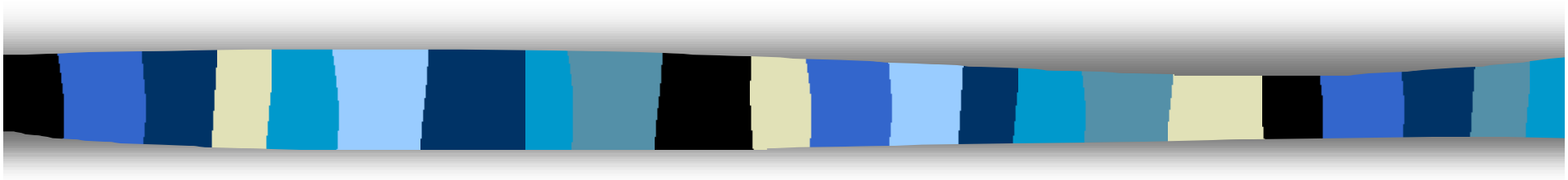
# Human Machine Interfaces in Minimally Invasive Surgery

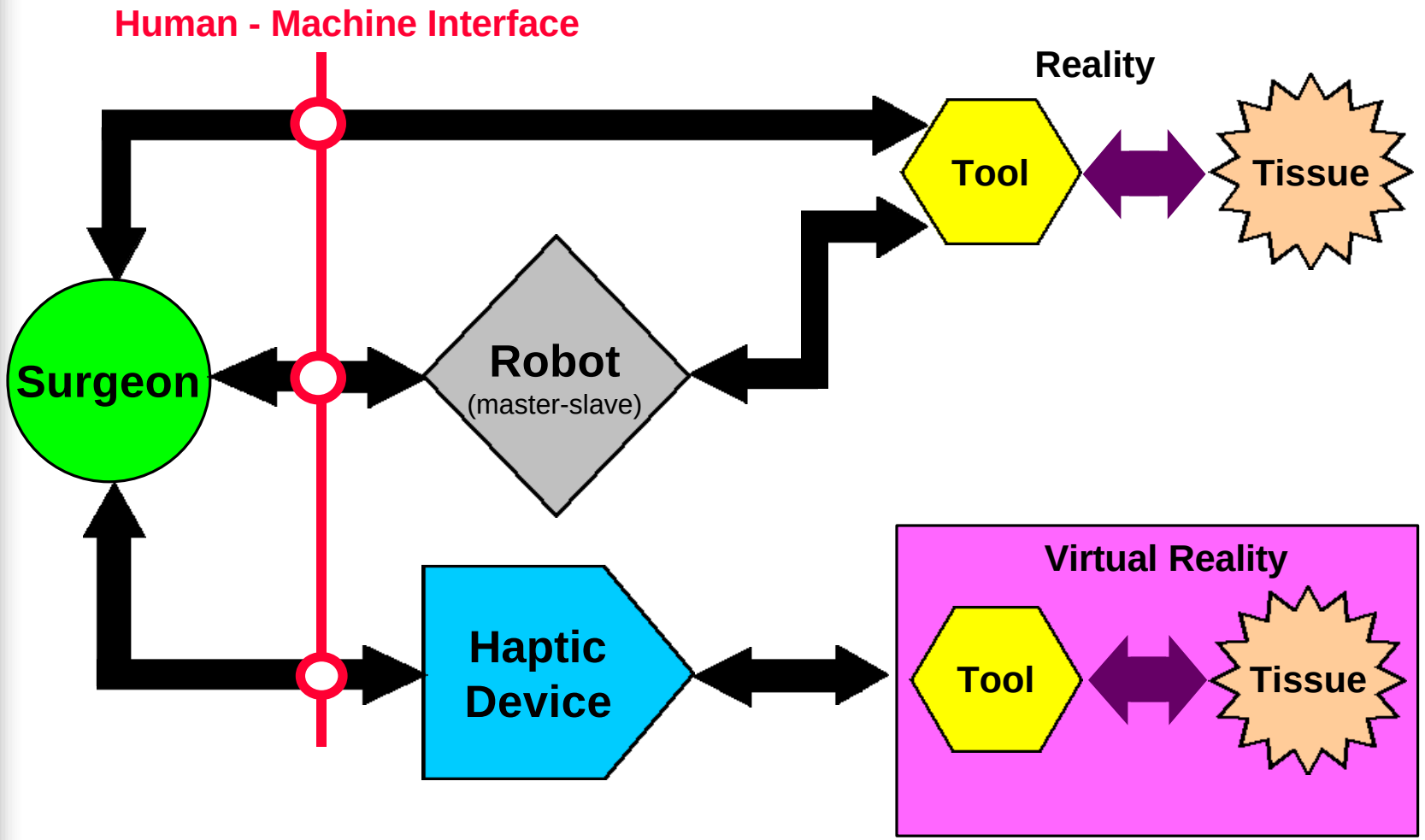


**Jacob Rosen Ph.D.**

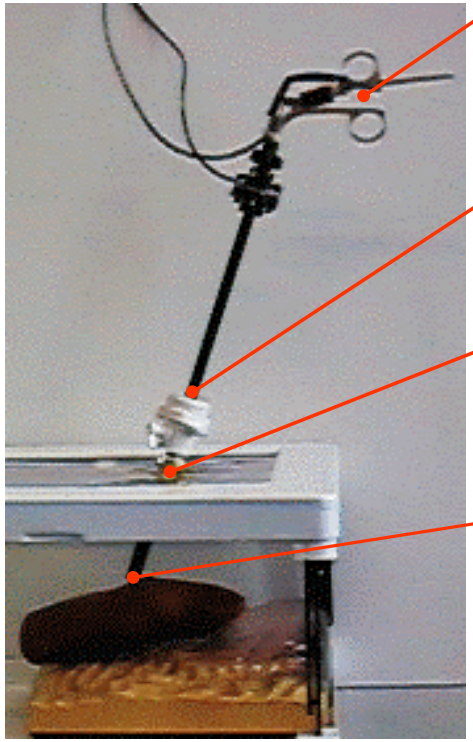
**Department of Electrical Engineering**
**University of Washington**
**Seattle, Washington**

**MMVR 2001 - Workshop**
**Simulating Minimally Invasive Surgical Procedures in Virtual Environments - Modeling**
**Newport Beach, CA - January 24-27, 2001**

# Surgery - The Big Picture



# Interfaces in MIS



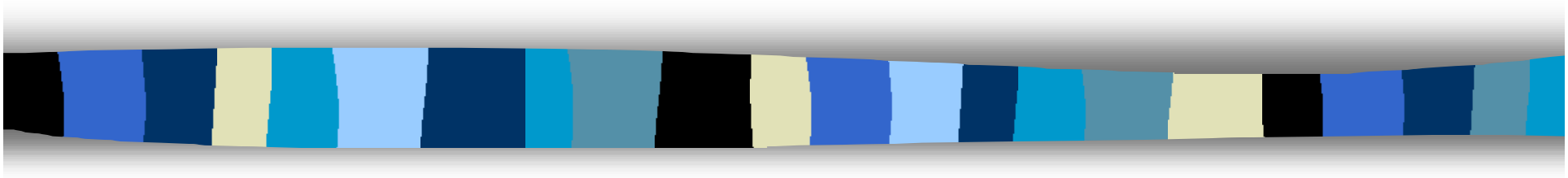
Human hand / Tool

Tool / Port

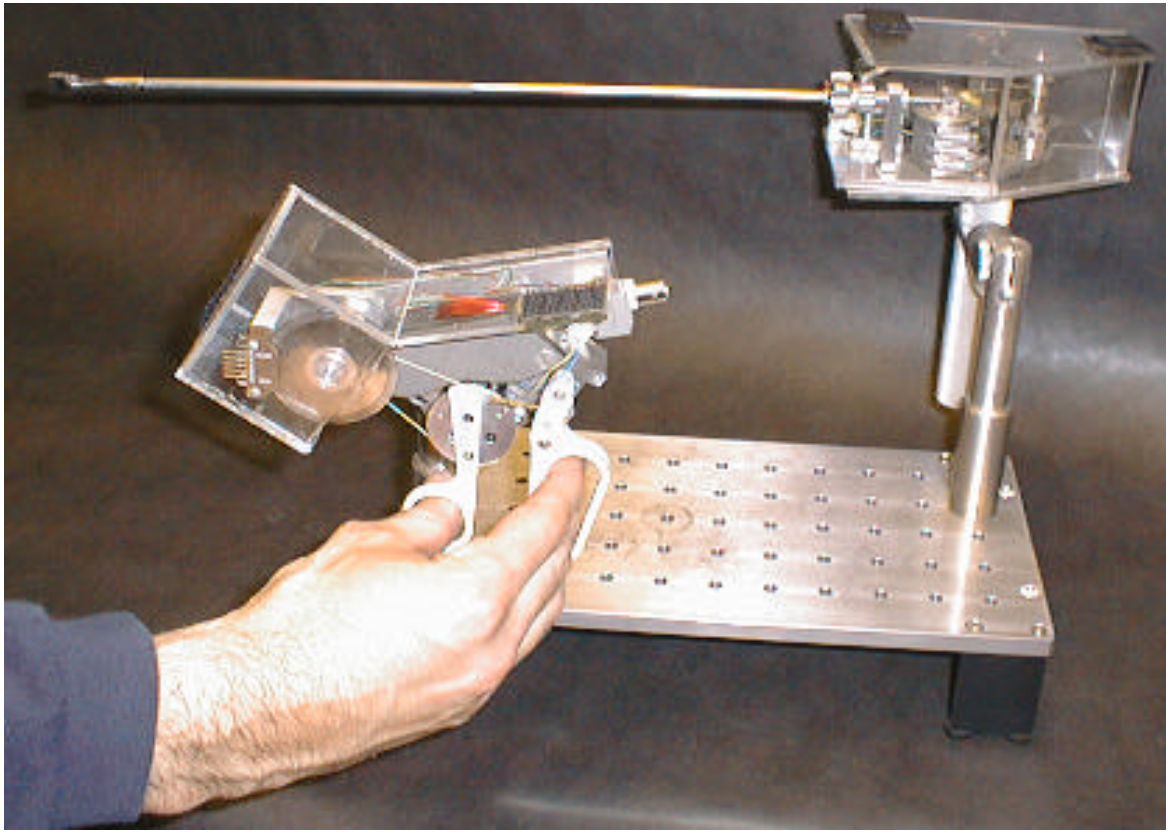
Port / Abdominal Wall

Tool Tip / Organ

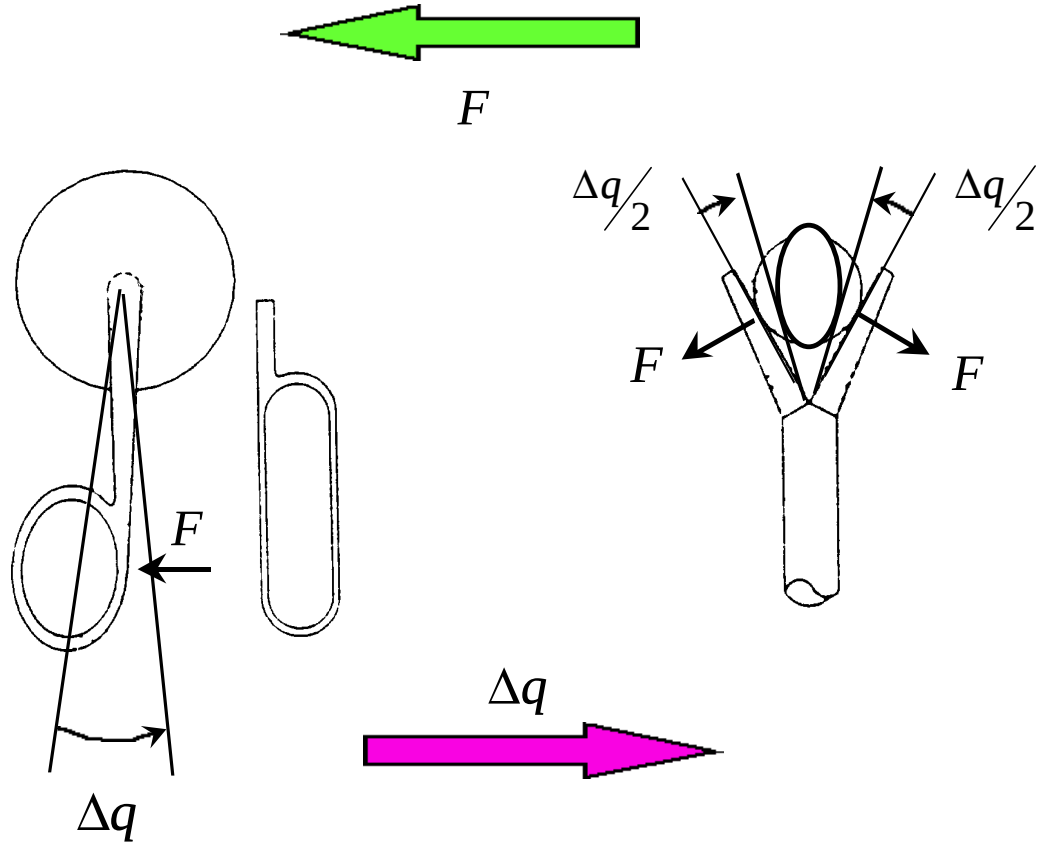
# In-Vivo Measurements of Soft Tissue Biomechanical Characteristics



# Force Reflecting Endoscopic Grasper FREG



# FREG - One DOF Bi-Lateral Control

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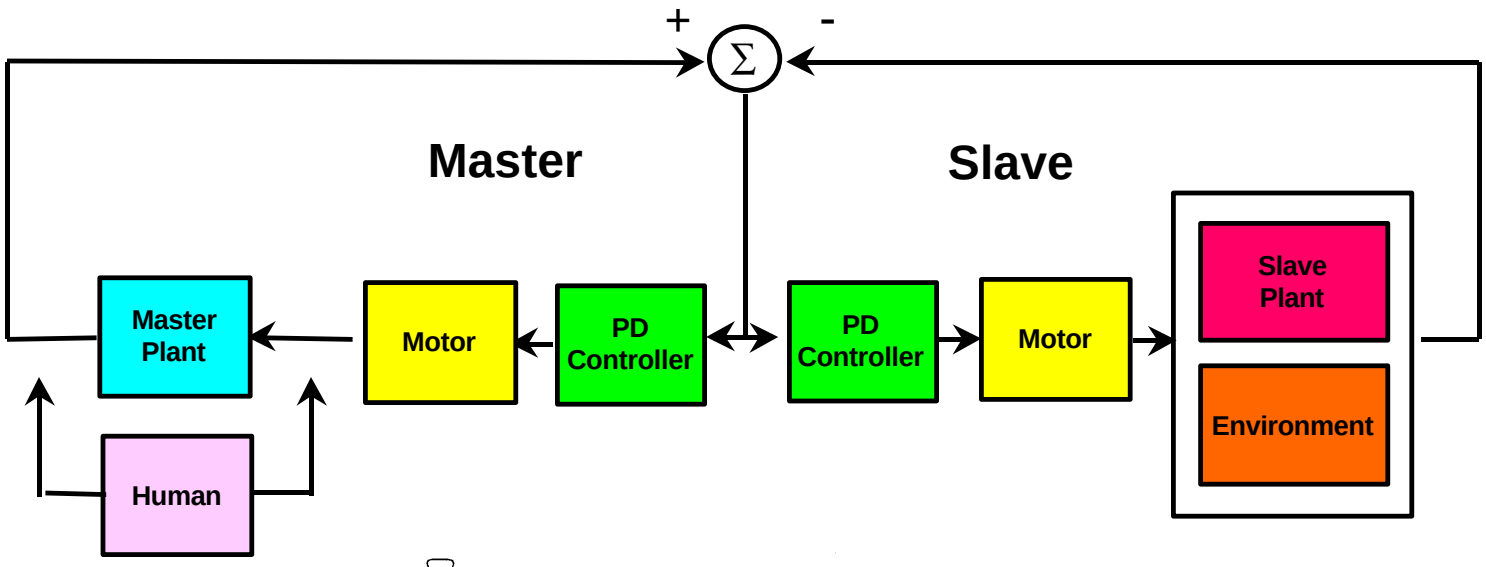
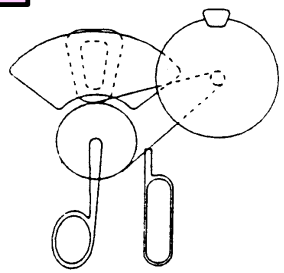
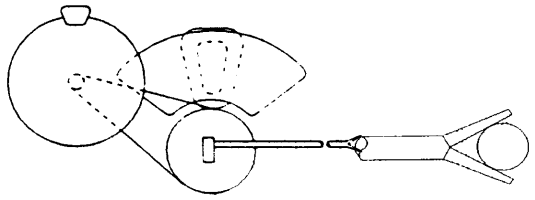
# FREG - Control Algorithm





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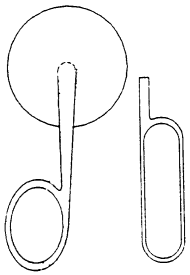
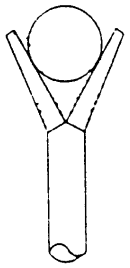
# FREG - Modes of Operation

| Mode | Master (Handle) | Slave (Grasper Tip) |
|---|---|---|
| Bi - Lateral | + | + |
| Automatic | - | + |





