INTERACTIVE DEFORMATION THROUGH MESH-FREE STRESS ANALYSIS IN VIRTUAL REALITY

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Daniela Faas

Department of Mechanical Engineering
Virtual Reality Applications Center
Iowa State University

Dr. Judy M. Vance

Program Director
Engineering Design and Innovation
National Science Foundation

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OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

Interactive Shape Manipulation in VR

- Interaction with geometry
- Analysis tied with CAD and shape deformation
- Easier identification of problematic stresses in early design
- Faster product development
- Collaborative design
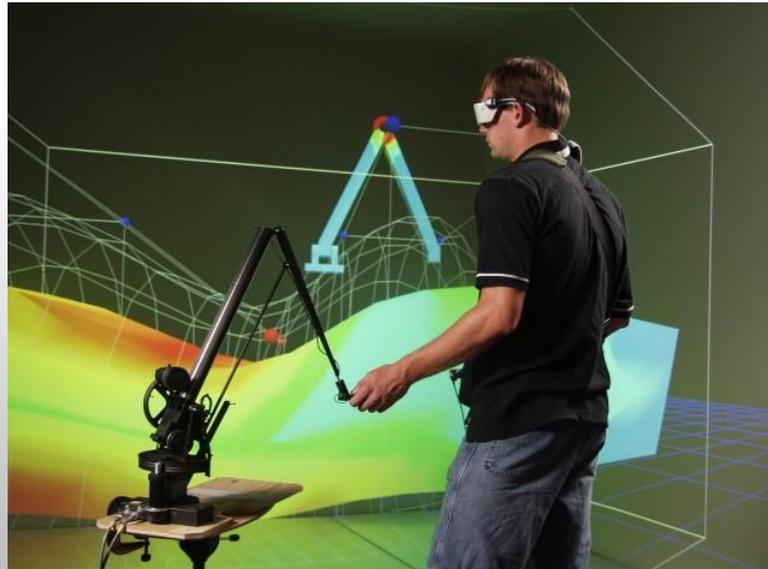
Virtual Reality Environment

- Developed for C4 and C6 at VRAC, Iowa State

- Can run on desktop, single wall screen

- Renovated C6:
  - 4000x4000 pixel resolution per wall
  - 48 dual-CPU workstations
  - 24 Sony SRX-S105 digital cinema projectors

