Sparse somatosensory coding

Explaining and predicting the response properties of rodent afferent pathway neurons

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Motivation and Background

The efficient coding hypothesis (Barlow 1961) has been influential and important in theoretical neuroscience for decades.

Big picture: neural codes are adapted to efficiently process the natural statistics of the world:

Representational sparseness $\Longrightarrow$ Tuning curves efficiently tile the input space

Lifetime sparseness $\Longrightarrow$ Transmit a signal with fewest spikes

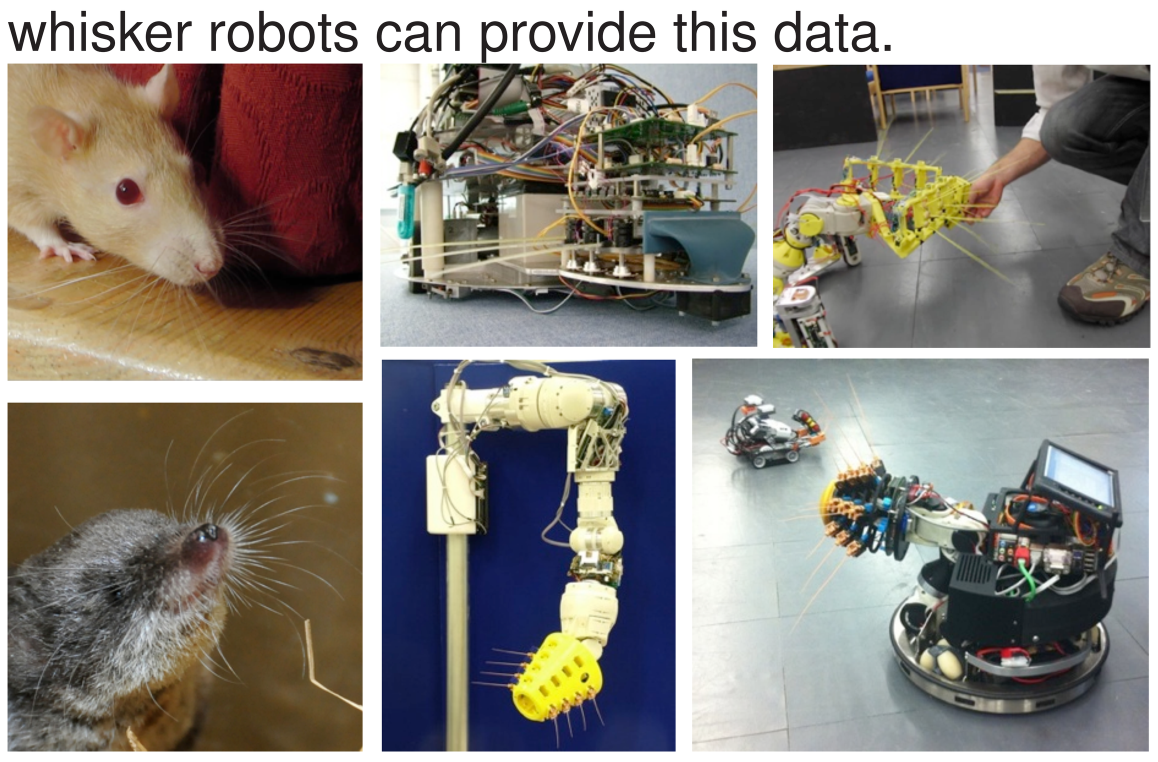
Progress beyond initial sensory areas remains limited, partly due to incomplete knowledge of functional circuit activity (i.e. activity of all neurons involved in a behaviour).

Whisker Sensing: from rodents to robots

The whisker system provides an ideal test bed for experimental neuroscience – a mammalian sensorimotor circuit amenable to a wide variety of powerful protocols.

To date whisker sensing hasn't been explored with modern theoretical neuroscience approaches.