# Soft Tissue Biomechanics

## Quasi Linear Viscoelasticity Theory (Fung 1993)

$$K(l,t) = G(t) * s(l) \qquad \textbf{Relaxation}$$

$$C(l,t) = J(t) * l(s) \qquad \textbf{Creep}$$

$K(l,t)$ – Relaxation Function

$s(l)$ – Elastic Responce

$G(t)$ – Reduced Relaxation Function

$C(l,t)$ – Relaxation Function

$l(t)$ – Elastic Responce

$J(t)$ – Reduced Relaxation Function

$l$ – Length Ratio

$t$ – Time

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# Soft Tissue Biomechanics

## Uni axial Elastic Response (Fung 1993)

$$s = \frac{F}{A} \qquad l = \frac{L}{L_0}$$

$$s\,(l) = b\,\left(e^{a\,(1-l)} - 1\right)$$

$a$ , $b$ - Parameters

$l$ - Compression Ratio

$s$ - Uniaxial Compression Stress [Pa]

$A$ - Compression Cross Section Area [$m^2$]

$F$ - Compression Force Applied by the grasper

$L$ - Length of the Material Commpressed by the Load [m]

$L_0$ - Initial Length with Zero Load [m]

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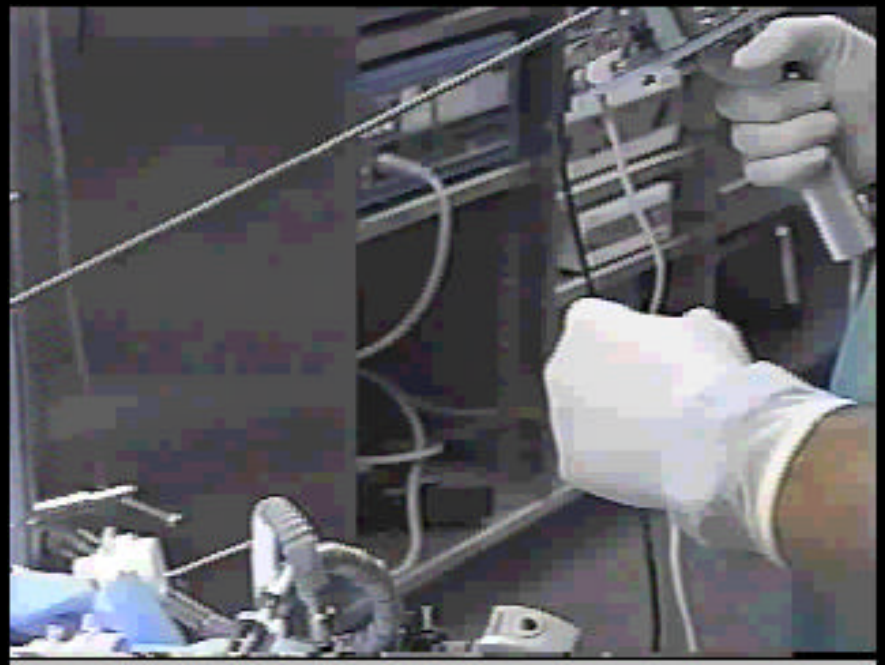
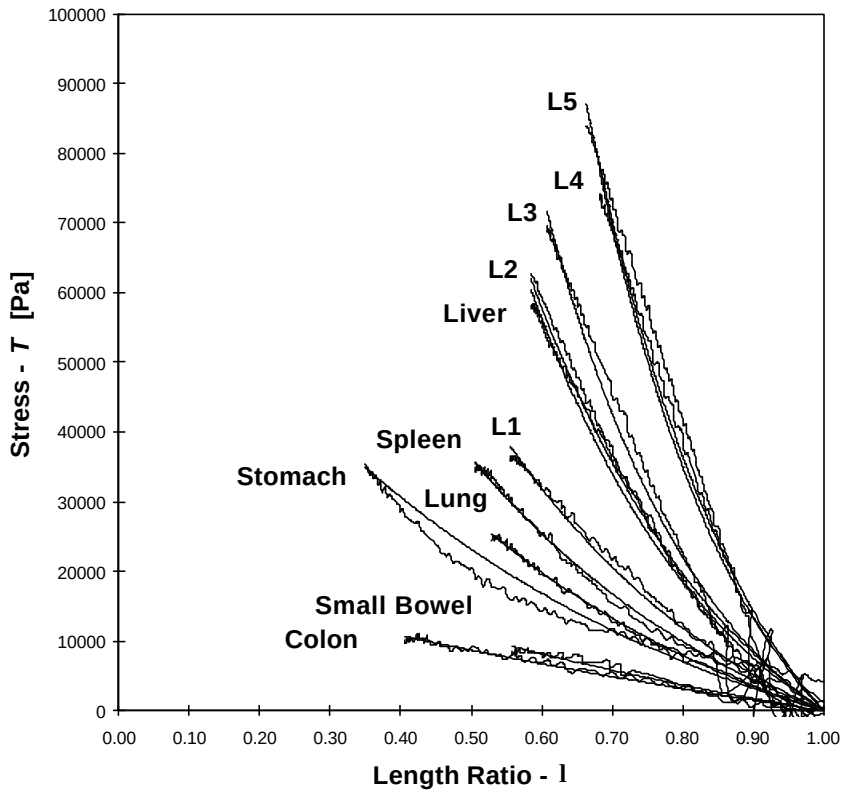
# FREG - Experimental Protocol (Video Clip)

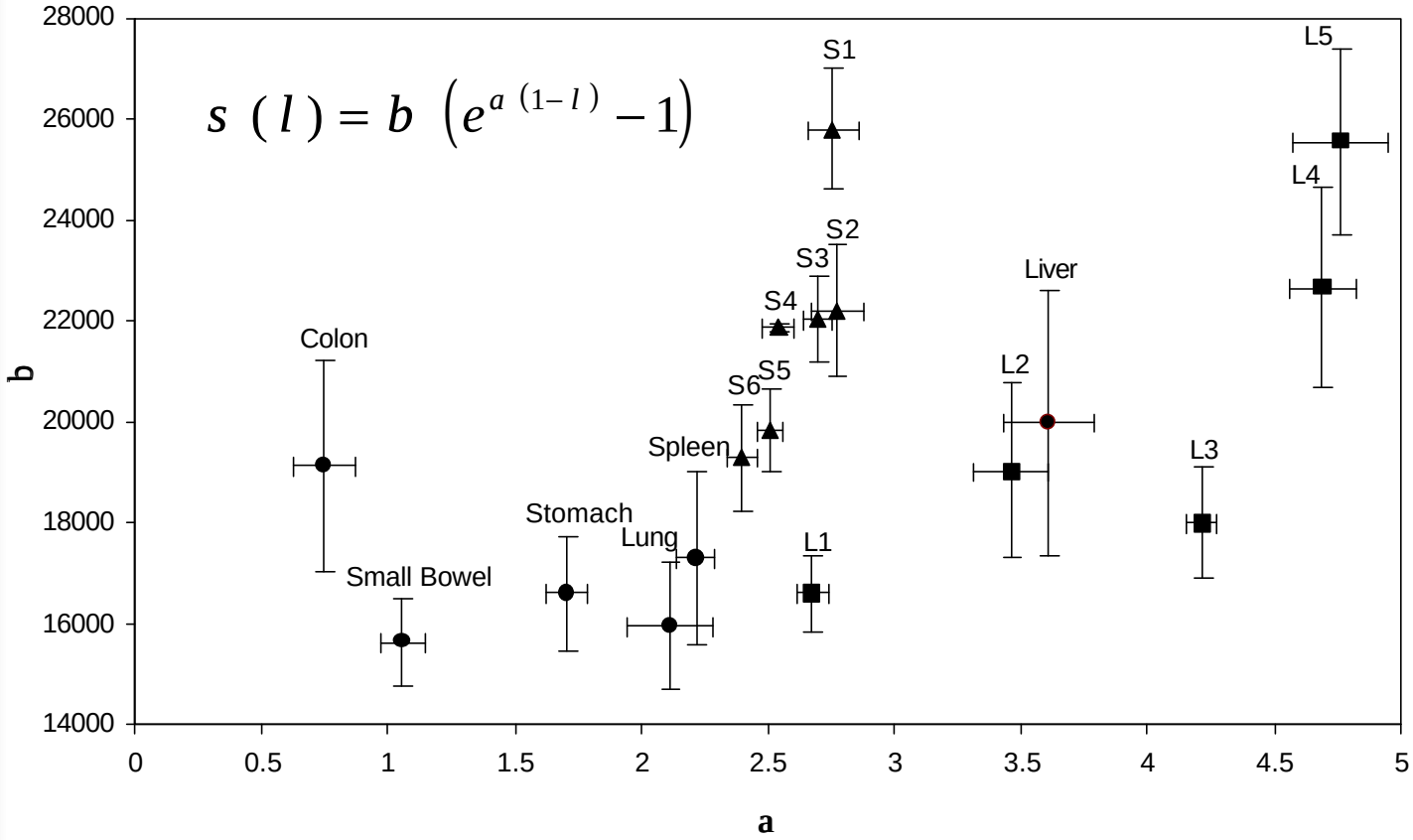


FREG_Auto

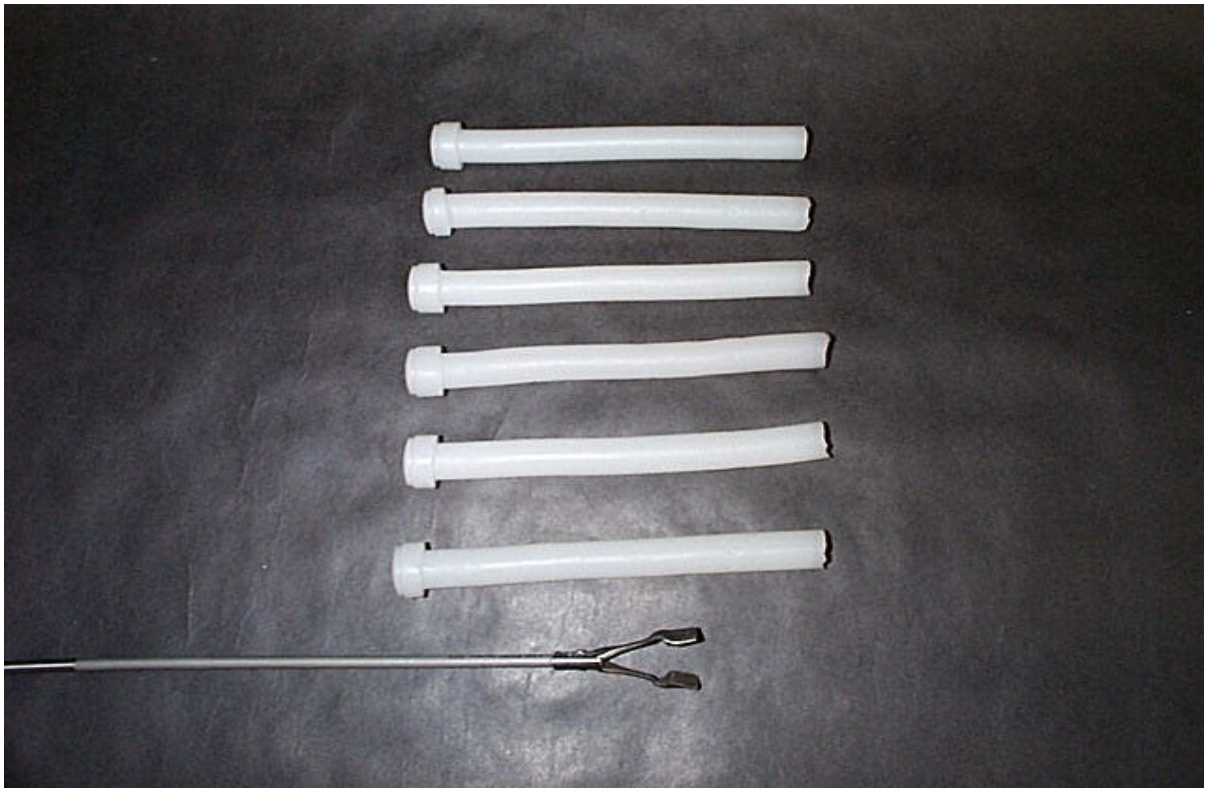
# Soft Tissues & Latex Materials
# Stress - Compression Ratio



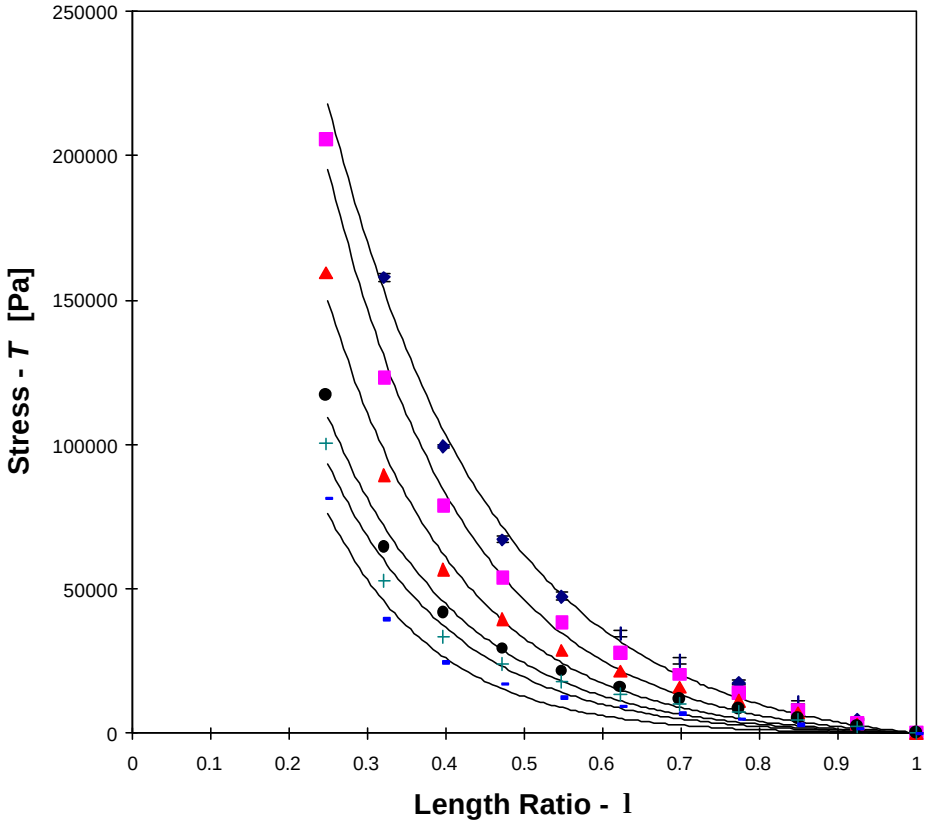
# Soft Tissue, Latex and Silicone Materials - Scatter Plot



