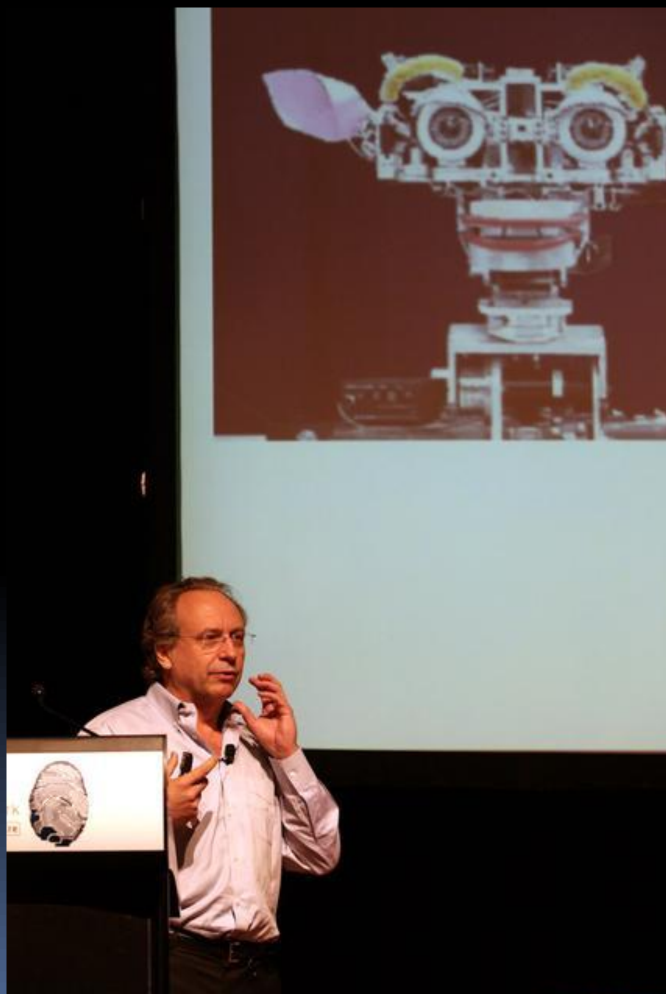
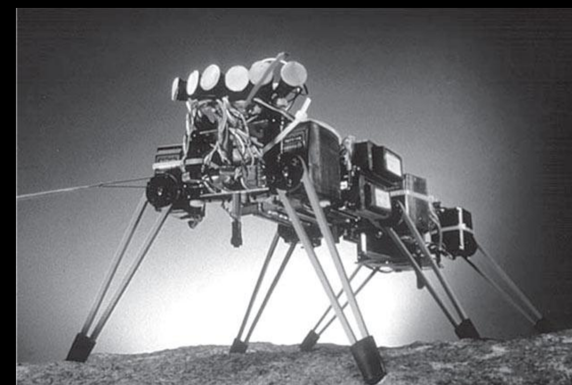
Steps towards the Open Worm project

Stephen D. Larson
http://openworm.googlecode.com
NeuroML 3rd Annual Meeting
London, 4/1/2011

What neuroscience can learn from AI: embodiment





What neuroscience can learn from AI: embodiment

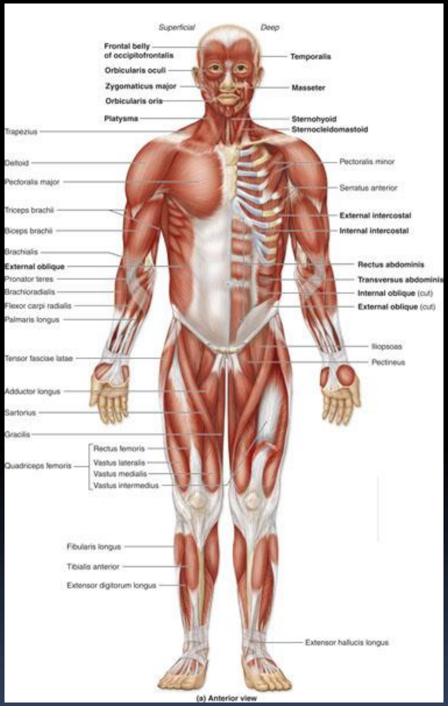
World

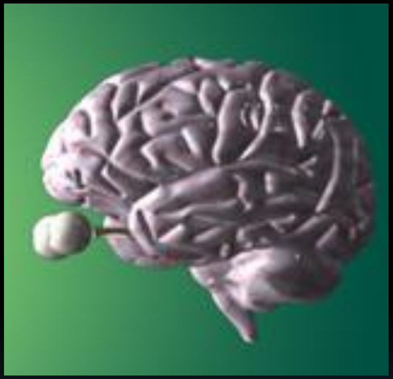
"body"

Sensor input, Control System, Moto r output

What neuroscience can learn from AI: embodiment

World

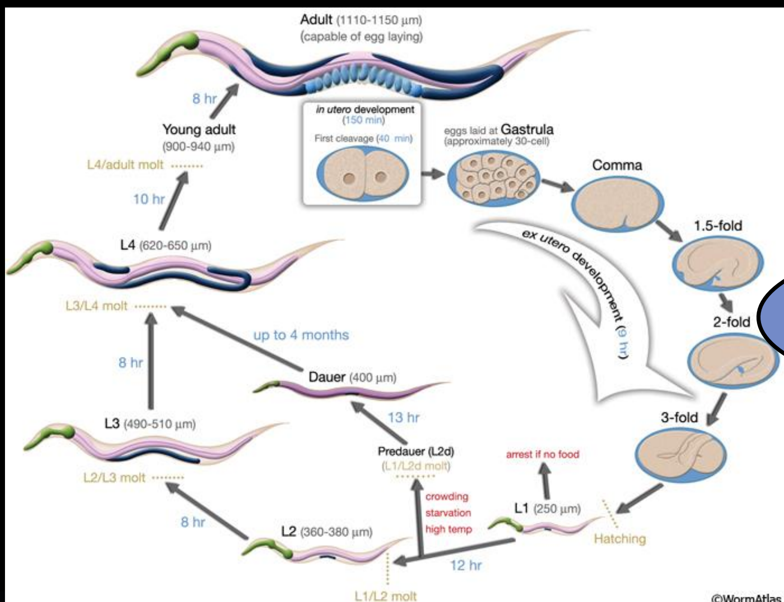


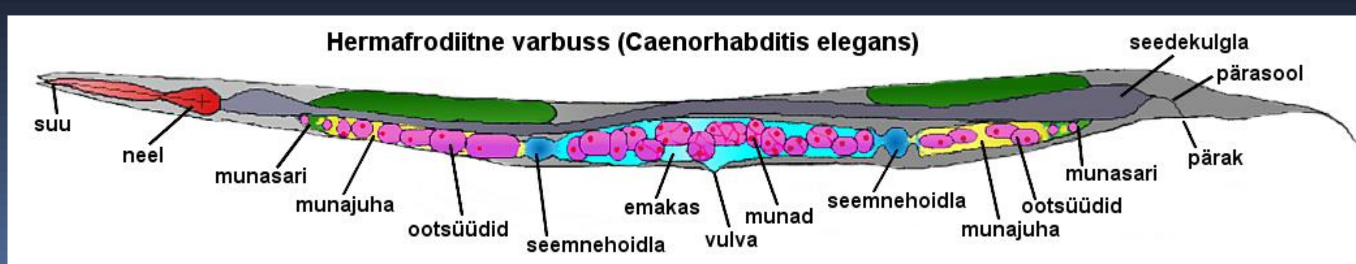


Virtual physical organisms in a computer simulation

AnimatLab
www.animatlab.com

Enter the worm: c. elegans

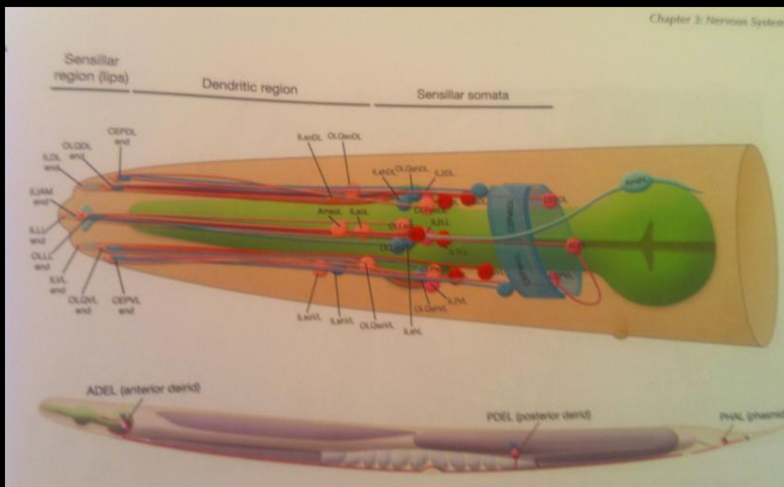


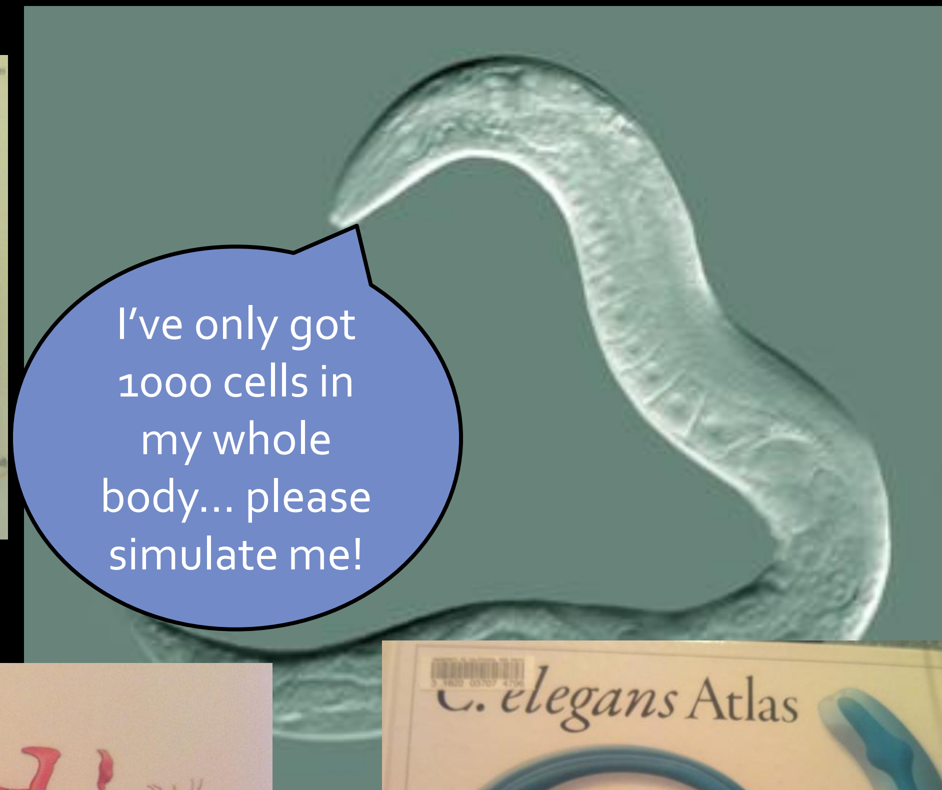


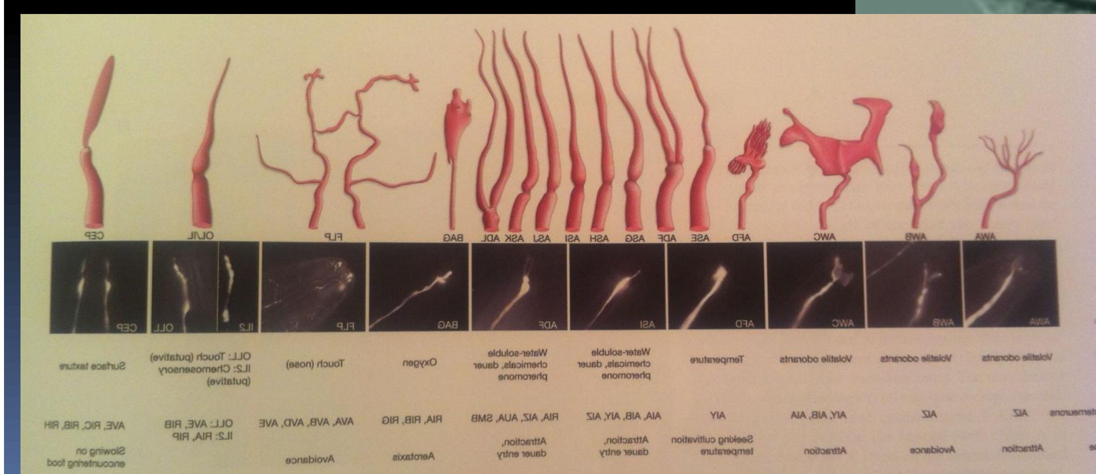
In search of nature’s design principles via simulation

