



Robotic touch : looking at a surface through a frictionnal joint

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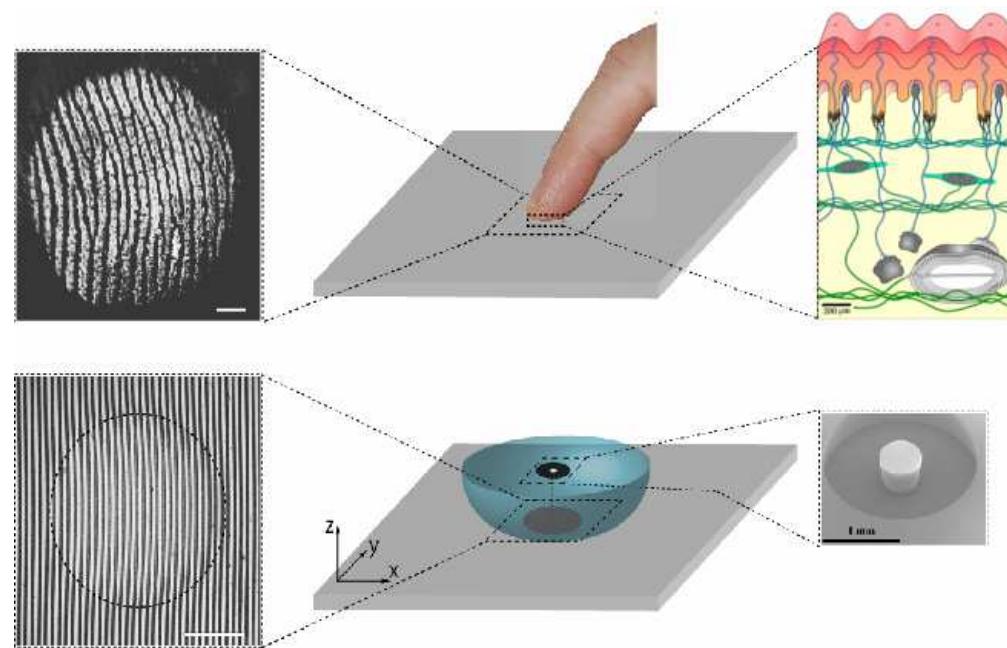
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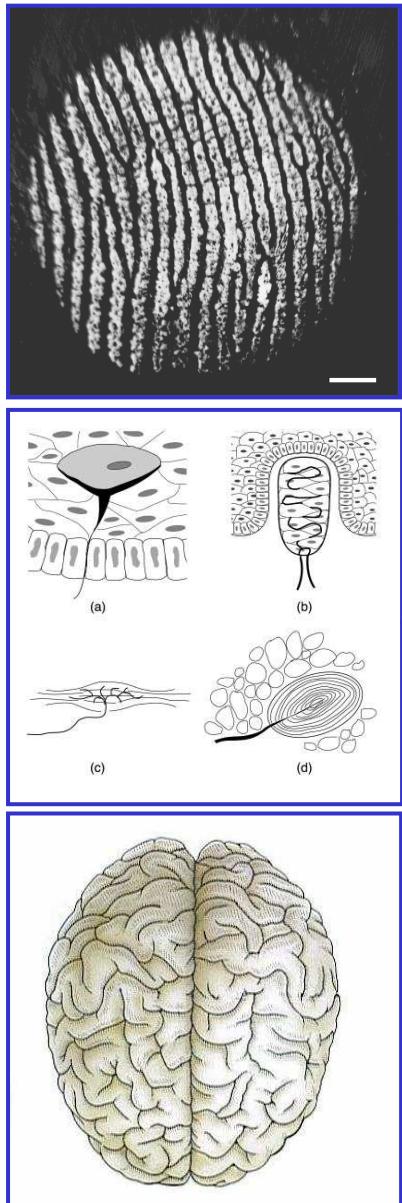


Patrice Rey (CEA-LETI)
Joël Frelat (LMM, Paris 6)



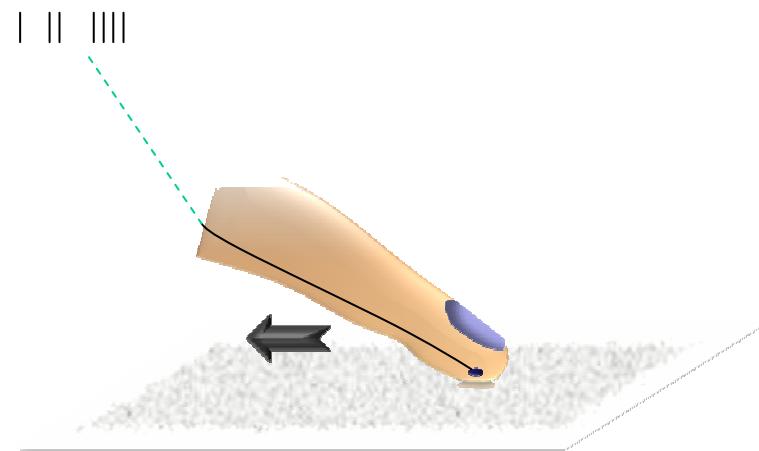


Information transduction in tactile perception

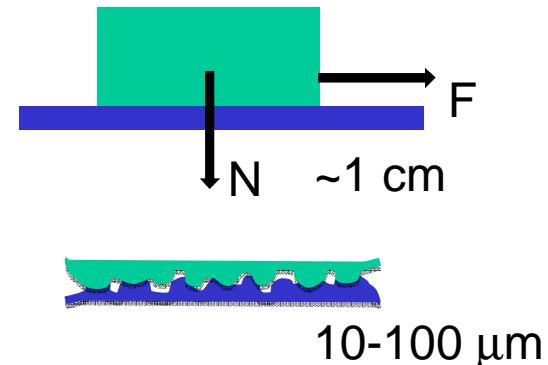




Friction joint as a communication interface



Extended frictionnal rough contact



Questions :

- 1 – How can one relate the physical properties of the object and exploratory conditions to the subcutaneous mechanical signals.
- 2 – What are the consequences of this filtering process on the transduction of tactile information.
- 3 – How to take this process into account in an inversion procedure.





Outline

1 – Biomimetic tactile sensing – design and calibration.

2 – Response to a single defect on a flat surface – effects of the exploratory conditions.

3 – Response to randomly rough substrates - A possible role for fingerprints.

5 – Conclusions and perspectives.





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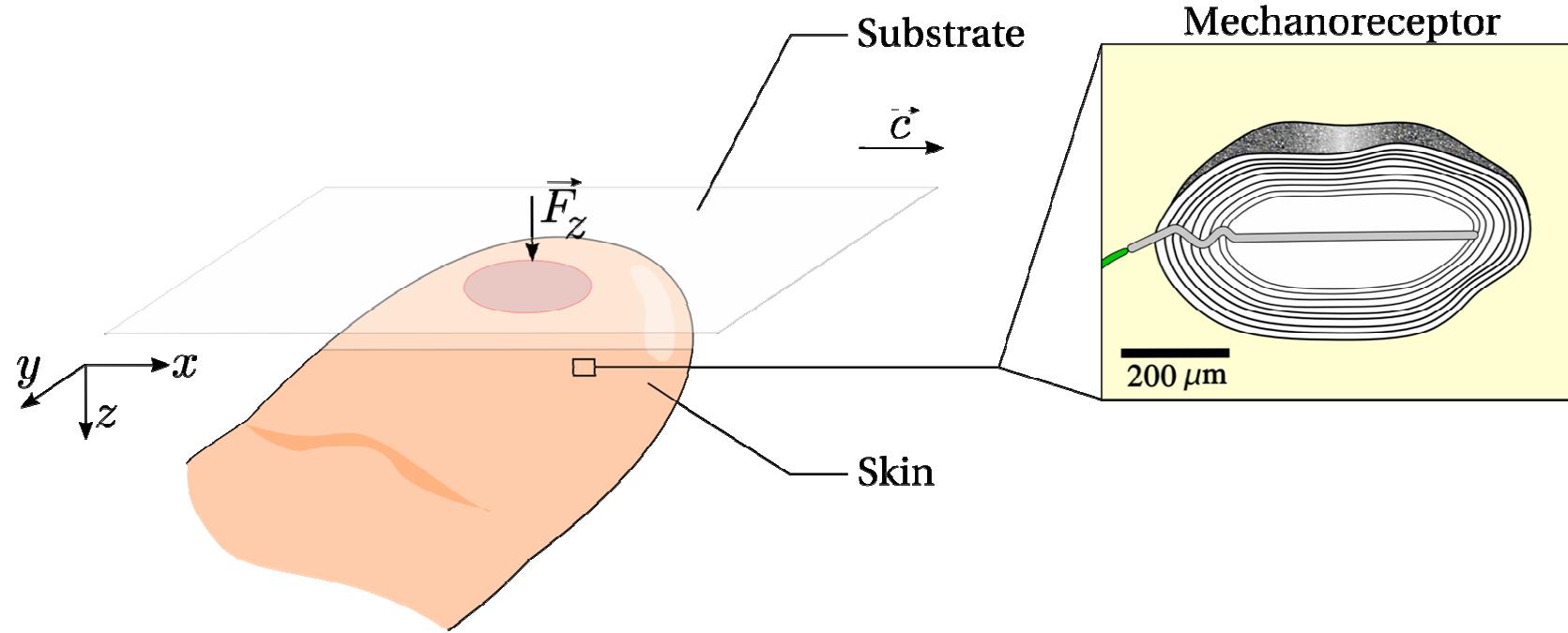
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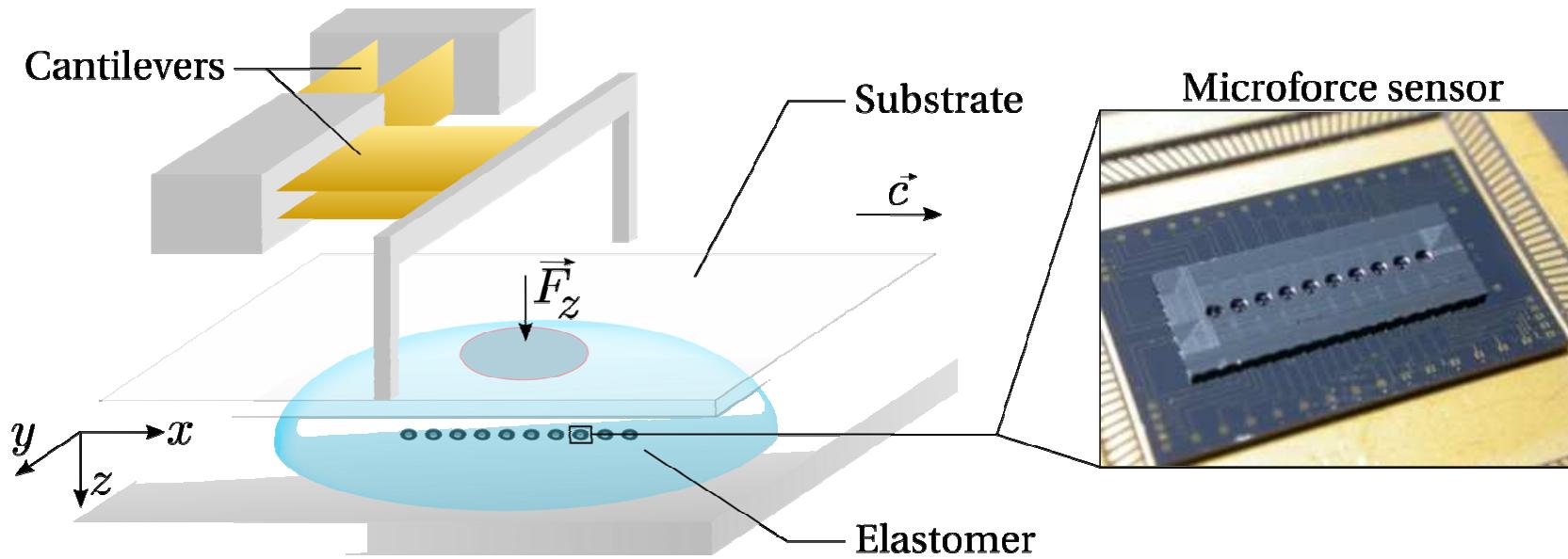


The biomimetic approach





The biomimetic approach

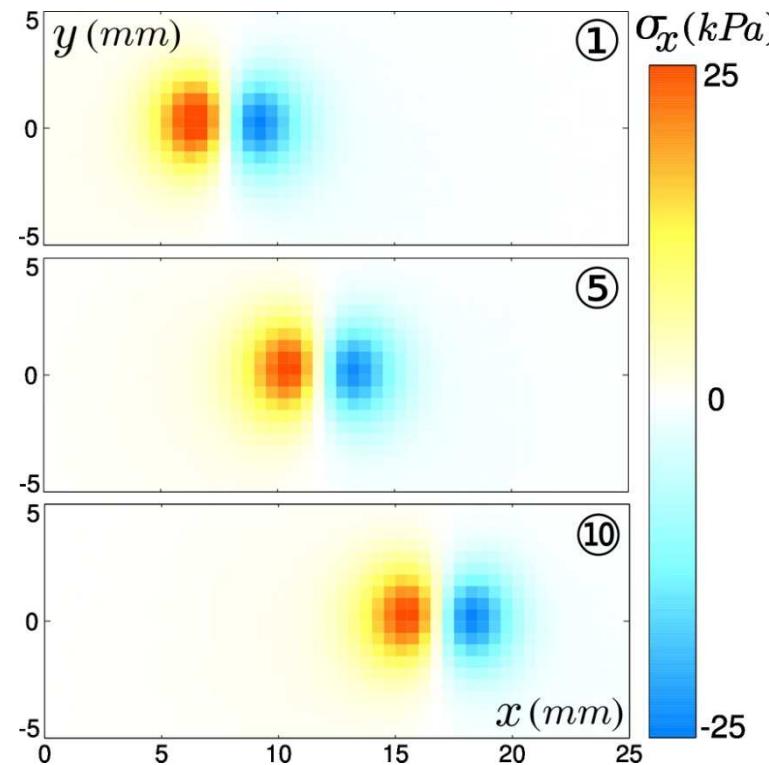
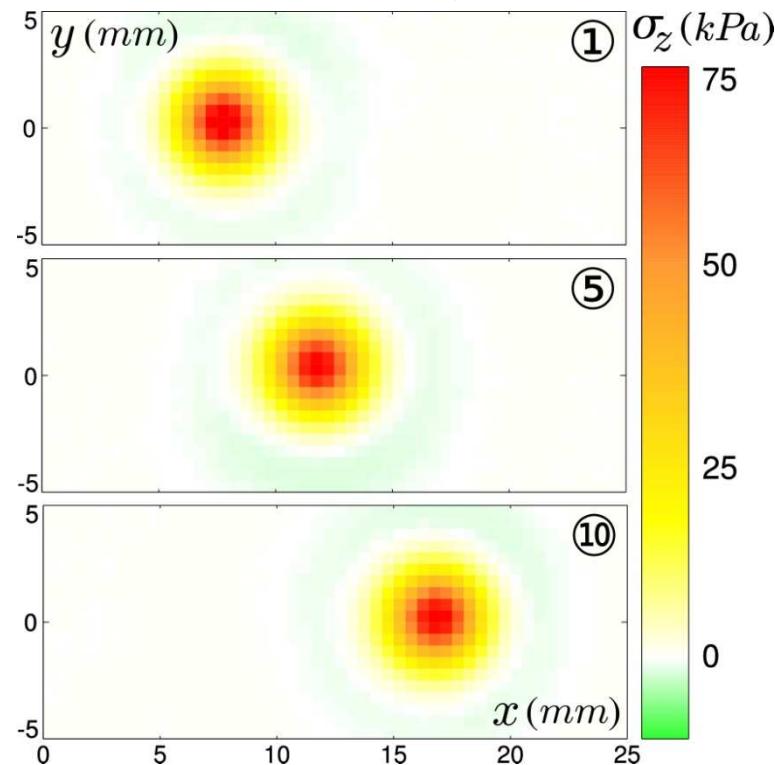
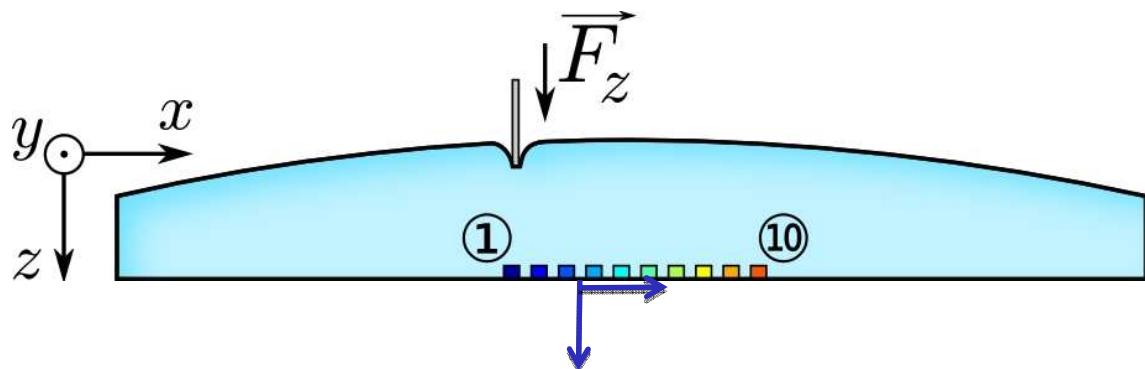


