Digital Human Modeling with Applications

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Digital Human Modeling (DHM)

- **What is DHM? Using computer technology to develop digital models to describe humans**
- **Why is DHM needed?**
  - The human body is a complicated system
  - Humans differ from each other with vast variations
  - Humans need to understand themselves
  - Humans are at the center of various activities
- **Application areas**
  - Aerospace
  - Defense
  - Automotive
  - Sports
  - Heavy Duty Trucking
  - Farm Equipment
  - Service
  - Manufacturing
  - Human Factors
  - Ergonomics
  - Medical
  - Fashion

DHM Scope and Category

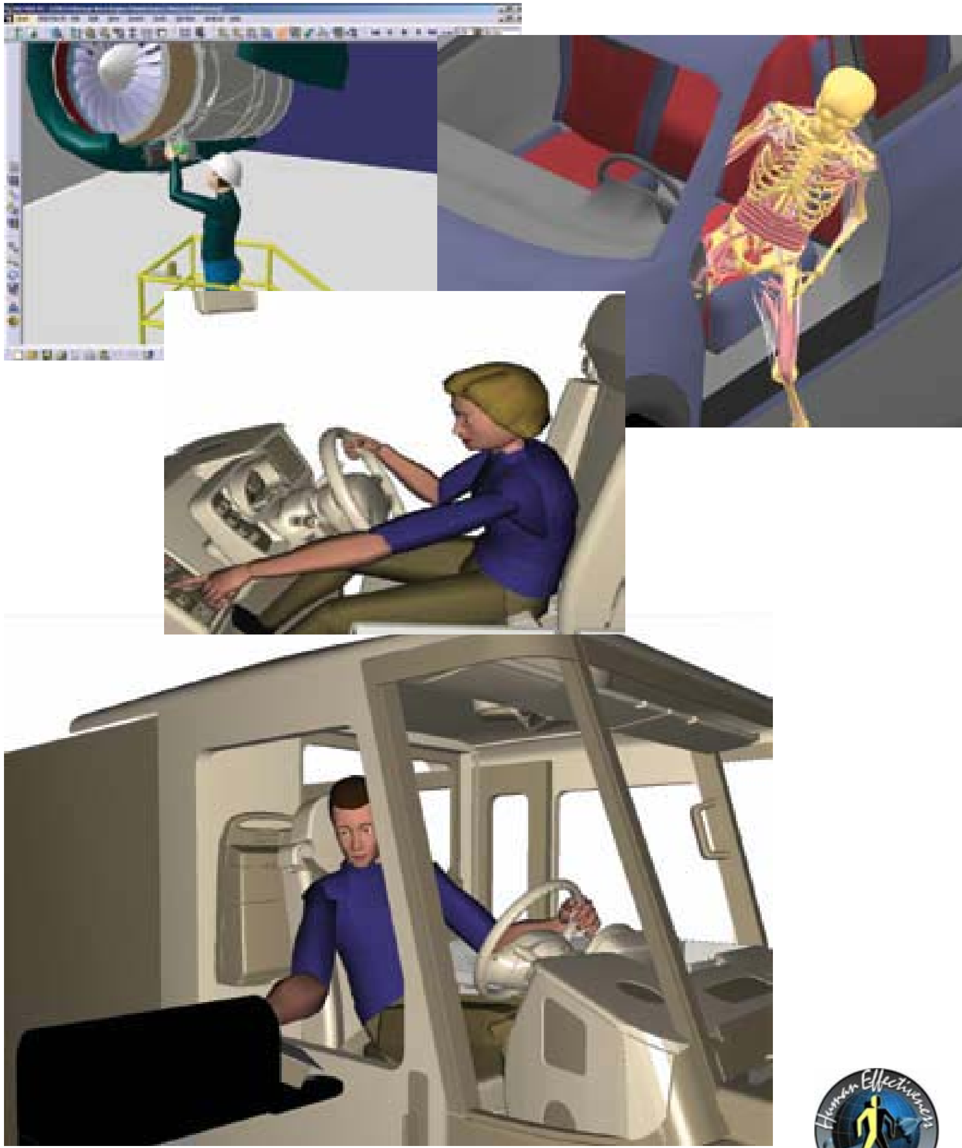
- Ergonomics
- Anthropometrics
- Biomechanics
- Gait and motion analysis
- Physiology
- Pathology
- Behavior
- Performance

✓ Multi-dimensional modeling for apparel fit and equipment interaction

✓ Biomechanical modeling for injury prevention and reduction

Ergonomics Modeling

- **Ergonomics (or human factors):** Application of scientific information concerning humans to the design of objects, systems and environment for human use
- **Modeling**
  - Posture
  - Movement
  - Physical capabilities
  - Cognitive capabilities
- **Applications**
  - Workload or task design
  - Human-machine interface
  - Workspace or work environment design
  - Accommodation



Anthropometrics Modeling

- Anthropometrics: concerned with the physical sizes and shapes of humans, including height, size, weight, and body segment proportion
- Variation with gender, age, and ethnicity
- Applications ranging from clothing, furniture, automobiles, buses, and subway cars to space shuttles and space stations