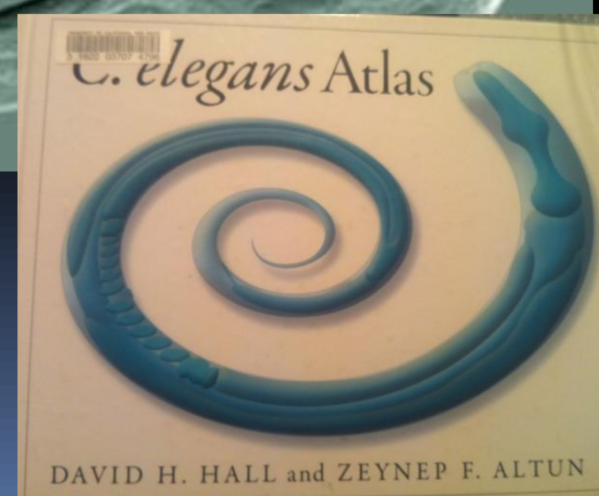
- How can a humble worm regulate itself?
  - Reproduces
  - Avoids predators
  - Survives in different chemical and temperature environments
  - Seeks and finds food sources in an ever changing landscape
  - Distributes nutrients across its own cells
  - Manages waste and eliminates it

Enter the worm: c. elegans









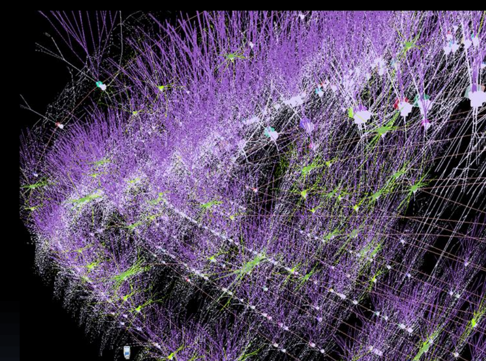
Worm structure

- ~1000 cells
- 302 neurons
- 50k synapses
- 95 muscles

A complete simulation of the worm’s brain, body and environment

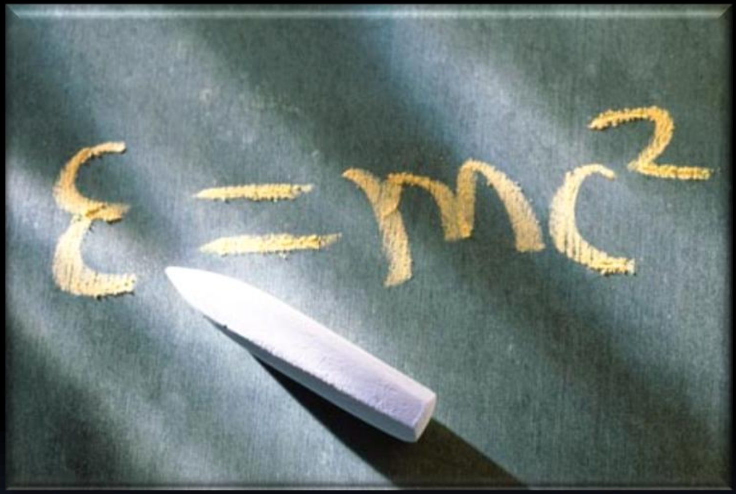
Simulated World

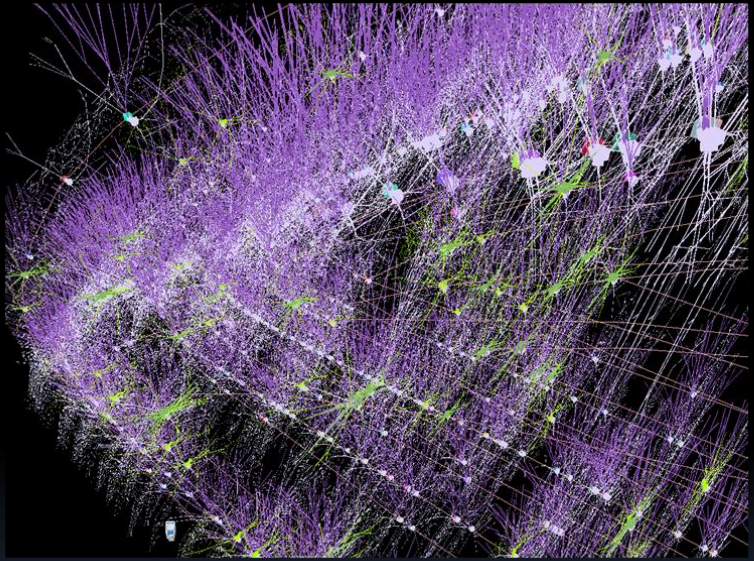
Detailed simulation of worm body



Detailed simulation of worm neurons

The goal: **understanding** a faithfully simulated nervous system end to end



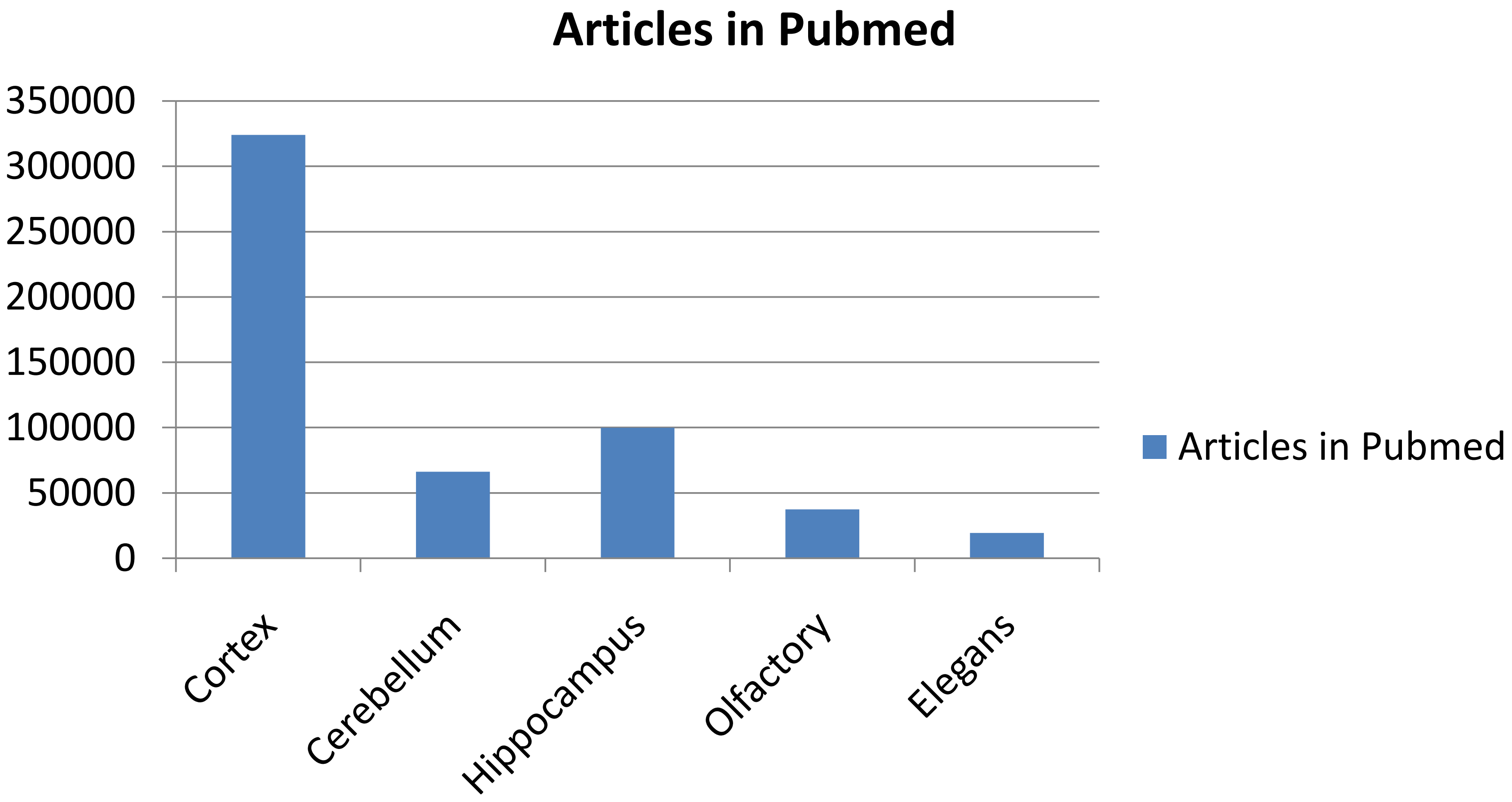


Extracting mathematical principles from simple nervous systems is necessary if we are going to understand and reconstruct the much larger nervous system of the human.

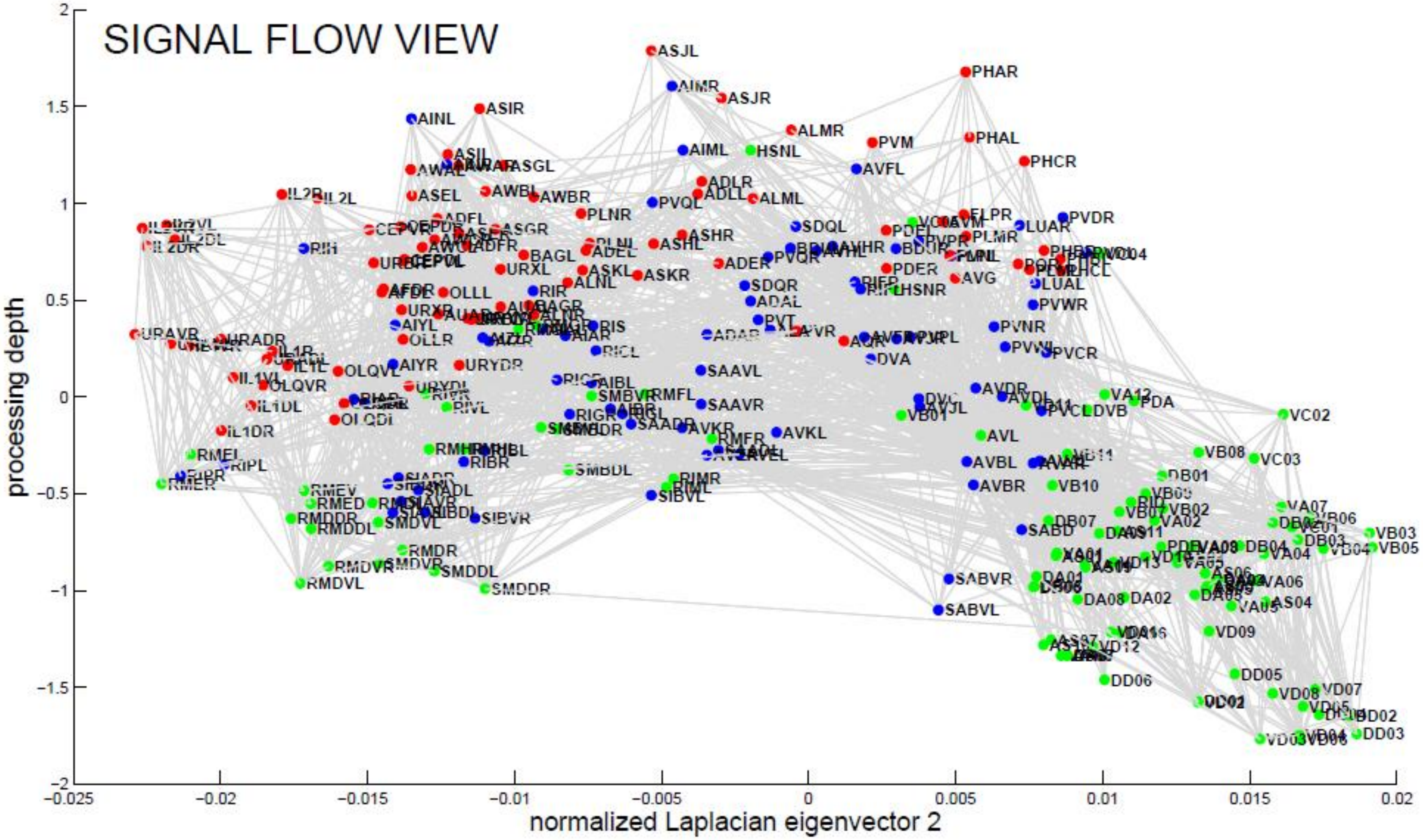
Outreach: put the model online and let the world play with it

- Sex: *Hermaphrodite*
- Interested in: *Escaping my worm Matrix*
- Relationship status: *Its complicated.*

How much do we know about the worm?