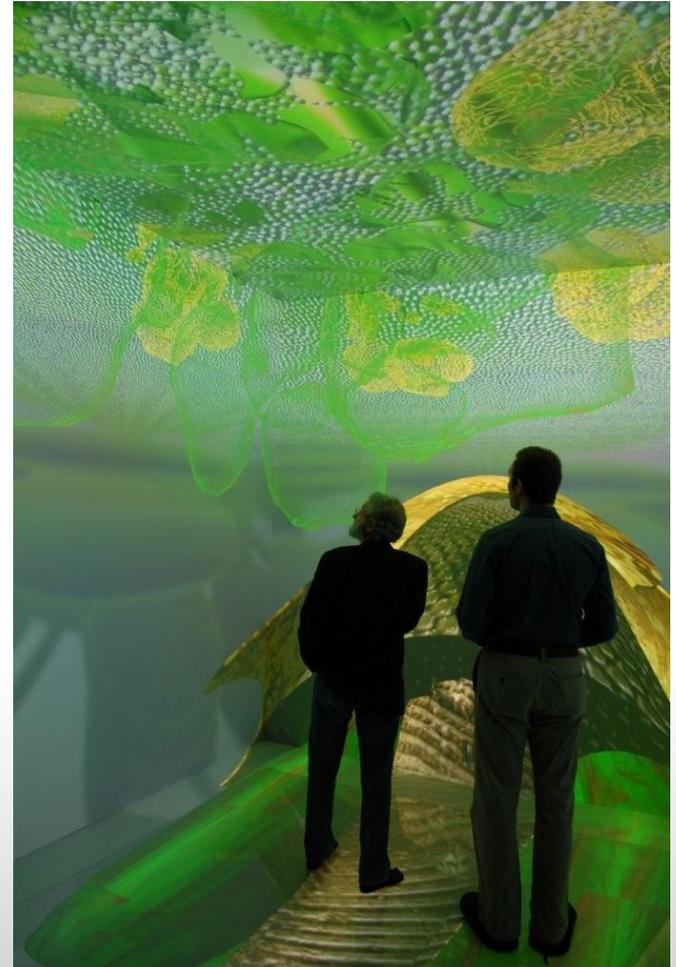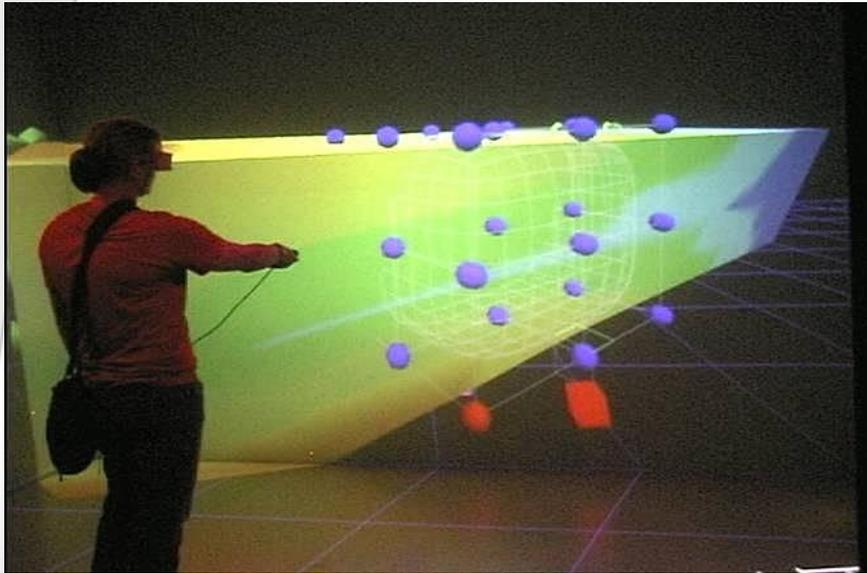- SensAble Technology Phantom haptic device

Image courtesy of the Meta!Blast project, Iowa State University. Funded in part by NSF grants IOB-0219366 and DBI-0520267; ISU College of Liberal Arts and Science."
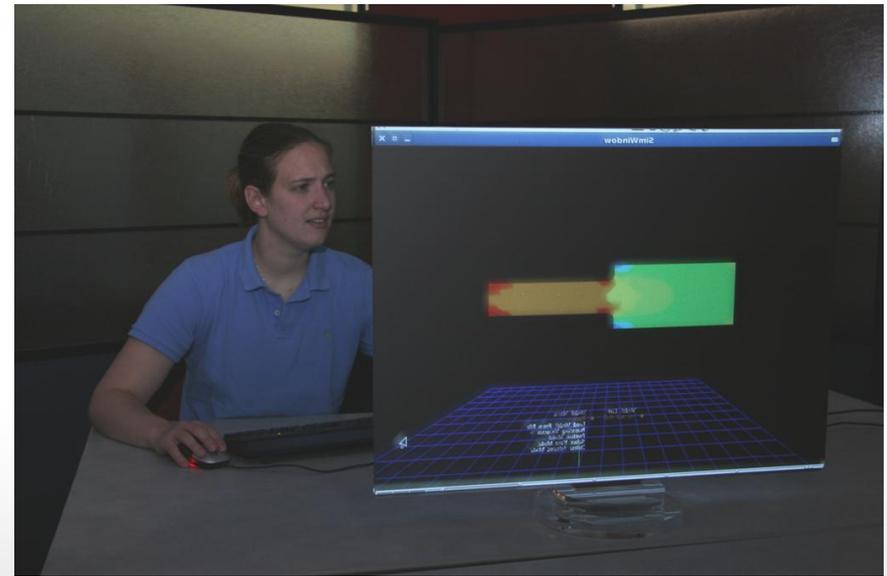
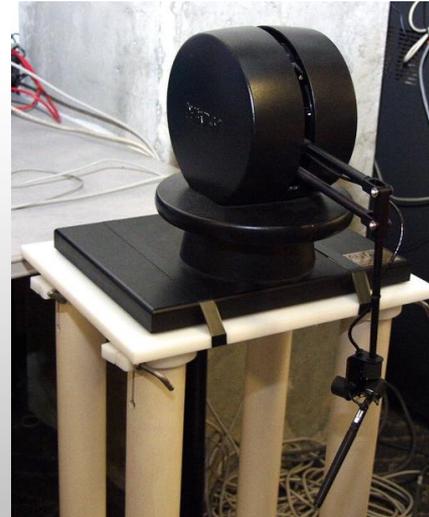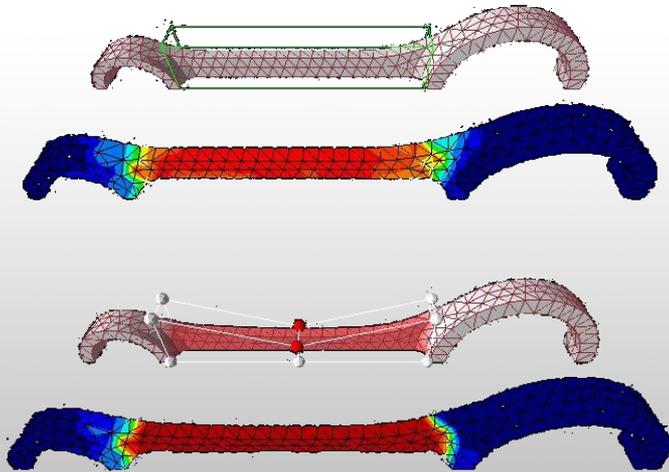# IVDA Virtual Environments