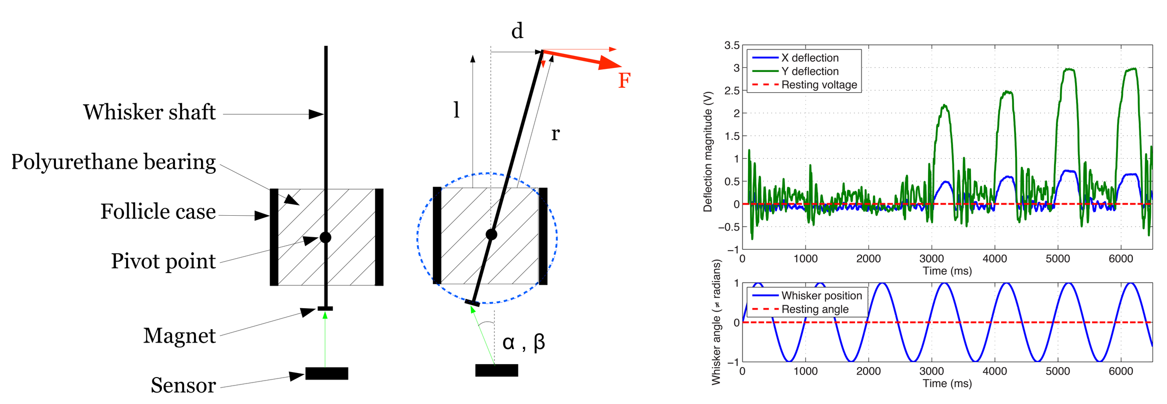
A large factor has been the lack of appropriate datasets for developing models. Artificial whisker robots can provide this data.



Clockwise from top left: a rat, Whiskerbot (Pearson et al 2007), SCRATCHbot (Pearson et al 2010), Shrewbot (Pearson et al 2011), BIOTACT G1 (Sullivan et al 2012), an etruscan shrew.

Artificial whiskers

Scaled (x4) model of rat whiskers, 3-D printed from ABS plastic to match real-whisker mechanical properties. Whisker bends and rotates around a soft pivot. Instrumented with a magnet at the whisker base and a hall-effect sensor. Measures a combination of bending and deflection magnitude at up to 50KHz.

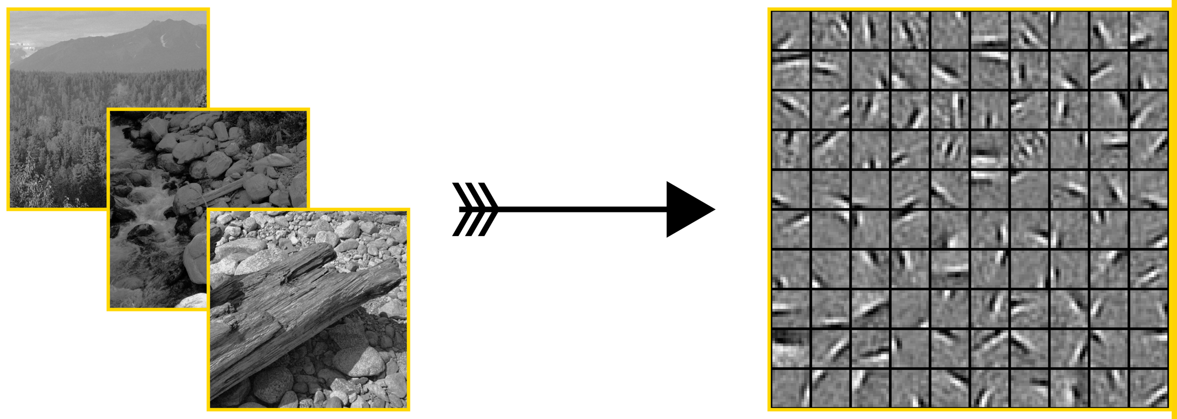


Sparse Coding Algorithms

Proposed by Olshausen and Field *Nature* 1995 to explain for V1 simple cell responses.

Goal: Learn an *overcomplete* set of basis vectors to *sparsely* represent an input.

