Closed-loop recordings in sensory electrophysiology

— how software can improve experiments —

Jan Benda

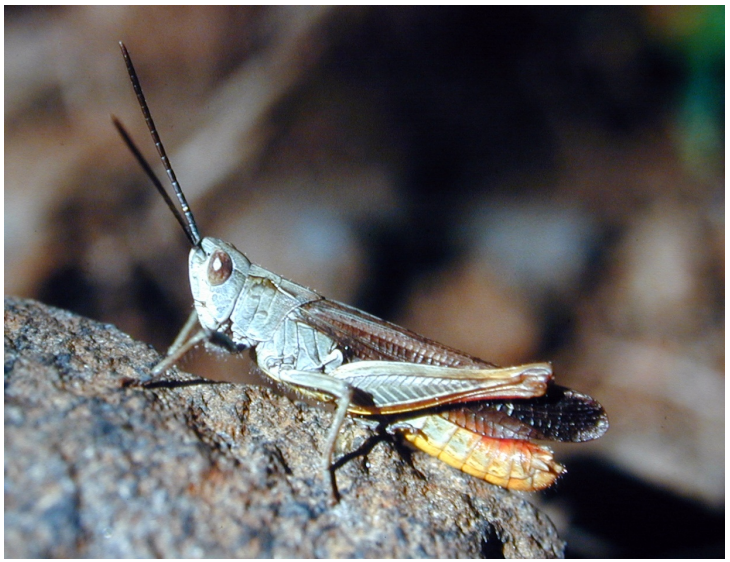
Biozentrum Martinsried
Ludwig-Maximilians Universität München

bpcn benda

Sensory electrophysiology

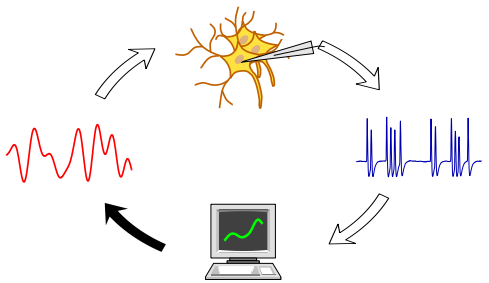
Electrosensory systems of weakly eletric fish

Auditory system of grasshopper and crickets

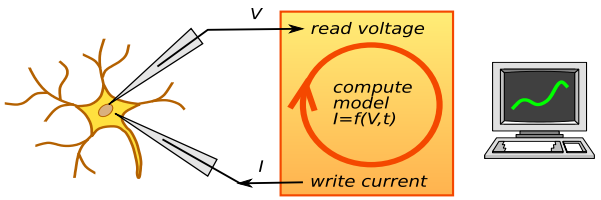


How are sensory stimuli processed by sensory systems?