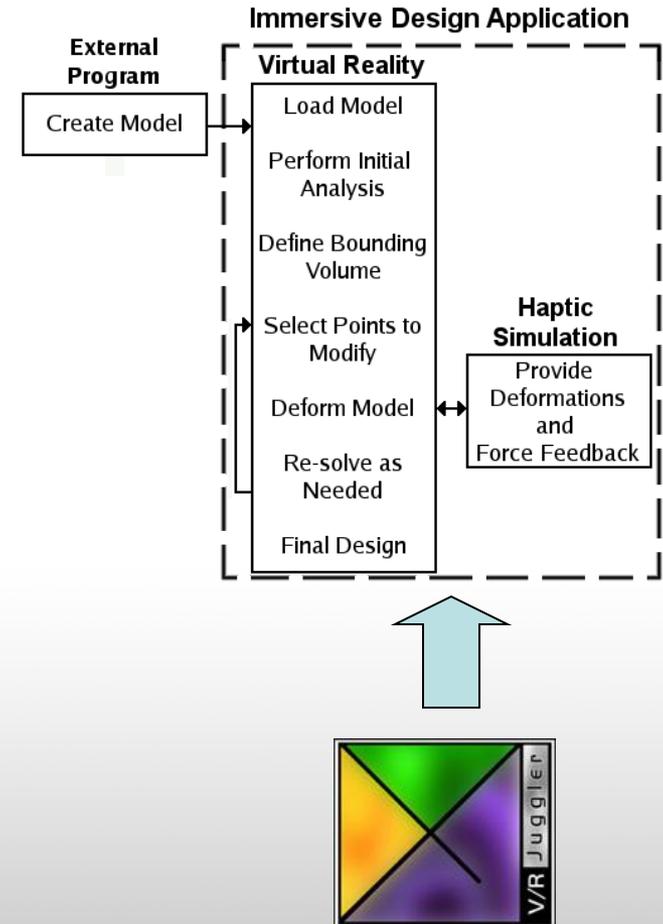- Immersive
- Desktop

Background

- Yeh and Vance, 1998: linear Taylor series approximations based on pre-computed stress sensitivities and NURBS bounding volume to deform part shape

- Chipperfield et al., 2006 : Mesh-free and PCG re-analysis method to accurately re-compute stress

