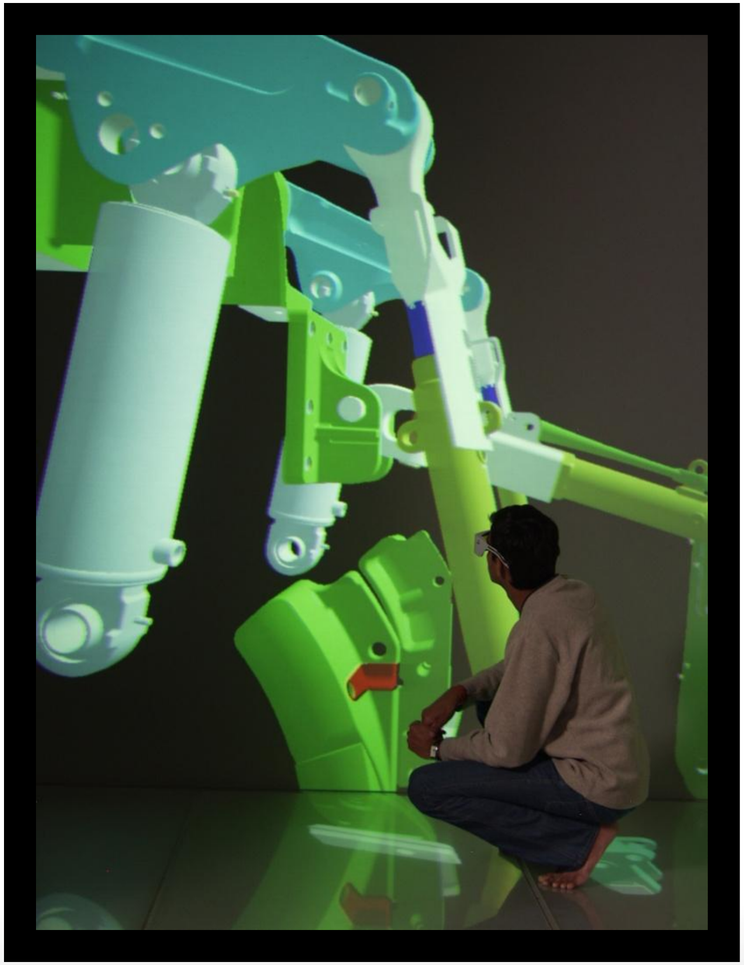
Virtual Reality as an Interface to Mechanical Design



Judy M. Vance, PhD
Professor
Mechanical Engineering Department
Iowa State University
Virtual Reality Applications Center
Ames, IA

February 3, 2010

Iowa State University

Virtual Reality Applications Center

To be a national leader in the application of virtual reality to the challenges of science and engineering

The Virtual Reality Applications Center

An interdisciplinary research center focusing on the rapidly expanding **interface** between **humans** and **computers**.

Virtual Reality Applications Center

- $23M in contract funding
- 50 active interdisciplinary projects
- 40 faculty investigators from 7 colleges
- 190 graduate & undergraduate researchers
- Sponsors

Industry DoD Other Federal

Human Computer Interaction (HCI) Graduate Progran

PhD and MS programs in Human Computer Interaction

68 HCI Faculty members who come from

- College of Design
- College of Engineering
- College of Liberal Arts and Sciences
- College of Human Sciences
- College of Business

Research Mission: HCI

Mobile

Wireless

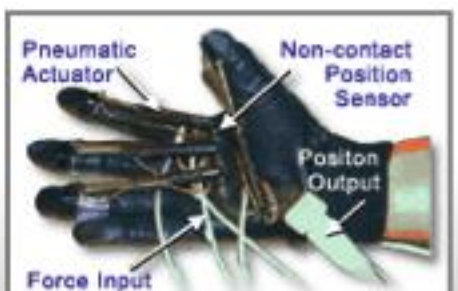
Virtual Reality

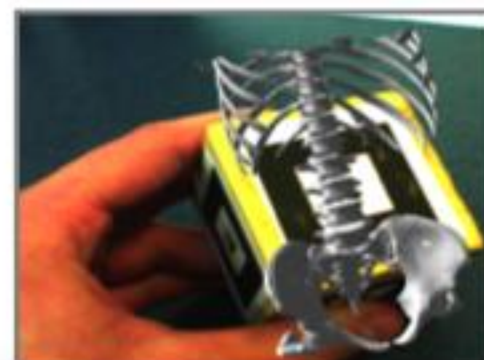
Convergence

Augmented Reality

Wearable

Haptics





Teleoperation

VRAC Facilities

C6
Six-sided Immersive Environment

C6
Six-sided Immersive Environment

10 ft. x 10 ft. x 10 ft.

49 dual core processor computers

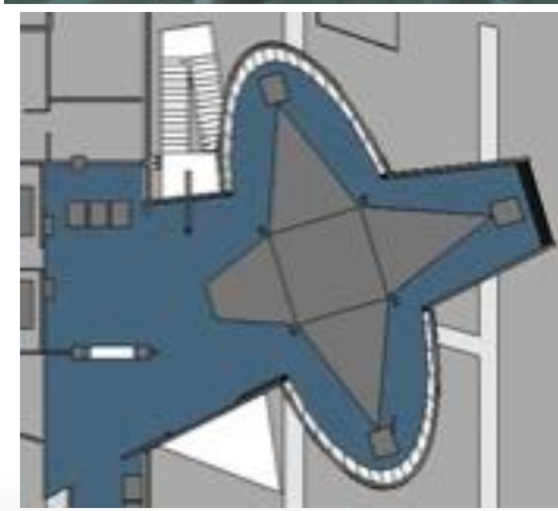
- 96 processors run the C6

96 graphics cards

24 Sony 4k SXRD digital projectors

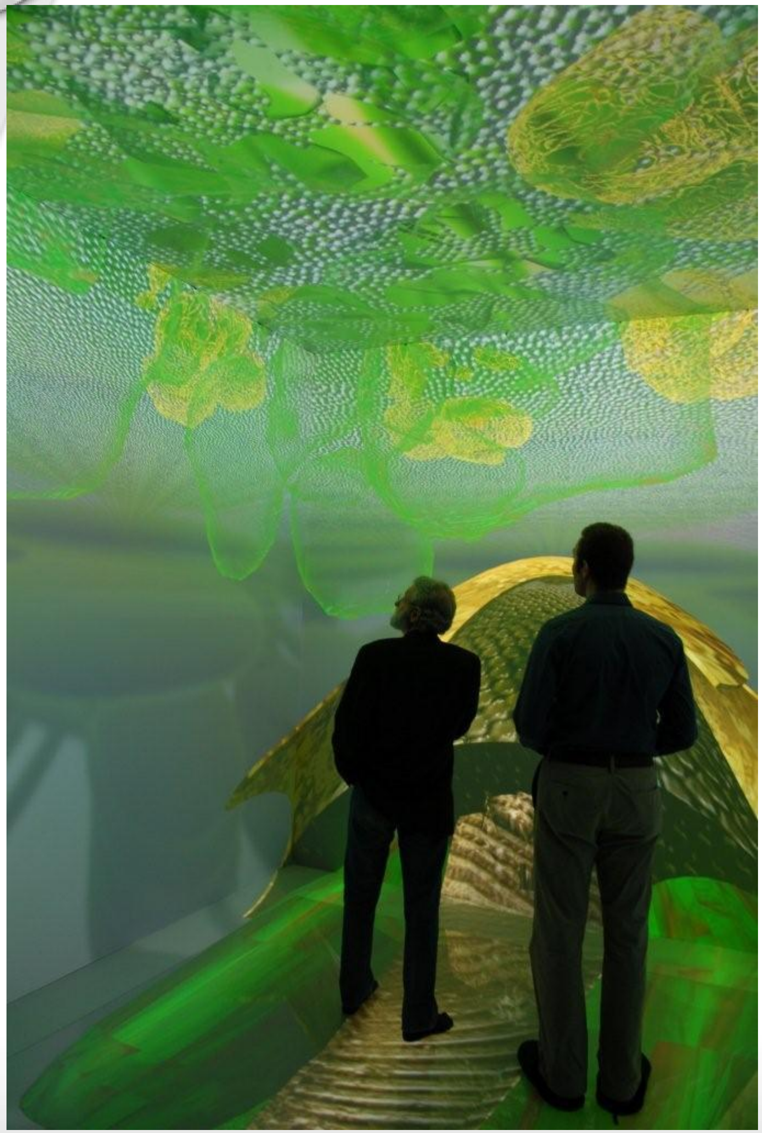
100 million pixels total

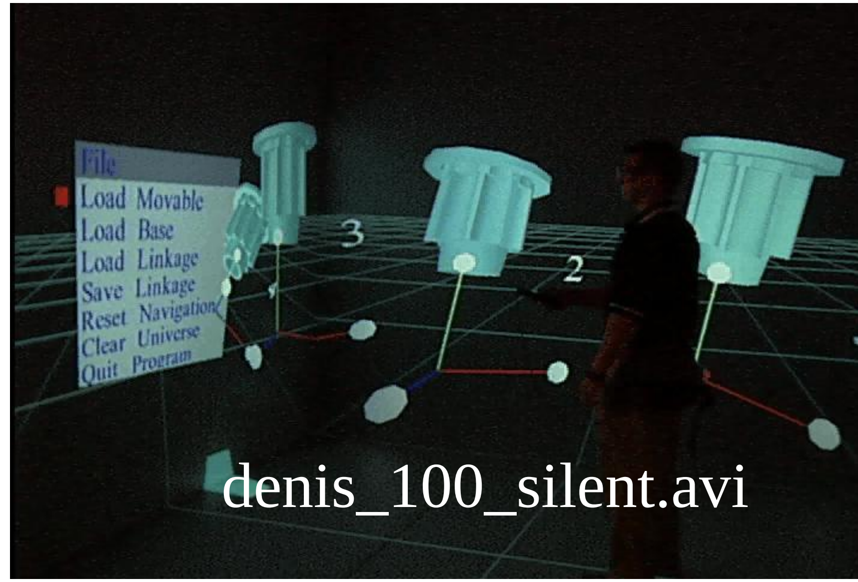
- 16.7 million pixels per wall
- 4096 x 4096 resolution for each eye