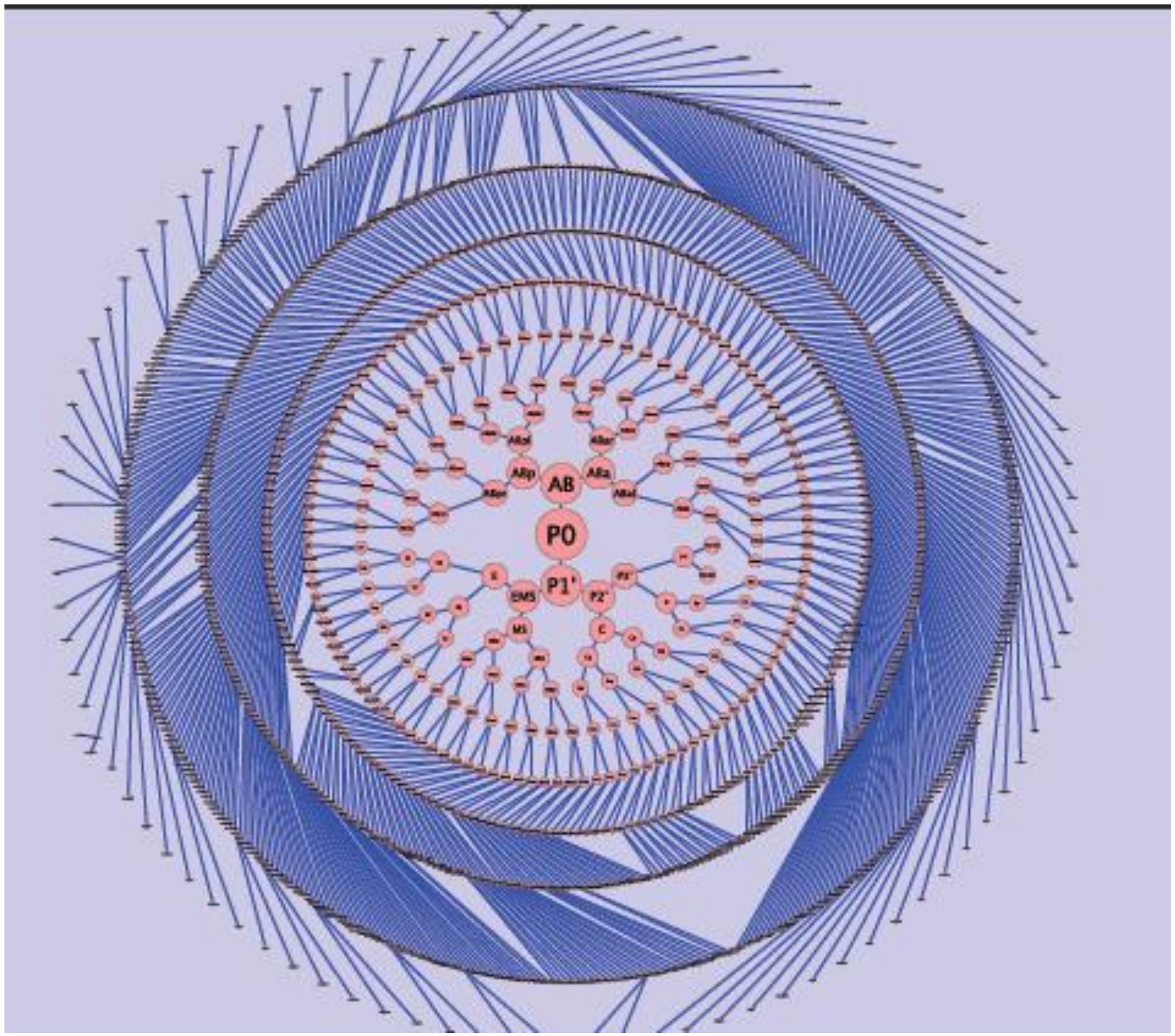


Full connectome

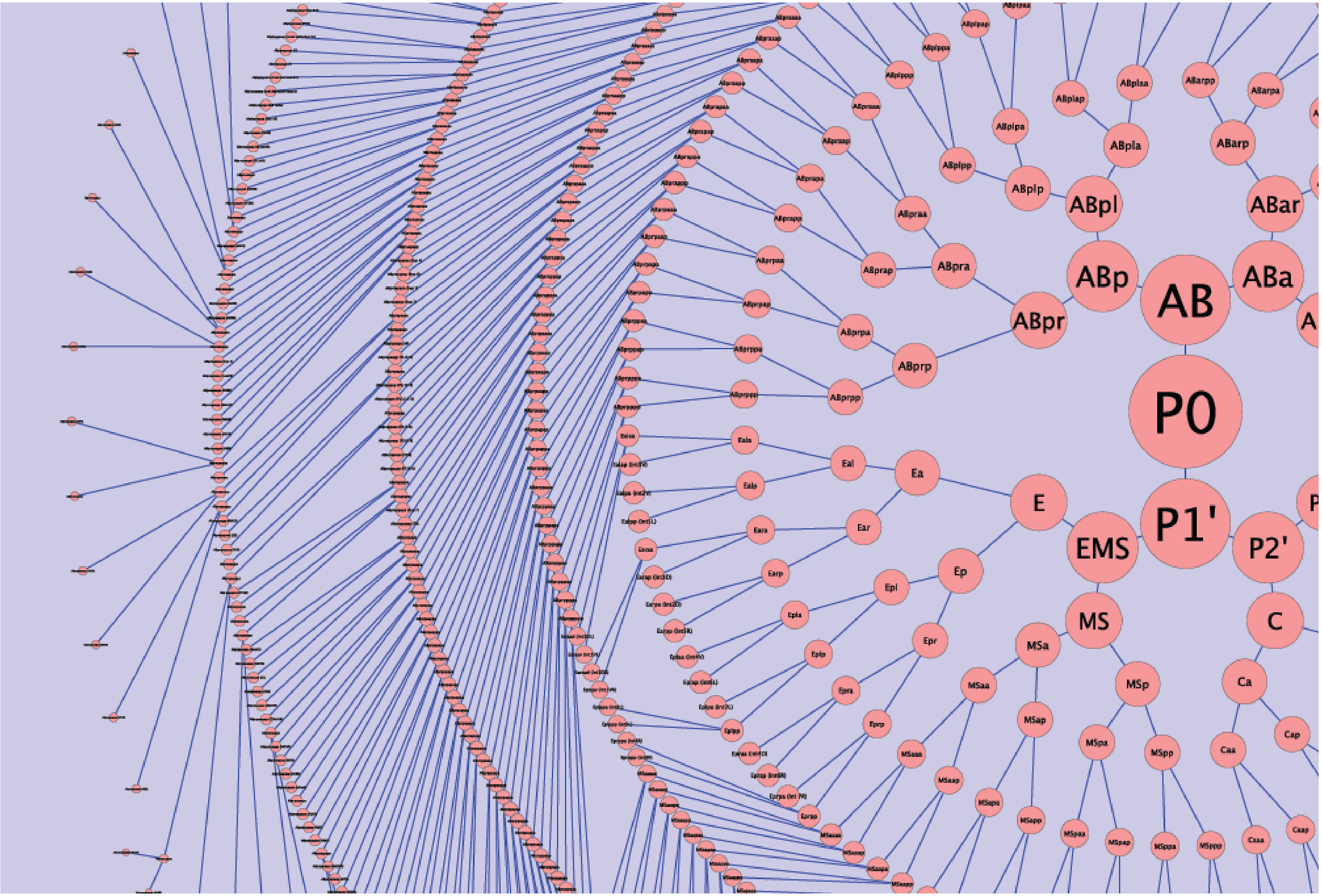


Varshney, Chen, Paniaqua, Hall and Chklovskii, 2011

Entire cell lineage mapped



Entire cell lineage mapped



Entire cell lineage mapped

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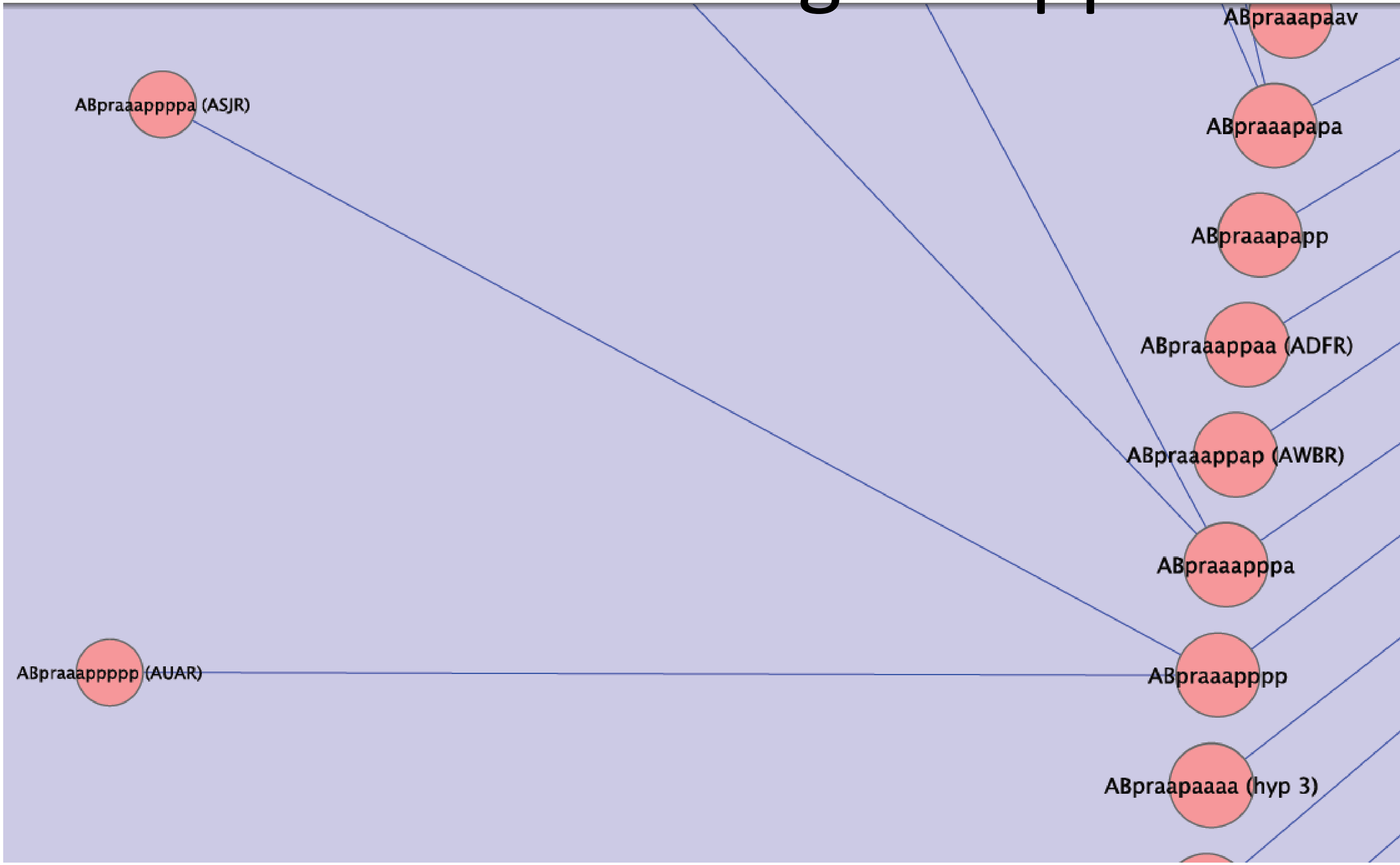


