Kinematic Studies of Octopus Movements: 3D Reconstruction and Analysis of Motor Control

by
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Talk plan

- Introduction: why study octopus movements?
- Three-dimensional reconstruction of octopus arm movements.
- The motor-primitives hypothesis.
- Conclusions and future research.

why study octopus movements?

Behaving octopuses

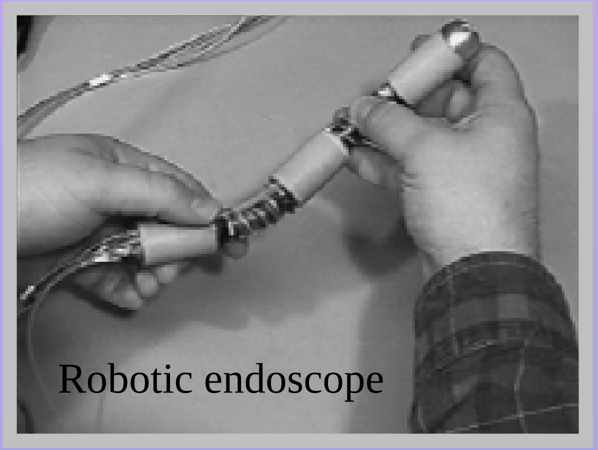
• Have muscular hydrostat arms , a non-rigid skeleton with a very large number of degrees of freedom.

• Are active predators with impressive motor behavior.

Robotic Arms

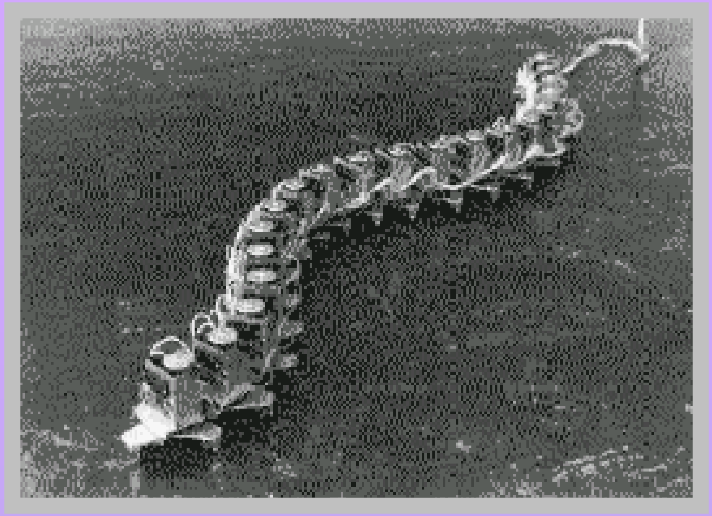
• Interesting applications for hyper-redundant robotic manipulators, but the control of such an arm is a very difficult task.

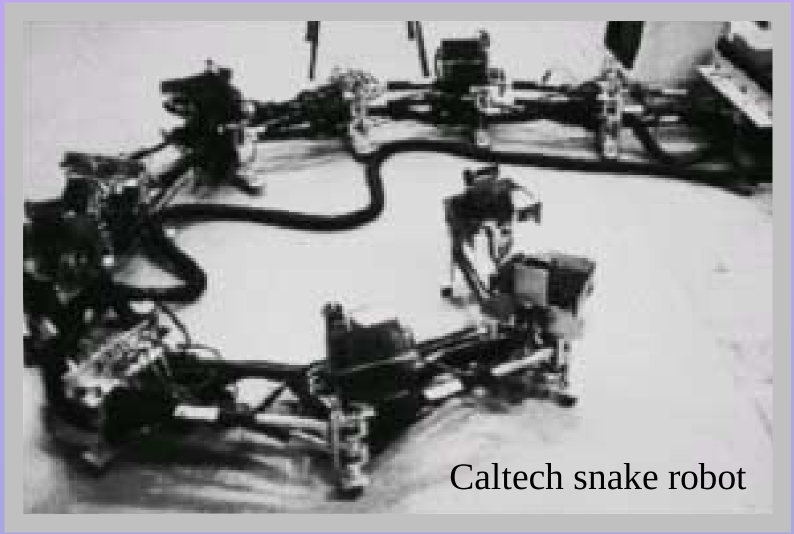
• The solutions evolution found for octopuses might be useful and applicable to robotics.



