Santos Hand Simulation

Jingzhou Yang

Faisal Goussous

Presentation Outline

- Current Hand Capabilities
- Ongoing Hand Research
- Future Work

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Current Capabilities

- ✓Biomechanical Model
  - Right Hand
  - Left hand
- ✓Graphical Interface
  - Scalable Anthropometry
- ✓Photorealism (and Skin deformation)
- ✓Grasping (16 power and precision grasps)
- ✓Grasp Morphing (changing of grasping from one to another)

- ✓Manipulation (individual joints, or coupled joints)
- ✓Forward Kinematics
- ✓Joint Torque Analysis
- ✓Reach Envelopes of each Finger

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Ongoing Research

- ✓Graphical Interface
- ✓Finger Pressure
- ✓Finger Wrapping
- ✓Grasping Quality Calculation

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Future Work

- ✓Validation
- ✓Grasp Artificial Intelligence
- ✓Local Biomechanics wrist and hand modeling
- ✓Compliant Pressure Mapping
- ✓Evaluation of Carpal Tunnel Pressure
- ✓Dexterity Analysis

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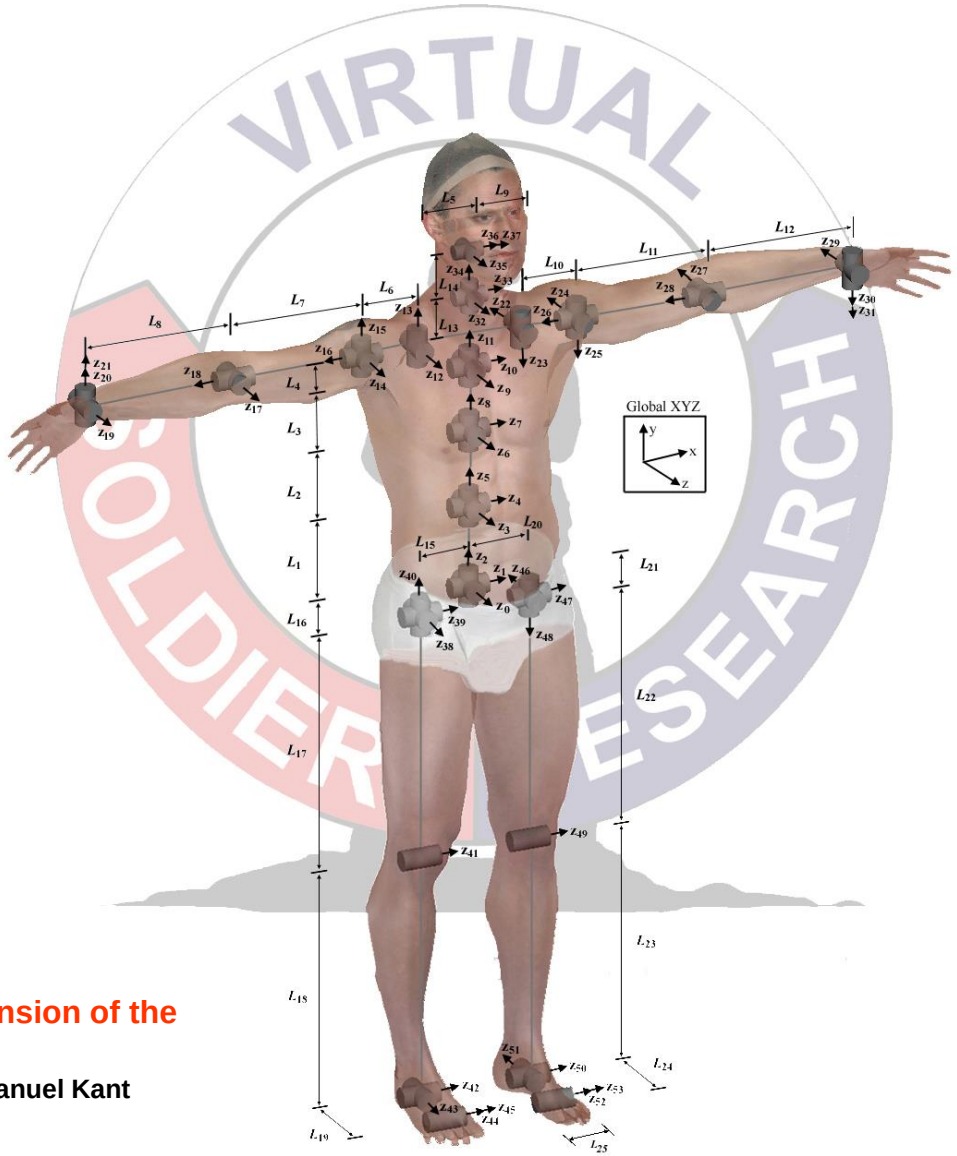
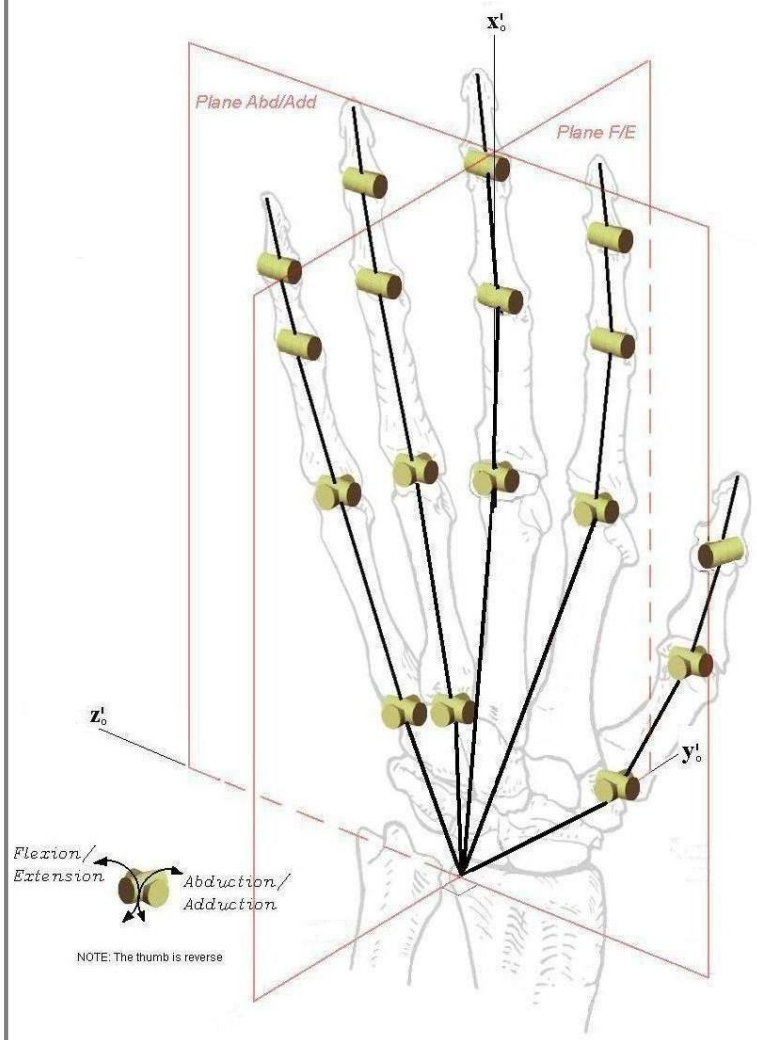
SANTOS™

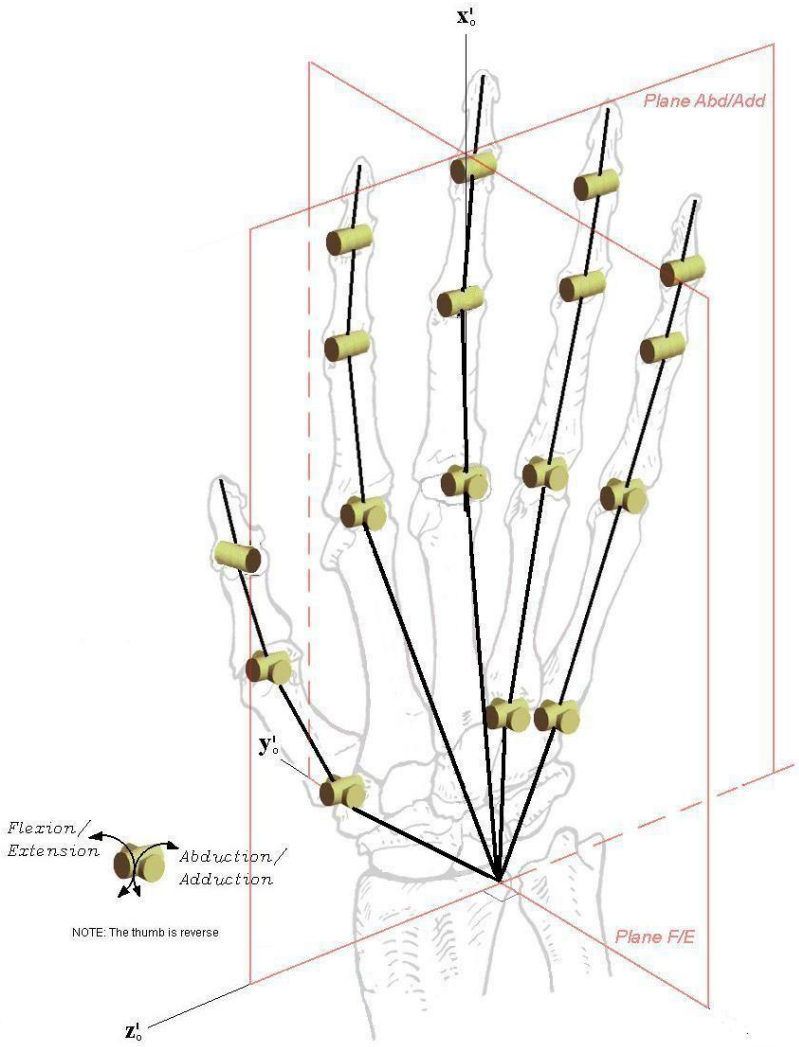


The hand is an extension of the human brain

Immanuel Kant

Hand Model


Plane Abd/Add
Plane F/E
Flexion/
Extension
Abduction/
Adduction
NOTE: The thumb is reverse


Plane Abd/Add
Flexion/
Extension
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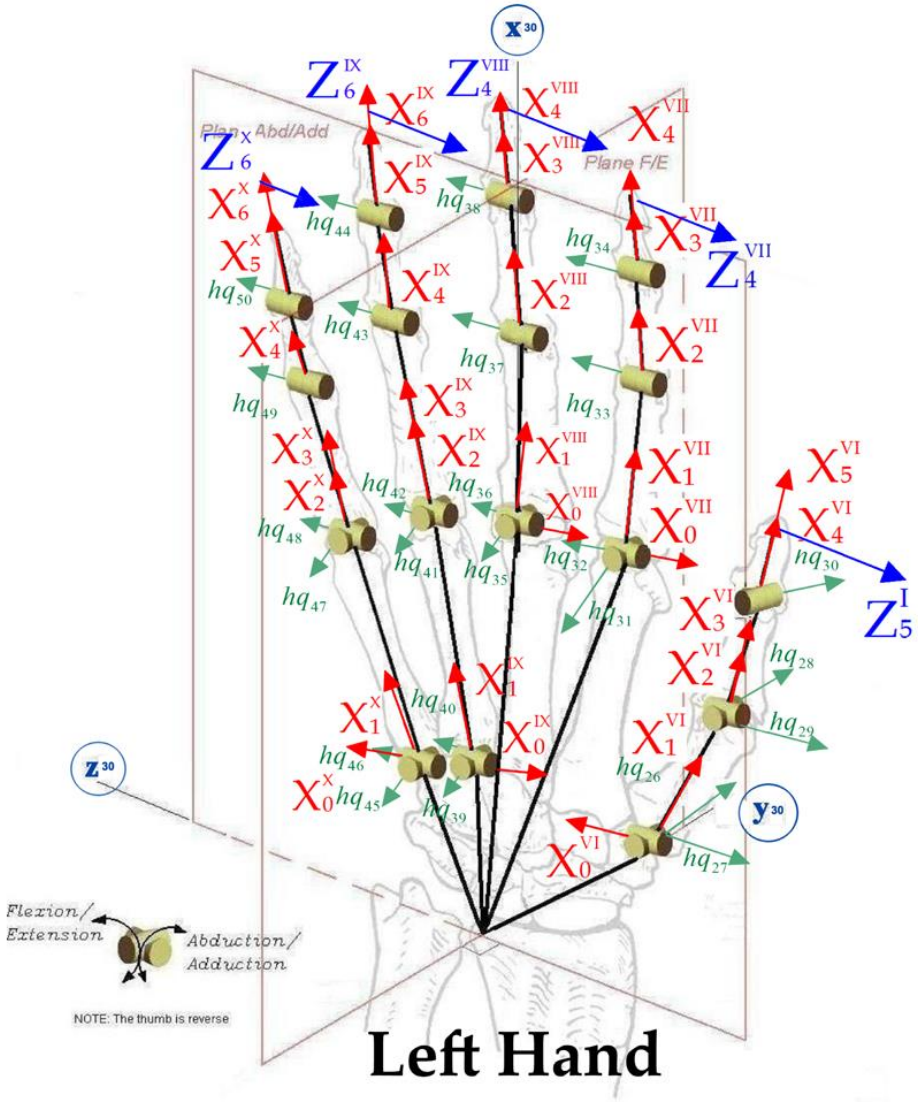
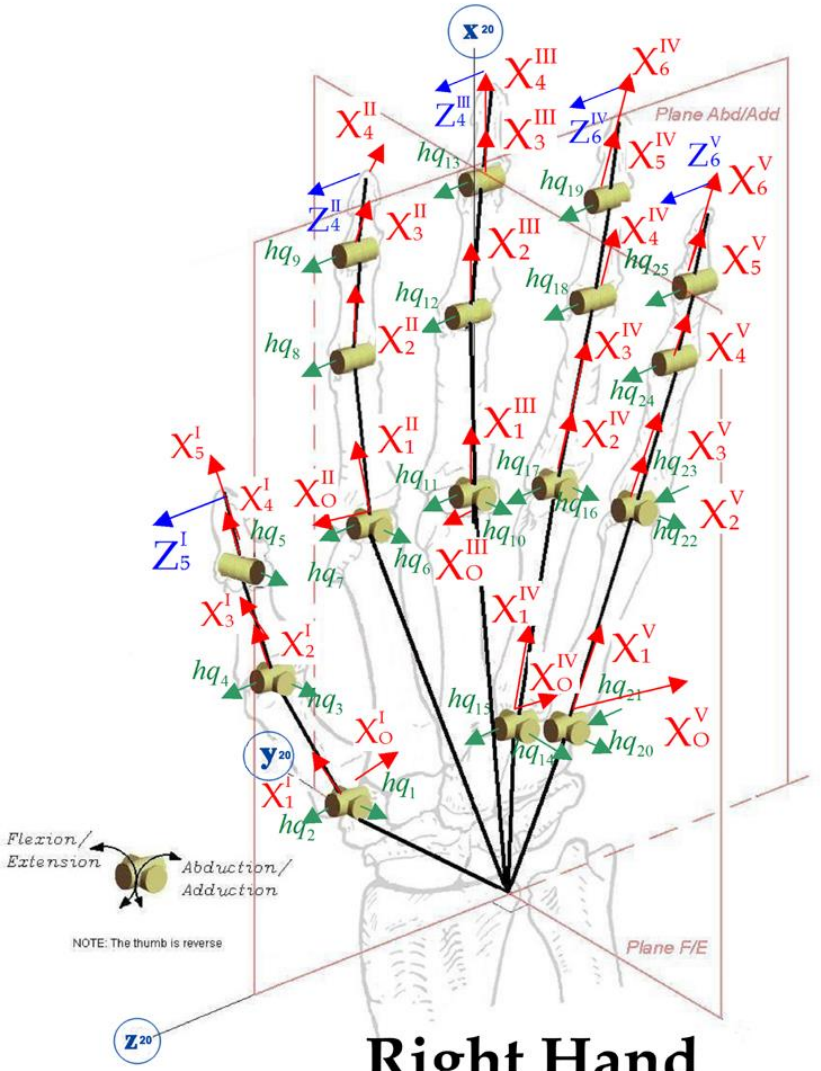
NOTE: The thumb is reverse
Plane F/E