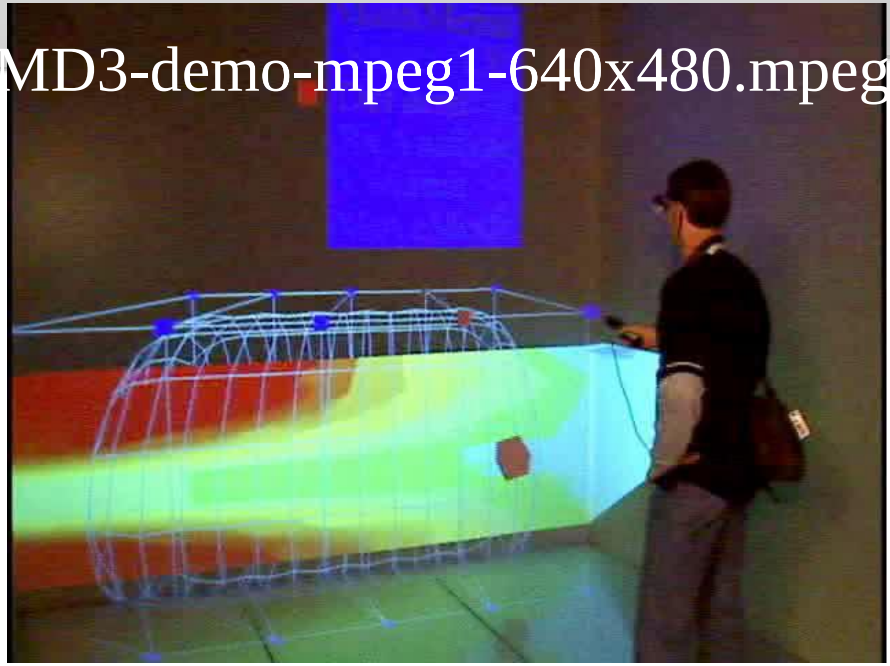


Sony
4K SXRD Projector

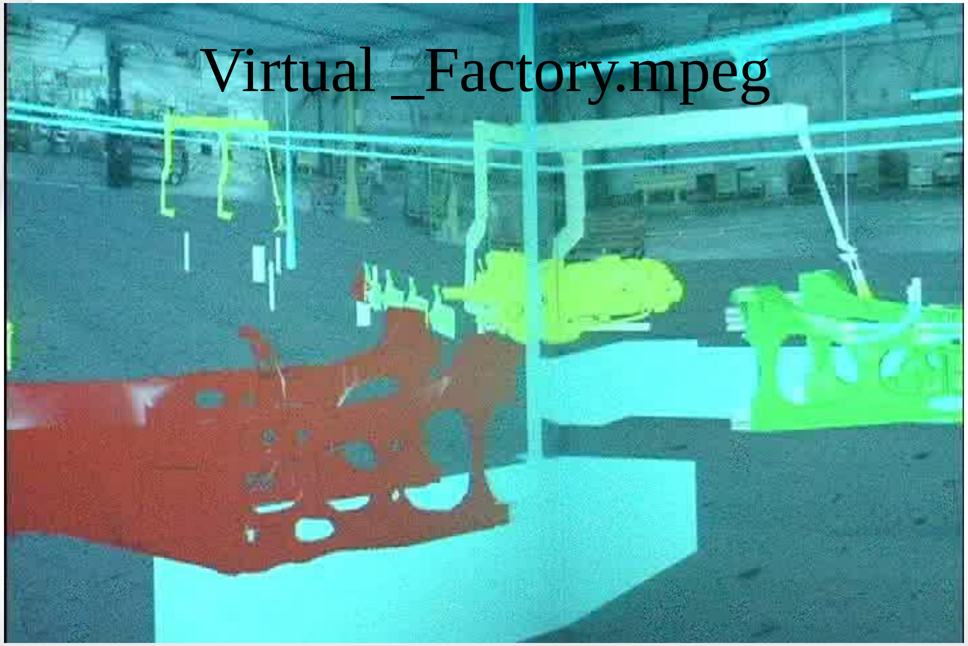
C6 Applications



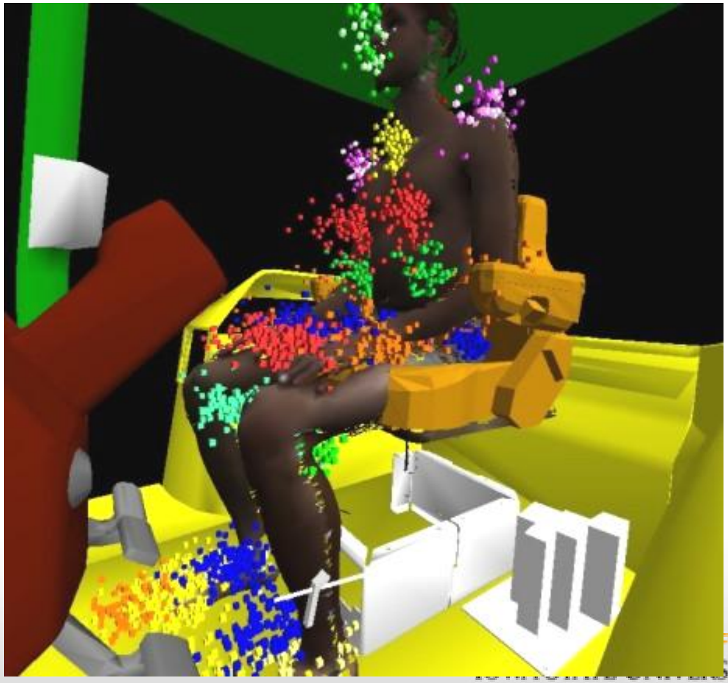




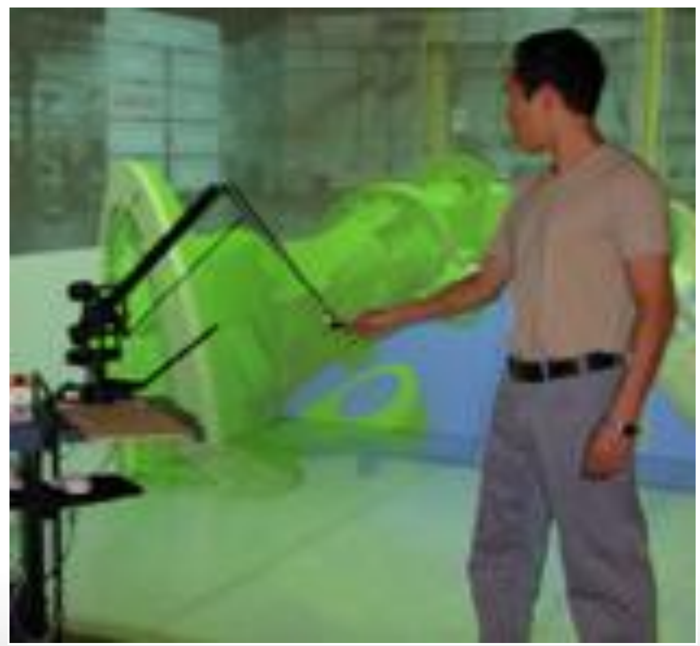
MD3-demo-mpeg1-640x480.mpeg



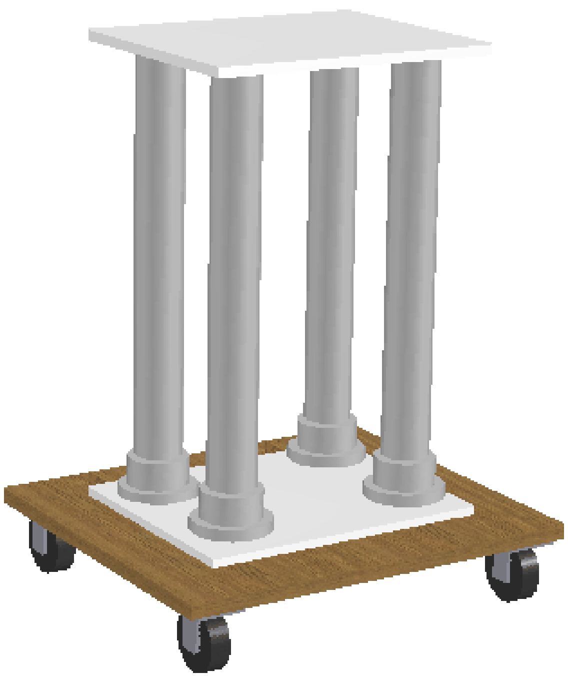
Virtual _Factory.mpeg

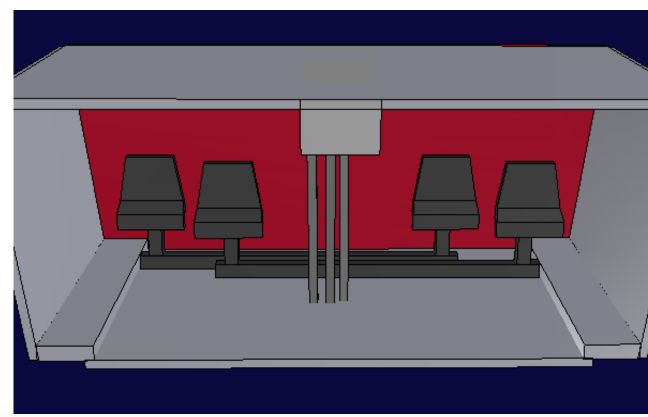


Networked Haptic Environment



Haptics Implemented in a Projection Screen Virtual Environment





SHARP

System for Haptic Assembly & Realistic Prototyping

- Collision detection
- Physics-based modeling
- Dual-handed haptic interface
- Complex CAD model assembly
- Subassembly support
- Swept volumes
- Network communication
- Portable to different VR Systems

Dual-handed Haptic Assembly

Sharp Final.wmv

Mechanism Design

- Spherical (VEMECS, Isis)
- Spatial (VRSpatial)
- Compliant

Haptics

- Dual Handed Haptic Assembly System (SHARP)
- Networked Haptic Environment (NHE)
- Implementing Haptics in a Large Projection Screen Environment
- Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics
- A Hybrid Method of Haptic Feedback to Support Virtual Manual Product Assembly

Other

- Hydraulic Hose Routing in VR
- Interactive Stress Analysis in VR (M3D, IVDA)
- Discrete Event Simulation in VR

Mechanism Design

- Spherical (VEMECS, Isis)
- Spatial (VRSpatial)
- **Compliant**

Haptics

- Dual Handed Haptic Assembly System (SHARP)
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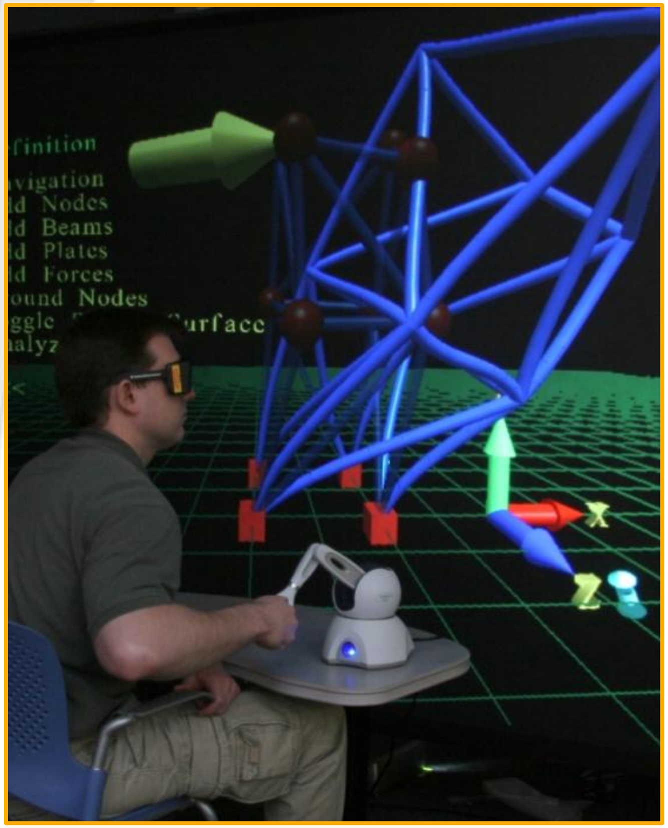
- **A Hybrid Method of Haptic Feedback to Support Virtual Manual Product Assembly**

Other

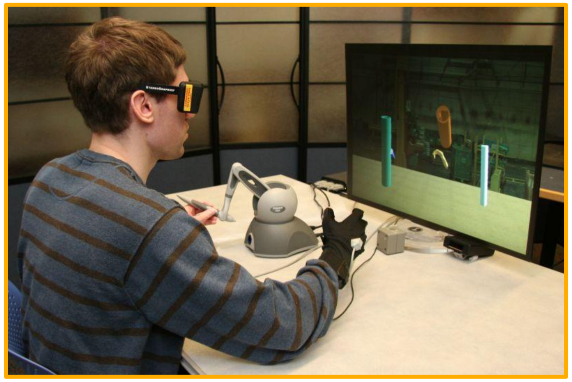
- Hydraulic Hose Routing in VR
- Interactive Stress Analysis in VR (M3D, IVDA)
- Discrete Event Simulation in VR

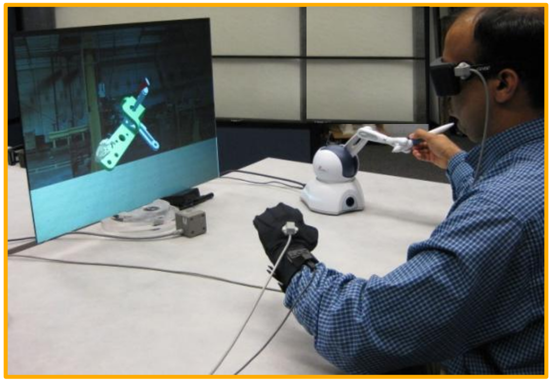
Current Projects

Constraint-based Compliant Mechanism Design using Virtual Reality as a Design Interface



A Hybrid Method to Support Natural Interaction of Parts in a Virtual Environment





The focus of research in the Vance group is on the use of haptics and immersive VR technology to improve the product design process. We are developing methods to support low clearance CAD model assembly with realistic force feedback to support virtual assembly process evaluation and new design methodology for compliant mechanism design.