Imaging of cellular dynamics

Sreekanth Chalasani, Salk Institute

Behavior

Biomechanics

P. Sauvage et al. / Journal of Biomechanics

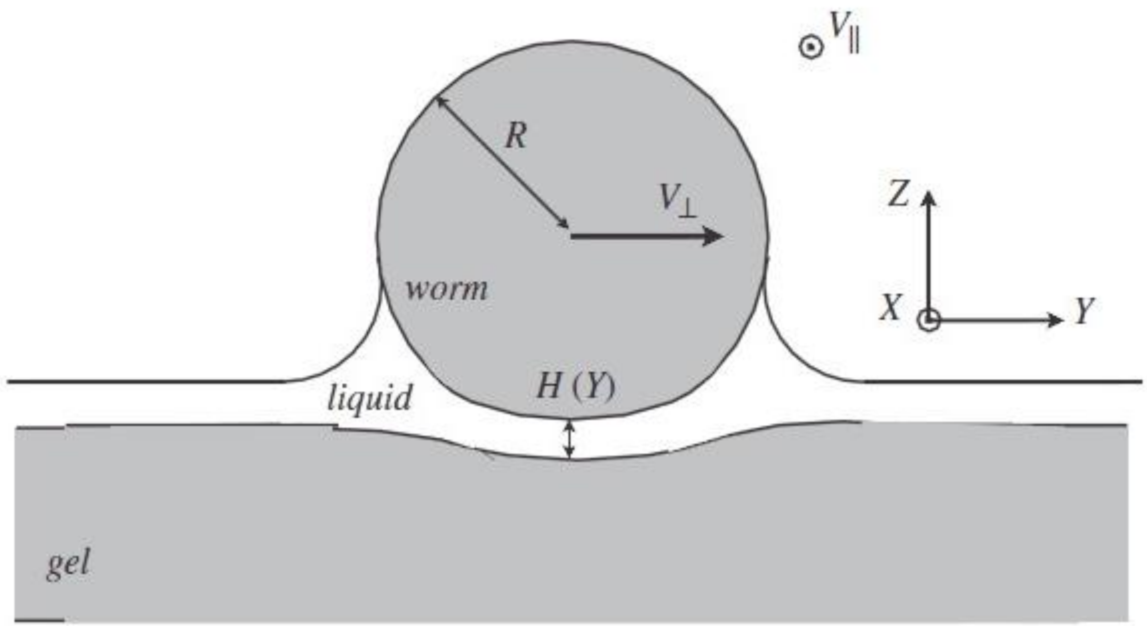


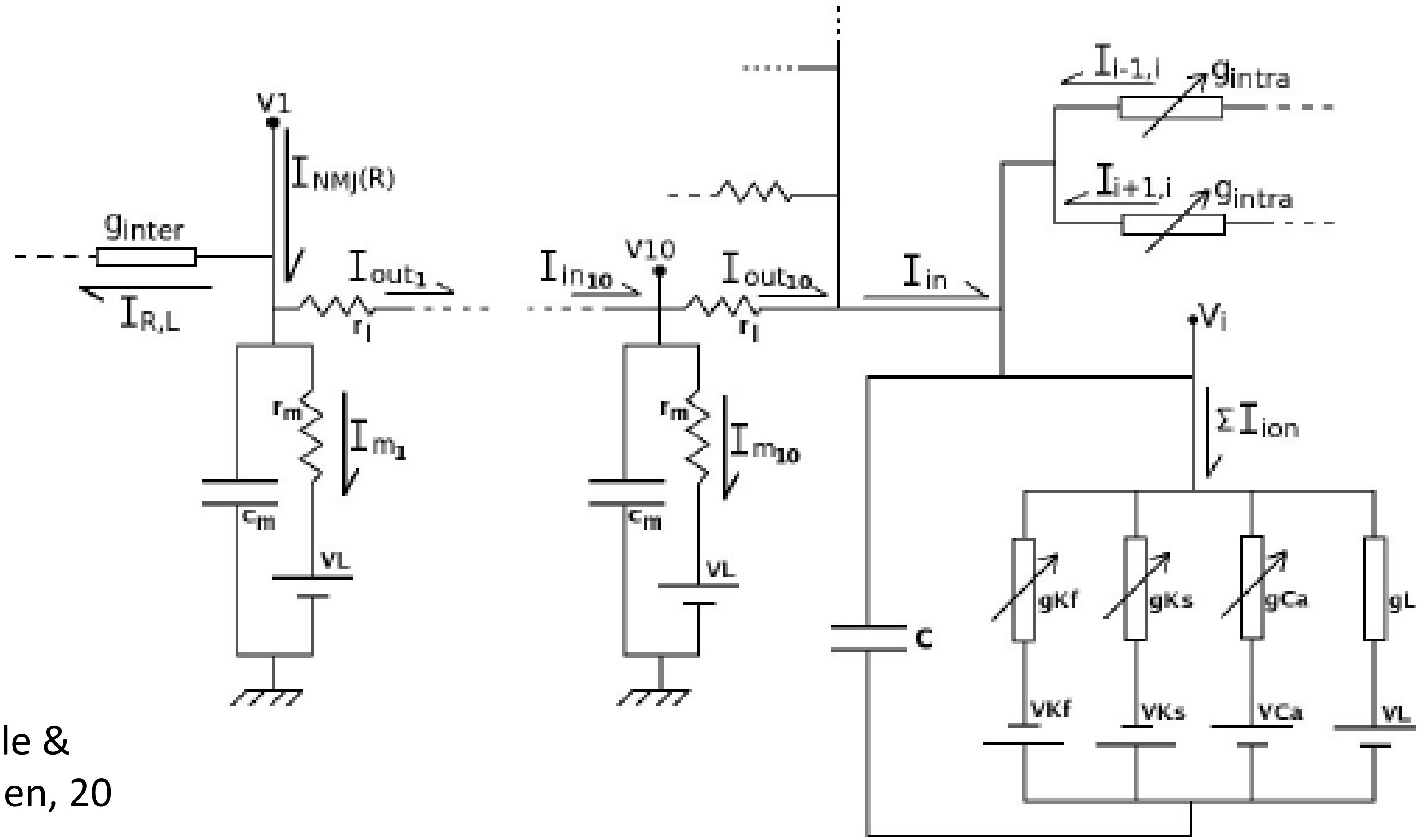
Fig. 3. Schematic representation of a cross-section of the worm. The worm (of radius R) is pinned down on the substrate by capillary forces created by the meniscus; the thickness of the lubrication film is noted $H(Y)$ and the components of the velocity of the body section (with respect to the substrate) are $V_{\perp}$ and $V_{\|}$.

P. Sauvage et al. / Journal of Biomechanics
2011

Plan overview

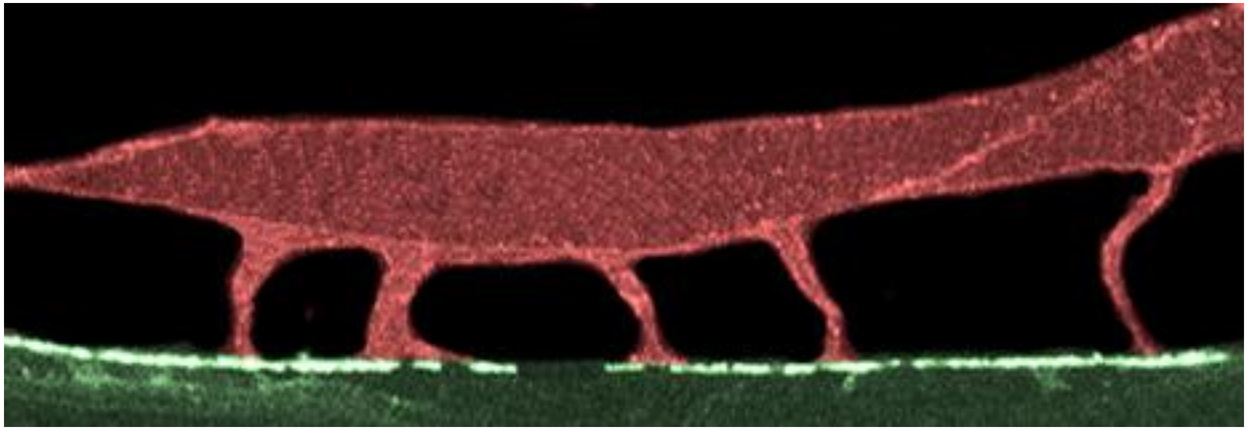
- Sooner
  - Conductance based model of muscle cells
  - Physical model of muscle cell forces
  - Physical model of worm body with forces from environment

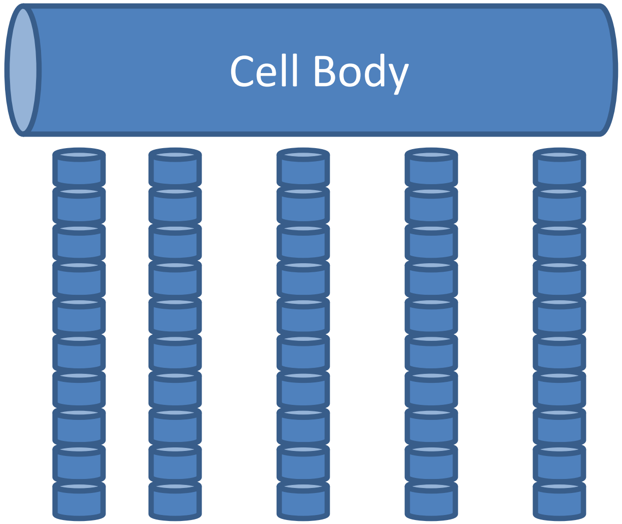
Conductance model of c. elegans muscle cell



Boyle & Cohen, 2007

Muscle cell with “arms”



