Extracellular Fields of Biologically Realistic Neurons

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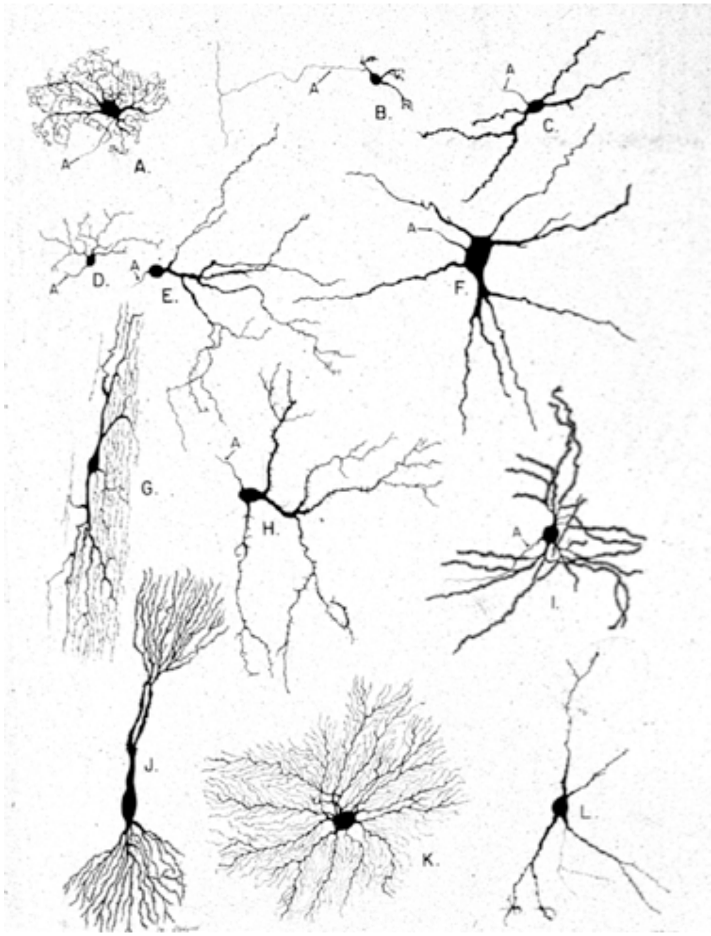
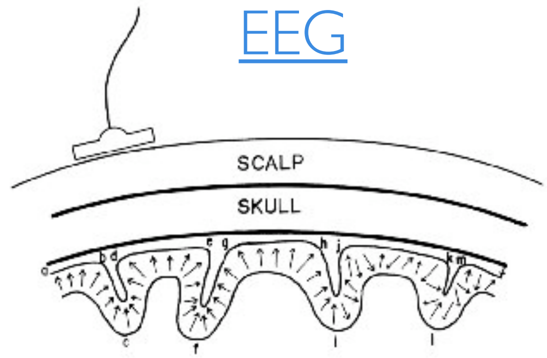
THE SWARTZ FOUNDATION

Connect single neuron biophysics to…



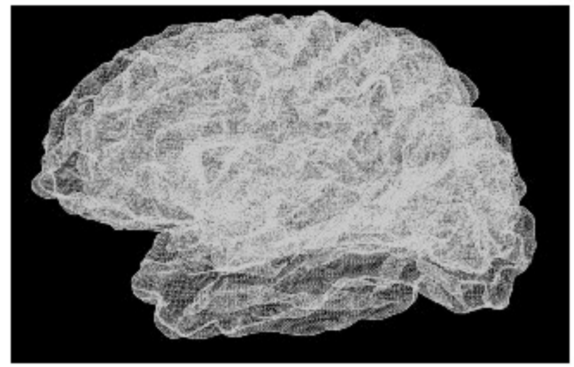
(http://cti.itc.virginia.edu/ ~psyc220/)