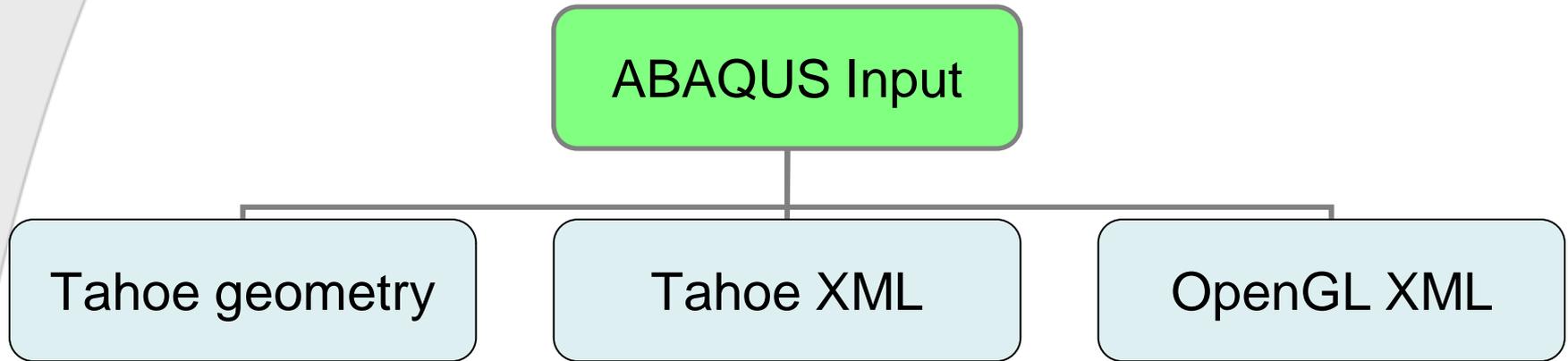- Fischer et al., 2007: haptic device implementation

Software

- IVDA
  - C++ programming language
  - VR Juggler software toolkit
  - OpenGl
  - OpenHaptics toolkit for Phantom haptic device
  - OPCODE (Optimized Collision detection)
  - Tahoe OpenSource toolkit (http://tahoe.ca.sandia.gov/)
- External:
  - ABAQUS

File Converter (ABAQUS - Tahoe)

```
            ┌──────────────────┐
            │   ABAQUS Input   │
            └──────────────────┘
                     │
    ┌────────────────┼────────────────┐
    │                │                │
┌────────────┐ ┌────────────┐ ┌────────────┐
│Tahoe       │ │Tahoe XML   │ │OpenGL XML  │
│geometry    │ │            │ │            │
└────────────┘ └────────────┘ └────────────┘
```

IVDA

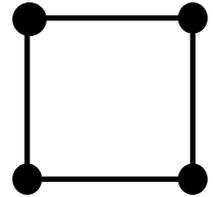| Read Tahoe files	→	Display Elements	→	Stress Analysis	→	PCG Matrix
• 2D • 3D		• 2D • 3D		• 2D • 3D		• 2D • 3D

Element Definitions

ABAQUS Geometry	Tahoe Geometry	Dimensions	# of Nodes
-	point	1	1
T2D2	line	1	2
CPS4	quadrilateral	2	4, 8
CPS3	triangle	2	3
C3D8	hexahedron	3	8
C3D4	tetrahedron	3	4
C3D6	pentahedron	3	6
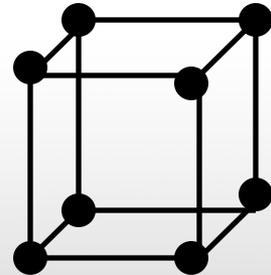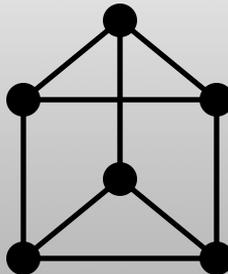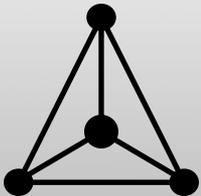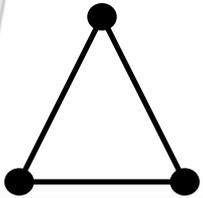
Abaqus

```
** PARTS
** ASSEMBLY
Element, type=CPS4
 1,   1,  15, 123,  57
 2,  15,   2, 124, 123
 3,   2,  16, 125, 124
*Node
    1,       210.,        25.
    2,  209.020569,   5.50202799
    3,       210.,       -25.
** MATERIALS
** BOUNDARY CONDITIONS
** LOADS
```