Content



Closed-loop experiments

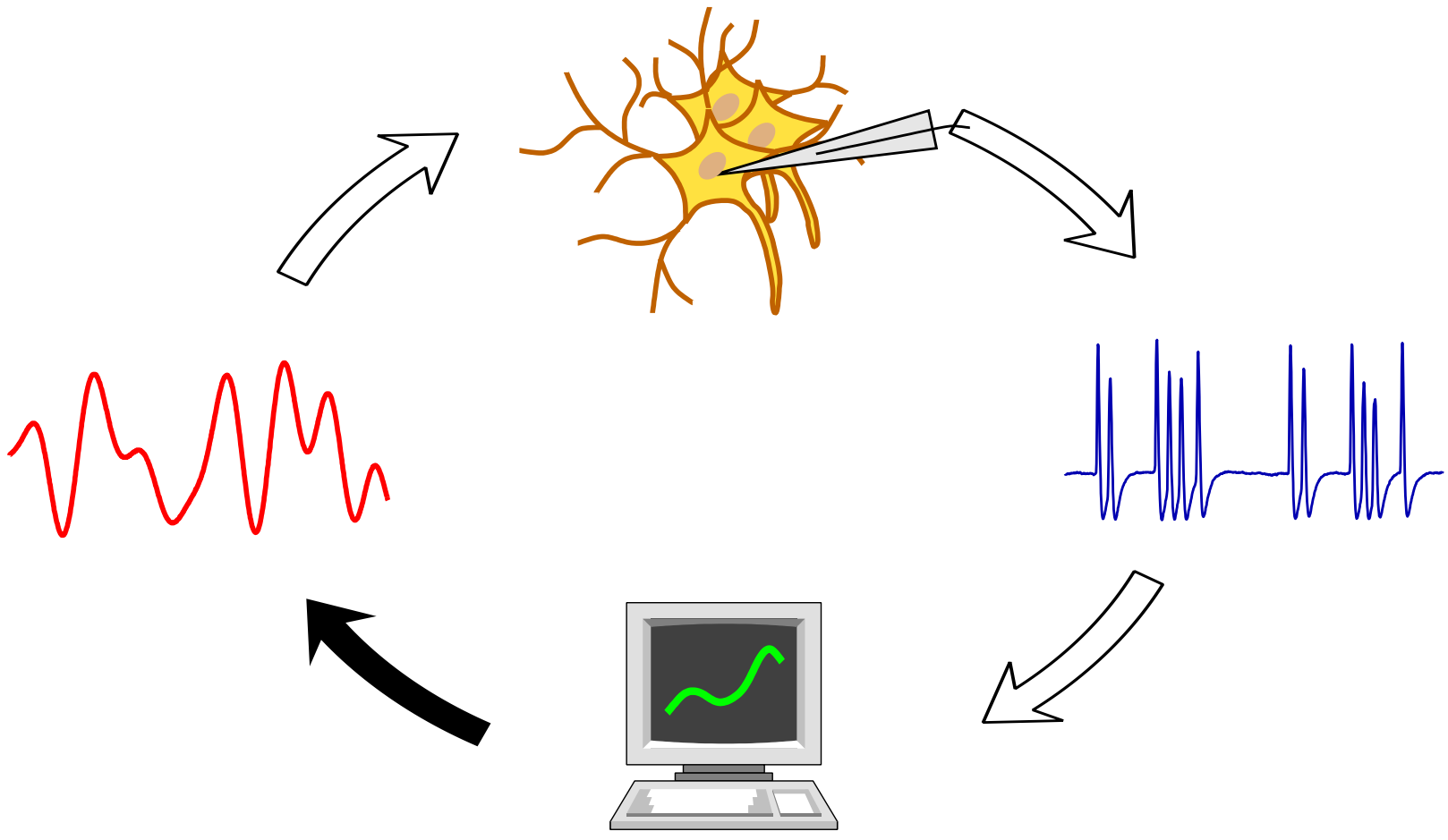


Dynamic clamp

RELACS — closed-loop software

Metadata — extending data-lifetime

Closed-loop experiments



“Traditional” experiments

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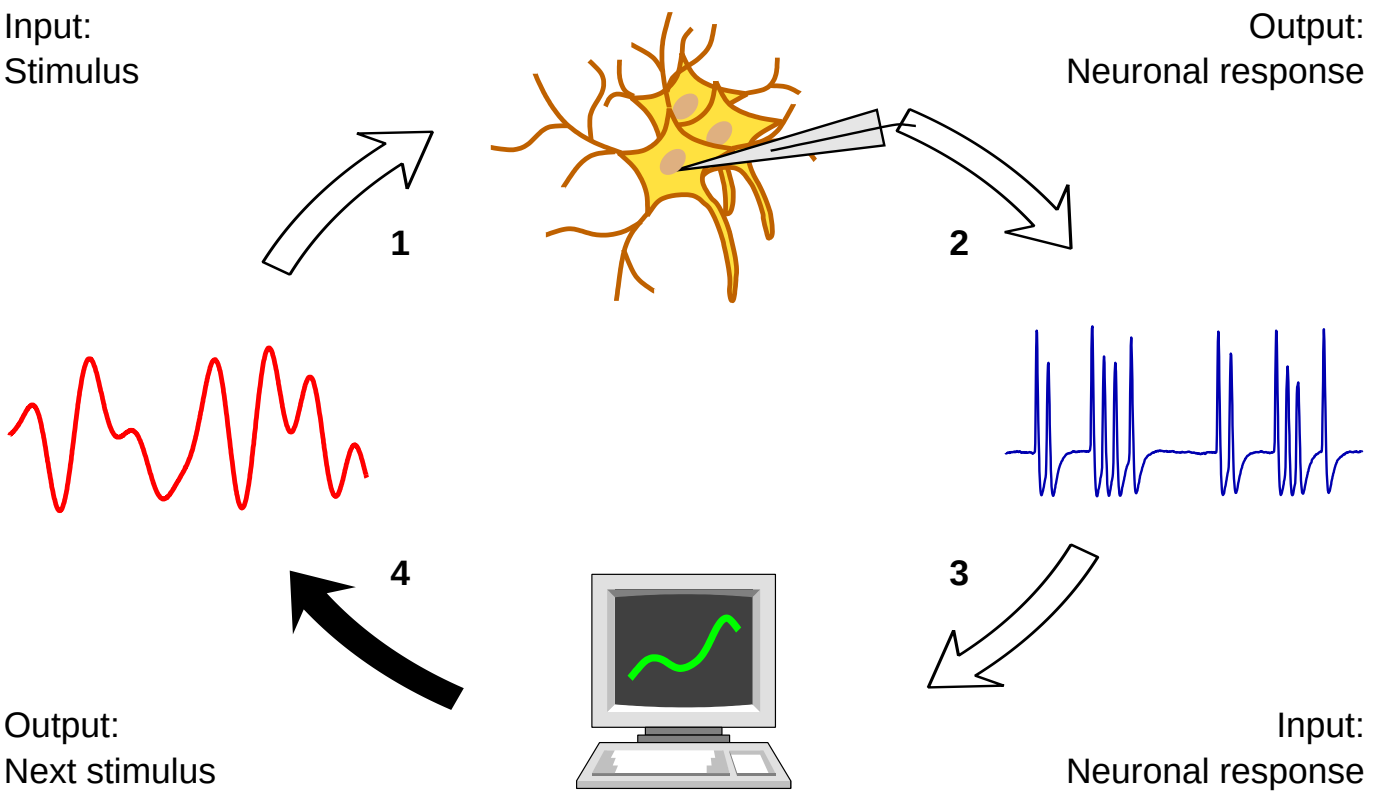
6. After several iterations a paper is written

Closed-loop experiments

1. Present a stimulus
2. Record the response
3. Immediately analyze and visualize the data
4. Generate the next stimulus



Simple closed-loop experiments

- Online visualization of processed data:
  - General infos, e.g. quality of spike detection, sensitivity of the cell, temperature, condition of animal, ...
  - Specific results, e.g. spike raster, firing rates, spike-triggered averages, ...

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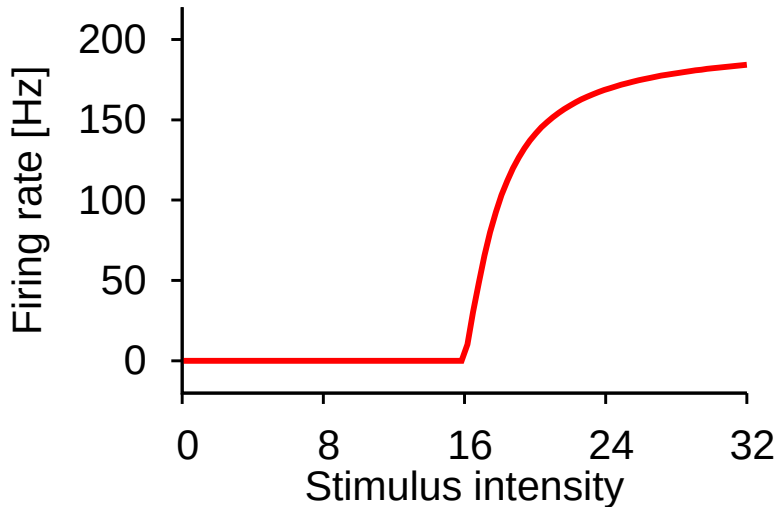
  $\Rightarrow$ Speeds up manual ("traditional") closed-loop
- Set stimuli relative to the neuron's dynamic range
- Automatically control motorized electrodes (great for dual unit recordings!)
- Optimize tuning curve measurements
- ...

