hours
Lesson 3: Solution of Unstable Problems

Lesson content:

- Unstable Quasi-Static Problems
- Globally Unstable Problems
- Stabilization of Local Instabilities
- Symptoms of Local Instability
- Automated Viscous Damping
- Implicit Dynamics
- Examples
- Stabilization of Initial Rigid Body Motion
- Workshop 2: Reinforced Plate Under Compressive Loads (IA)
- Workshop 2: Reinforced Plate Under Compressive Loads (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.

2.5 hours
Lesson 4: Why Abaqus Fails to Converge

**Lesson content:**

- The Basic Problems
- Understanding the Warning Messages
- Helping Abaqus Find a Converged Solution
- Workshop 3: Crimp Forming Analysis (IA)
- Workshop 3: Crimp Forming Analysis (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson content:

- Hourglassing in Reduced-Integration Elements
- Checkerboarding
- Ill-Conditioning
- Workshop 4: Element Selection (IA)
- Workshop 4: Element Selection (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson content:

- General Remarks
- Overconstraints Detected during Model Processing
- Overconstraints Detected during Analysis Execution
- Controlling the Overconstraint Checks
- Example: Four-bar Linkage
- Nonconservative Loads
Lesson 7: Convergence Problems: Materials

Lesson content:

- Large Strains and Linear Elasticity
- Unstable Material Behavior
- Example: Plate with a Hole
- Unsymmetric Material Stiffness
- Example: Concrete Slump Test
- Workshop 5: Limit Load Analysis (IA)
- Workshop 5: Limit Load Analysis (KW)
- Workshop 6: Ball Impact (IA)
- Workshop 6: Ball Impact (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.

1.5 hours
Lesson 8: Contact Workflow

Lesson content:

- Defining Contact Pairs
- Defining Surfaces for Contact Pairs
- Defining General Contact
- Workshop Preliminaries
- Workshop 7: Compression of a Rubber Seal (IA)
- Workshop 7: Compression of a Rubber Seal (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson content:

- Contact Formulations
- Contact Discretization
- Contact Enforcement Methods
- Relative Sliding Between Bodies
- Contact Output
- Summary
- Workshop 8: Lap Joint Analysis (IA)
- Workshop 8: Lap Joint Analysis (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson 10: Contact Properties

Lesson content:

- Pressure-Overclosure Models
- Friction Models
- Friction Enforcement
- Workshop 9: Disk Forging Analysis (IA)
- Workshop 9: Disk Forging Analysis (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson content:

- Initial Overclosure
- Strain-free Adjustments
- Interference Fit Problems
- Interference Fit Techniques for General Contact
- Interference Fit Techniques for Contact Pairs
- Interference Fit Example
- Precise Specification of Clearances
- Geometric Smoothing for Curved Surfaces
- Workshop 10: Interference Fit Analysis (IA)
- Workshop 10: Interference Fit Analysis (KW)
- Workshop 11: Syringe Analysis (IA)
- Workshop 11: Syringe Analysis (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson content:

- Initial Rigid Body Motion
- Overconstraint
- Contact with Quadratic Elements
- Unsymmetric Matrices in Finite-Sliding Problems
- Dynamic Instabilities
- Modeling Corners and Edges
- Workshop 12: Snap Fit Analysis (IA)
- Workshop 12: Snap Fit Analysis (KW)
- Workshop 13: Analysis of a Radial Shaft Seal (IA)
- Workshop 13: Analysis of a Radial Shaft Seal (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Appendix 1: Node-to-Surface Formulation

Appendix content:

- Discretization
- Finite Sliding: Surface Considerations
- Small Sliding Characteristics
- Small Sliding: Local Contact Plane
- Small Sliding: Surface Considerations
Appendix 2: Contact Elements

**Appendix content:**

- Surface-Based vs. Contact Element Approach
- Contact Elements
- Contact Element Output
- Contact Element Visualization
Appendix 3: Dynamic Contact using Implicit Integration

Appendix content:

- Time Integration Issues
- Implicit Dynamics
- Damping
- Impact Problems
Appendix 4: Contact Logic and Diagnostics Tools

Appendix content:

- Newton Method
- The Contact Algorithm
- Contact Diagnostics: Visual
- Contact Diagnostics: Text
- Workshop 14: Bolted Flange Analysis (IA)
- Workshop 14: Bolted Flange Analysis (KW)
- Workshop 15: Bolted Flange Analysis: Infinitesimal Sliding (IA)
- Workshop 15: Bolted Flange Analysis: Infinitesimal Sliding (KW)
- Workshop 16: Contact: Beam Lift-Off (IA)
- Workshop 16: Contact: Beam Lift-Off (KW)
- Workshop 17: Contact: Stabilization (IA)
- Workshop 17: Contact: Stabilization (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Appendix 5: Additional Features

Appendix content:

- Beam Contact
- Tie Constraints
- Rigid Bodies and Contact
- Analytical Rigid Surfaces
- Pre-Tensioning of Cross-Sections
- Pressure Penetration
- Contact in Linear Perturbation Procedures
- Workshop 7: Pipe Reel Analysis (IA)
- Workshop 7: Pipe Reel Analysis (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.