Tahoe geometry file
*dimensions
349 # num nodes
2 # num spatial dimensions
1 # num element sets
[ID] [nel] [nen]1 297 42
num node sets
[ID] [nnd]
1 112 6
*elements
*set
297 # num elements
4 # num nodes/element
1 1 15 123 57
2 15 2 124 123
3 2 16 125 124
*nodes
349 # num nodes
2 # num spatial dimensions
1 210 25
2 209.021 5.50203
3 210 -25

```xml
<nodes>
</dof_labels>
        <kinematic_BC dof="1" node_ID="1" />
        <kinematic_BC dof="2" node_ID="1" />
        <force_BC dof="1" node_ID="2" schedule="1" value="1000"/>
     </field>
   </nodes>
   <element_list>
     <small_strain_meshfree field_name="displacement">
        <quadrilateral num_ip="4"/>
        <solid_element_nodal_output principal_stress="1"/>
        <small_strain_element_block>
           <block_ID_list>
              <String value="1"/>
           </block_ID_list>
           <small_strain_material_2D>
                       <small_strain_StVenant_2D density="1.0">
                  <E_and_nu Poisson_ratio="0.35" Young_modulus="1e+08"/>
               </small_strain_StVenant_2D>
              </small_strain_material_2D>
           </small_strain_element_block>
<meshfree_support_2D>
           <RKPM>
              <cubic_spline_window support_scaling="1.51"/>
                    </RKPM>
</meshfree_support_2D>
           <meshfree_fracture_support/>
       </small_strain_meshfree>
```