Global Properties



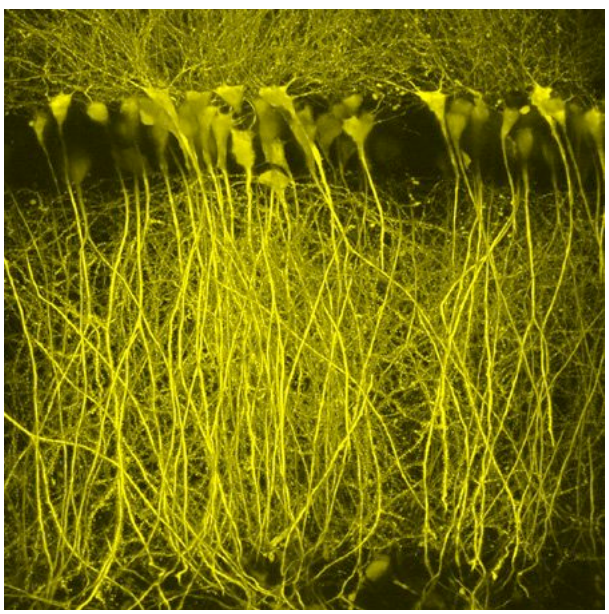
EEG

Distant Phenomena



(Srinivasan 2006)

Intracranial



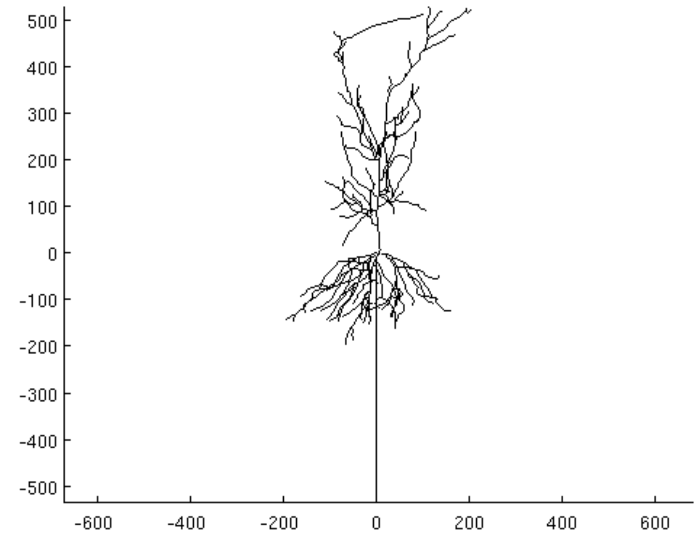
(Jackson Laboratories 2006)