Gender

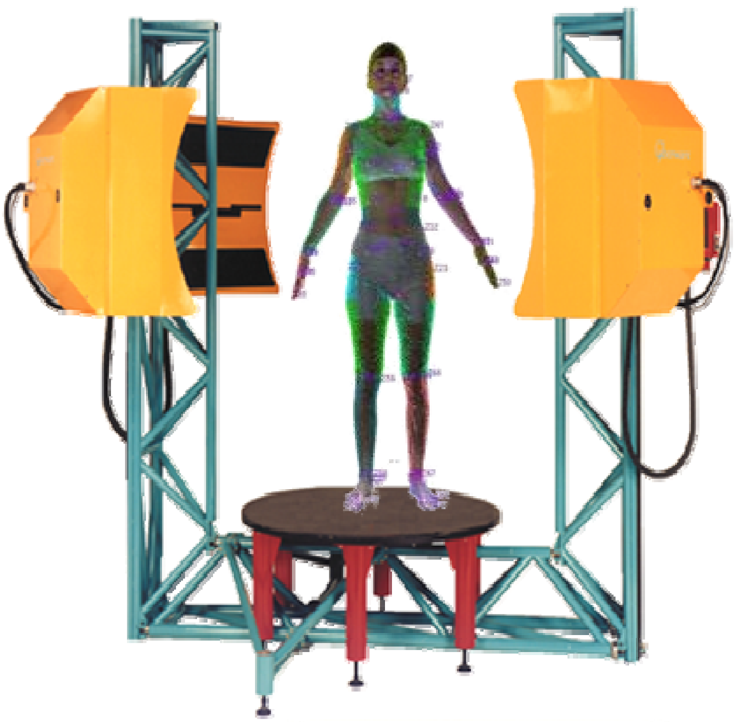
Age

Ethnicity

Human 3-D Shape
— Data Collection

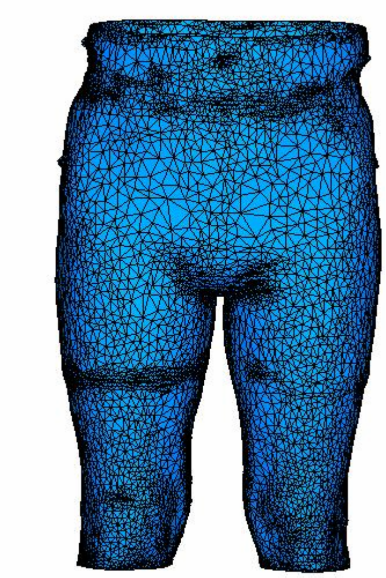
- 3-D whole body laser scanner
- High resolution, large volume of data
- CAESAR database
  - Civilian American and European Surface Anthropometry Resource
  - 2,400 U.S. & Canadian and 2,000 European civilians, men and women, aged from 18-65
  - Using 3D Laser scanner to collect body surface data
  - Each person in a standing pose, full-coverage pose, and relaxed seating pose