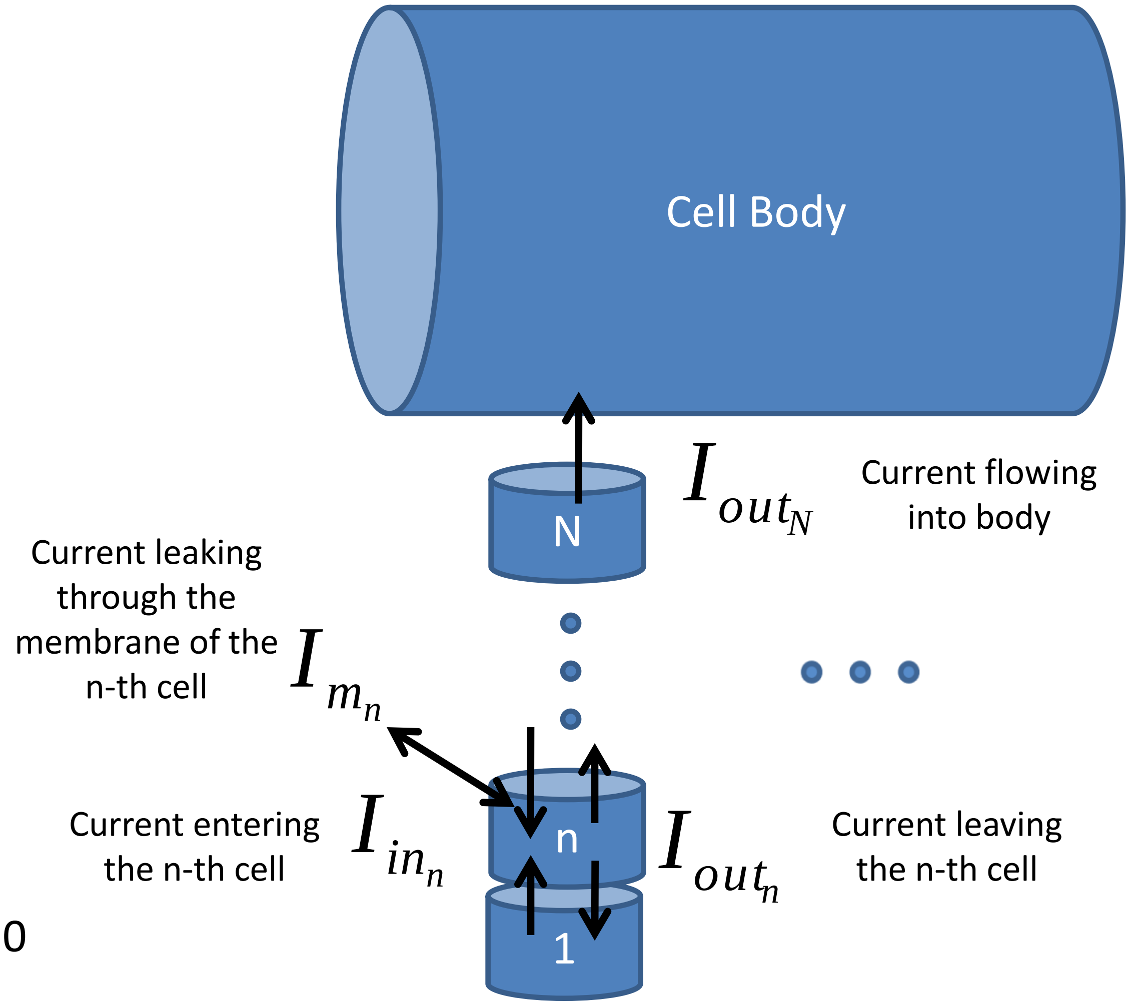


Cell body, 1 compartment, active currents

5 arms, 10 compartments each, passive currents

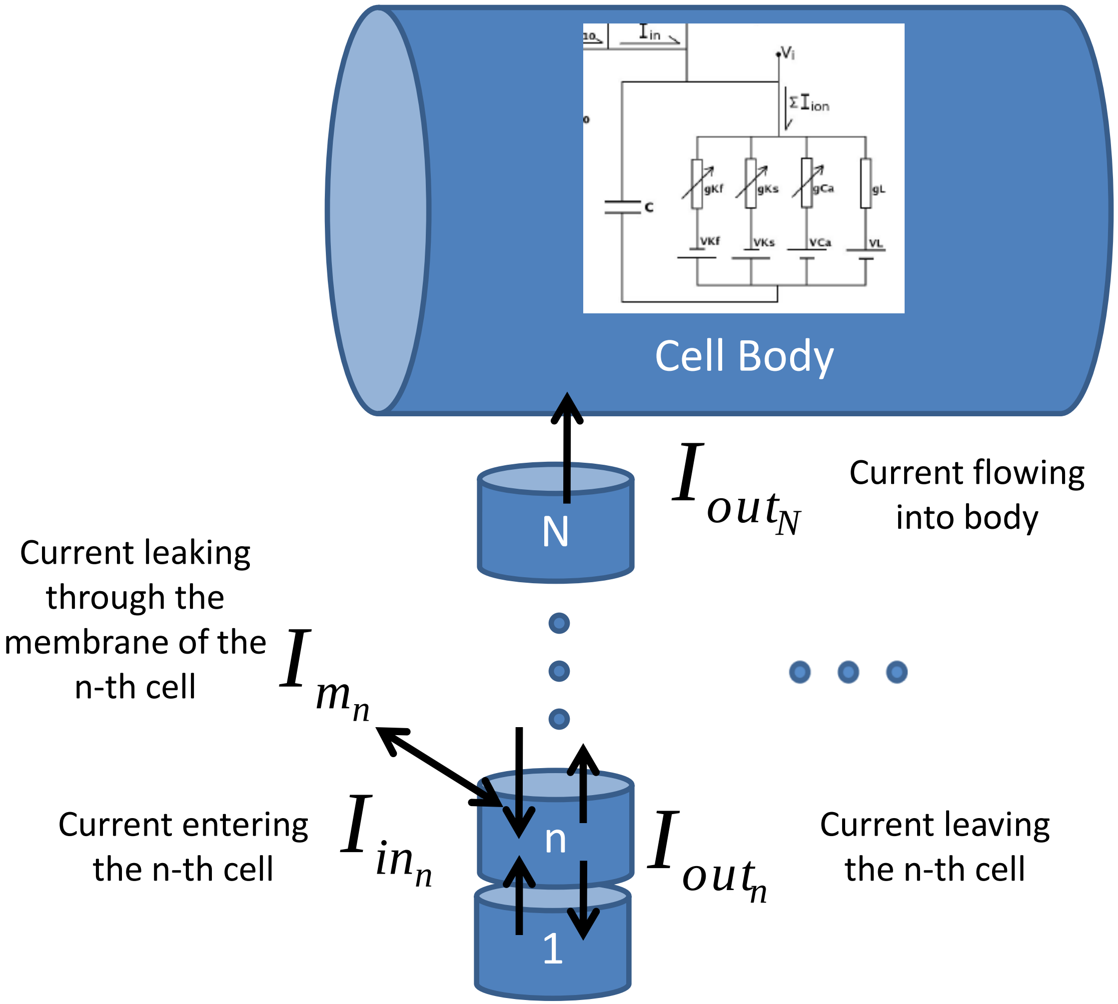
Boyle & Cohen, 2007

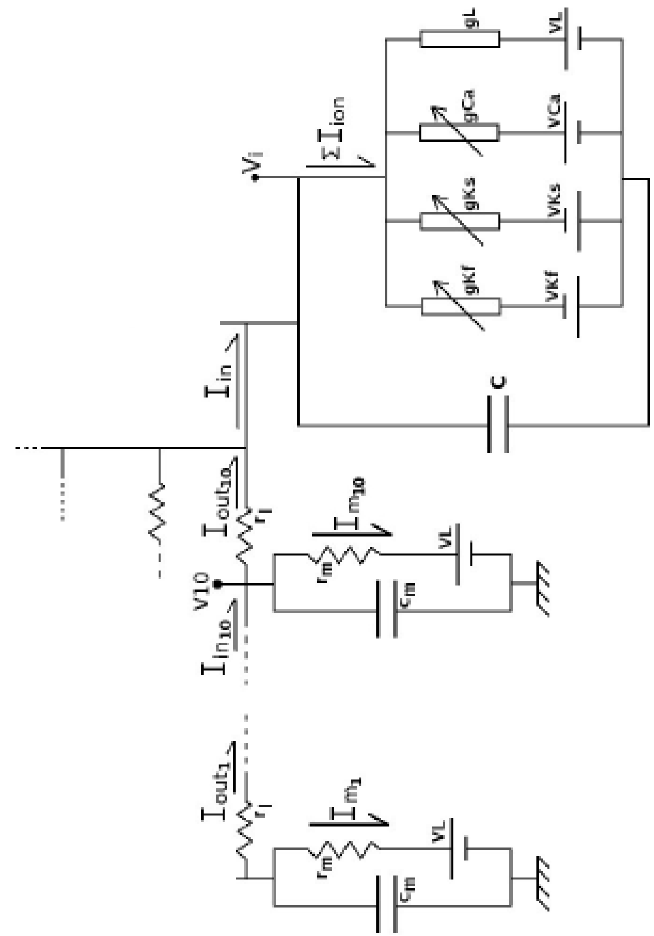
The connectional currents



Boyle & Cohen, 2007

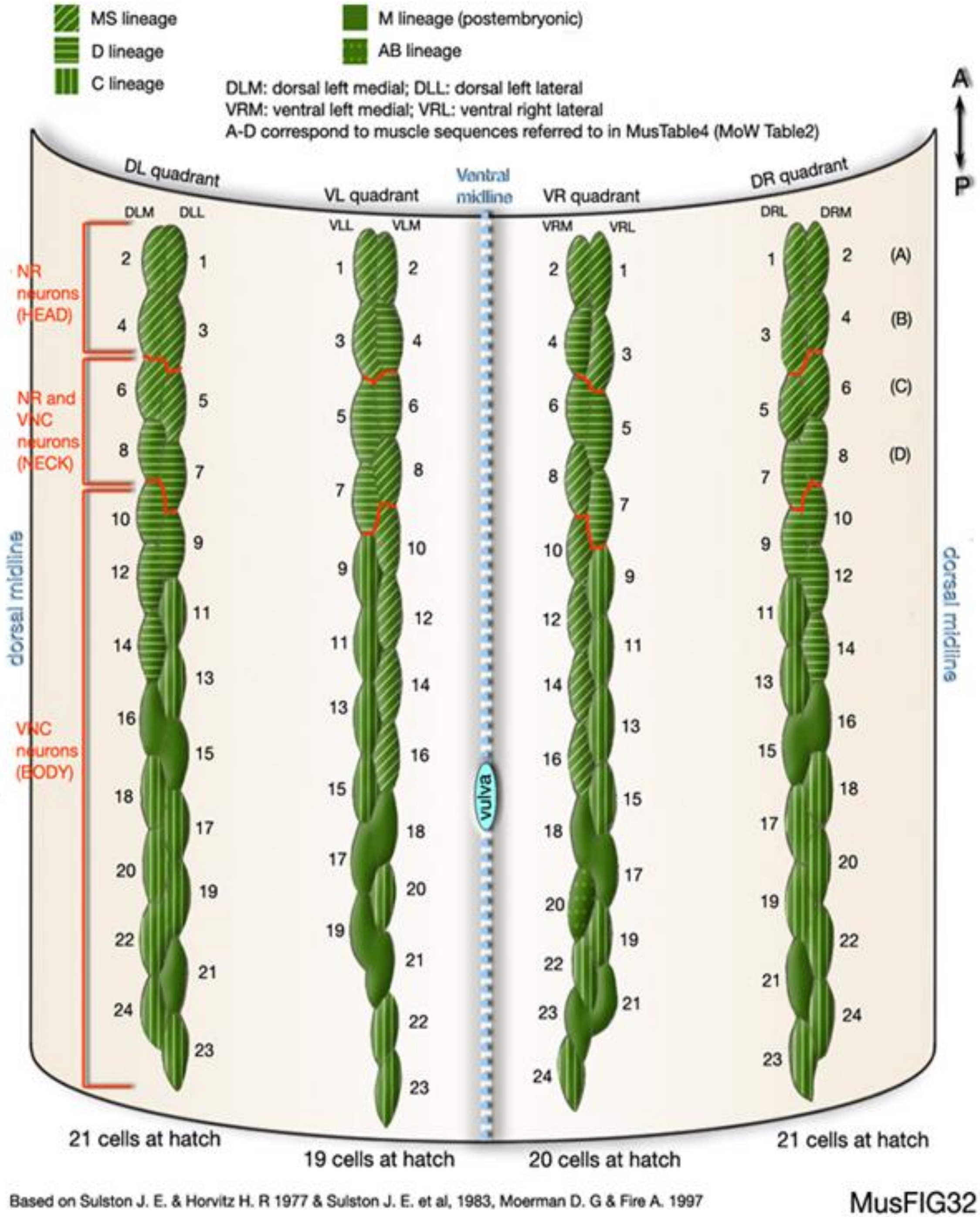
The connectional currents



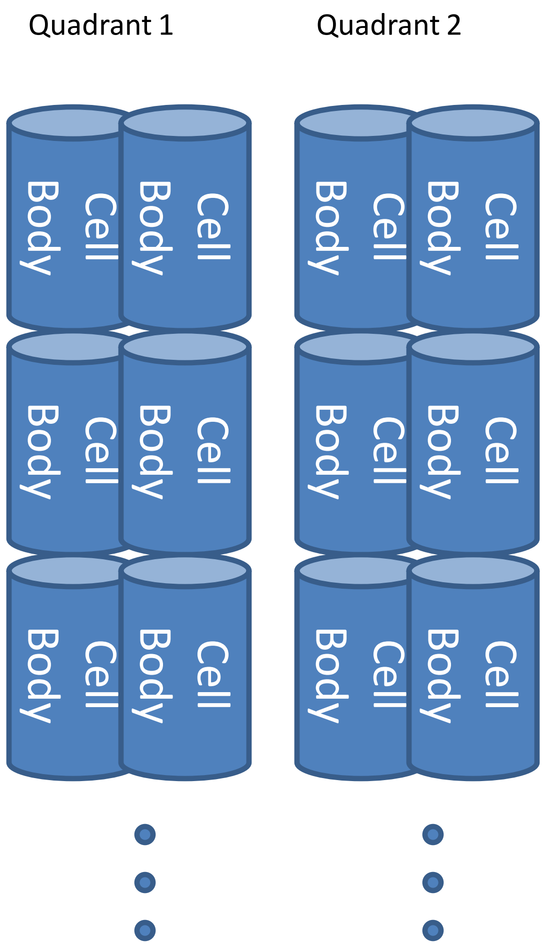