Local Phenomena

Compartmental Model

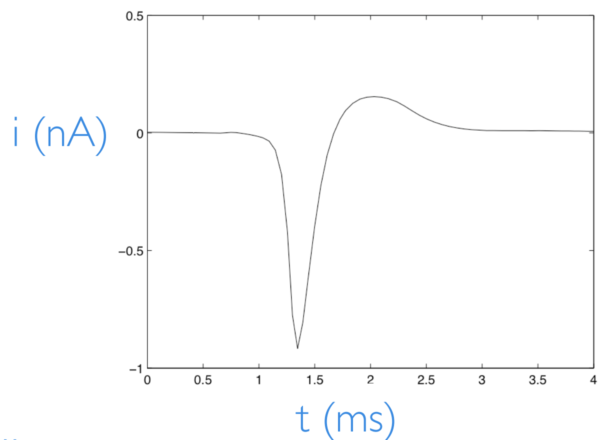
To generate the membrane currents

Pyramidal hippocampal cell within rat CA1



Hodgkin-Huxley Style Kinetics

- Voltage dependent Na^{+}, K^{+},Ca^{2+} currents
- 12 different processes



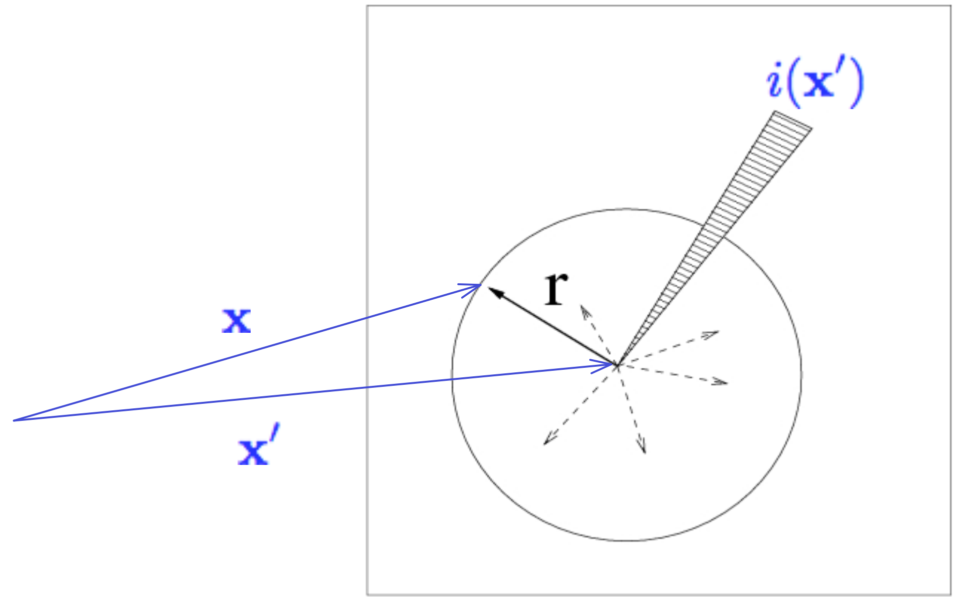
NEURON Simulation Environment

Used to compare intracellular to extracellular recordings

Henze (2000) & Gold (2006)

Point Source Approximation

Calculating the extracellular field from the membrane currents



$$\phi(\mathbf{x}) = \frac{1}{4\pi\sigma} \frac{i(\mathbf{x}')}{|\mathbf{x} - \mathbf{x}'|}$$