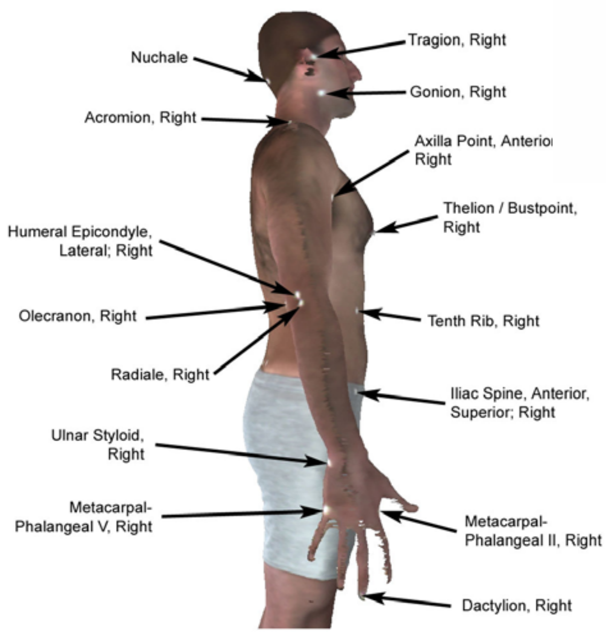
Cyberware 3-D whole body scanner

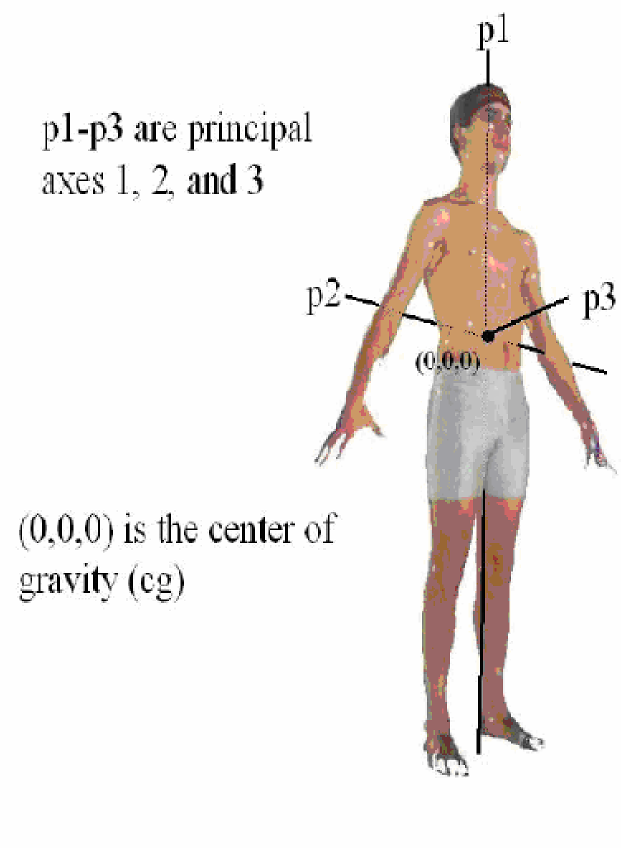


Human 3-D Shape Representation

- **Shape representation**
  - **Traditional metrics**
  - **Landmarks**

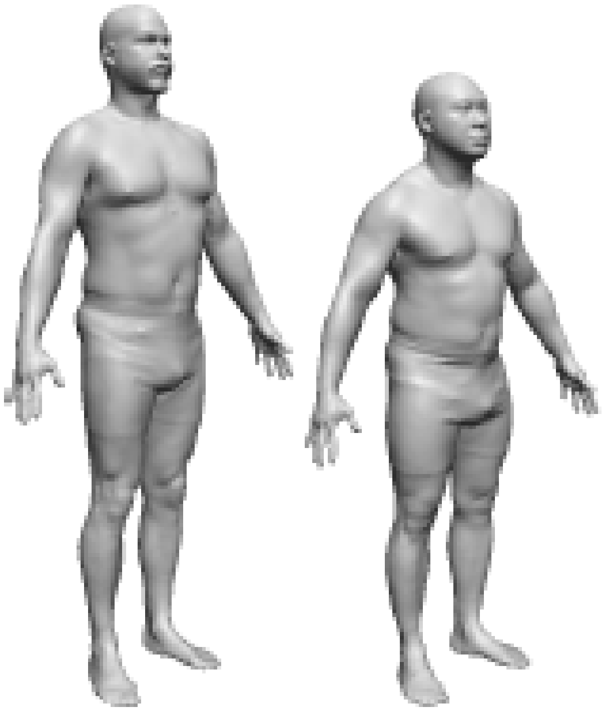






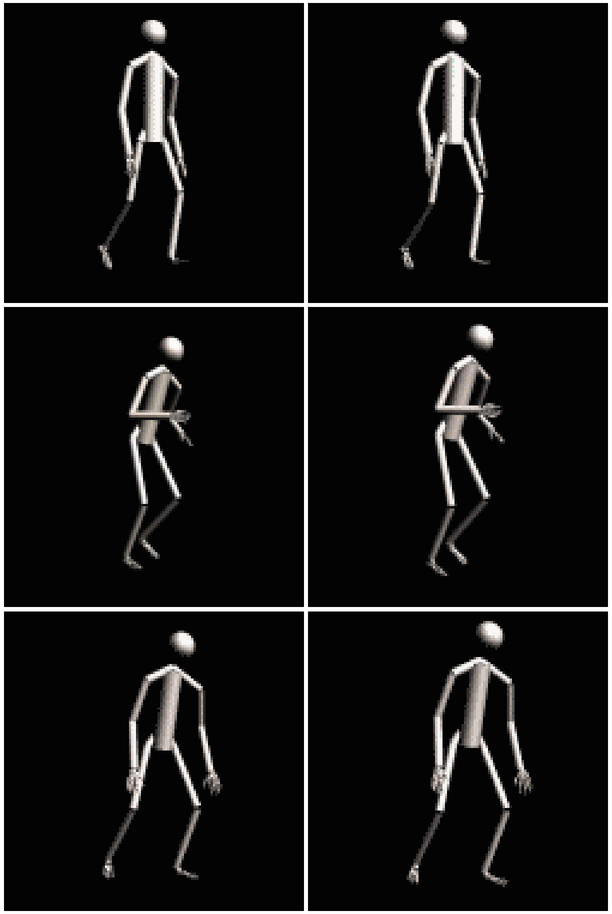
Human Shape Modeling and Morphing

- **Shape modeling**
  - Static modeling based on a shape descriptor
  - To reproduce a shape from scan data
  - To create a shape according to inputs of parameters
- **Shape Morphing**
  - From a base shape to produce variations
  - Anthropometric variations with respect to gender, age, and ethnicity
  - Within anthropometric variability limits



Human Gait Modeling

- Landmark trajectory, skeleton model, based on motion capture
- Kinematics of human motion
- Gait with respect to gender, age, or other anthropometrical factors
- Behavioral factors



Human Kinematic/Kinetic Modeling

- **Human motion modeling: kinetic modeling**
  - Musculoskeletal model with body shape
  - Bones, joints, muscles, and ligaments
  - Body motion governed by driving forces or based on optimization
- **Example models**
  - Anybody, AnyBody Technology, A company of Denmark, http://www.anybodytech.com/
  - Santos, a virtual human model, VSR (Virtual Soldier Research), The University of Iowa, http://www.digital-humans.org/santos/