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OpenGl XML

```
<model format="XML From ConvertBase">
<geometry num_nodes="349" num_elements="297">
<node id="0">210,25,0</node>
<node id="1">209.021,5.50203,0</node>
<node id="2">210,-25,0</node>
<node id="3">400,-25,0</node>
<elem id="0" type="CPS4">0,14,122,56</elem>
<elem id="1" type="CPS4">14,1,123,122</elem>
<elem id="2" type="CPS4">1,15,124,123</elem>
<elem id="3" type="CPS4">15,16,125,124</elem>
```
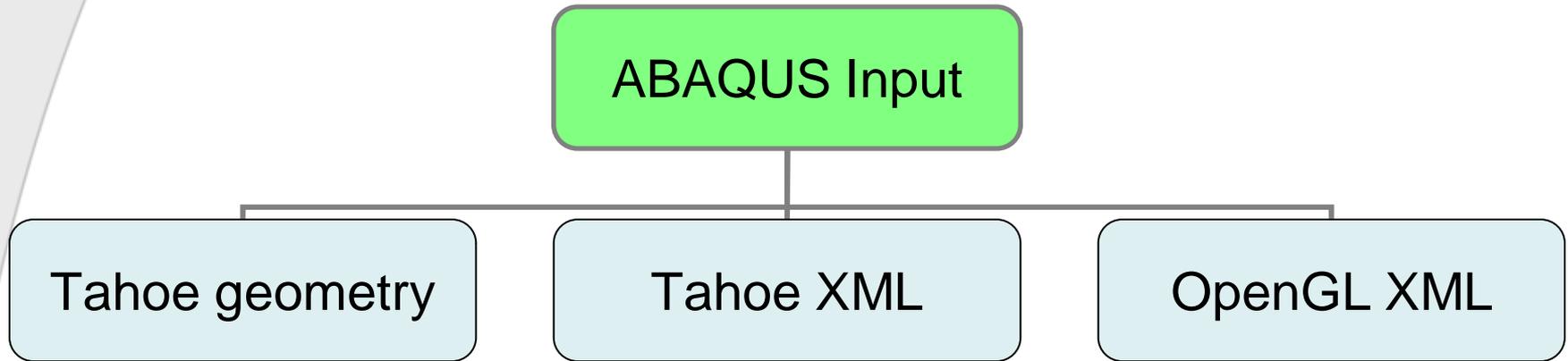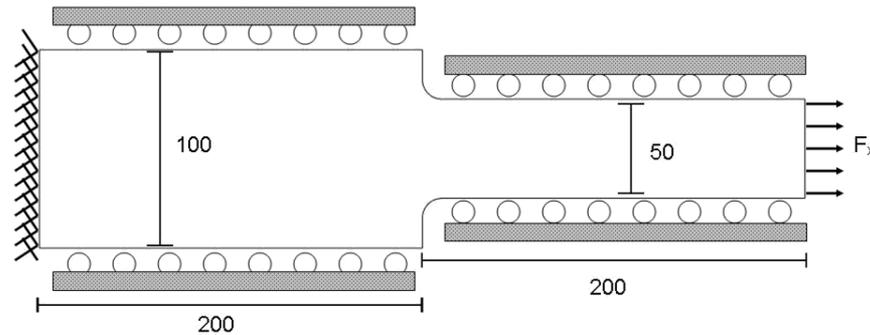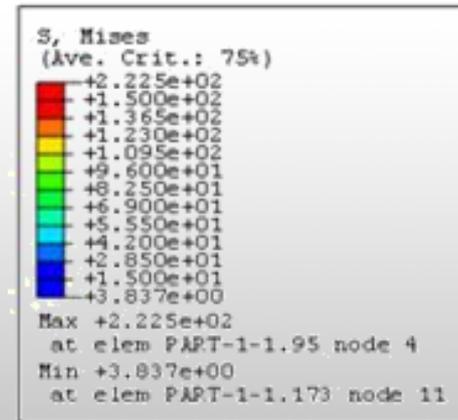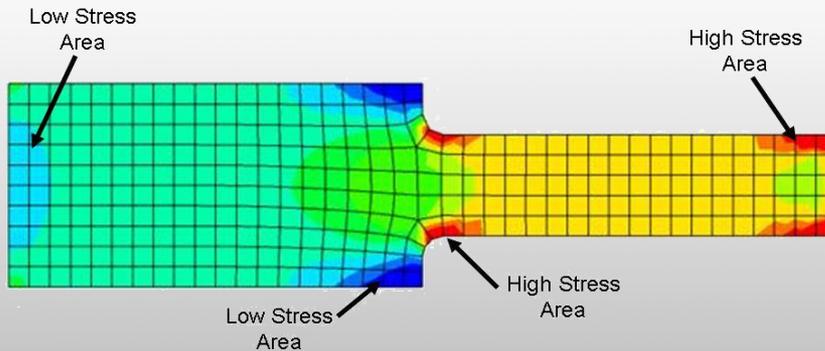
File Converter (ABAQUS - Tahoe)

```
                    ┌─────────────────────┐
                    │    ABAQUS Input     │
                    └──────────┬──────────┘
         ┌─────────────────────┼─────────────────────┐
┌────────────────┐   ┌─────────────────┐   ┌─────────────────┐
│ Tahoe geometry │   │    Tahoe XML    │   │   OpenGL XML    │
└────────────────┘   └─────────────────┘   └─────────────────┘
```