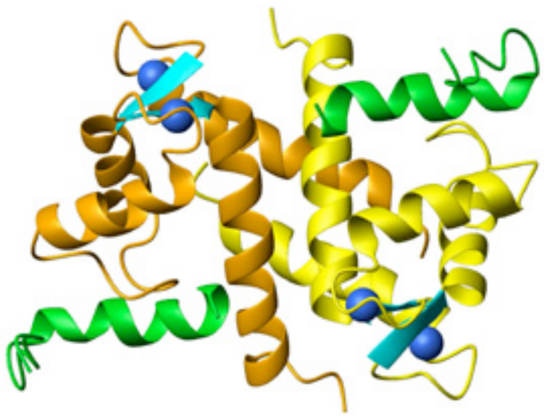
Electrostatics

Charge <> Current

Conductivity <> Permittivity

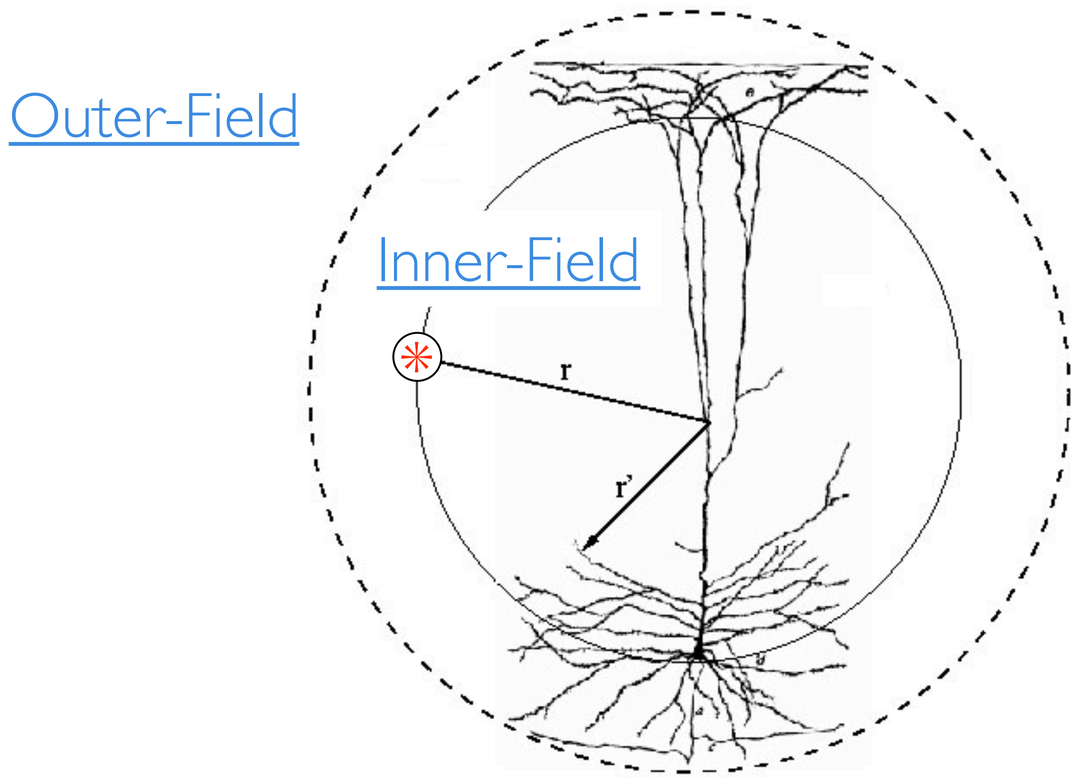
Multipole Techniques are Ubiquitous

We often need to simplify complex electrostatic sources



A few examples

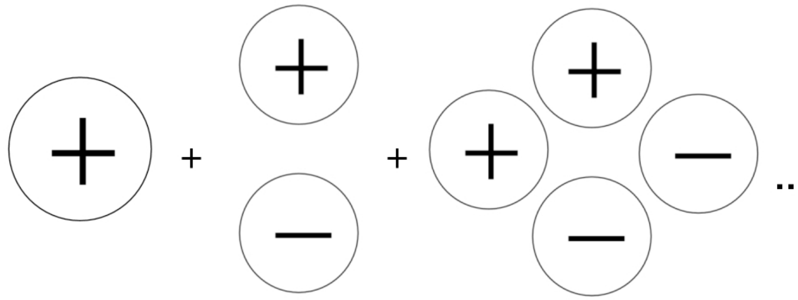
- protein-protein/ protein-DNA interactions
- phase transitions in viscous materials
- crystallization