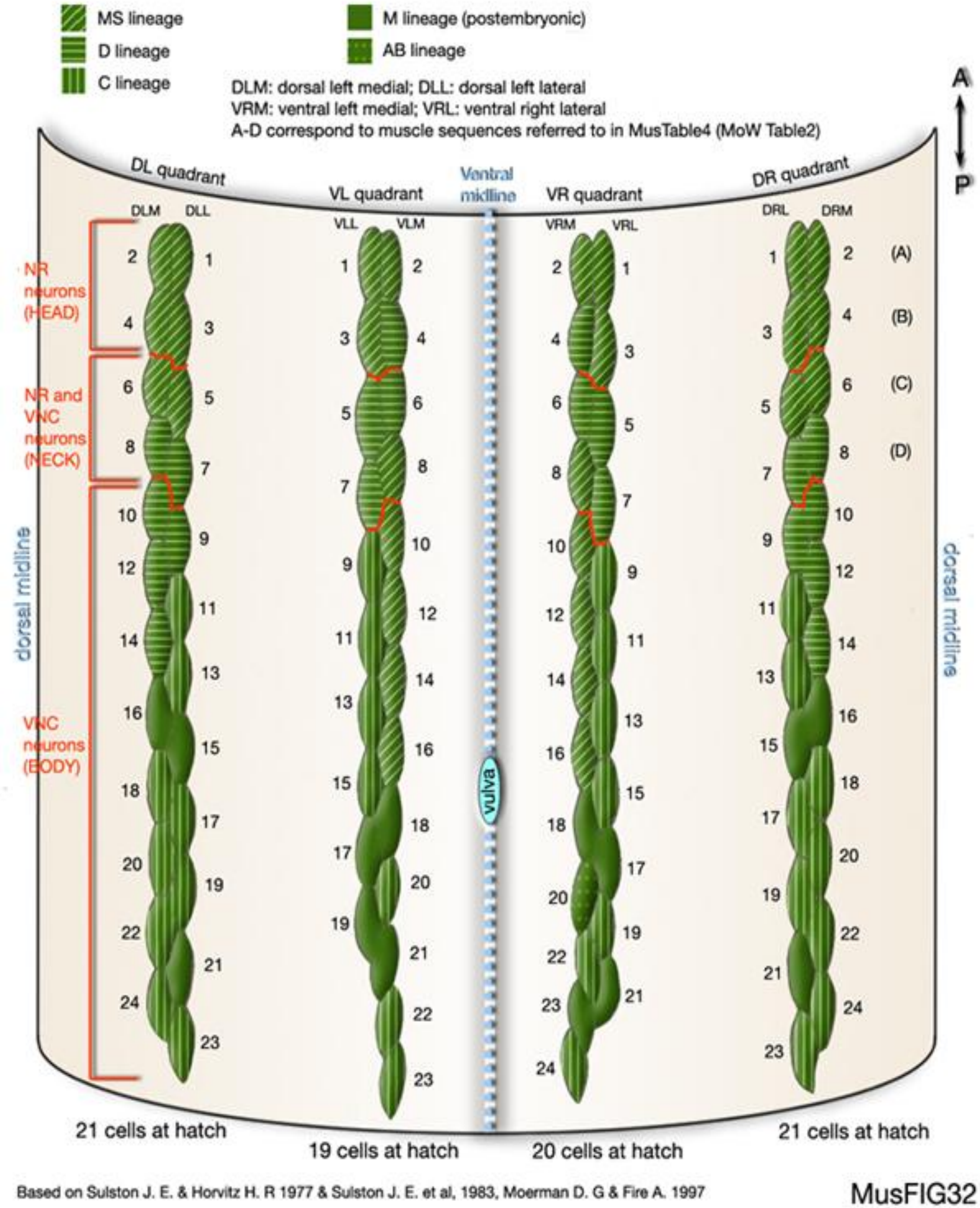
Boyle & Cohen, 2007

body wall muscle cells (adult worm)
cell lineage shown:

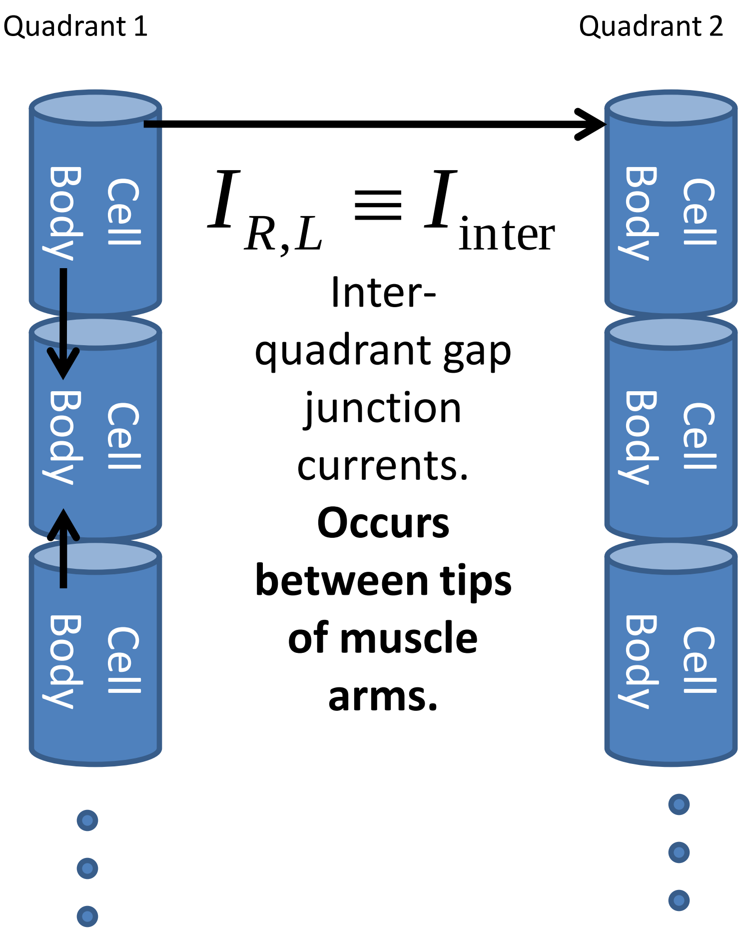


Quadrants of muscle cells





Simplified quadrants of muscle cells



$$I_{j,k} \equiv I_{\text{intra}}$$

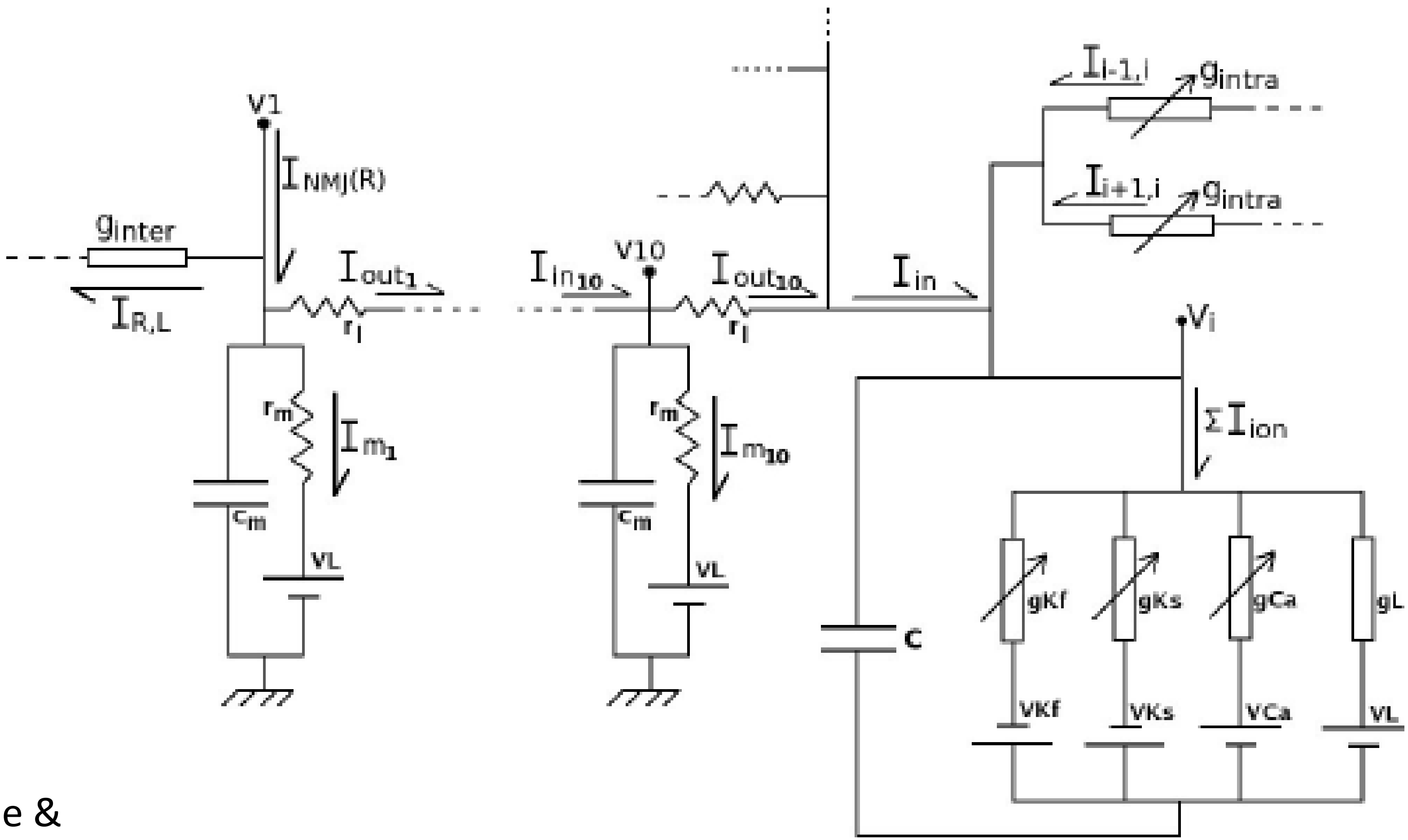
Inter-muscular, Intra-quadrant gap junction currents. **Occurs between cell bodies**