Example: tuning curve measurement

Traditional:



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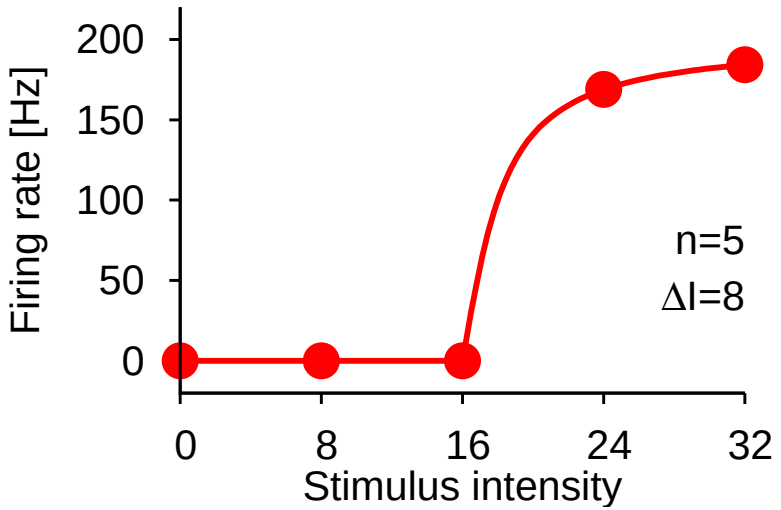

either:

fast $\longrightarrow$ low resolution

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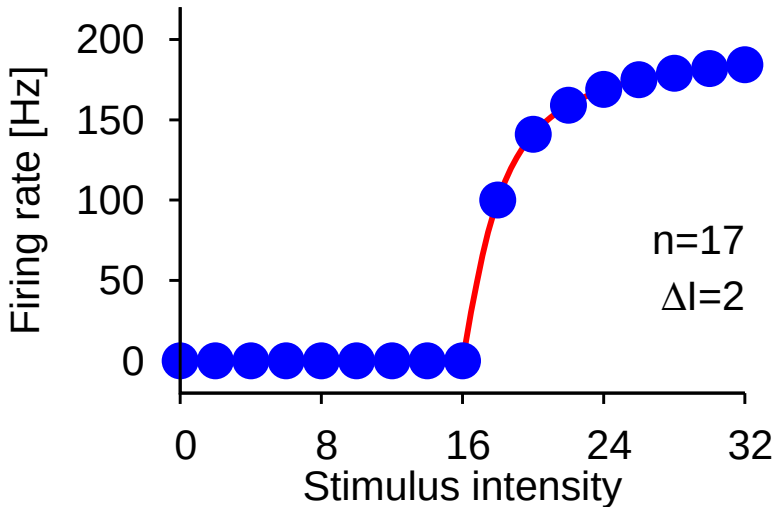

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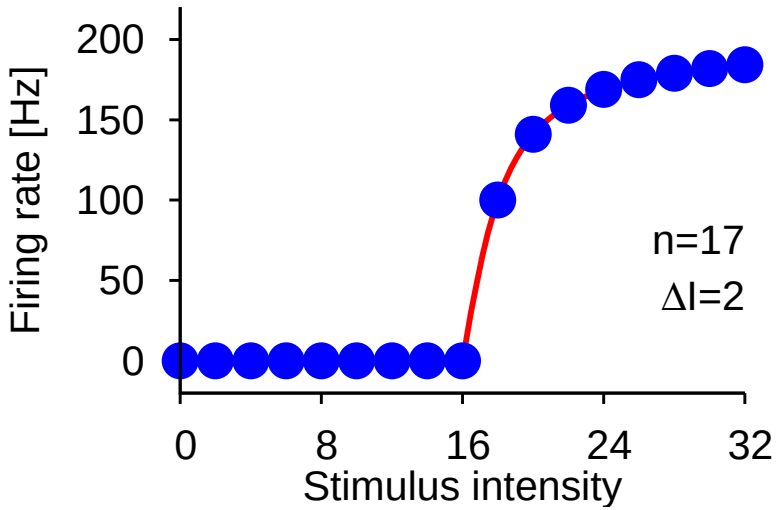

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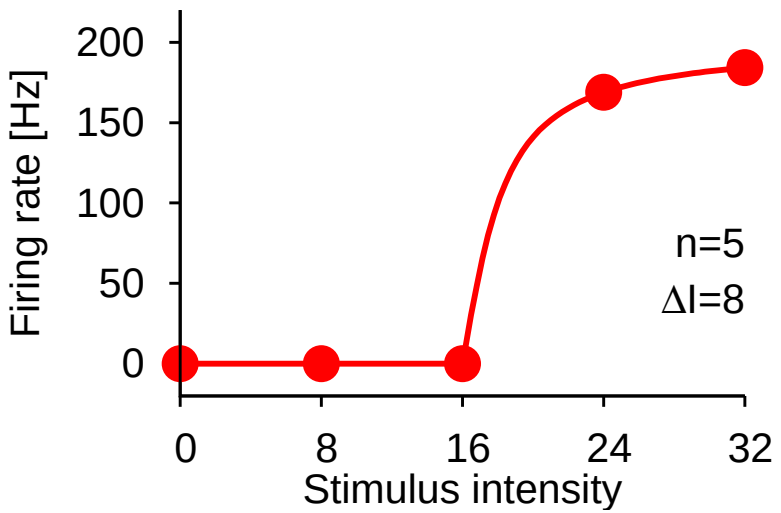