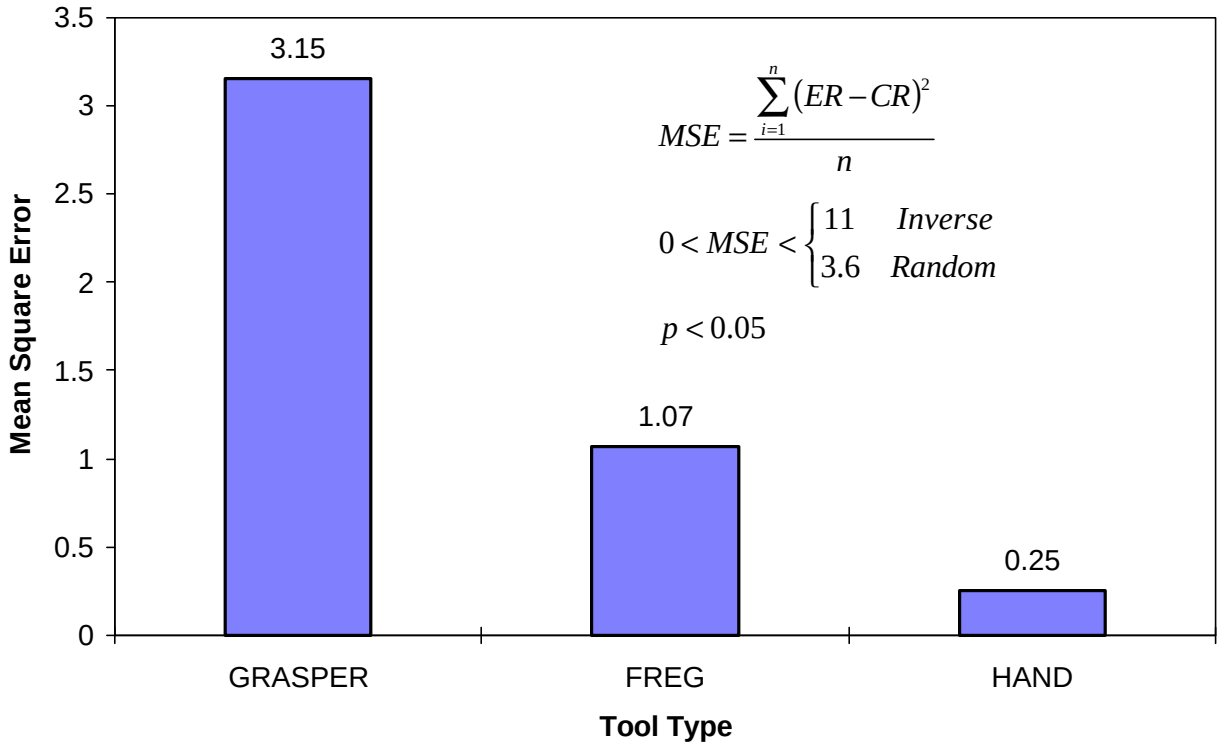
# Silicone Materials



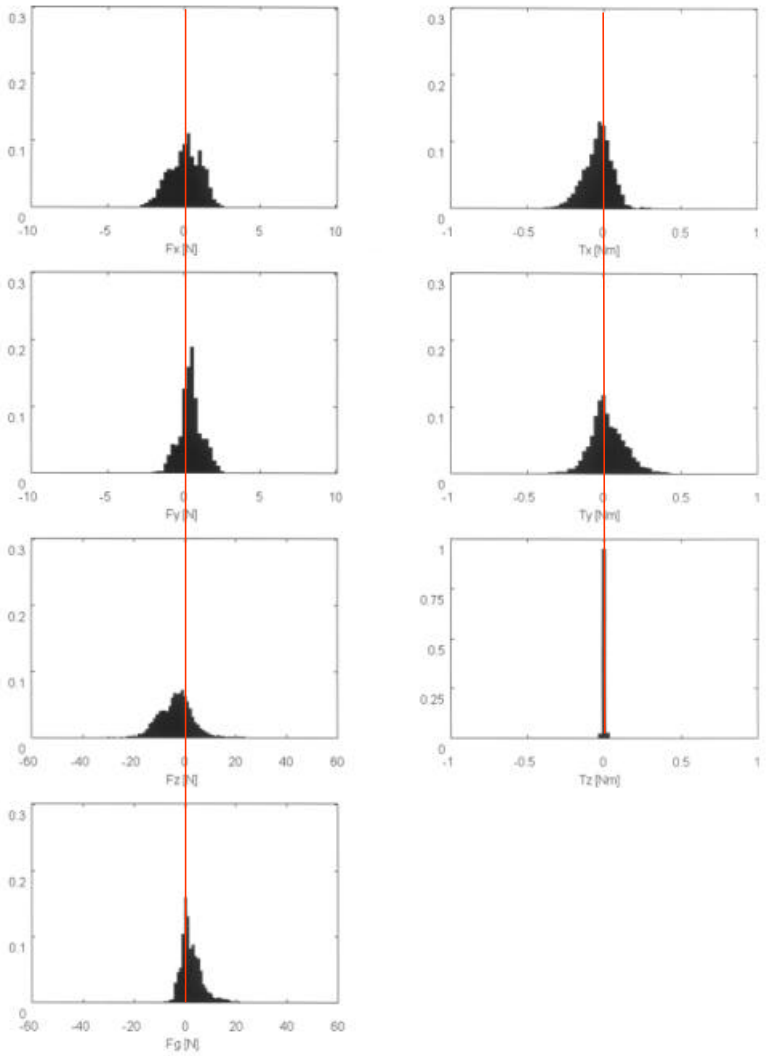
# Silicone Materials - Stress - Compression Ratio

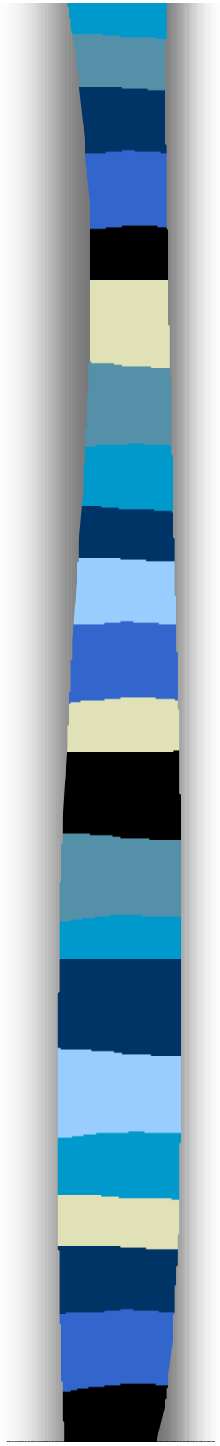


# Subjective Experiment - Stiffness Ranking

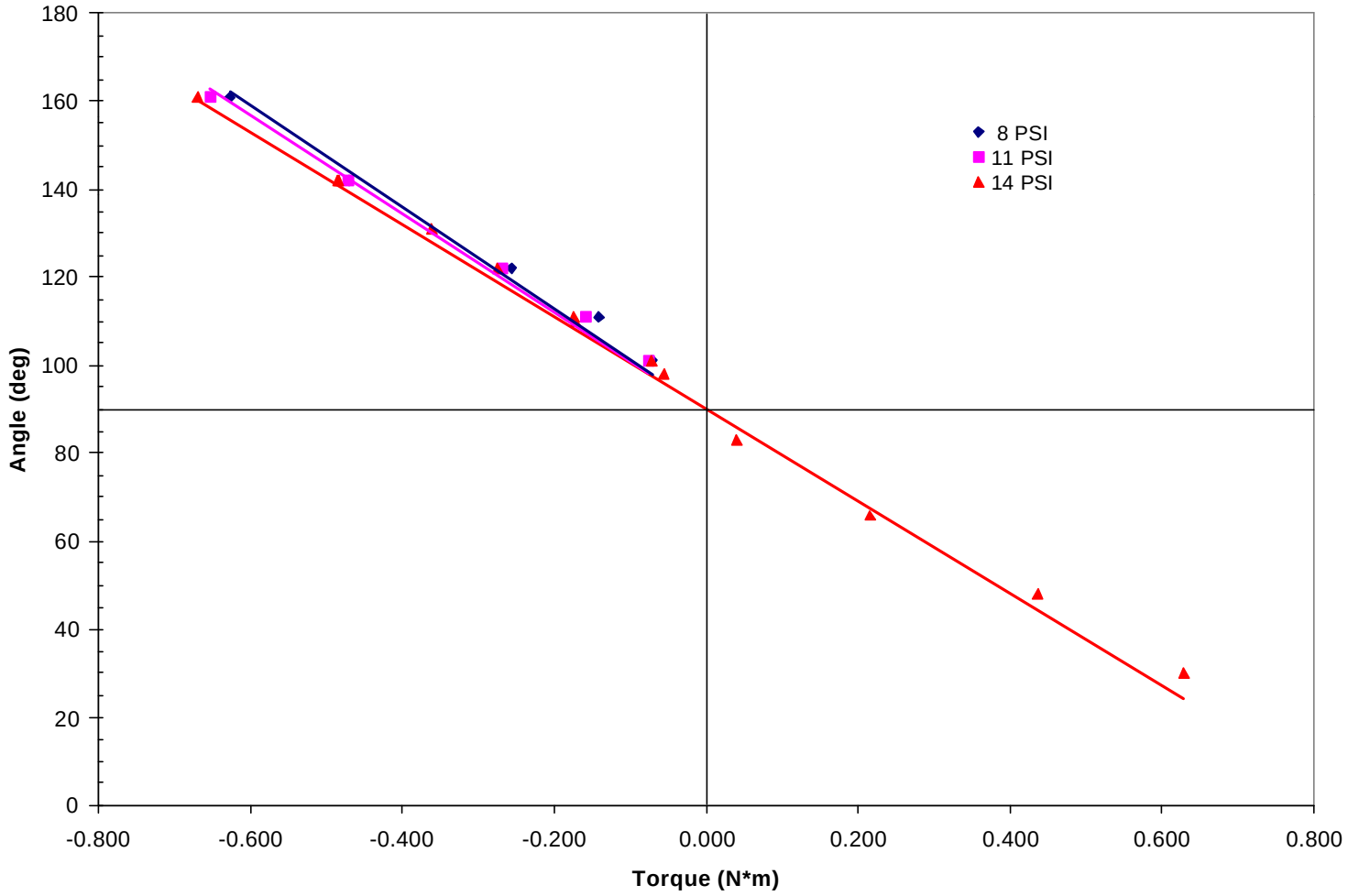


# Endoscopic Tool / Abdominal Wall Interface

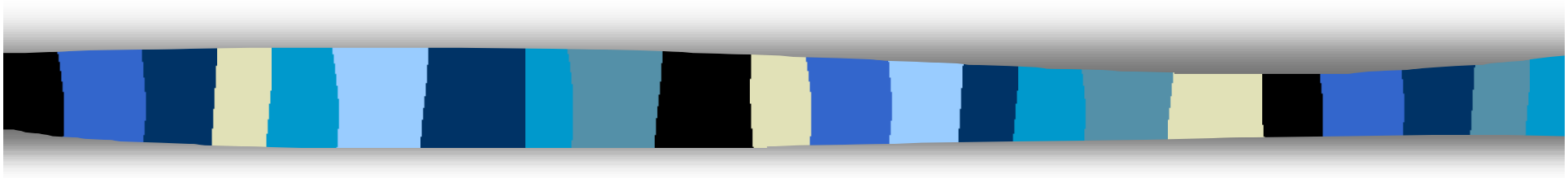




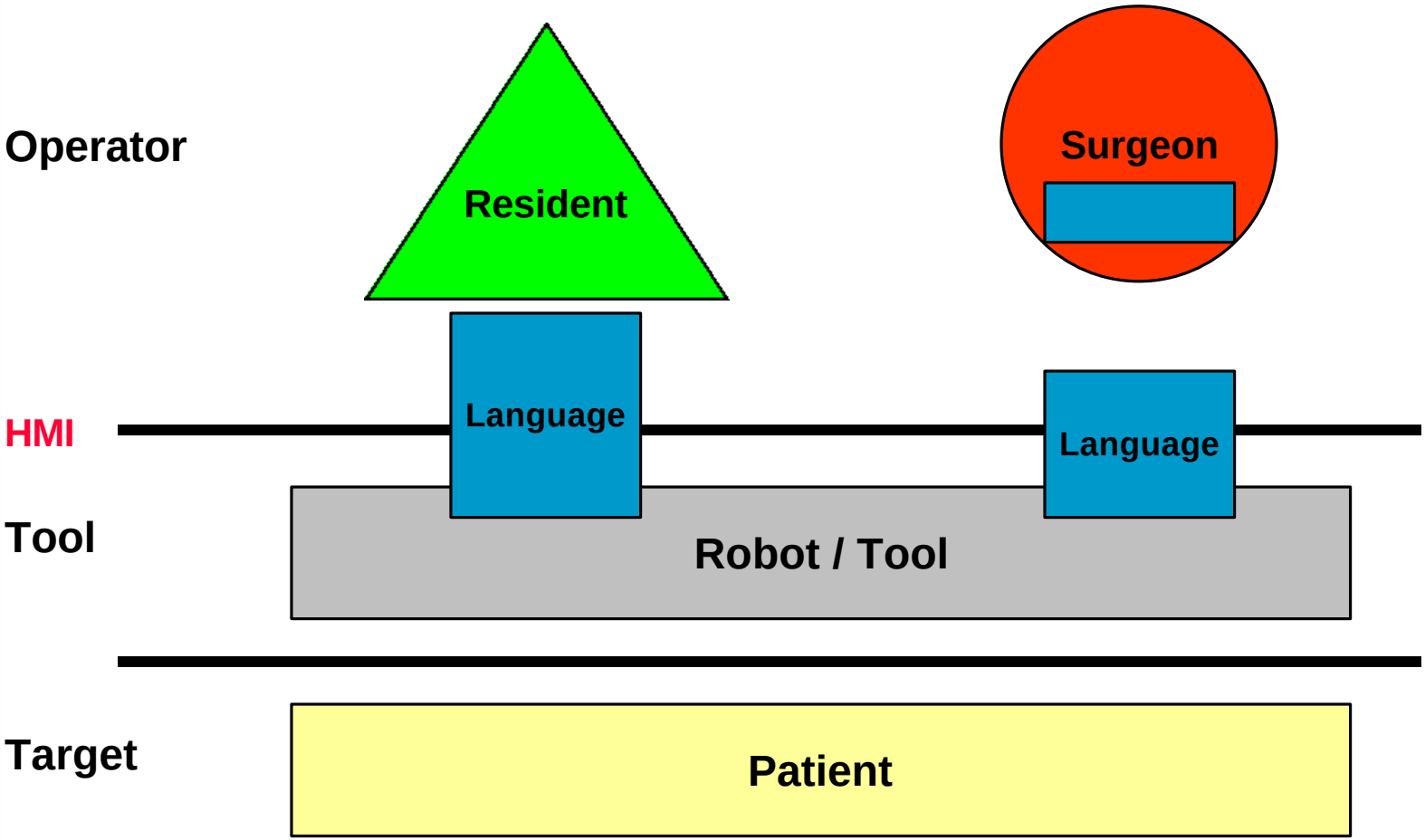
# Endoscopic Tool / Abdominal Wall Interface



# Hidden Markov Models of Minimally Invasive Surgery
# Objective Evaluation of Surgical Skills



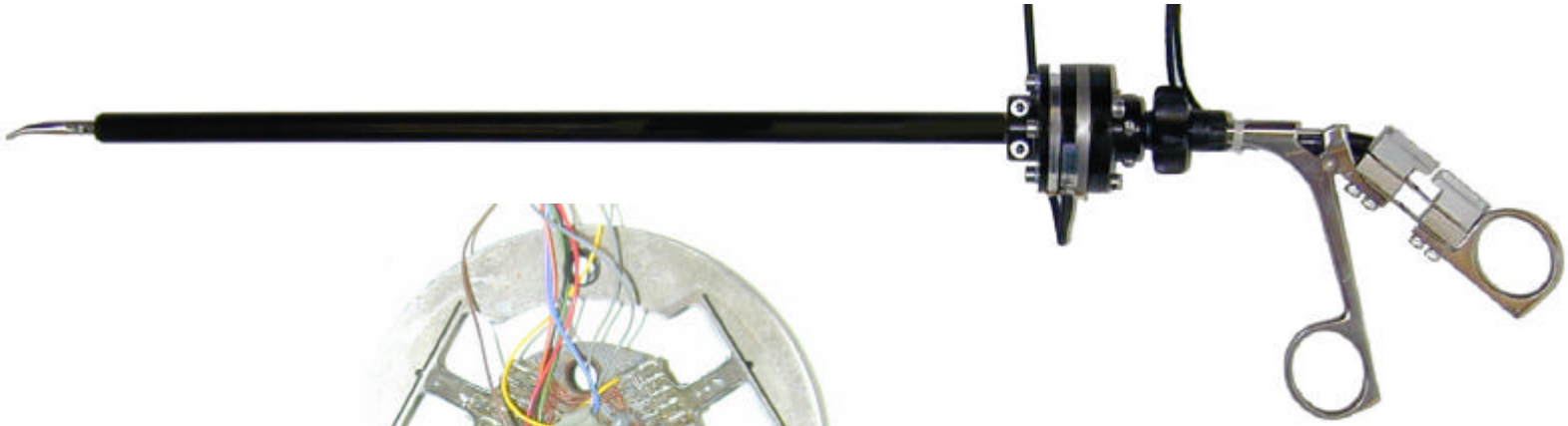
# Surgery - The Hidden Language Metaphor