Virtual Training, Assembly and Maintenance Methods

Constraint-Based Synthesis of Shape-Morphing Structures in Virtual Reality

Denis V. Dorozhkin

Judy M. Vance

Compliant Mechanisms

Achieve motion guidance via the compliance and deformation of the mechanism's members

Successful design of compliant mechanisms requires an understanding of solid mechanics (deformation, stress, strain, etc.) and mechanism kinematics (properties of motion)

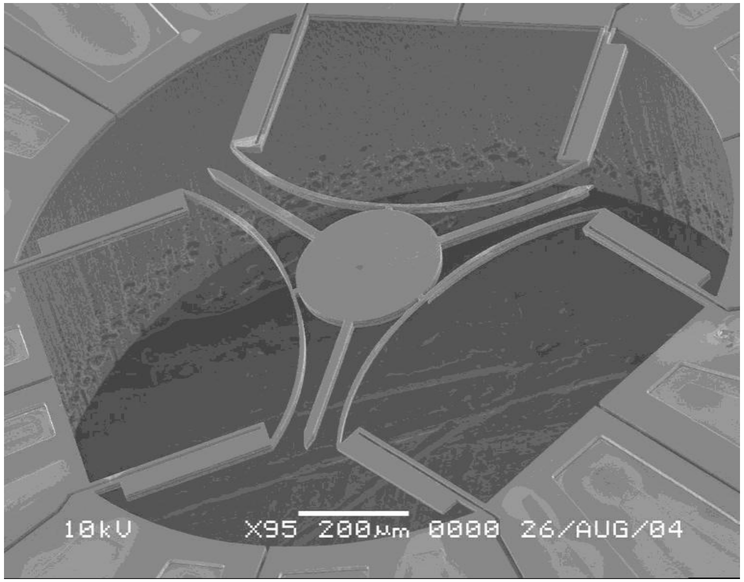
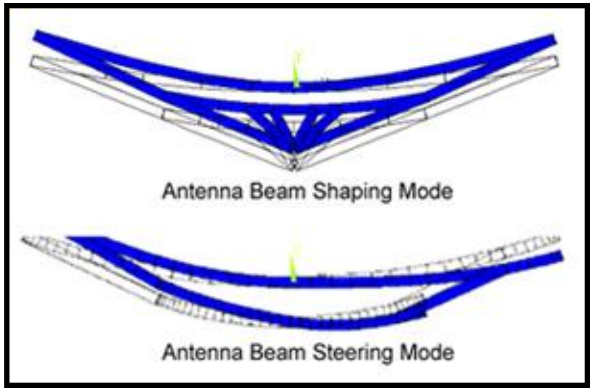


Image © PCSL, MIT

Shape-morphing Compliant Structures

Geometric shapes of the individual system components, such as aircraft wings and antenna reflectors, directly affect the performance of the corresponding mechanical systems



The goal is to design a single-piece flexible structure capable of morphing a given curve or profile into a target curve or profile while utilizing the minimum number of actuators

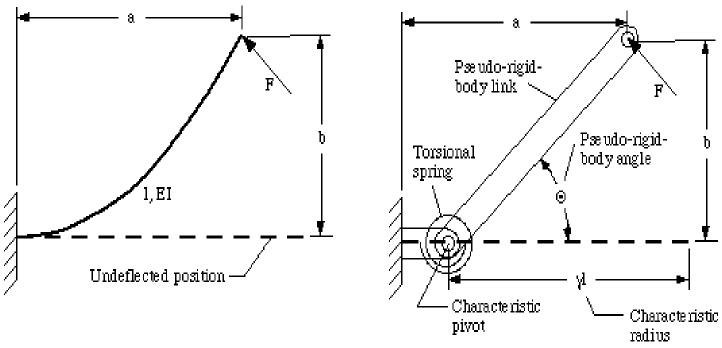
Images © Lu, Kota, UMich

Current Research

Pseudo-Rigid Body Modeling

Primarily aimed at modeling rather than synthesis

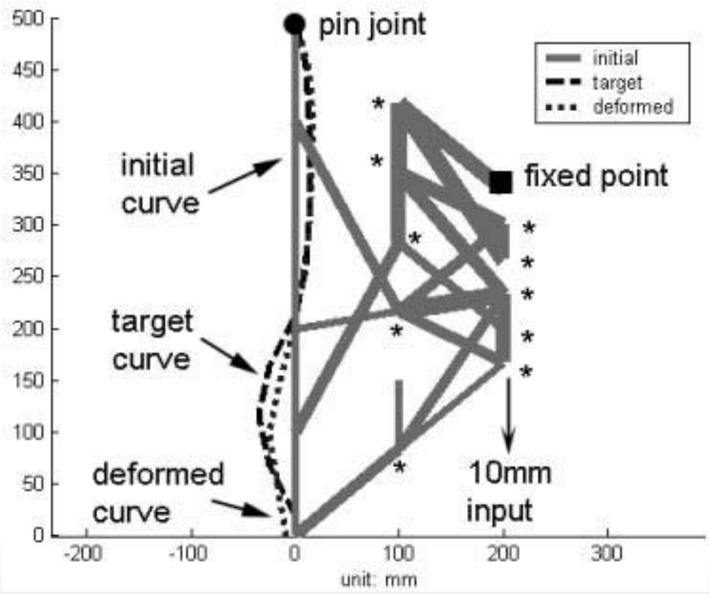
Cannon, B.R., Lillian, T.D., Magleby, S.P., Howell, L.L., Linford, M.R., *A compliant end-effector for microscribing.* Precision Engineering, 2005. **29**(1): p. 86-94



Topological Synthesis

Designers have little control over the resulting solution (overly-complex topologies)

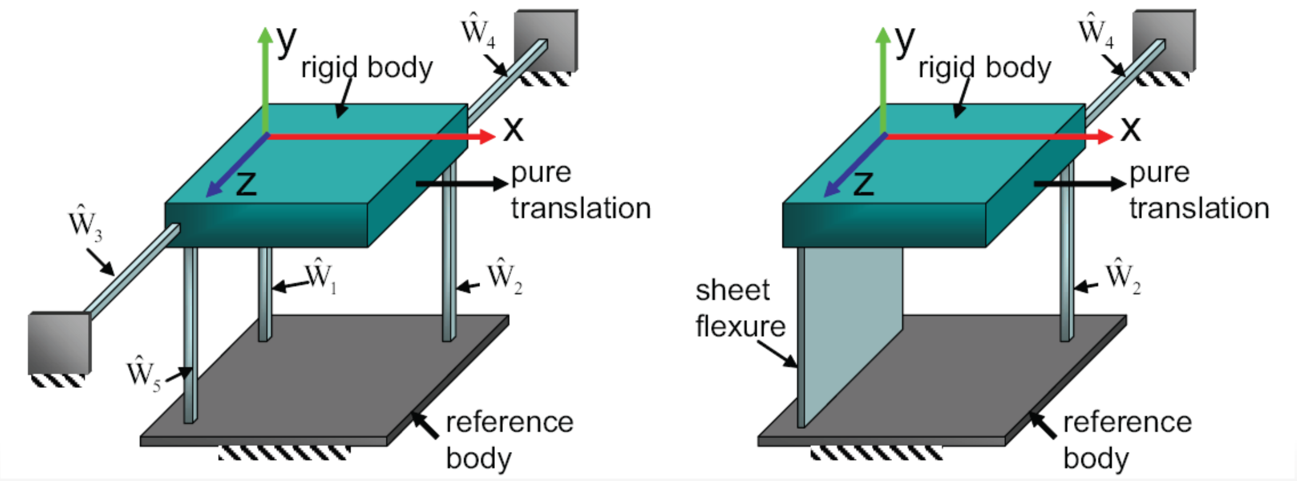
Lu, K.-J., Kota, Sridhar, *Topology and Dimensional Synthesis of Compliant Mechanisms Using Discrete Optimization.* Journal of Mechanical Design, 2006. **128**(5): p. 1080-1091.



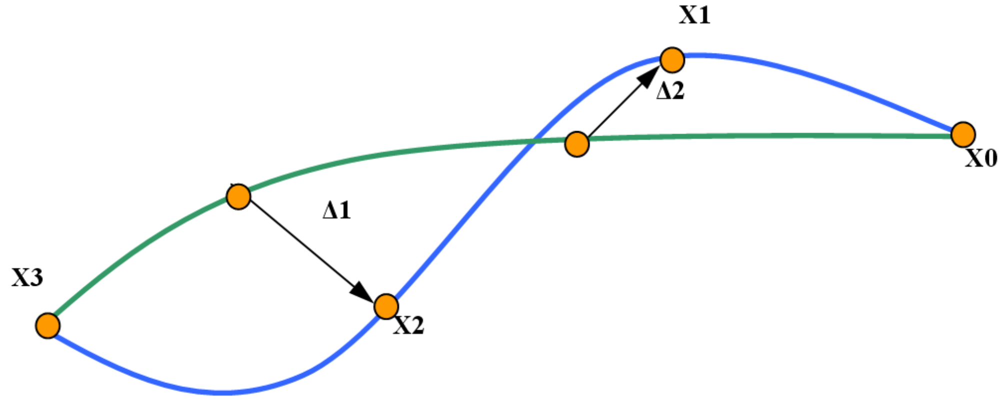
Images © Howel, BYU; Lu, Kota, UMich

Constraint-based Design Method (CBDM)

- Fundamental premise - all motions of a rigid body are determined by the position and orientation of the constraints (constraint topology) placed upon the body
- Any mechanism motion path may then be defined by the proper combination of constraints



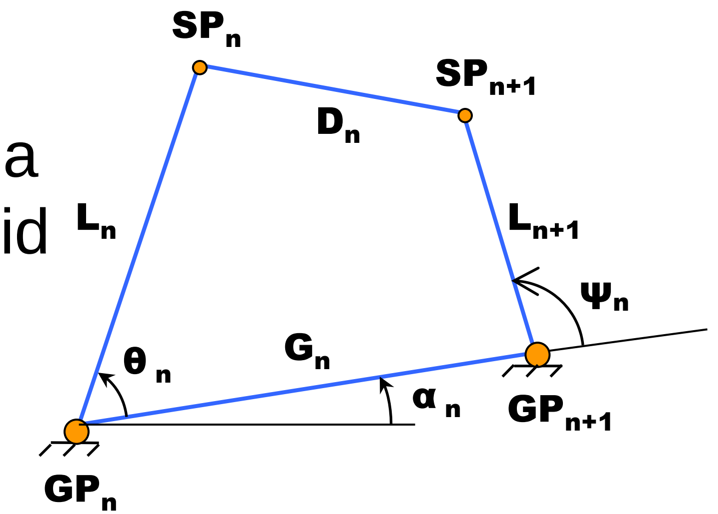
CBDM Shape Morphing

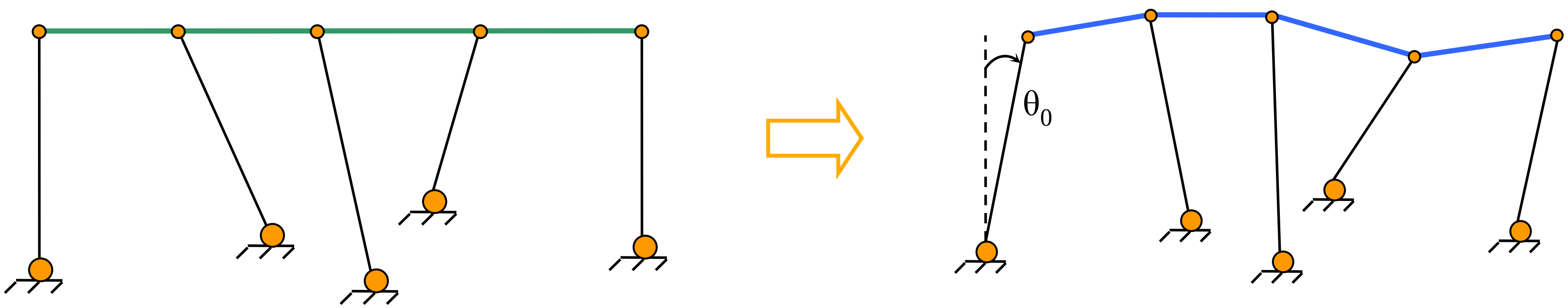


- Flexible element that comprises the active shape surface is discretized at multiple points in both the initial and the target configurations
- Individual elements are then treated as 3- or 6-DOF rigid bodies that undergo a planar or general spatial displacement
- Goal is to identify the number and the topology of the constraints that will impart these motion characteristics