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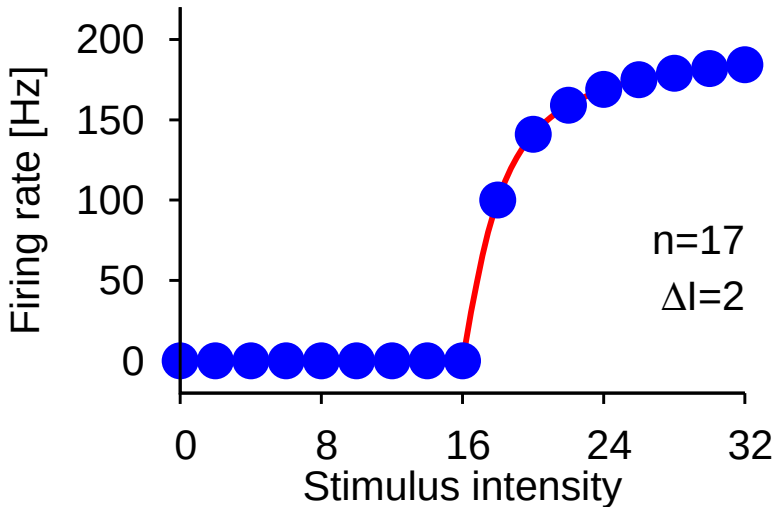

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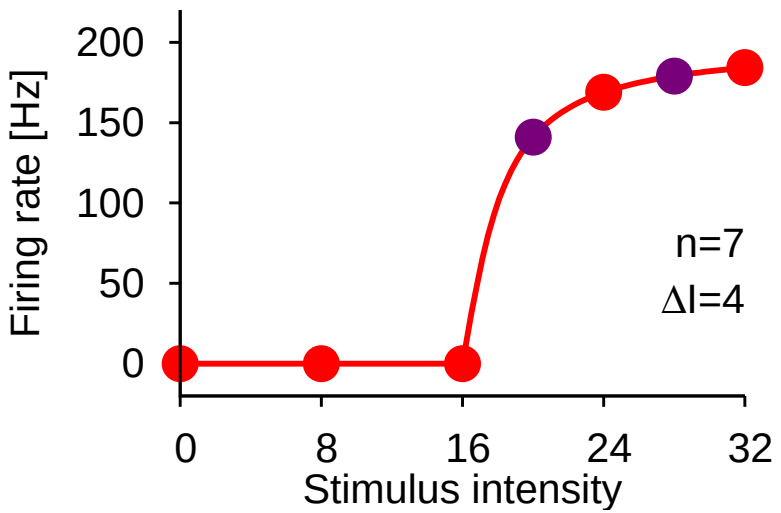

1. start with low resolution
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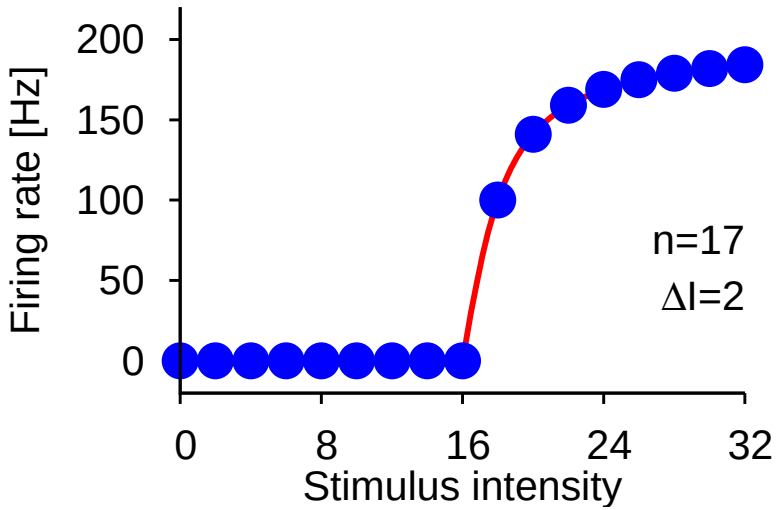

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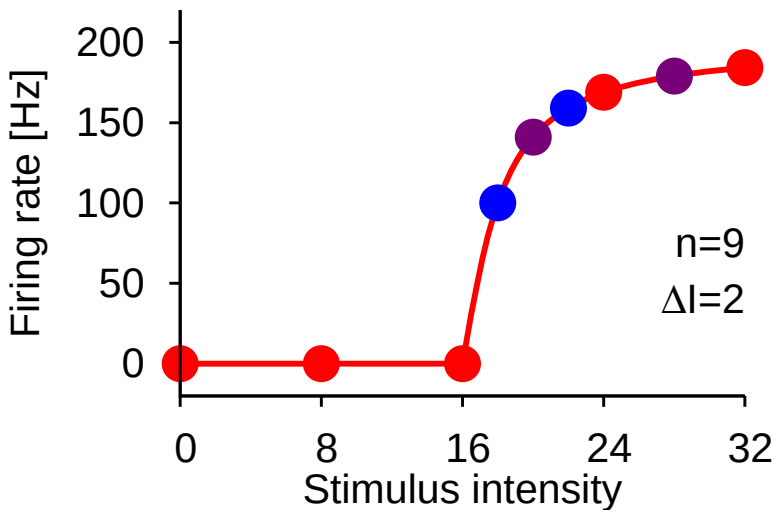

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3. further increase resolution

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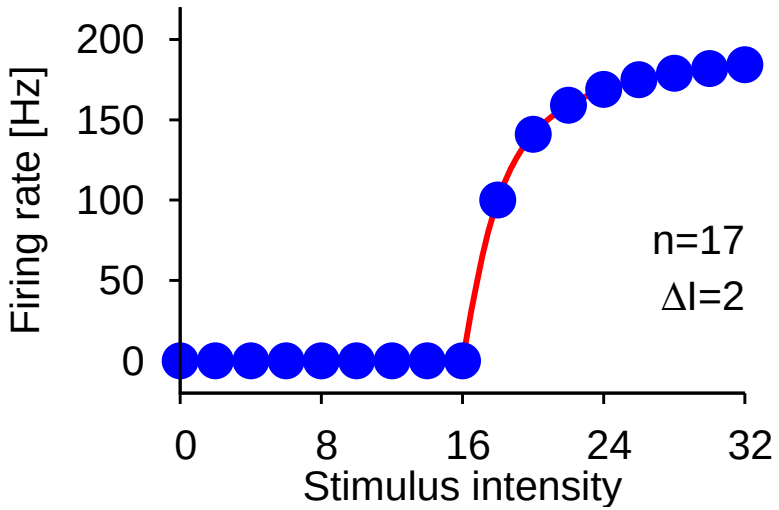