	Sensor depth	Sensitive area diameter	Contact diameter	Normal force	Skin elastic modulus
Human finger	~2 mm	0.5 – 1 mm	~10 mm	0.5 – 1 N	1 – 4 MPa
Artificial finger	3.0 mm	~1 mm	~5 mm	~1 N	~3 MPa





Calibration : Intrinsic Receptive Fields



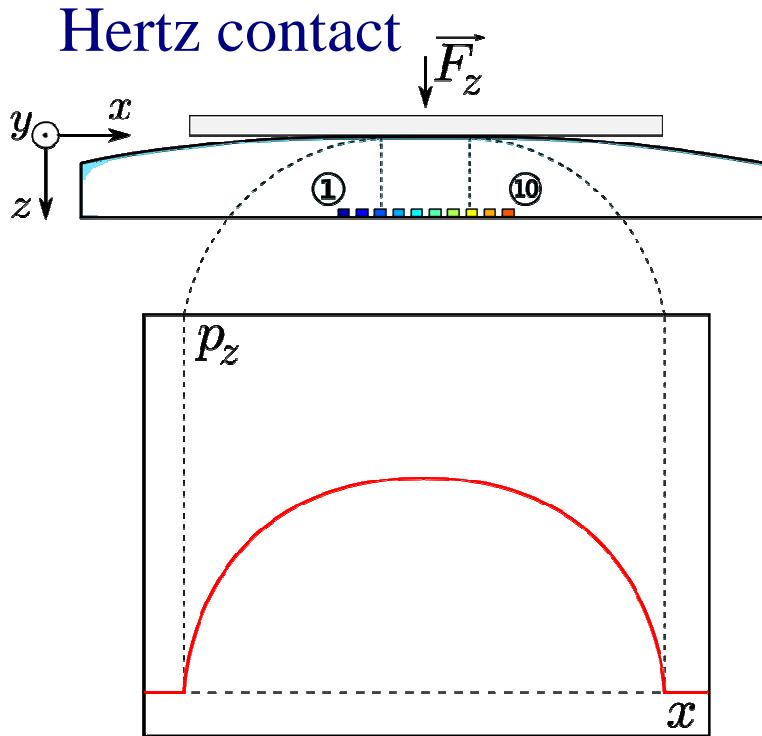
Indentation protocol:

Apply a punctual force \vec{F}_z at (x, y) on the surface with a $500\mu m$ rod.





Linear model of tactile transduction



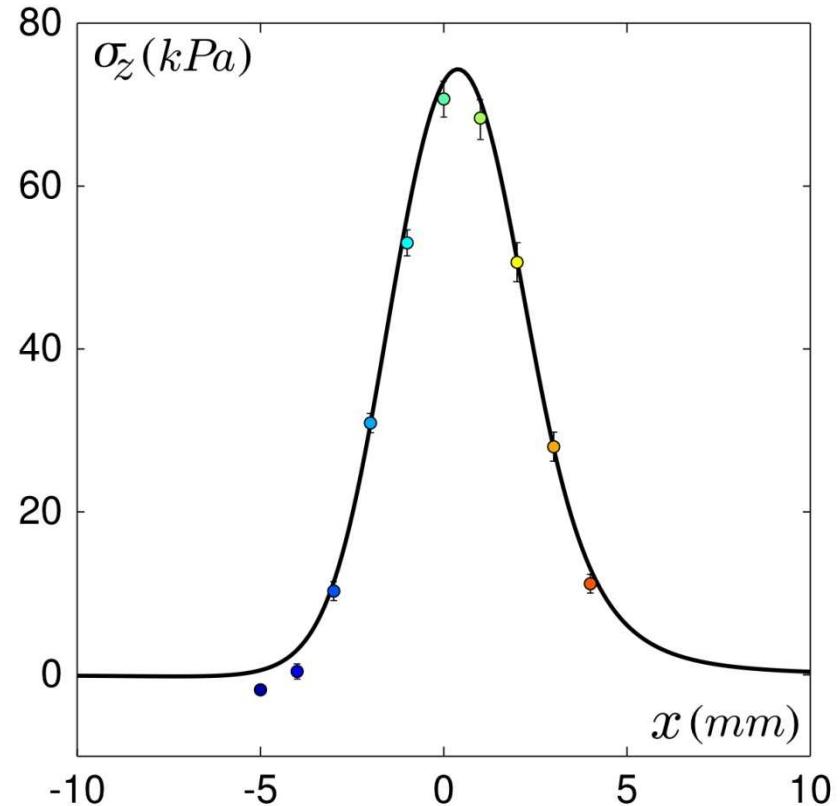
+

Green function for a ponctual
force at the surface:

$$\sigma_j = \sum_k g_{jk} F_k$$

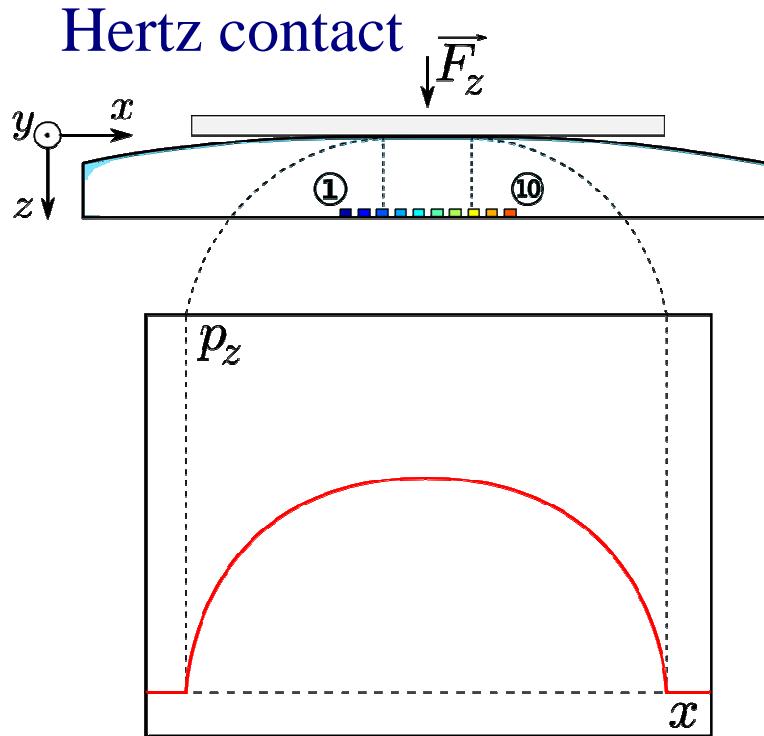
The stress measured by the sensor reads:

$$\begin{aligned}\sigma_z(x_i, y_i) = & \iint_S p_x(x, y) g_{xz}(x - x_i, y - y_i) dx dy \\ & + \iint_S p_z(x, y) g_{zz}(x - x_i, y - y_i) dx dy\end{aligned}$$





Linear model of tactile transduction



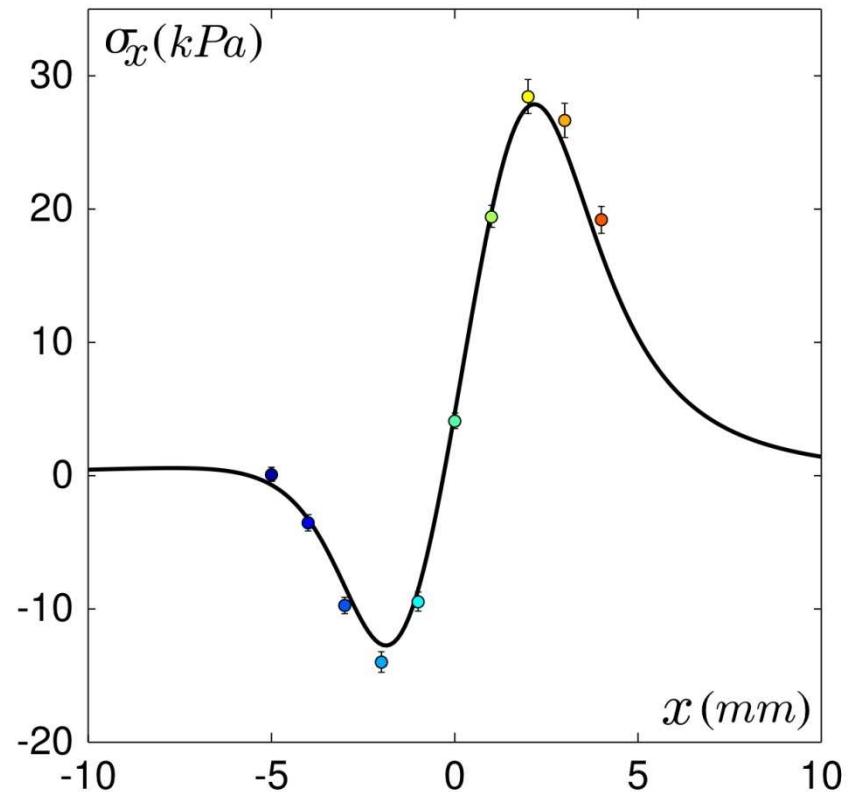
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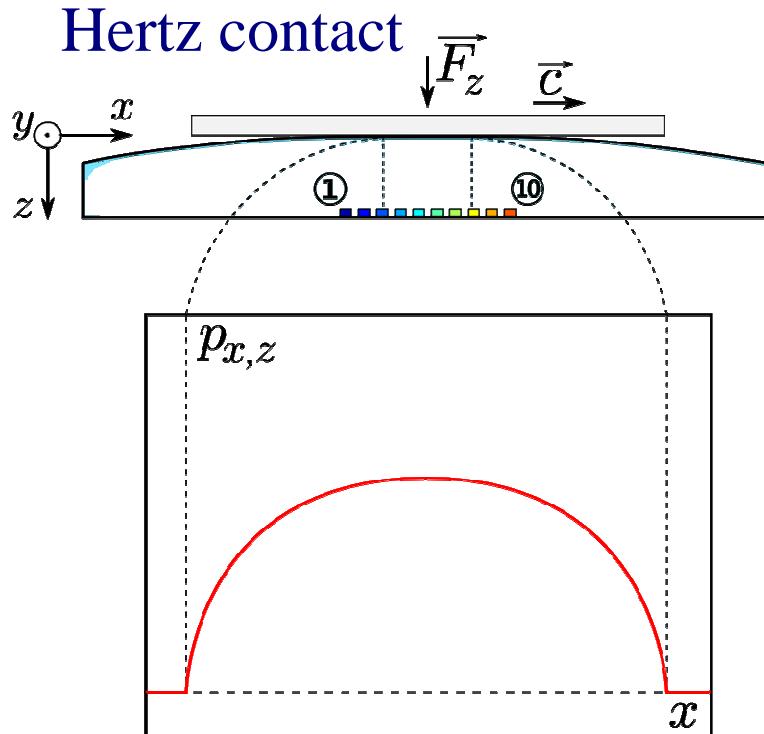
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Linear model of tactile transduction



Local law of friction: $p_x = \mu_d p_z$

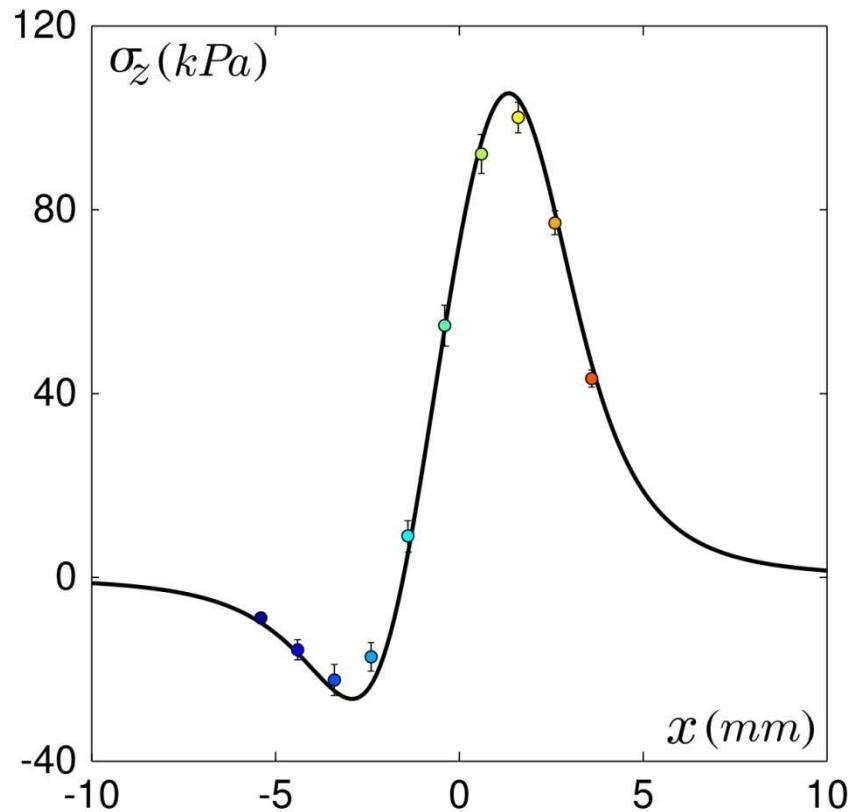
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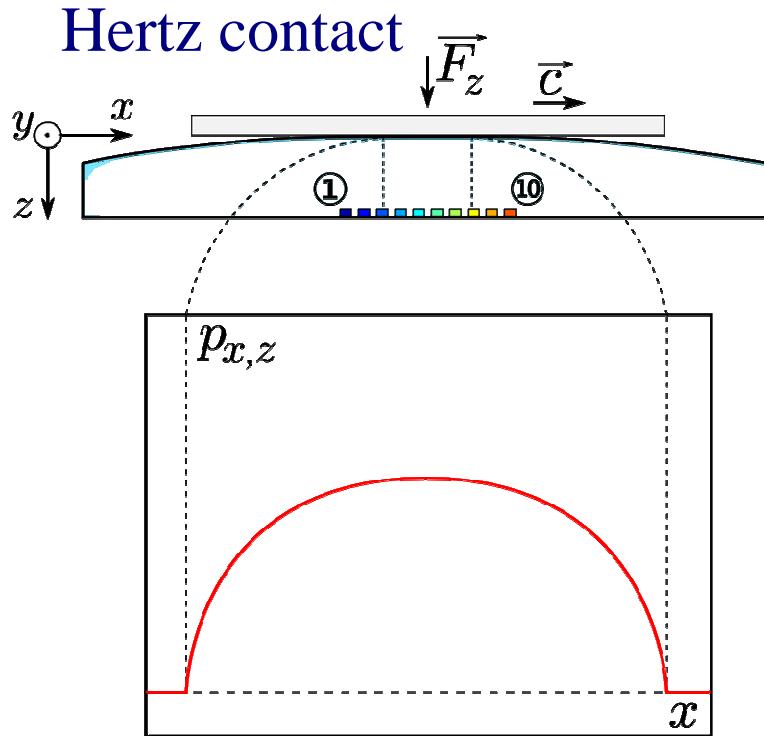
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Linear model of tactile transduction