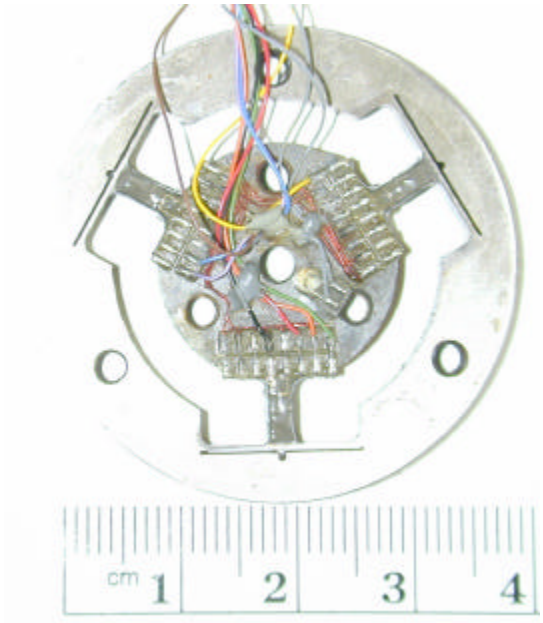


# Objectives

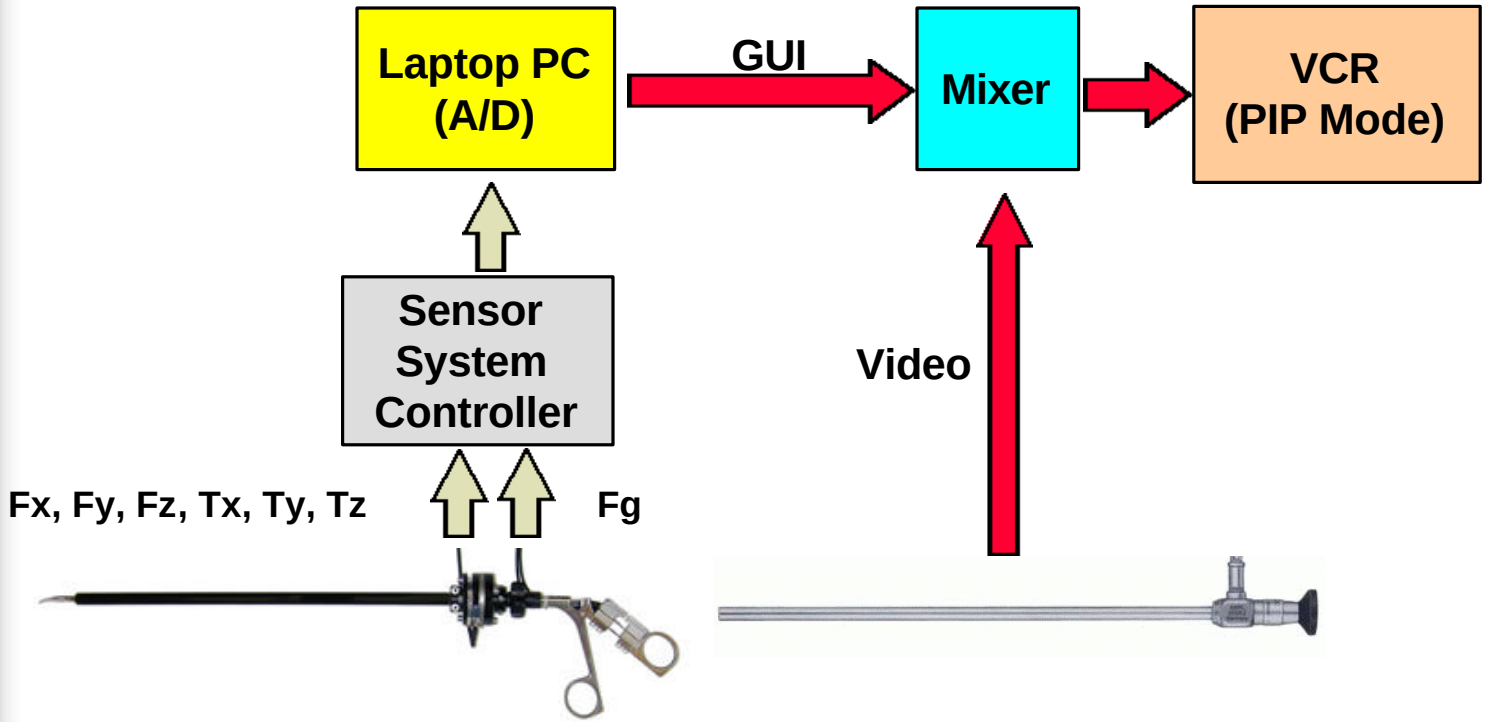
- **Develop surgical instruments with embedded sensors capable of measuring forces/torques**
- **Generate a data-base of forces/torques acquired during actual operating conditions on experimental animals**
- **Develop models of the surgical process for objective evaluation of surgical skills**

# Instrumented Endoscopic Grasper

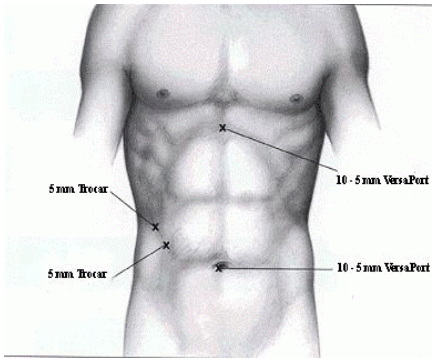


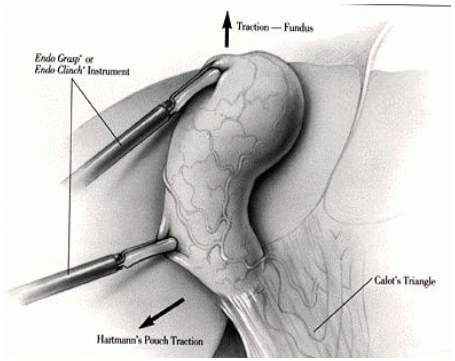


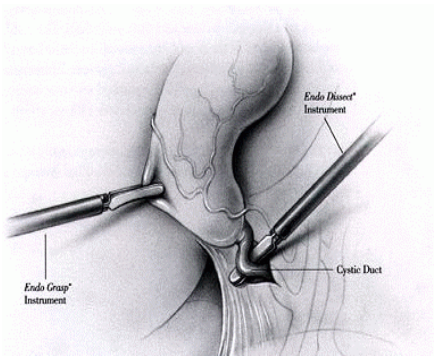

# Experimental System

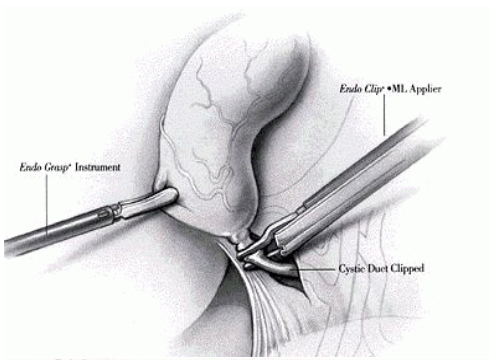


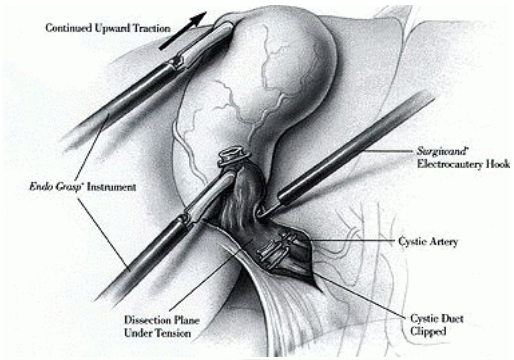

# Laparoscopic Cholecystectomy

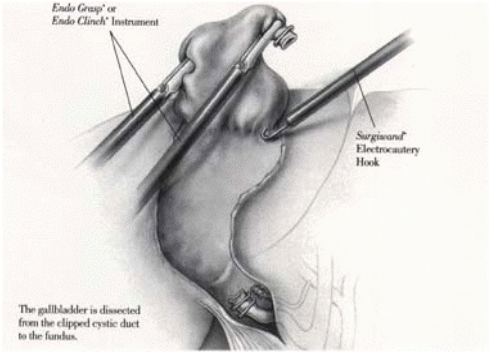


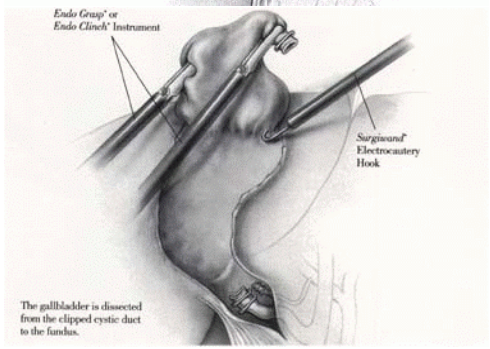



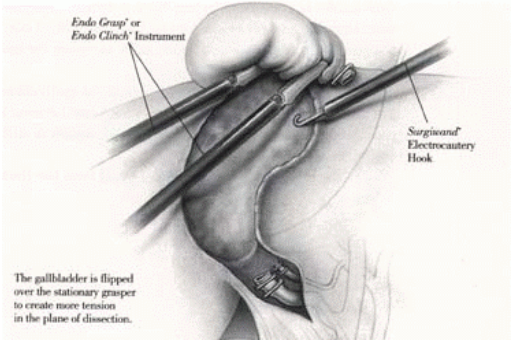



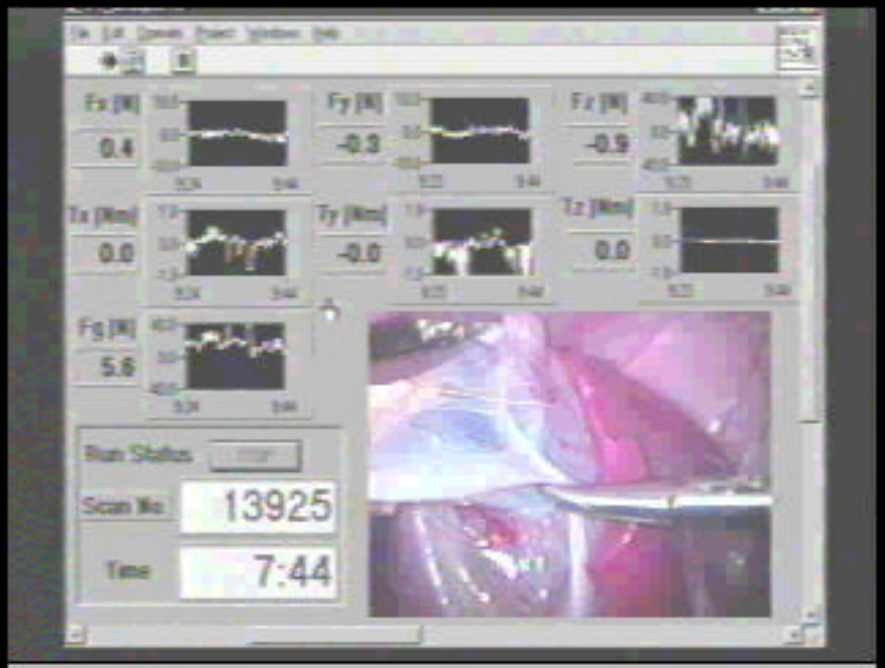



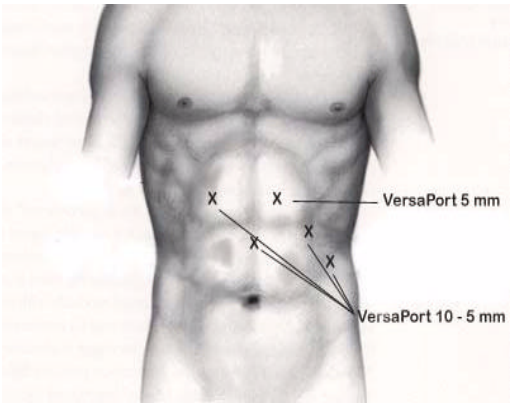



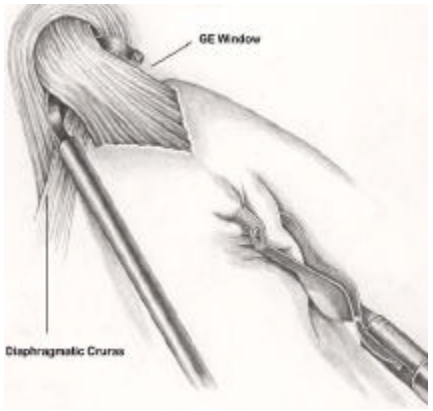
# Laparoscopic Cholecystectomy (Video Clip)