$$I_{R,L} \equiv I_{\text{inter}}$$

Inter-quadrant gap junction currents. **Occurs between tips of muscle arms.**

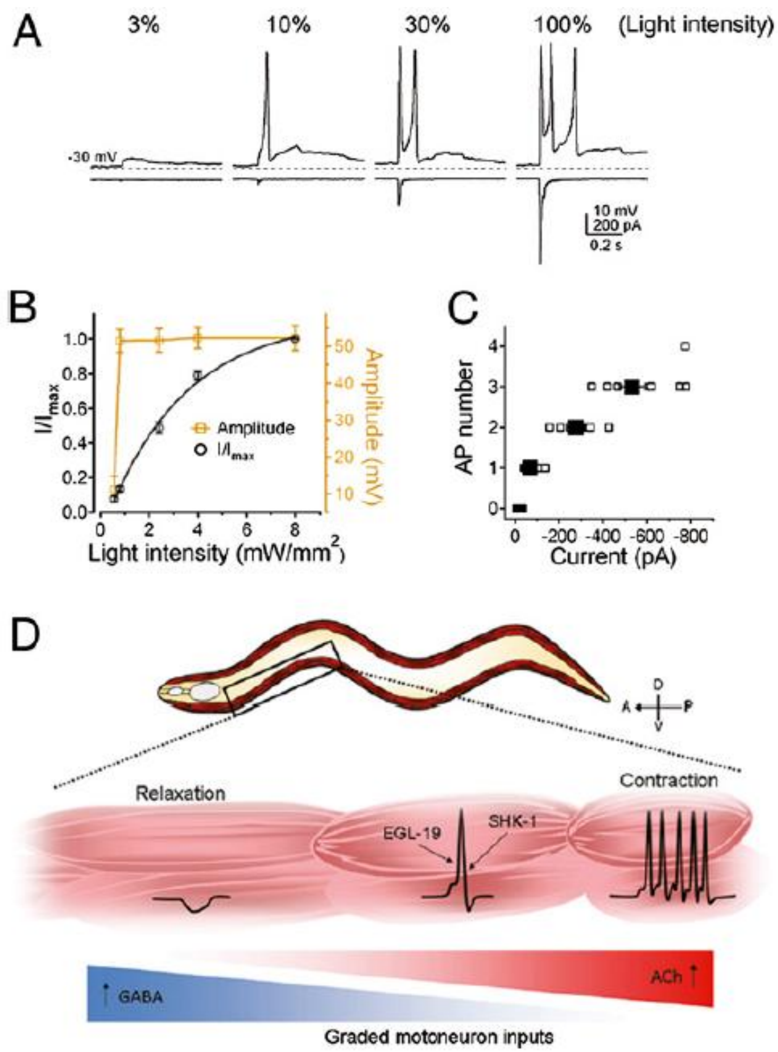
Boyle & Cohen, 2007

Equivalent circuit diagram



Boyle & Cohen, 2007

Relationship between muscle action potentials and muscle contraction

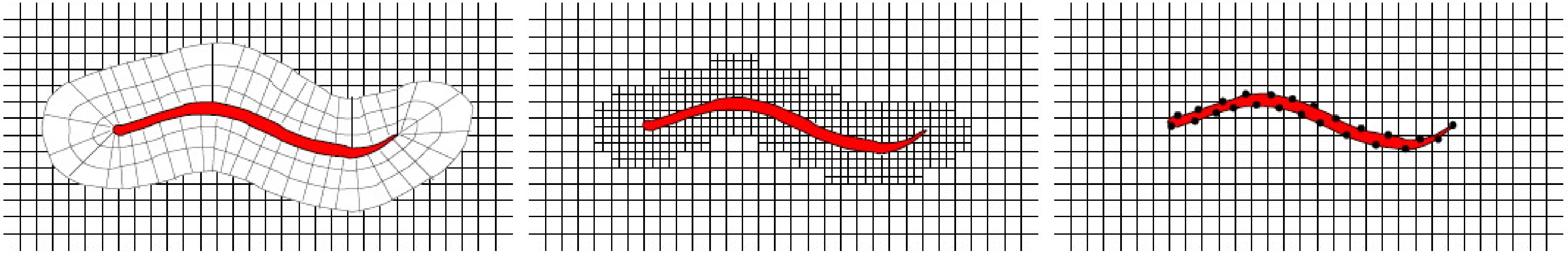


Gao et al, 2011

Contemplating options for physical body and environment simulation

Options:

- boundary-layer mesh joining regular mesh
- adaptive mesh-refinement of regular mesh
- immersed boundary method

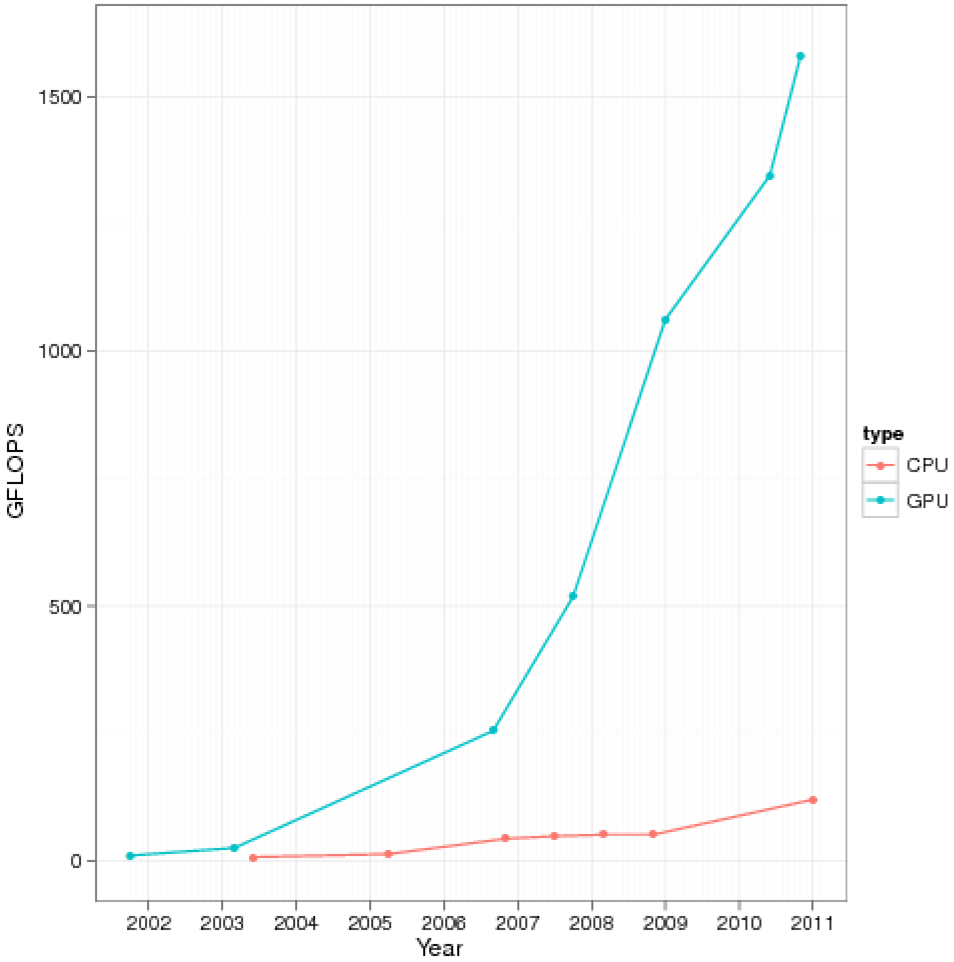


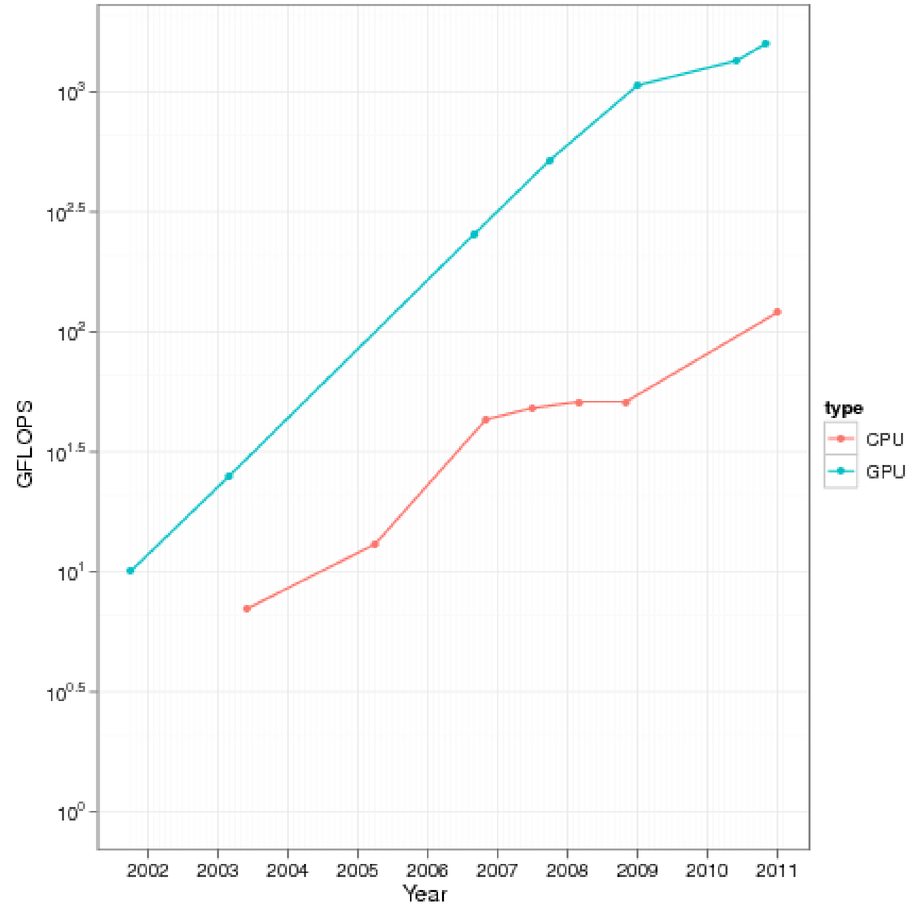
Simulation of swimming organisms: coupling internal mechanics with external fluid dynamics (2004). R. Cortez, L. Fauci, N. Cowen, R. Dillon. Simulation of 3D c. elegans (interaction of an elastic structure with its surrounding fluid) is discussed among other things.
Modeling nematode swimming (2008) R. Tyson, J. Hebert, C. Jordan, L. Fauci.
Options: boundary-layer mesh joining regular mesh /
adaptive mesh-refinement of regular mesh / immersed boundary method.

Estimates of computational complexity

- Mechanical model
  - ~5 Tflops
- Muscle / Neuronal conductance model
  - ~240 Gflops

GPU vs CPU performance increase



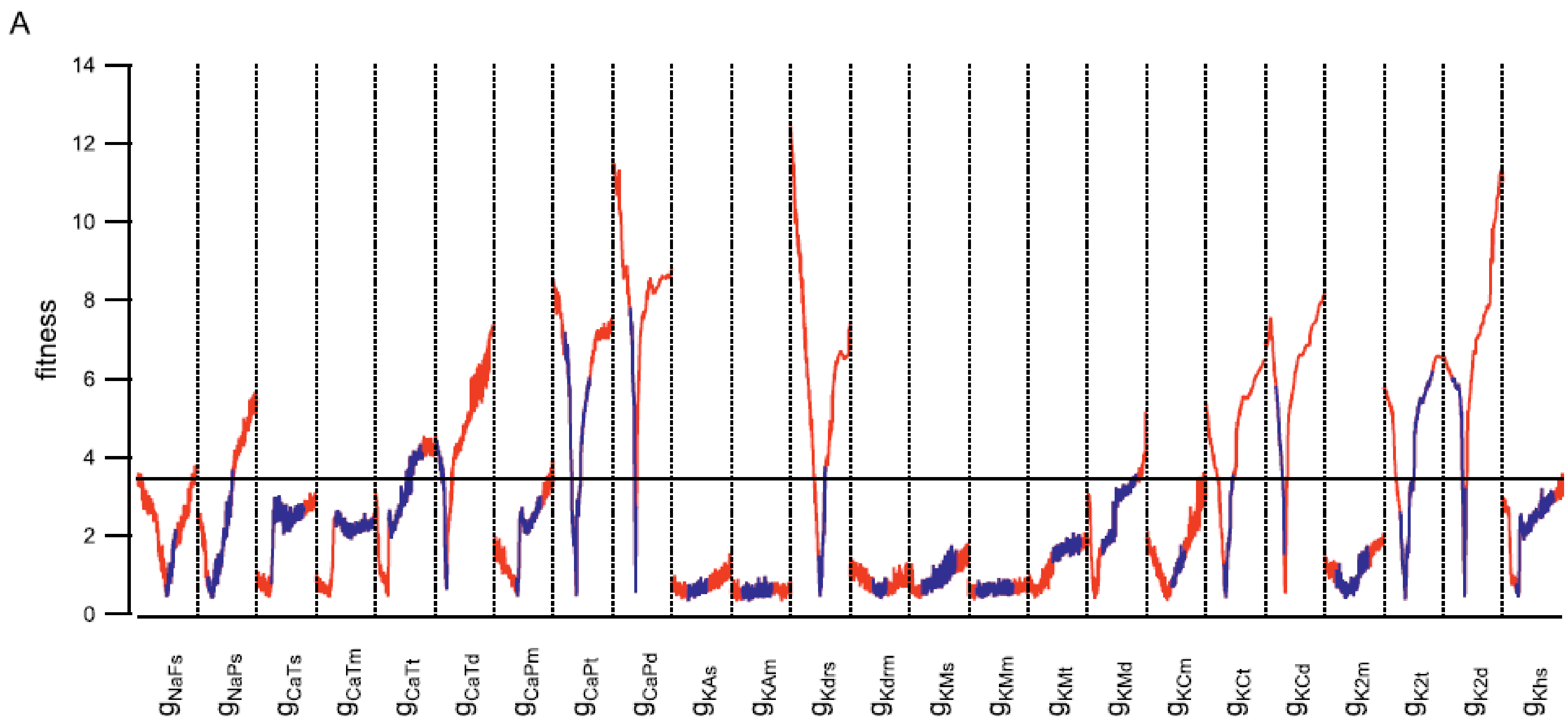


Source: http://csgillespie.wordpress.com/2011/01/25/cpu-and-gpu-trends-over-time/