AnyBody

- **Musculoskeletal model**
- **Joint function and muscle function**
- **Gait analysis**
- **Activity simulation**
  - carrying a 20 kg rucksack
  - body posture accommodation to the changed weight distribution

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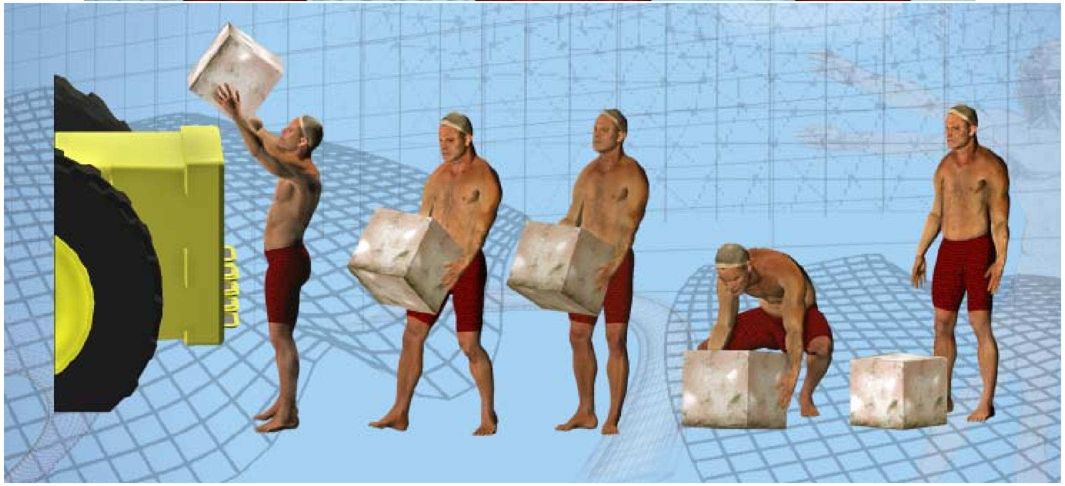
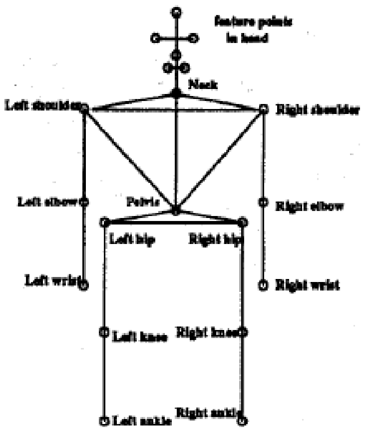
Santos

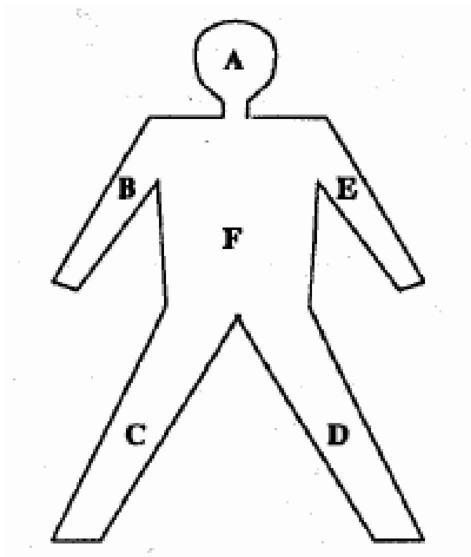
- Skeletal structure
- Kinematics system
- Optimization to determine the joint motion
- Gait analysis
- Activity simulation

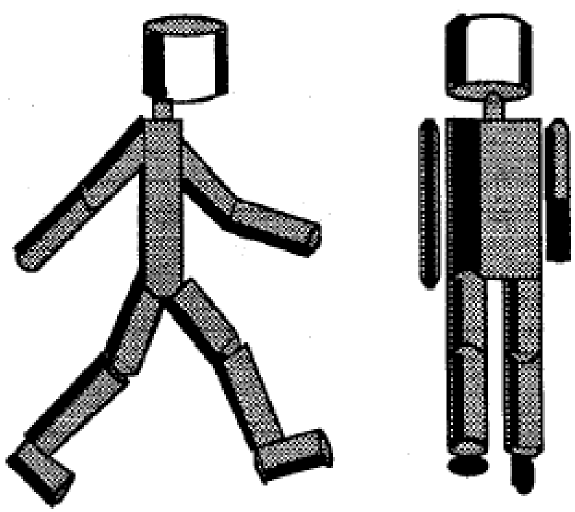


Human Modeling in Human Motion Analysis

- **Human motion analysis methods: model-based or non model-based**
- **Models used in motion analysis**
  - Stick figure
  - 2D contour
  - 3D or volumetric models