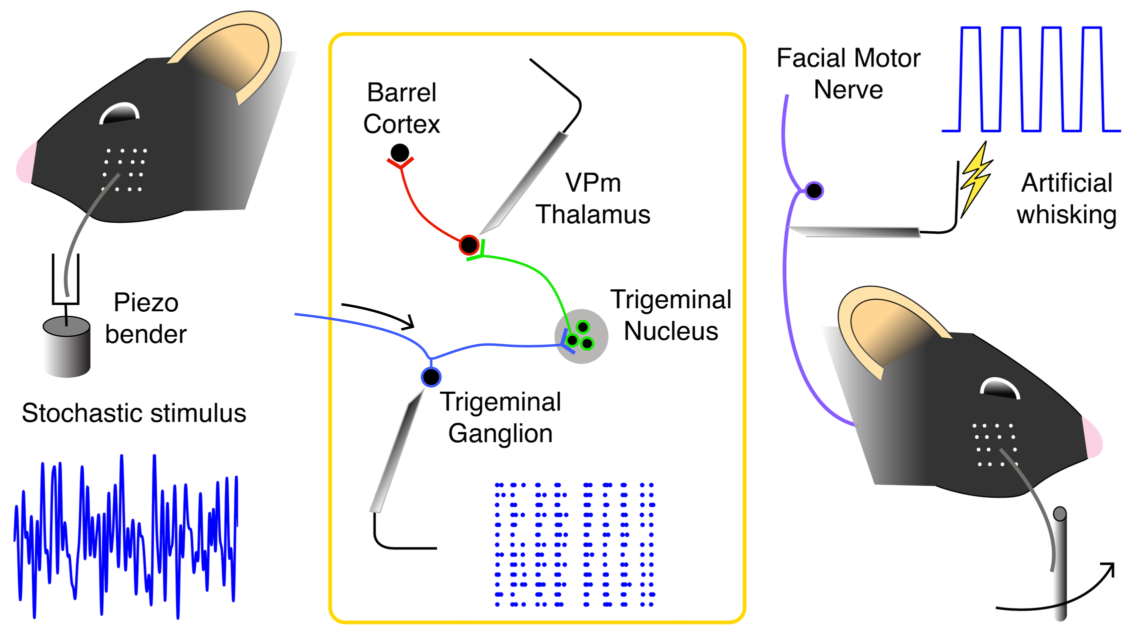
More recently has seen a resurgence in machine learning following the development of efficient sparse coding algorithms Lee et al *NIPS* 2006 allowing larger sparse codes, providing benchmark performance in classic supervised classification tests Le et al *CVPR* 2011, and avenues for deep Lee et al *ICML* 2009 and 'self-taught' learning Raina et al *ICML* 2007.



Experimental Paradigms

Comparing to results from Szwed et al *Neuron* 2003 (**A**), and Petersen et al *Neuron* 2008 (**C**).

In anaesthetised rats, neural activity was recorded (extracellular, single units) from the trigeminal ganglion during artificial whisking into a pole (Szwed et al, right), and the ventro posteromedial nucleus of the thalamus during whisker deflection with stochastic stimuli.



Sparse Somatosensory Coding

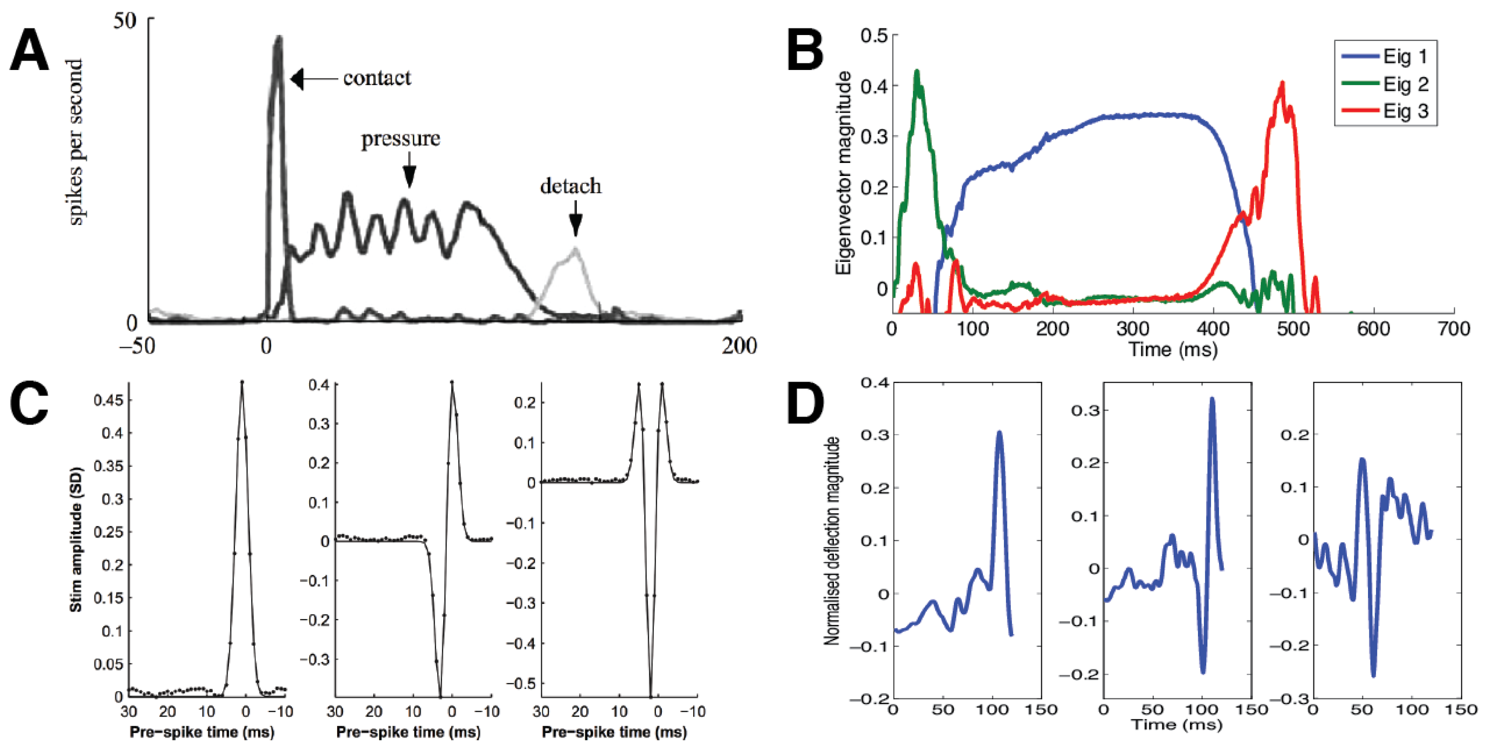
Trigeminal ganglion responses to ramp stimuli (**A**) are aligned to first three principal components of artificial whisker deflections (**B**). This decomposition accounts for 99% of signal variance in this instance (efficient), and neural responses are orthogonal (reducing redundancy across the population).