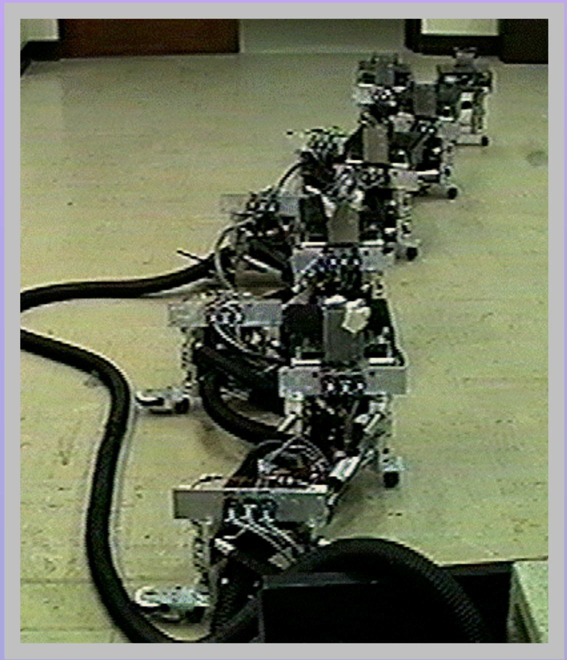
Robotic endoscope

Planar
hyper-redundant robots

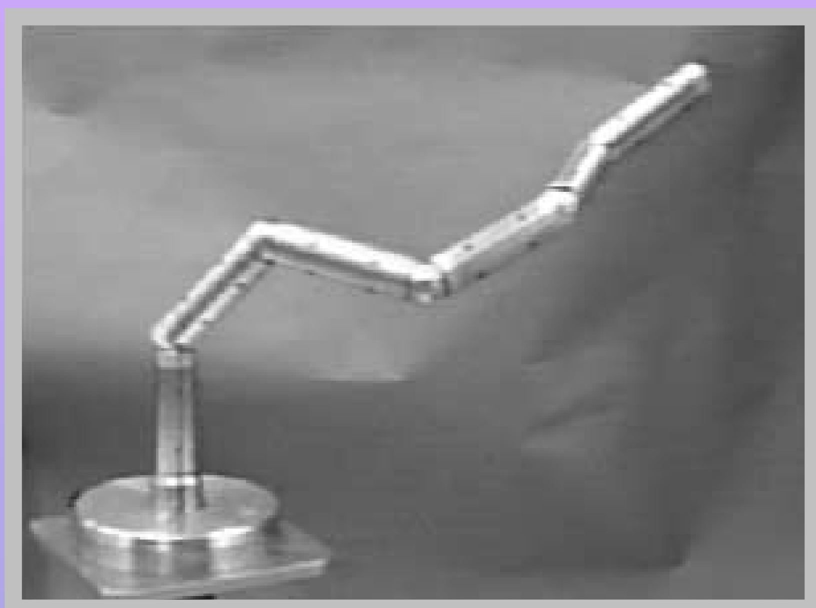


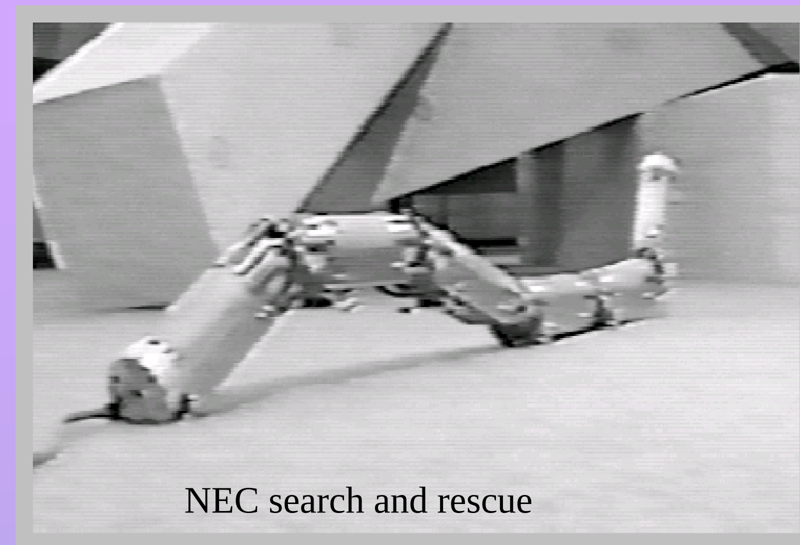


Caltech snake robot



Spatial hyper-redundant robots





NEC search and rescue

3D reconstruction of octopus’ arm movement

- Raw data acquisition

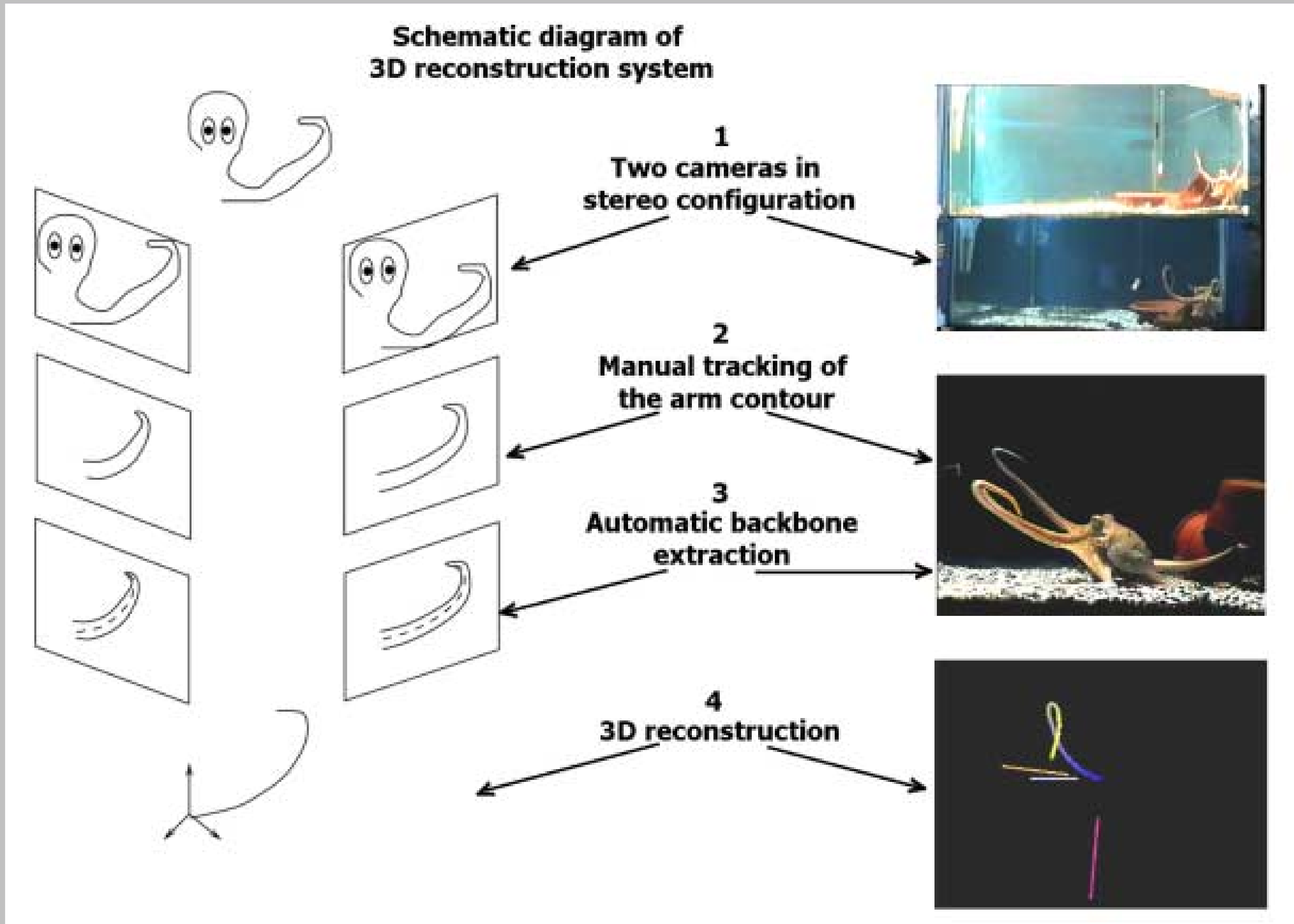
  Two or more video cameras.

- Tracking an arm during motion

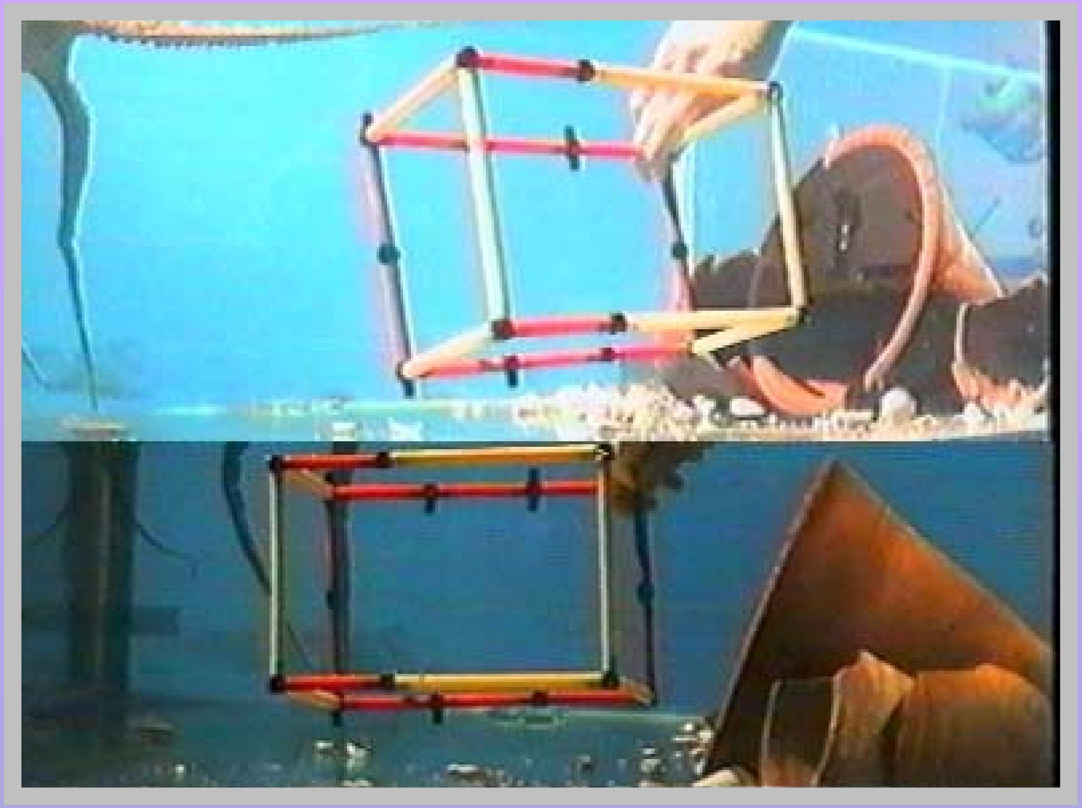
  The arm is a non-rigid body.