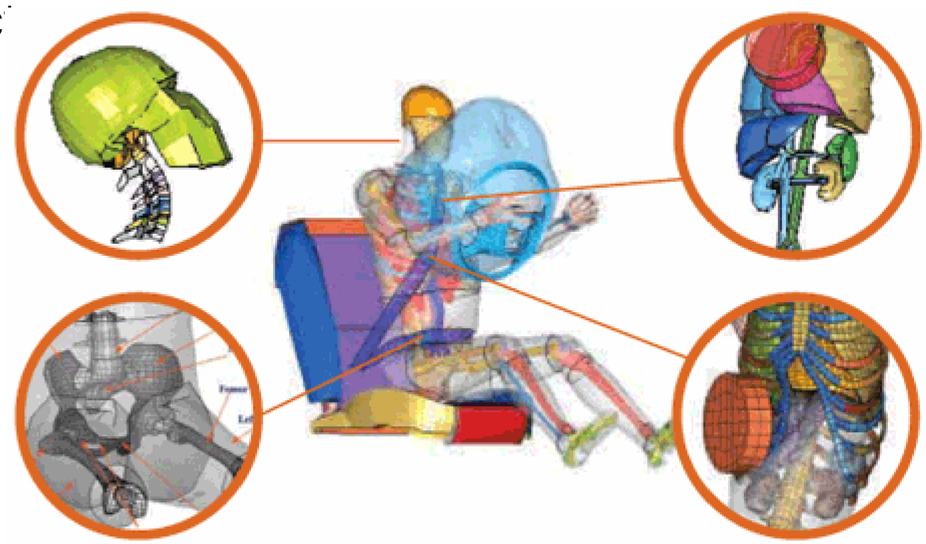




Biomechanics Modeling

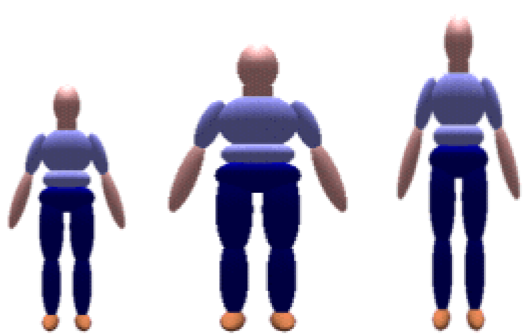
- **Goals**
  - To model the human response under dynamic loading
  - To understand injury mechanism
  - To improve crashworthiness of struc

- **Applications**
  - Auto safety
  - Injury prevention and reduction
  - Sports
  - Rehabilitation

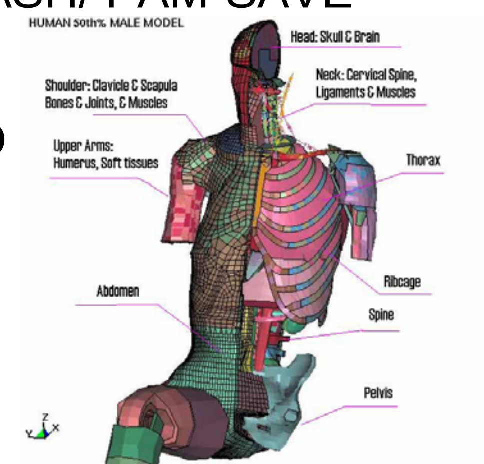


Biomechanical Modeling Techniques

- **Rigid multi-body dynamics**
  - Entire body divided into a number of segments
  - Each segment treated as a rigid body, linking to another with joints
  - Describing kinematics
- **Model tools**
  - MADYMO (MAthematical DYnamic MOdeling)
  - ATB (Articulated Total Body)



- **Finite element method**
  - Using small elements (cubes) to describe the bones, soft tissues, and organs
  - Incorporating biological material models
  - Describing stress and strain
- **Modeling tools**
  - LSDYNA
  - PAM-CRASH/ PAM-SAVE
  - DYTRAN
  - MADYMO



Model Development Activities

- **Humos: http://humos2.inrets.fr/**
  - A Set of HUman MOdels for Safety
  - Funded by the European Commission
- **A research consortium of smart dummies**
  - Involving nine automakers and a pair of auto suppliers
  - Support from university biomechanical research groups
  - First set of adult models--three males and three females in small, medium and large sizes by March 2011
  - Models of children to follow
  - 1 million to 3 million elements for each model

Research Institutions

- **Government agencies**
  - NIH/NLM
  - NHTSA
- **Universities**
  - Bioengineering Center of Wayne State University
  - Center for Applied Biomechanics, Virginia University
  - Washington University
  - University of Michigan
- **Industries**
  - Automobile manufacturers’ R&D department
  - FE software vendors
- **Associations**
  - International Society of Biomechanics (ISB)
  - American Society of Biomechanics (ASB)
  - Society of Automobile Engineers (SAE)