Outer-Field: classical multipole expansion

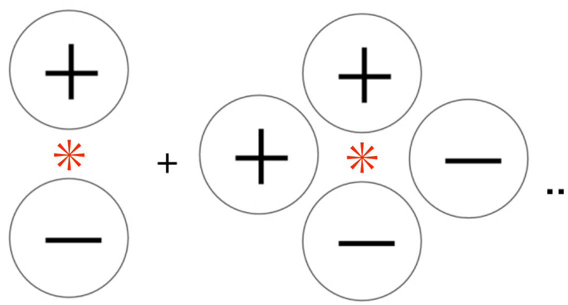
Inner-Field: classical and inverse moments have *radial dependence*

Classical Terms



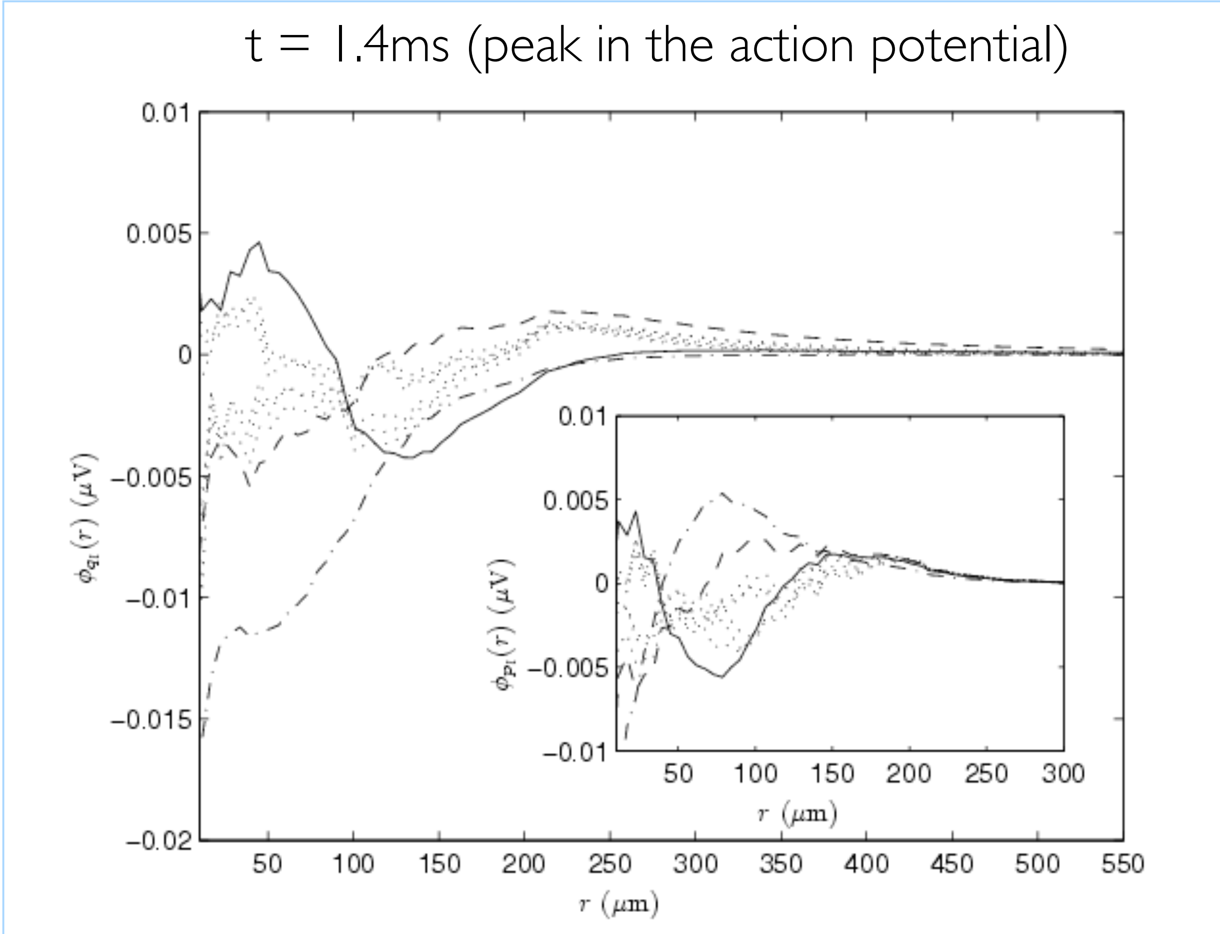
$$V(r,\theta,\varphi) = \frac{1}{\sigma}\left(\frac{q_{0,0}}{r} + \sum_{m=-1}^{1} Y_{1,m}(\theta,\varphi)\frac{q_{1,m}}{r^2} + \sum_{m=-2}^{2} Y_{2,m}(\theta,\varphi)\frac{q_{2,m}}{r^3} + \dots\right)$$