Hand Model

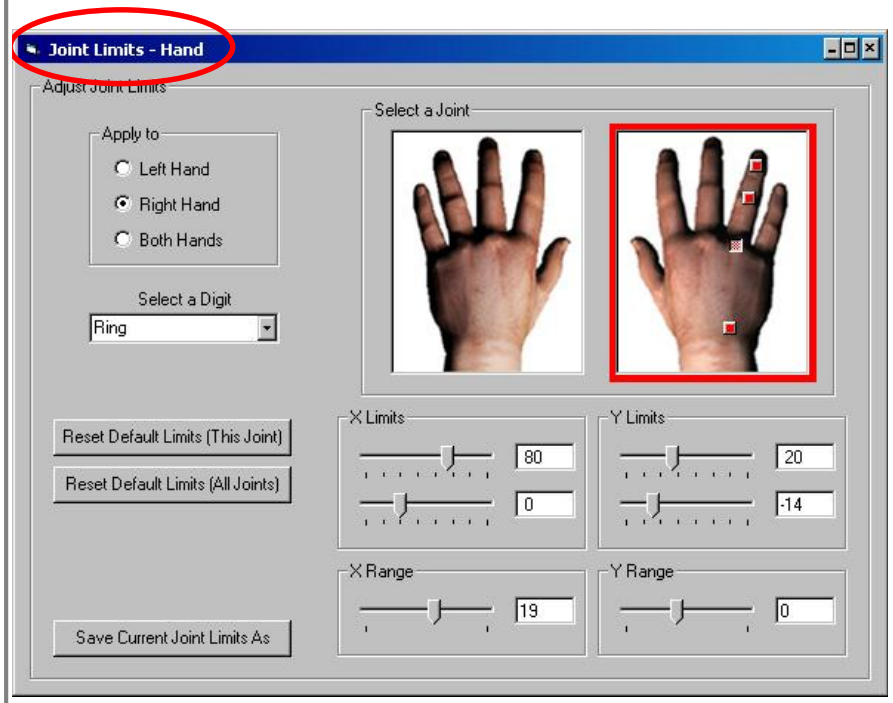


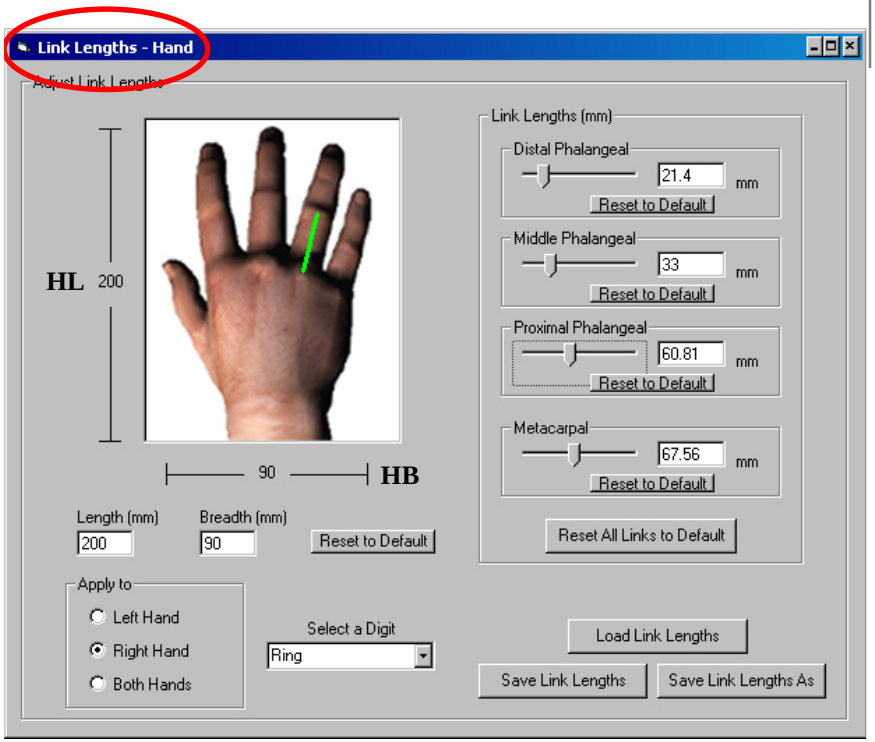
Left Hand



Right Hand

Hand Scalable Anthropometry





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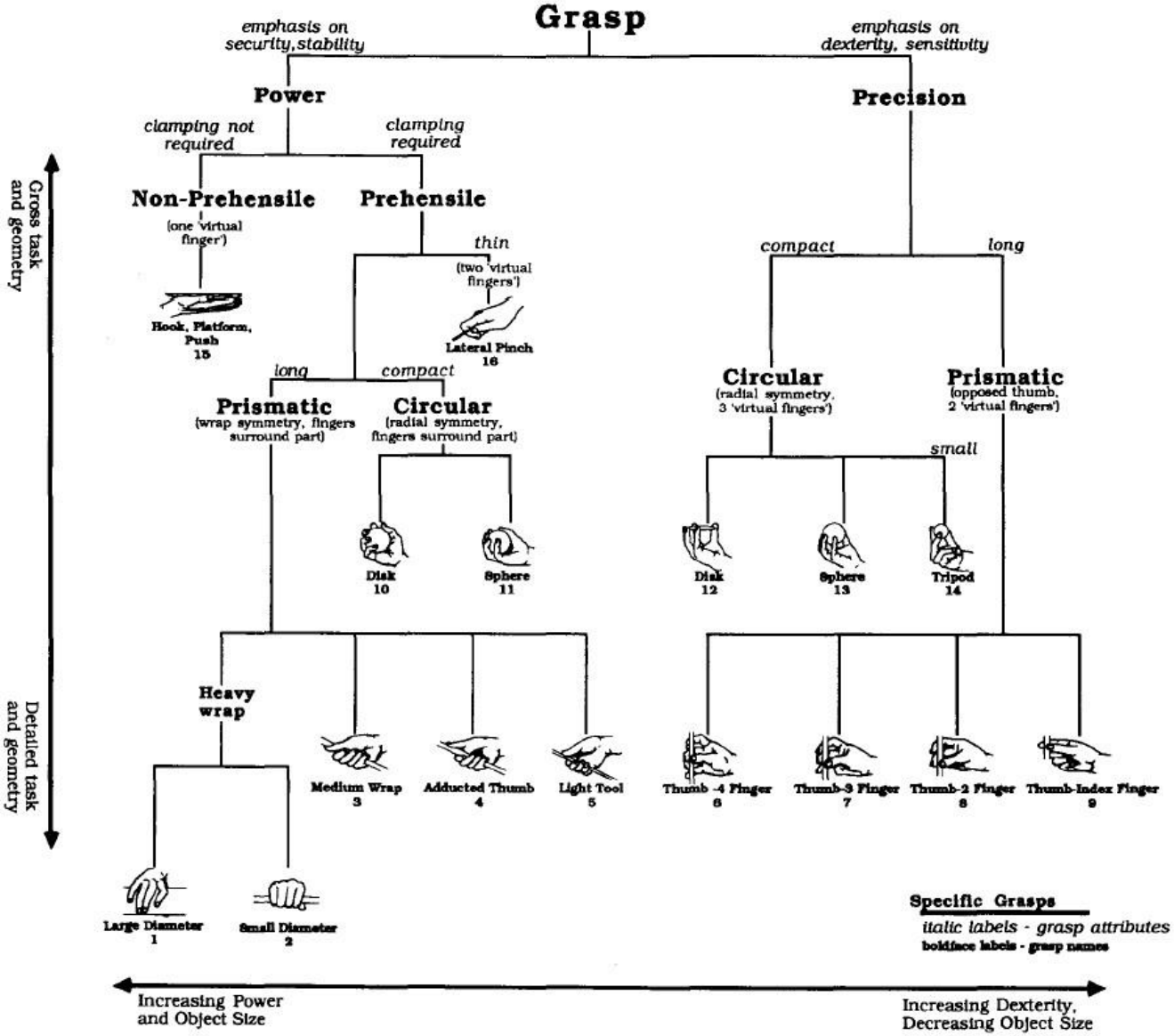
Human Grasping (Classification)



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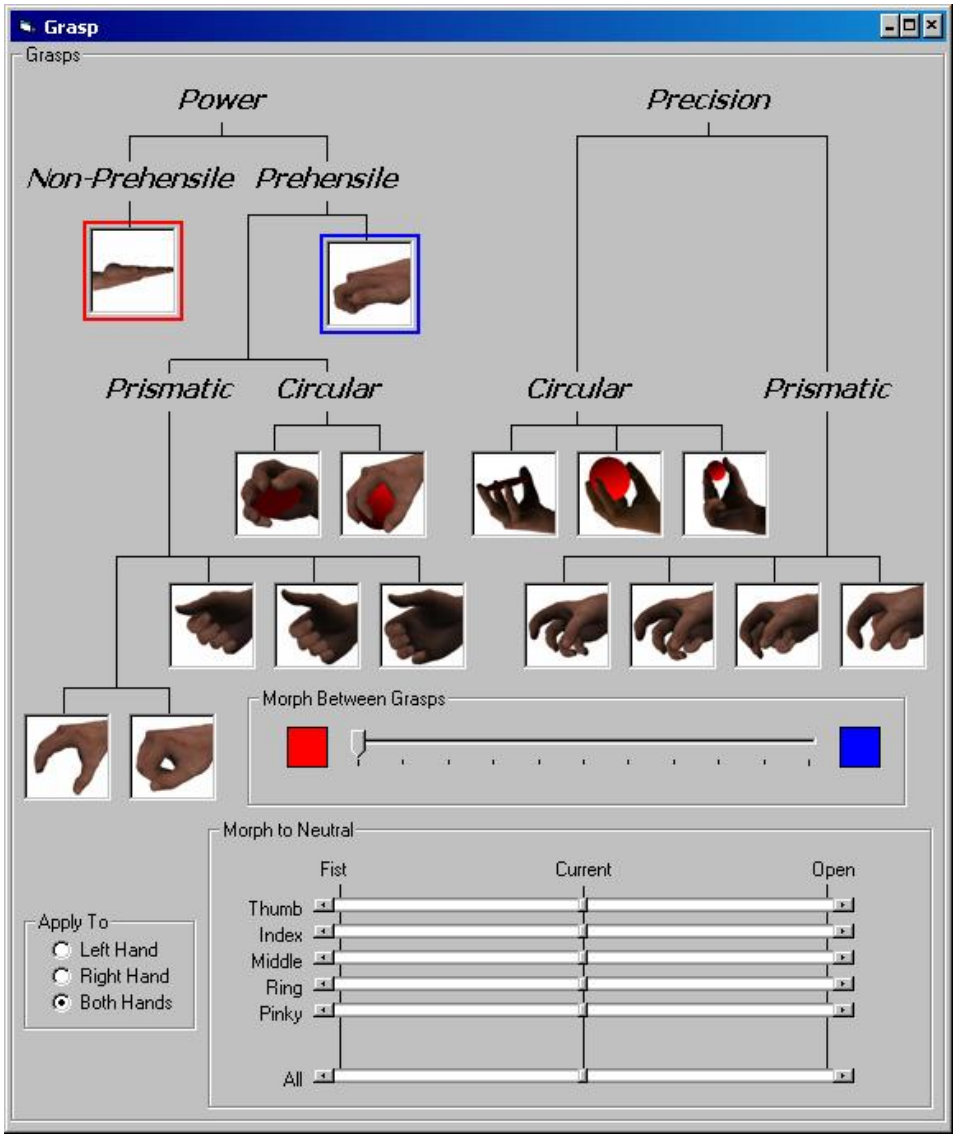
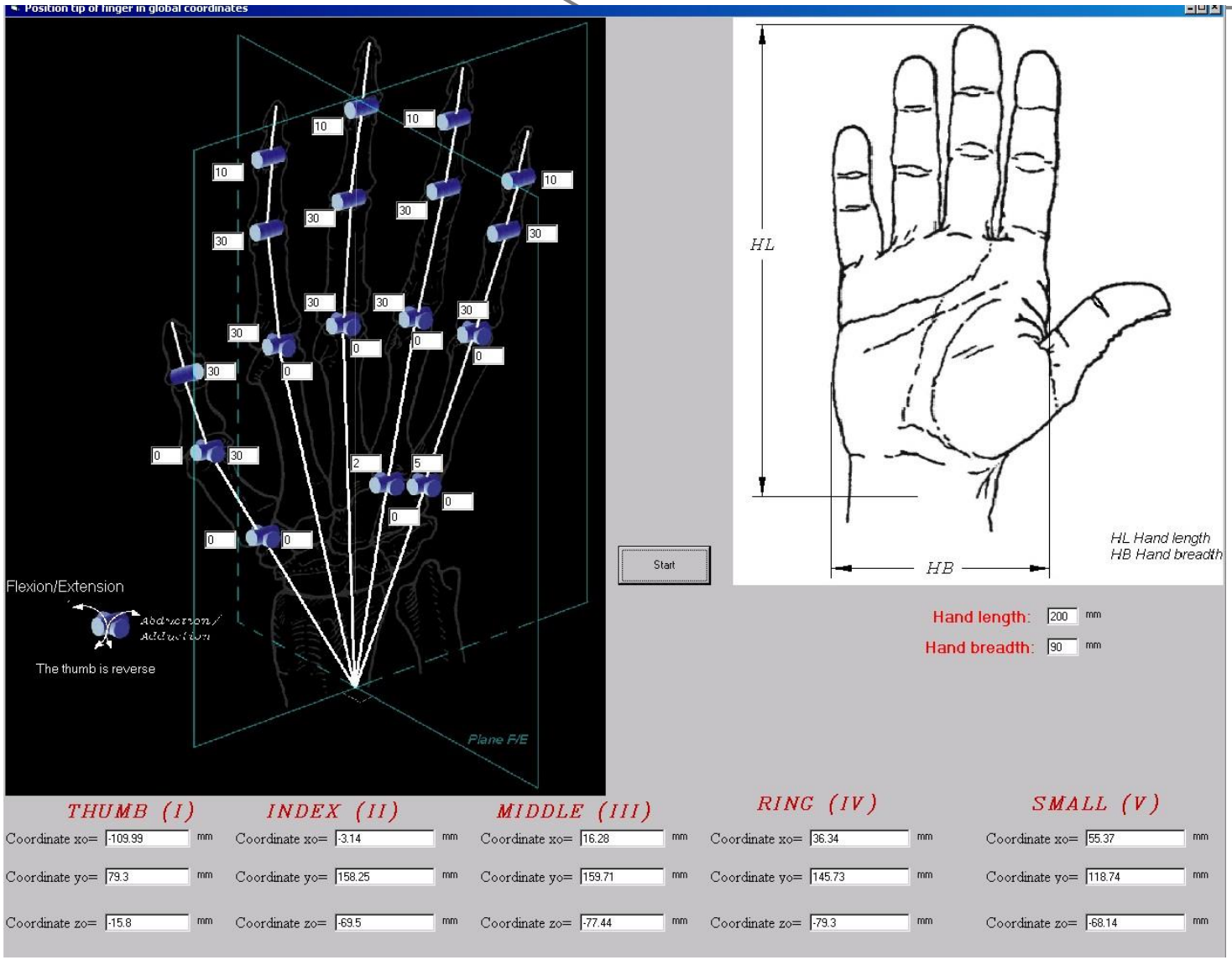
Grasping Interface (16 Styles)