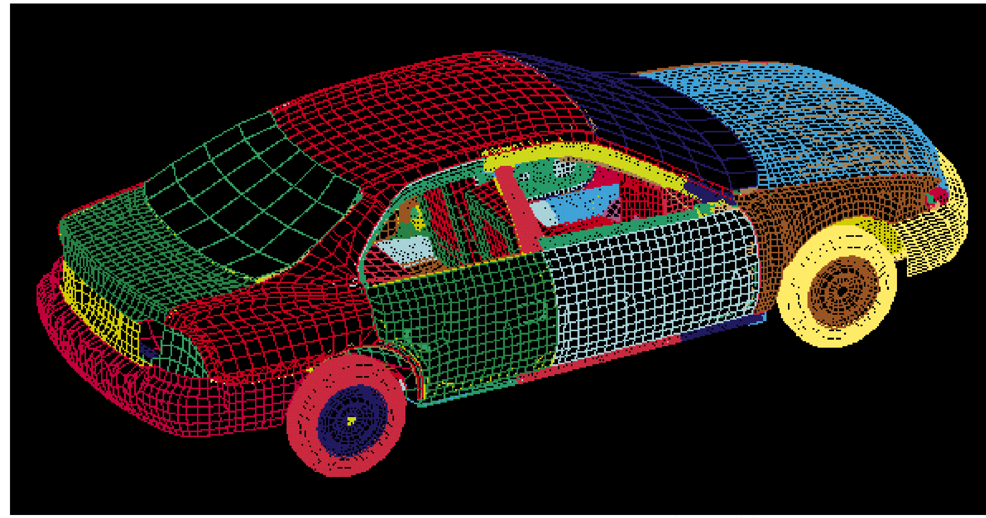
Open Data Resources

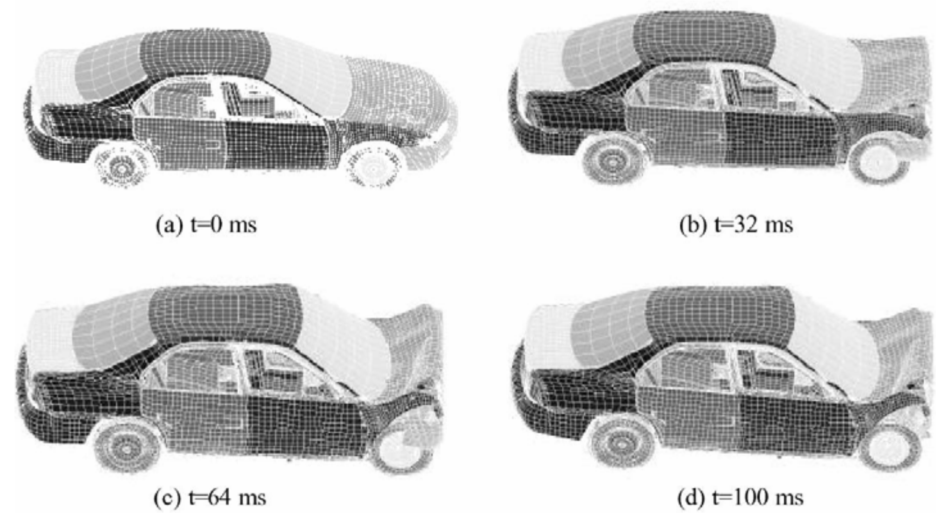
- **Bony structure**
  - VAKHUM: http://www.ulb.ac.be/project/vakhum/public_dataset/public-data.htm (University of Brussels)
  - ISB: http://isbweb.org/o/content/view/66/73/ (International Society of Biomechanics)
  - BEL: http://www.tecno.ior.it/VRLAB/researchers/repository/BEL_repository.html#ULB%20Virtual%20Human (Biomechanics European Laboratory)
- **Soft tissues**
  - NLM: http://www.nlm.nih.gov/research/visible/visible_human.html (National Library of Medicine)
  - HUMOS2: http://humos2.inrets.fr/about.php (Project funded by the European Commission)
- **Material models**
  - Soft tissue material models

    http://wwwiaim.ira.uka.de/web/SoftTissueDB/SoftTissueWiki/index.php/Material_Models (Institut für Technische Informatik)

Automobile Crashworthiness Modeling

- **A finite element model of a four-door 1997 Honda Accord DX sedan**
- **Using a reverse engineering technique, with 220 parts and 117,353 elements**
- **Simulations of full and offset frontal, side, and car-to-car impact**

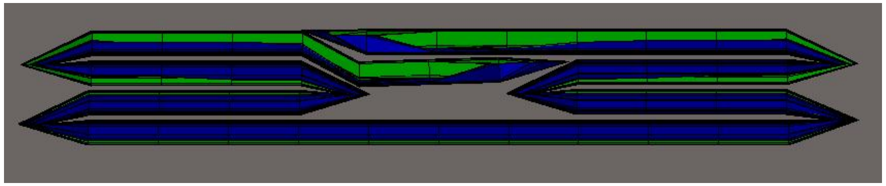




(a) t=0 ms (b) t=32 ms (c) t=64 ms (d) t=100 ms

Occupant-Airbag Interaction Modeling

- FE modeling of airbag using LSDYNA
- Rigid multi-body modeling of occupant using ATB
- Vehicle and interior structures modeled by respective planes using ATB
- Integration of FE airbag model with ATB occupant model
- Model used for
    - Safety performance assessment
    - Injury analysis and prediction
    - Airbag design and optimization



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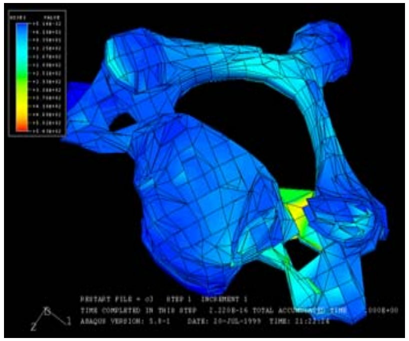
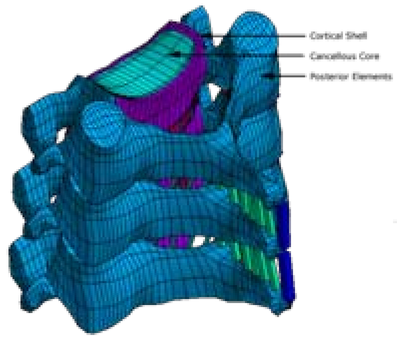
Head-Neck Injury Modeling

