Biomechanics of Living Tissues and Organs

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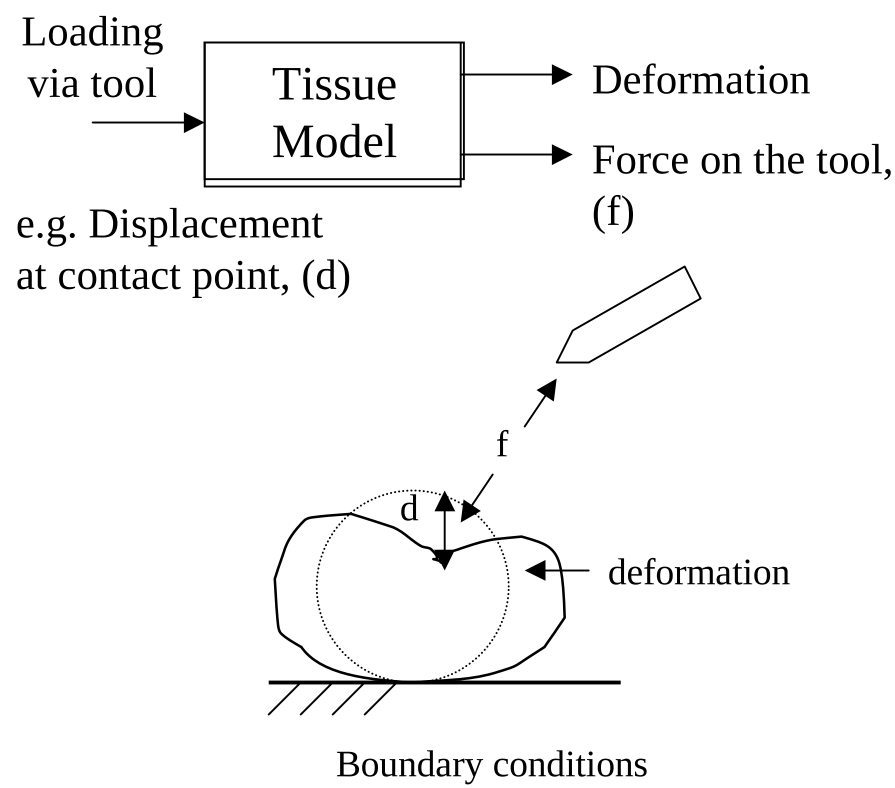
Simulation of Medical Procedures

<u>Procedures to be Simulated</u>

- Palpation
- Incision
- Cutting
- Catheter insertion
- …

<u>Biomechanical Problem</u>



Simulation Accuracy

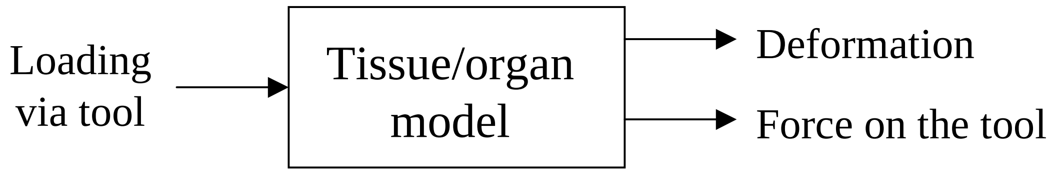
What is needed depends on:

- Goals of the training task
- Trainee's perceptual and motor abilities

What is achieved depends on:

- Limitations of tissue models and software algorithms
- Limitations of computational speed and display devices

Complexities in Accurate Simulation



- Tool-organ contact mechanics
- Large deformations
- Friction conditions
- Temperature
- Dynamics
- Incision
- Cutting

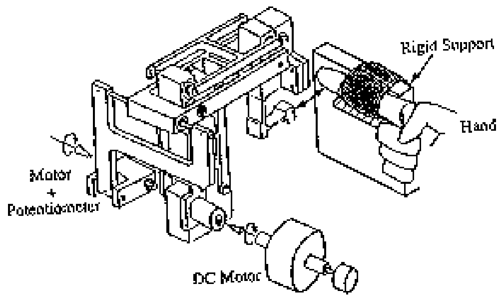
- Extent
- Geometry
    - Irregular 3D
    - Homogeneous, layered, ……..
- Material properties
    - Homogeneity
    - Anisotropy
    - Non-linearity
- Boundary/interface condition specification
- Organ-organ contact mechanics