Inverse Terms



$$V(r,\theta,\varphi) = \frac{1}{\sigma}\left(\sum_{m=-1}^{1} Y_{1,m}(\theta,\varphi)p_{1,m}r + \sum_{m=-2}^{2} Y_{2,m}(\theta,\varphi)p_{2,m}r^2 + \dots\right)$$

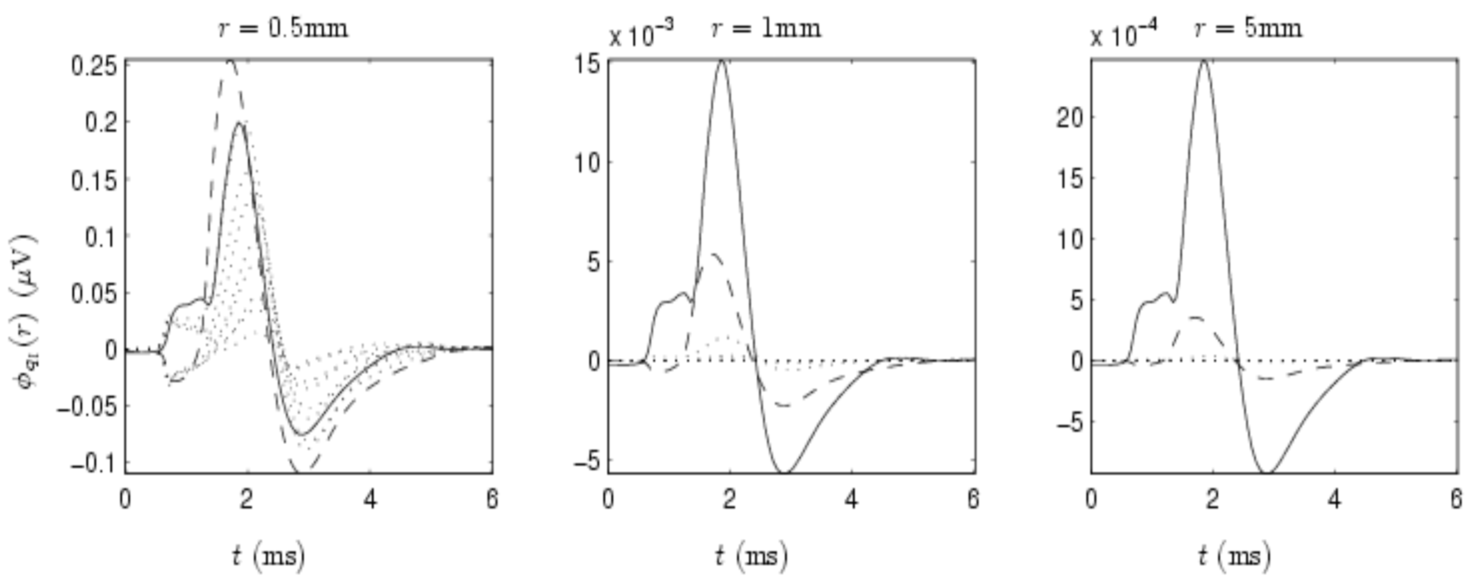
Inner-Field Potentials



Slow Convergence, No clearly dominant moments

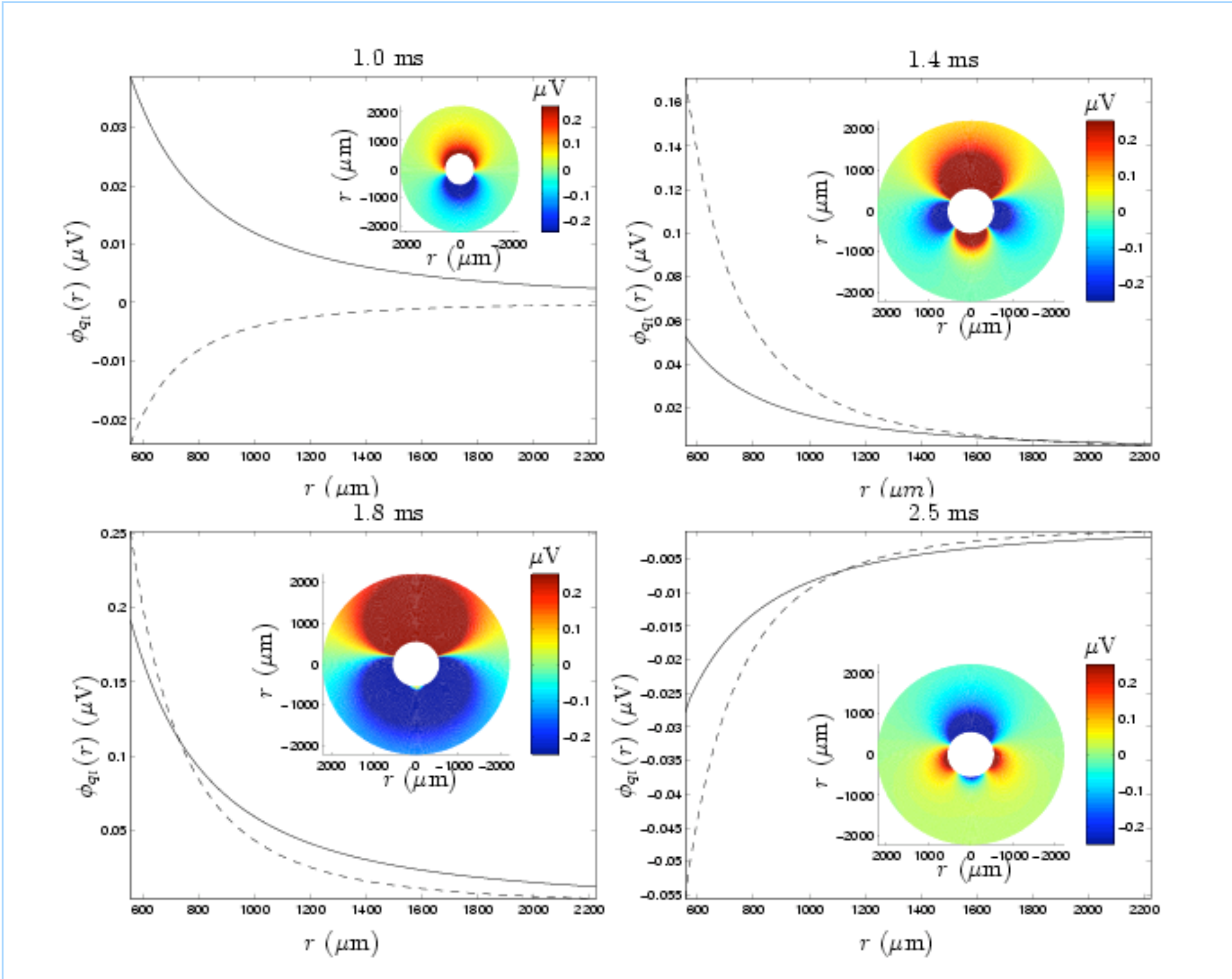
Requires ~ 25 inv. and 25 class. moments to converge

Outer-Field Potentials I.