Kinematic Analysis

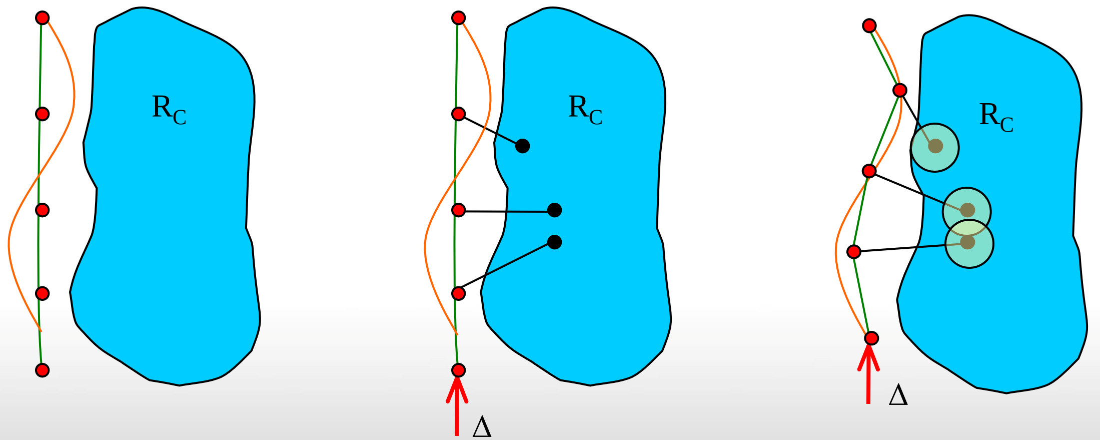
Model the compliant mechanism as a series of cells composed of 4-bar rigid link mechanisms.





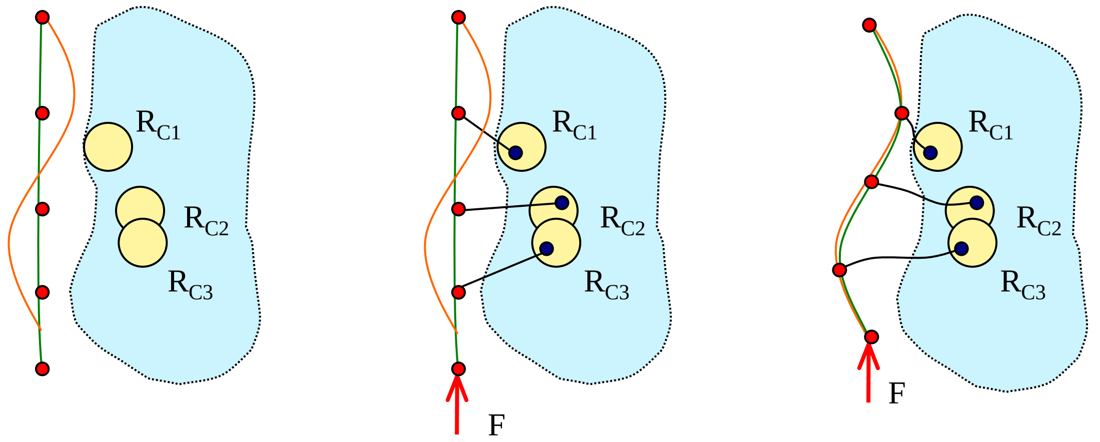
Determine approximate location for anchor points

- Vary the location of the anchor points within the available anchor region, and change the value of the input angle within the specified bounds, while computing the cumulative difference from the reference profile.
- Optimize to reduce error between desired shape and original shape.



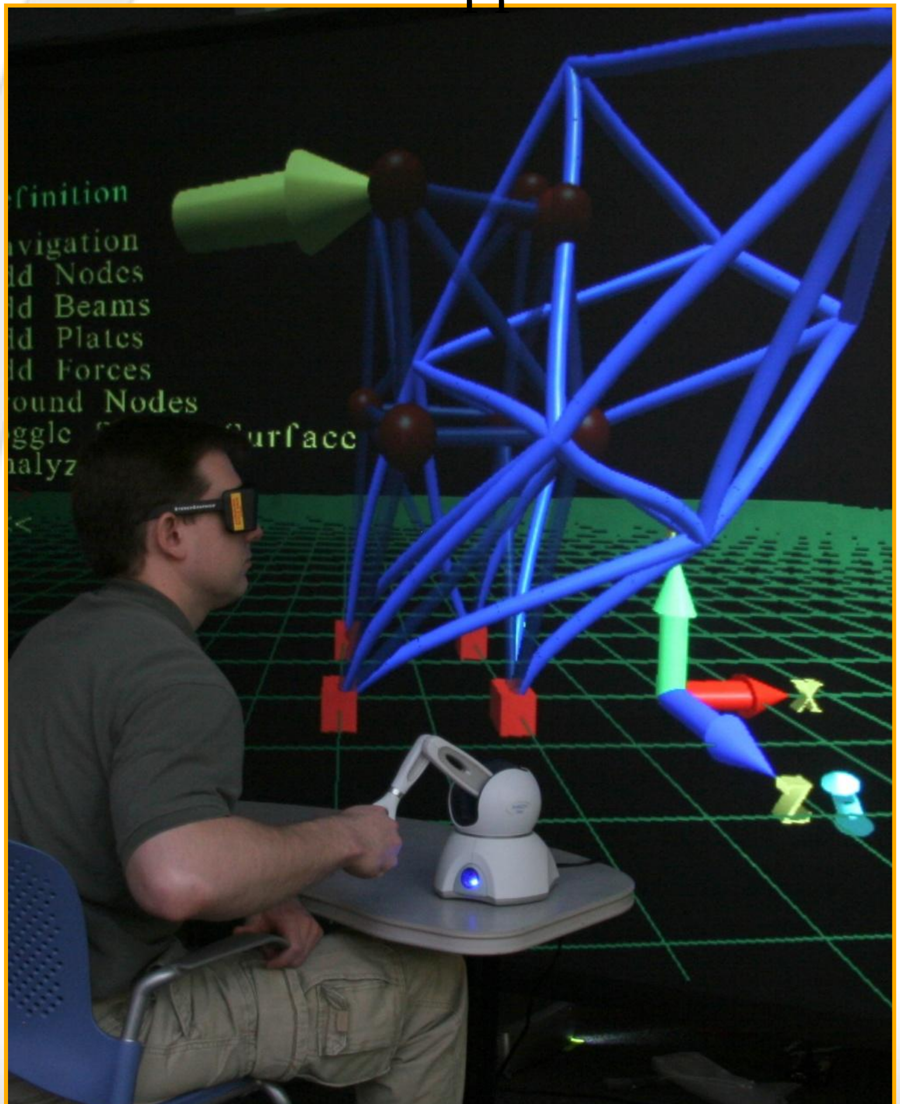
Final Anchor Point Locations

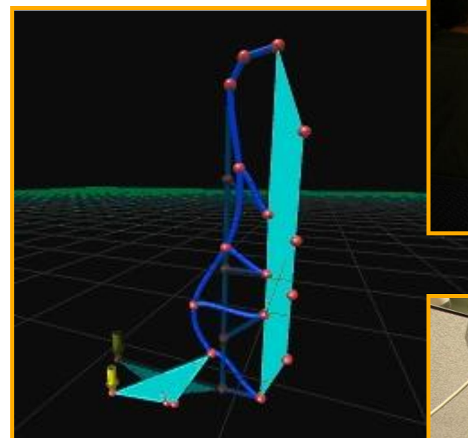
- Discard the rigid-body approximation, and model the structure using finite element methods
- Repeat optimization using the refined anchor regions and computing compliant structure response