Plan overview

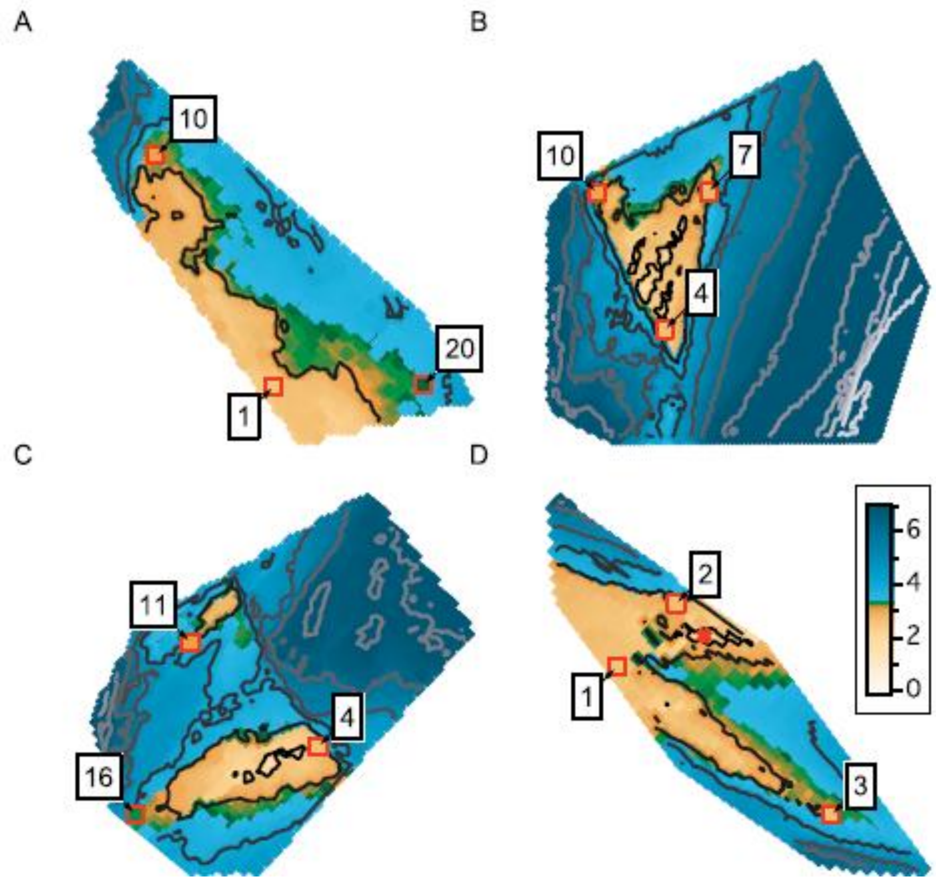
- Sooner
  - Conductance based model of muscle cells
  - Physical model of muscle cell forces
  - Physical model of worm body with forces from environment
- Later
  - Conductance based model of neurons
  - Diffusion based model of neurons
  - …?
  - Parameter optimization system…

Parameter optimization



Achard, De Schutter, 2006

Parameter optimization



Achard, De Schutter, 2006

Team – A brief history

- Stephen Larson, Ph.d student, UC San Diego
- Marius Buibas, Ph.d student, UC San Diego

twitter

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- Stephen Larson, Ph.d student, UC San Diego
- Marius Buibas, Ph.d student, UC San Diego
- **Giovanni Idili, Software engineer, Cork, Ireland**
- **Tim Busbice, Senior software engineer, Los Angeles, CA**
- **Matteo Cantarelli, Software engineer, Cagliari, Italy**
- **Jay Coggan, Project scientist, Computational Neurobiology lab, Salk Institute**

YouTube

Broadcast Yourself™

Mechanical model

Palayanov, Khayrulin, Dibert (submitted)

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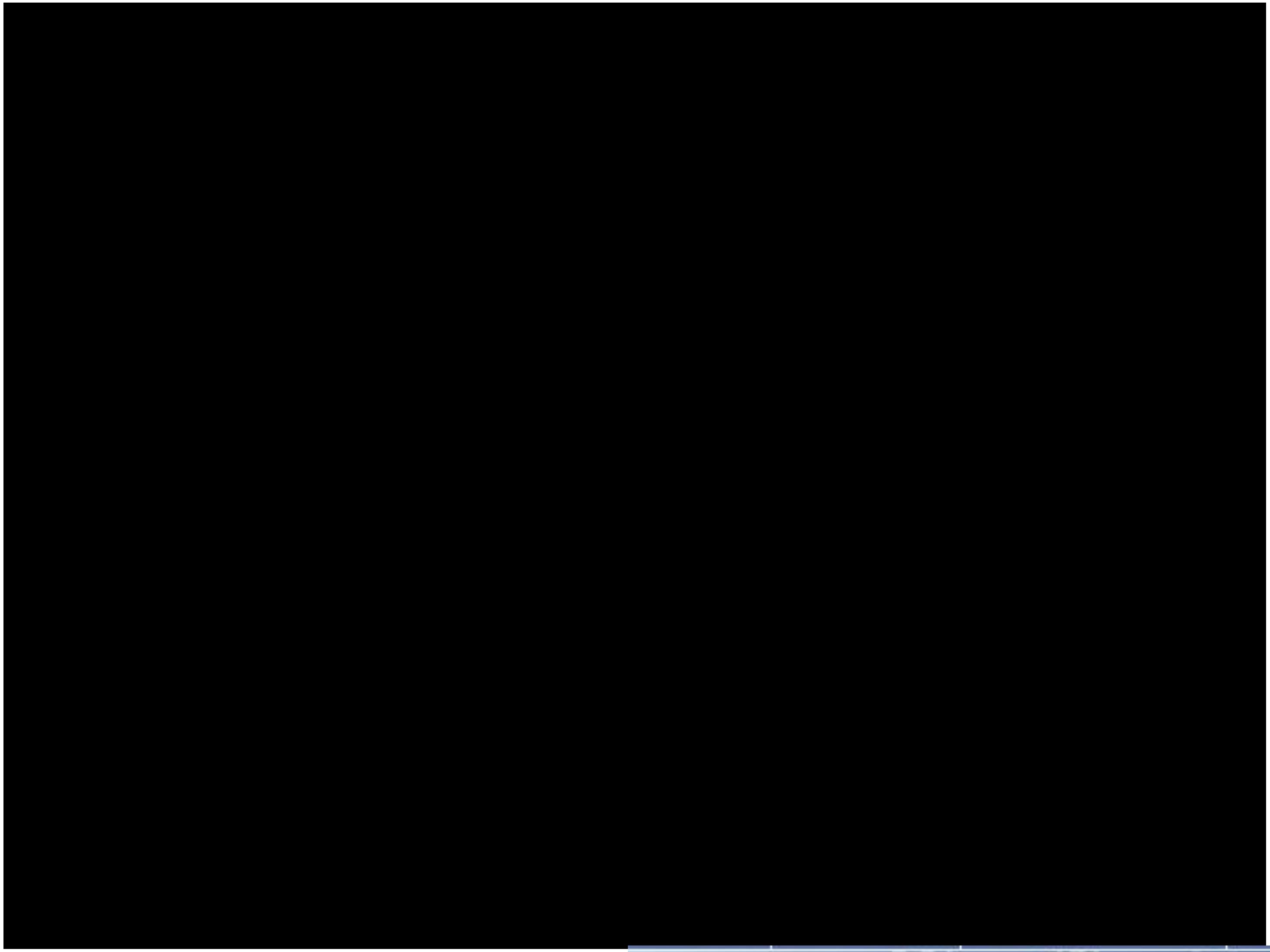
- **Andrey Palyanov, Project scientist, A.P. Ershov Institute of Informatics Systems SB RAS, Lab. of Complex Systems Simulation, Acad. Lavrentjev, Novosibirsk, Russia**

3D body plan



Christian Grove, Wormbase

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- **Christian Grove, Project scientist & curator, Wormbase, Caltech**
- **Sergey Khayrulin, Ph.d student A.P. Ershov Institute of Informatics Systems SB RAS, Lab. of Complex Systems Simulation, Acad. Lavrentjev, Novosibirsk, Russia**

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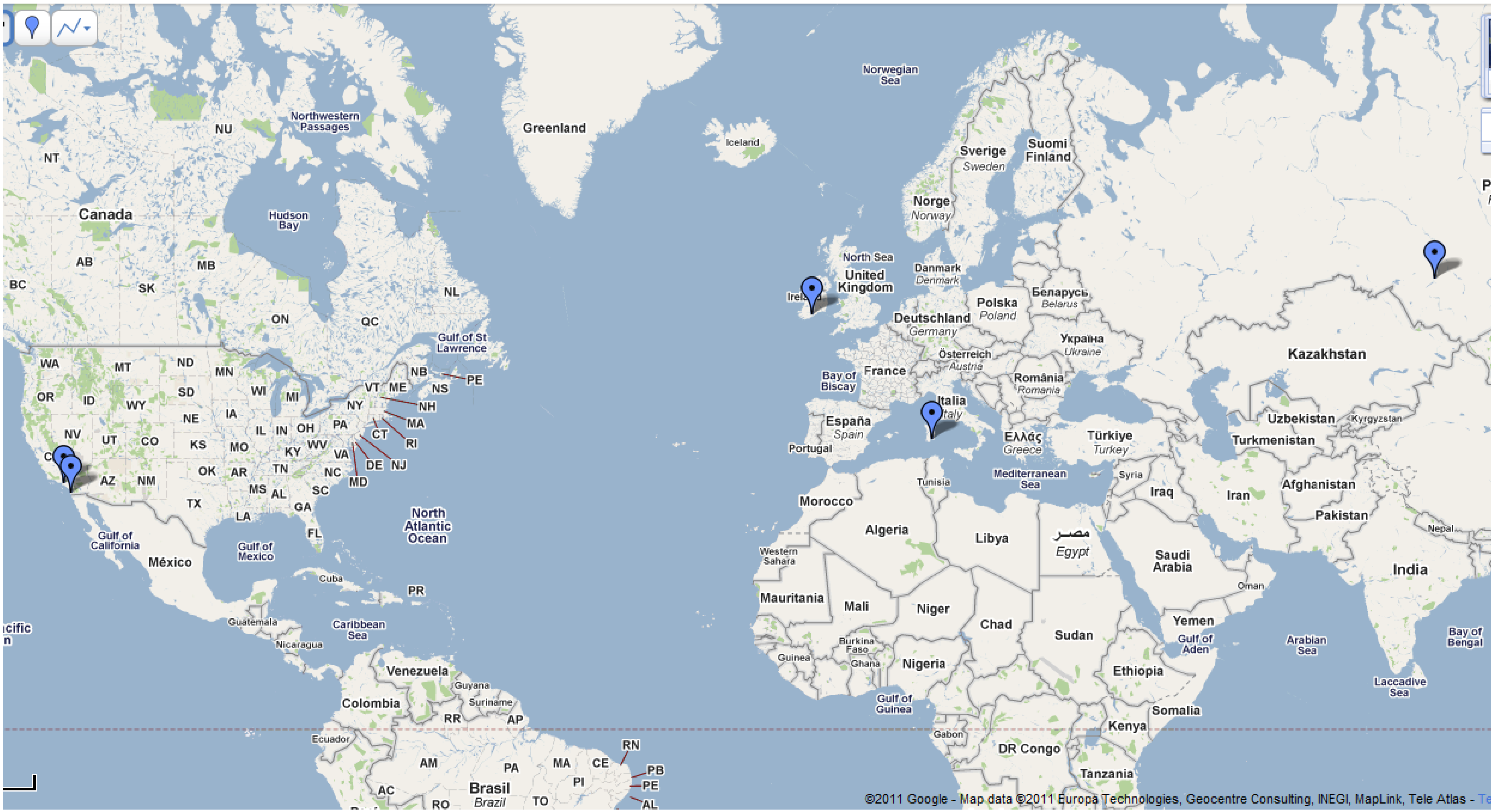

Collaboration technologies used

LUCIDCHART

Google code

Google Docs

Teambox

skype

Dropbox

ScheduleOnce
Find a time in no time

amazon web services™

MENDELEY
RESEARCH NETWORKS

Contributions

- Explanation of role of embodiment in understanding interactive systems
- Description of the advantages of c. elegans as a model system
- Summarized key existing understanding of c. elegans biology
- Described steps towards implementing a multi-scale, multi-algorithm c. elegans model
- Described a novel collaboration model for open source science and modeling