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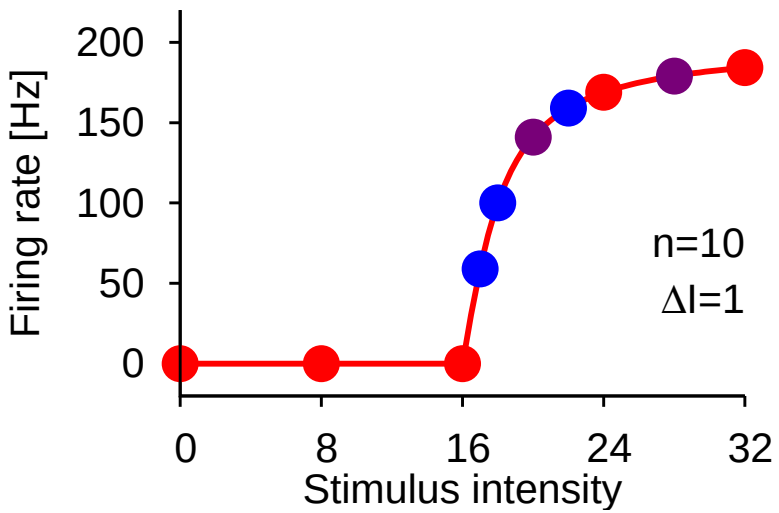

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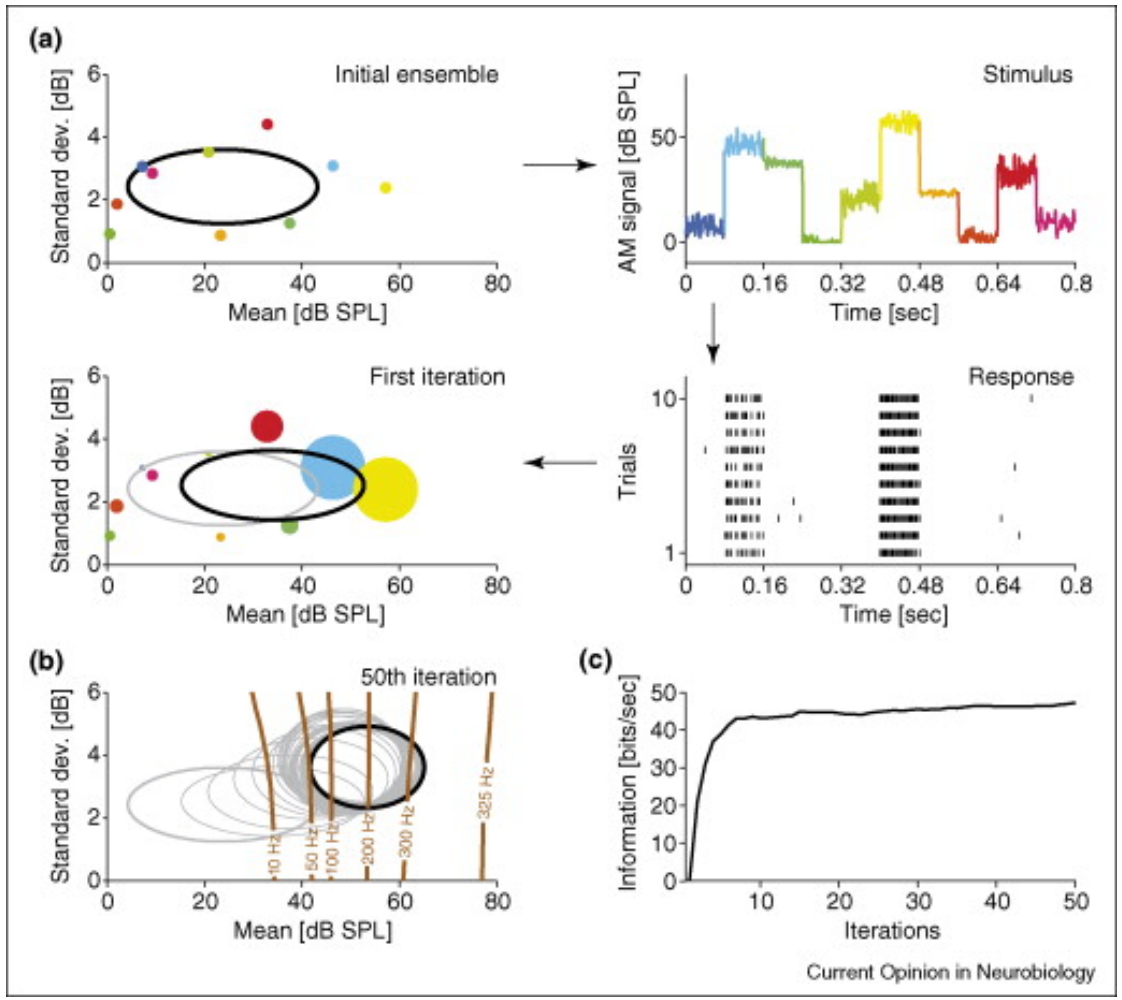
Advanced closed-loop experiments

New experimental designs are possible:

- Optimal search for a neuron's receptive field.
- Search for stimuli that drive a neuron in an "optimal" way.
- Find set's of stimulus parameter that result in the same response (iso-response method).
- ...