Display modes

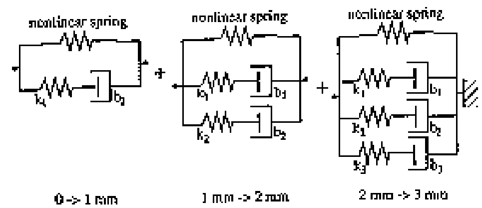
- Graphics (30Hz update)
- Haptics (1kHz update)

Force Response of the Human Fingerpad to Indentation

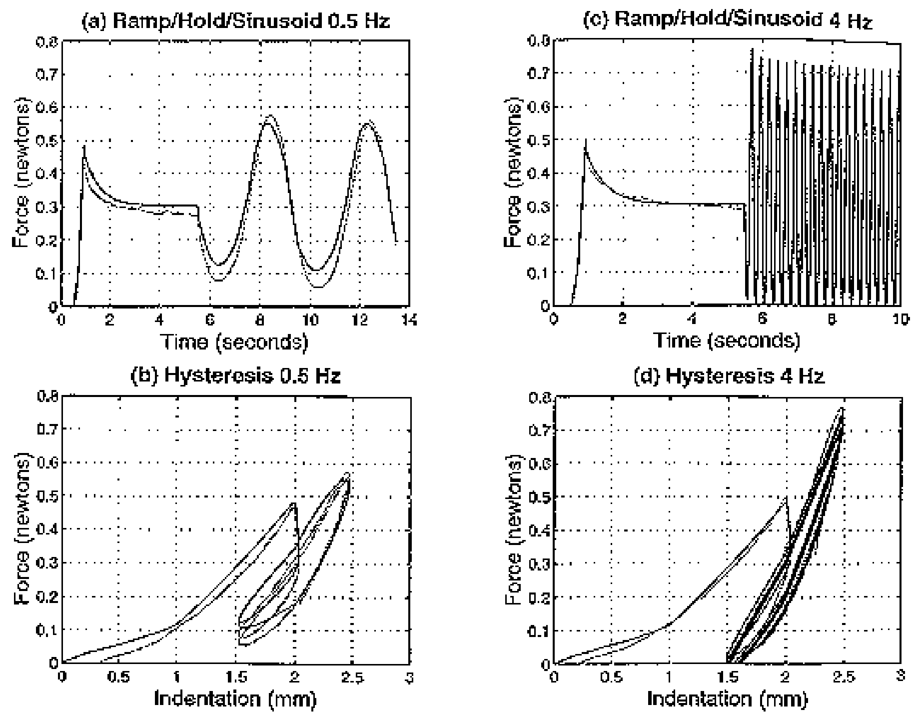
Tactile Stimulator Setup



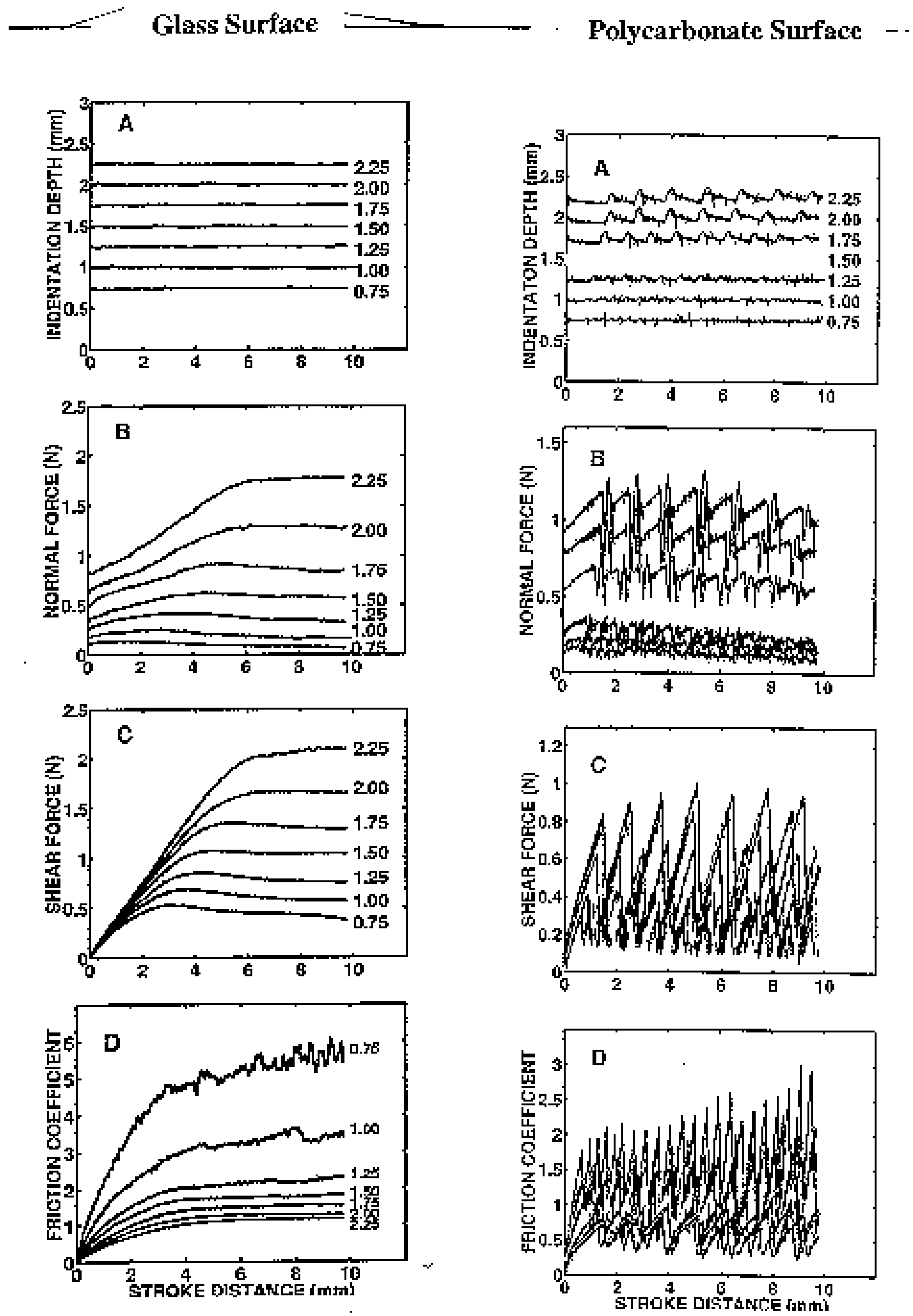
Model of Force Response



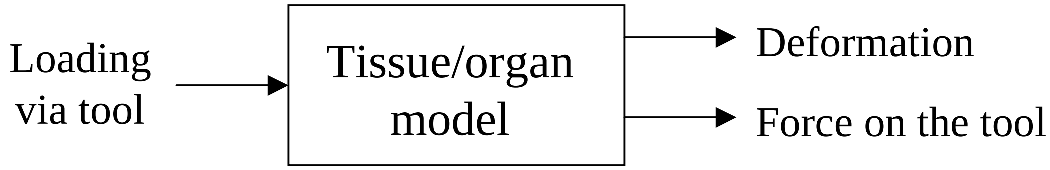
Indentation Depth



Model Predictions (black) vs. Experimental Data (grey) for Cylindrical Indentor


Glass Surface
Polycarbonate Surface
A
B
C
D
INDENTATION DEPTH (mm)
NORMAL FORCE (N)
SHEAR FORCE (N)
FRICTION COEFFICIENT
STROKE DISTANCE (mm)
INDENTATON DEPTH (mm)
2.25
2.00
1.75
1.50
1.25
1.00
0.75