Forward Kinematics



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Finger Posture

Optimization-based method

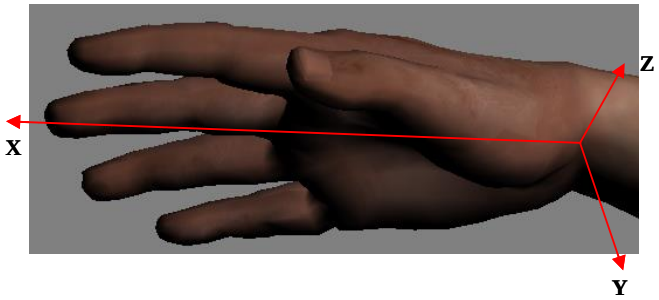
Find: $\mathbf{q}^i$

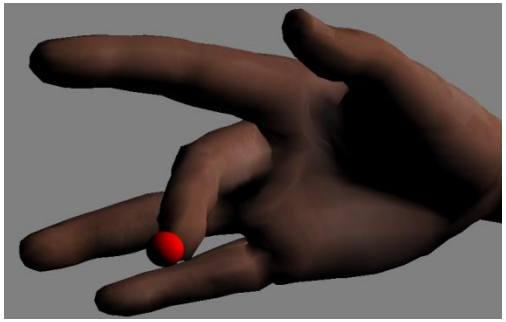
Minimize: $f_d = \sum_{i=1}^{n} w_i \left| q_i - q_i^N \right|$

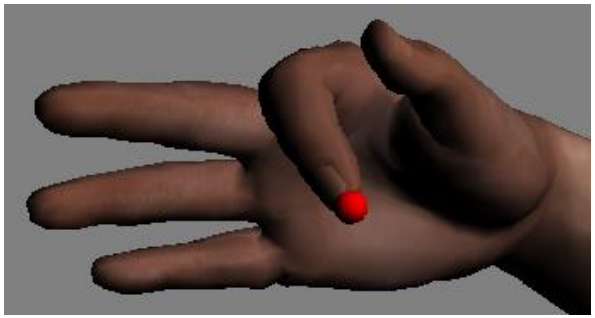
Subject to:

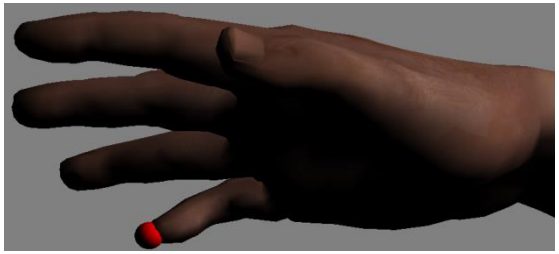
$$q_j^{iL} \le q_j^i \le q_j^{iU}$$

$$\left\| \mathbf{p}^i - \mathbf{x}^p \right\| = 0$$

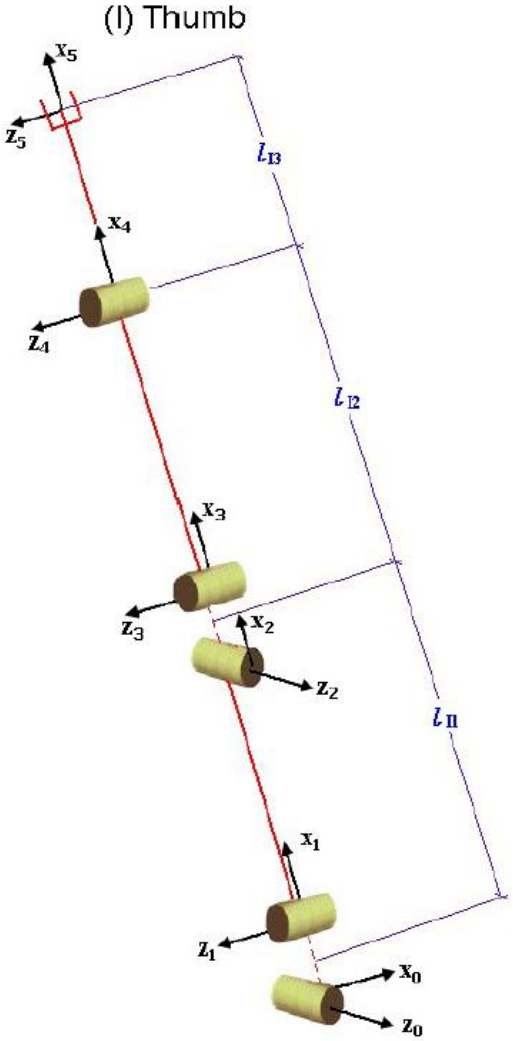








Finger Workspace

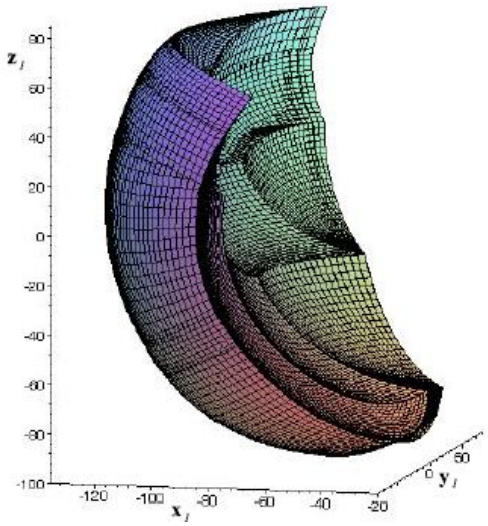


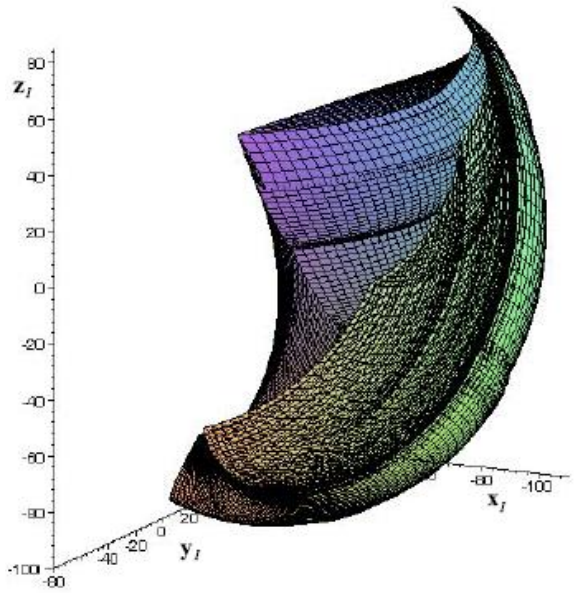
	θ_i	d_i	a_i	α_i
1	$q_1 + \frac{\pi}{2}$	0	0	$\frac{-\pi}{2}$
2	q_2	0	l_{I1}	$\frac{\pi}{2}$
3	q_3	0	0	$\frac{-\pi}{2}$
4	q_4	0	l_{I2}	0
5	q_5	0	l_{I3}	0

D-H Table

	Min.	Max.
q_1	0	60
q_2	-25	35
q_3	0	60
q_4	-10	55
q_5	-15	80

Range of motion





95% Male HB=90 mm, HL=190 mm

Two views of workspace for thumb

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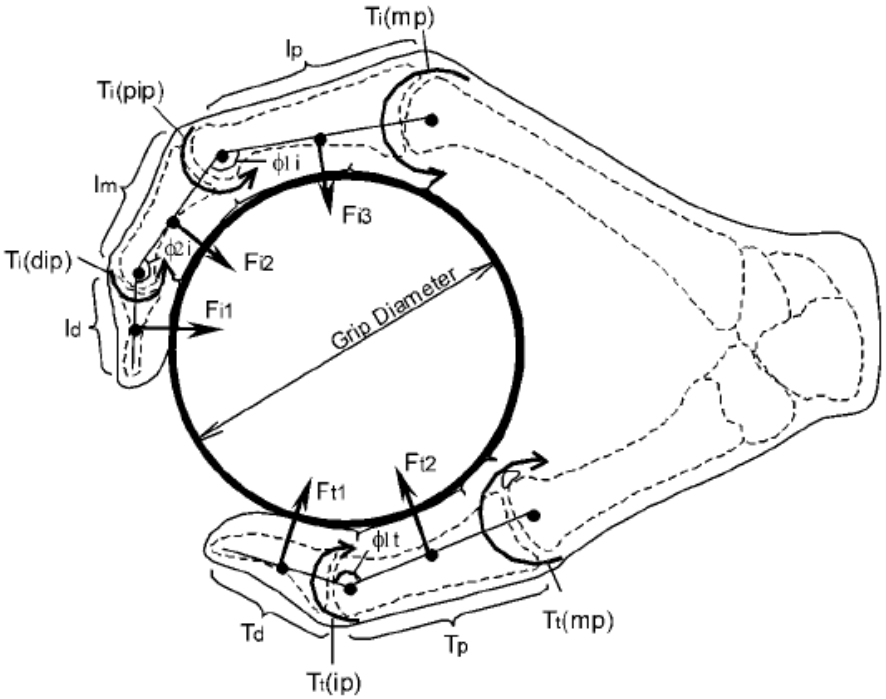
Joint Torques

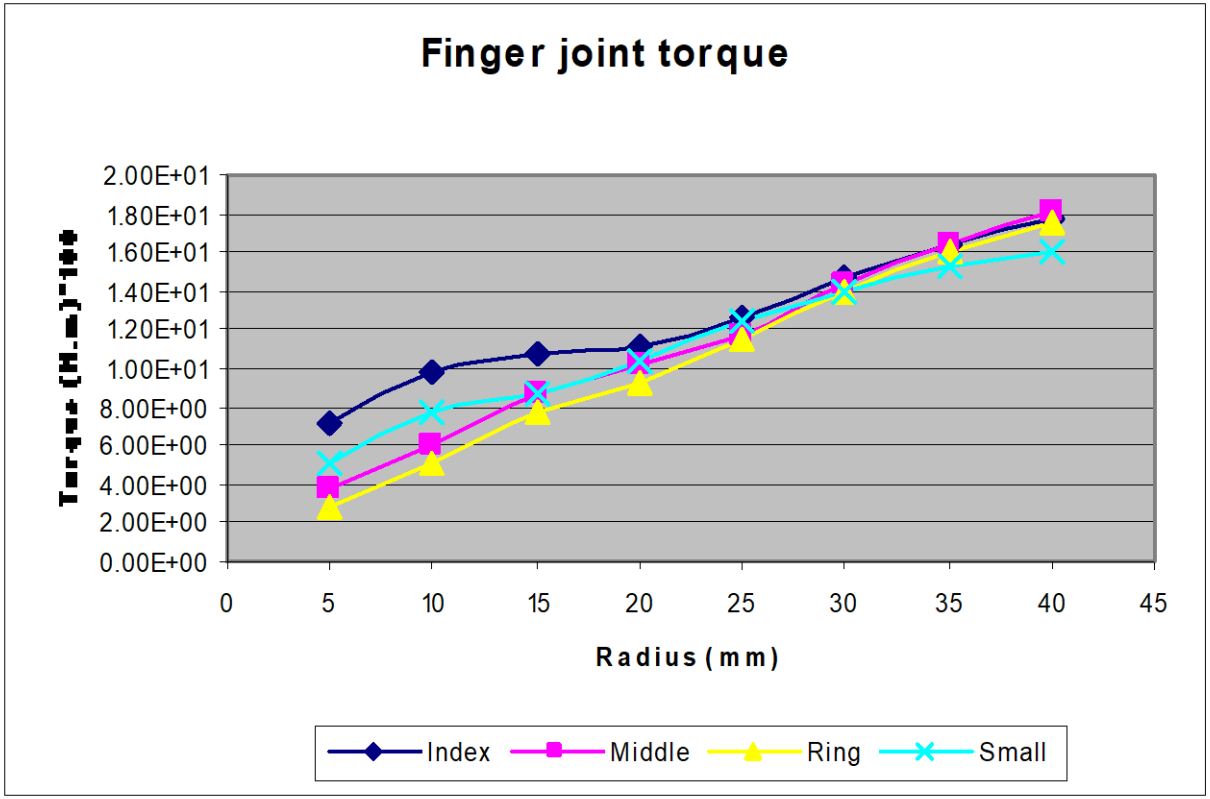
$$\boldsymbol{\tau} = \sum_k \mathbf{J}_k{}^{\mathbf{T}} \mathbf{F}_k$$

Where $\boldsymbol{\tau} = [\tau_1, \tau_2, ..., \tau_n]^T$

$$\mathbf{J}_k(\mathbf{q}) = \begin{bmatrix} \frac{\partial {}^0\mathbf{T}_1(\mathbf{q})}{\partial q_1} {}^k\mathbf{r}_k & \cdots & \frac{\partial {}^0\mathbf{T}_i(\mathbf{q})}{\partial q_i} {}^k\mathbf{r}_k & \cdots & \frac{\partial {}^0\mathbf{T}_k(\mathbf{q})}{\partial q_k} {}^k\mathbf{r}_k \\ \mathbf{Z}_0(\mathbf{q}) & \cdots & \mathbf{Z}_{i-1}(\mathbf{q}) & \cdots & \mathbf{Z}_{k-1}(\mathbf{q}) \end{bmatrix}_{6\times k}$$