Local law of friction: $p_x = \mu_d p_z$

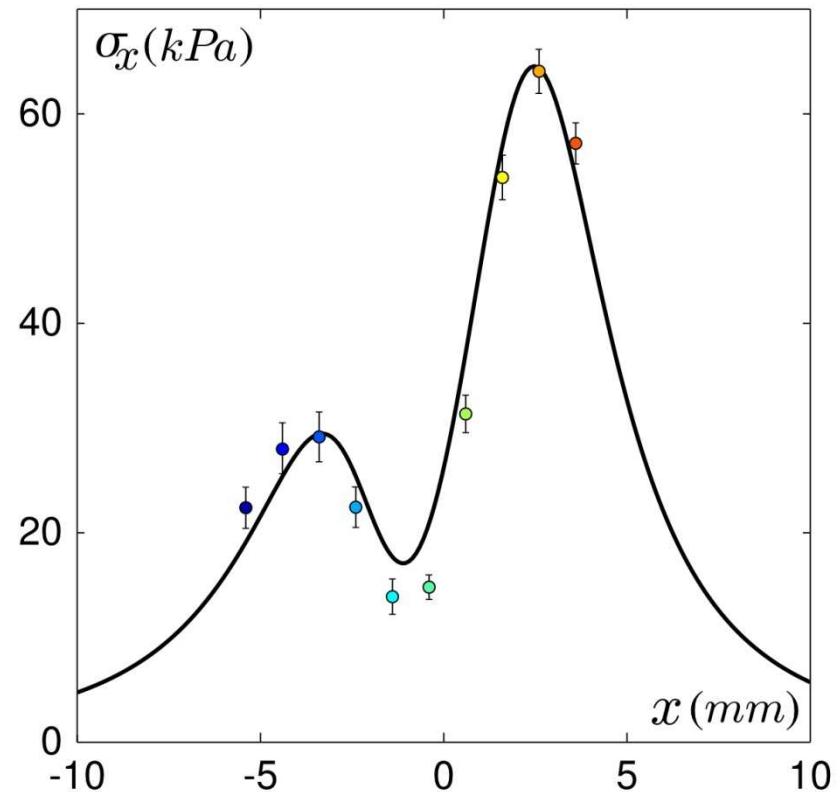
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Green function for a punctual force at the surface:

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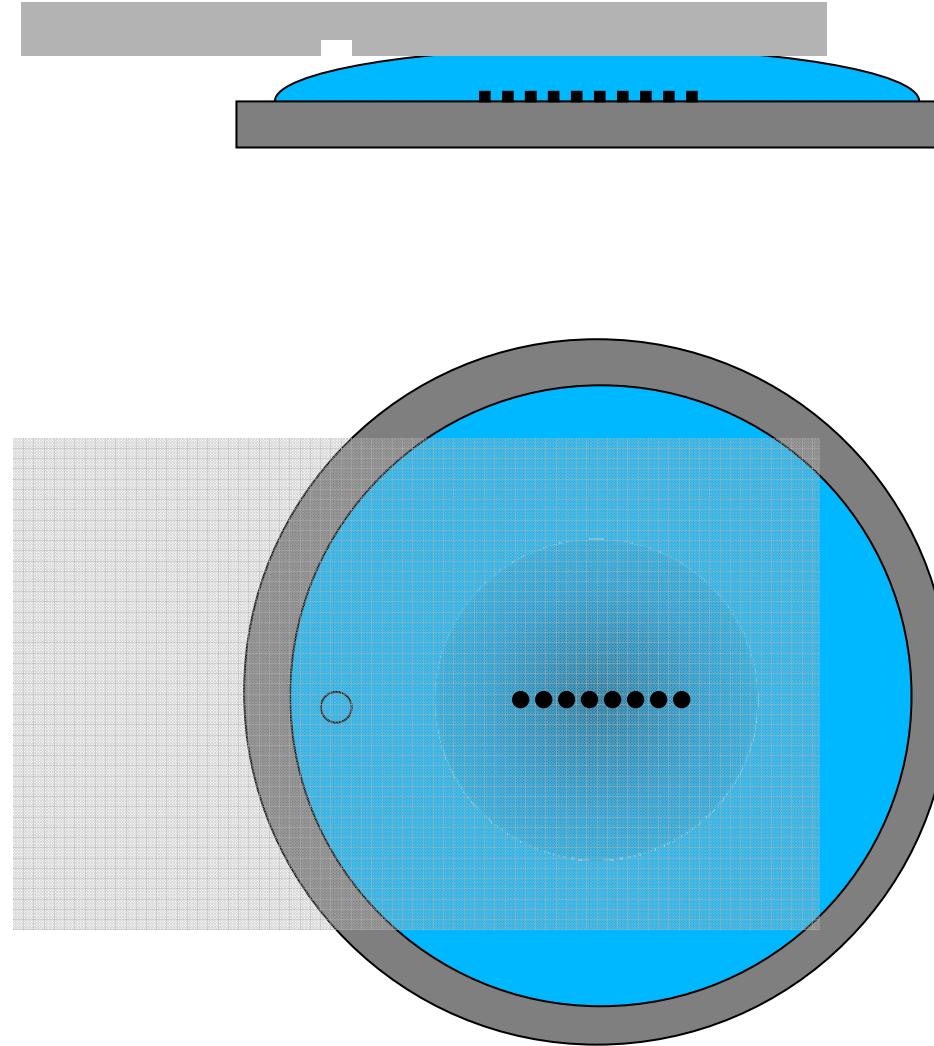
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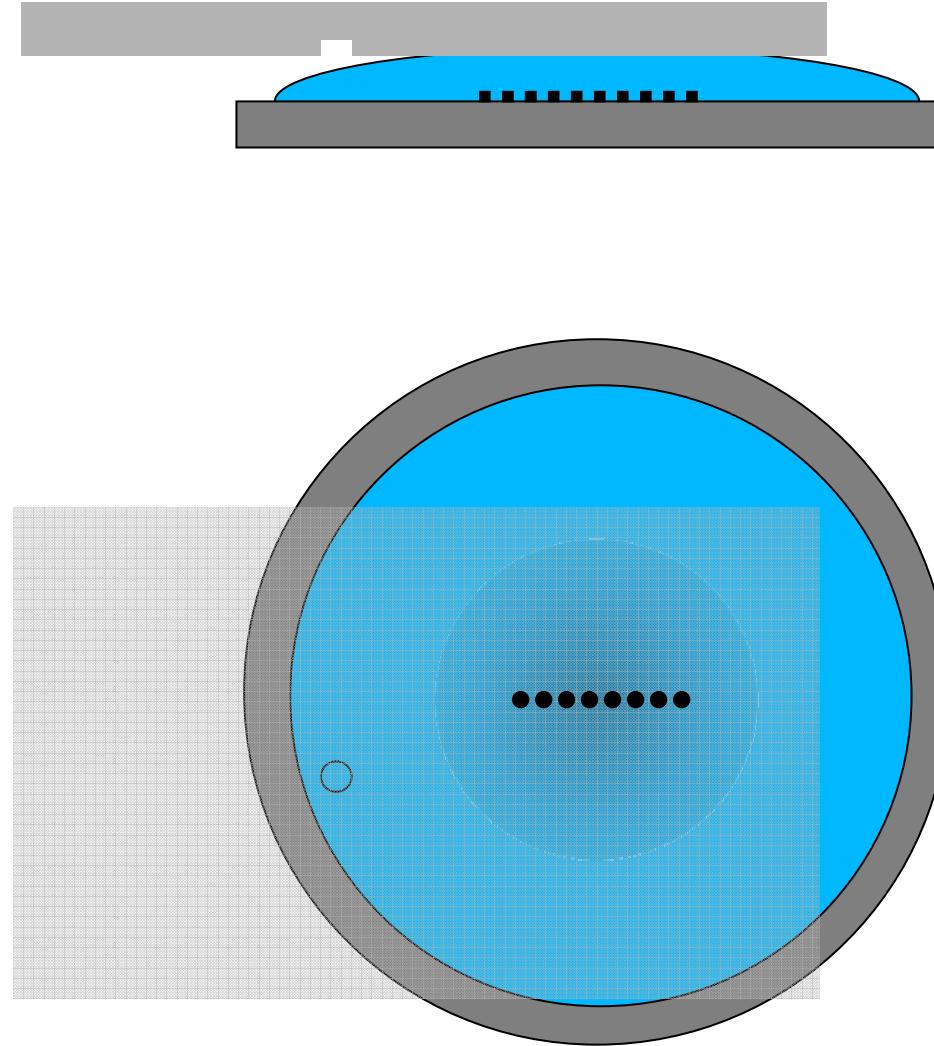


Response to a single defect.



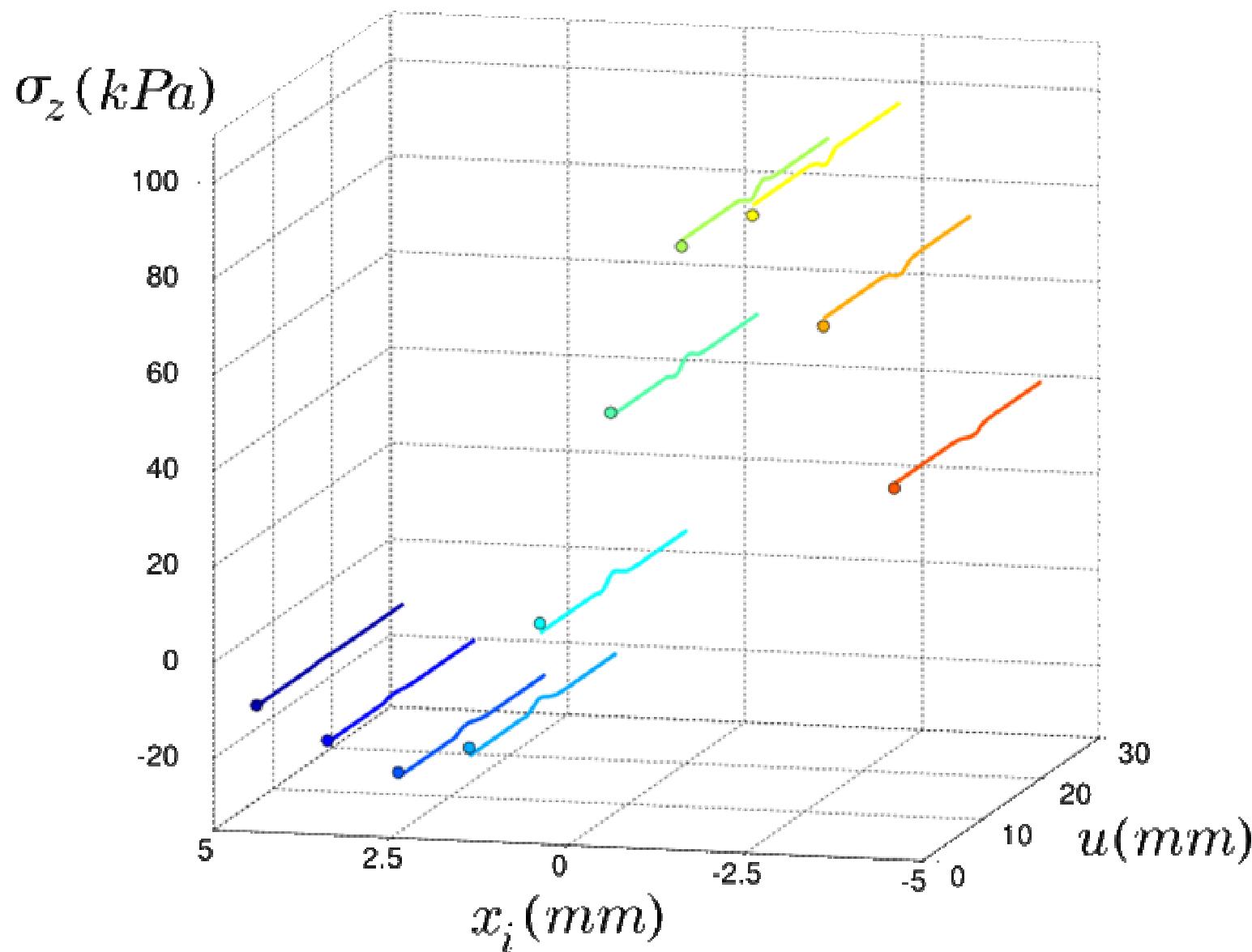


Response to a single defect.





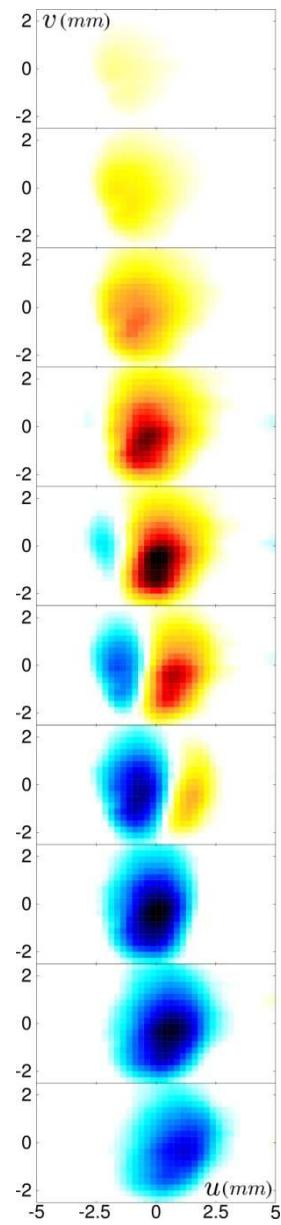
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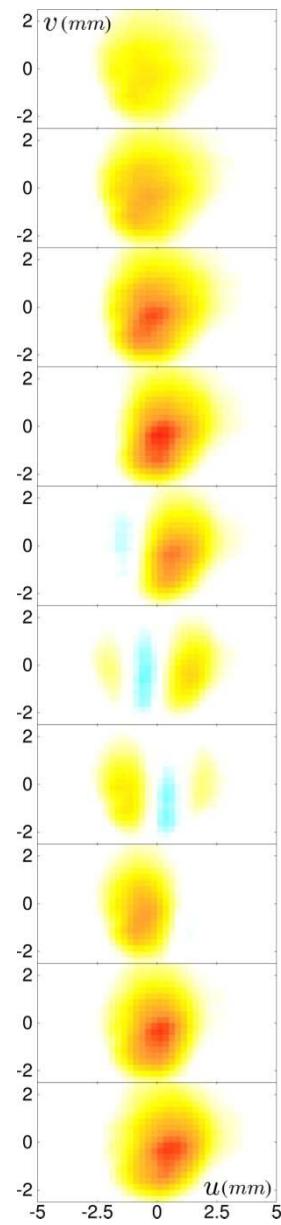