Approximations in Simulation



- Point or line contact
- Small deformations
- Ignore friction, temperature effects
- Quasi-static conditions

- Restricted extent
- Simplified geometry
- Homogeneous, isotropic, linear material properties
- Idealized boundary/interface conditions
- Ignore organ-organ contact mechanics

Model updates can be slower than display refresh rates

Essential Tissue/Organ Physical Properties

- Elasticity - Young’s modulus
- Compressibility - Poisson’s ratio
- Viscosity - damping coefficient
- Density - mass/unit volume
- “Strength” - piercing, cutting
- Organ boundary conditions

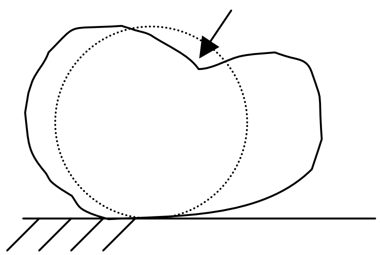
Measurements of Tissue/Organ Physical Properties

- In vitro on excised tissue
- Cadaver - needs to be fresh
- In vivo with instrumented tools - animals
  - humans

Stimuli for Physical Property Measurements

- Ramp and hold - tensile or compressive
- Sinusoidal vibrations
- White noise / pink noise
- …………..

Inferring Tissue Elemental Properties



Experimental Data

Determine model parameters that match
(e.g. Young's modulus, Poisson's ratio)

Loading via tool → Tissue/organ model → Deformation, Force on the tool

e.g. particle model,
"waterbed" model,
finite element model

Tactile Sensory System

(Data mainly for the fingerpad)

Absolute detection threshold	
	- 20 *u*m @ static
	- 10 *u*m @ 10 Hz
	- 0.1 *u*m @ 250 Hz
Pressure threshold	**- 0.3 mN/mm^2**
Feature detection	**- 0.1 *u*m for texture**
	- 2 *u*m for single dot
Temporal resolution	**- 10 ms between two taps**
Frequency range	**- 1 kHz**
Frequency resolution	**- 10% to 80%**
Spatial resolution	
localization	**- 0.15 mm**
2-point limen	**- 1 mm**

Kinesthetic Sensory System

Position resolution	**- 1^0 to 2^0 at joints**
	- 0.5 mm at fingertip
Position reproduction	**- 5^0 to 10^0**
Bandwidth	**- 20 to 30 Hz**

Motor System

Motion:

Range of motion		**- 20^0 to 100^0**
Velocity		**- 0.1 m/s at fingertip**
		- 1 m/s at wrist
Bandwidth		
	unexpected signals	**- 1 to 2 Hz**
	periodic signals	**- 2 to 5 Hz**
	reflex action	**- 10 Hz**

Forces:

single finger		
	typical range	**- 1 to 10 N**
	controllable range	**- up to 100 N**
	control resolution	**- 0.05 to 0.5 N**
grasp force range		**- 50 to 100 N**

Active touch including tactile, kinesthetic, and motor systems

Resolution (JND)

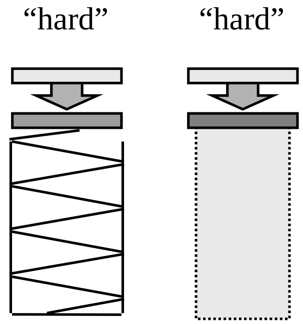
Length	**- 10 % or less**
Velocity	**- 10 %**
Acceleration	**- 20 %**
Force	**- 7 %**
Compliance	
Rigid surface (e.g. piano key)	**- 8 %**
Deformable surface (e.g. rubber)	**- 3 %**
Viscosity	**- 14 %**
Mass	**- 21 %**