- **Finite element modeling of the head-neck complex**
  - ➢ Actual geometrical data of a 68-year old male cadaver specimen
  - ➢ Cervical spine C0~C7
  - ➢ Muscles and ligament
  - ➢ Rigid skull
  - ➢ Original model developed by DSO, Singapore
- **Challenges to the model validation and modification**
  - ➢ Accurate anatomical description
  - ➢ Material properties of bones, muscles, ligaments, and soft tissues
  - ➢ Function of muscles
- **Simulation of head-neck response under dynamic tensile loading**





Cervical Segment C4-C6

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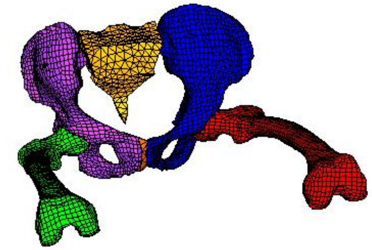
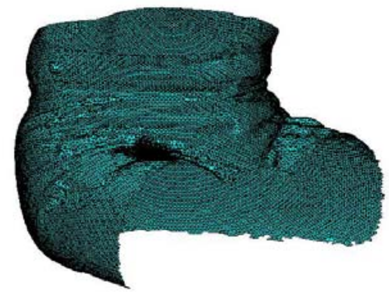
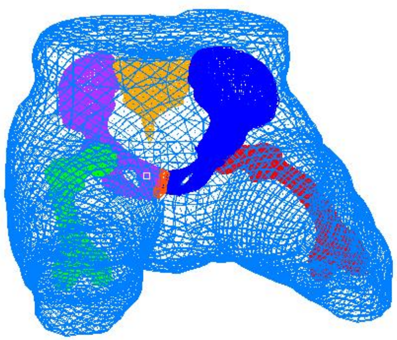
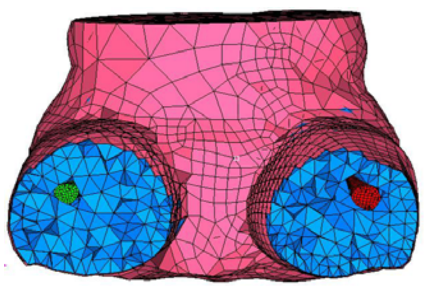
Seating Comfort Modeling

- Bony Structure model
- 3-D scan data and outer shape model
- Integrated Model
  - Multiple layers of solid elements for fat/muscles
  - A layer of shell elements for skin
- Simulation of pressure distribution between the seat cushion and buttock



