Optimized Tissue Modeling

Computer Integrated Surgery II

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Team 10

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Introduction

- Accurately reconstruct a tissue/surface from finite number of force sensor palpation readings
  - Functional Geometry remodeling
    - : MSE ~1.17
  - Functional Stiffness remodeling
  - Combined geometry/stiffness remodeling
  - Optimal Palpation trajectory on unknown surface
- Potential application: guiding exploratory surgery
  - Accurate real time localization of tumors

The Problem

- How can we accurately reconstruct a surface without any assumptions on the underlying structure?
- How do we select the fewest number of points to perform this reconstruction?

The Solution

1. Create Gaussian Process (GP) algorithm to independently model both geometry and stiffness.
   - Use force sensor palpations to measure tissue height and stiffness
   - After each palpation, the two independent GP's will be updated in light of the new data
   - A GP modeling is achieved by sampling from a multivariate Gaussian distribution such that:

$$k(x,x') = \sigma_f^2 \exp\left[\frac{-(x-x')^2}{2l^2}\right] + \sigma_n^2\delta(x,x')$$

$$\begin{bmatrix} y \\ y_* \end{bmatrix} \sim \mathcal{N}\left[0, \begin{matrix} K & K_*^T \\ K_* & K_{**} \end{matrix}\right]$$

$$y_*|y \sim \mathcal{N}(K_*K^{-1}y, K_{**} - K_*K^{-1}K_*^T)$$

$$\overline{y*} = K_*K^{-1}y$$

$$var(y_*) = K_{**} - K_*K^{-1}K_*^T$$

Symbol	Meaning
y	Values from training points
y*	Values at test set inputs
K	Training set covariances
K*	Training-test set covariances
K**	Test set covariances
k(x,x')	Covariance element
ξ	Reference Point
$\tilde{x}$	Query Candidate

   - GP modeling is advantageo[us as each] predicted point has an associated confidence interval

2. Approaches taken to selecting the next point:
   - Randomly select nearby points to choose from based on these criteria:

   a) $\max(a * predicted\ mean + b * predicted\ variance)$

   b) $\max(predicted\ change\ in\ variance)$

   a) Dynamic Sampling Area

$$Interest\ Factor = \frac{|Boring - Previous|}{Max\ Difference} + Correction\ Factor$$

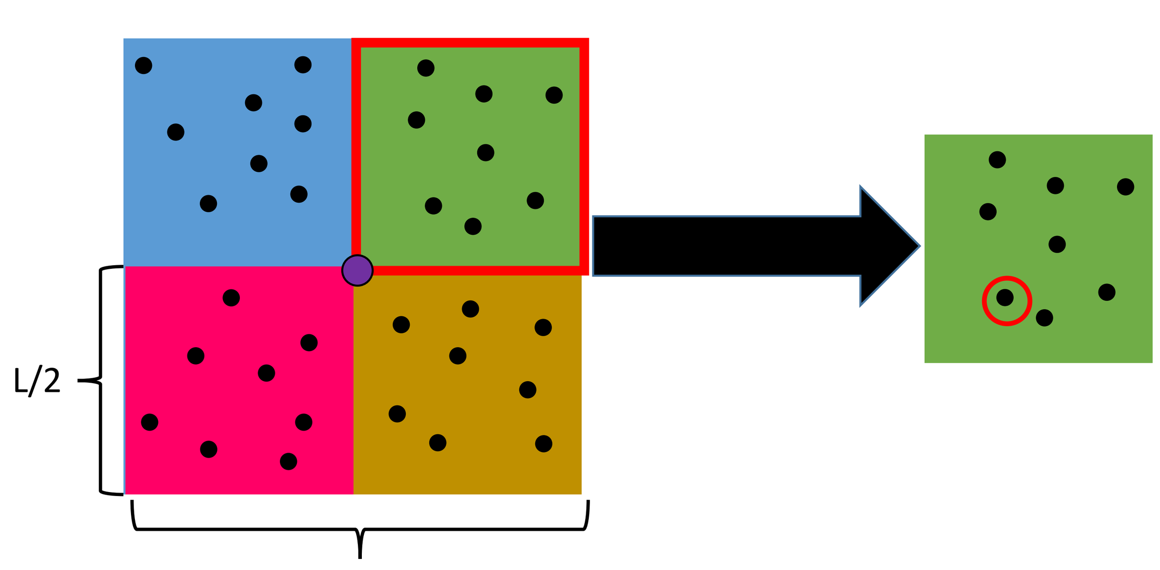
$$L = \frac{Minimum\ L}{Interest\ Factor}$$

   b) Predicted Change in Variance:

$$\Delta\sigma^2_{\overline{y(\xi)}}(\tilde{x}) = \frac{(K_N K^{-1} K_* - Cov(\tilde{x},\xi))^2}{(Cov(\tilde{x},\tilde{x}) - K_*^T K^{-1} K)}$$

$$K_N = [C(x_1,\xi), \ldots, C(x_N,\xi)]$$

   a) Quadseek



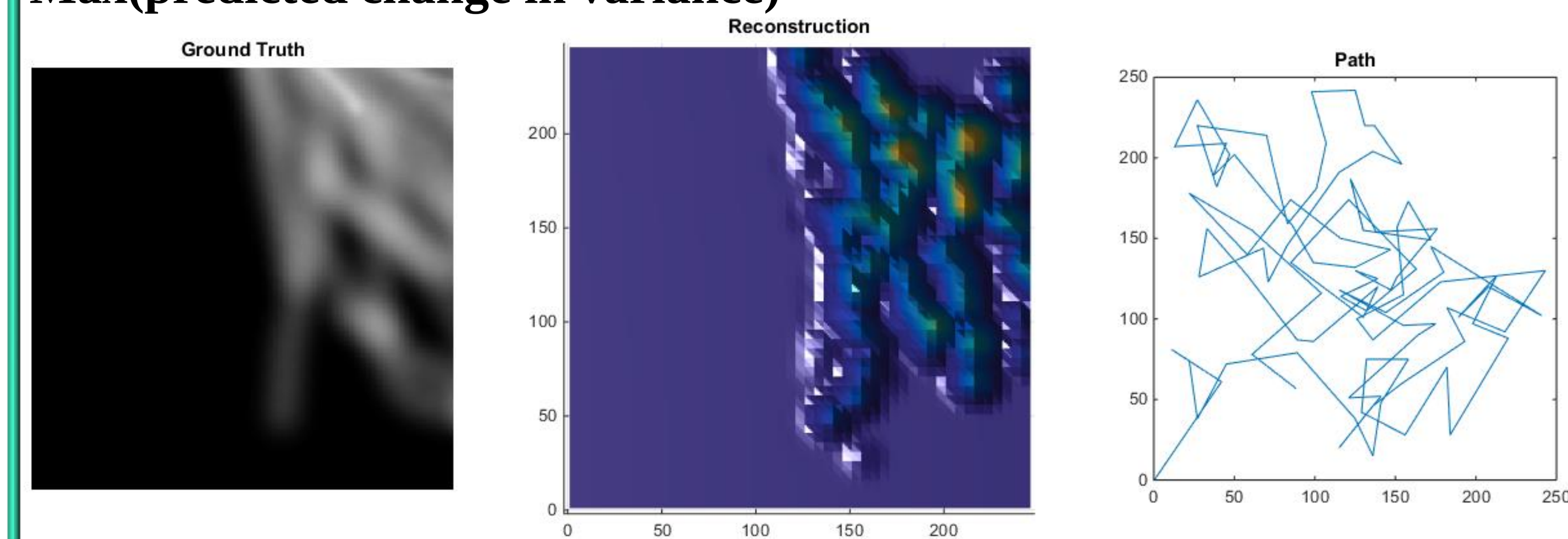
c) $$\max\left(a * \frac{Predicted\ Mean}{Previous\ Predicted\ Mean} + b * \frac{Predicted\ Variance}{Previous\ Predicted\ Mean}\right)$$

Lessons Learned

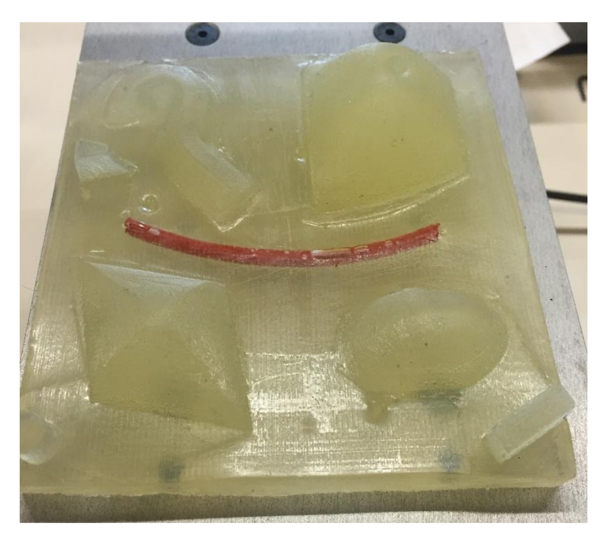
- While GPs are versatile, they do have their limits
- Adaptive searching is no small feat
- Algorithms that work well on simulated data may not perform perfectly in practice
- Reports are good for thinking.
- Procrastination is not good ☺