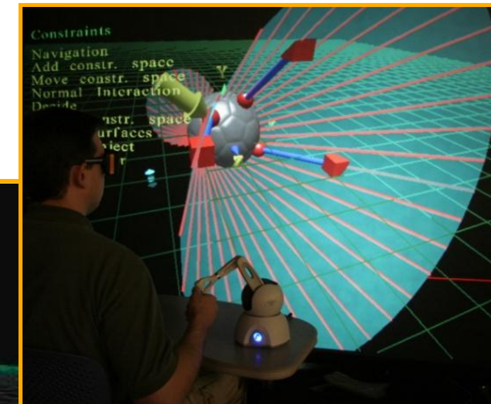


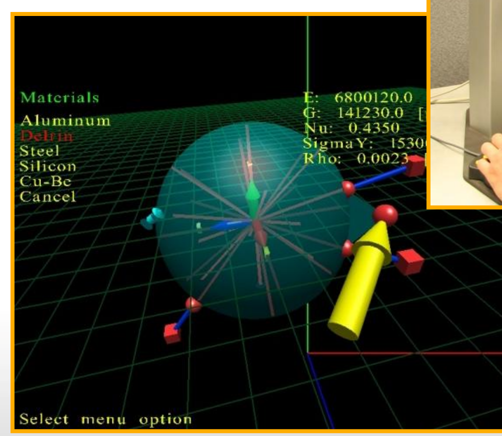
VR Application

Lumbar support stress animation.avi







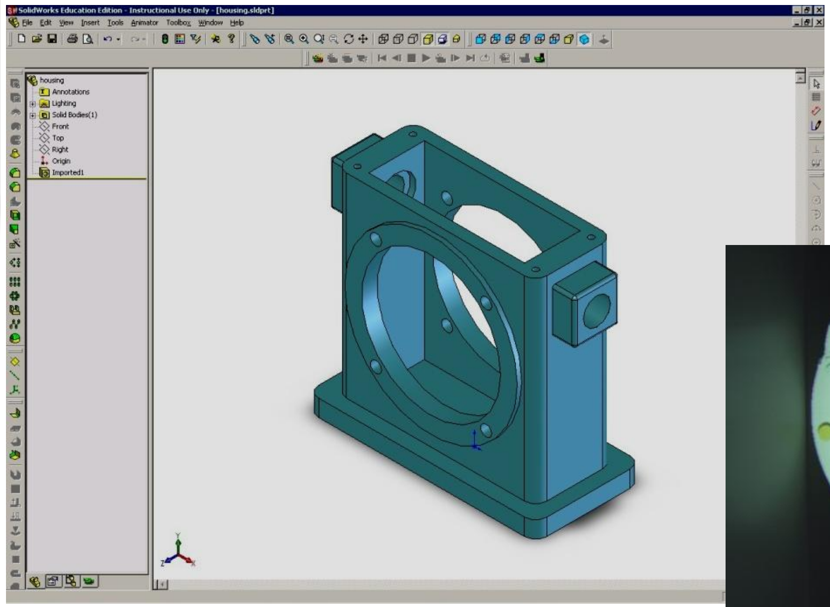


Future Work

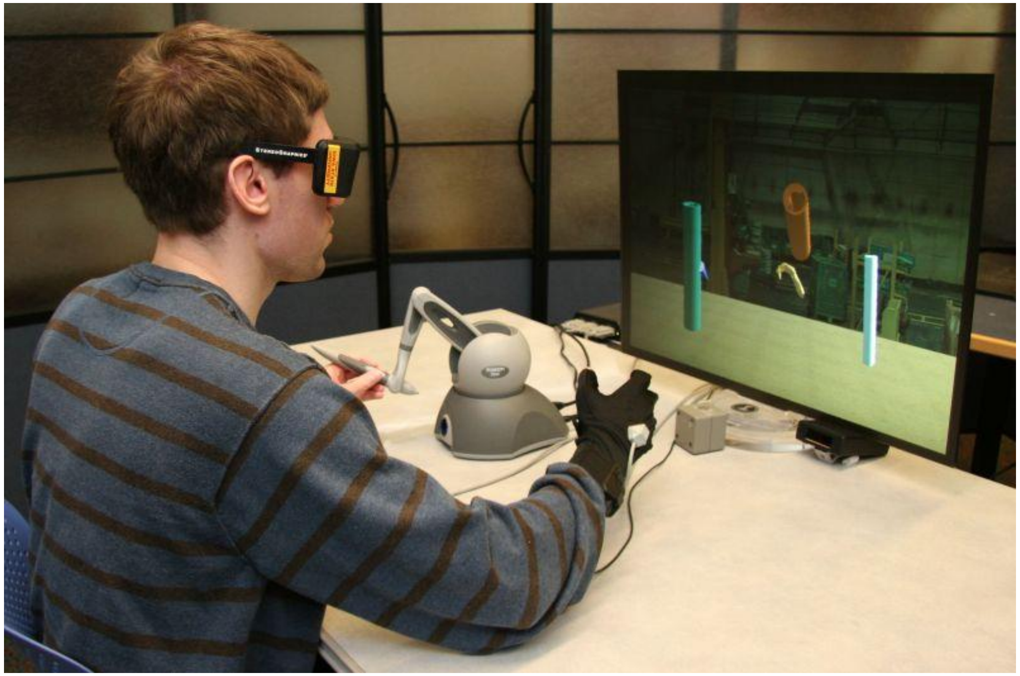
- Real-time haptic interaction with the deformable structure
- Non-planar shape morphing compliant structures
- Secondary design modules
  - Sensitivity analysis
  - Manufacturing tolerance/process analysis

Virtual Assembly

Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics
Virtual Manual Assembly for Low Clearance Parts
Haptic Interaction for Large Area Virtual Environments



Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics



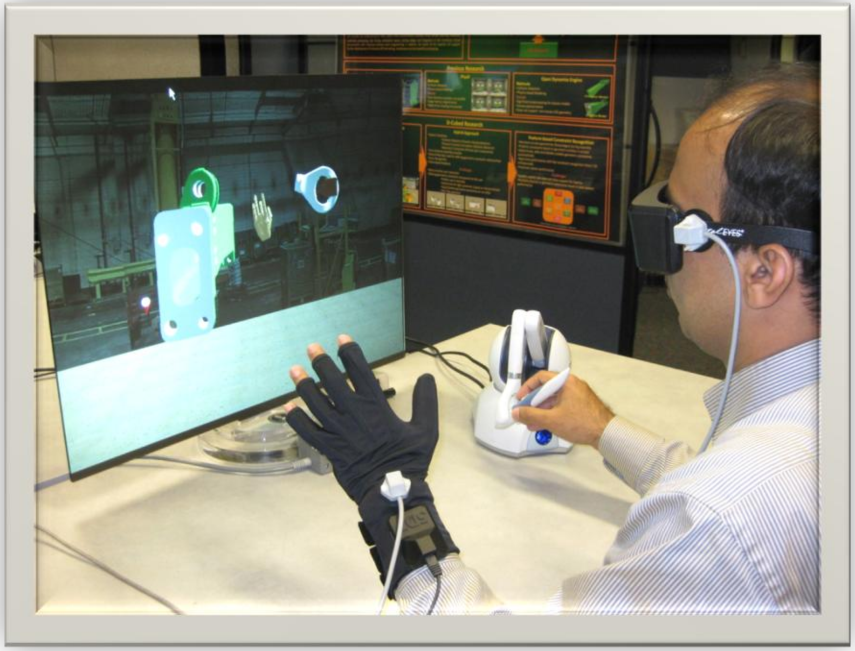
Patrick Carlson
Vikram Vyawahare
Judy M. Vance

Motivation

Research has shown that we naturally use our “non-dominant hand” to select and manipulate objects while we use our “dominant hand” to perform fine motor skill

Approach

Use a non-haptic glove on the non-dominant hand
Provide a haptic device for interaction with the dominant hand



Expands the workspace of the haptic device
Allows us to perform two handed interaction for less cost

User Study

Hardware

- 2 x Phantom Omni from Sensable
- 5DT Data Glove
- Patriot Tracker from Polhemus
- 120 Hz projector display for stereo
- Crystal Eyes active stereo glasses

Software

- VRJuggler
- Voxel Point Shell (VPS) for collision detection

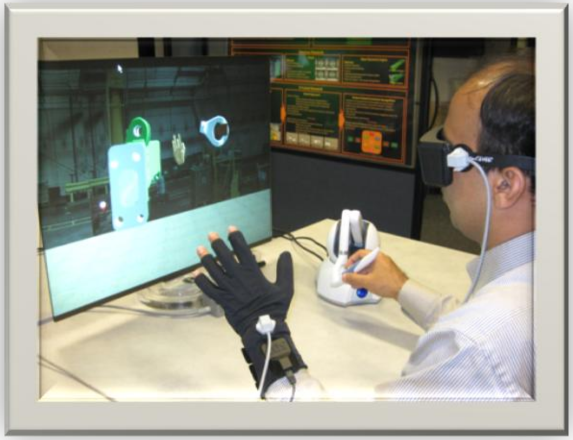
User Study Variables

Dependent Variable

- Time taken for task

Independent Variables

- Device Configuration
  - Haptic - Haptic
  - Nonhaptic – Haptic
  - Glove - Haptic
- Hand (dominant / nondominant)
- Task (simple / hard)



Research Approach

	Haptic-Haptic (Omni-Omni)	Nonhaptic-Haptic (Omni-Omni)	Glove-Haptic (Glove-Omni)
Simple Task		Nonhaptic in dominant hand Nonhaptic in nondominant hand	Glove in dominant hand Glove in nondominant hand
Hard Task		Nonhaptic in dominant hand Nonhaptic in nondominant hand	Glove in dominant hand Glove in nondominant hand

Hypothesis

Remove haptic ability from non-dominant hand

- Results in equal or better performance than haptic enabled devices in both hands.

Use of glove in non-dominant hand and haptic device

- Results in the best performance.

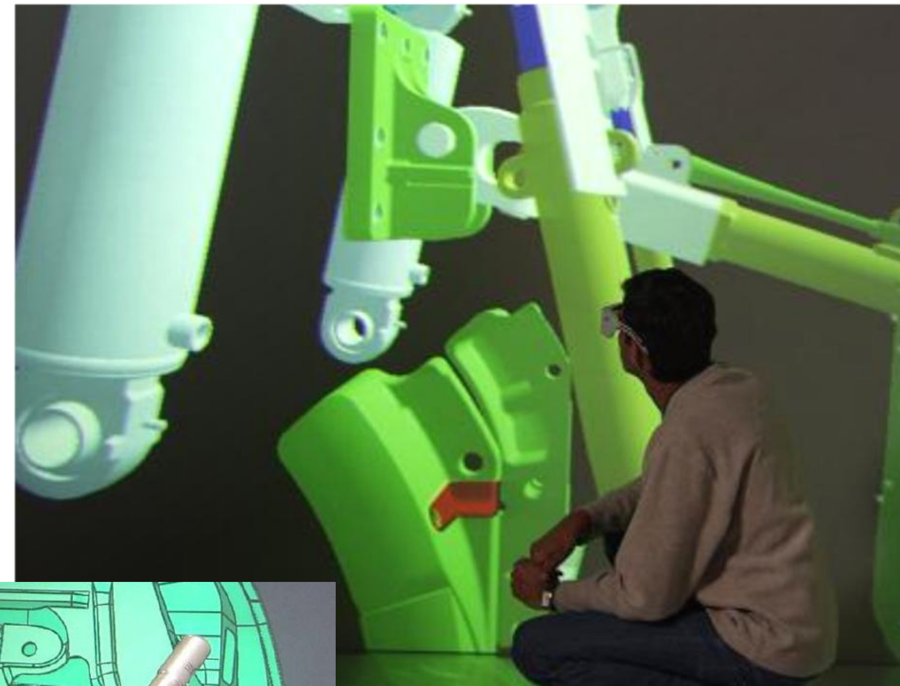
User Centered Haptics for Virtual Assembly

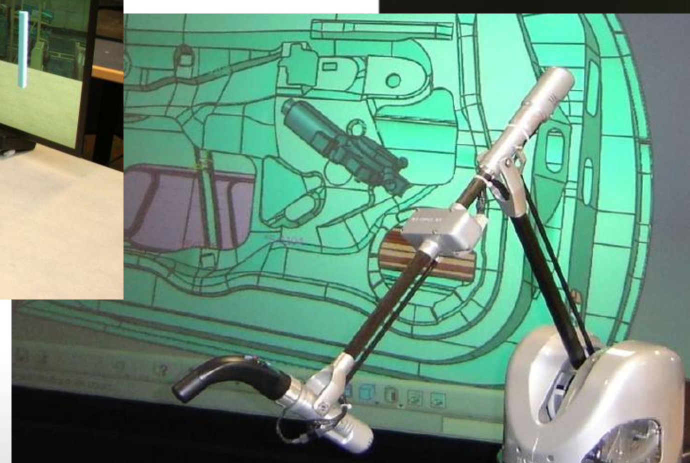
Vikram Vyawahare

Judy M. Vance

Putting it all together

Immersive displays
Whole body tracking
Haptics for large work areas
Bimanual Interaction



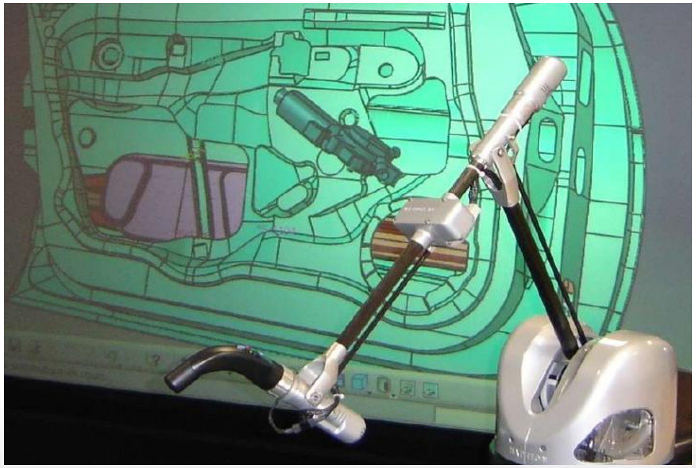


Human Scale Haptics

Combine

- Virtuose 6D-35-45 from Haption
- Mobile platform
- 5DT data glove

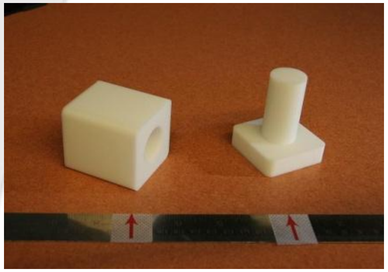
Implement in a large scale projection screen environment



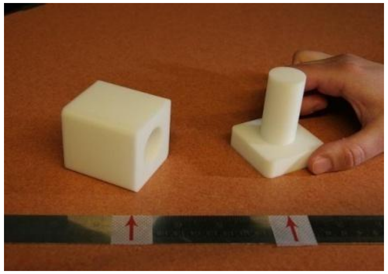
Combining Physical Constraints with Geometric Constraint-Based Modeling for Virtual Assembly