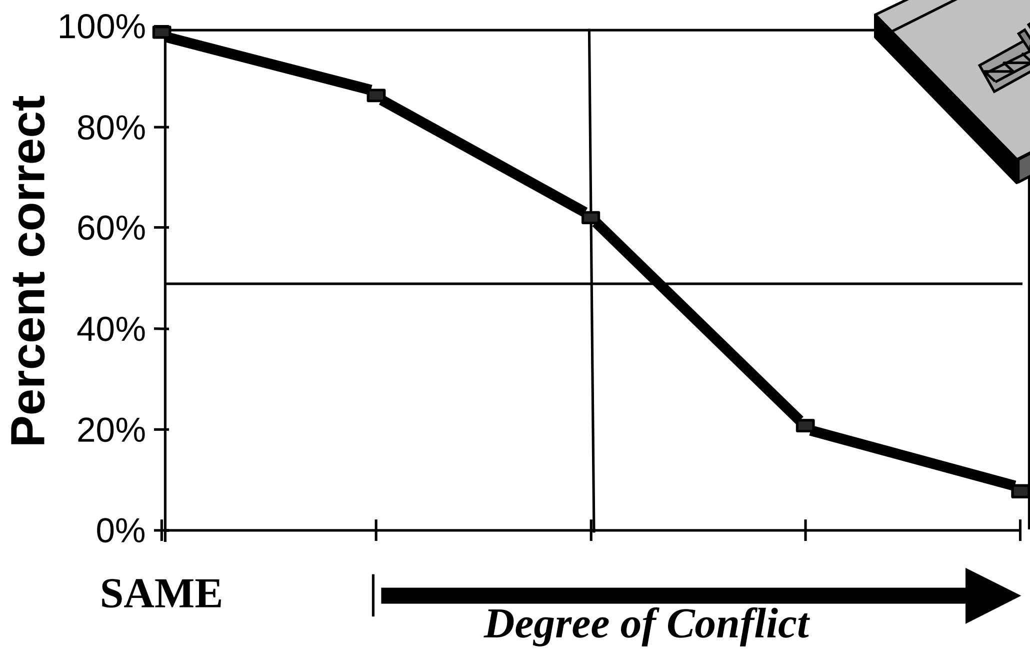
Rigidity perception - 25 N/mm or greater

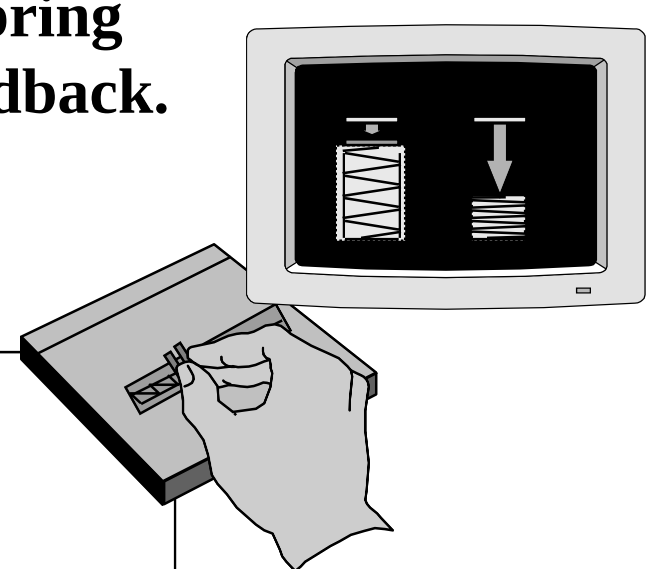
Vision Dominates Haptic Feedback

With conflicting visual and haptic cues, perceived stiffness of virtual spring depends on visual not haptic feedback.

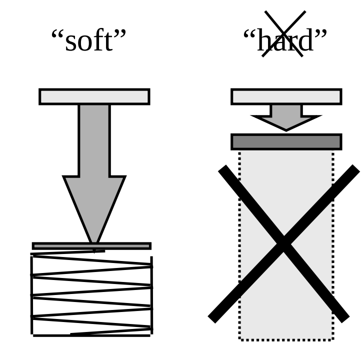
Vision / Haptic
SAME







Vision / Haptic
CONFLICT



MOTION: APPARENT ACTUAL

2-Alternative Forced Choice; JND = 10%
Actual Stiffness Difference held constant at 50%
All visual feedback via computer monitor.