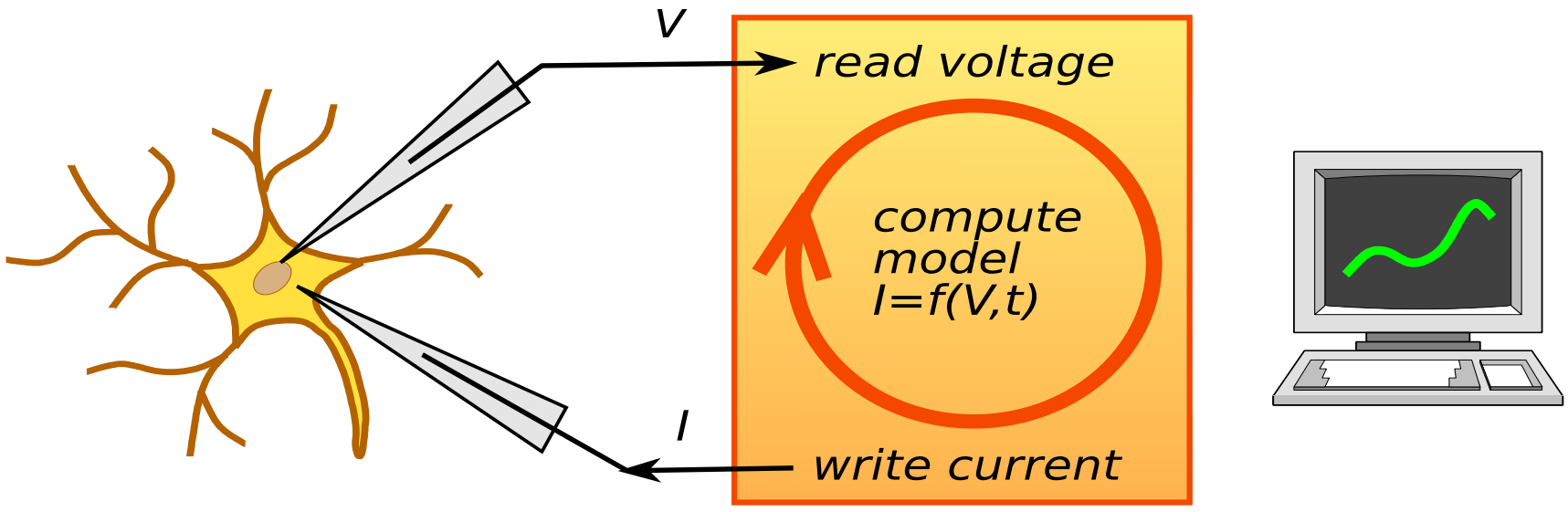
Benda et al. (2007): "From response to stimulus: adaptive sampling in sensory physiology." *Curr. Opin. Neurobiol.* **17**: 430–436.

Example: optimal stimulus ensembles



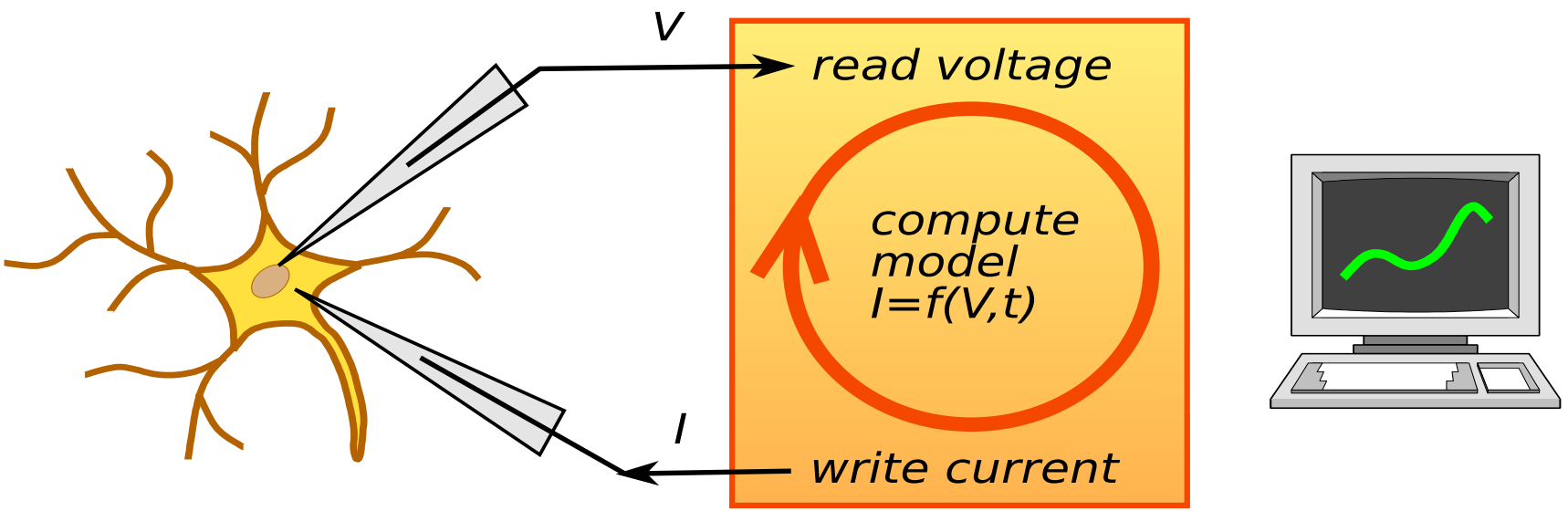
Machens et al. (2005) *Neuron* **17**: 47–56.