- Metric 3D reconstruction

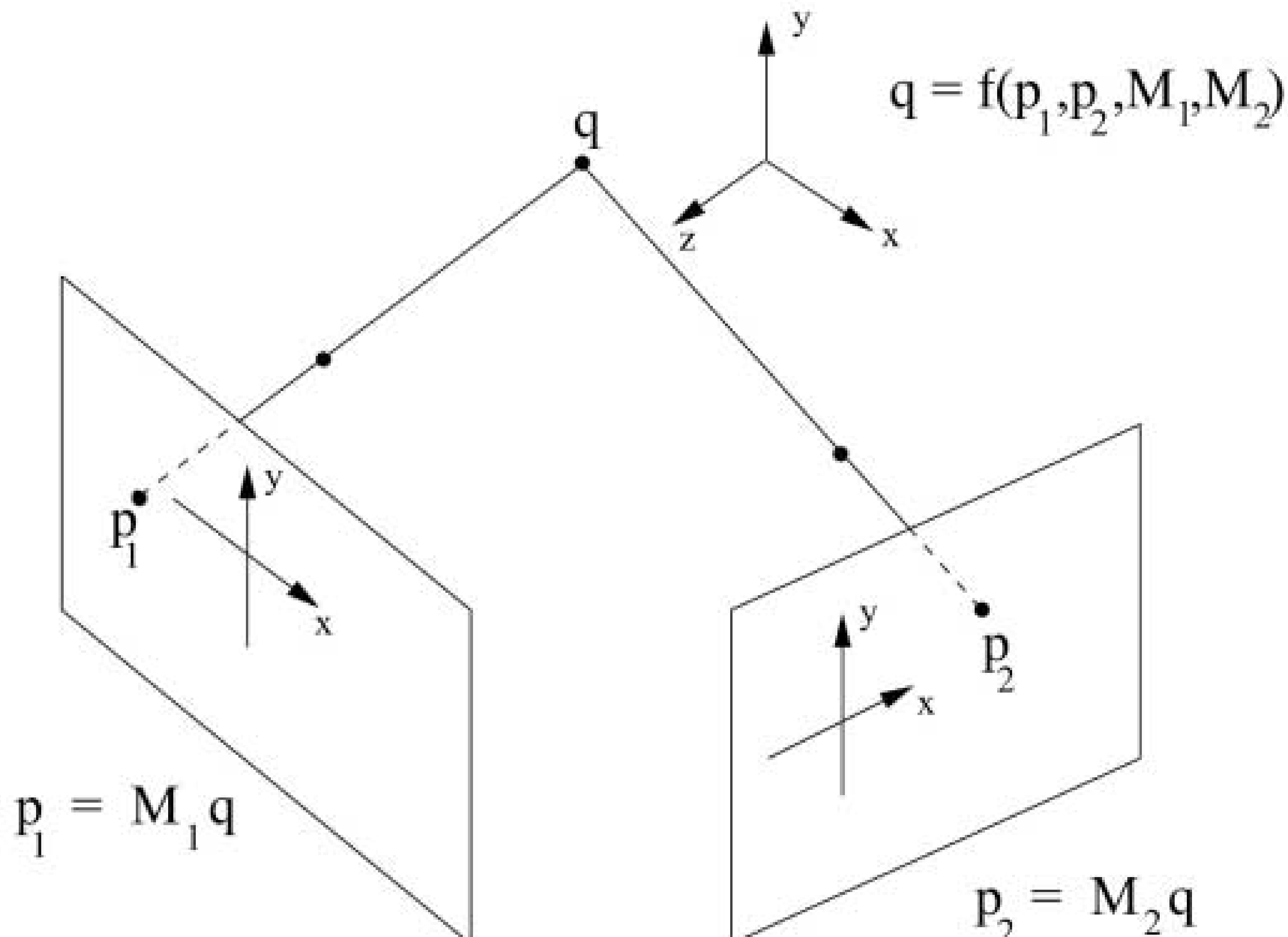
  Calibration of the cameras.
  Choosing an appropriate arm feature to reconstruct.
  Geometric relations relevant to reconstruction.


Schematic diagram of
3D reconstruction system
1
Two cameras in
stereo configuration
2
Manual tracking of
the arm contour
3
Automatic backbone
extraction
4
3D reconstruction

Camera calibration for 3D reconstruction

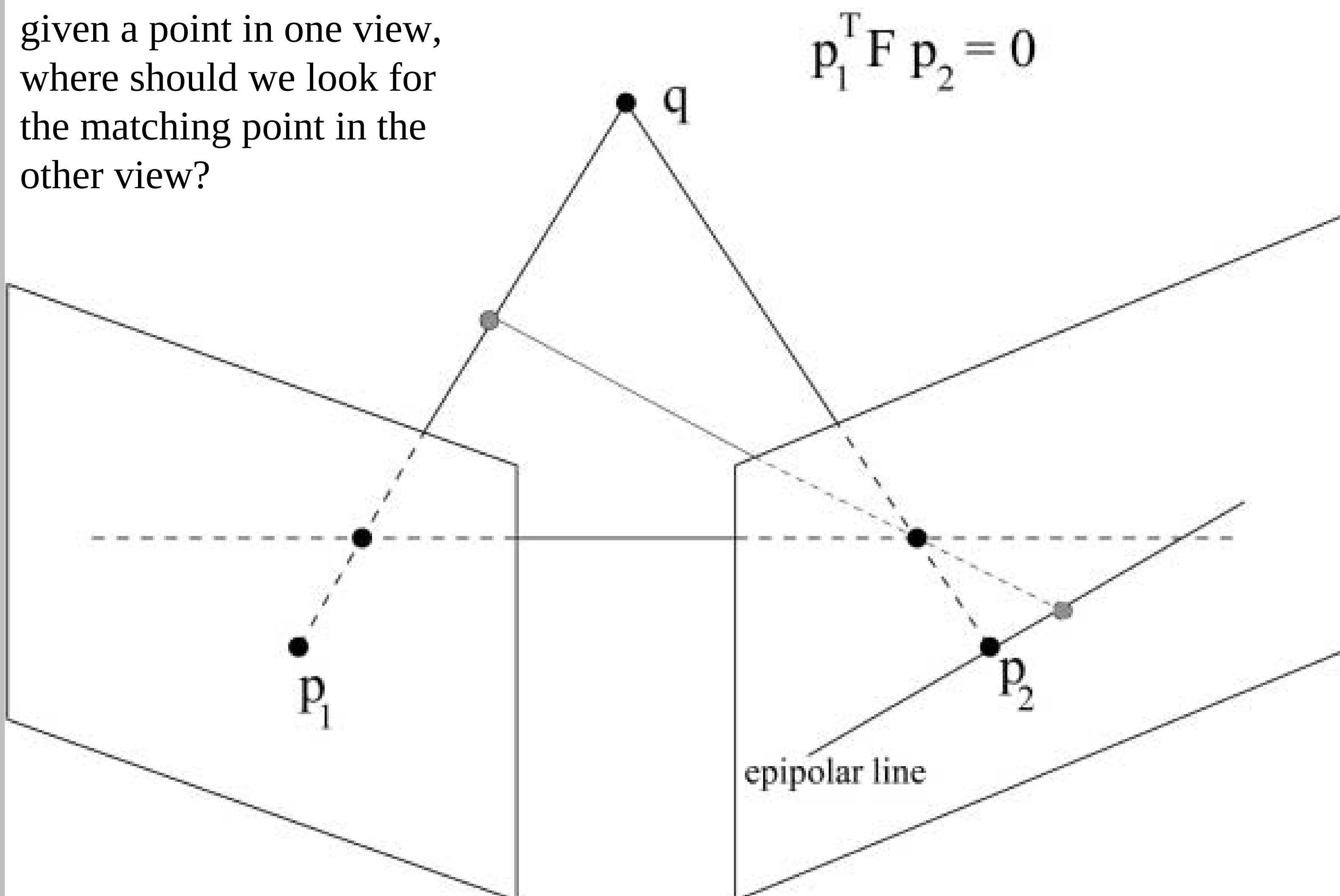


Three-dimensional reconstruction of one point

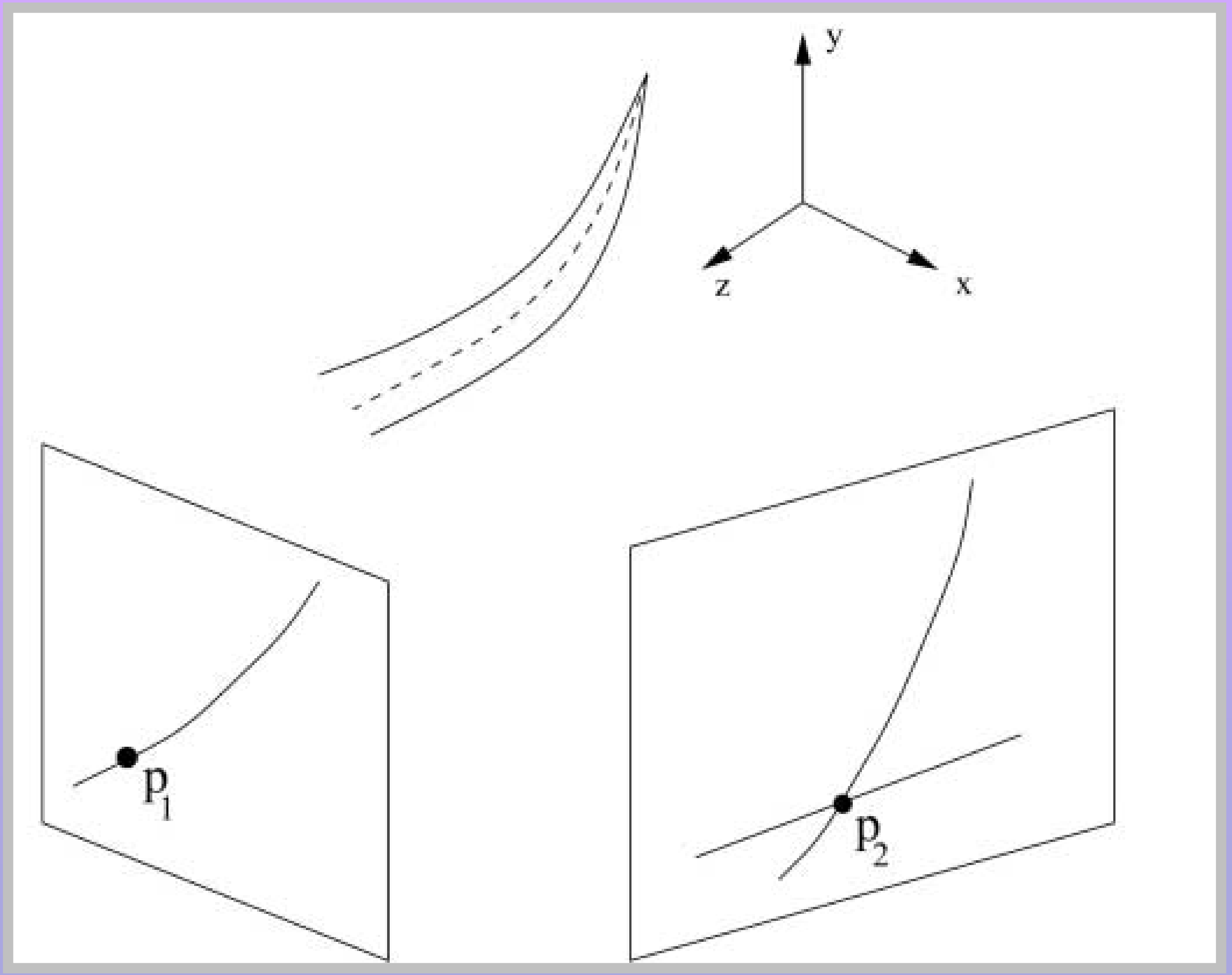


The matching problem and epipolar geometry

given a point in one view, where should we look for the matching point in the other view?