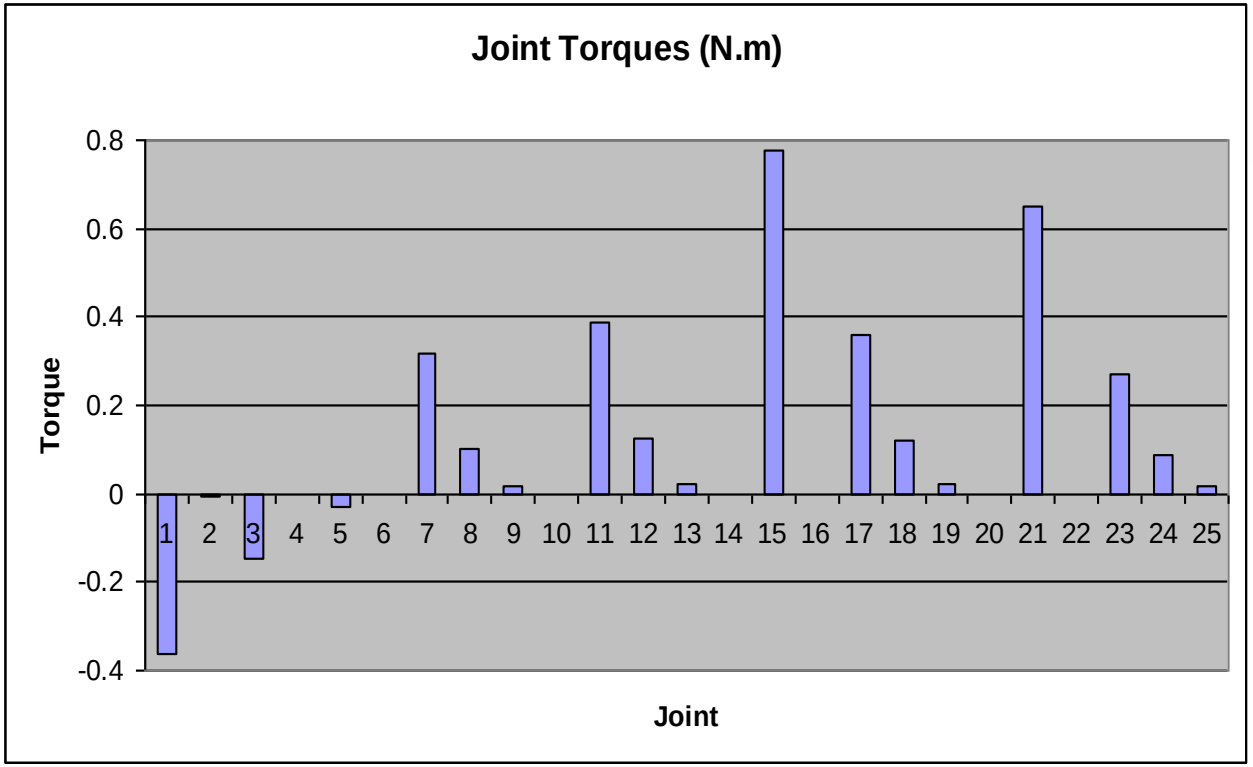


Joint Torques

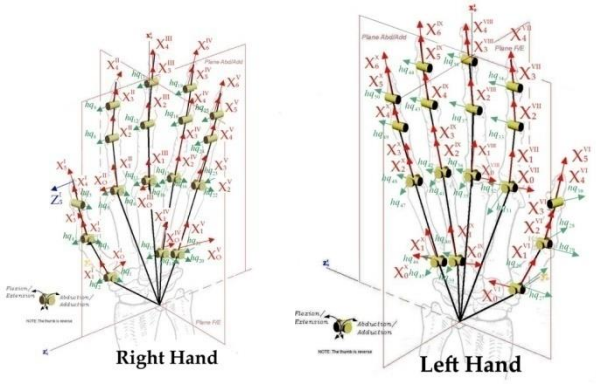


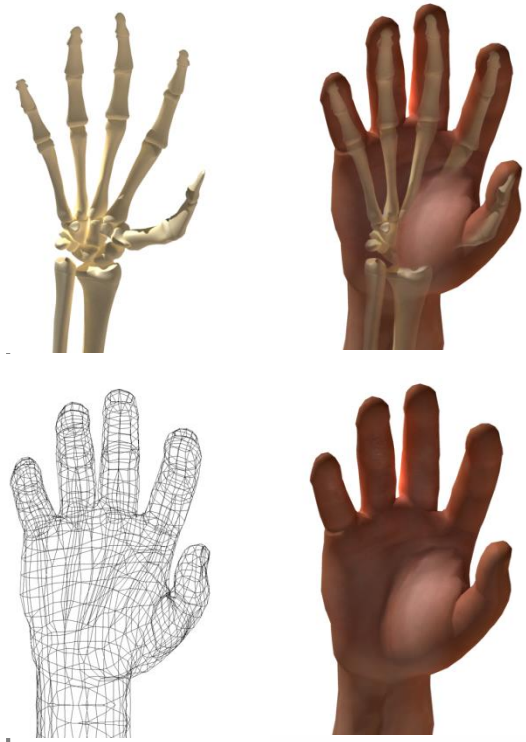
Contact force for each segment is 1N

Joint Torques

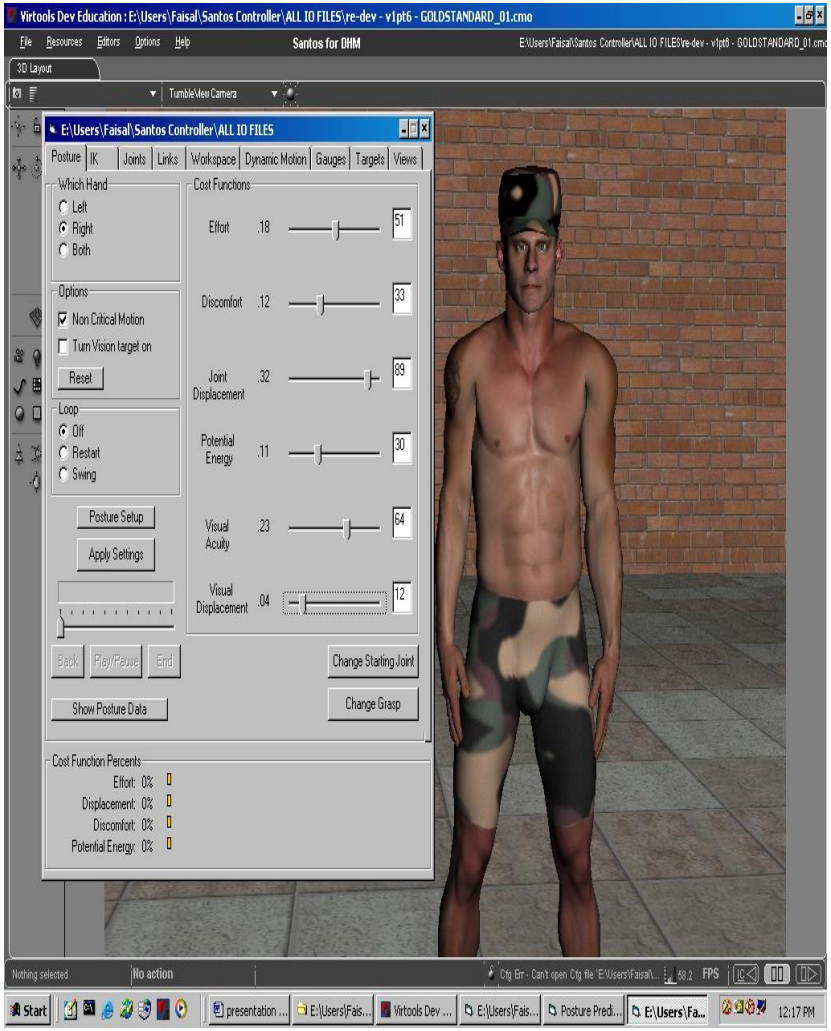


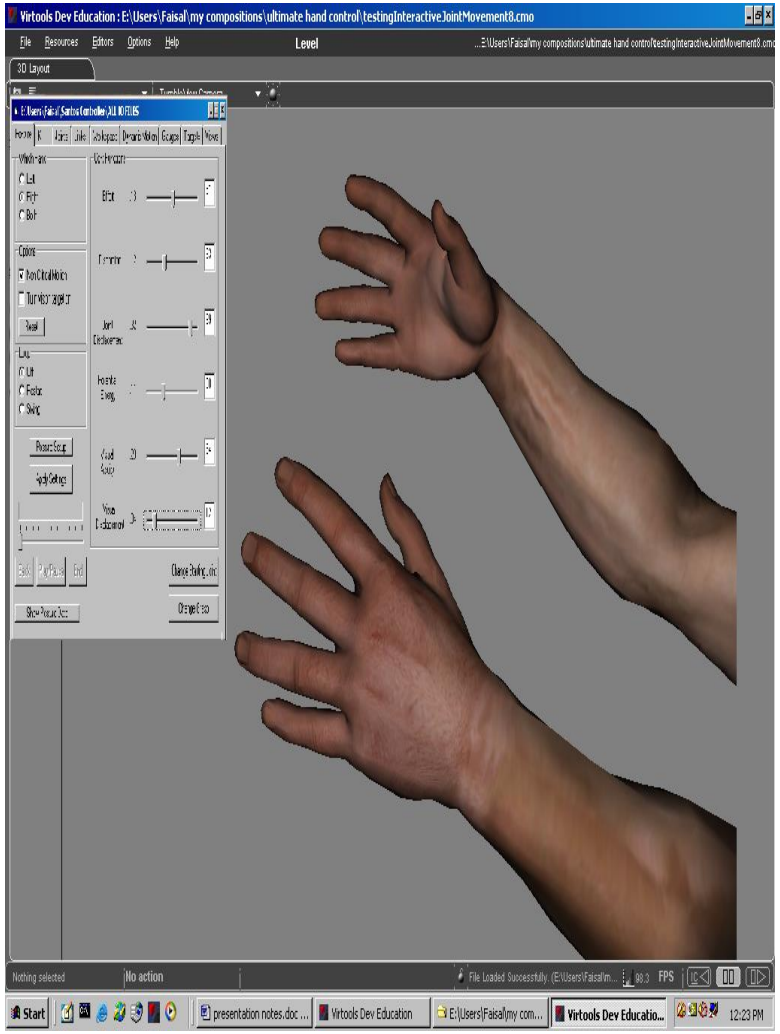
Dexterity





Graphical Interface for Hand





Finger Pressure

Recursive method:

$$\tau_1^n = f_1(q_1, q_2, ..., q_n, F_n)$$

$$\tau_2^n = f_2(q_1, q_2, ..., q_n, F_n)$$

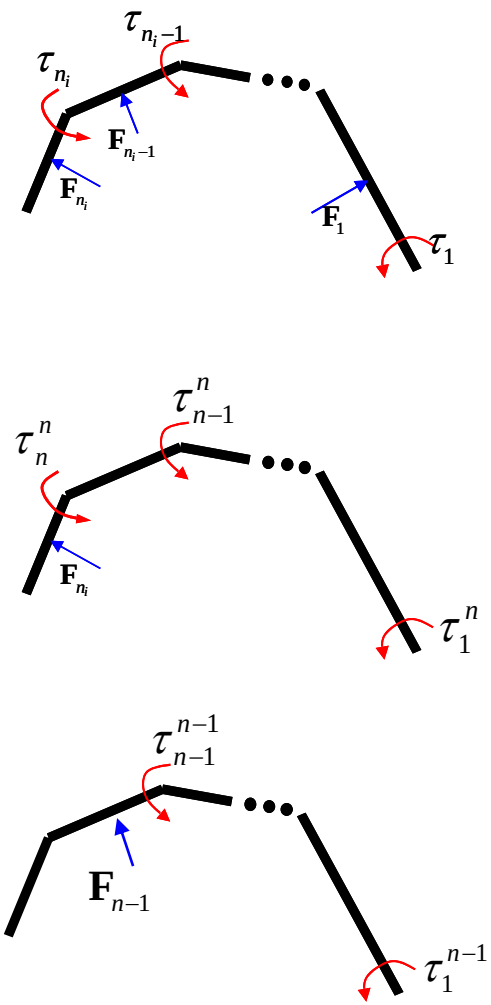
...