Dynamic clamp



Dynamic clamp

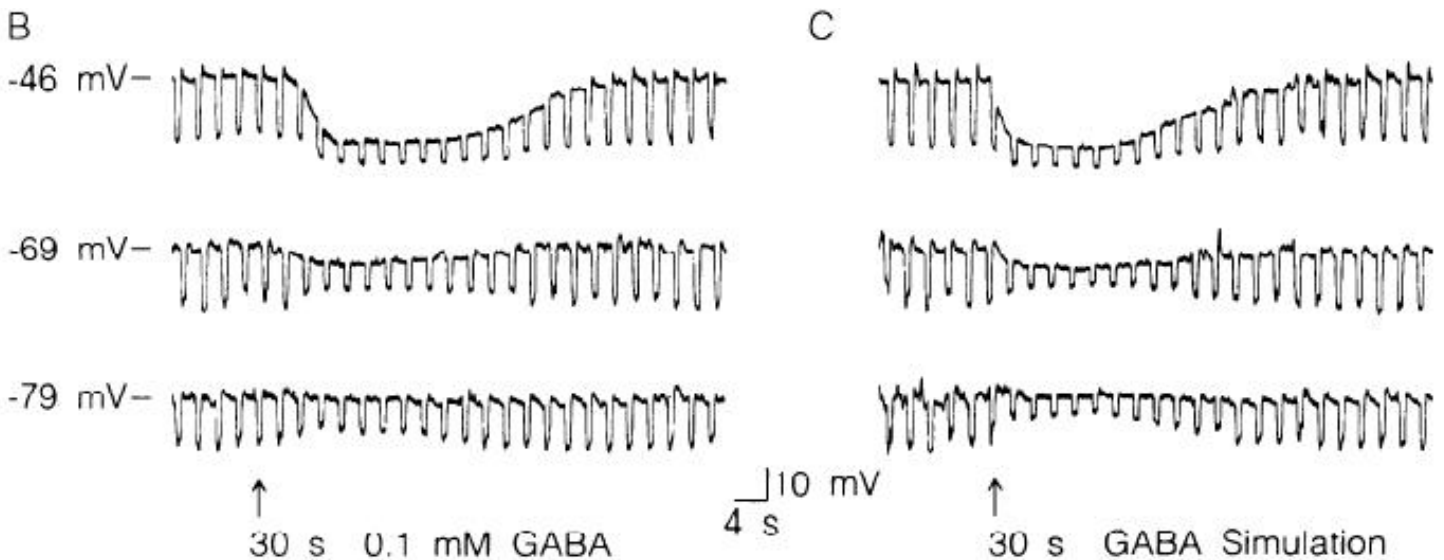
Current-clamp, with the current I computed as a function of the measured membrane potential V.



Closed-loop at a per sample time scale (tens of kHz).

Artificial conductances

$$I = g(t) \cdot (V - E)$$



Andrew A. Sharp, Michael B. ONeil, L. F. Abbott, & Eve Marder (1993) *J Neurophysiol*

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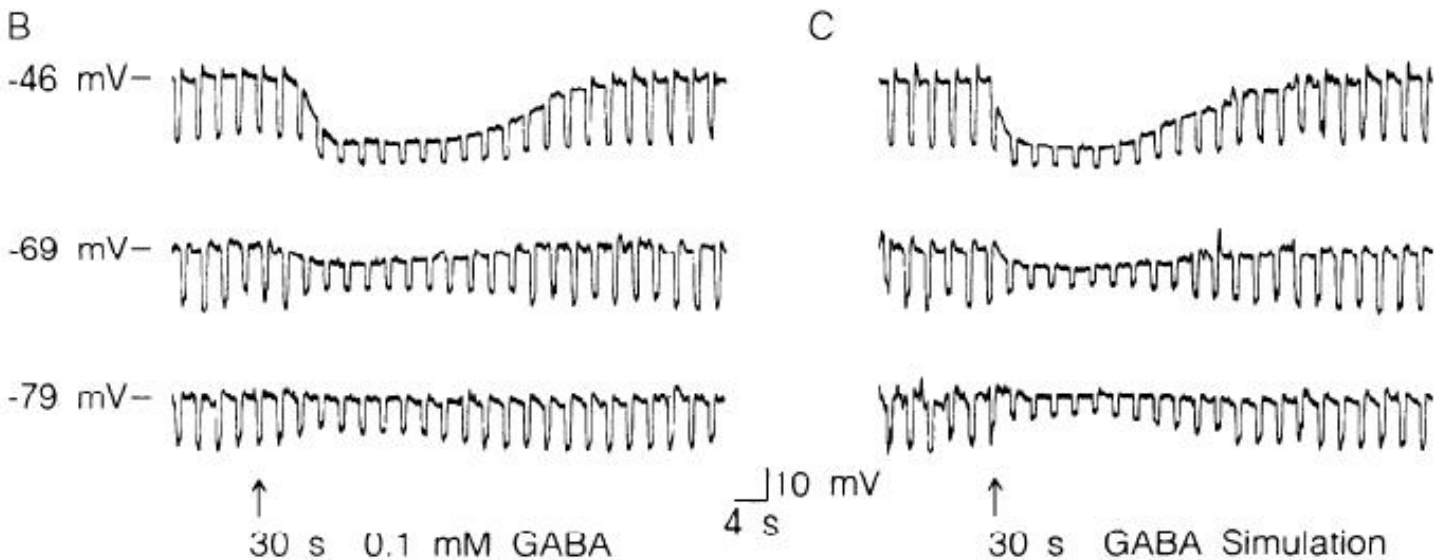

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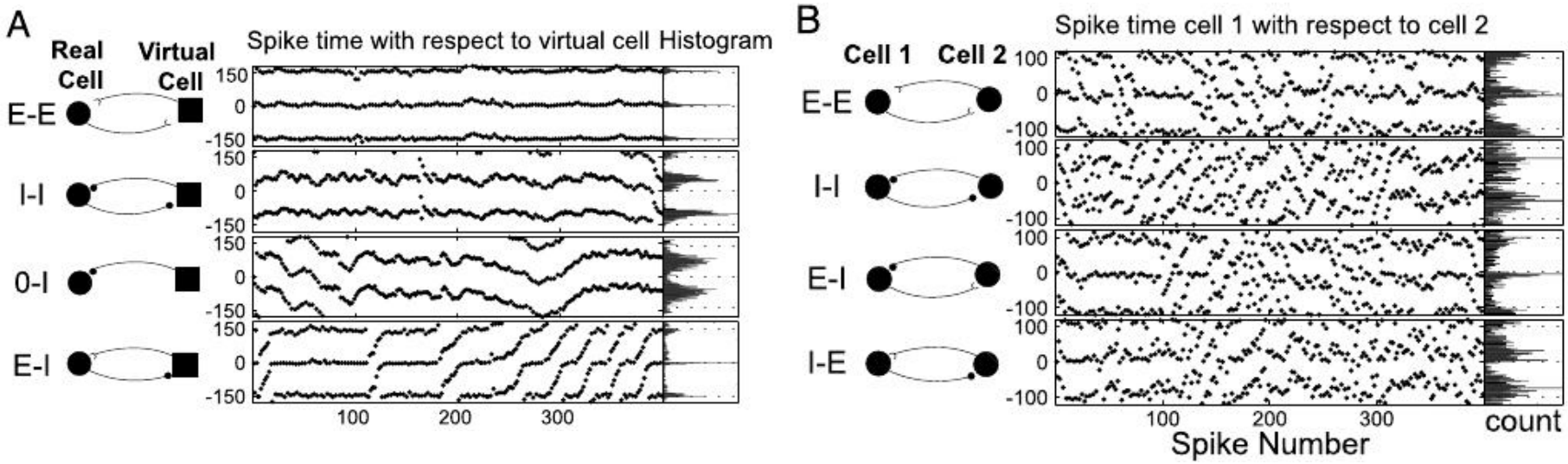
- Synaptic conductances
- Voltage-gated conductances