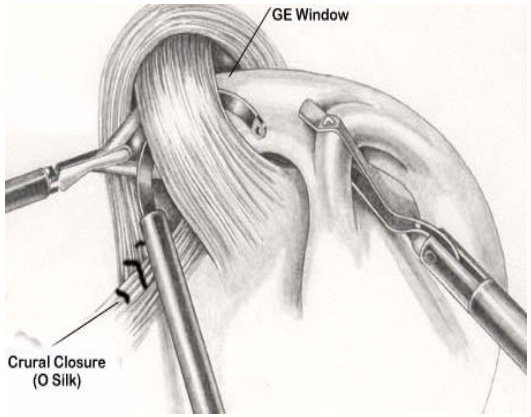


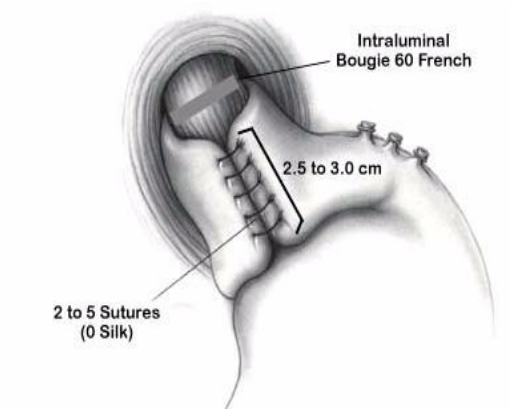

FT_LC_short

# Lapaproscopic Nissen Fundoplication

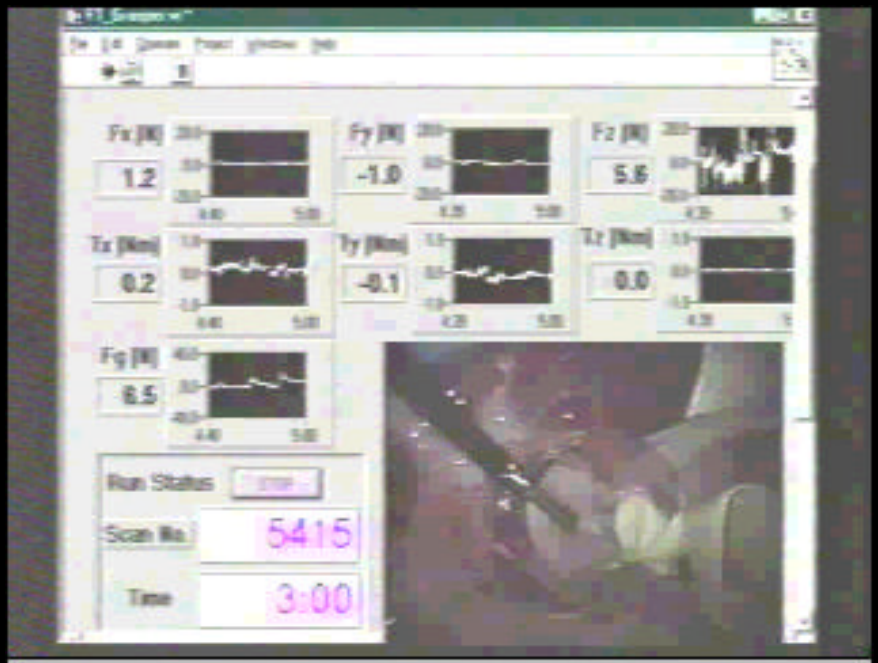


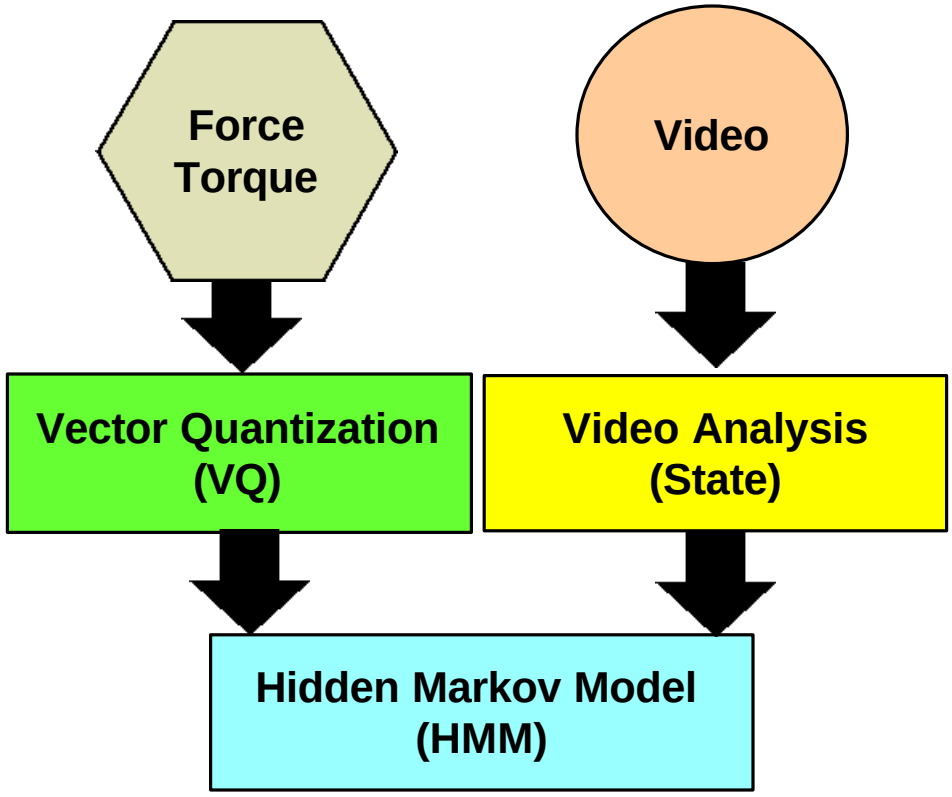



# Lapaproscopic Nissen Fundoplication (Video Clip)

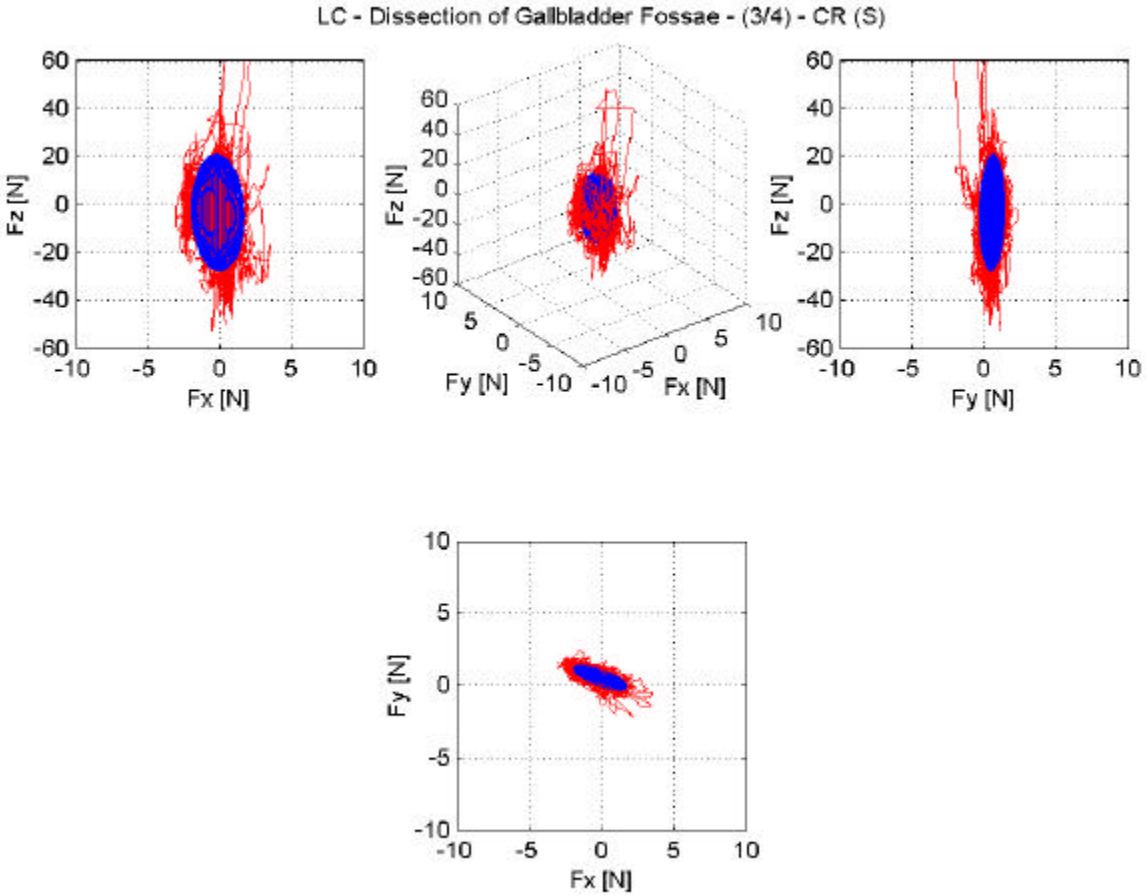



FT_LNF

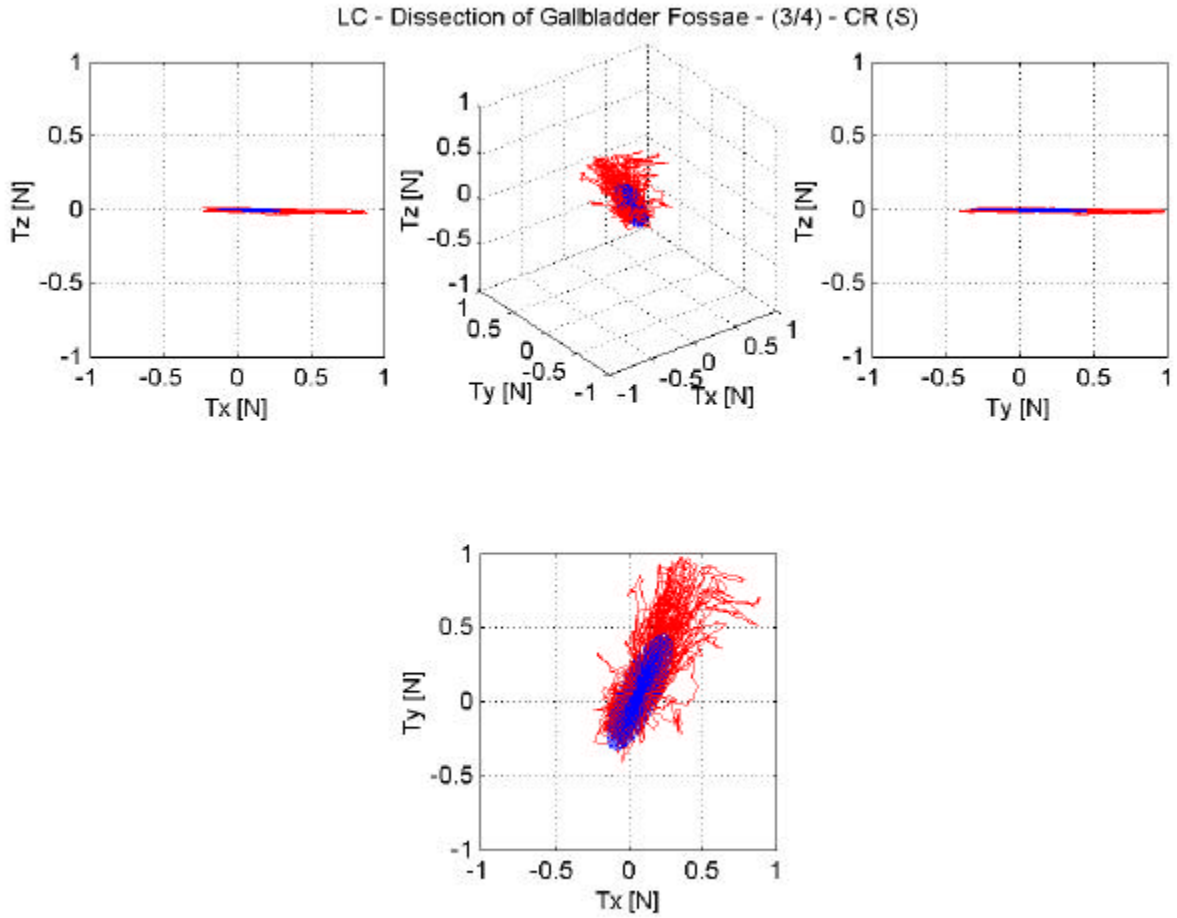
# Data Processing




# Forces - Raw Data



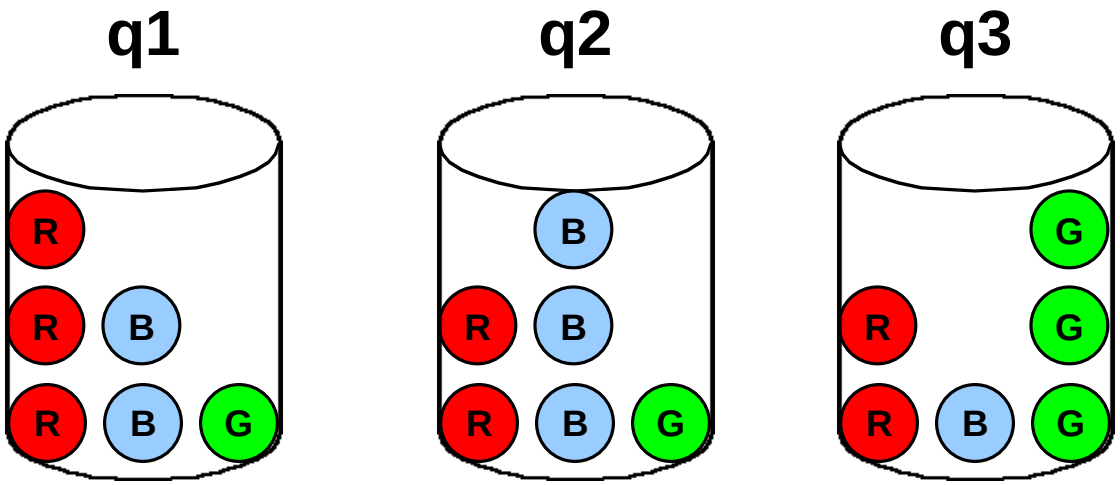
# Torques - Raw Data

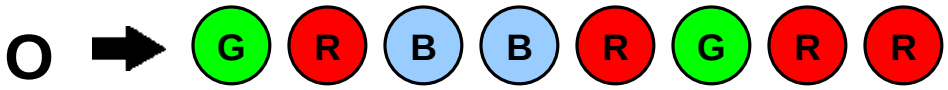


# Surgery - The Hidden Language Elements

| Human Language | Surgical Language | HMM |
|---|---|---|
| Words | Tool/Tissue Interaction | State |
| Pronunciation | Forces / Torque | Observation |
| Chapter | Step of the Operation | Single Model |
| Book | Operation | Multiple Models |

# Hidden Markov Model



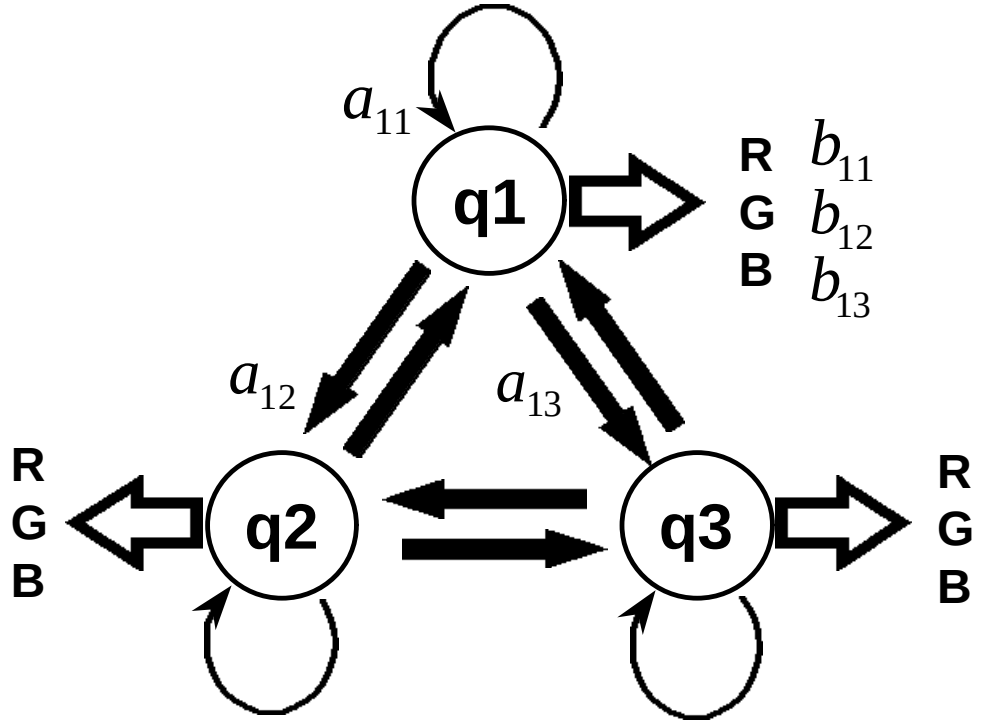




# Hidden Markov Model

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

$$B = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}$$

$$\Pi = \begin{Bmatrix} p_1 & p_2 & p_3 \end{Bmatrix}$$




# HMM - Training Problem

**Adjusting the model parameters to maximize the probability of the observation sequence**

**Given:** $\{ \lambda(A, B, p)$

**Adjust:** $\lambda A, B, p$

**Maximize:** $P(O \mid \lambda)$

# HMM - Evaluation Problem

**Computing the probability of the observation sequence given the model**

**Given:**

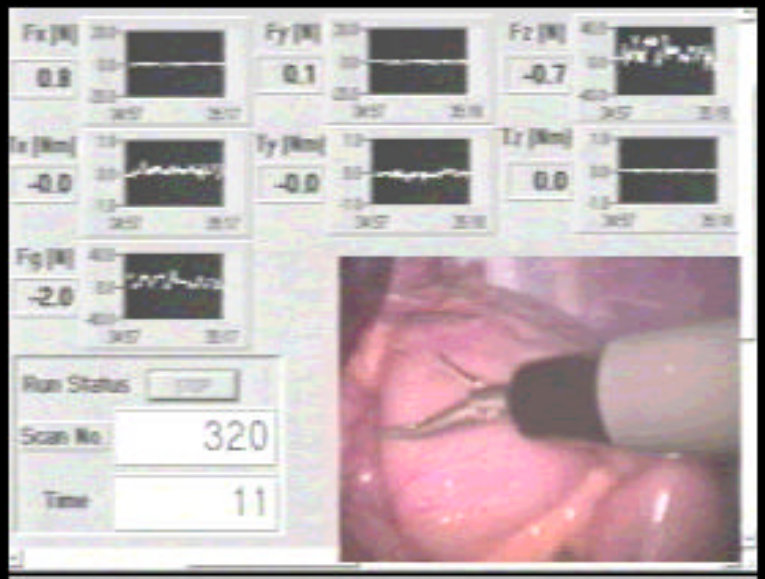
$$\begin{cases} O = o_1, o_2, \ldots, o_T \\ \lambda(A, B, p) \end{cases}$$

**Compute:** $P(O \mid \lambda)$

# Tool/Tissue Interactions - Definitions

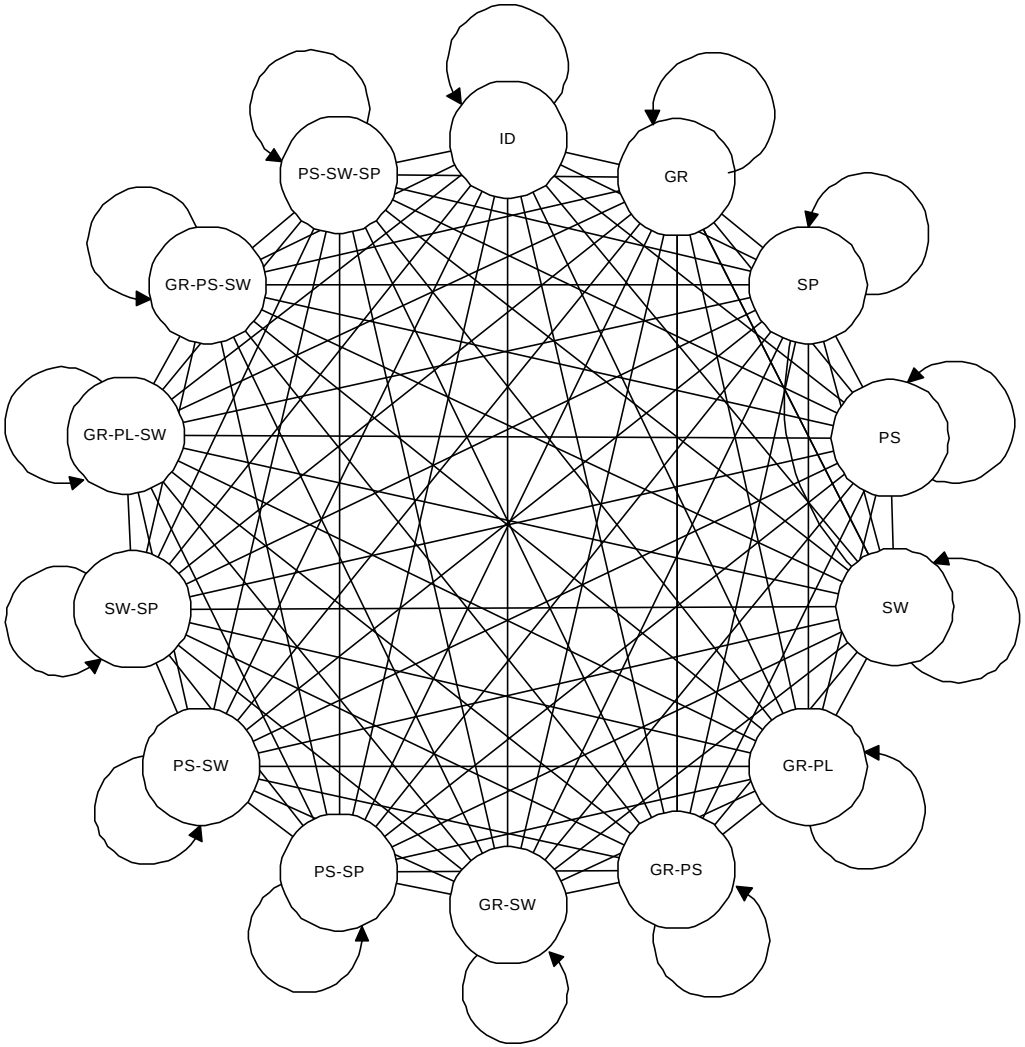
| Type | State Name | State Acronym | Force / Torque | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Fx | Fy | Fz | Tx | Ty | Tz | Fg |
| *I* | Idle | ID | * | * | * | * | * | * | * |
| | Grasping | GR | | | | | | | + |
| | Spreading | SP | | | | | | | - |
| | Pushing | PS | | | - | | | | |
| | Sweeping | SW | +/- | +/- | | +/- | +/- | | |
| *II* | Grasping - Pulling | GR-PL | | | + | | | | + |
| | Grasping - Pushing | GR-PS | | | - | | | | + |
| | Grasping - Sweeping | GR-SW | +/- | +/- | | +/- | +/- | | + |
| | Pushing - Spreading | PS-SP | | | - | | | | - |
| | Pushing - Sweeping | PS-SW | +/- | +/- | - | +/- | +/- | | |
| | Sweeping - Spreading | SW-SP | +/- | +/- | | +/- | +/- | | - |
| *III* | Grasping - Pulling - Sweeping | GR-PL-SW | +/- | +/- | + | +/- | +/- | | + |
| | Grasping -Pushing - Sweeping | GR-PS-SW | +/- | +/- | - | +/- | +/- | | + |
| | Pushing - Sweeping - Spreading | PS-SW-SP | +/- | +/- | - | +/- | +/- | | - |