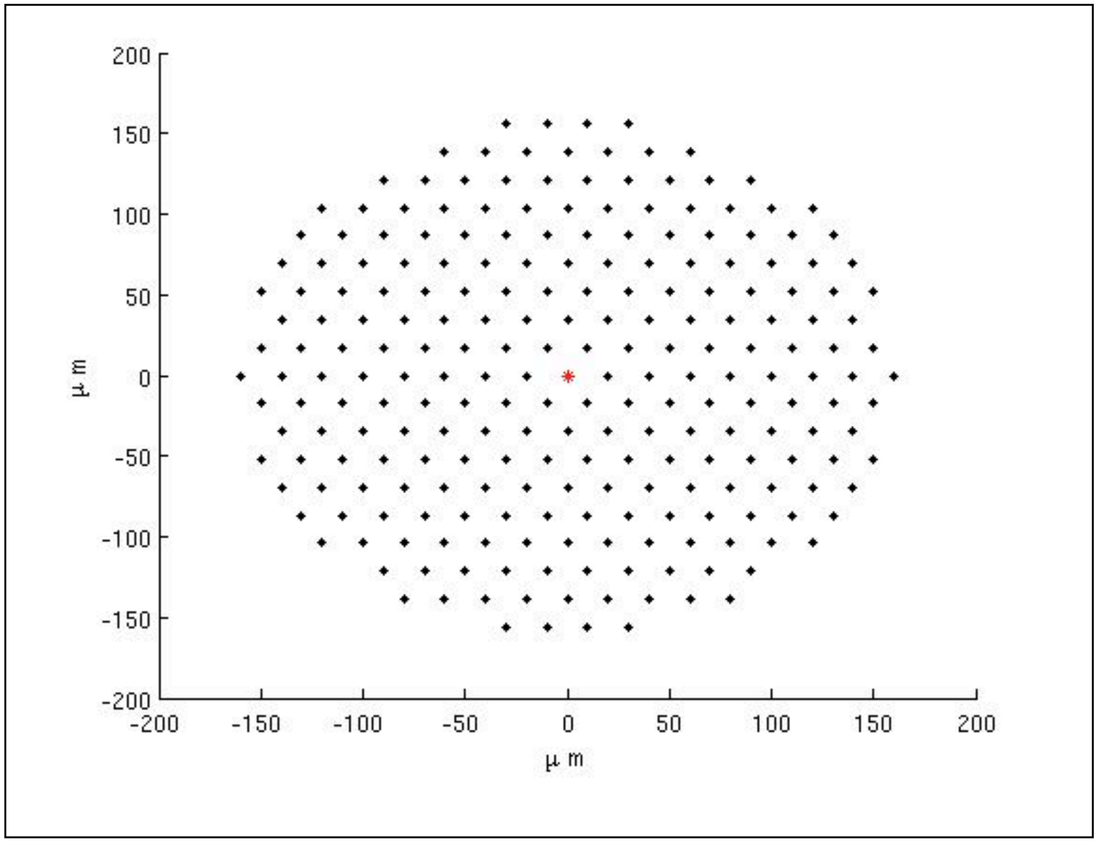
Dipole (solid-line)
Quadrupole (dashed-line)

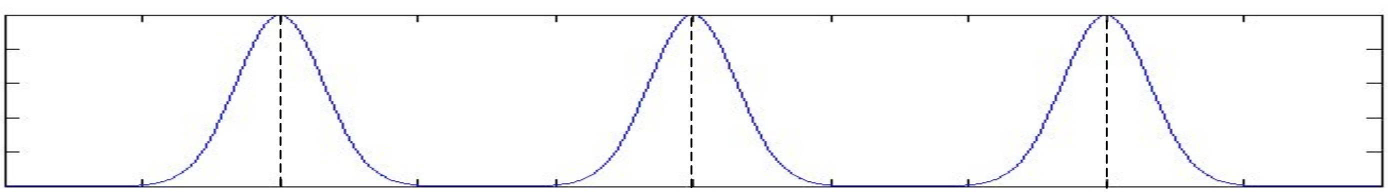
Outer-Field Potentials II.