Three-dimensional reconstruction of the backbone curve



Finding the middle line of an arm

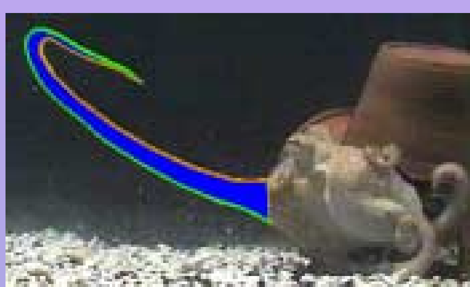
- Naïve implementation:

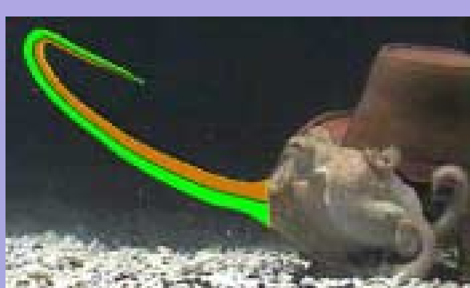
  Match evenly spaced points on the 2 sides of the arm contour.

Works ok

- Potential field algorithm:

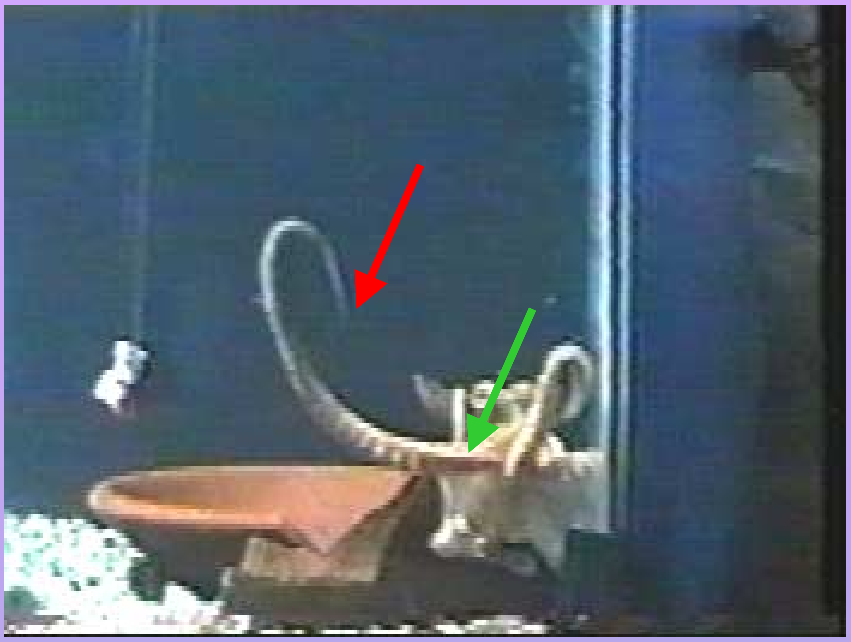
  Paint in equal speed from the 2 sides of the arm contour using different colors.



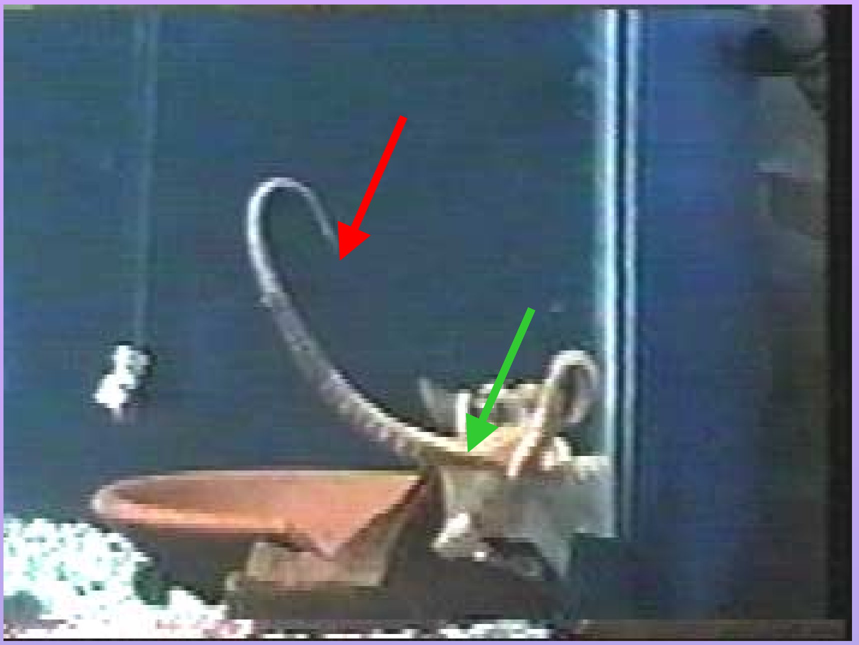


Doesn't work

See movie on VCR



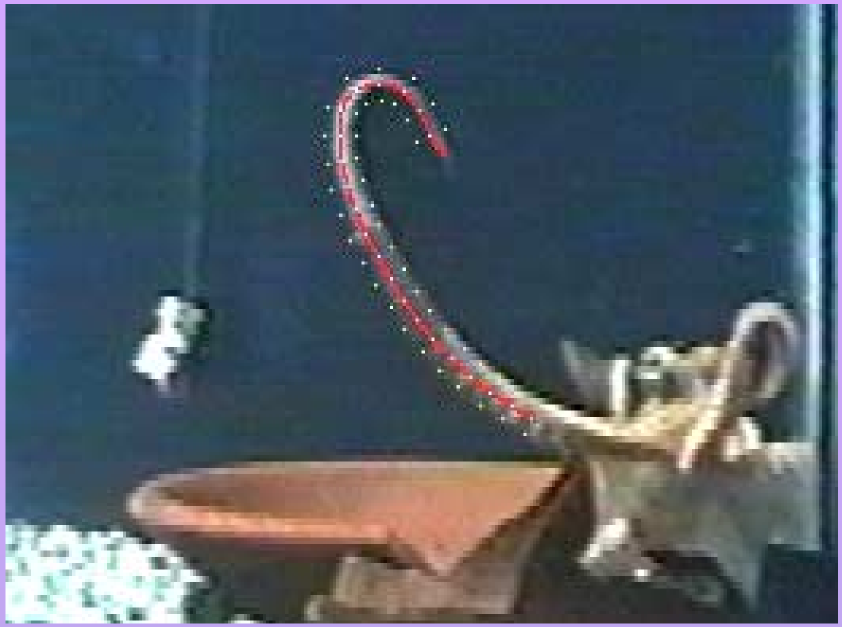
t



$t + \Delta t$

There is an uncertainty in the position of the first and last points of the reconstructed curve along the arm, so we need to align arms in consecutive times.