IVDA

Read Tahoe files
- 2D
- 3D

→

Display Elements
- 2D
- 3D

→

Stress Analysis
- 2D
- 3D

→

PCG Matrix
- 2D
- 3D

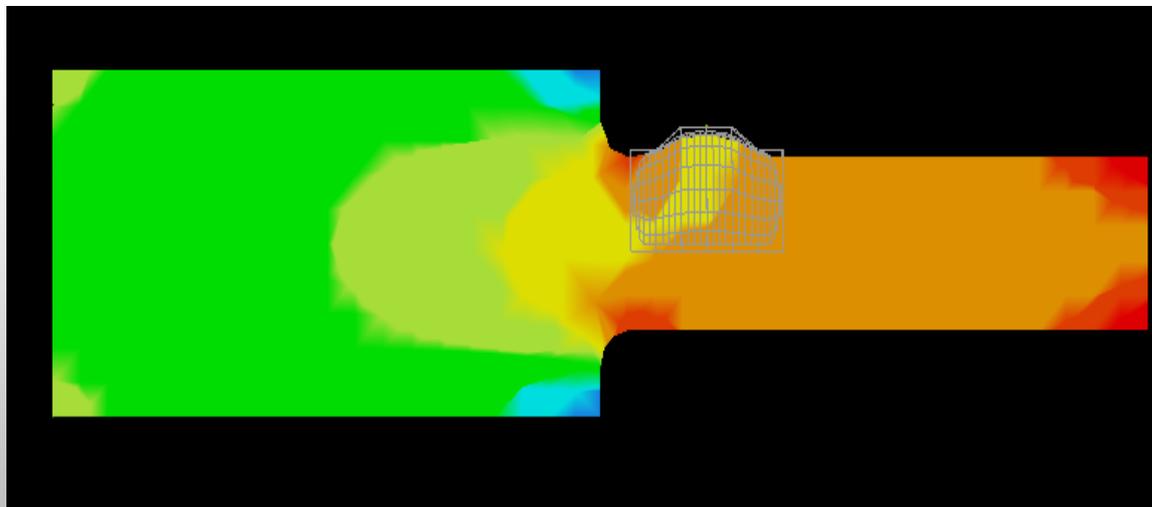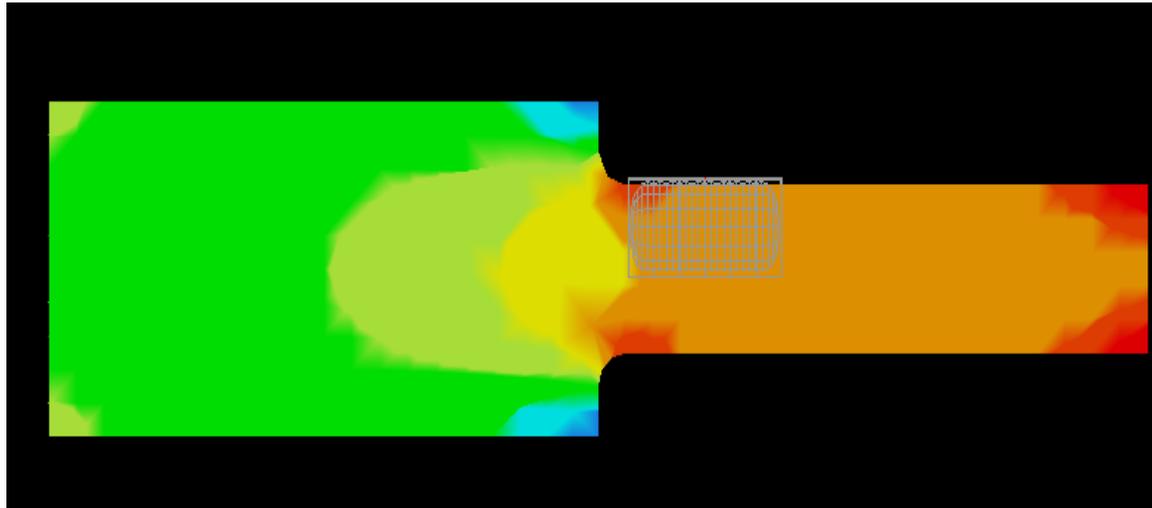# 2D Analysis Example

- Stepped beam example

- ABAQUS mesh

IVDA Results

Conclusion

- Investigation of shape through interactive design coupled with mesh-free analysis
- Able to perform mesh-free analysis
  - 2D, 3D elements
- Able to deform model with stress updates
- Able to assemble parts during deformation
- During assembly operations, collision detection prevents interpenetration

Acknowledgements

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Questions?

IVDA

Mesh-Free Design
In VR