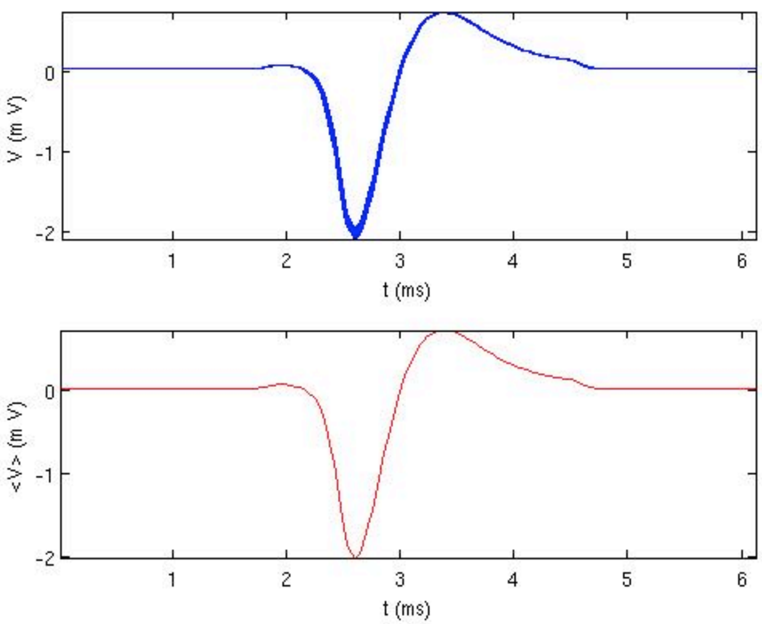
Dipole (solid-line)
Quadrupole (dashed-line)

Synchronization and the Extracellular Field

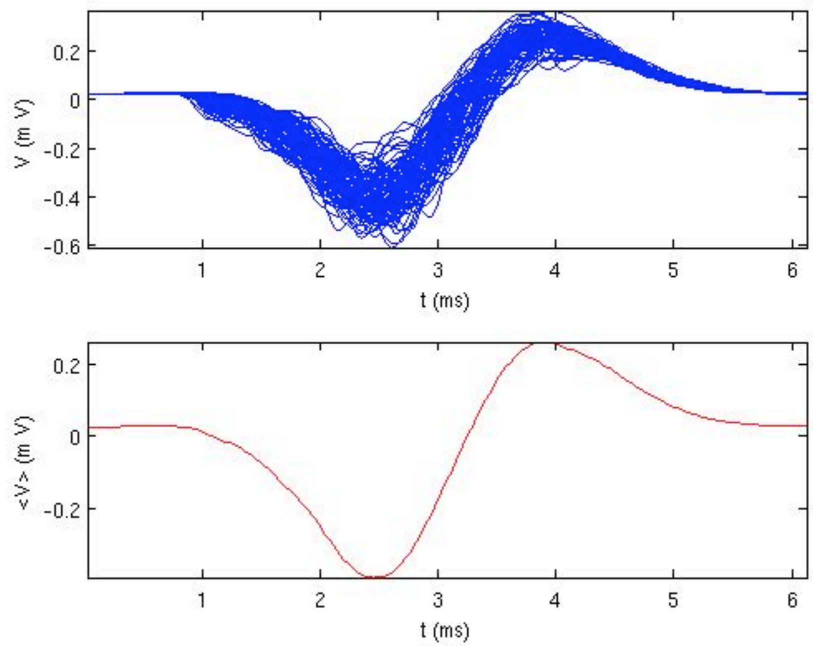




Synchronized Activity



Unsynchronized Activity



Summary and Outlook

A. Study effects of:

- Orientation of neurons
- Synchrony of activity
  - Grids of ~500 cells for several seconds
  - Look for filtering (capacitive?) effects
  - More realistic firing statistics

B. Developing a simplified mathematical description

C. Move beyond the action potential

- Incorporate slower components
  - short / longer-lasting after-hyperpolarizations
  - on / off states of activity