Exploratory Receptive Fields

Normal
stress
variations

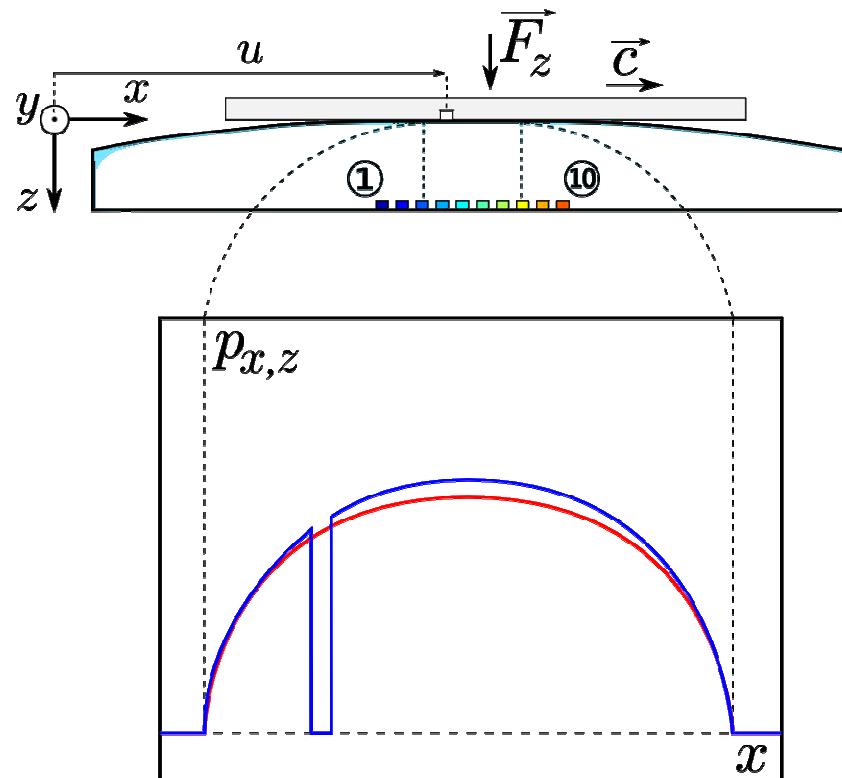


Tangential
stress
variations





Exploratory Receptive Fields



Surface stress variations induced by an isolated defect

Feature-induced stress variations measured by the sensors :

$$\varsigma_z(u) \simeq -[p_x(u)g_{xz}(u - x_0) + p_z(u)g_{zz}(u - x_0)] S_d$$

$$\varsigma_x(u) \simeq -[p_x(u)g_{xx}(u - x_0) + p_z(u)g_{zx}(u - x_0)] S_d$$

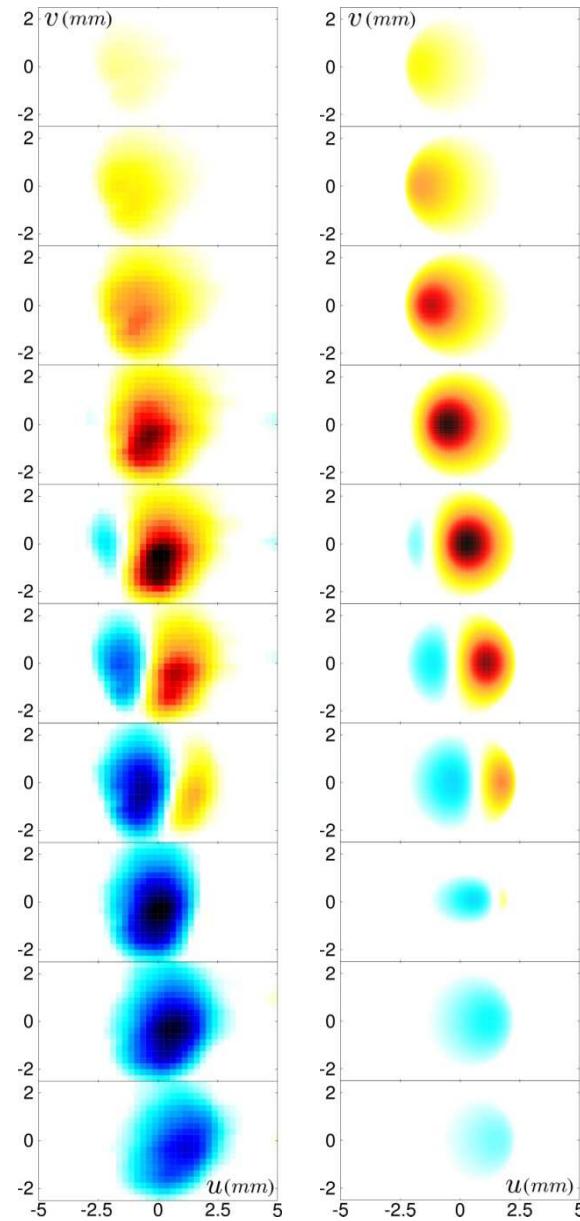
The response depends on the sensor's position inside the skin



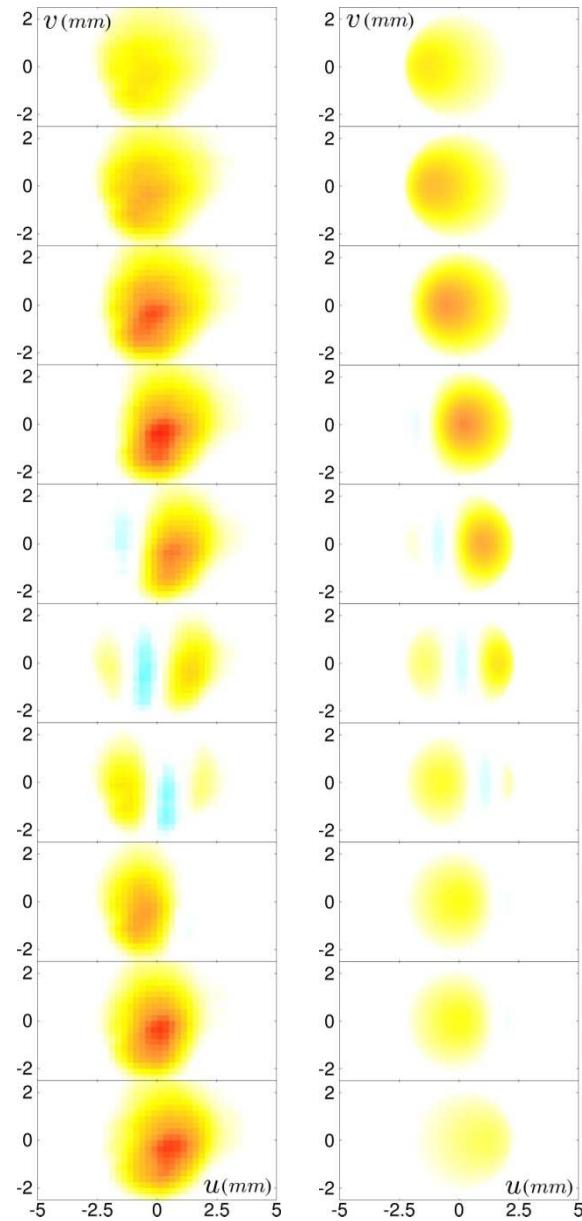


Exploratory Receptive Fields

Normal
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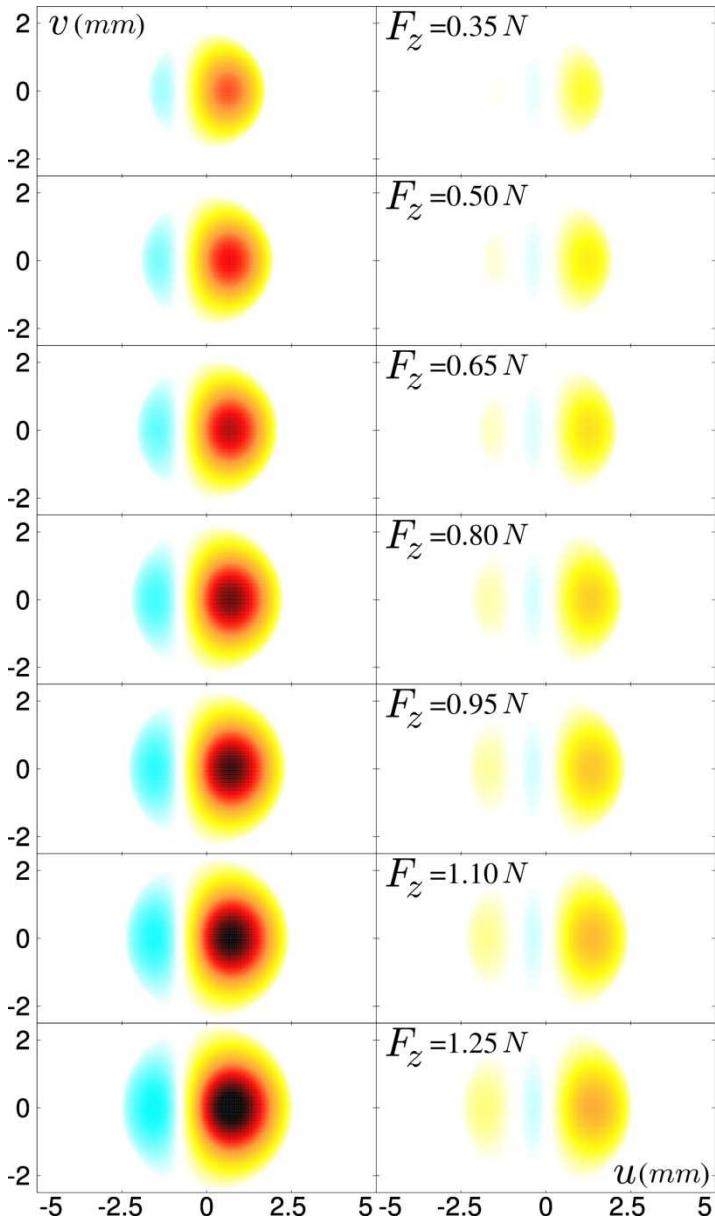


Tangential
stress
variations





The role of exploratory conditions



What parameters do significantly change the *shape* of the response?

- Position x_i (with respect to the contact zone)

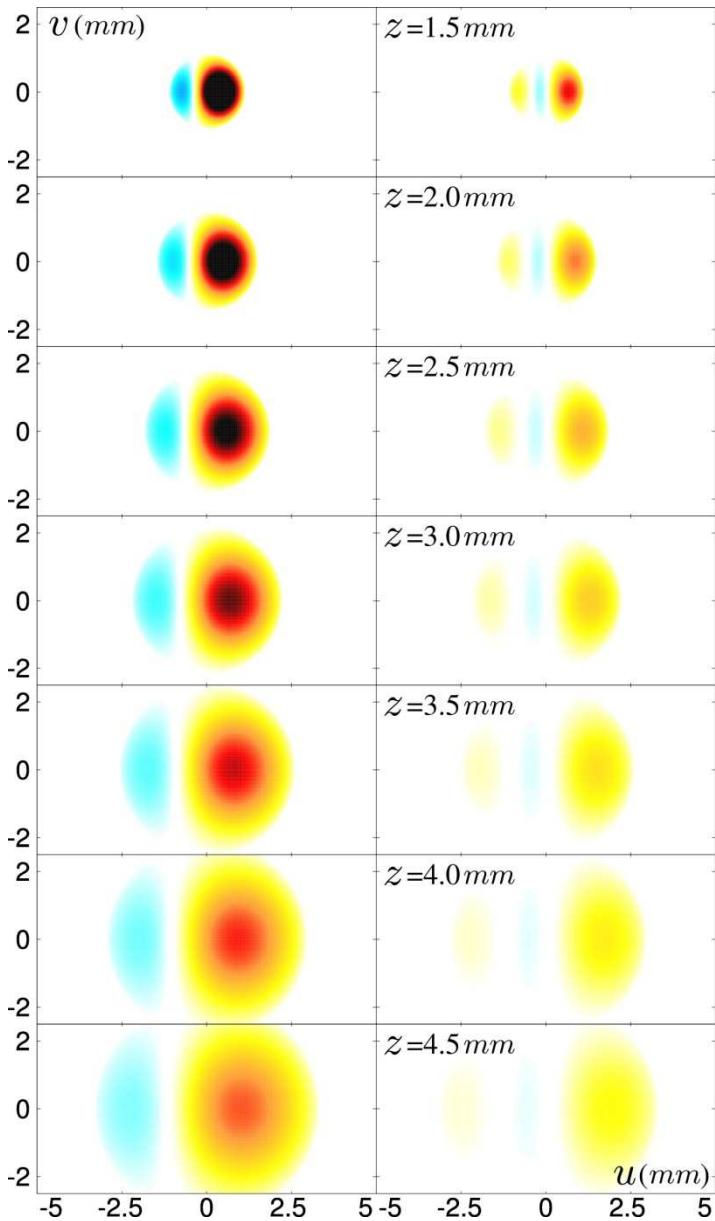
What parameters do not?

- Global normal force F_z





The role of exploratory conditions



What parameters do significantly change the *shape* of the response?

- Position x_i (with respect to the contact zone)

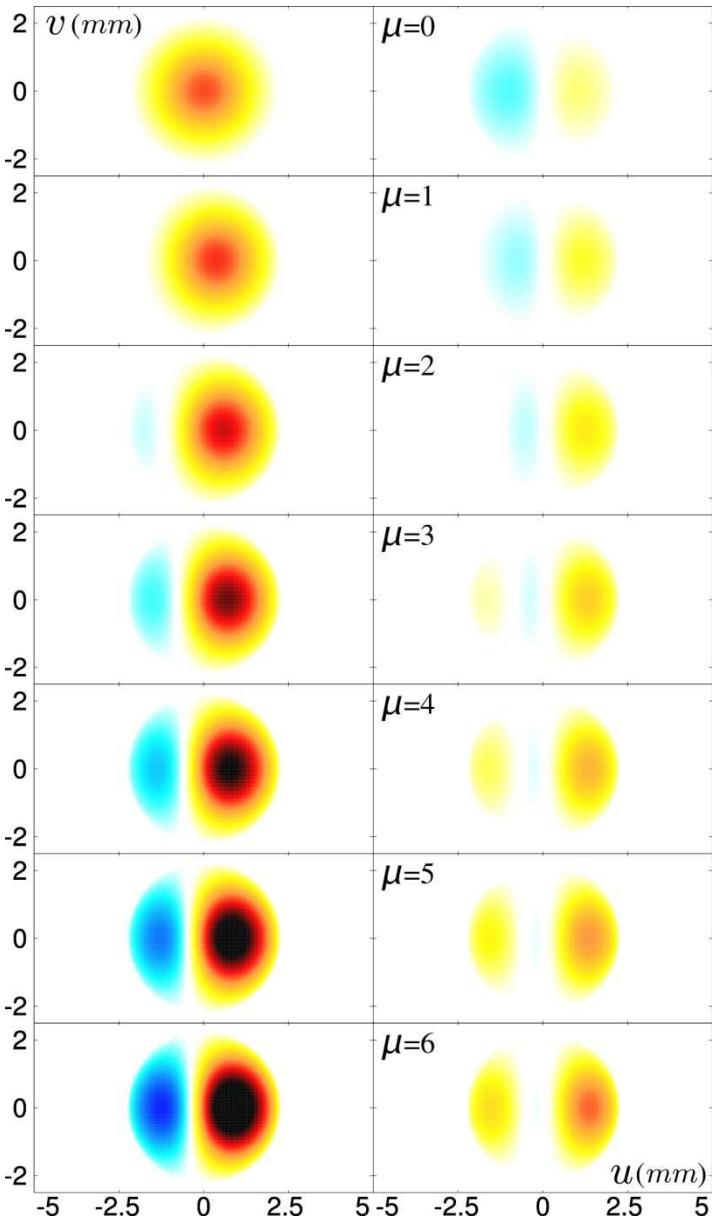
What parameters do not?

- Global normal force F_z
- Depth z of the sensors
- Position y_i (with respect to the contact zone)
- Exploration speed c
- Young modulus E
- Poisson ratio ν
- Radius of curvature R of the skin





The role of exploratory conditions



What parameters do significantly change the *shape* of the response?

- Position x_i (with respect to the contact zone)
- Friction coefficient μ_d

What parameters do not?