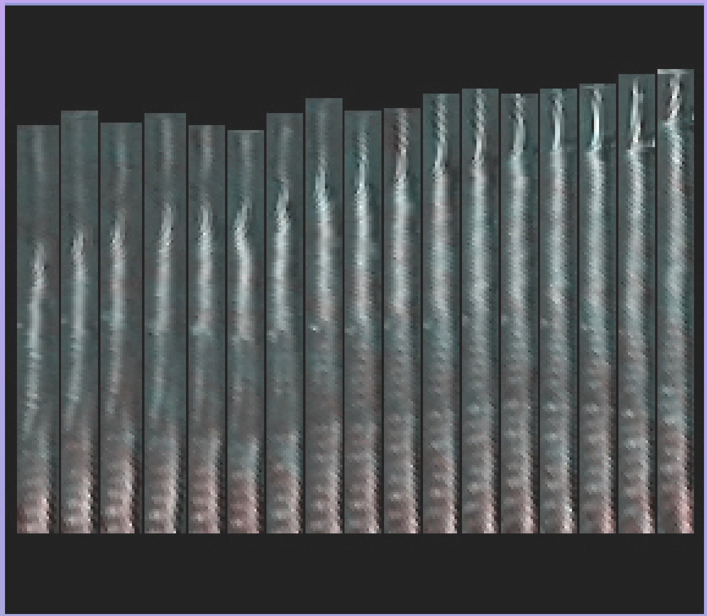
A curved coordinate system is fitted to each arm, using the backbone curve and its normals.



The arm texture is sampled and transformed to create a normalized texture map.

A translation value along the main axis (backbone curve) was found using correlation between every two consecutive normalized texture maps, and was used to align the whole set to the first map.