$$\tau_n^n = f_n(q_1, q_2, ..., q_n, F_n)$$

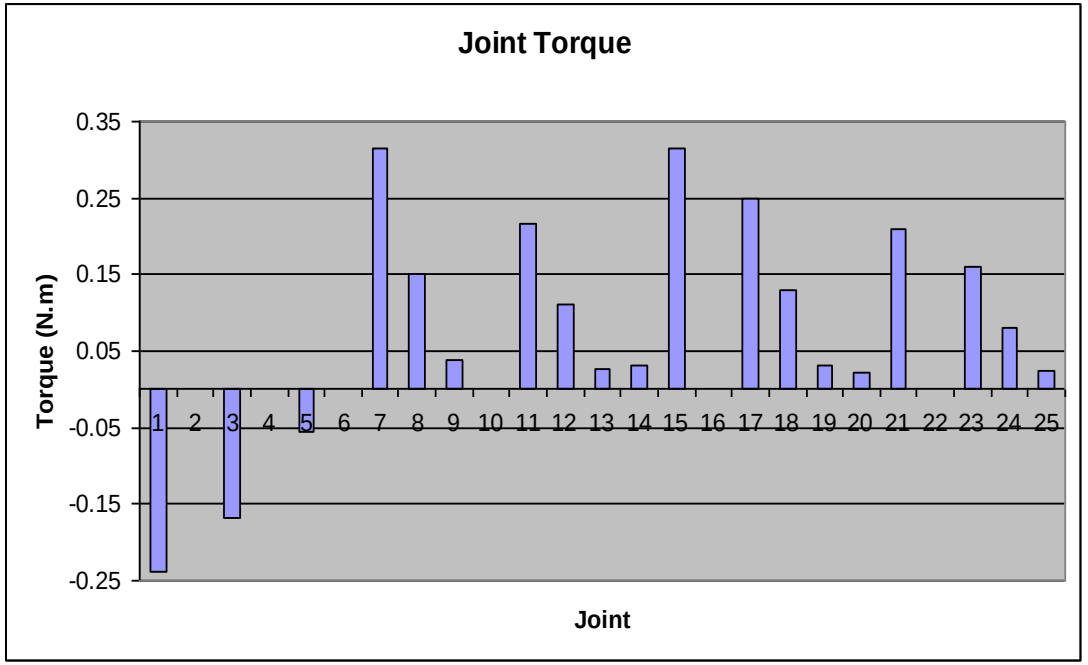
Given one of $\tau_1^n \cdots \tau_n^n$

Solving above equations to find the rest of τ_i^n and $\mathbf{F}_n$

Repeat the above procedure to find all other finger pressures

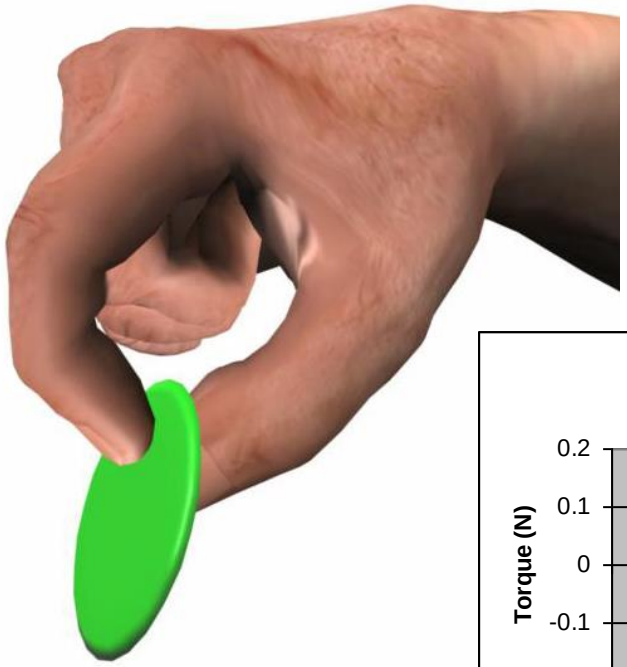


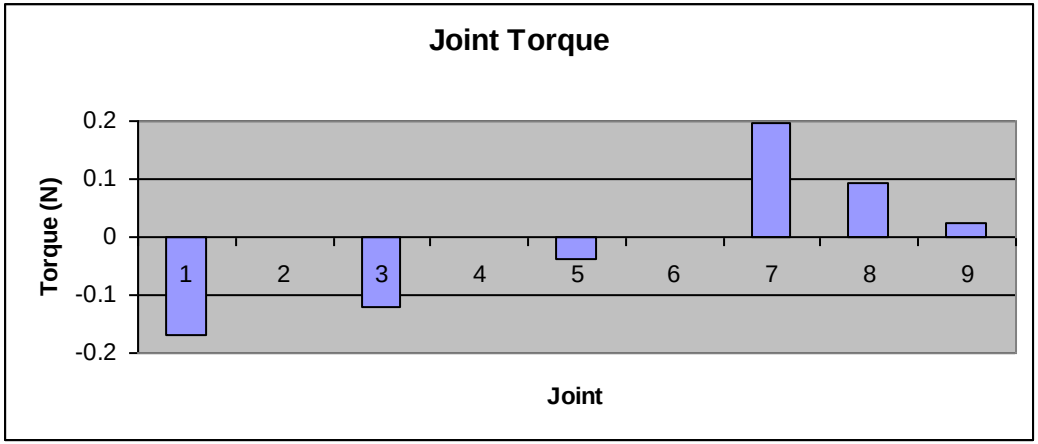
Finger Pressure



Finger contact forces: 3.5N, 4.0N, 2.5N, 3.0N, and 2.5N

Finger Pressure

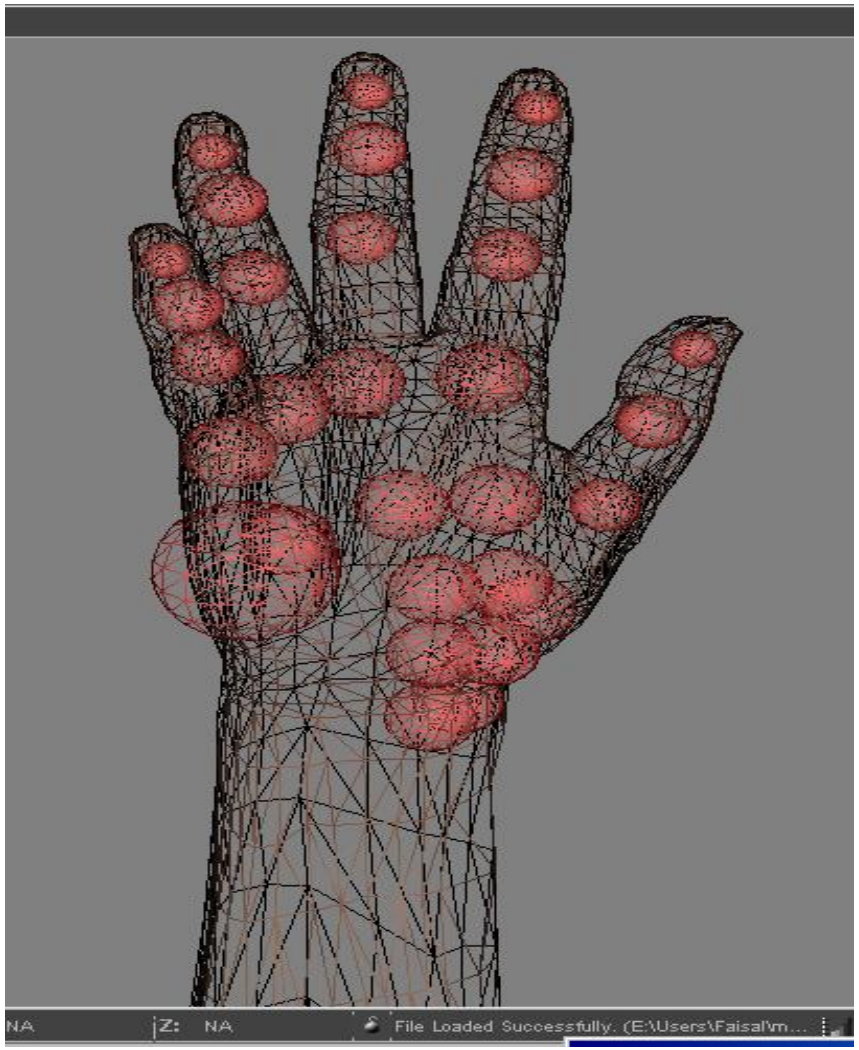




Finger contact forces: 2.5N, and 2.5N

Grasping

Spherical Sensors



- **Simplified Collision Detection**
- **Finger Wrapping**

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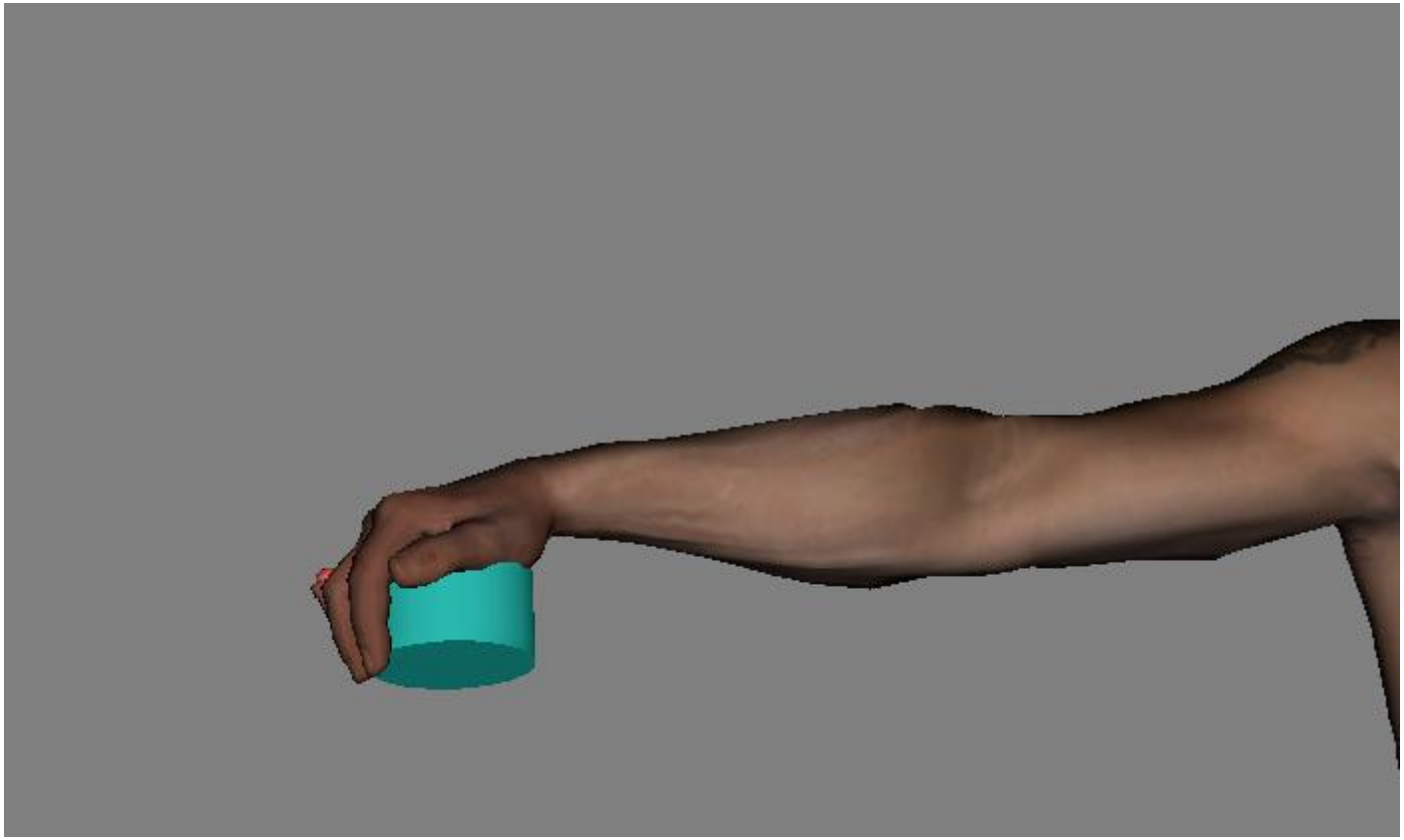
Grasping

Finger Wrapping



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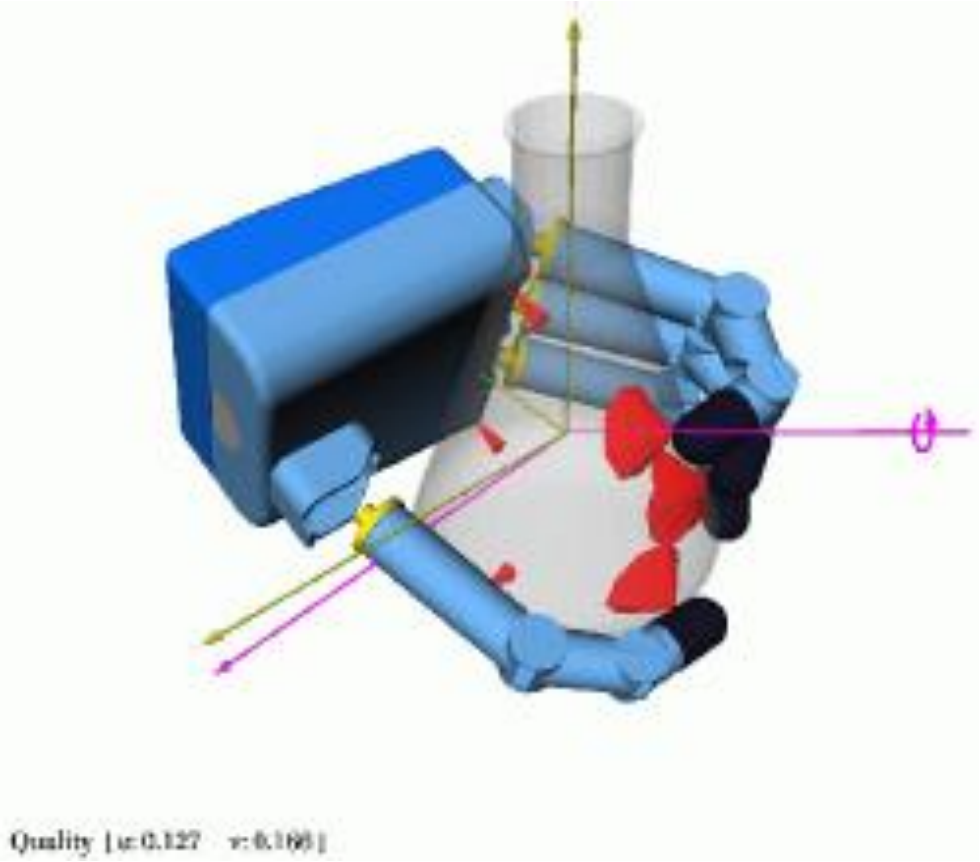
Grasping Quality

Given : Object Model, Hand Model, Grasp



Find : The quality of the grasp

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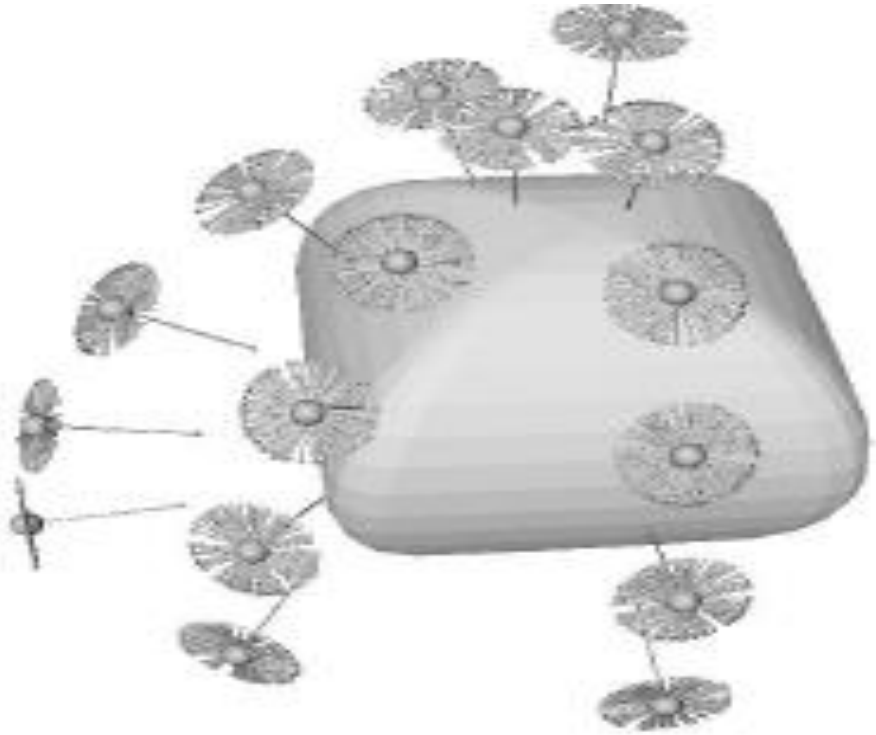
Grasping Quality

- **Given** : Object Model, Contact points



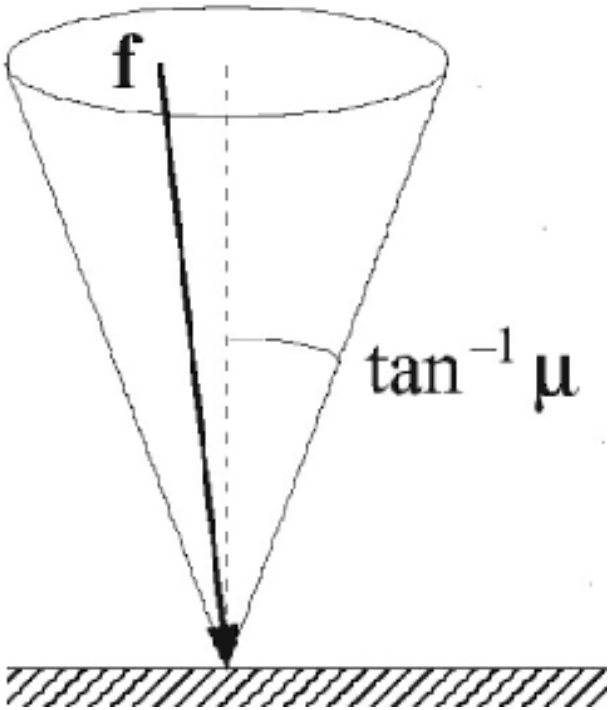
- **Find**: Space of forces and torques that can be exerted on the object

Friction cone

Constraints:

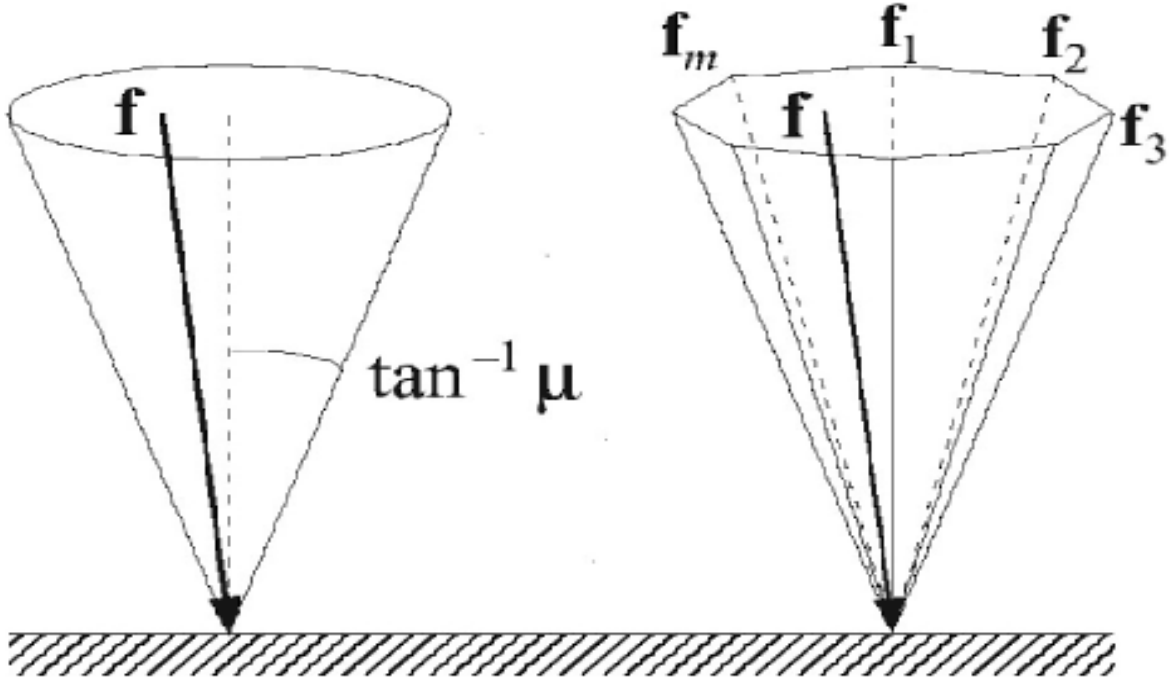
- Can exert both tangential and normal forces.

- Fingers must not slip !