- Global normal force F_z
- Depth z of the sensors
- Position y_i (with respect to the contact zone)
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Variability in ERF in digital perception

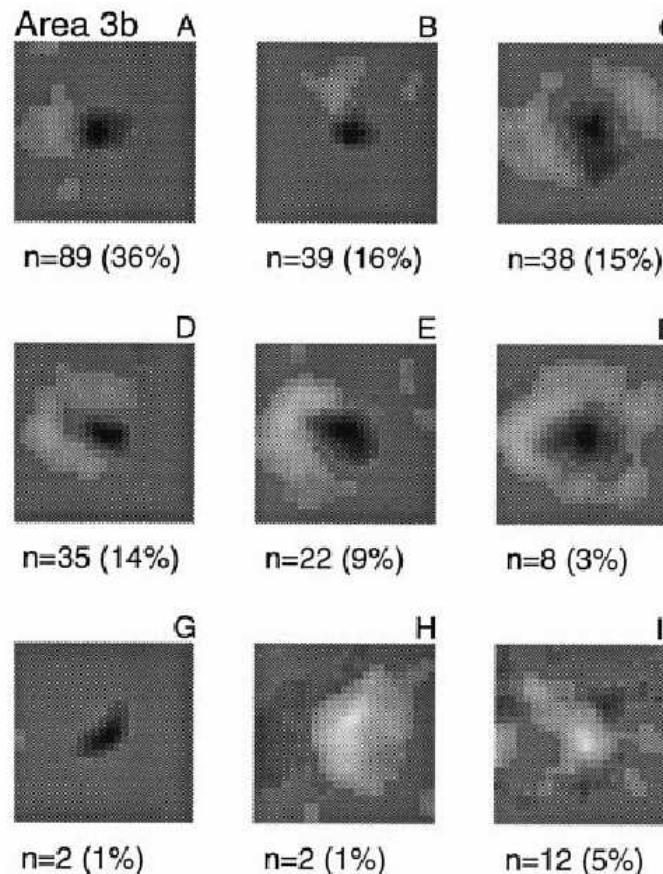
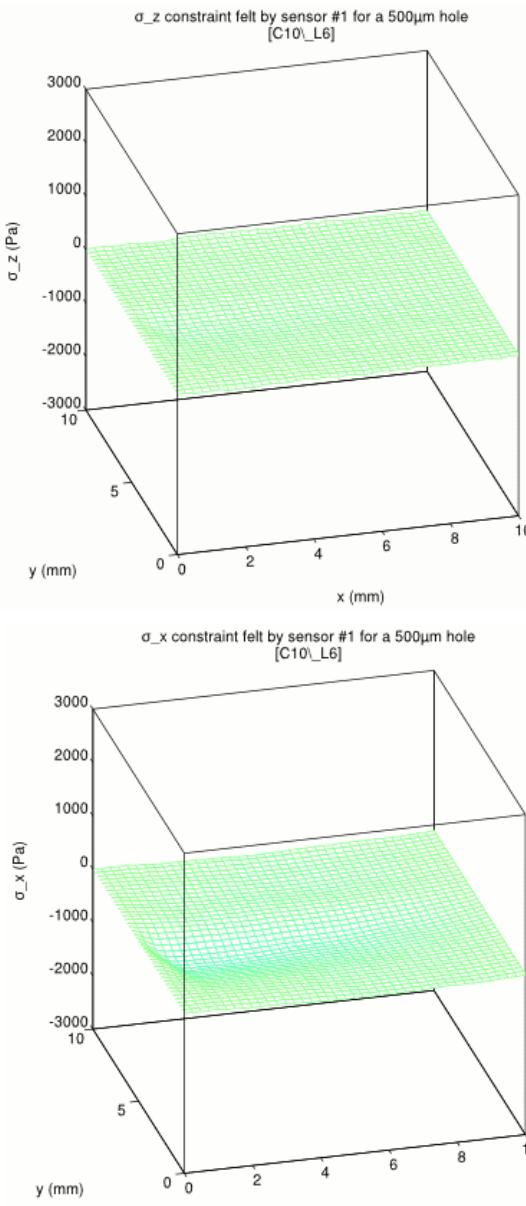
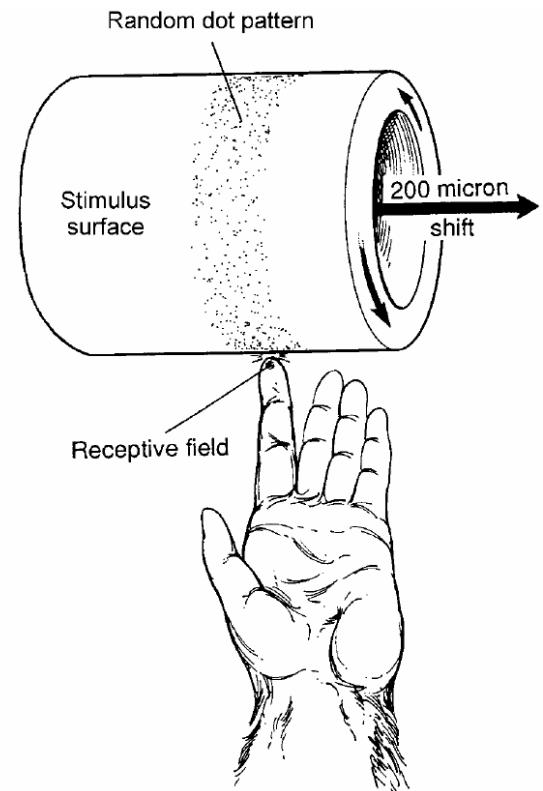


Figure 3. RF structures observed in area 3b. Each panel gives a typical example of the type, the total number of RFs fitting the description, and their percent of the total RF sample ($n = 247$).



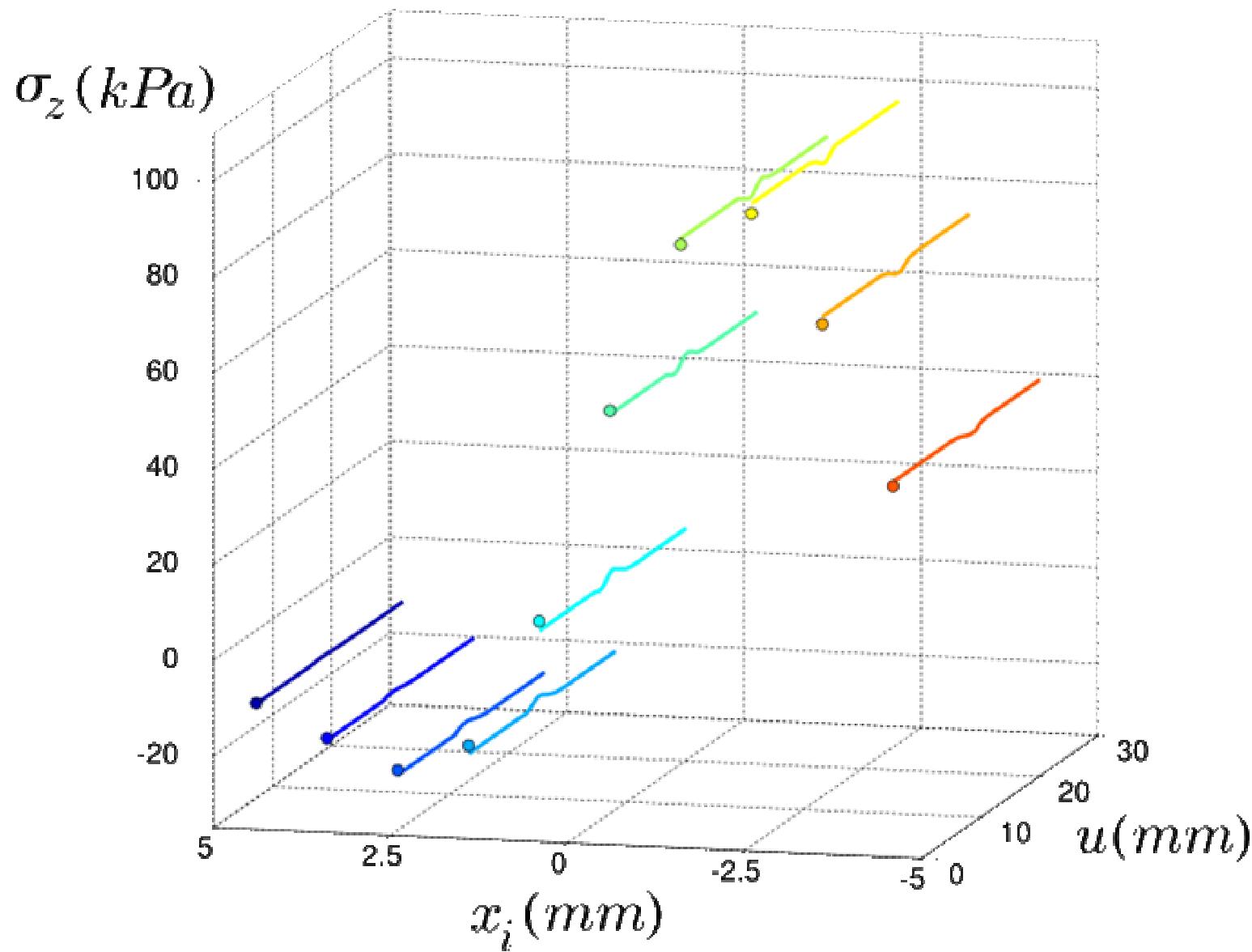
DiCarlo *et. al.*, 1998
The journal of Neuroscience

« *The shape, area and strength of excitatory and inhibitory receptive fields regions ranged widely.* »



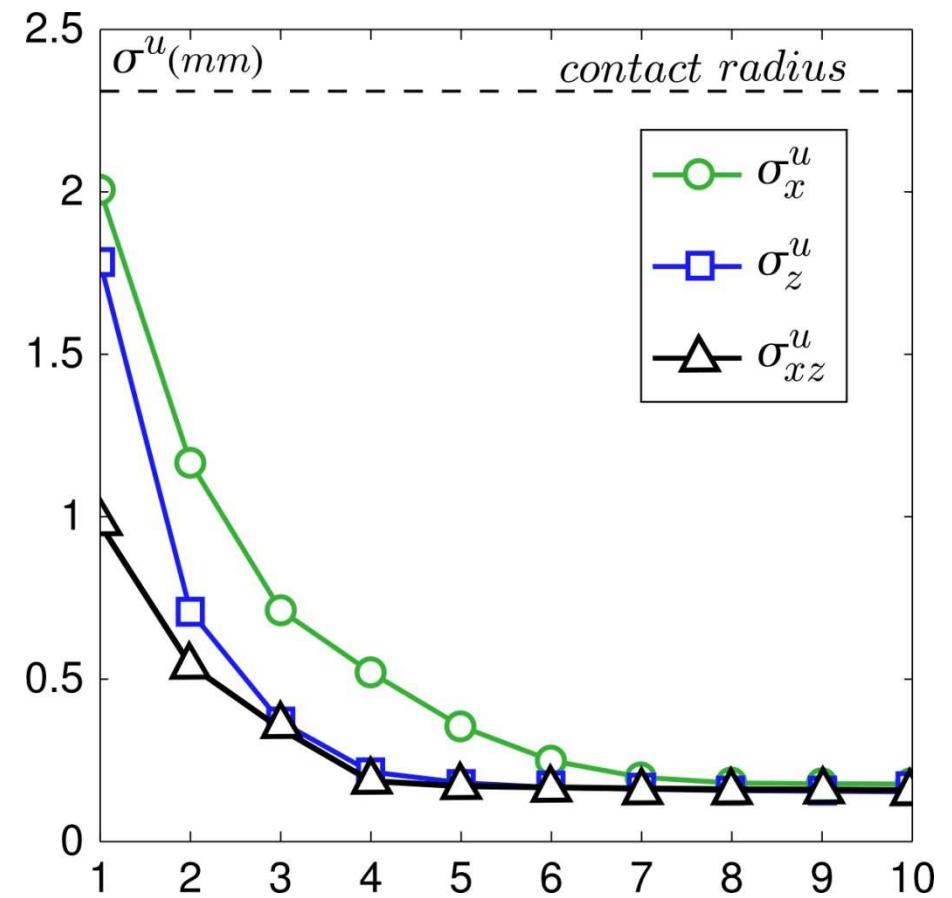
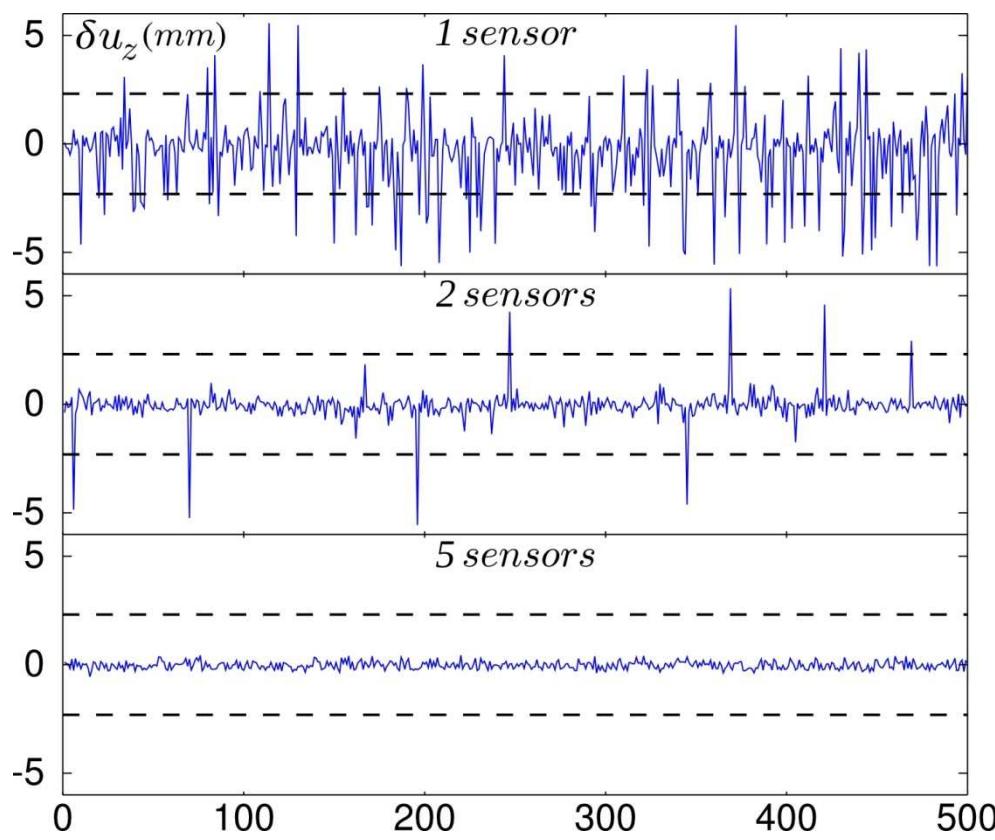


Predicting the defect's position





Predicting the defect's position



The accuracy of the prediction of the defect's position depends on the amount of information used (number of sensors, x - z stress)





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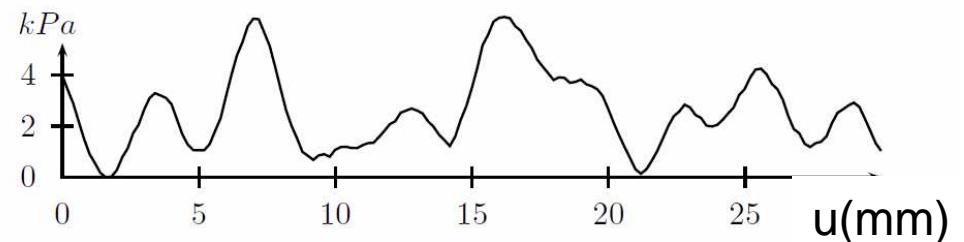
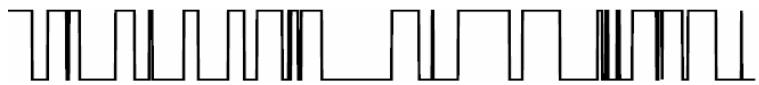
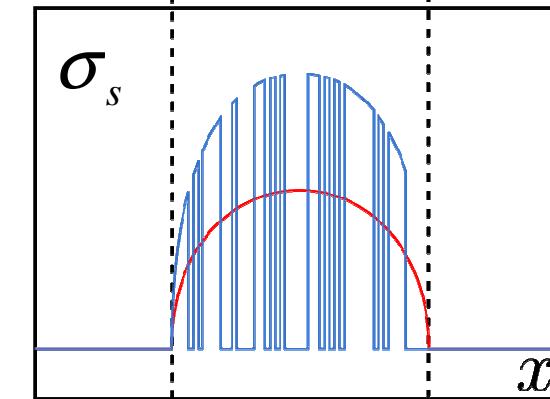
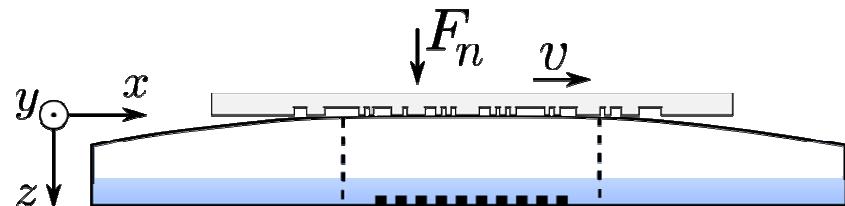
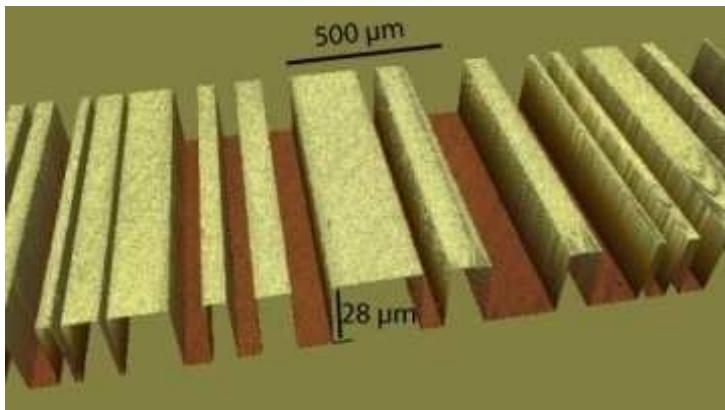
5 – Conclusions and perspectives.





