Overview
1. Why Plant Neurobiology?
2. Evolving Concepts in Neurobiology
3. Neurons: From Molecules to Cell-Cell Communication
4. Plant Synapses and Synaptotagmins
5. Auxin as Plant Neurotransmitter?
6. Root Apex as Plant Command Centre?

Gathering in Biosemiotics – Salzburg, 5-9 July 2006

Why Plant Neurobiology?
Mysteries Not Explainable With The Classical Plant Sciences
Action Potentials
Root Gravirepsonse
Vesicle Recycling at End-Poles
Complex Auxin Transport Patterns at Root Apices

Plant Neurobiology
Root Gravireponse
Sensory Events at the Root Cap.
Motoric Events Initiated in the Transition Zone and Accomplished in the Elongation Region.
Electric Responses in the Elongation Region Scored Already After Few Seconds of Gravistimulation.

Plants are Masters of Adaptation
A) Sensing of Environmental Signals
B) Long-Distance Communication
C) Plant-to-Plant Communication
D) Effective Information Processing
E) Learning and Memory
F) Adaptive Responses

Electrical Long-Distance Communication Based on Excitable Plant Cells

Discovered in plants by John Burdon-Sanderson in 1873

Nervous Molecules in Plants

Synaptic Proteins: Glutamate Receptors, Synaptotagmins, SNAP, Synaptic Tetraspannin Proteins, Copines, ...

Classical Neurotransmitters: Glutamate, Glycine, GABA (g-Aminobutyric Acid), Dopamine, Acetylcholine, ATP, ...

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All biological systems are embedded within physical environment that shapes their organization and behaviour.

In order to survive, all biological systems continuously retrieve information from their physical environment and use it for their effective adaptation.

Neurobiological apparatus translates sensory information first into electrical impulses and then into biological signals to induce adaptive behaviour.

Evolutionary and ecological success is dependent on intraorganismal and interorganismal communication.

Neurobiological Apparatus Supports:
1. Integrated Signal/Information Perception
2. Coherent Signal/Information Processing
3. Robust Signal/Information Output (Adaptation)

Neuronal Aspects of Plant Life
Balušška F et al (Eds) Communication in Plants: Neuronal Aspects of Plant Life

Plant Neurobiology
Acquisition, Storing and Processing of Information: Intra- and Inter-Plant Communication.

Diffuse Nervous Net in Hydra
Neurons
**Excitable and Sensory Cells with Robust Vesicle Trafficking Apparatus:**

- **SNAREs**
  - Rice Genome: 74
  - Arabidopsis Genome: 68
  - Human Genome: 35
  - Yeast Genome: 21


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Synapses

**Vesicle Recycling Based on Endocytosis via Clathrin/Dynamin Apparatus and on Calcium-Regulated Secretion via Secretory Endosomes**

- Present in Plants but Lacking in Yeast
- Yeasts Lack also:
  - Annexins, Synaptotagmin, COPines...


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Plant Synapses

**Actin**

- **Myosin VIII**


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Plant Synapses

**Synaptotagmins at Root Synapses**

- **Auxin Efflux Carrier (PIN1) Recycles at Plant Synapses**

Bazbek Davletov, Molly Craxton

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Synaptotagmins Localize to

- **Arabidopsis**

- **Yeast**

- **Human**

- **Rice**


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Yeast, human, and rice genomes encode 6, 5, and 7 synaptotagmin (ST) genes, respectively. Yeast and human genomes encode ST genes that are similar in sequence, while the rice genome encodes a synaptotagmin with an extended C-terminus that is not found in yeast and that is not the ortholog of any human ST gene. The maize genome encodes 6 ST genes, but ST genes are absent from the sequenced genome of the oomycete *P. infestans*.

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SYMPTOMATIC ACTIVITY

- **Asymmetric Actin/Myosin-Based Apparatus**
- **Current Broader Definition:**
  - Mediating Calcium Regulated Exocytosis and Vesicle Recycling
  - Mediating Calcium Regulated Exocytosis and Vesicle Recycling

- **Plant Synapses**

- **Arabidopsis Genome Encodes Six Synaptotagmin Genes**

- **Arabidopsis Synaptotagmins Localize to Plant Synapses in Root Cells of the Transition Zone**

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**Translation Zone**

- **Annexin, Synaptotagmin, Copine...**

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**Term was Coined in 1897 for Neurons**

By Charles Scott Sherrington

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MRC Cambridge, UK

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**P. infestans**, the oomycete that causes potato late blight, is an example of a synaptotagmin gene content of the sequenced genome. *P. infestans* has 4 ST genes (11-49).

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**Plant Synapses**

**Endocytosis and Vesicle Recycling**

- **Asymmetric Vesicle Recycling**
  - Presynaptic
  - Postsynaptic

**Auxin as Plant Neurotransmitter**

**Very Rapid Electrical Responses in Plant Cells**


**Auxin-Transporting Synapses**


**Auxin in Roots**


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**Maize Root Apex**

**Developmental Zones**

- Elongation Region
- Transition Zone

**Maize Root Apex**

**Root Apices as Plant Command Centres**

**Transition Zone**

- Root Apex Transition Zone has the Highest Number of F-Actin and Auxin-Based Synapses
- Root Apex Transition Zone is Extremely Sensitive Towards External Auxin (Plant Neurotransmitter)
Root Apices as Plant Command Centres

**Auxin Influx into Root Apices**

- Maize
- Arabidopsis

**Oxygen Uptake**

- Brefeldin A (BFA) Sensitive

**Brain-like Status of the Transition Zone**

- Rhythmic Oscillations of Oxygen Uptake in the Transition Zone

**Transition Zone**

Brain-like features in root apices

**University of Bonn:**
- Plant Cell Biology
- Faculty of Biology

**University of Florence:**
- Plant Electrophysiology
- Faculty of Biotechnology

**International Laboratory of Plant Neurobiology**
- Florence & Bonn
Changes in the oxygen influx upon gravistimulation in the upper and lower side of the transition zone. Values are means (SE), n = 15.

Root Apices as Plant Command Centres
Oxygen Uptake is Sensitive to Gravistimulation

Evolving Concepts in Neurobiology
1. Integrated Signal/Information Perception
2. Coherent Signal/Information Processing
3. Robust Signal/Information Processing
Output: Adaptation

Surface Potential is Sensitive to Gravistimulation

Root Apices as Plant Command Centres
Surface Potential is Sensitive to Gravistimulation

Neurobiology
All biological systems (organisms) are embedded within physical environment which shapes their organization and behaviour.

In order to survive, all biological systems needs effective retrieval of information from their physical environment.

In humans, neurons translate sensory information obtained from environment into electrical impulses which are then transformed into biological signals to induce motoric responses.

Similarly in plants, numerous parameters of the physical environment, especially light and gravity, are monitored and there are specialized cells (such as e.g. root cap statocytes and root transition zone cells) which are evolutionally optimised to translate sensory information obtained from physical environment into motoric responses (e.g. gravitropism). Electric signals are induced by all known physical factors in plants, suggesting that electricity is also mediating physical-biological communication.

As the plant body is literally shaped via polar and transcellular auxin transport, which is sensitive towards such physical parameters like light, gravity, and temperature, as well as mediated via bioelectrical signals, plant neurobiology as a new branch of plant sciences is justified.