Abhishek Seth
Judy M. Vance

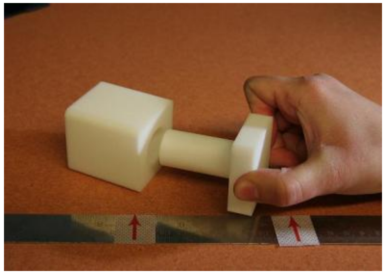
Sample Assembly Task



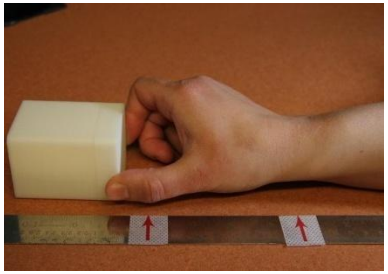
Realistic
Representation



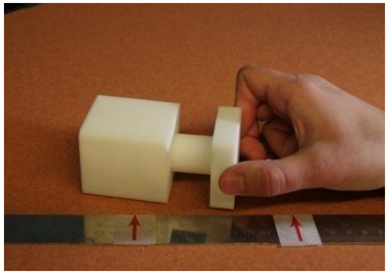
Tactile Force
Feedback
Depth Perception



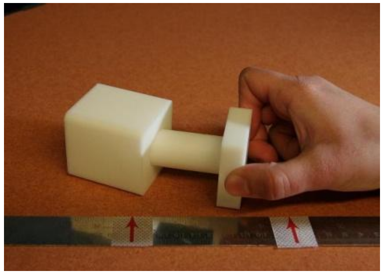
Dexterous & Intuitive
Manipulation



Realistic Part Behavior



Realistic Part Behavior
Collision + Tactile force feedback
Precise Part Manipulation



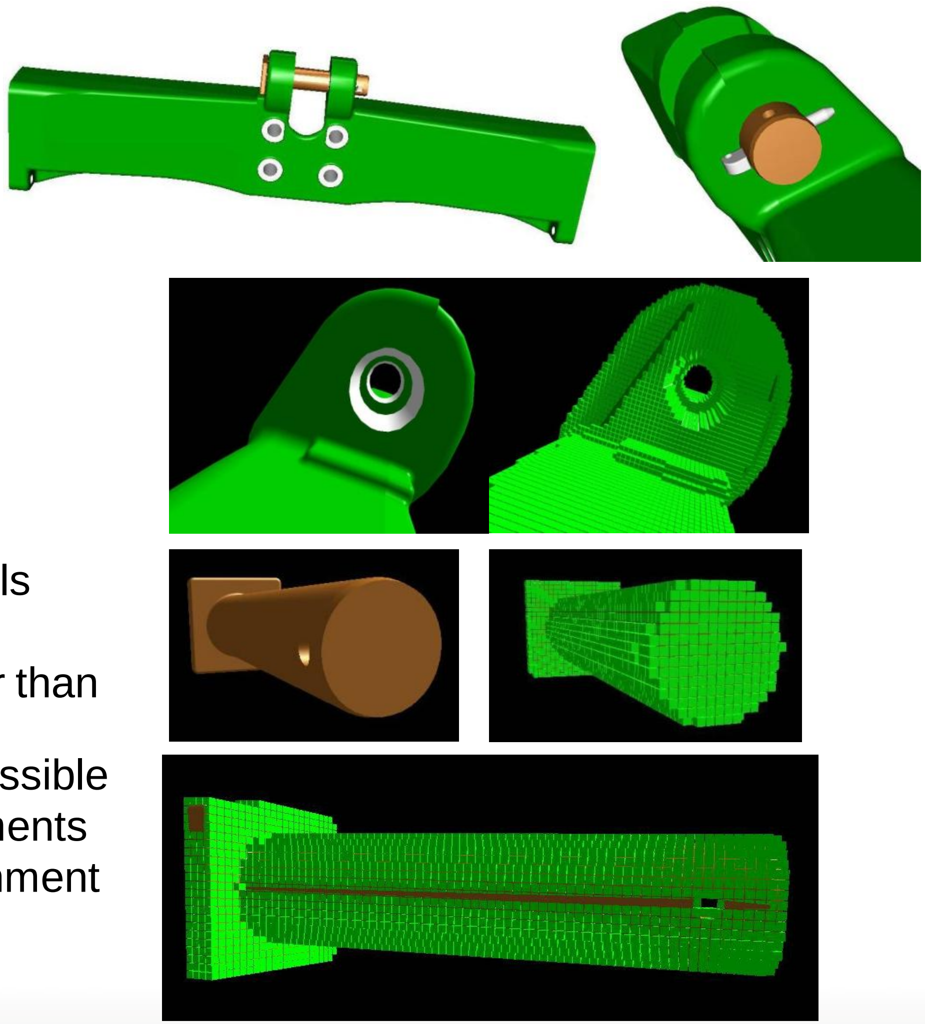
Simulating Physical
Constraints

Research Challenges

- Realistic environment behavior
  - Real-time visualization
  - Collision detection
  - Physics-based modeling
- Intuitive interaction
- Support for complex CAD geometry
- CAD system independence
- Direct CAD-VR data transfer
- Portability to different VR systems

SHARP Assembly Results

- Advantages
  - Realistic environment behavior
  - Intuitive interaction
  - Complex CAD geometry support
  - CAD system independence
  - Portability to VR systems
  - Haptic feedback
- Limitations
  - CAD model approximation using voxels
  - Low clearance assembly not possible
  - System insensitive to features smaller than voxel size
  - Large and small part assembly not possible
  - High memory & computation requirements
  - Limited number of parts in the environment

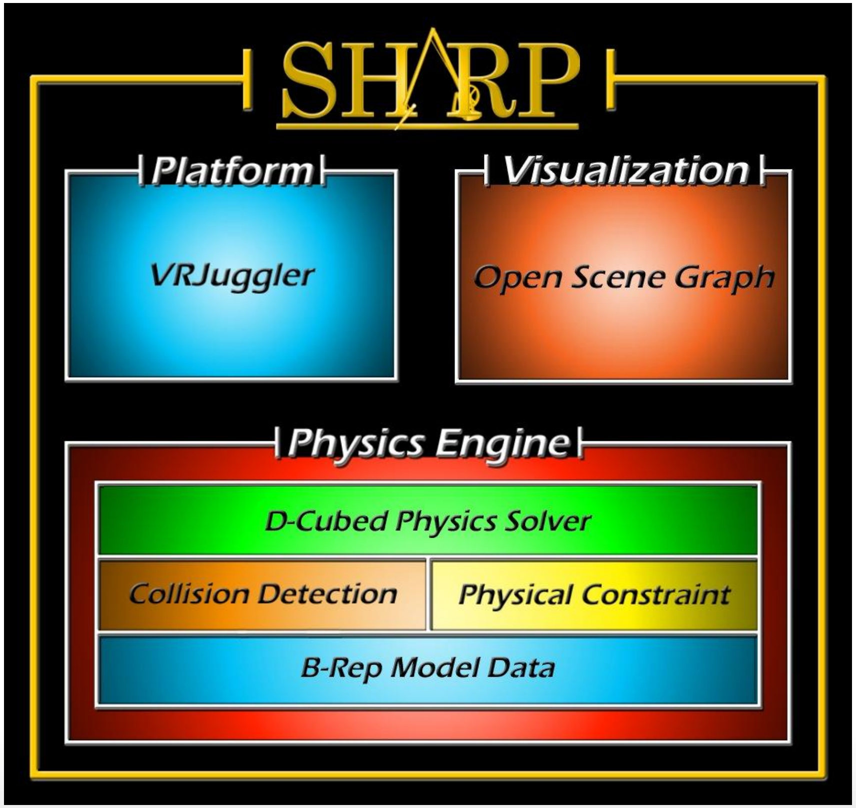


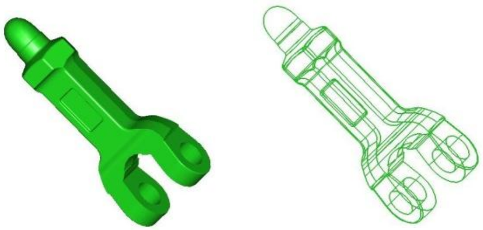
Challenges Redefined

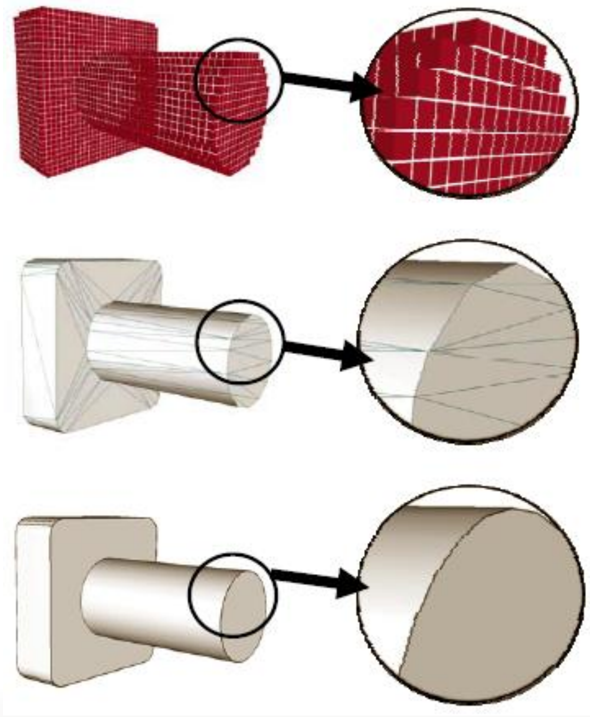
- Realistic environment behavior
  - Real-time visualization
  - Collision detection
  - Physics-based modeling
- Intuitive interaction
- Support for complex CAD geometry
- CAD system independence
- Direct CAD-VR data transfer
- Portability to different VR systems
- Low clearance assembly
- Large and small parts in the environment
- Highly accurate collision detection & physics modeling

Addressing New Challenges

- Precise CAD model representations (B-Rep)
  - Collision detection
  - Physical Constraint Simulation



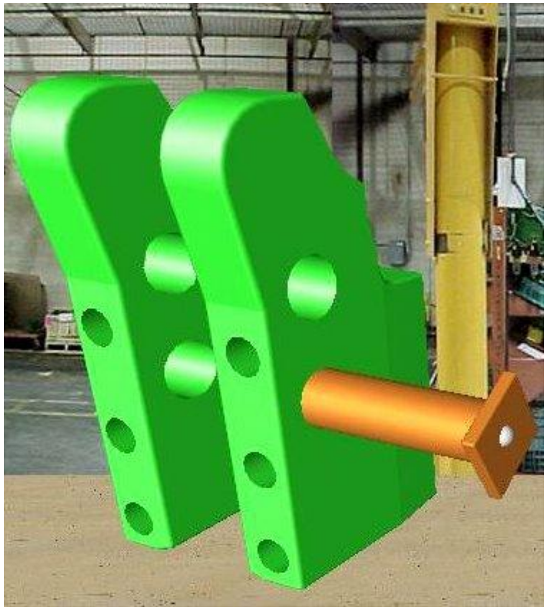




Voxel, tri-mesh and B-Rep representations of a model

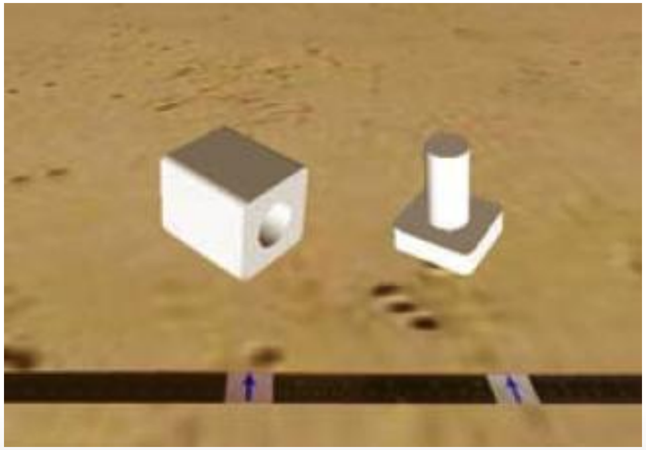
Initial Results

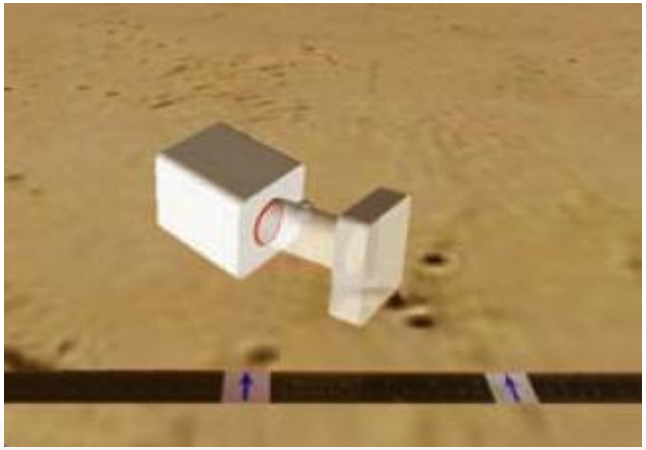
- Advantages
  - No approximation
  - Very accurate collision/physics response
  - Successfully handle complex CAD data