Friction Cone

Linear FC Approximation



For m = 4 → 30% error

For m = 8 → 8% error

Mathematics

$$w_i = \begin{pmatrix} f_i \\ D_i \times f_i \end{pmatrix}$$

Definition of a wrench (6dimensional)

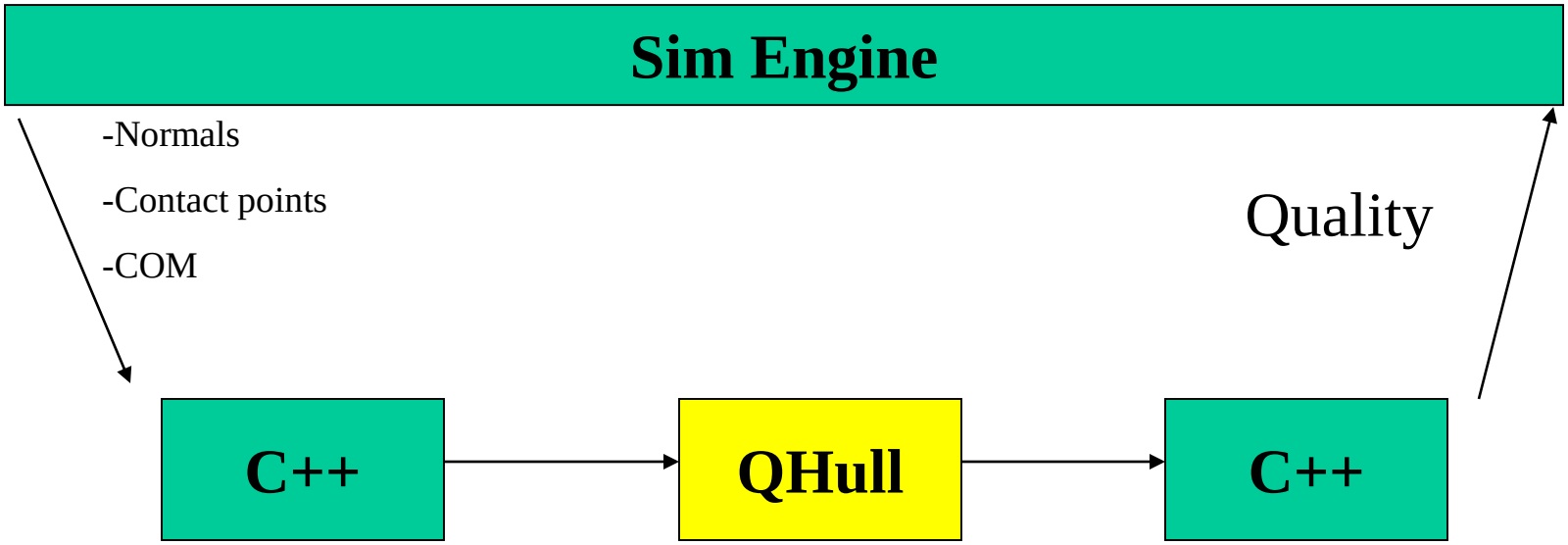
$$\sum_{j=1}^{j=m} \alpha_j . f_j$$

Friction Pyramid Approximation

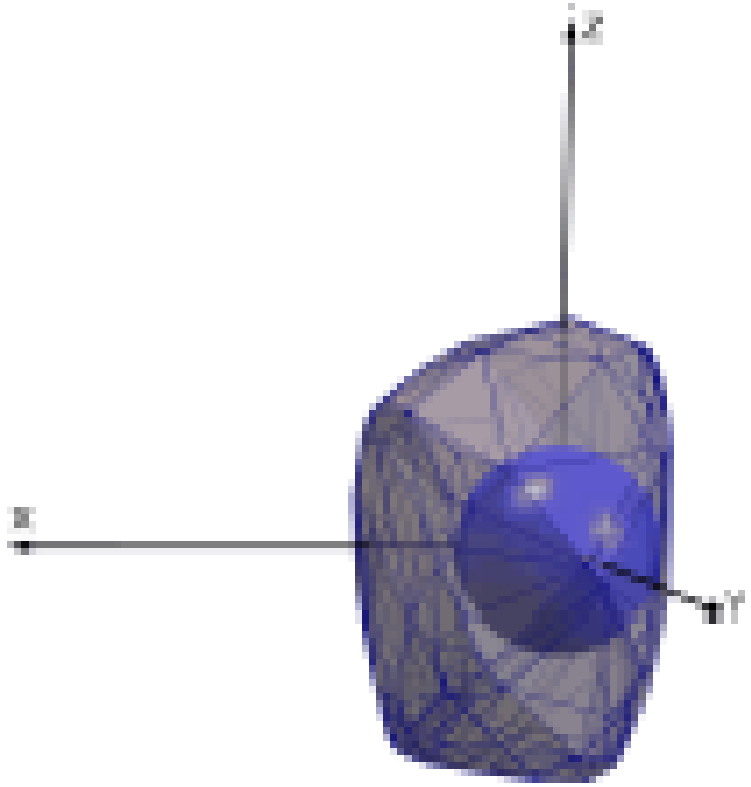
$$W = \left\{ w \,|\, w = \sum_{i=1}^{n} \sum_{j=1}^{m} \alpha_{ij} . w_{ij} \right\}$$

$$W_{L1} = ConvexHull\left(\bigcup_{i=1}^{n} \{ w_{i1}, w_{i2}, \ldots, w_{im} \} \right)$$

Implementation



What Do they Mean in Reality ?



Measure#1 :

Radius of inscribed sphere

Measure#2 :

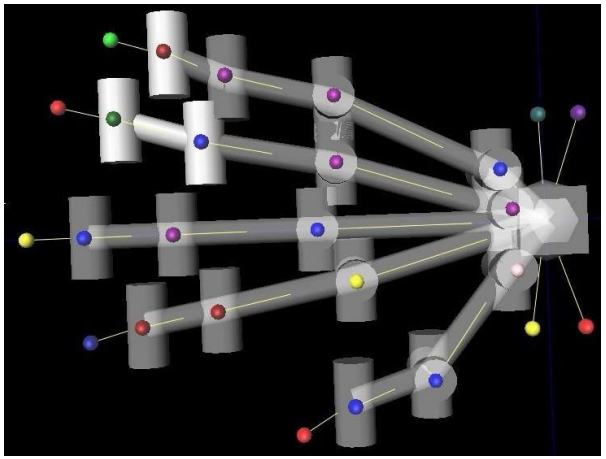
The volume of the convex hull

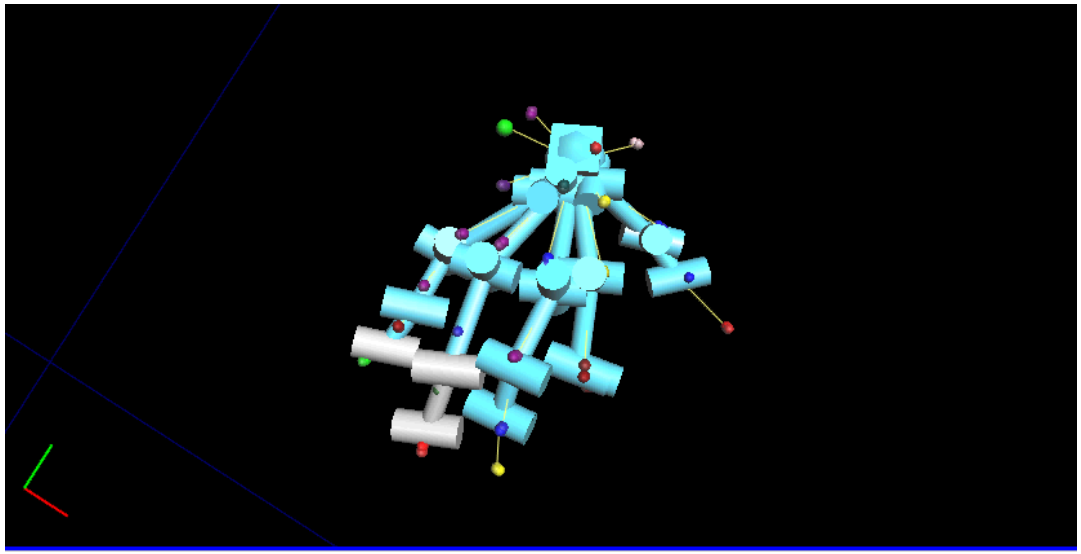
3D Force-Space Projection of Original 6D Hull

Future Work

- ✓Validation
- ✓Evaluation of Carpal Tunnel Pressure
- ✓Grasp Artificial Intelligence
- ✓Local Biomechanics wrist and hand modeling
- ✓Compliant Pressure Mapping
- ✓Dexterity Analysis

Validation model:Motion Capture





CTS

Carpal tunnel syndrome
Cost function:

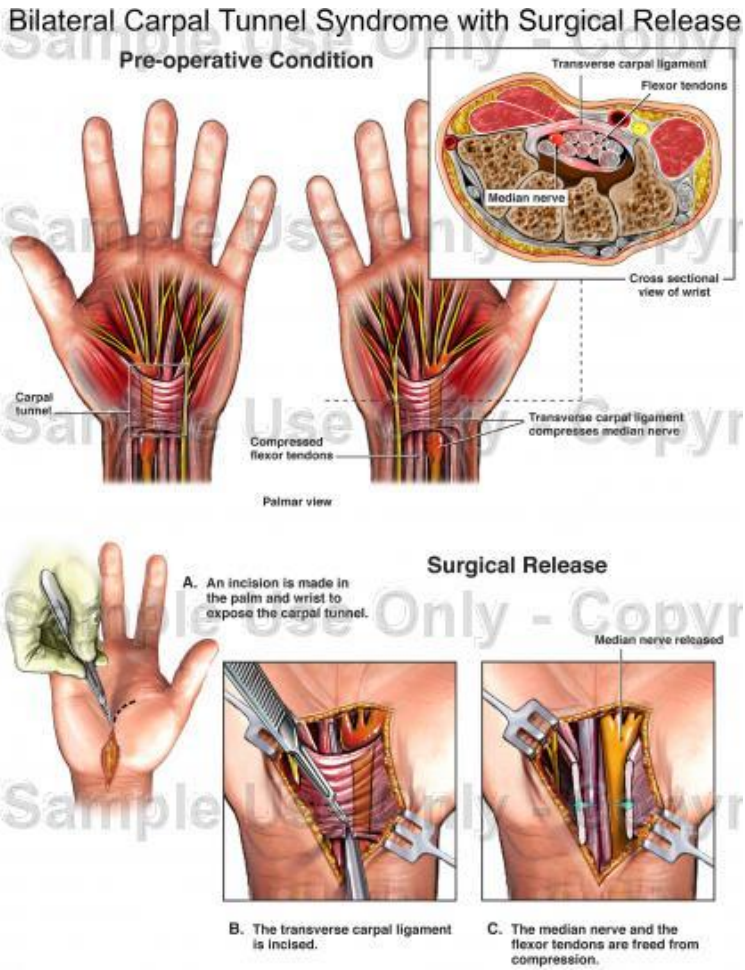
Pronation/supination angles

Metacarpophalangeal (MP) angle

Wrist angles (flexion/extension)

Wrist angles (radial/ulnar)

Fingertip loads



Future Goals

Grasp Quality

Learning

- **Pattern Recognition**
- **Neural Nets**

Optimization

- **Maximize Quality**
- **Constraints**

Cost Function for the Hand Model

- 1) Biomechanical Model
- 4) Forward Kinematics
- 16) Graphical Interface
- 3) Photorealism (and Skin deformation)
- 5) Manipulation (individual joints, or coupled joints)
- 6) Grasping (16 power and precision grasps)
- 7) Grasp Morphing (changing of grasping from one to another)
- 8) Grasp Artificial Intelligence
- 9) Finger Pressure
- 10) Joint Torque Analysis
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- 13) Compliant Pressure Mapping
- 11) Reach Envelopes of each Finger
- 14) Evaluation of Carpal Tunnel Pressure
- 15) Dexterity Analysis

Rempel, et al. (1994, 1997, 1998),
Keir, et al. (1998, 1999),
Szabo and Chidgey (1989),
Weiss (1995),
Guo, et al. (2005)
DeKrom, et al. (1990),
Zatiorsky, et a. (2000, 2001)
Gonzalez, Buchanan, Delp (1997)
Matias, et al. (1998),
McCauley and Crumpton (1997),
Delp, et al. (1996)
Dannion, et al. (2001)
Gelberman, et al. (1981),
Rydevik and Lundborg (1977),
Werner and Armstrong (1997),
Deshpande, et al. (1997),
Neiman, et al. (1995),
Tarinelli and Nowak (1999)
Li, et al. (1999, 2004a, 04b, 05)

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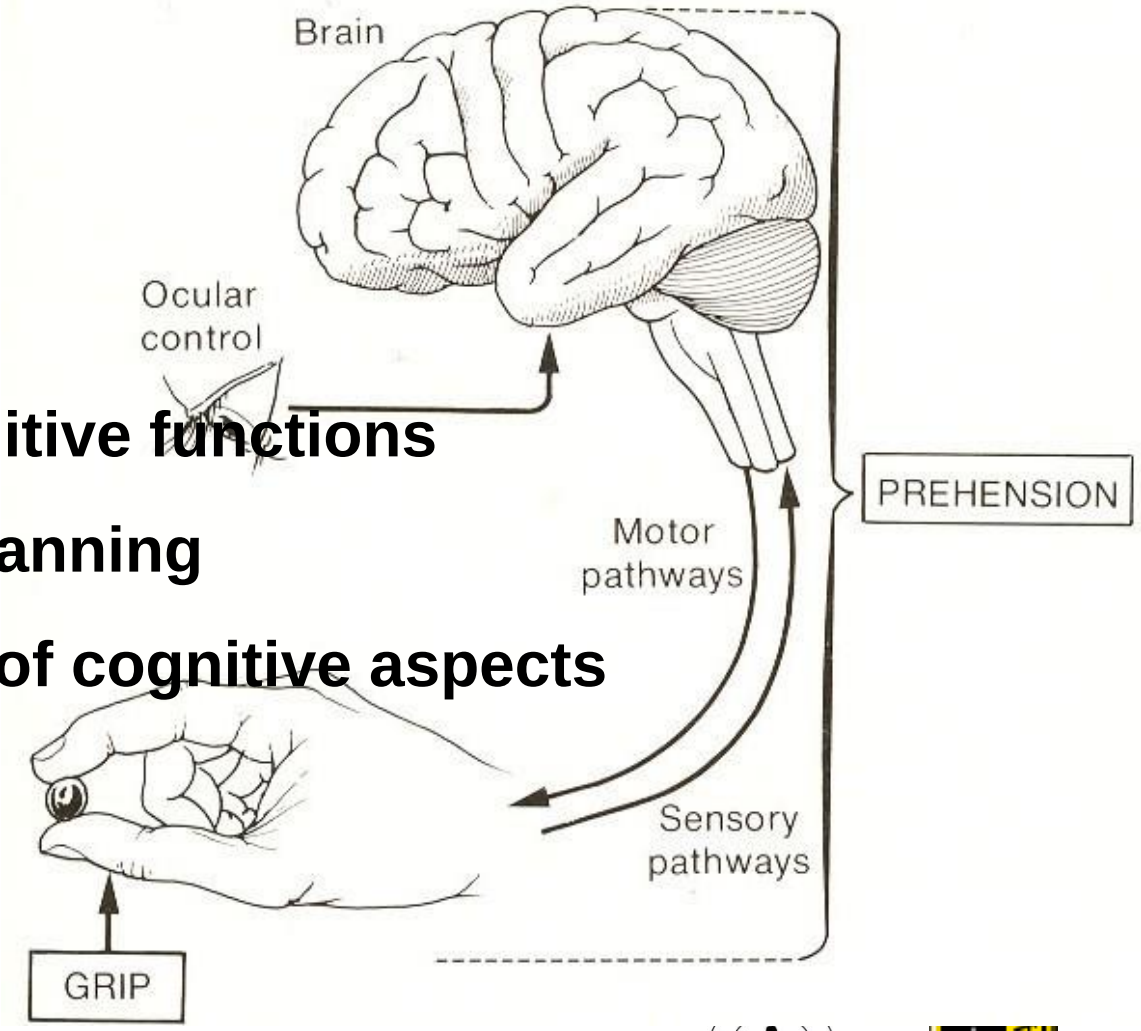
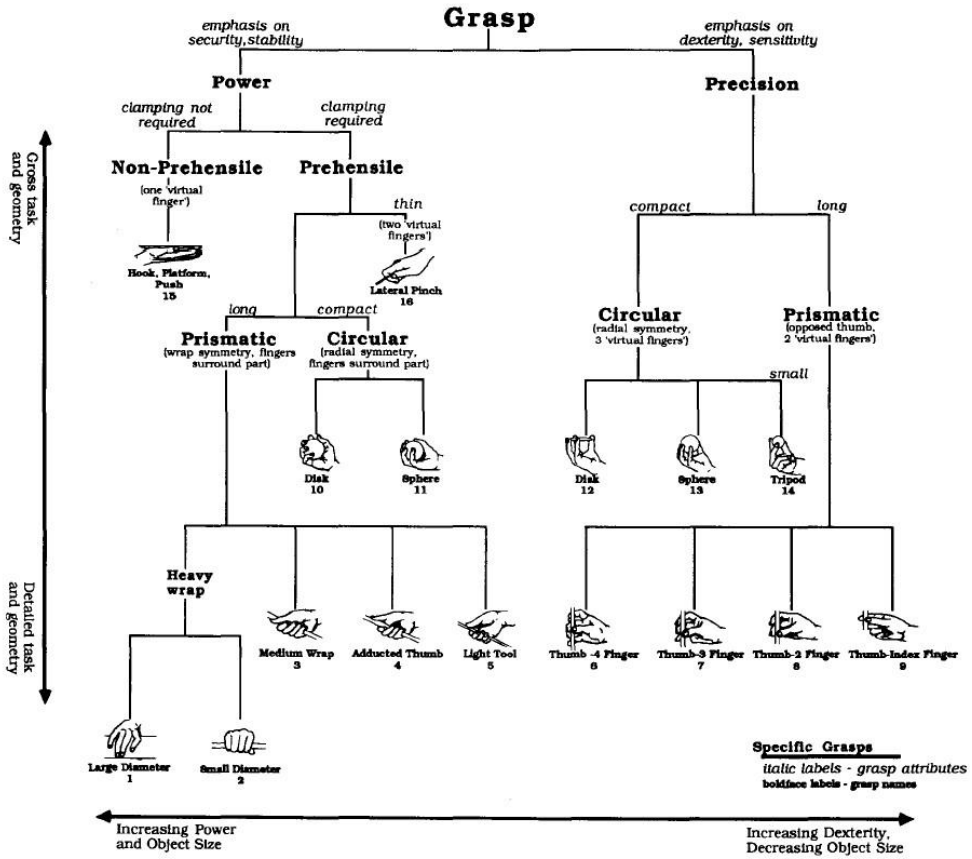
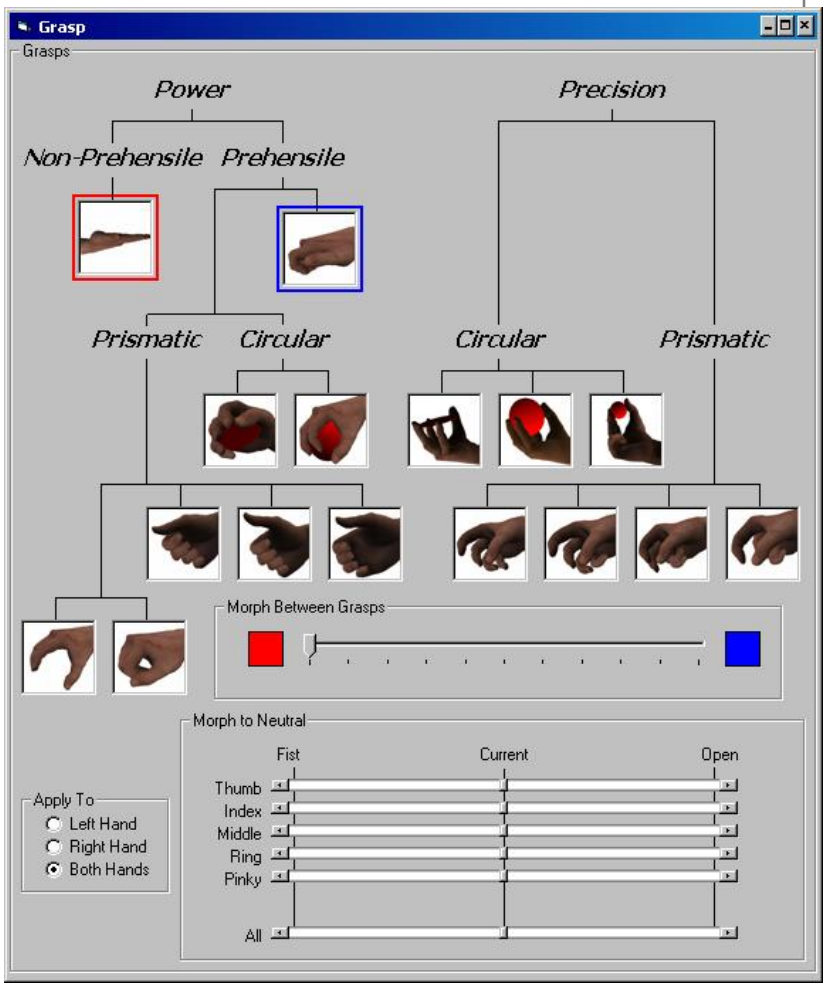
Artificial Intelligence