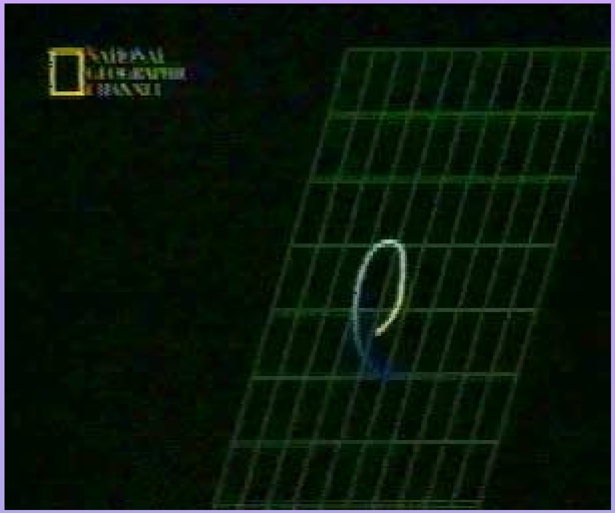
Before alignment



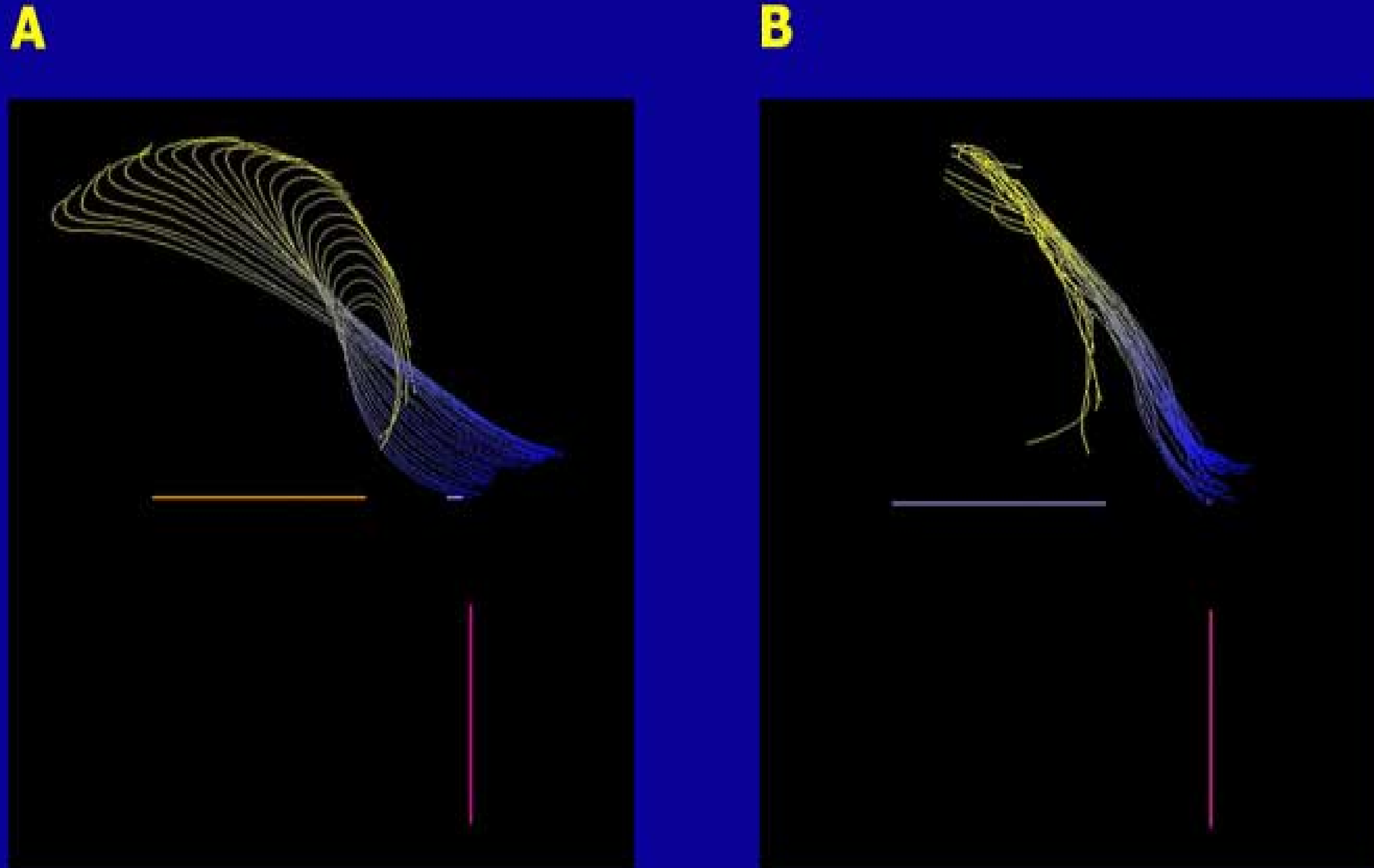
After alignment

data

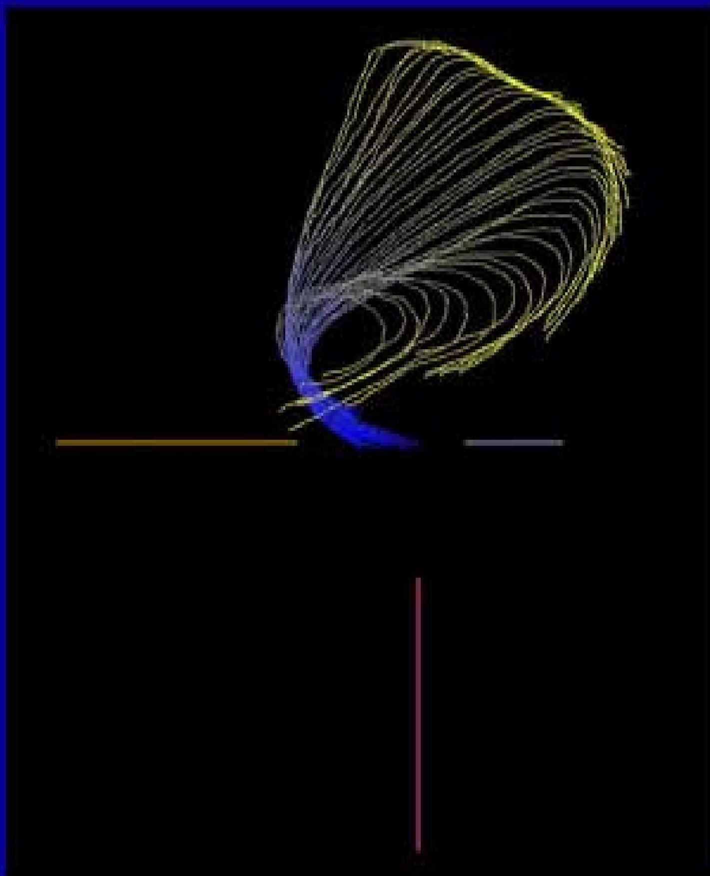
Reconstruction



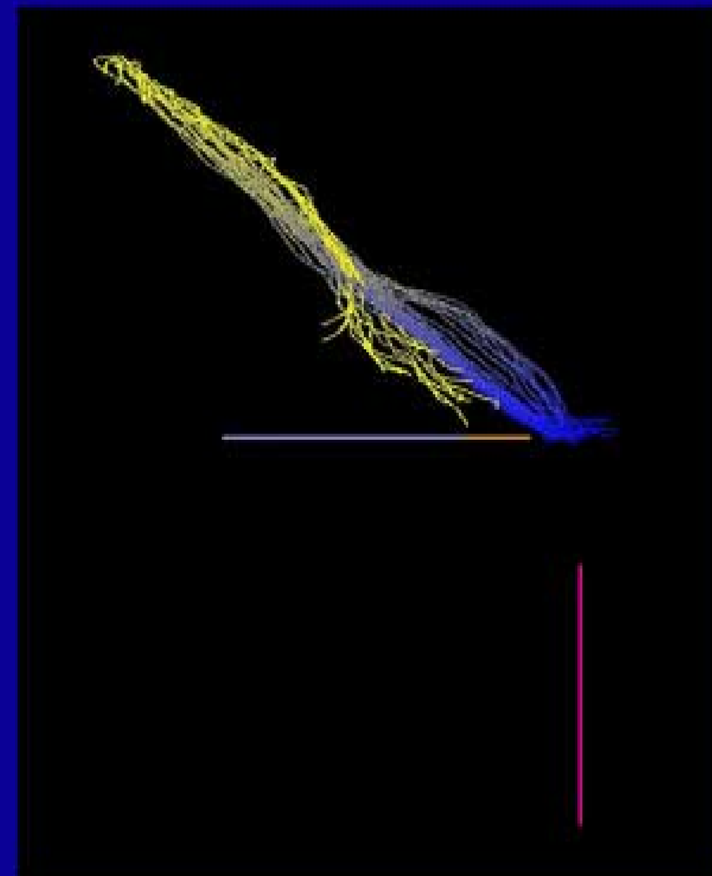
See movie on VCR


A
B

A



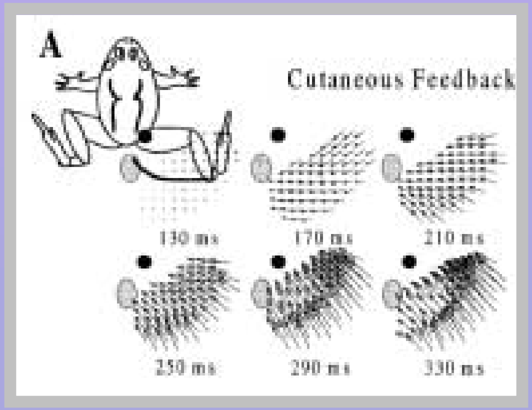
B



The motor-primitives hypothesis

"The complex and high-dimensional control problem
Could be addressed by structuring the motor system as a collection of *primitives* which can then be sequenced and combined to produce the complete and complex repertoire of movement."
(Demiris & Mataric 1998)

Coupling degrees of freedom to reduce the number of controlled variables.



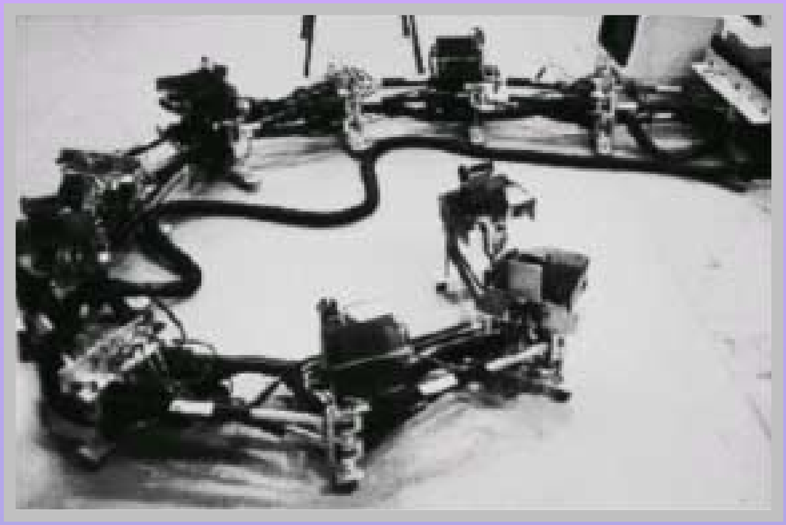
Kargo WJ & Giszter SF, 2000. J. Neurosci 20(1):409-426

Tresch MC, Saltiel P & Bizzi E, 1999. Nature Neurosci 2(2):162-167.

Mussa-Ivaldi FA, 1997. Proc of CIRA 97.

Control of hyper-redundant robots by using modal functions.

By Burdick JW, Choset H, Chirikjian GS & Takanashi N



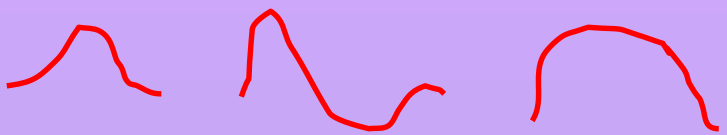
$$F(s,t) = \sum_{i=1}^{n} a_i(t) g_i(s)$$

Octopus Arm characteristics and the search for motor primitives

Any part along the arm is similar to any other, and the movement looks as if it is composed of similar shapes that travels along the arm. There is a large number of degrees of freedom, but these DOF are not independent.

Assumptions:

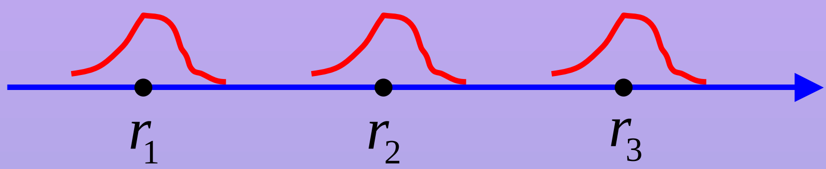
- Existence of a small set of simple functions:

$g_i =$ 

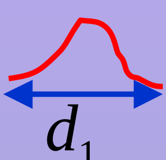
- Some representation of the arm is a sum of transformed functions :

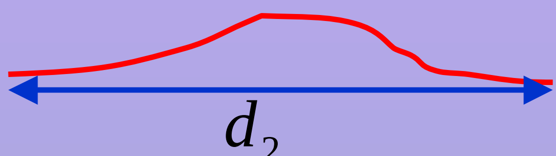
$$F(s,t) = \sum_{i=1}^{n} a_i(t) \cdot g_i\left(\frac{s}{d_i(t)} - r_i(t)\right)$$

$r_i(t)$ translation along the arm

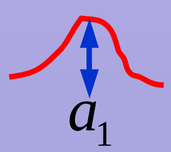


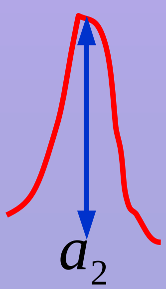
$d_i(t)$ dilation





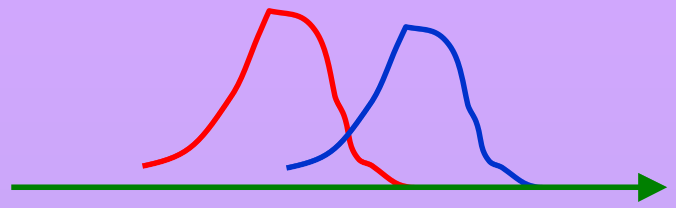
$a_i(t)$ amplitude





- $r_i(t), d_i(t), a_i(t)$ change slowly in time.

But this is not an orthogonal set, so the $a_i(t)$ are not an inner product like in other transforms



$$F_1 \cdot F_2 \neq 0$$

Questions:

A. What is the relevant representation ?

x, y, z ?

$\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt}$?

K,T (spherical coordinates) or their time derivatives ?

κ, τ (Curvature & torsion) ?

Combinations of spatial variables and their time derivatives ?

B. Given the representation:

1. How to find the 'basis' functions ?
2. How to find the coefficients: $r_i(t), d_i(t), a_i(t)$?

Current solutions:

A. try different representations.

- focus on the curvature-torsion representation because of the relation between muscle contraction and shape of the octopus arm that might link dynamics and kinematics.