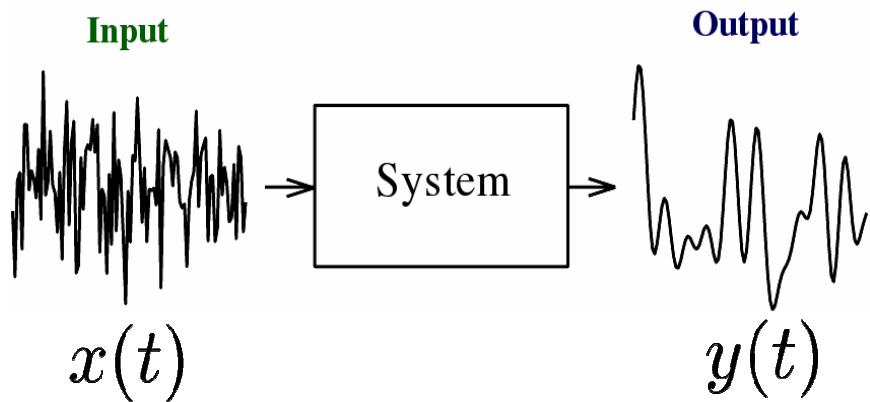
Response to randomly rough substrates

Scanning over a random square-wave grating



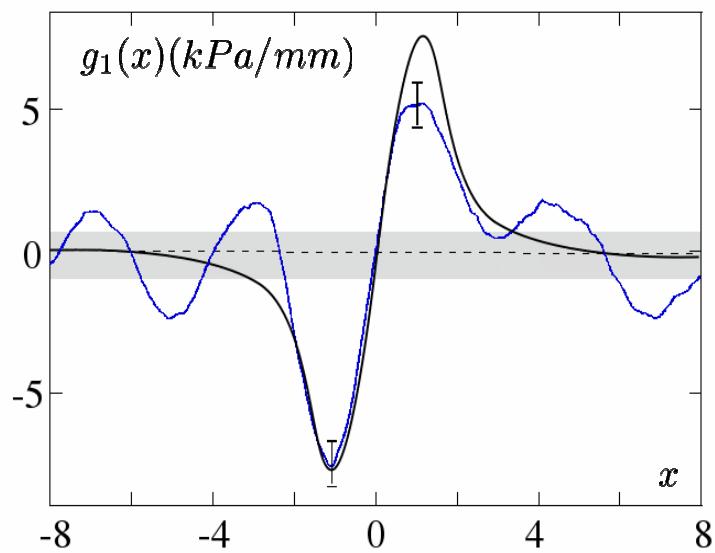


Extracting the linear kernel

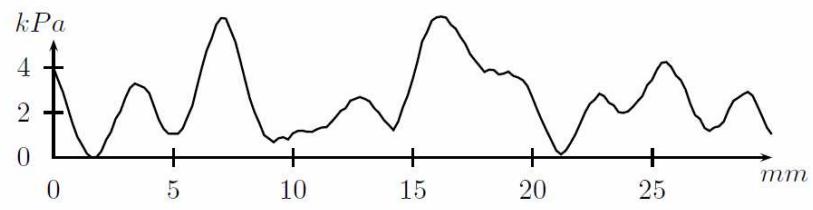


For *Gaussian white noise* inputs the linear response $g_1(\tau)$ can be computed as the correlation between the input signal $x(t)$ and the output response $y(t)$

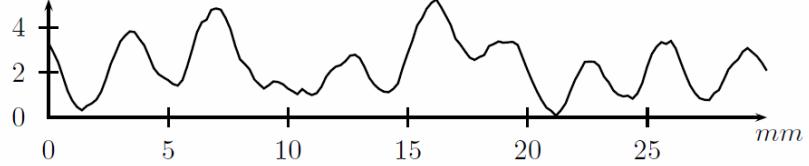
$$g_1 = \text{[square wave]} \otimes \text{[measured signal]}$$



measured



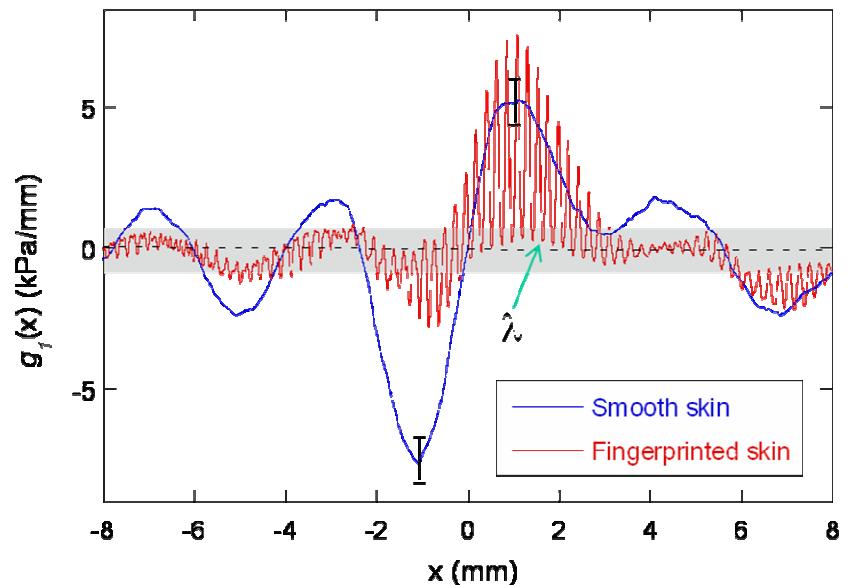
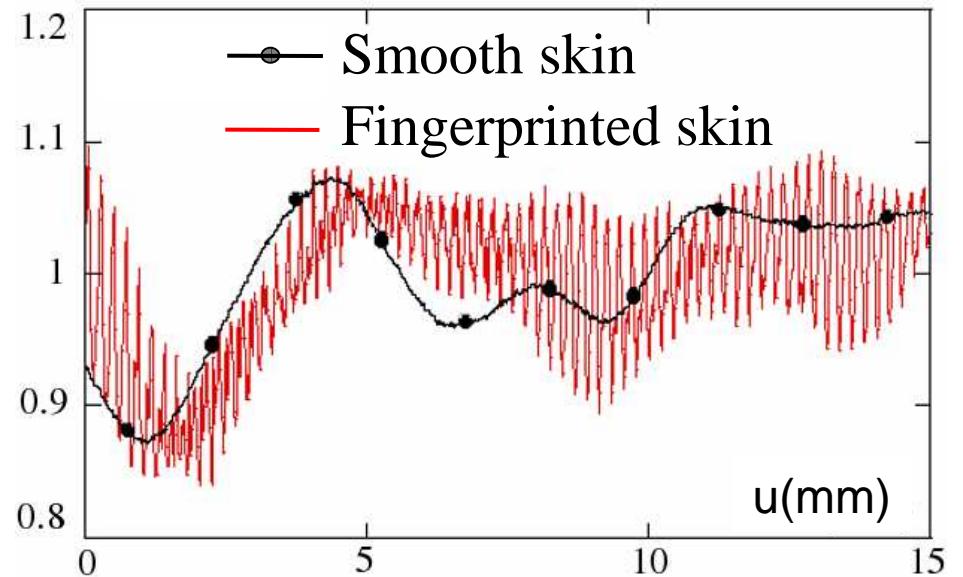
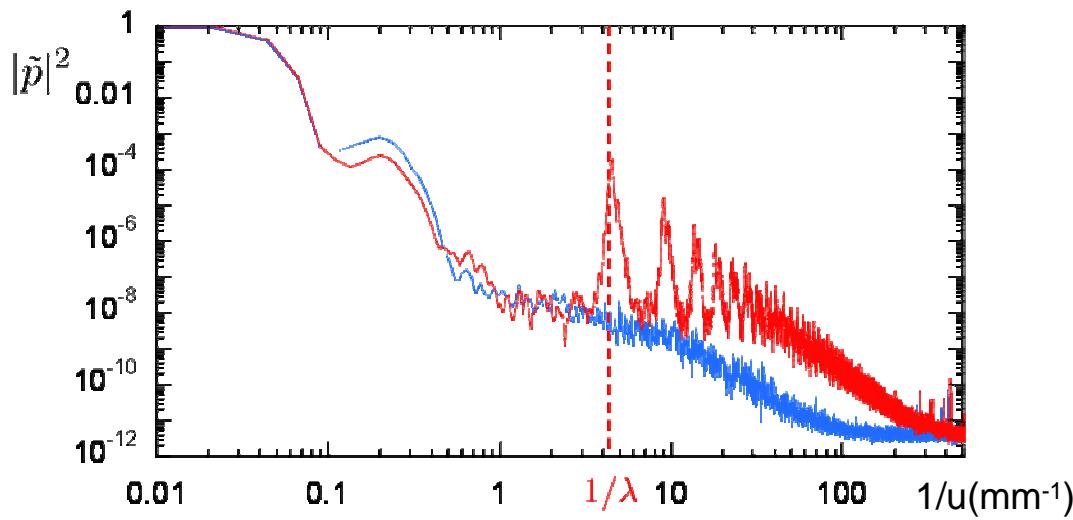
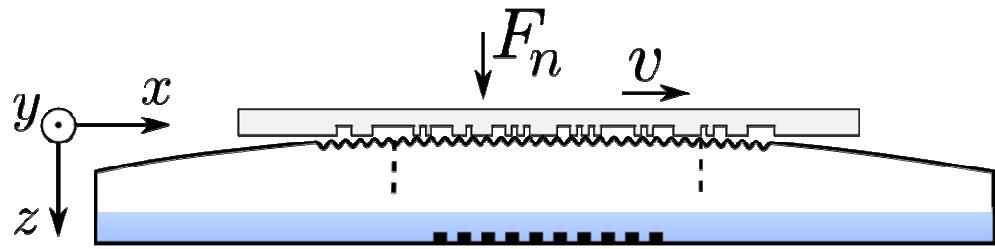
Predicted





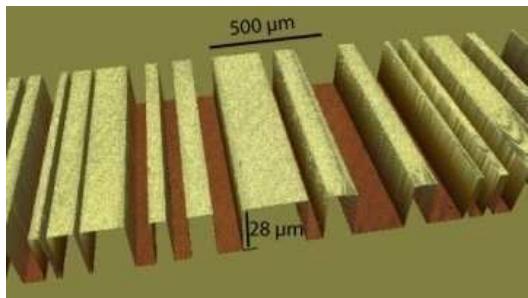
Consequences of skin patterning (e.g. fingerprints)

Artificial fingerprints
Regular square-wave grating
(period $\lambda=220\mu\text{m}$)
on the skin surface

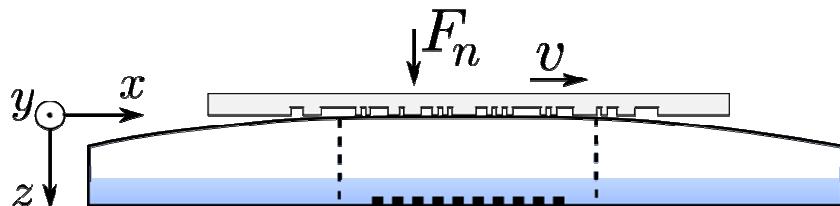




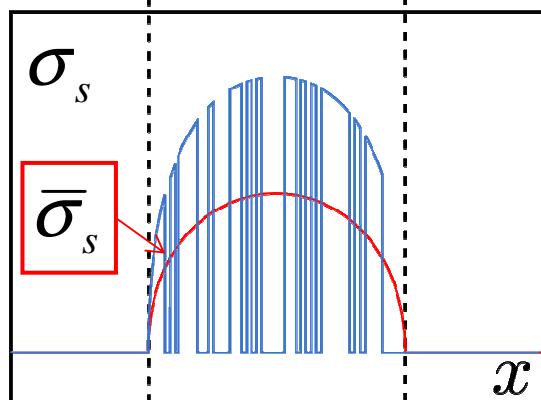
Linear model of mechanical transduction



Square wave gratings: $T(x) = \pm 1$



Interfacial stress profile: $p(x) \approx \bar{p}(x).T(x - u)$



Force signal :

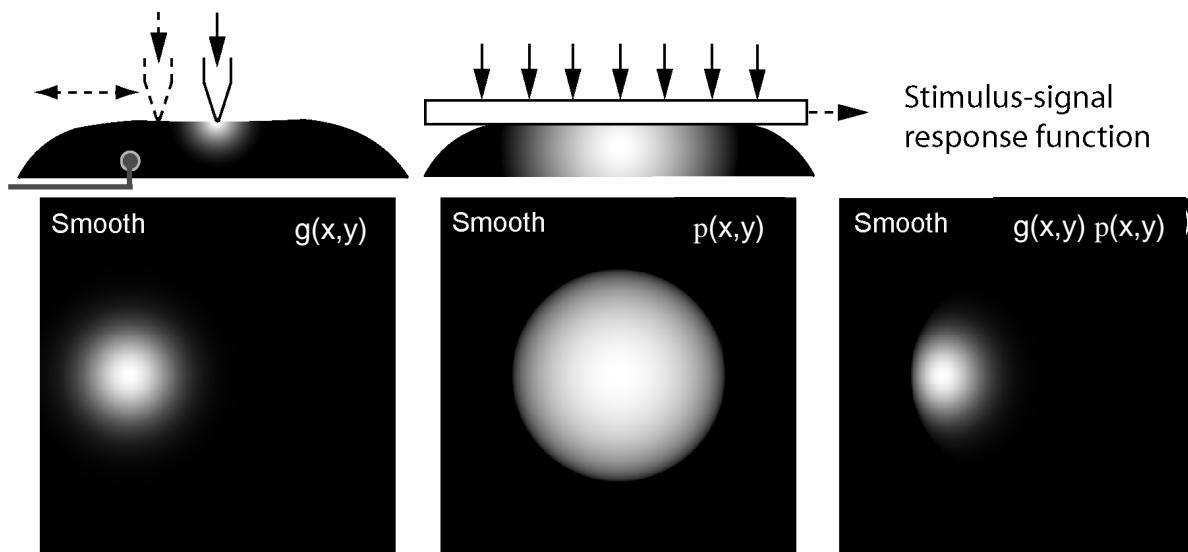
$$s(u) = \langle s \rangle + \int p(x) g(x - x_0).T(x - u) dx$$