Low clearance assembly in SHARP

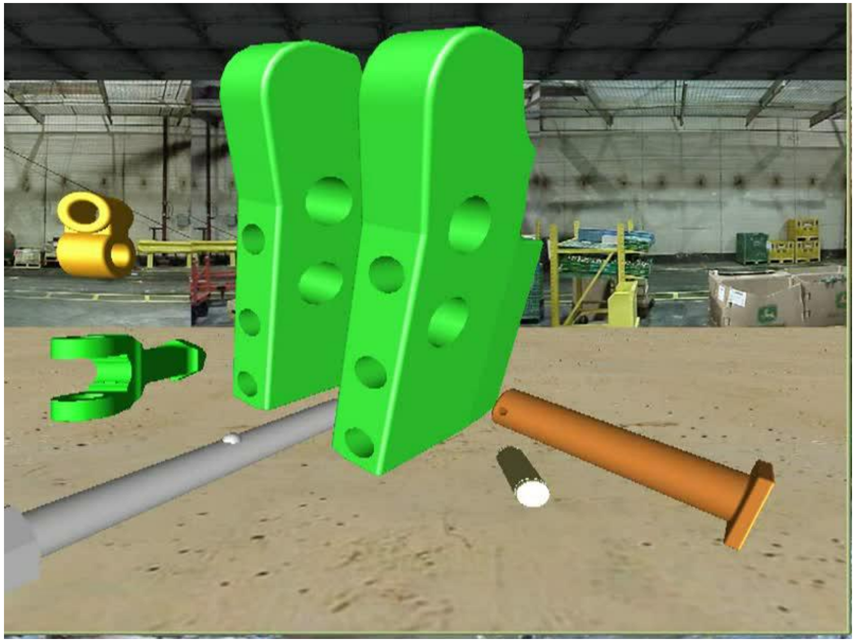
- Case 1 - Collision Only





Initial Results

- Case 2 – Collision + Physical Constraints
  - Successfully simulate realistic part behavior
  - Difficult to assemble low clearance parts with small clearance
  - Precise part movements can't be achieved
  - Intermittently occurring simultaneous contacts affect system performance



Physics.mpg

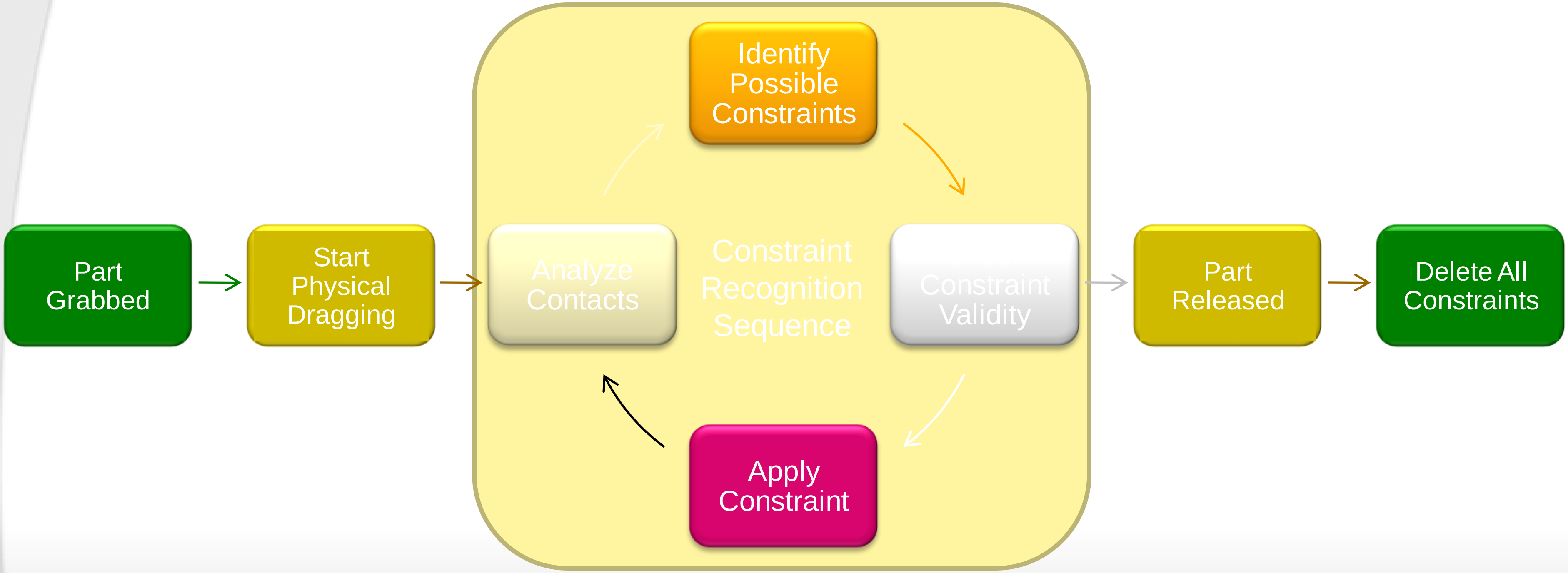
Constraint-Based Modeling

- Uses predefined relationships among geometric features
- Computes reduced degree-of-freedom of parts
- Allows precise part manipulation

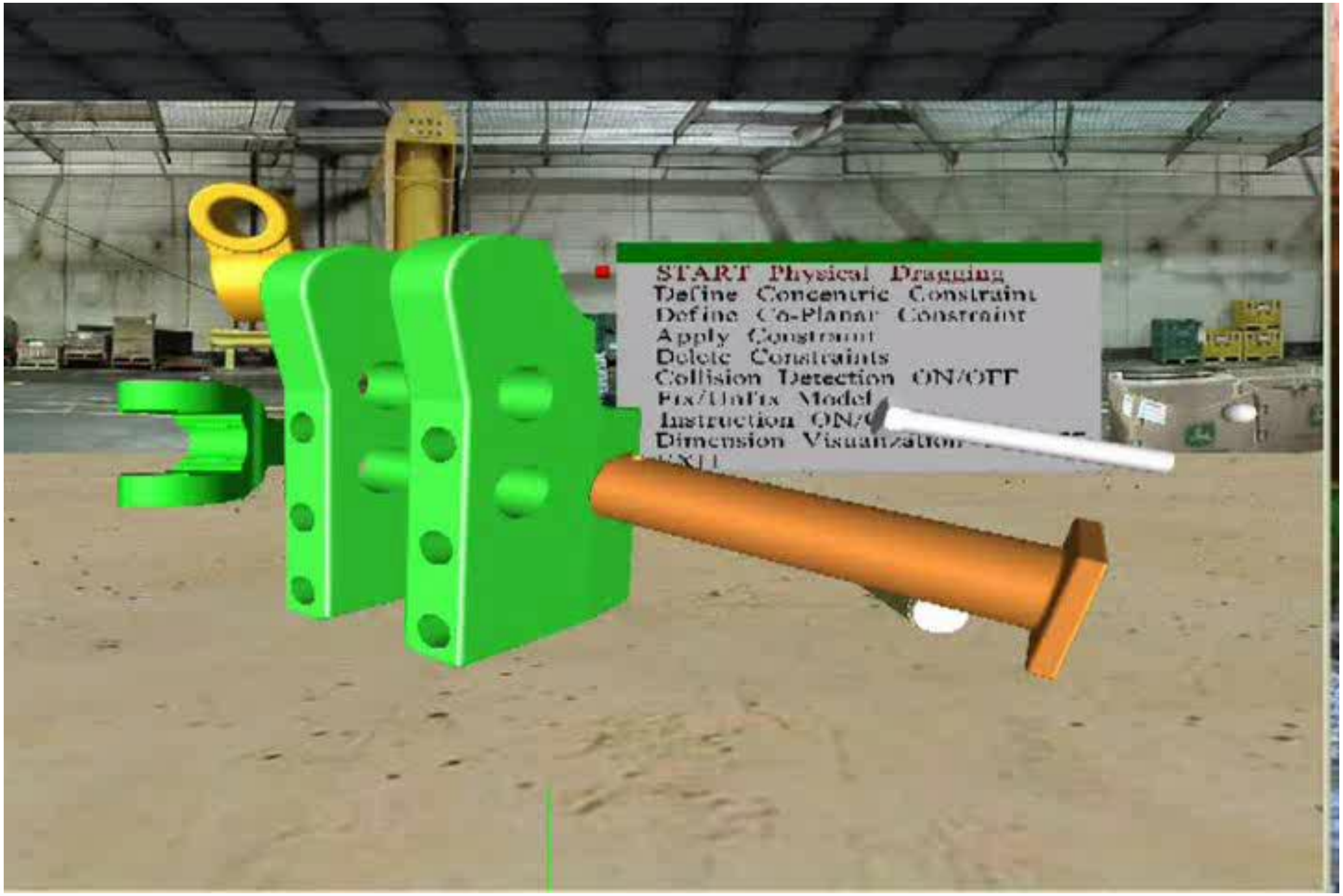
	Constraint-Based Modeling	Physics-Based Modeling
Low Computation Load	X	
Precise Part Movement	X	
Prevent Part Interpenetration		X
Realistic Behavior Simulation		X

Automatic Constraint Recognition

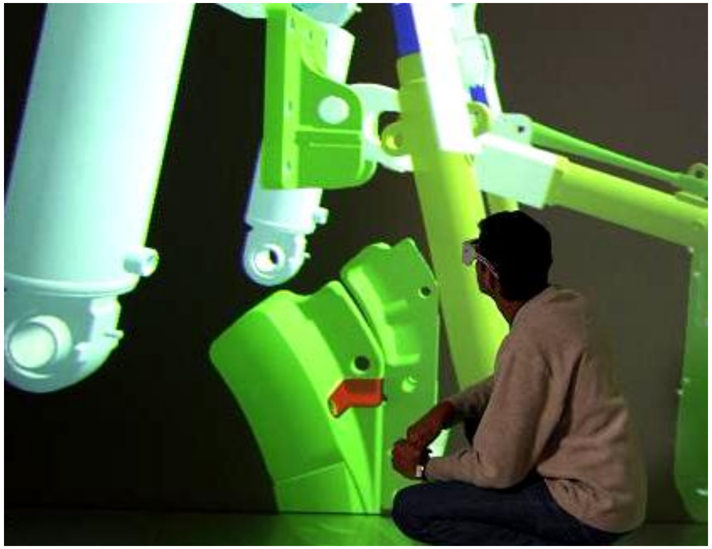
- Feature-based approach
  - Monitors exact contacting geometries (faces/edges) during assembly to predict user's assembly intent
  - Identifies, adds and deletes geometric constraints automatically



hybrid_voice.wmv



Summary



SHARP running in a six-sided CAVE System

- Realistic part behavior
- Support for different VR systems
- Dual-handed haptic interface
- Ability to handle arbitrary CAD data
- Direct data transfer from CAD - VR
- Highly accurate collision/physics responses
- Runtime definition of geometric and physical constraints
- Feature-based automatic constraint recognition
- Low clearance assembly possible (0.001% clearance)
- Intuitive user interaction
- Optimized system performance