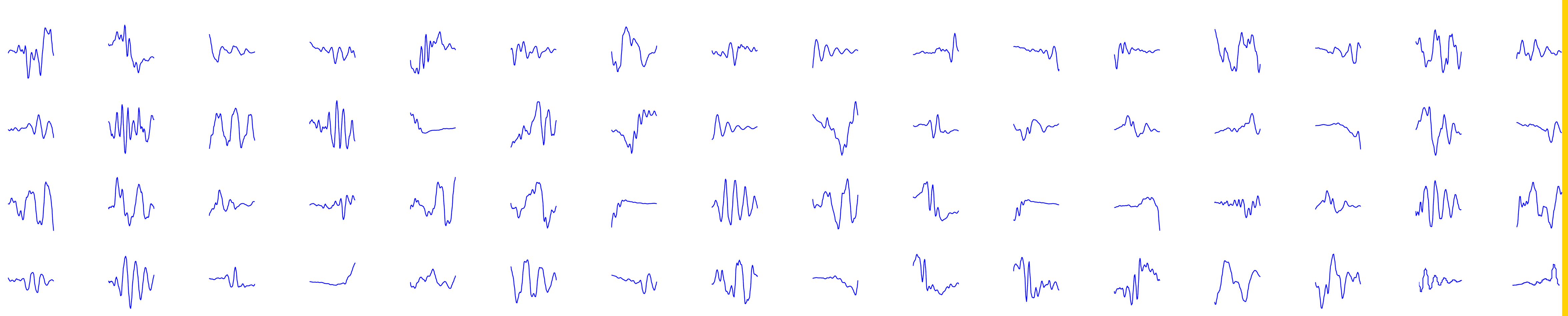
VPm thalamus responses to stochastic stimuli (**C**) resemble a subset of basis functions derived from sparse coding of artificial whisker deflections (**D**).

Petersen et al 2008 reported VPm cell tuning curves to 'diverse kinetic features'. Comparing these cells to the complete population of sparsely-generated tuning curves (such as is shown below) could explain these diverse responses. Current work is focussed on testing the robustness of sparsely coded representations and comparing bases to GLM-derived neural tuning curves.

Applying similar sparse coding algorithms to multi-whisker inputs could guide the search for multi-whisker tuning curves in the brain.

Exploring different parameter spaces, such as complex objects, or varying whisker movement could also provide insights into higher-level somatosensory representation and touch-invariant encoding.





Conclusions and Future Plans

Work in progress, but sparse coding algorithms may predict and explain the response properties of rodent afferent pathway neurons.

Machine-learning approaches like deep learning may provide insights for processing in other hierarchical loops and circuits in the brain.

Given the success of sparse coding in machine learning, may provide powerful pre-processing for tactile sensing or in robotics more generally.

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