$\underbrace{\qquad\qquad\qquad}_{g_1(x)}$



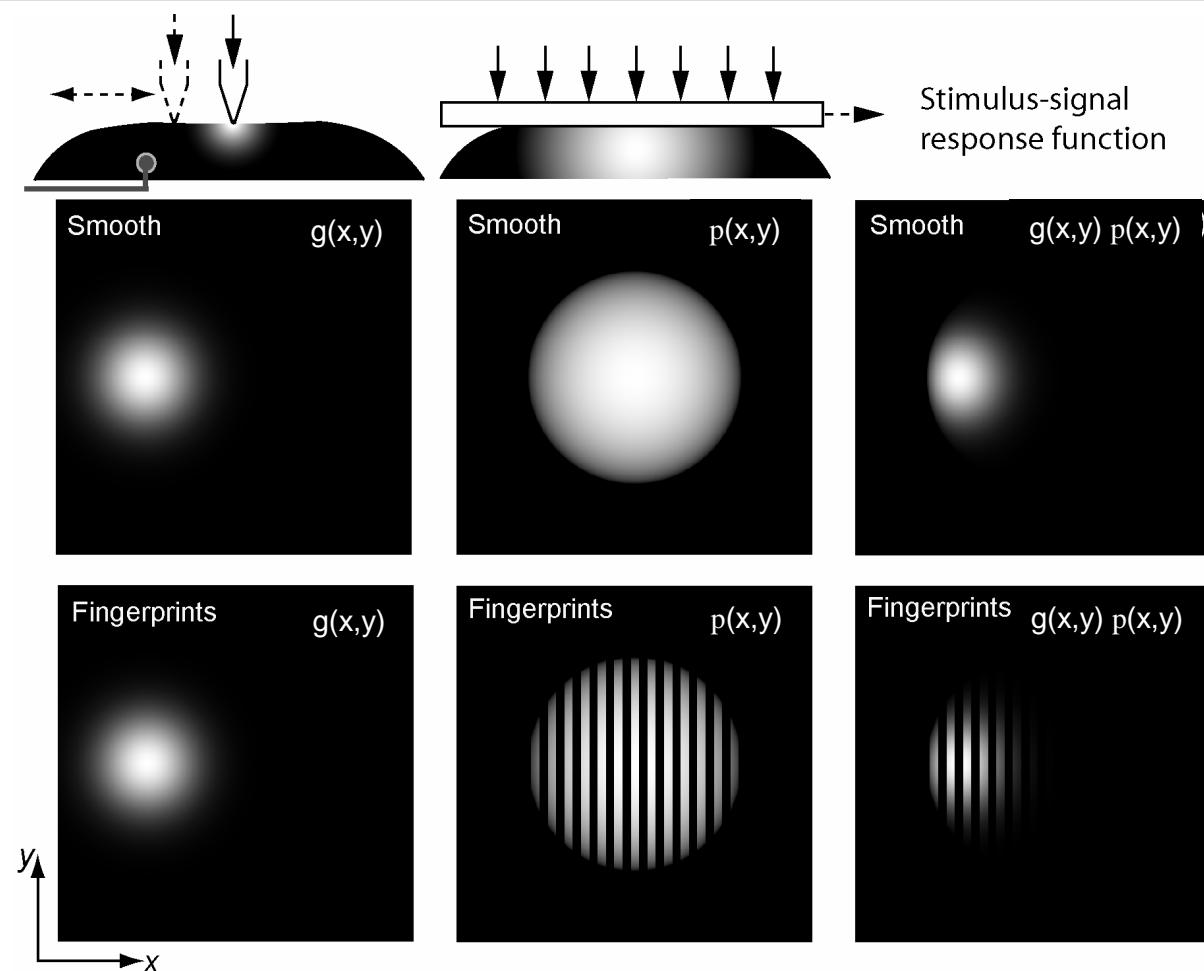


Stimulus- signal response function



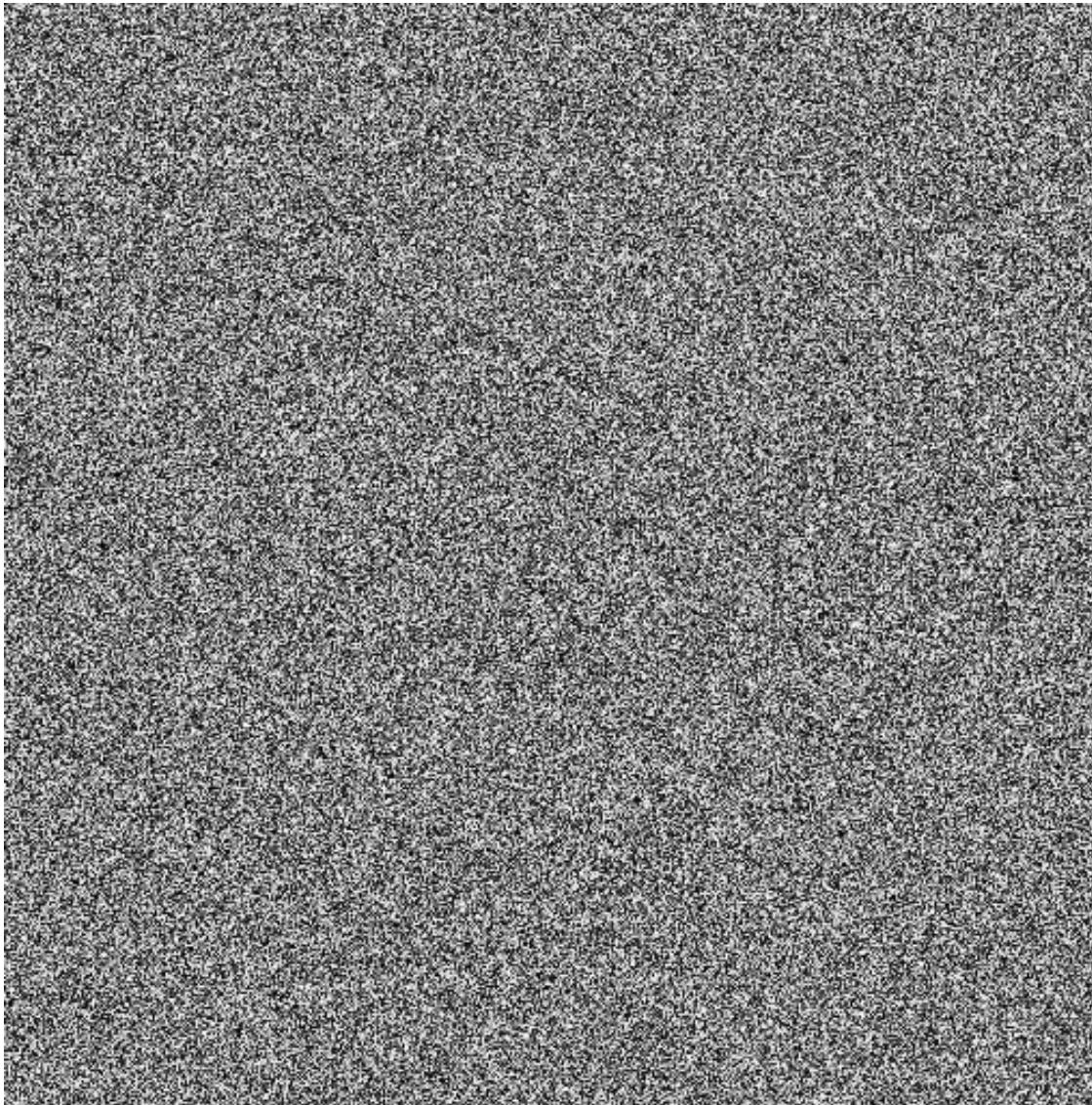


Stimulus- signal response function



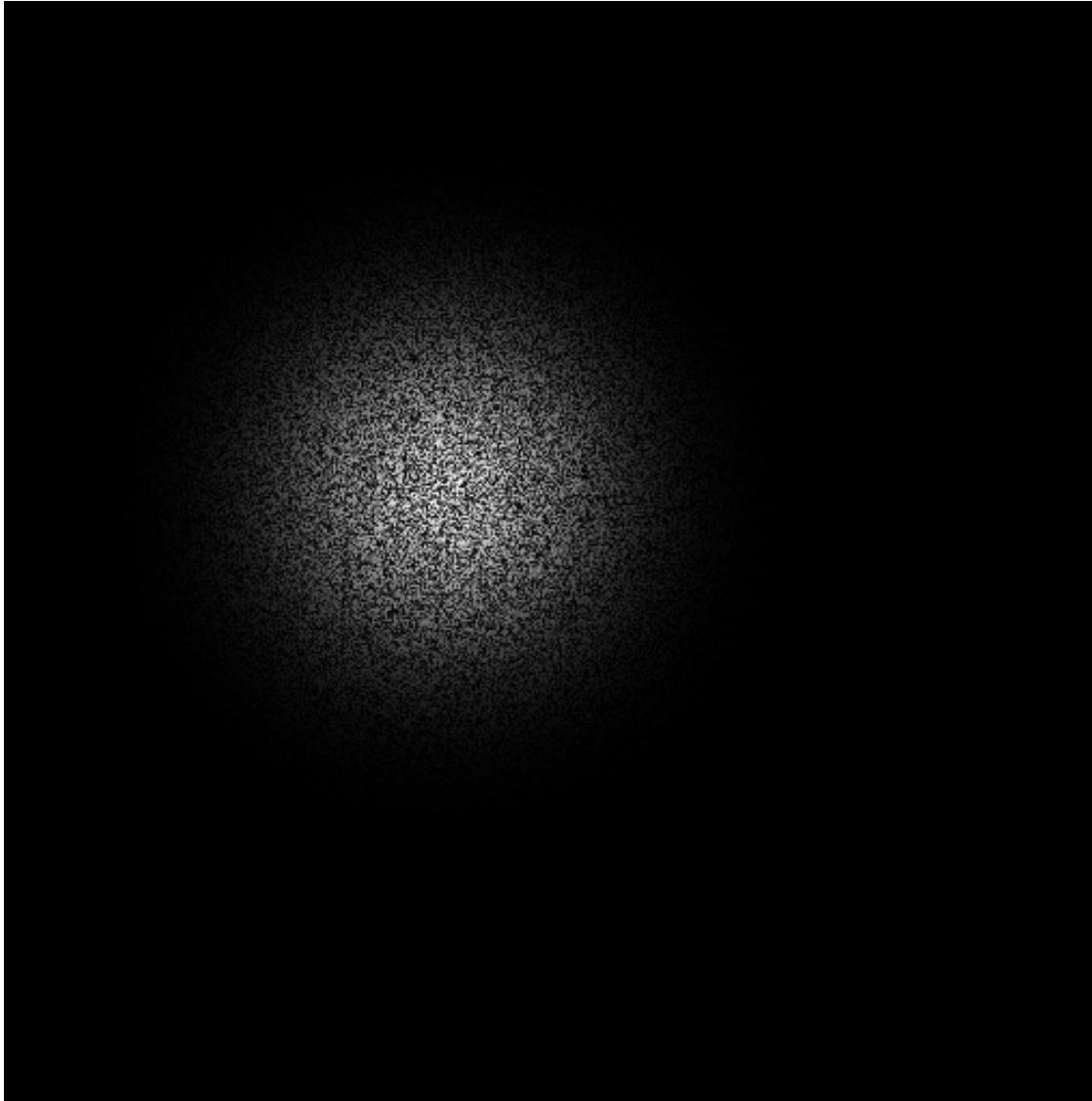


Numerical illustration of the filtering process



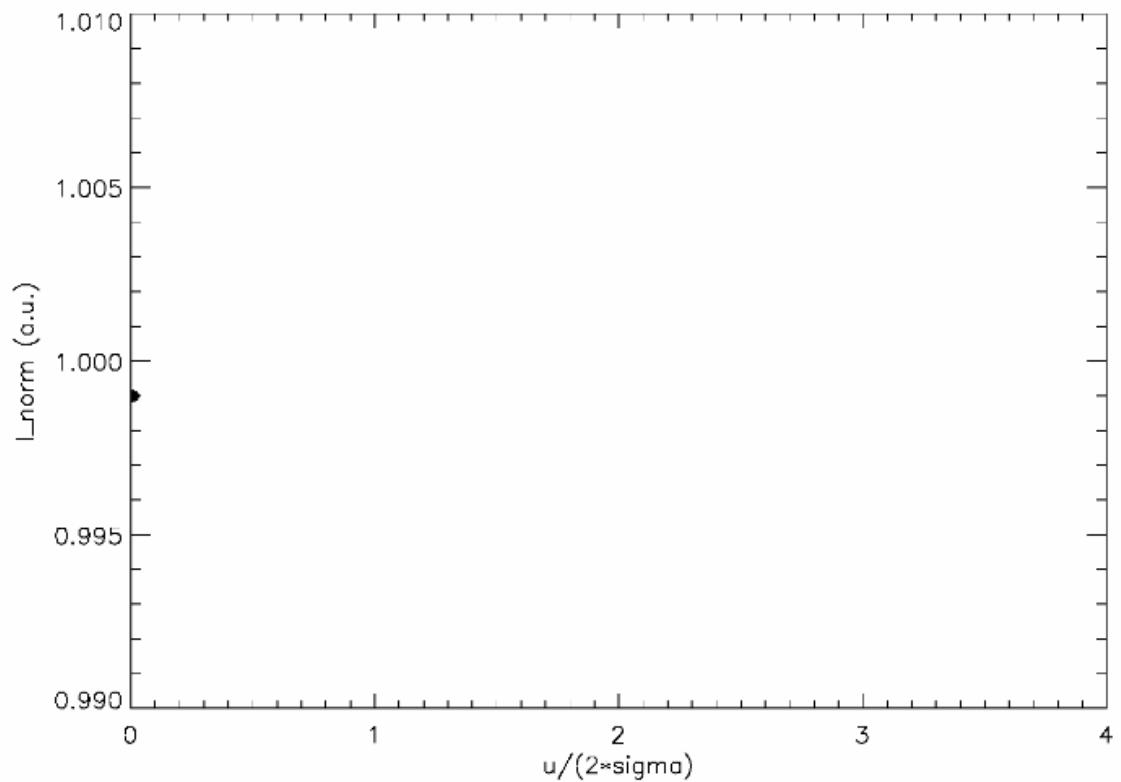
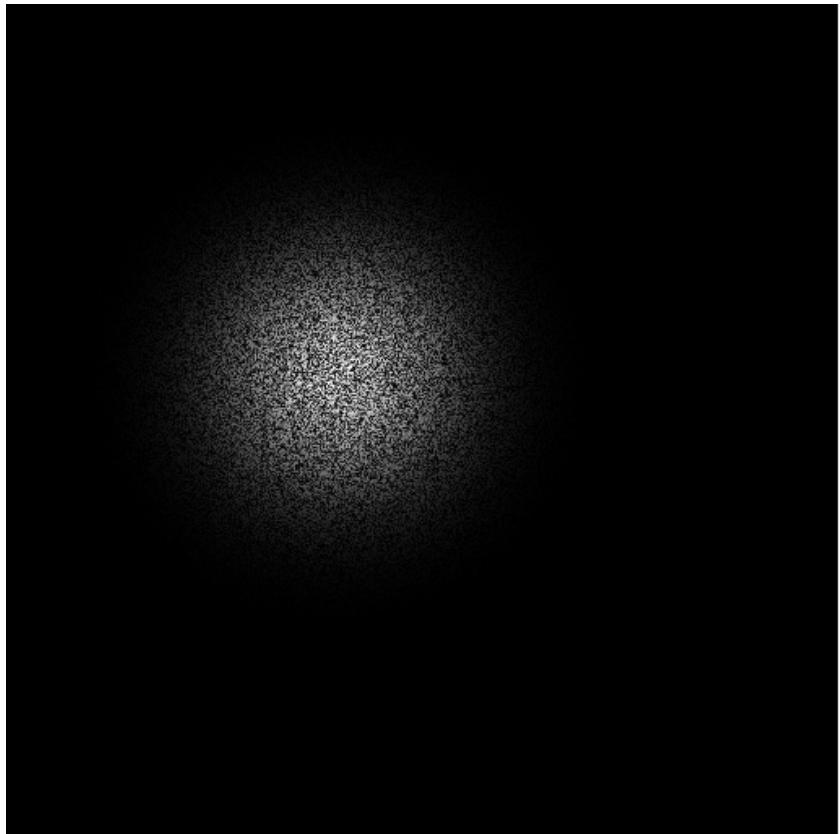