# Tool/Tissue Interactions (Video Clip)

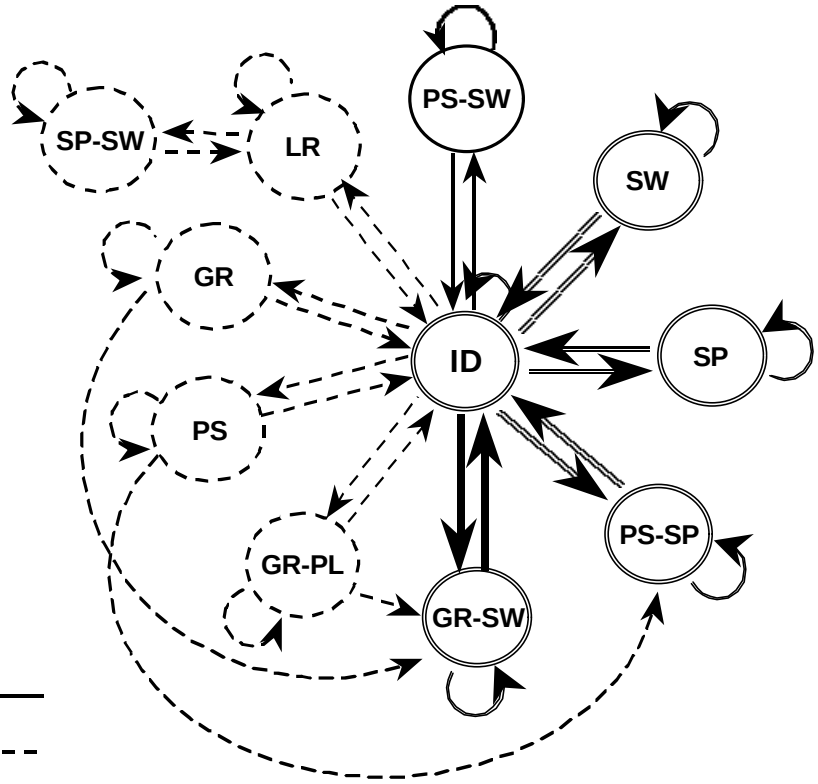



S_GR_PS_SW

# Generalized HMM of Surgery



# Laparoscopic Cholecystectomy
# Exposure of Cystic Duct (2/4)

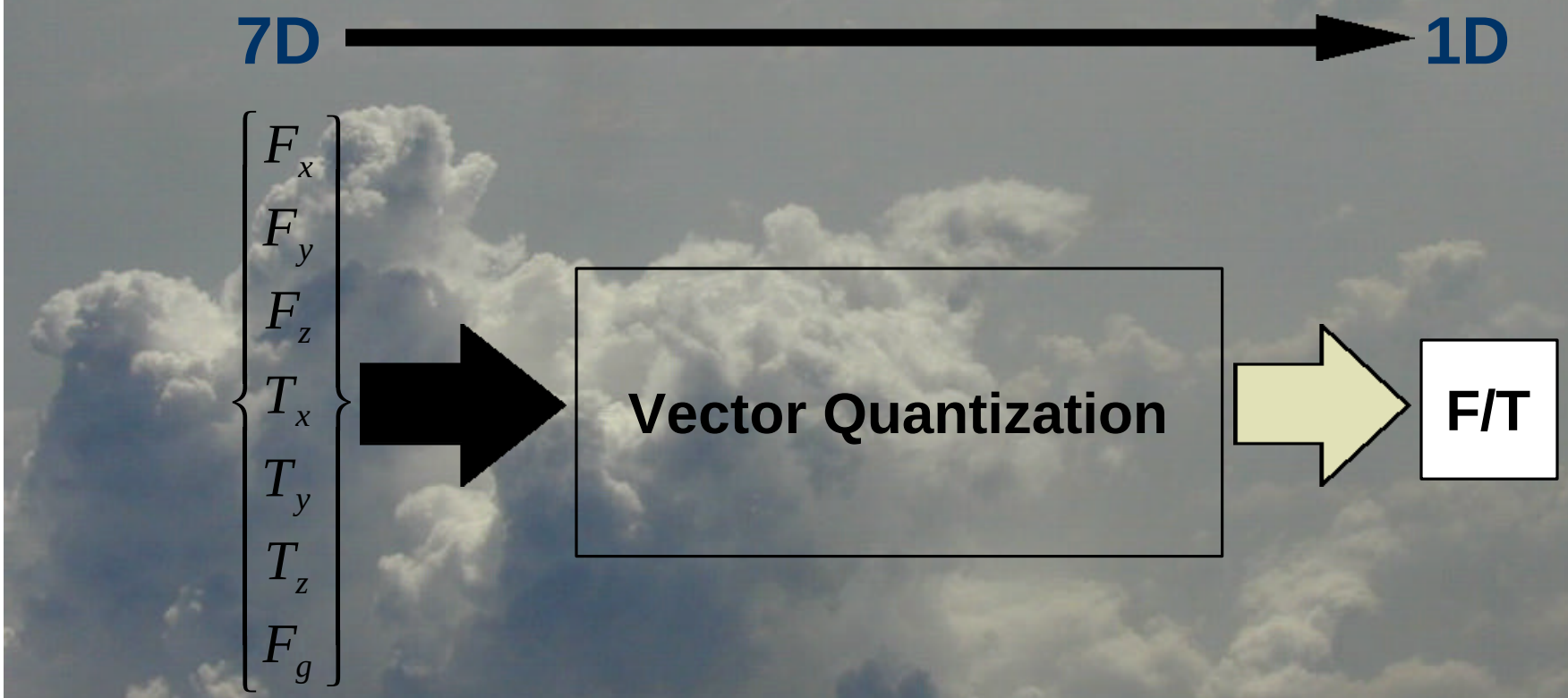



Surgeon ——
Non - Surgeon - - - - -
Both ═══

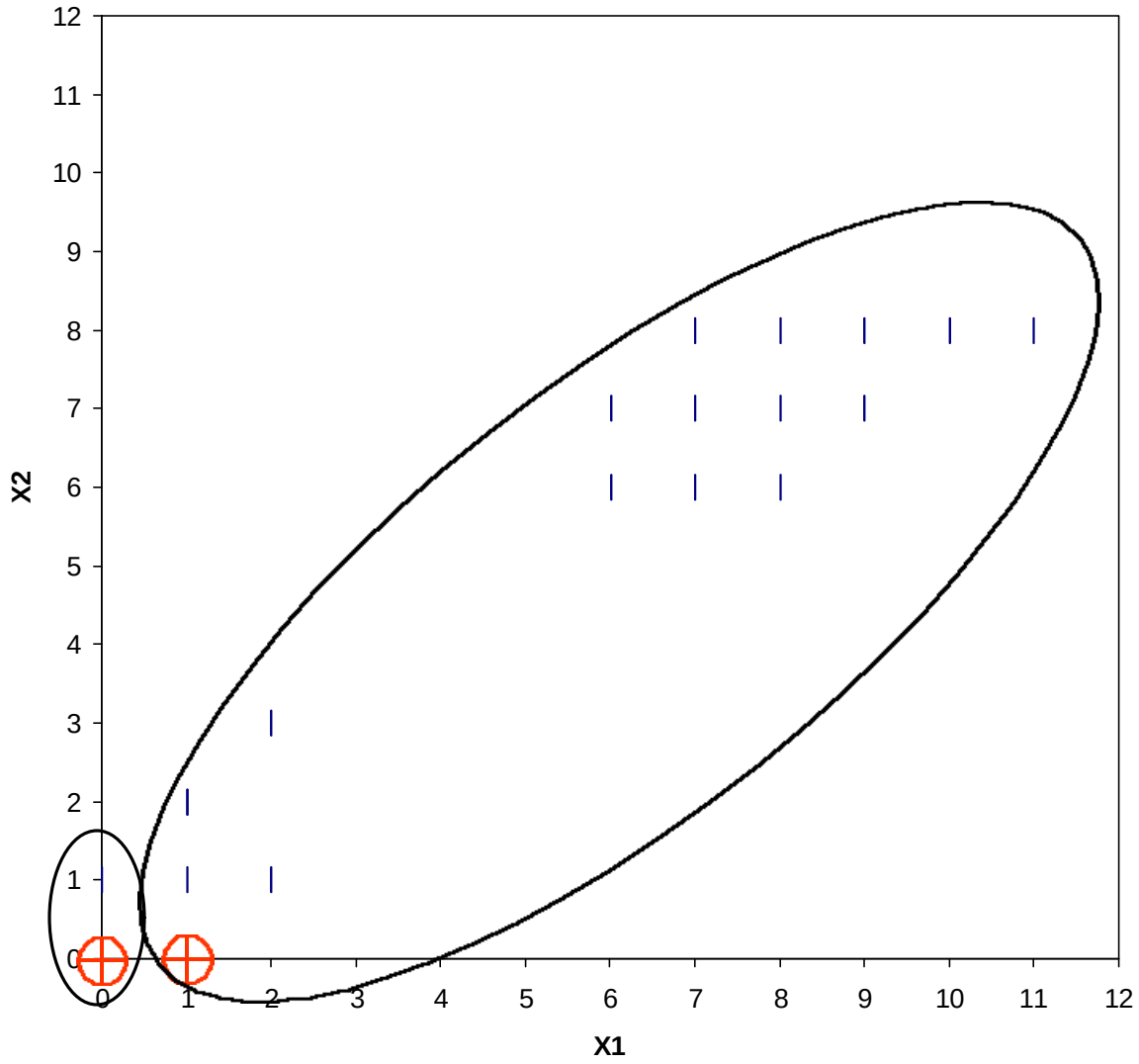


UW

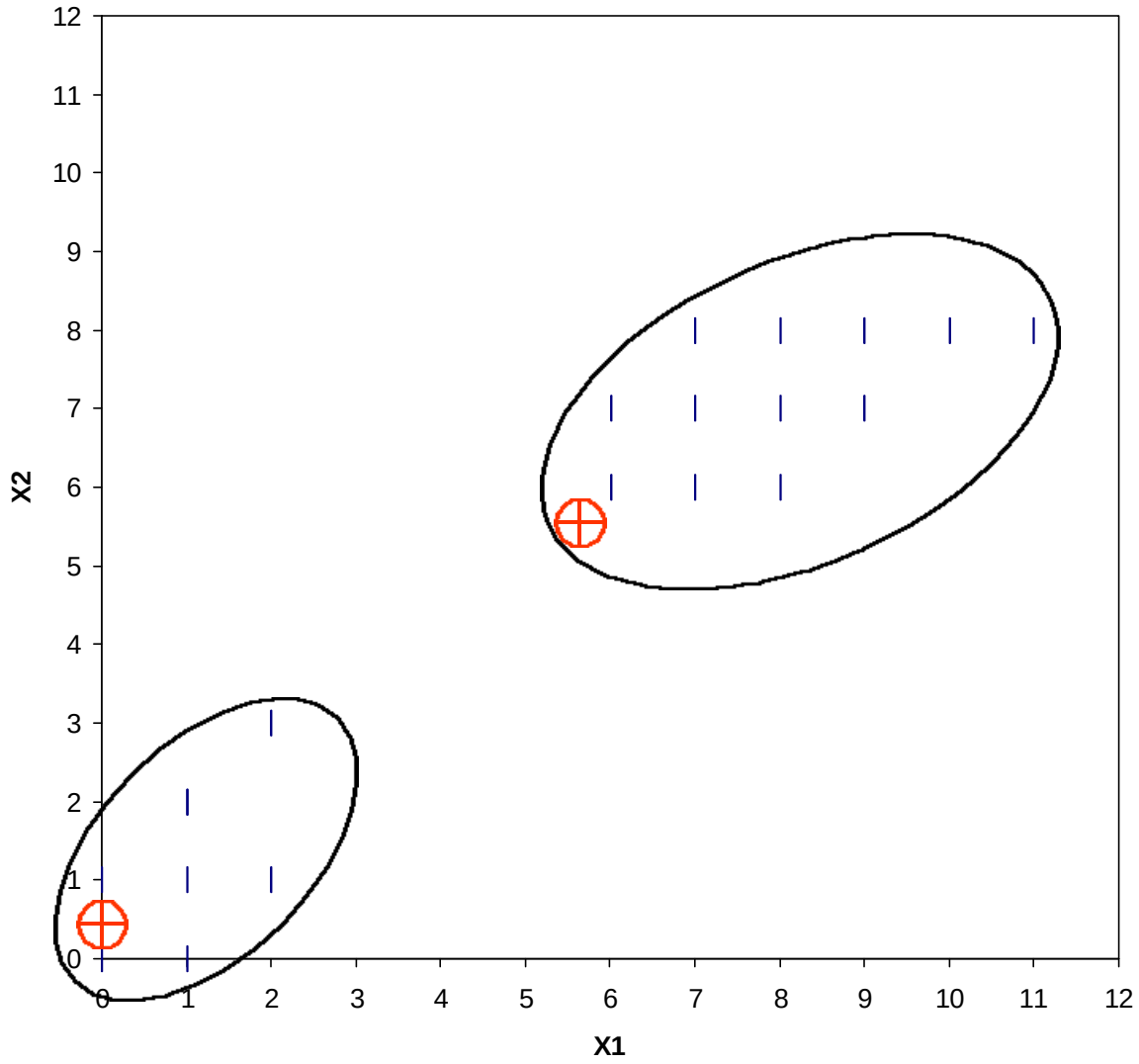
# Data Reduction



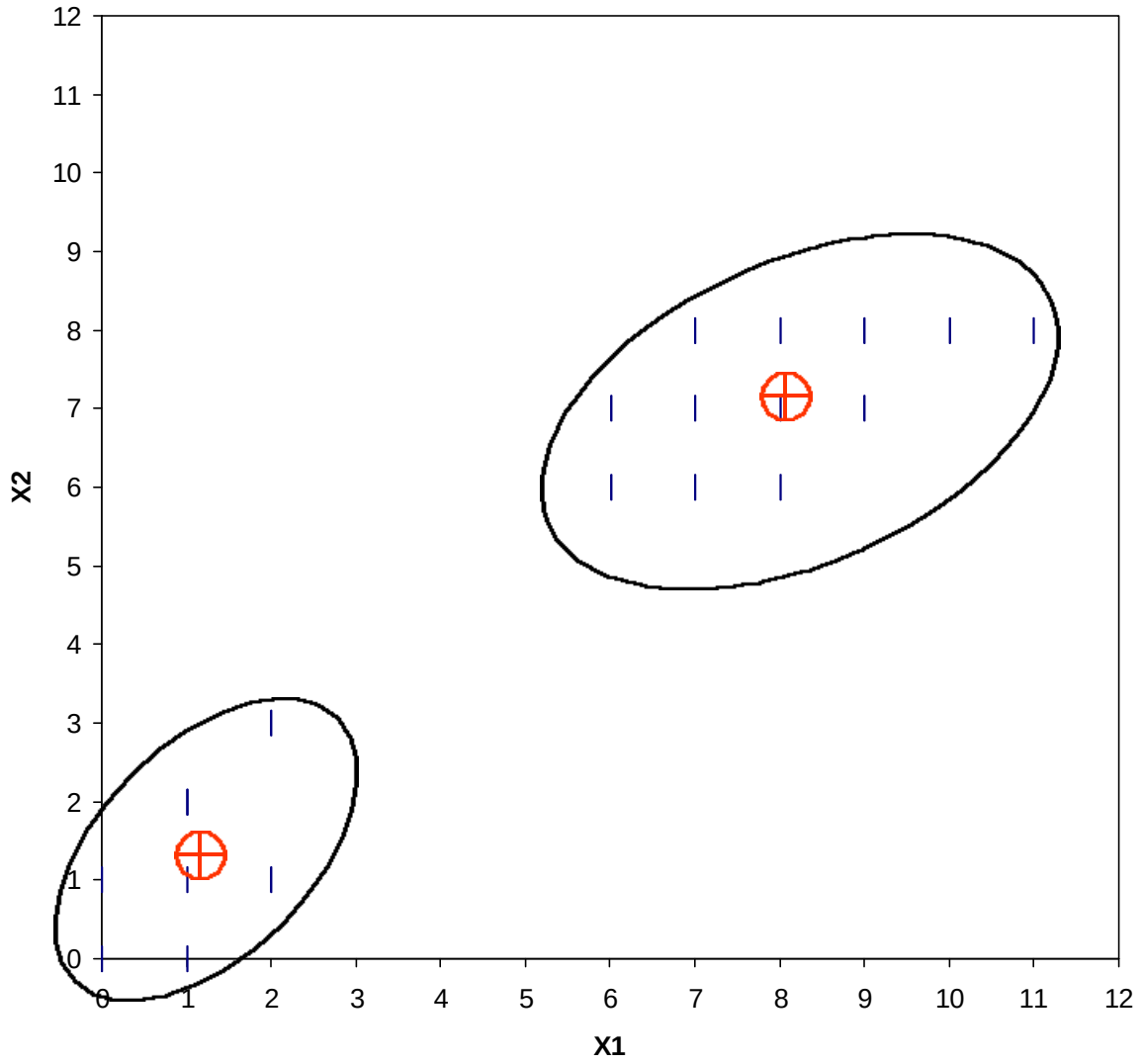
# Vector Quantization (VQ) - Step 1



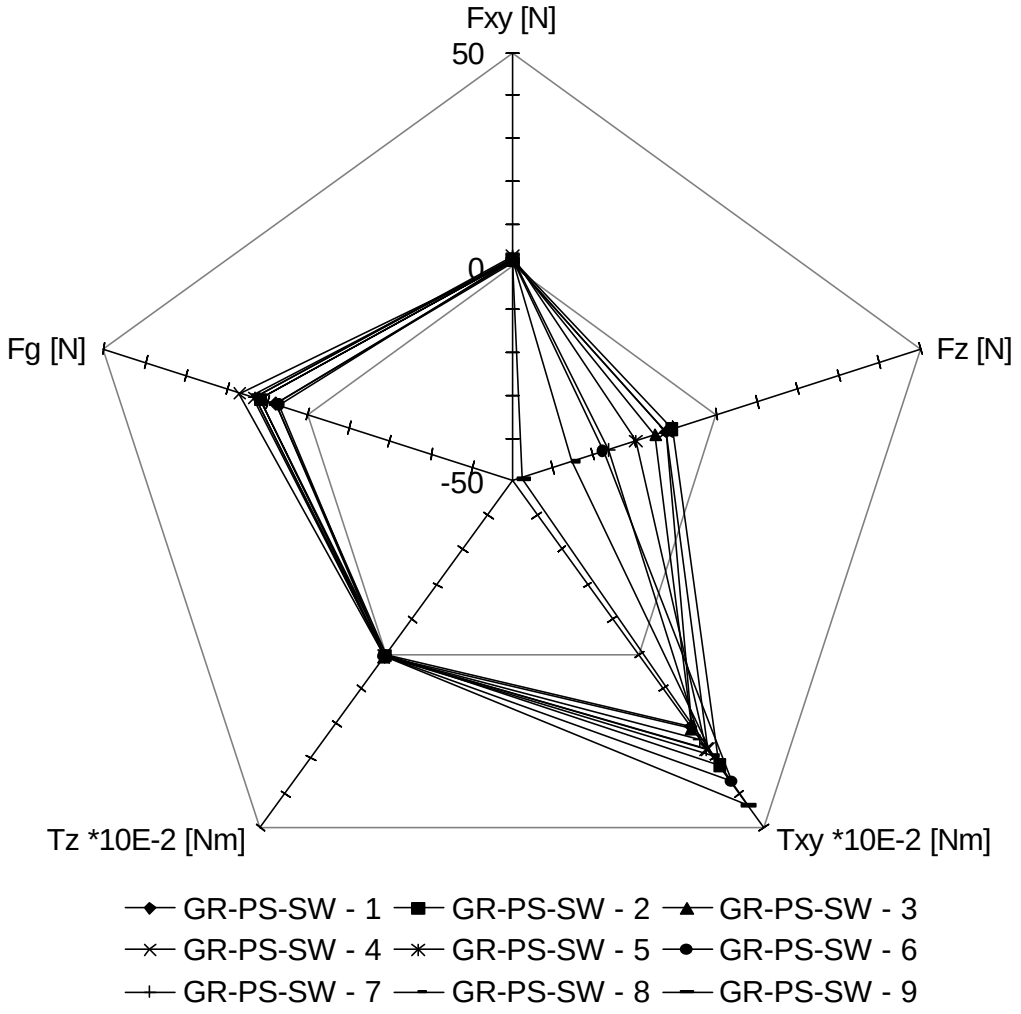
# Vector Quantization (VQ) - Step 2



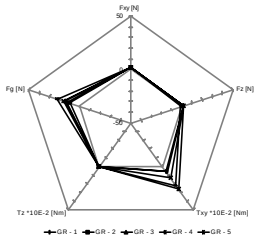
# Vector Quantization (VQ) - Step 3

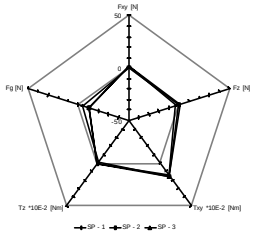


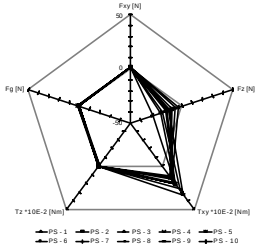
# F/T Clusters

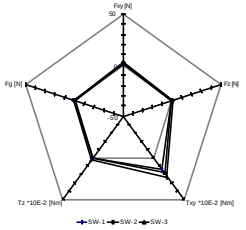

Fxy [N]
50
0
-50
Fg [N]
Fz [N]
Tz *10E-2 [Nm]
Txy *10E-2 [Nm]
GR-PS-SW - 1
GR-PS-SW - 2
GR-PS-SW - 3
GR-PS-SW - 4
GR-PS-SW - 5
GR-PS-SW - 6
GR-PS-SW - 7
GR-PS-SW - 8
GR-PS-SW - 9