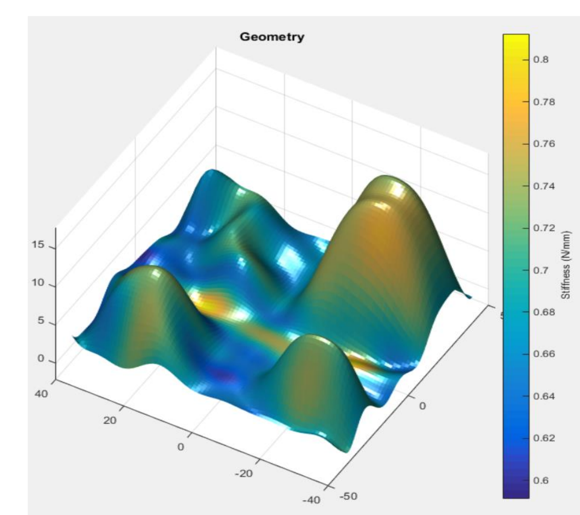
Outcomes and Results

Max(predicted change in variance)



Phantom | **Uniform (grid) Sampling**

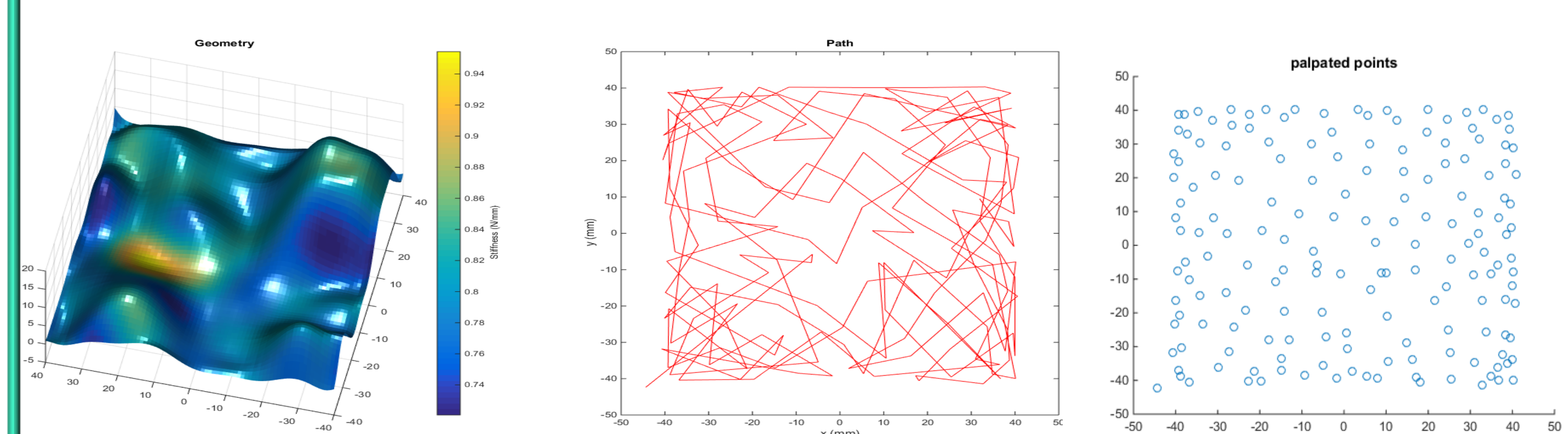




Num. points: 324 | **Geo. MSE:** .755

Adaptive Maximum Search: Height

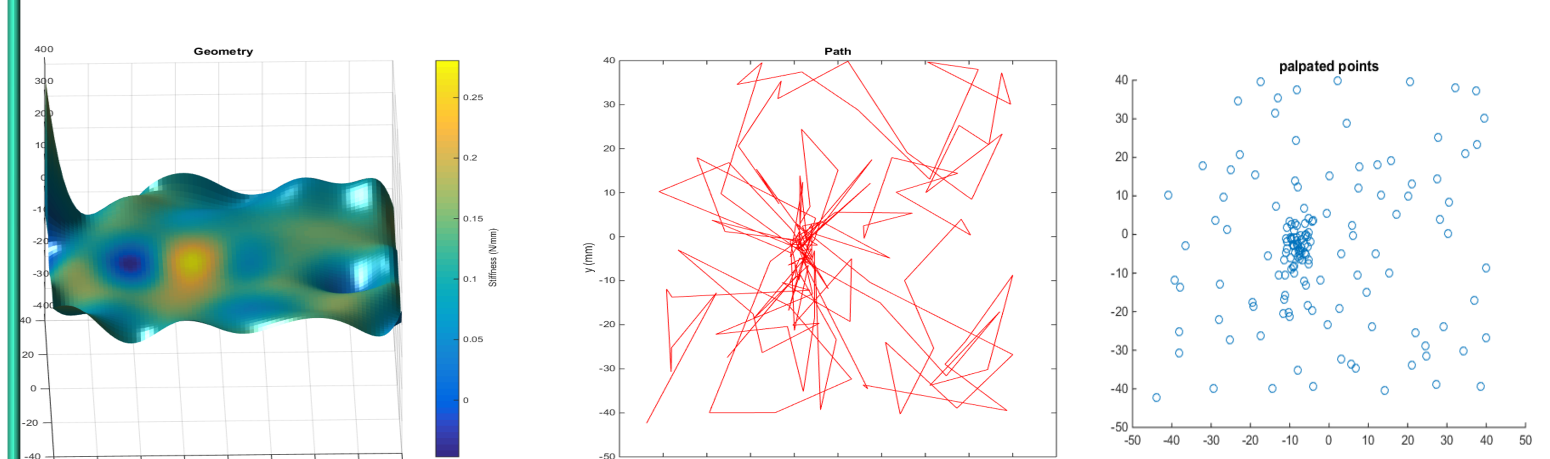
$$\max\left(\frac{Predicted\ Mean}{Previous\ Predicted\ Mean} + \frac{Predicted\ Variance}{Previous\ Predicted\ Mean}\right)$$



Geo. MSE: 1.17 **Num. points:** 150

Adaptive Maximum Search: Stiffness

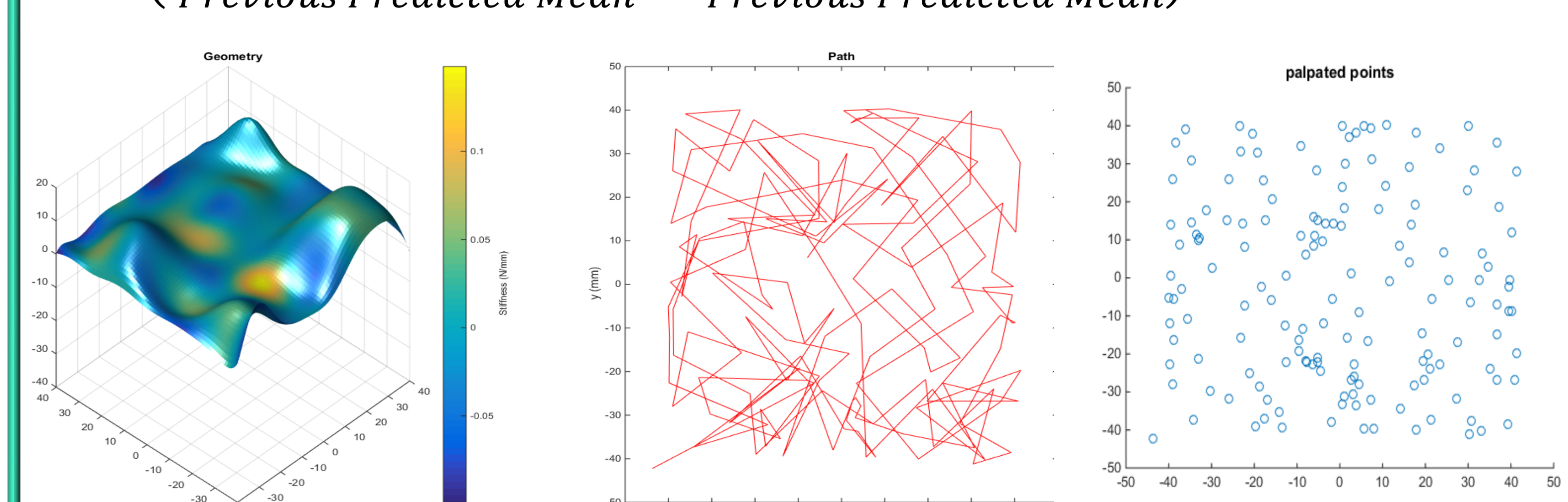
$$\max\left(\frac{Predicted\ Mean}{Previous\ Predicted\ Mean} + \frac{Predicted\ Variance}{Previous\ Predicted\ Mean}\right)$$



Geo. MSE: 17.84 **Num. points:** 150

Adaptive Maximum Search: Height + Stiffness

$$\max\left(\frac{Predicted\ Mean}{Previous\ Predicted\ Mean} + \frac{Predicted\ Variance}{Previous\ Predicted\ Mean}\right)$$



Geo. MSE: 2.54 **Num. points:** 150

Future Work

- Grid Initialization and Adaptive Grid Search
- Test on other stiffness distributions.
- Assume stiffness to be a non-linear model.
- GP with co-dependent outputs

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