B. Given the basis functions, use a genetic algorithms to find the coefficients.

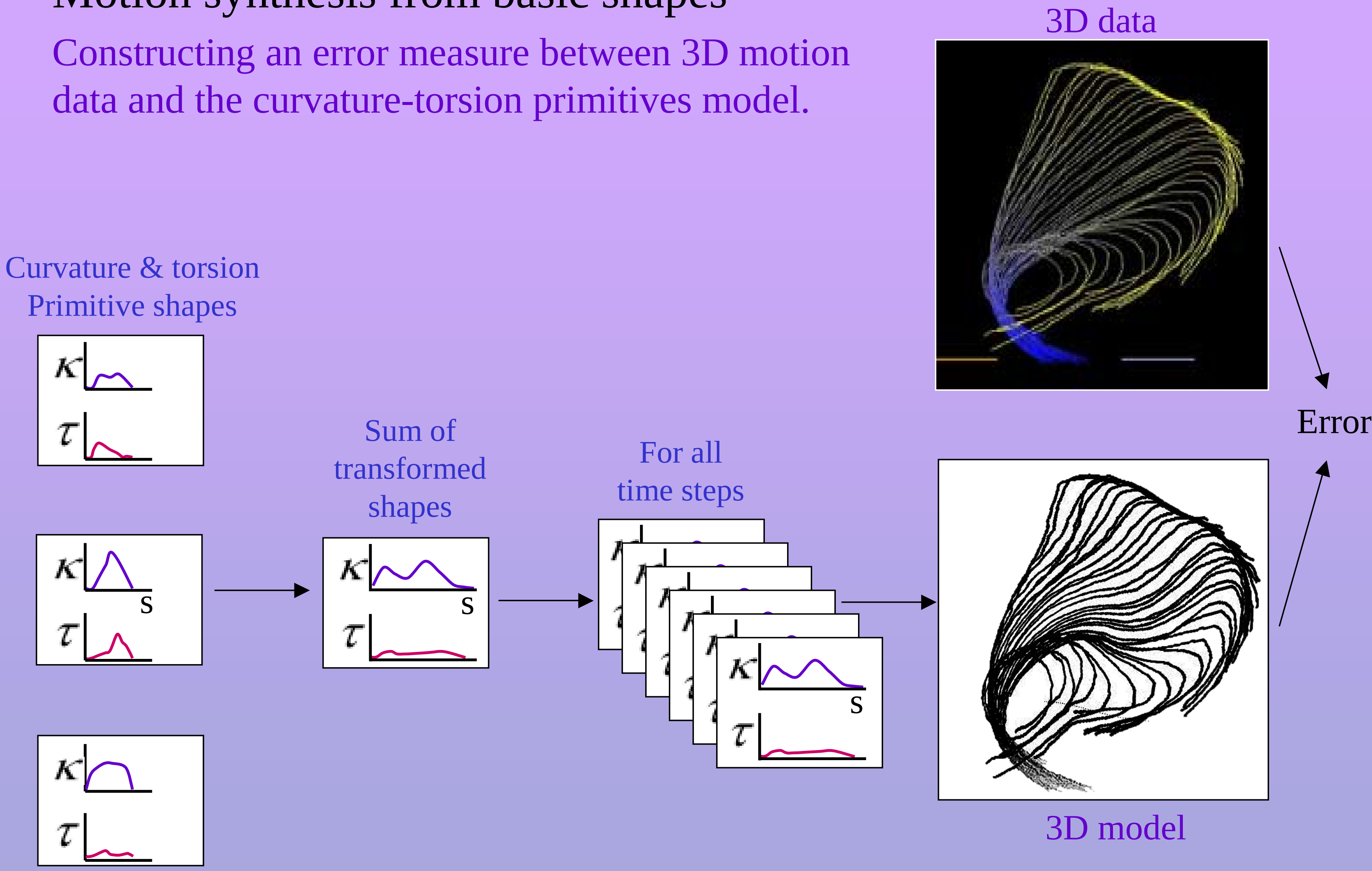
- the search for the coefficients should be performed simultaneously for the different basis functions.
- the search space is large with a lot of minima.
- It is possible to evaluate different sets of basis functions.

C. Using a genetic algorithm to search for the basis functions.

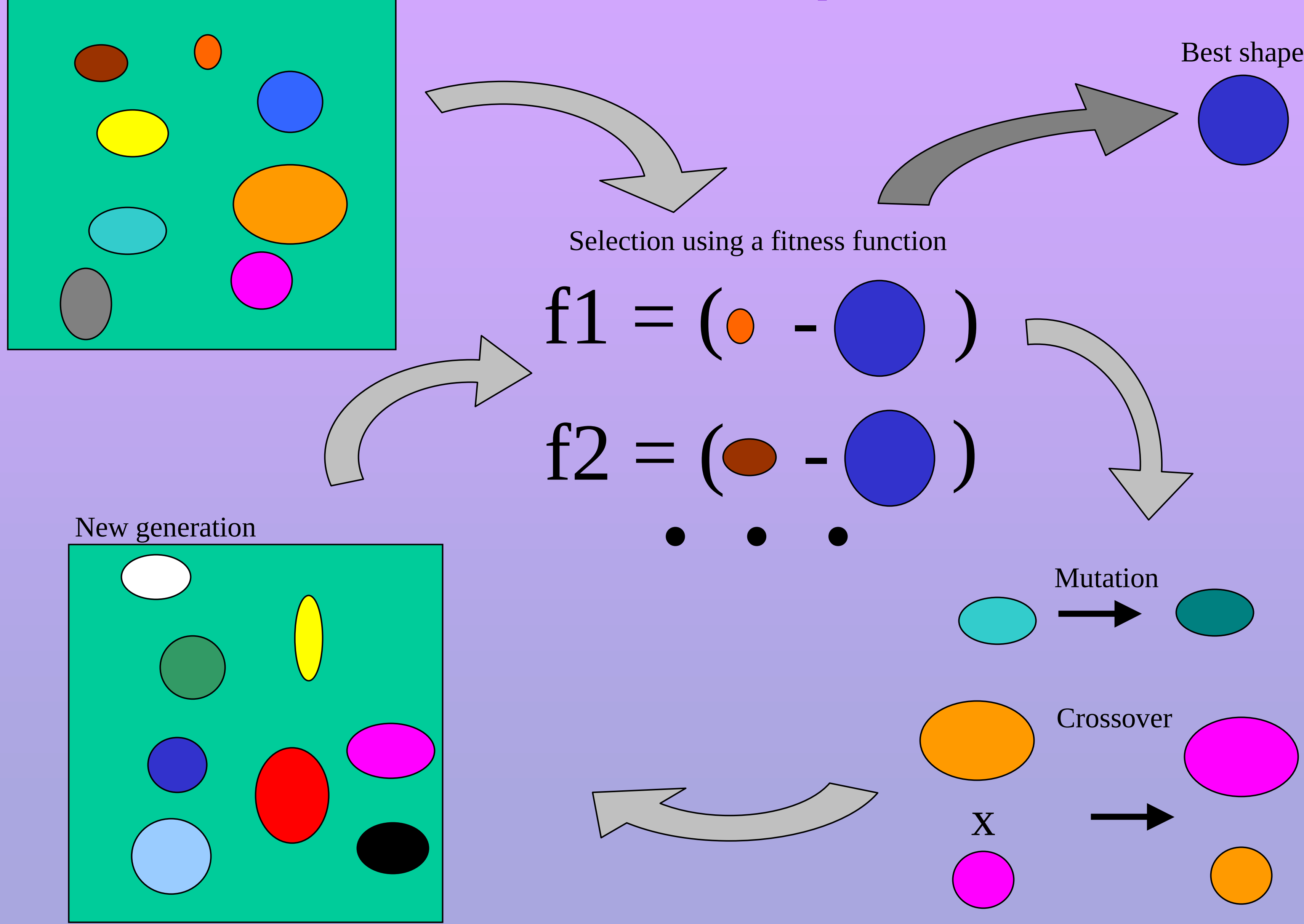
- A meta algorithm that uses step B as an inner module.

Motion synthesis from basic shapes

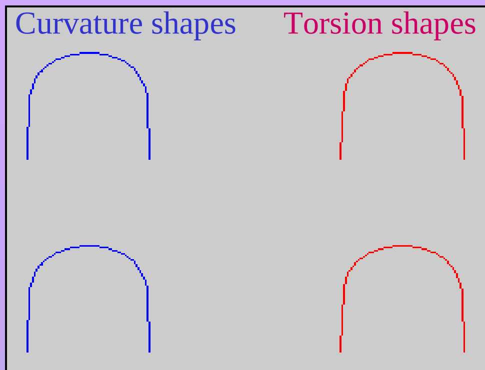
Constructing an error measure between 3D motion data and the curvature-torsion primitives model.