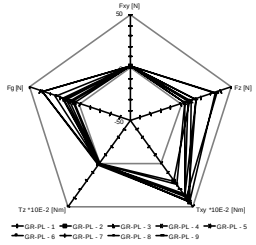
# F/T Clusters (Code Book) - 87

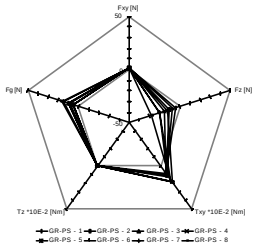


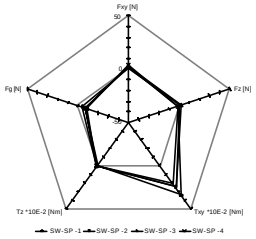



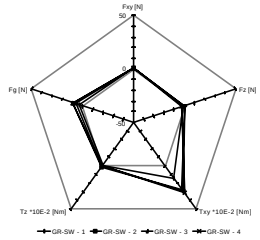



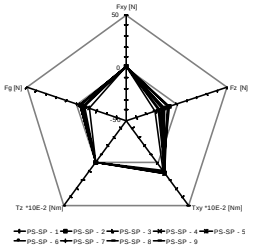



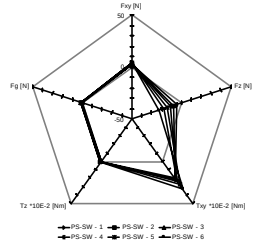



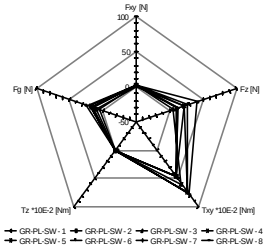



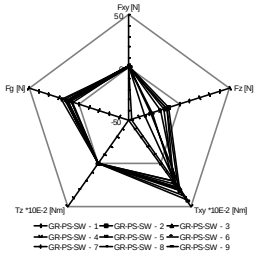



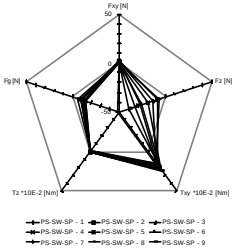



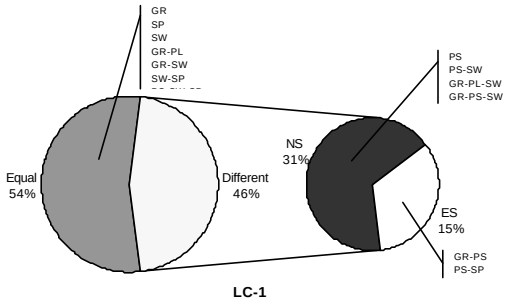



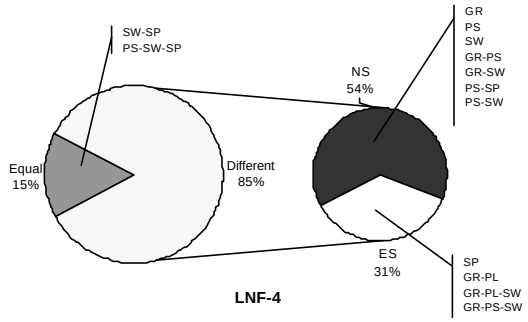



# Distributions of Clusters

## Tissue Manipulation

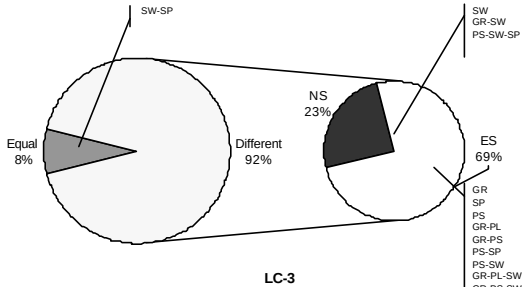



LC-1

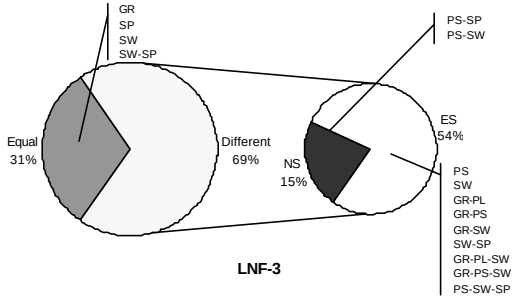



LNF-4

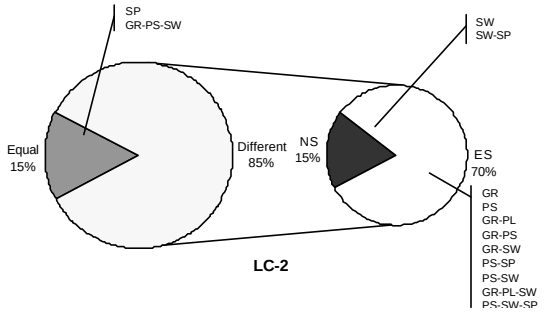
## Tissue Dissection




LC-3

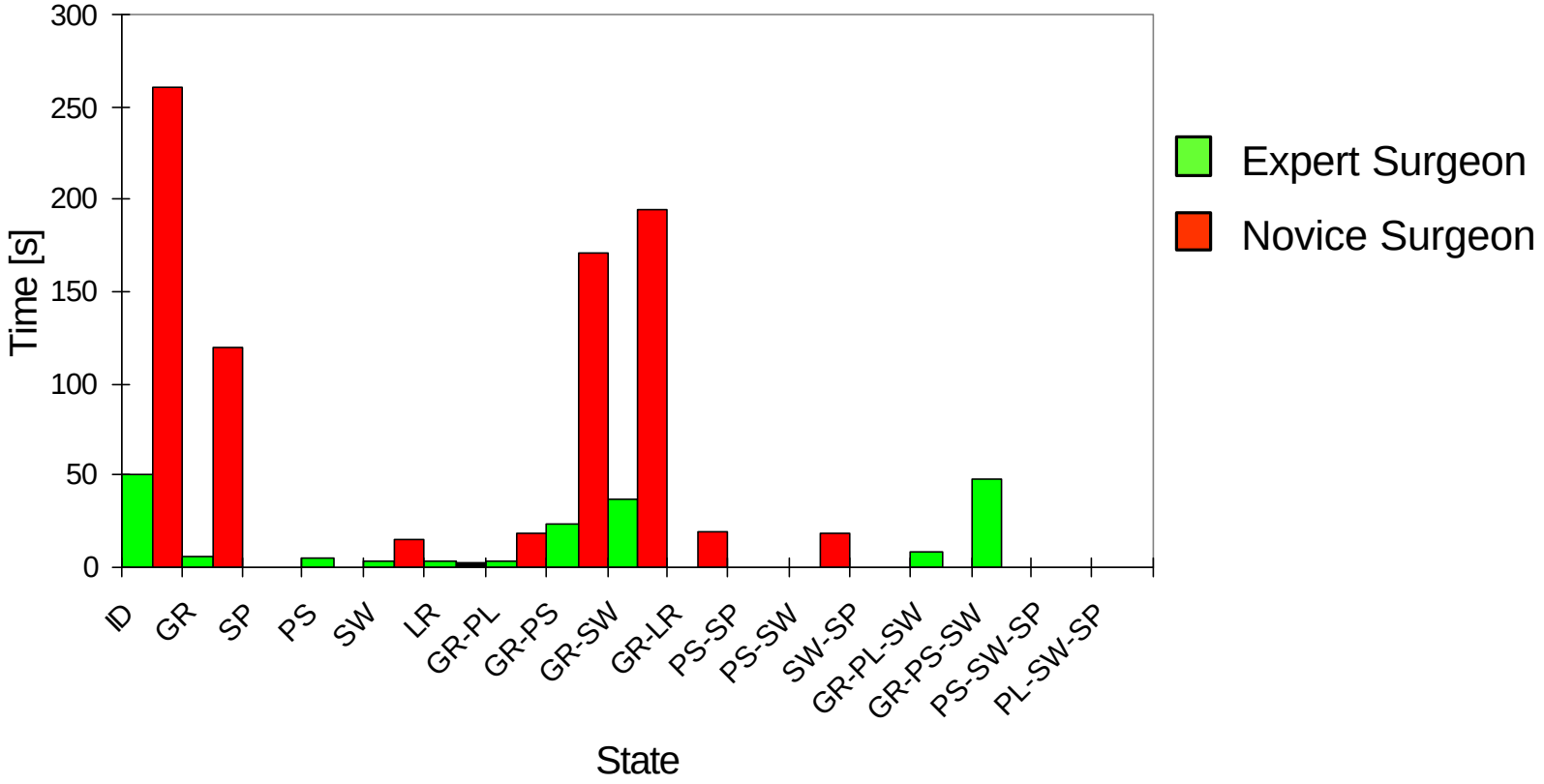



LNF-3

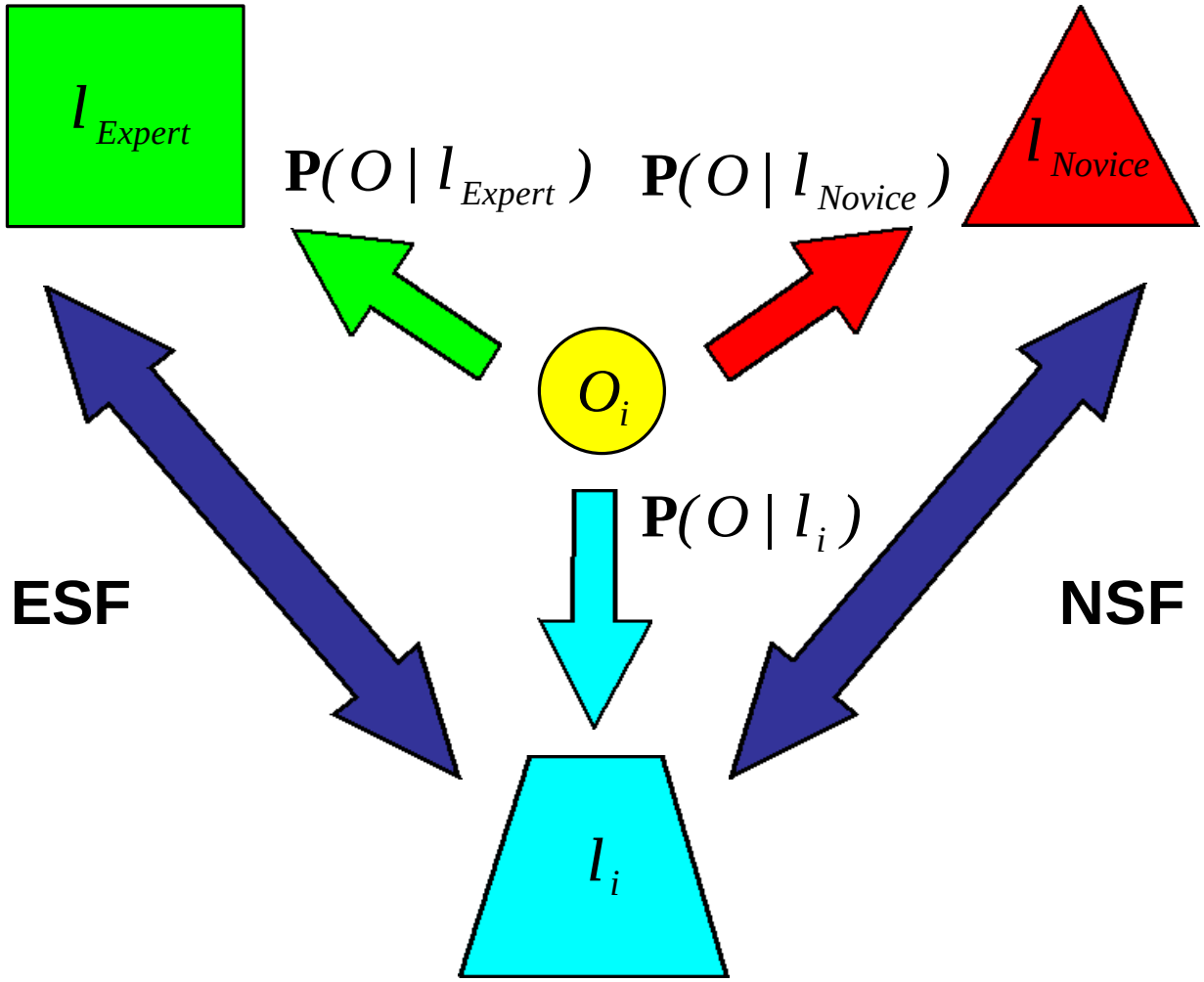



LC-2

# State Analysis - Time Sharing in States



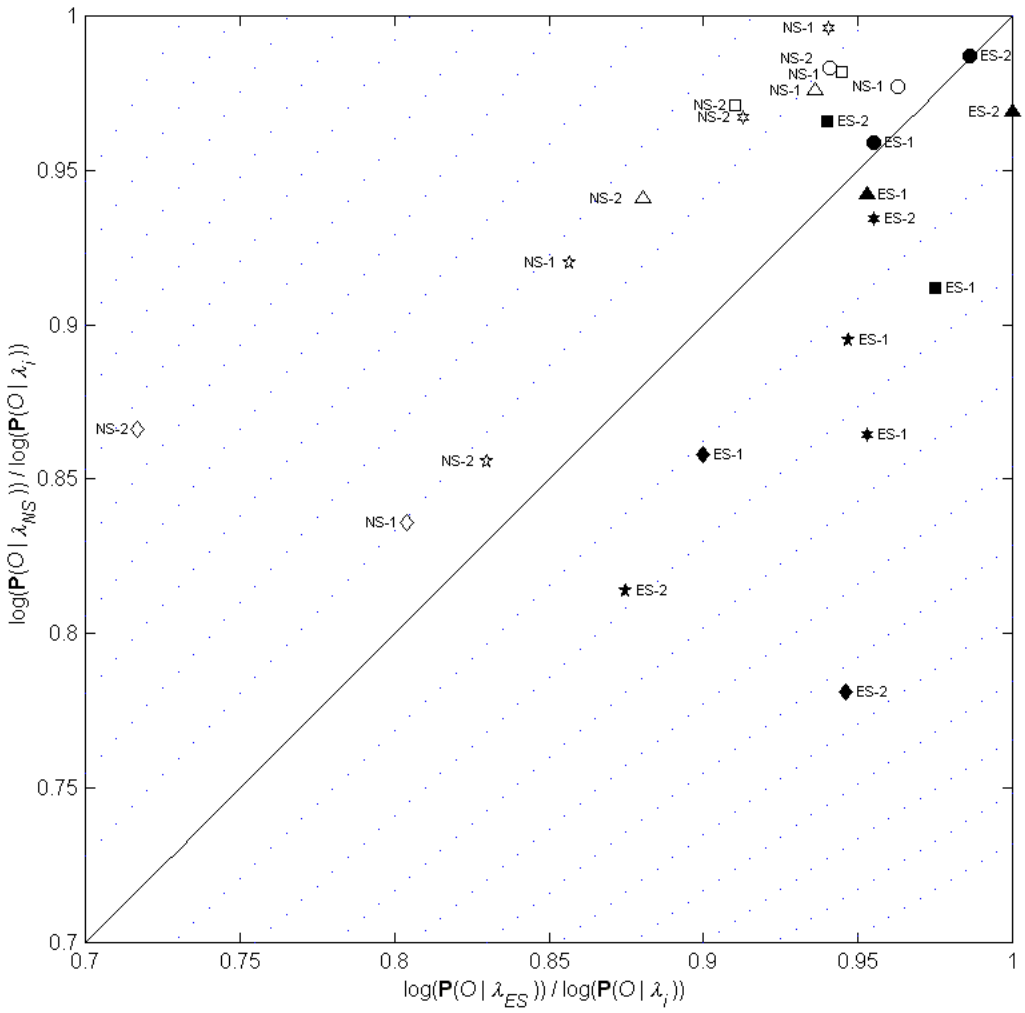

# Markov Model - Performance Scale



# HMM Classification

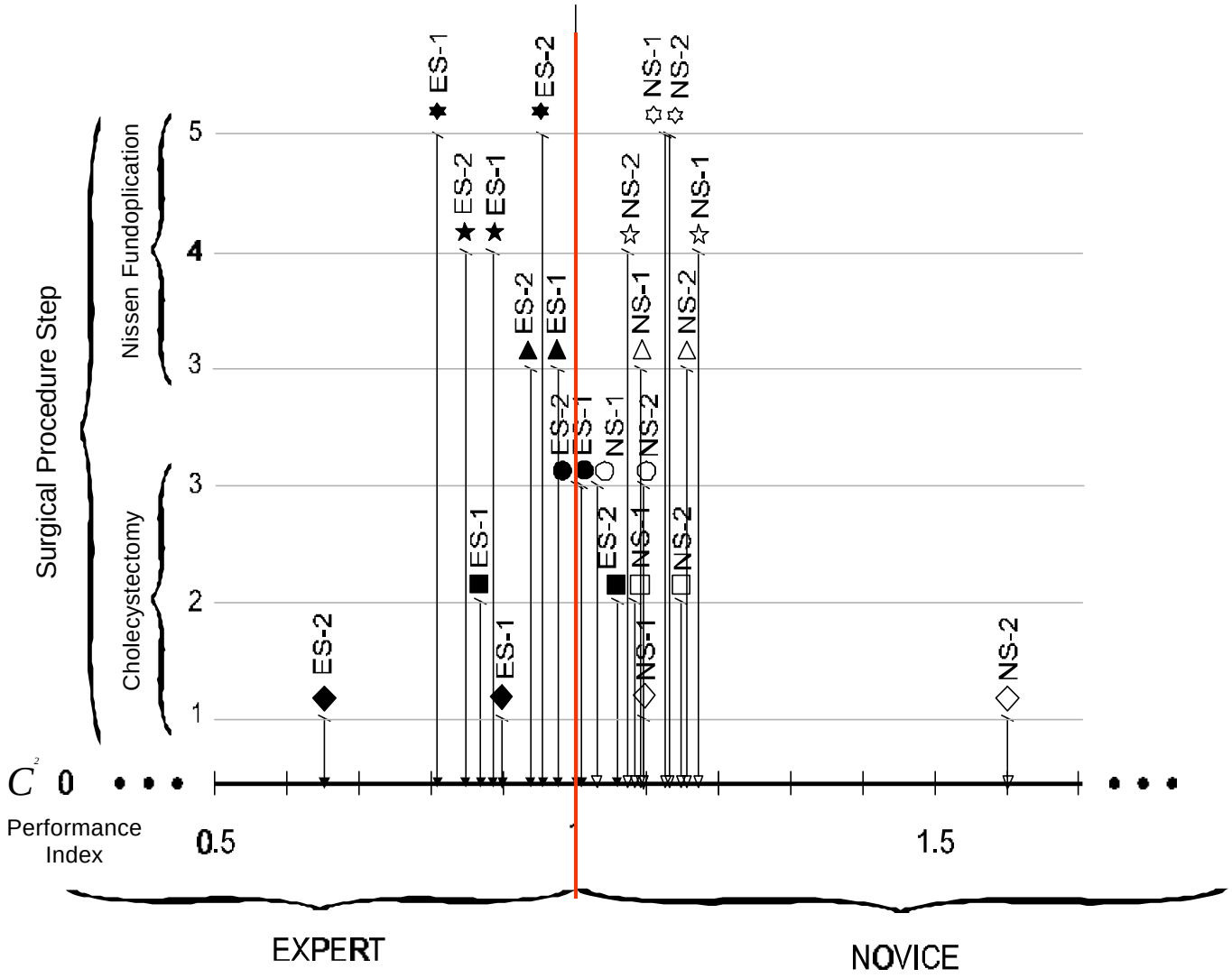
**Novice (0,1)**

$$C^2 = \{ d((NSF_i, ESF_i),(0,1)) / d((NSF_i, ESF_i),(1,0)) \}^2$$

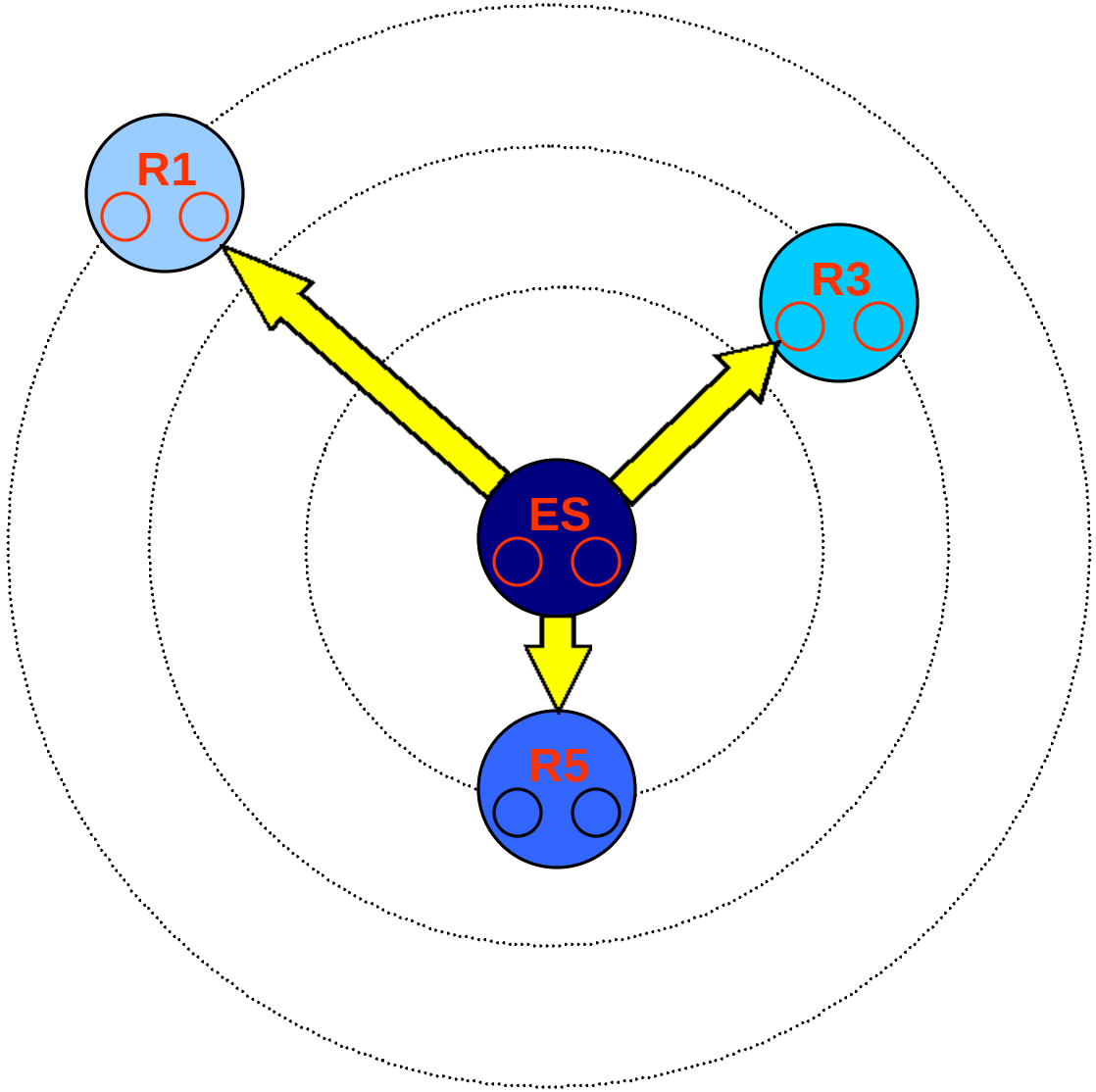



**Expert (1,0)**

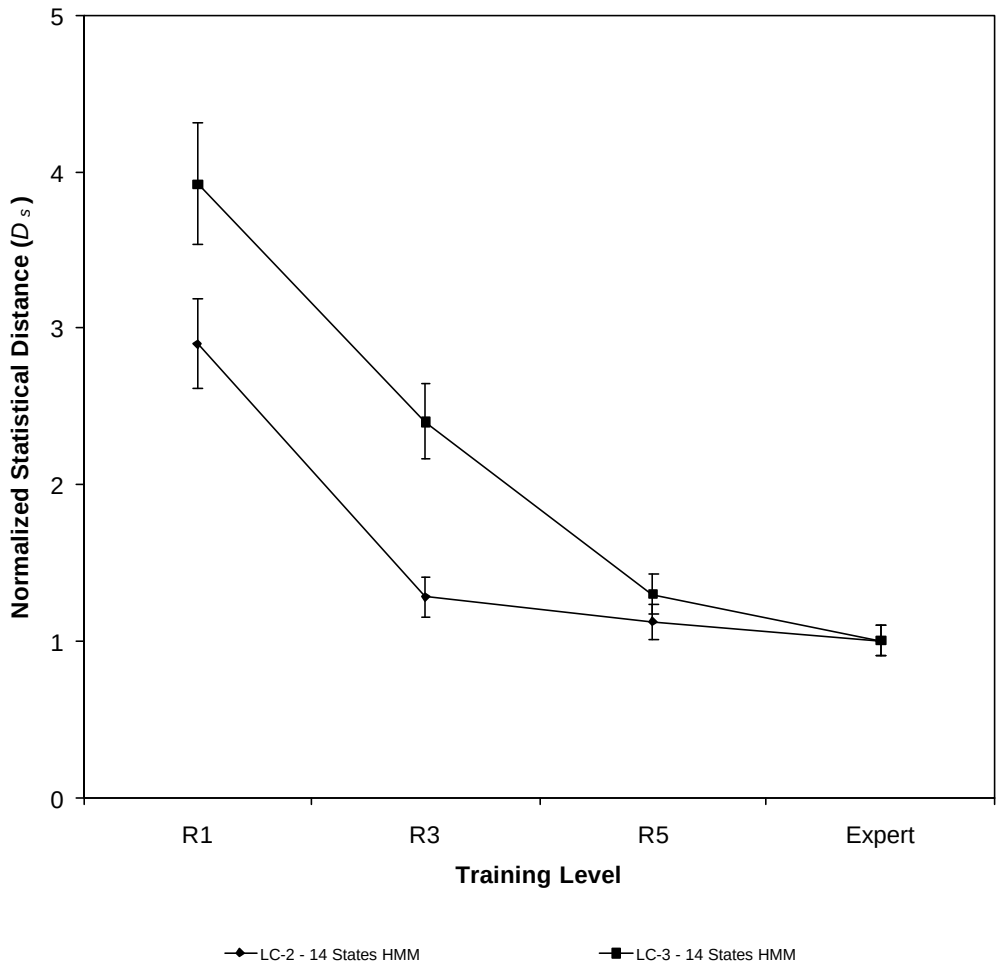
# HMM Classification



# Learning Curve of Surgical Residents - Method



# Learning Curve of Surgical Residents - Results



# Conclusions

- **Analyzing Minimally invasive surgery requires a synthesis between visual and haptic information.**

- **Differences between expert and novice surgeons can be defined in terms of:**
  - **Force/Torque signatures**
  - **State transitions**
  - **Time spent in each state**

# Application

- **Visual and haptic information Combined into a Hidden Markov Model may be used as an objective criterion or an index of performance.**

- **Potential applications - evaluating the performance of**
  - **Student performing MIS**