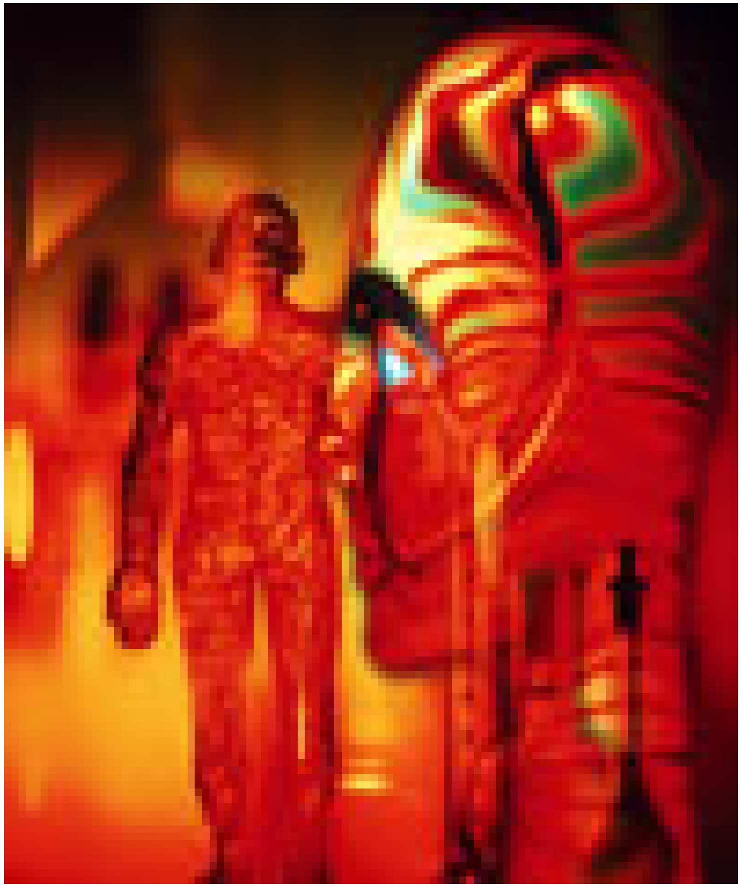






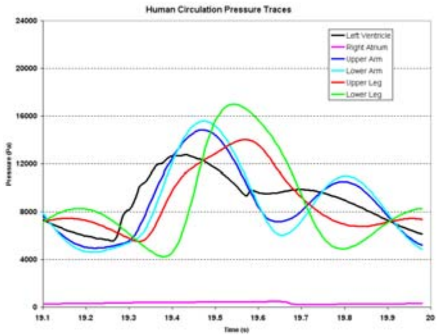
Human Physiological Function Modeling

- Physiological function modeling
  - Cardiovascular function: blood circulation
  - Lung function: Inhalation/exhalation
  - Other Physiological Function Modeling
- Key Competencies
  - Fluid physics and fluid-structure interaction
  - Finite element analysis: organ level, tissue level, and cell level
  - Advanced analytical tissue models
- Applications
  - Human performance optimization
  - Status assessment: live or dead
  - Injury evaluation
  - Intention prediction

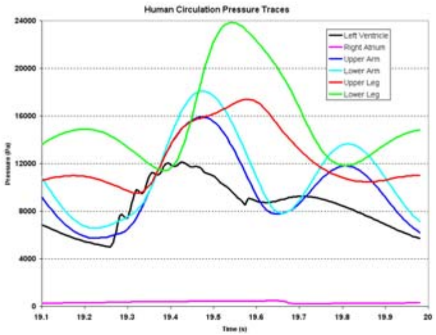


Sitting Arterial/Venous Circulatory Simulation

- Sitting posture arterial/venous circulation simulation with and without gravity
- Shown below: posture, arteries/veins, generated grid, and simulation pressure distribution at instant in time with and without gravity
- Shown at right: pressure traces in time of single heart beat at different points in body with and without gravity

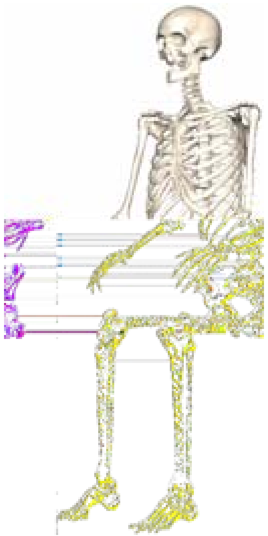


Simulation Pressure Results (No Gravity)

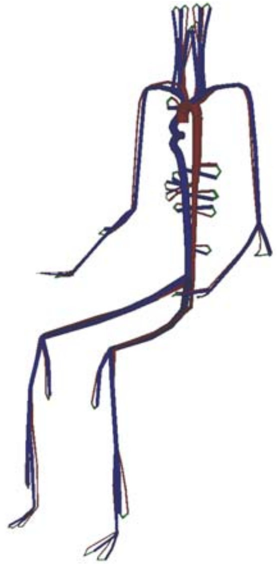


Simulation Pressure Results (With Gravity)

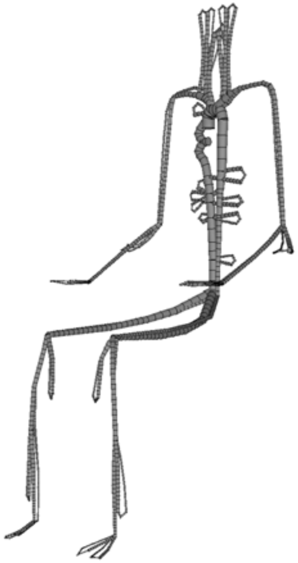
Sitting Posture

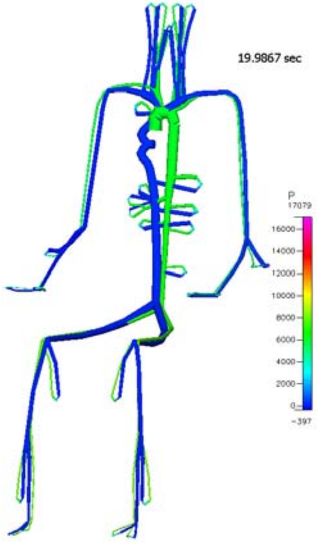


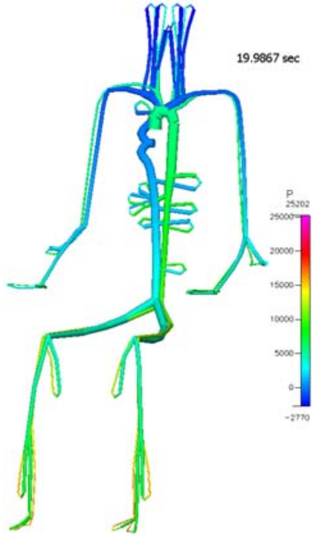
Arteries & Veins



Generated Grid







An example, work done by CFDRC

DHM Recent Developments

- **Multi-Scale, Multi-Physics Modeling**
  - From organ level to tissue level and to cell level
  - From biomechanics to physiology, and pathology
  - From bones and soft tissues to vessels, nerves, and neurons
- **Blast induced injury modeling**
  - Blast: shock wave and wind force
  - High rate, short duration impact on human body
  - Modeling of lung, vascular, etc.
  - Modeling of traumatic brain injuries
- **Integration into virtual testing environment**
- **Model validation**
- **Distributed computation**
- **Web based applications**