- ✓ Decision making
- ✓ Emotion-based cognitive functions
- ✓ Robotics-like task planning
- ✓ Computer modeling of cognitive aspects



Grasping (Direct Manipulation)





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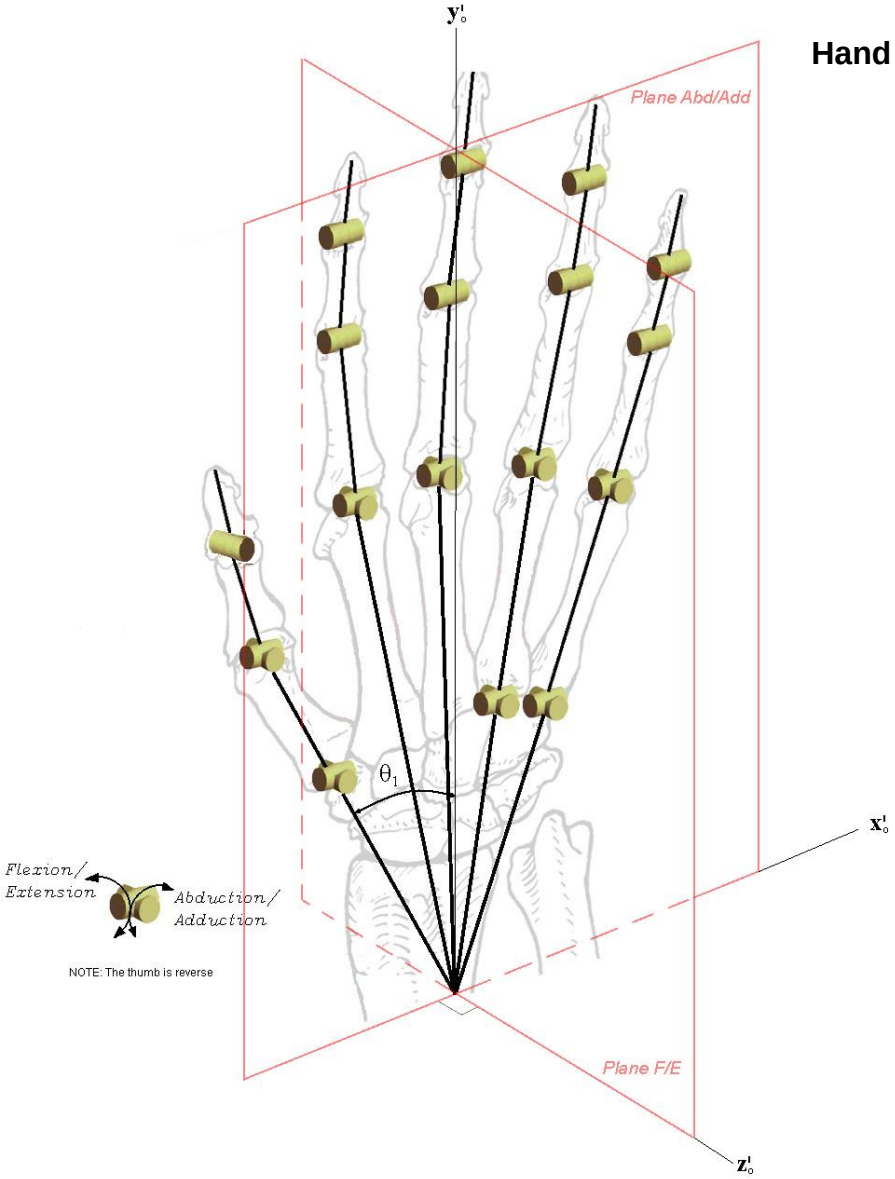
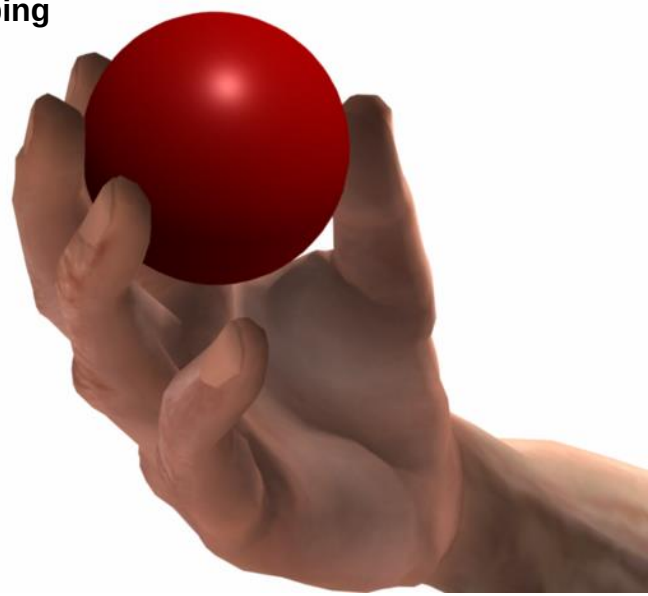
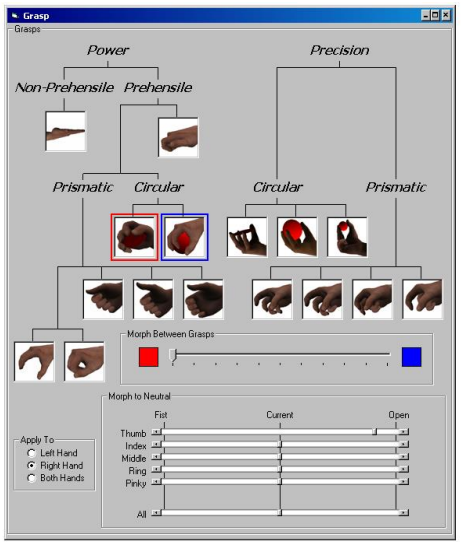
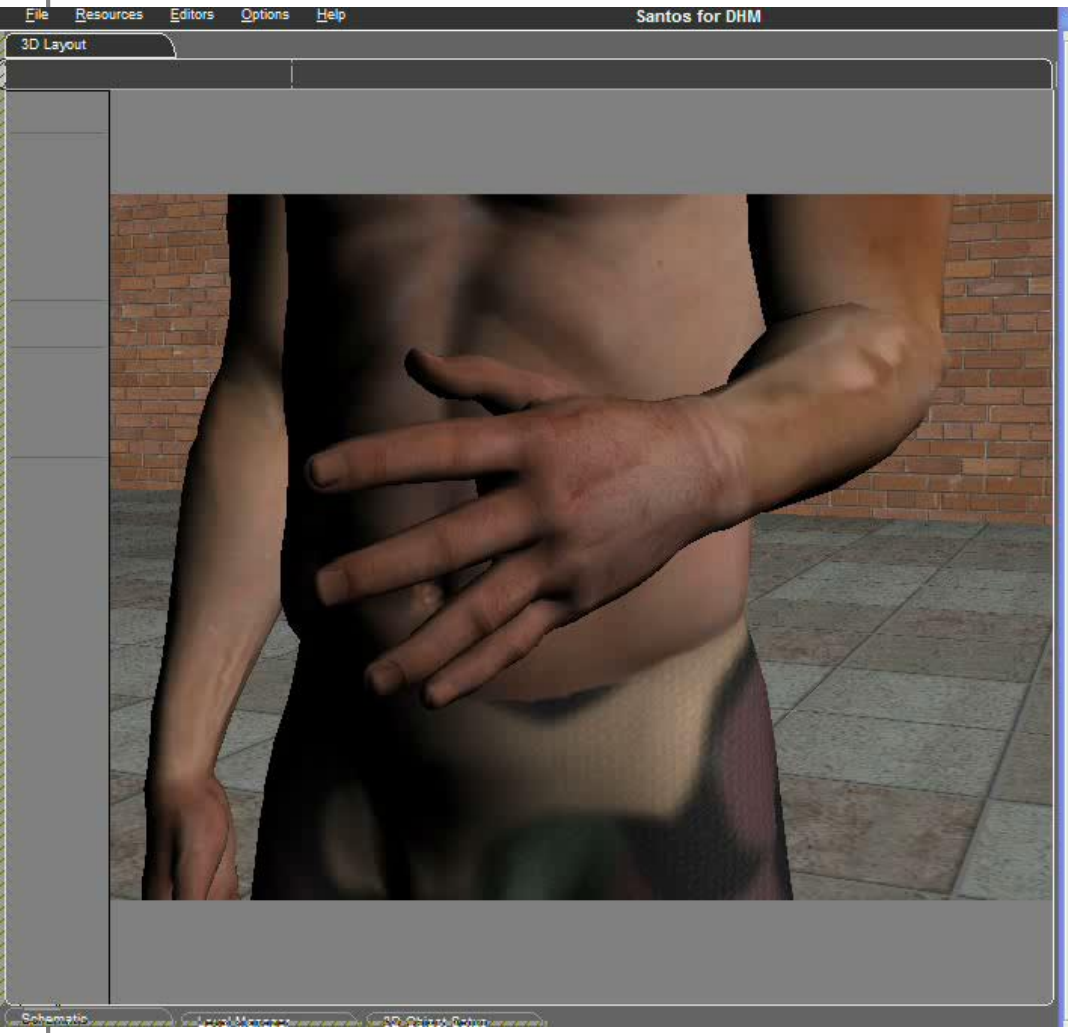
Hand Models and Grasping





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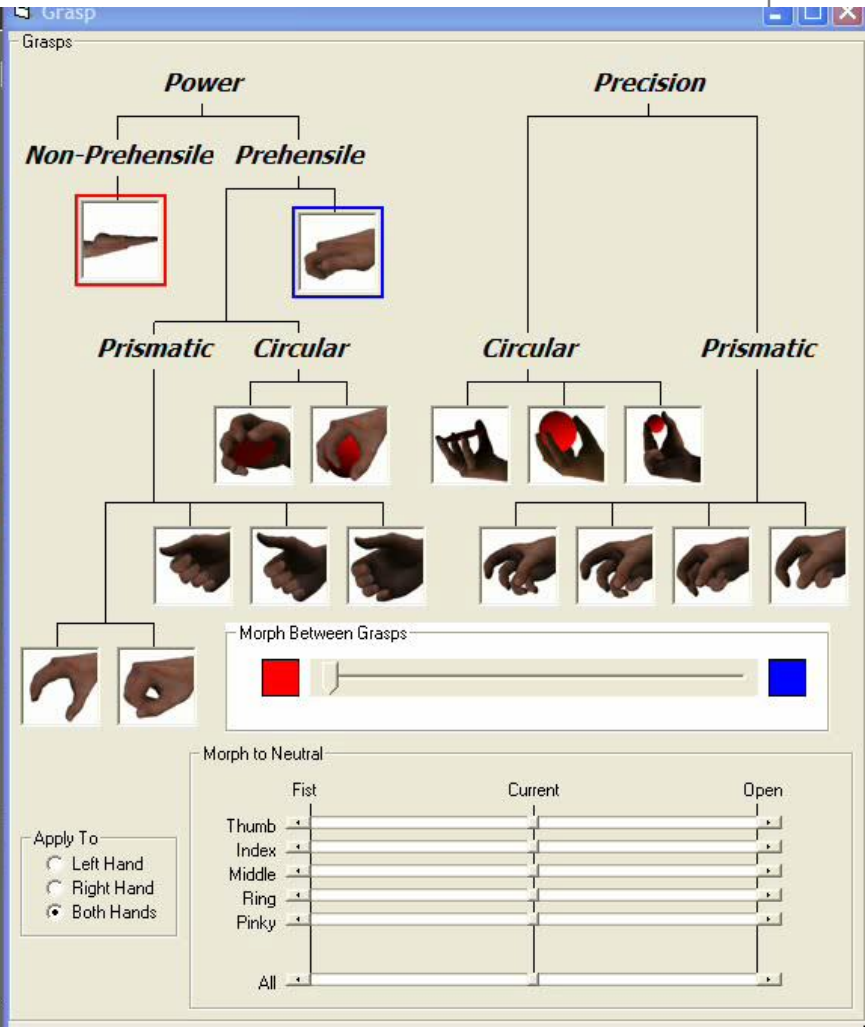
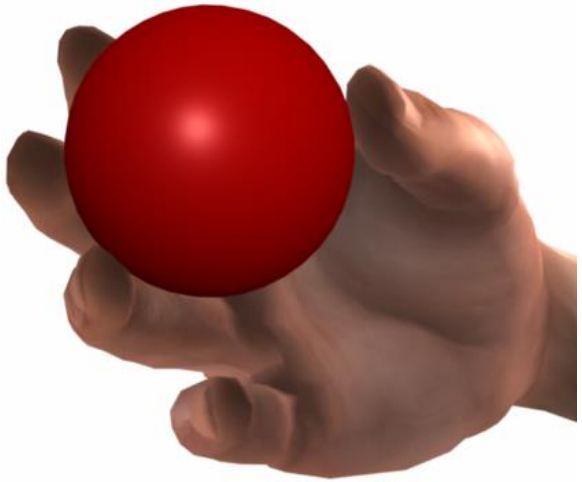
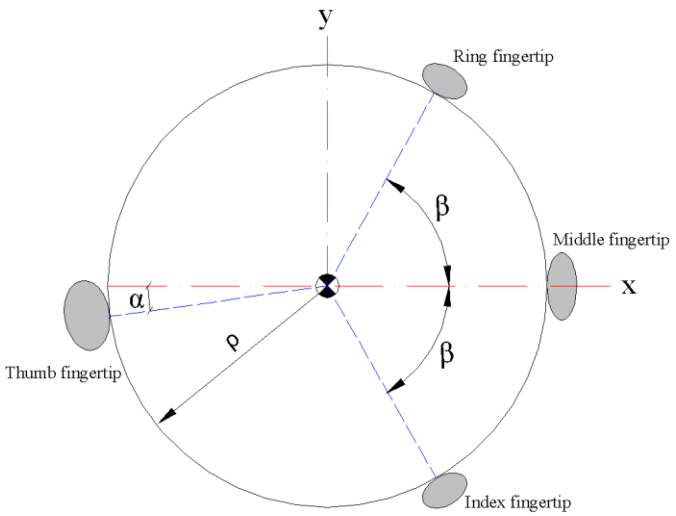
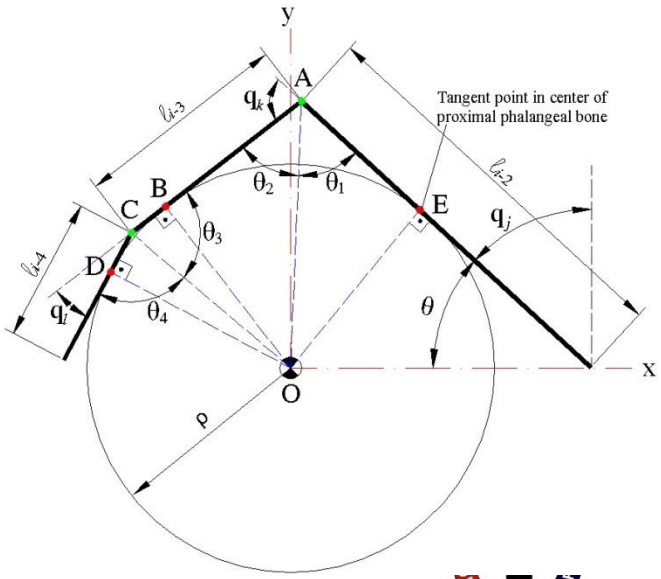
Resources
Editors
Options
Help
Santos for DHM
3D Layout