  - **Master/slave robotic system for teleoperation**
  - **Haptic device for virtual reality simulations.**

# BioRobotics Lab - University of Washington

# http://rcs.ee.washington.edu/brl/

**http://brl.ee.washington.edu/reports/papers/Rep136.html**


**Contact Information**

Jacob Rosen

University of Washington, EE Dept., Box 352500

Seattle, WA, 98195-2500

Phone: 206-616-4936

E-mail: rosen@rcs.ee.washington.edu

# References


## HMM -Tutorial

- Rabiner L.R., a Tutorial on hidden Markov models and selected application in speech recognition, Proceedings of the IEEE, Vol. 77, No. 2, Feb 1989.

## Tool/Tissue Interaction

- Rosen J., B. Hannaford, M. MacFarlane, M. Sinanan, Force Controlled and Teleoperated Endoscopic Grasper for Minimally Invasive Surgery - Experimental Performance Evaluation, IEEE Transactions on Biomedical Engineering, Vol. 46, No. 10, pp. 1212-1221, October 1999.
- MacFarlane M., J. Rosen, B. Hannaford, C. Pellegrini, M. Sinanan, Force Feedback Grasper Helps Restore the Sense of Touch in Minimally Invasive Surgery, Journal of Gastrointestinal Surgery, Vol. 3, No. 3, pp. 278-285, May/June 1999.

## HMM & Surgery

- Richards C., J. Rosen, B. Hannaford, M. MacFarlane, C. Pellegrini, M. Sinanan, Skills Evaluation in Minimally Invasive Surgery Using Force/Torque Signatures, Surgical Endoscopy, Vol 14, No. 9, pp. 791-798.
- Rosen J., C. Richards, B. Hannaford, M. Sinanan, Hidden Markov Models of Minimally Invasive Surgery, Studies in Health Technology and Informatics - Medicine Meets Virtual Reality, Vol. 70 pp. 279-285, January 2000.
- Rosen J., M. Solazzo, B. Hannaford, M. Sinanan , Objective Laparoscopic Skills Assessments of Surgical Residents Using Hidden Markov Models Based on Haptic Information and Tool/Tissue Interactions, Studies in Health Technology and Informatics - Medicine Meets Virtual Reality, January 2001.