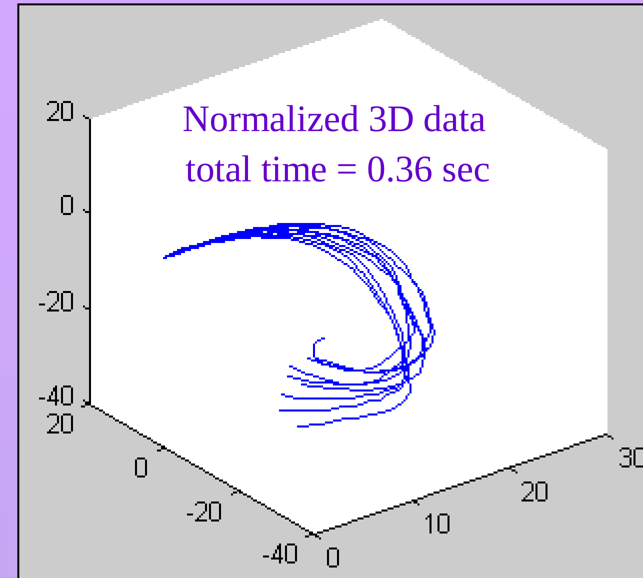


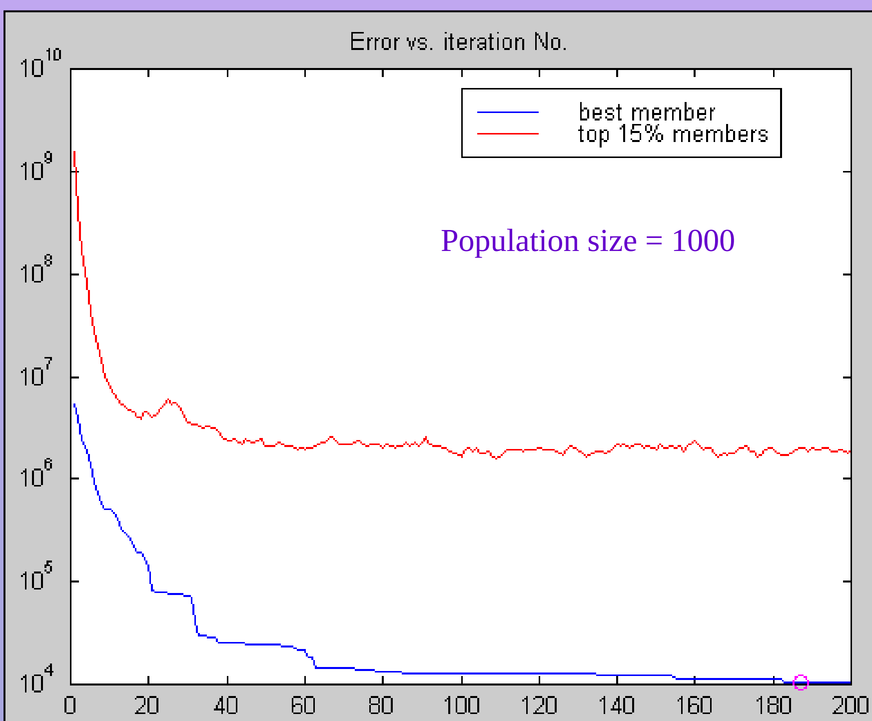
A schematic diagram of the genetic algorithm used to find common patterns in the data

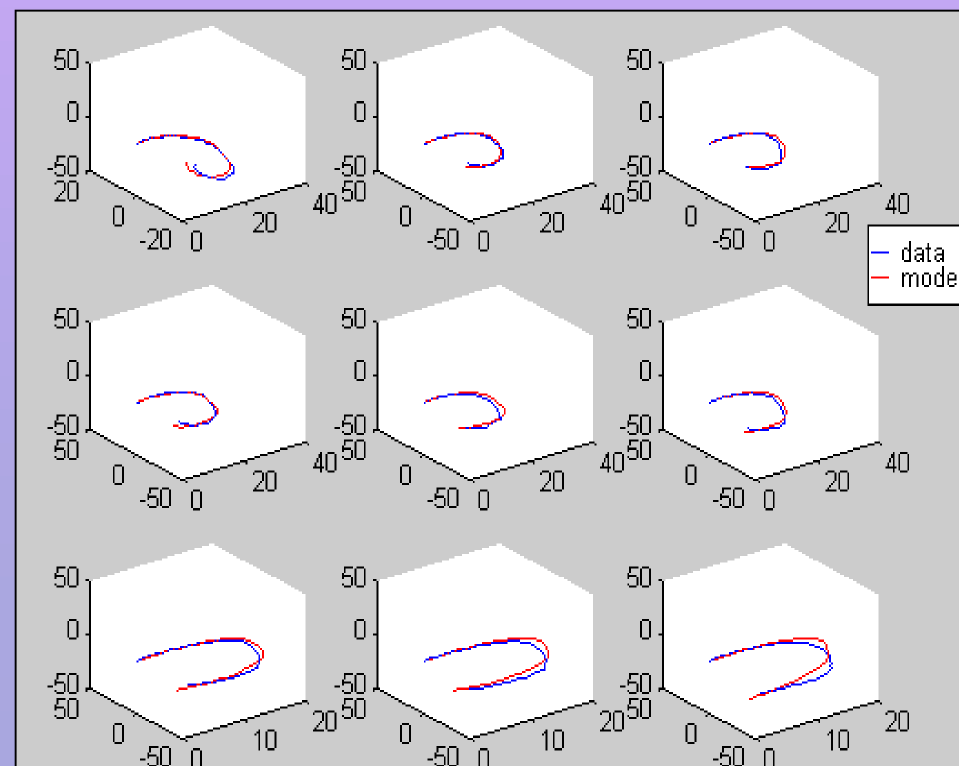


An example:
Given the shapes of the 'basis' functions the genetic algorithm found their position and size that best match the data.

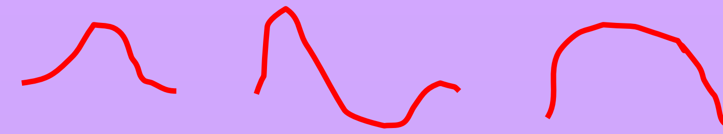






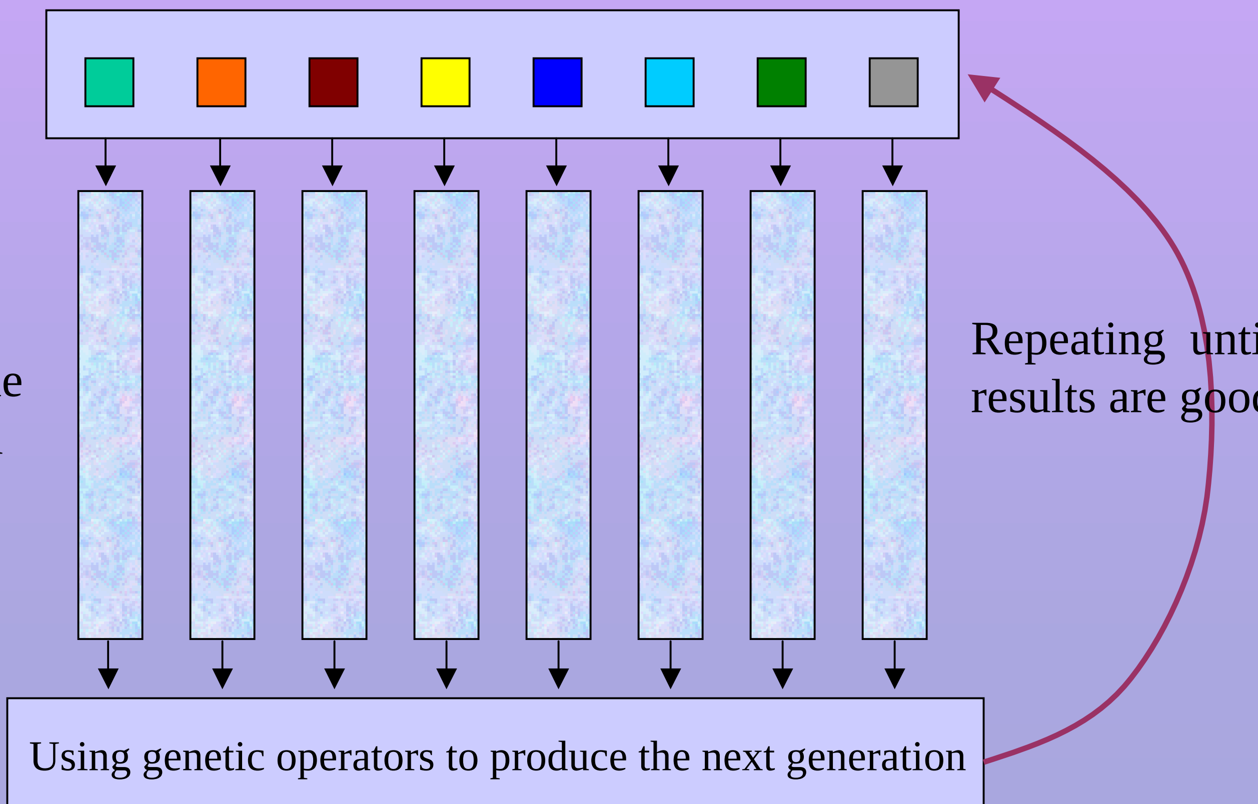


Finding the basic shapes



It is possible to evaluate different sets of basis functions and use the results to search in the shape space.

A large population of shapes



Using a genetic algorithm to find the coefficients of each shape

Repeating until the results are good enough

Conclusions and future research

1. 3D reconstruction of octopus arm movements is possible.

2. The search for motor primitives is difficult but promising. The results could be used to classify movement and help in understanding octopus motor control.

3. Other parts of the octopus project could be linked to this research. Please see our posters.

THANK YOU