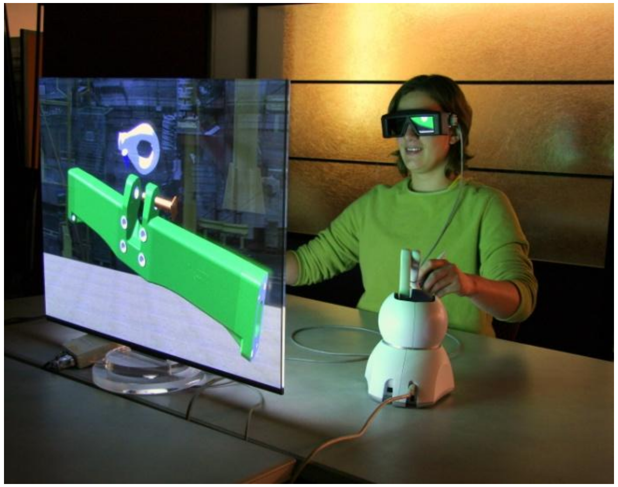
Future Work

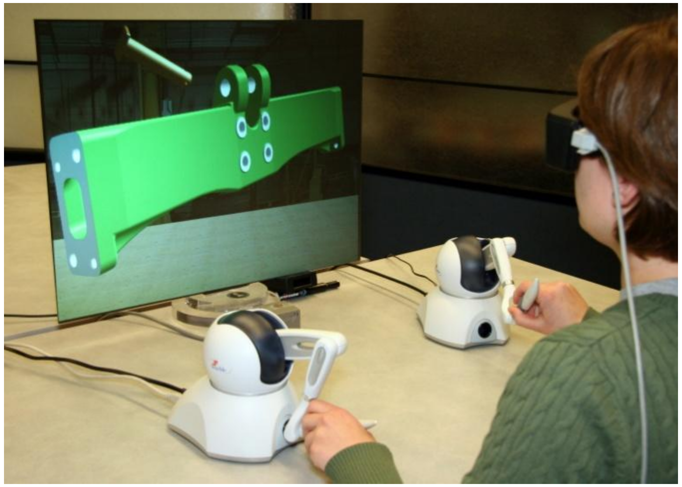
- Limitations
  - System performance when handling large assemblies
  - Haptic Interaction

- Future Work
  - Using tri-mesh data for collision detection
  - Combining constraint management with open-source dynamics engines
  - Design modifications in VR

A Hybrid Method of Haptic Feedback to Support Virtual Manual Product Assembly

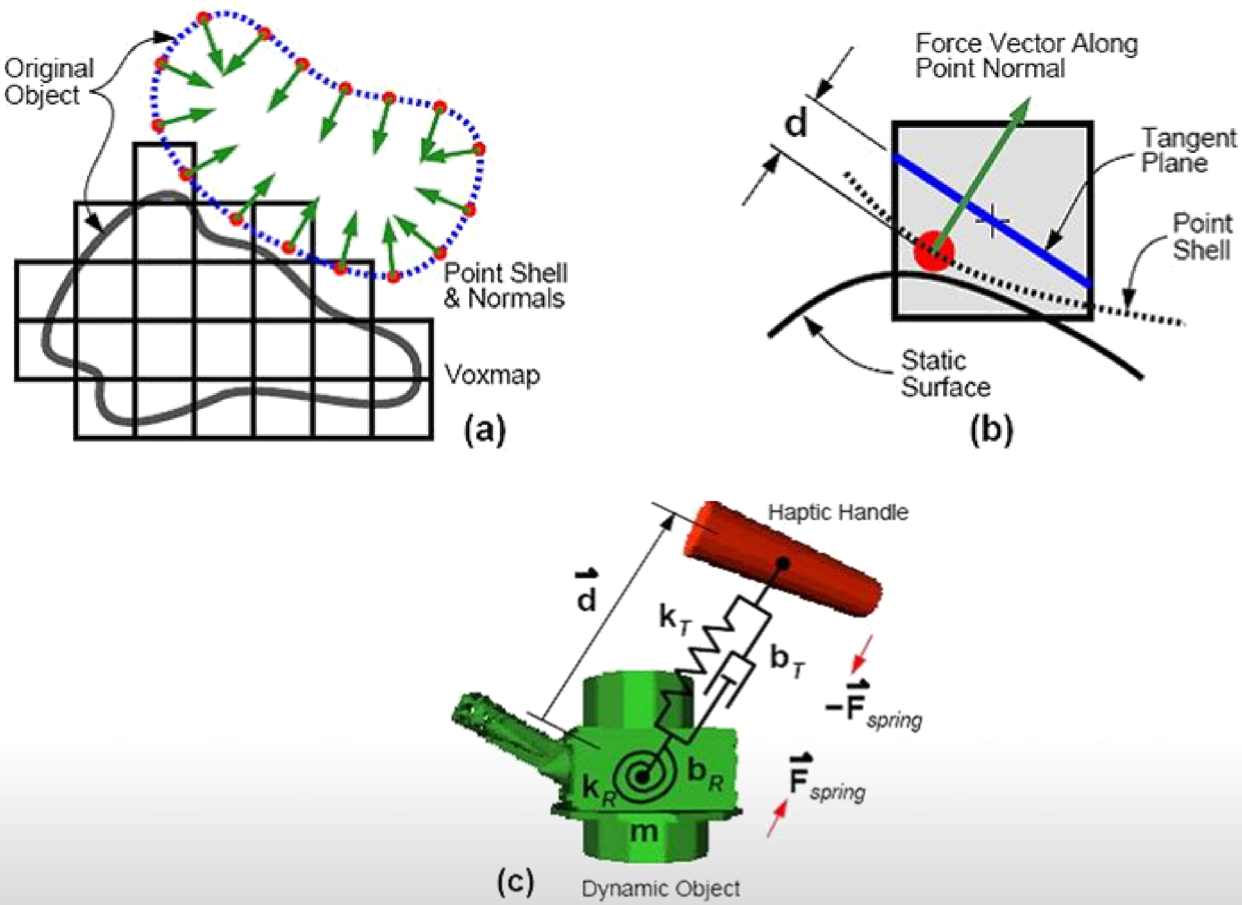
Develop and evaluate a new hybrid method of collision detection and haptic modeling that will more realistically simulate natural interaction of low clearance parts in a virtual environment.





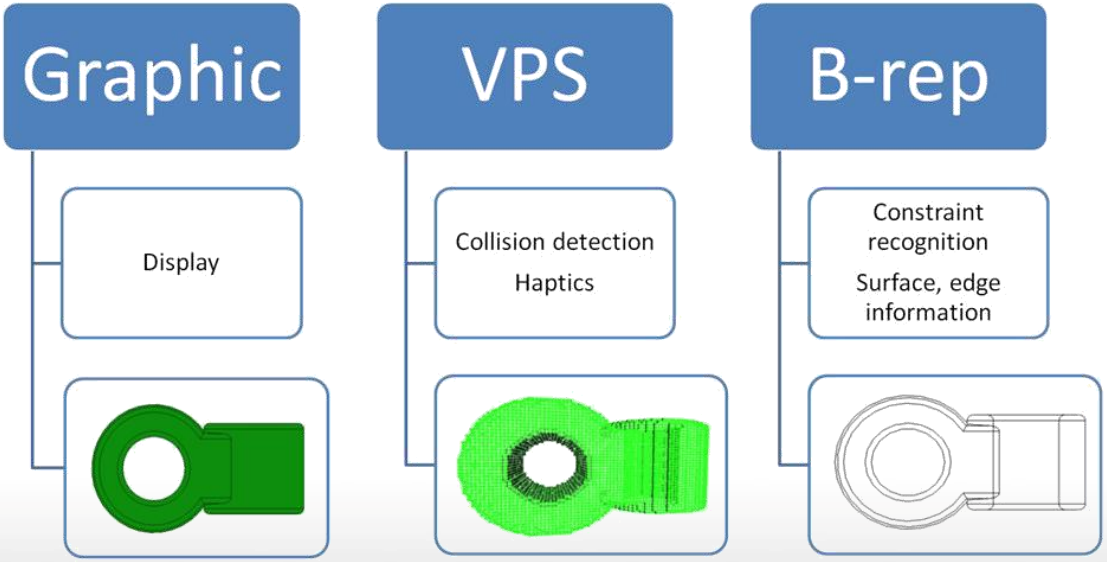
Voxmap PointShell Method

Developed by McNeely, Puterbaugh, Troy at Boeing

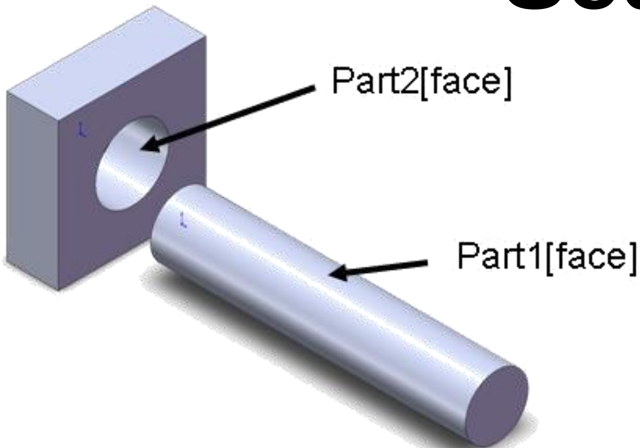


Hybrid Approach

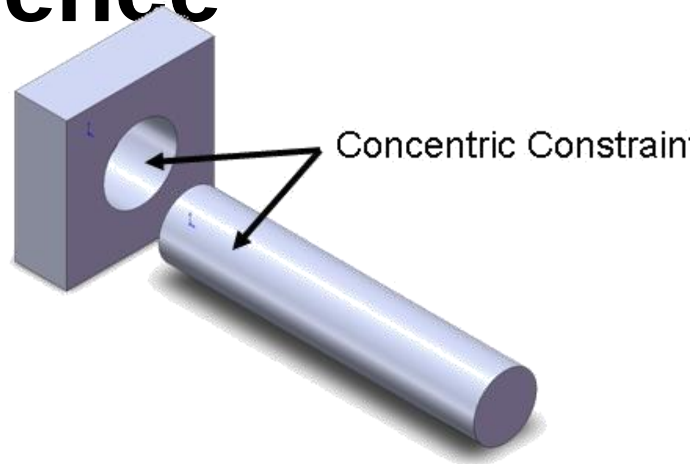
- Use voxels to carry BREP data
- Voxel-pointshell collision returns BREP data
  - Automatic constraint recognition to guide parts
- Force blending required to smooth voxel-based and constraint-based forces and torques



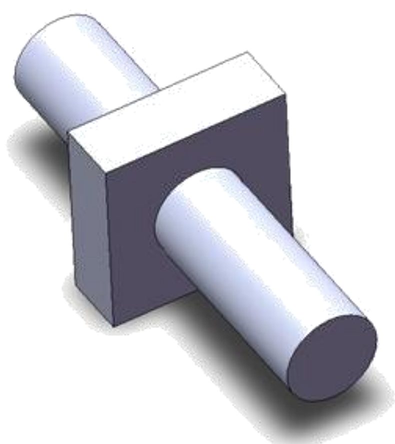
Hybrid Method Assembly Sequence



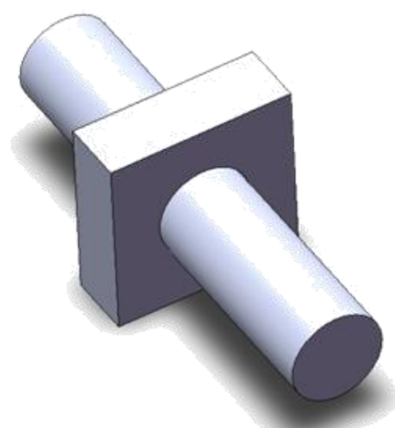
1. Collision occurs:
Identify faces and edges



2. Constraints determined based on identified faces or edges



3. Constraints activated: calculate new position



4. Calculate new collision and constraint forces and torques

Thank You