Grasp
Grasps
Power
Precision
Non-Prehensile
Prehensile
Prismatic
Circular
Circular
Prismatic
Morph Between Grasps
Morph to Neutral
Fist
Current
Open
Thumb
Index
Middle
Ring
Pinky
All
Apply To
Left Hand
Right Hand
Both Hands

Geometric-based Grasping







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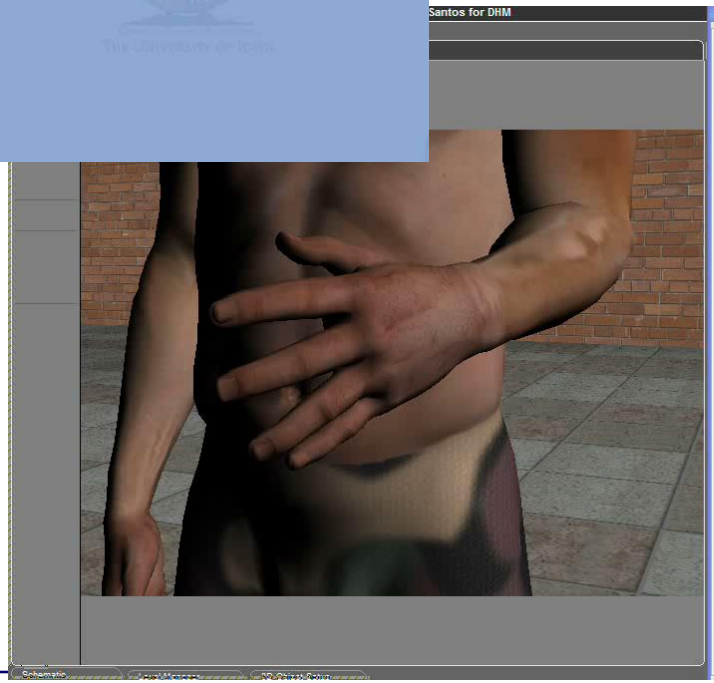
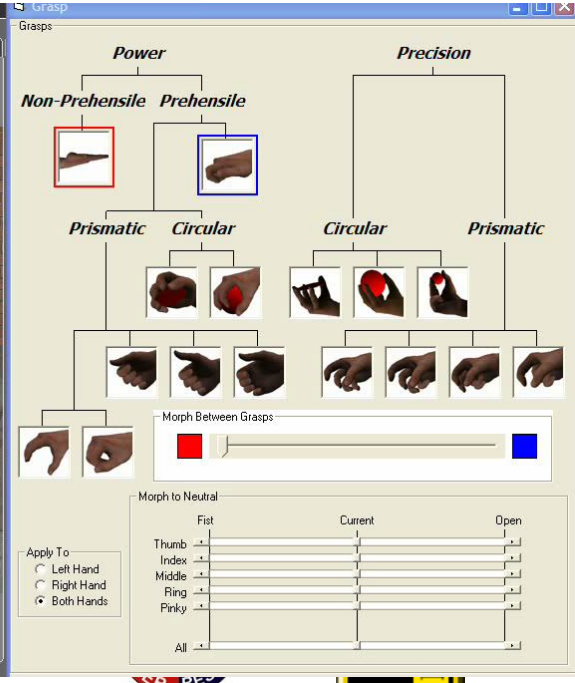
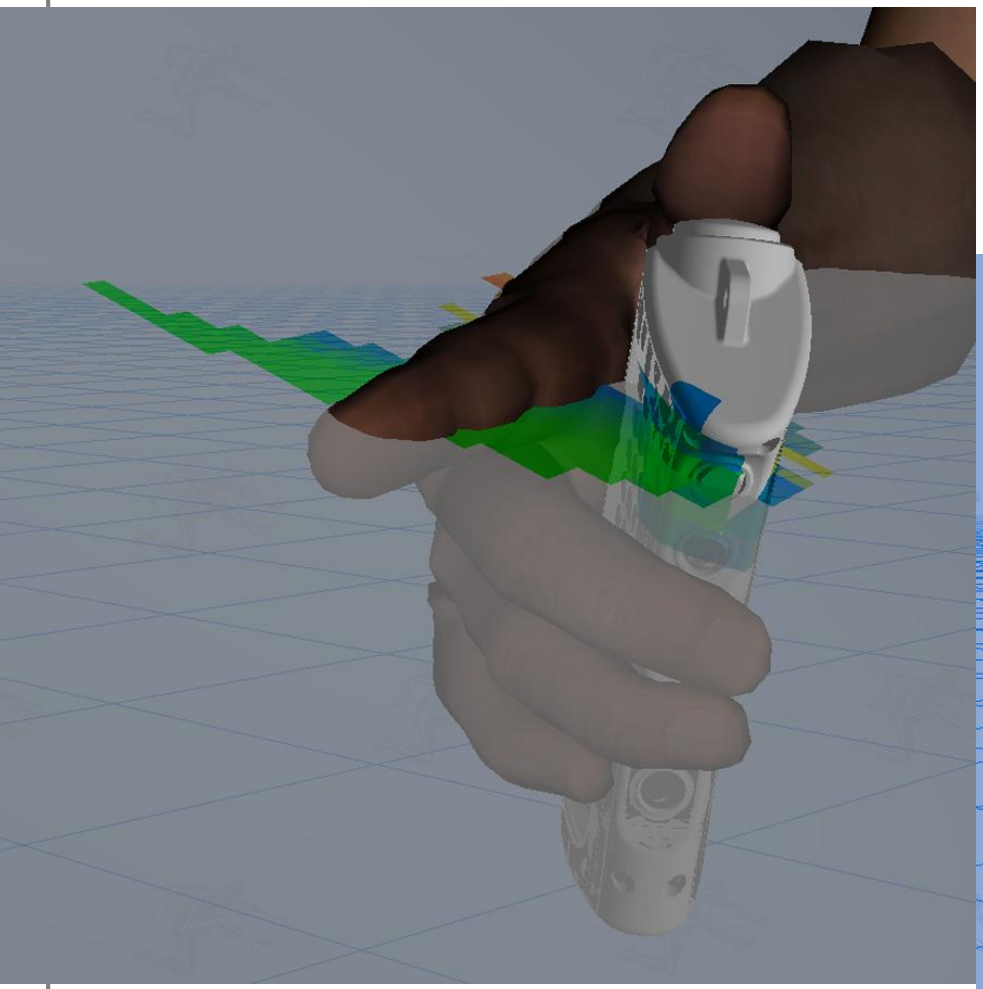
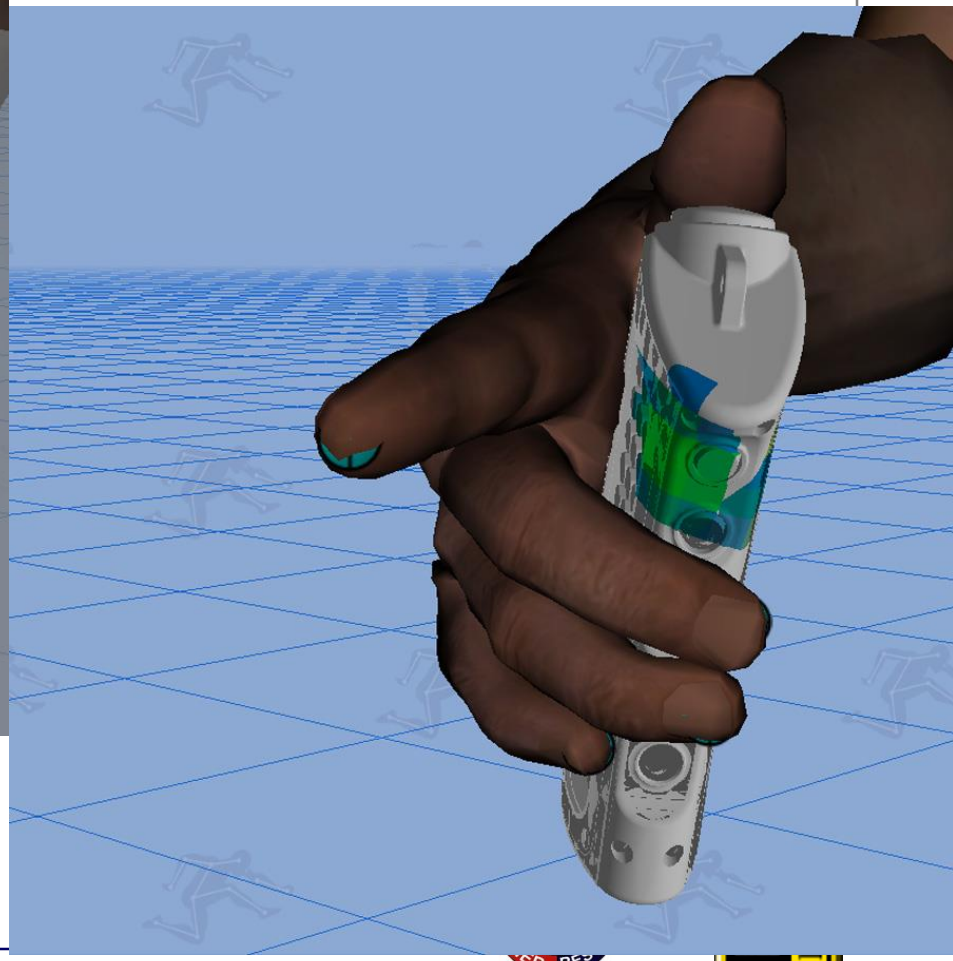
Hand Modeling



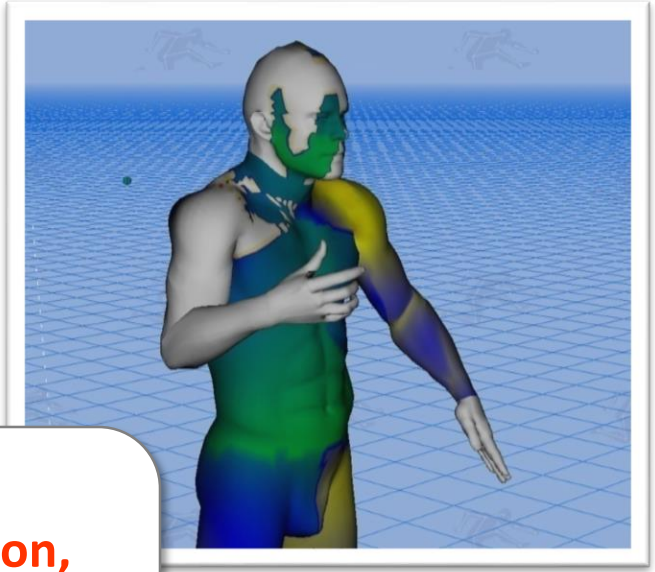


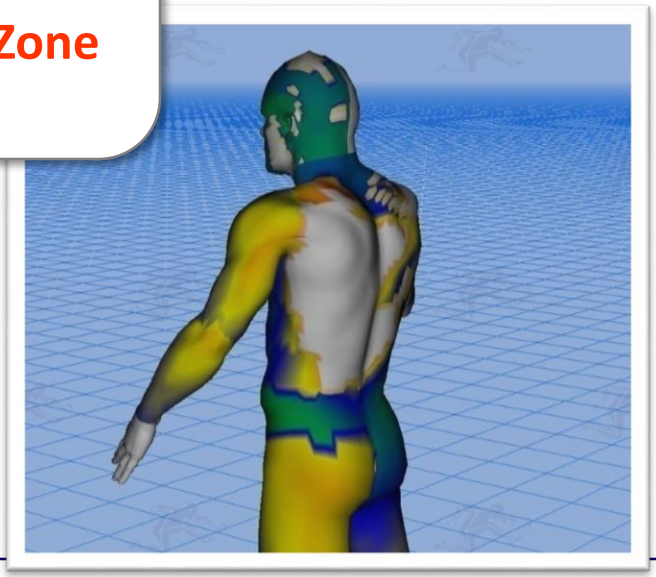
Hand Zone Differentiation

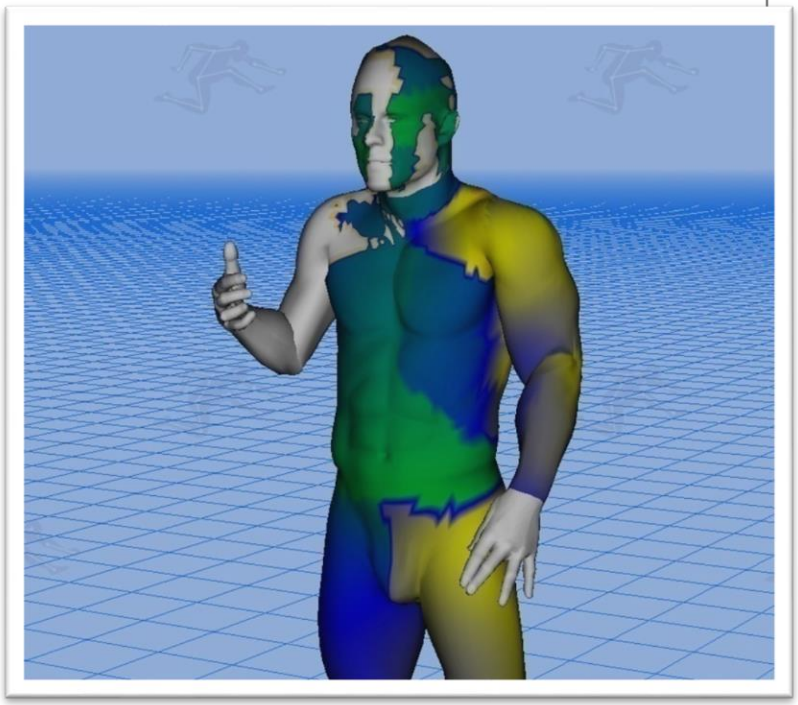




Body Zone Differentiation







Body Zone Differentiation, analyzed from the same Hand Zone End Effector

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Thank you

Santos

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