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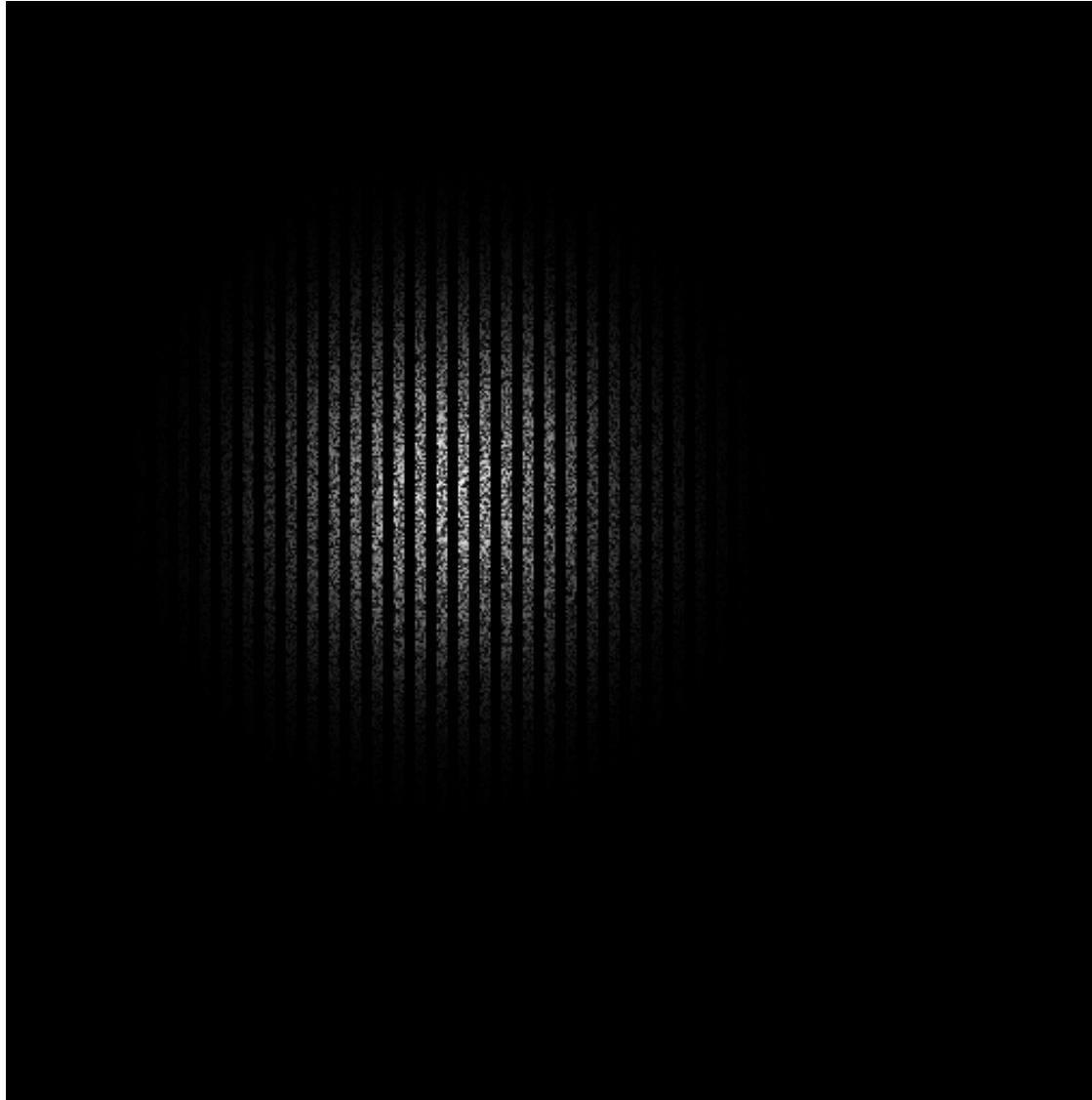


Numerical illustration of the filtering process



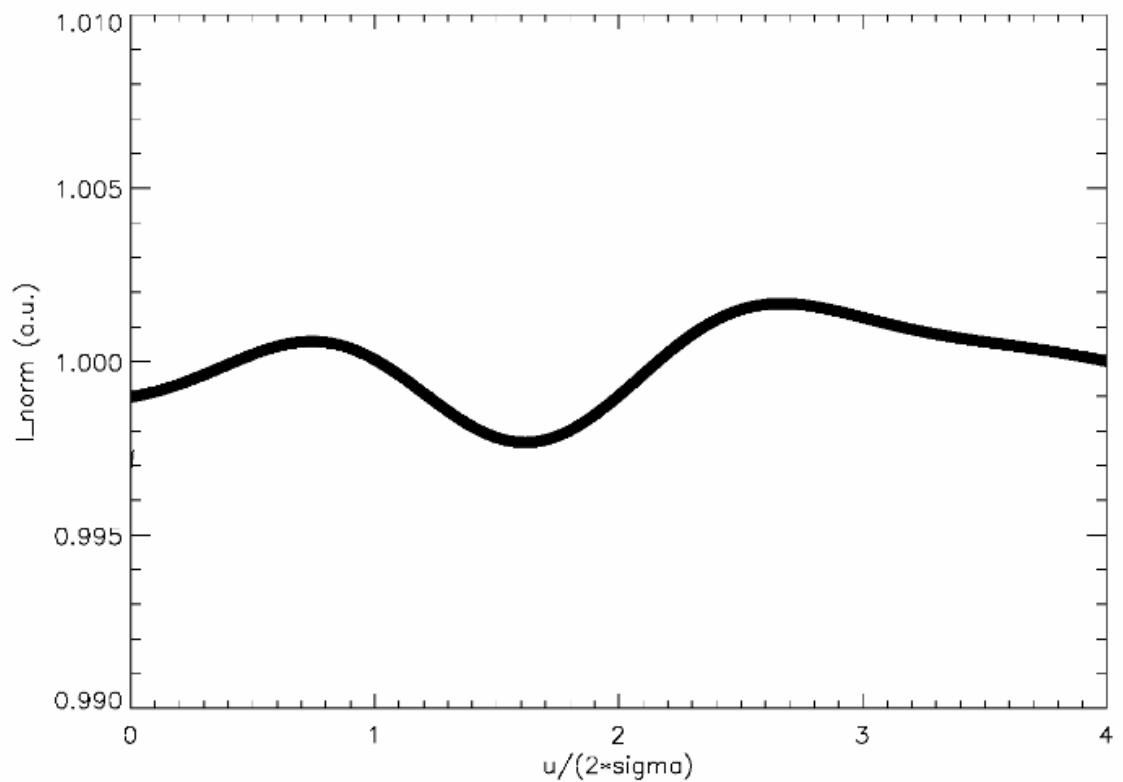
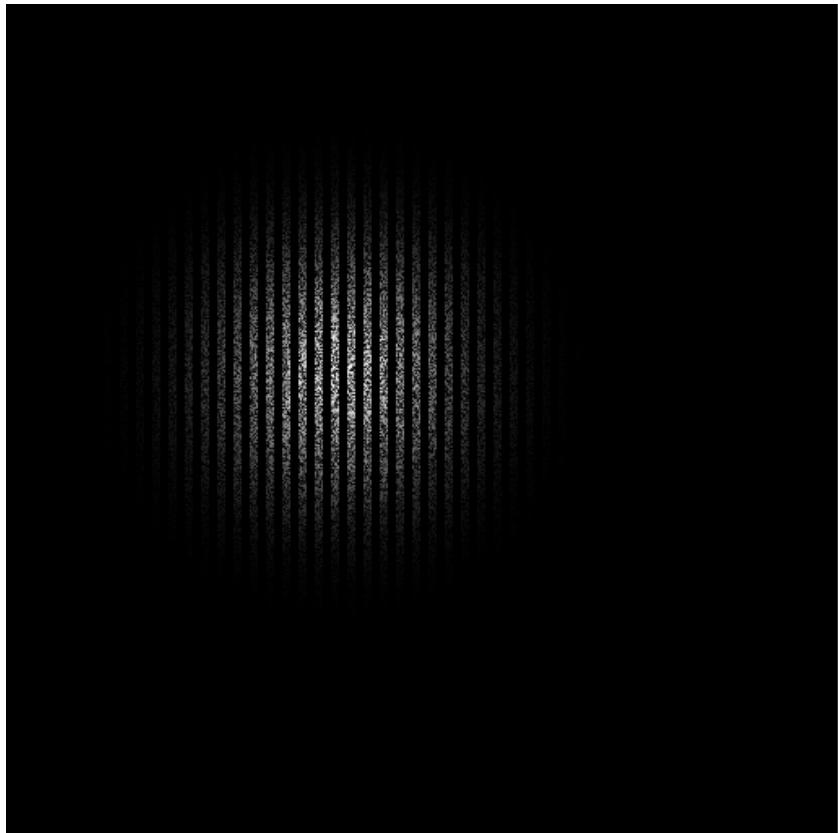


Numerical illustration of the filtering process



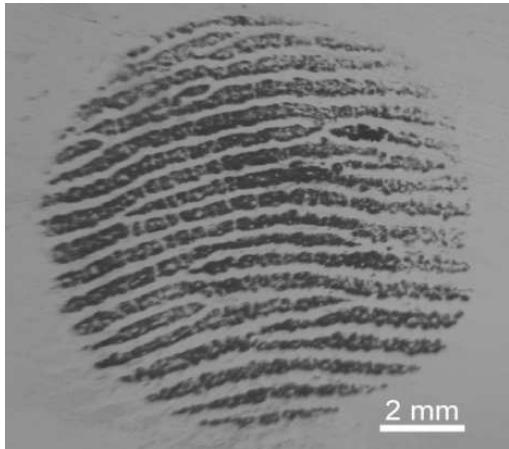


Numerical illustration of the filtering process





Consequence of fingerprints for tactile perception

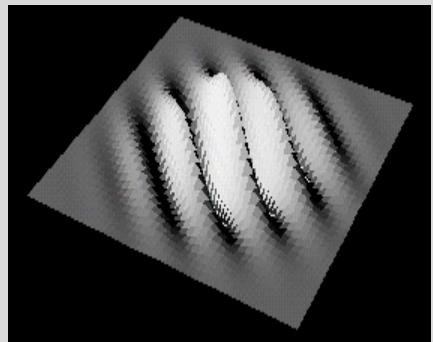


Inter-ridge distance $\lambda=500\mu\text{m}$
« Natural » scanning speed $v=10\text{cm/s}$

→ Peak frequency $f = v/\lambda = 200\text{Hz}$
= Maximum sensitivity of Pacinian fibers

- Fingerprints provide pre-neural spectral selection and amplification of textural component of wavelength λ .
- They shape the subcutaneous stress signal for optimal encoding by Pacinian channel.

Gabor filters



Other relevant filtering characteristics:

- Edge detection
- Contrast enhancement
- Motion detection
- Texture discrimination.





Conclusions

Transduction of tactile information depends on intrinsic response properties of the sensors, contextual exploratory conditions and skin texture.

A naive linear model of tactile transduction is proposed that takes into account these effects – the linear response function is the product of the interfacial stress field and the point-load response.

Open questions :

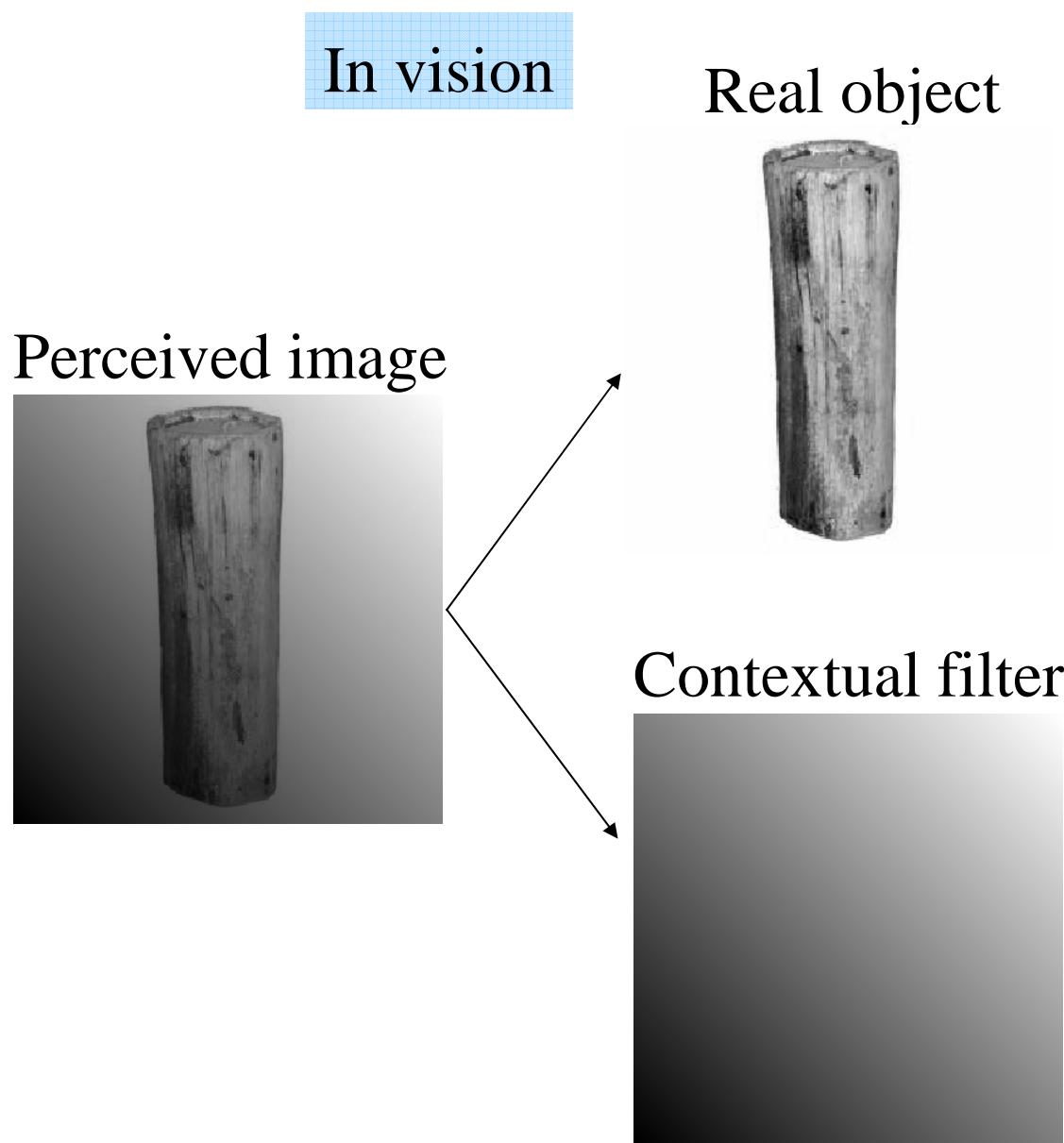
How to deal with such context dependent variability of individual sensors' response. What encoding strategies may yield a stable representation of the probed surface.

Non-linear effects (interaction between defects) might be important.





Perception and context



In tactile sensing

Action for perception

- Shape recognition
- Surface properties
- Hardness/softness
- Mass evaluation

Perception for action

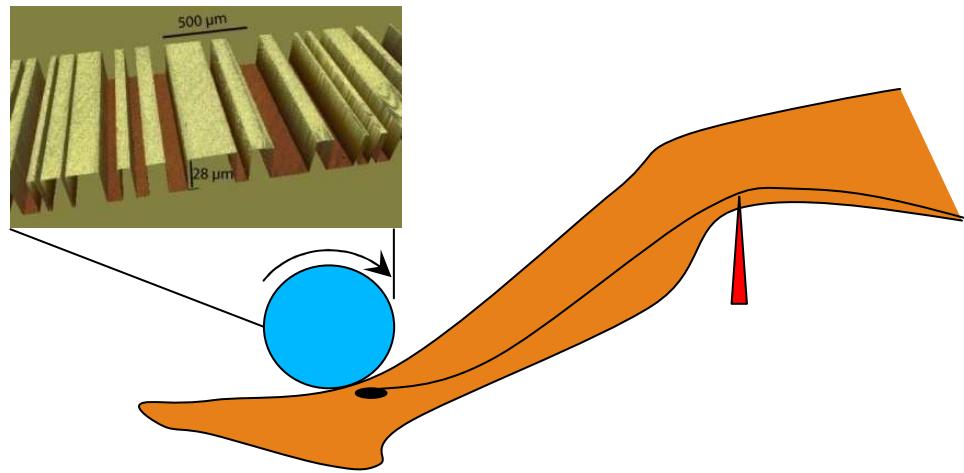
- Grasp control
- Dexterous manipulation
- Contact point estimation
- Slip detection





Comparing biomimetic and human touch

Can one relate the subcutaneous stress field measured with the biomimetic sensor with actual neurographic data ?



JP Roll - LNH – Marseille