Artificial networks

$$I_1 = g_{syn}(V_2) \cdot (V_1 - E) \qquad I_2 = g_{syn}(V_1) \cdot (V_2 - E)$$

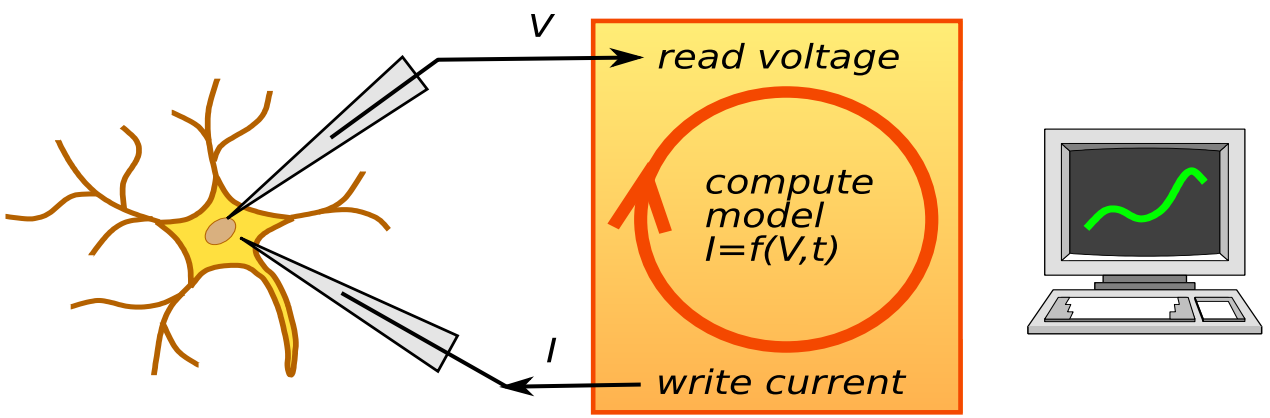


Theoden I. Netoff, Matthew I. Banks, Alan D. Dorval, Corey D. Acker, Julie S. Haas, Nancy Kopell, & John A. White (2005) *J Neurophysiol*

- Artificially couple real neurons
- Couple with simulated neurons

Dynamic clamp: artificial conductances

+ Fine tuned control of conductances
– Use high sampling rates!
– Conductances are only “inserted” at the electrode.



relacs

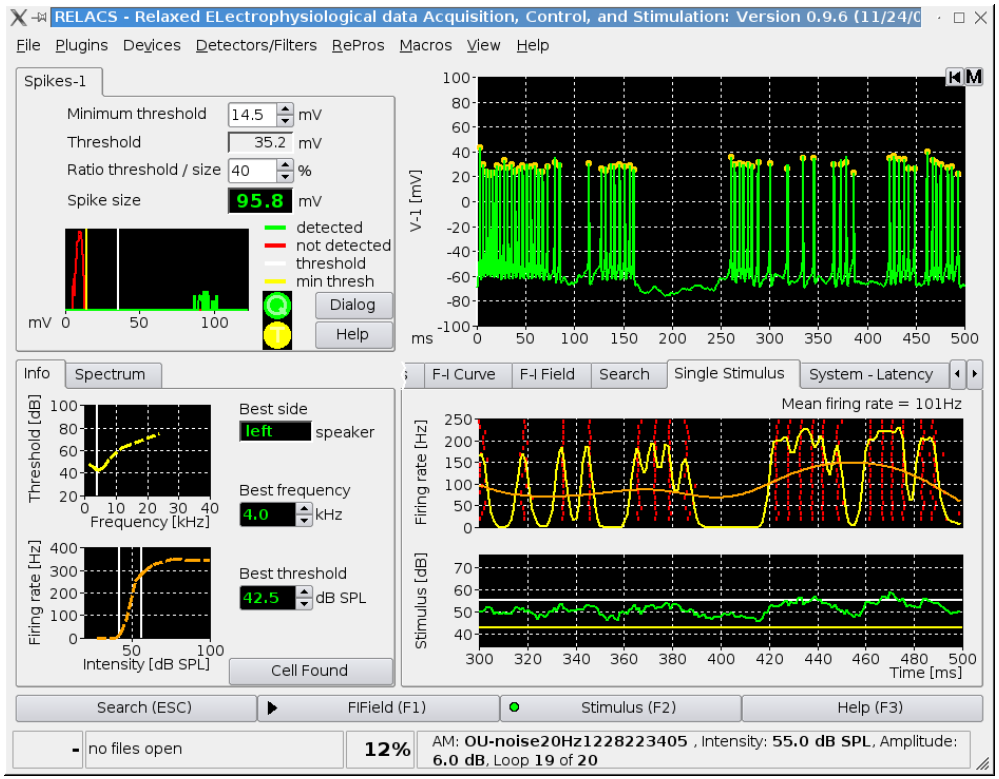
... enjoy your recordings

www.relacs.net

RELACS ... enjoy your recordings

Relaxed Electrophysiological data Acquisition, Control, and Stimulation

RELACS is a framework for closed-loop experiments

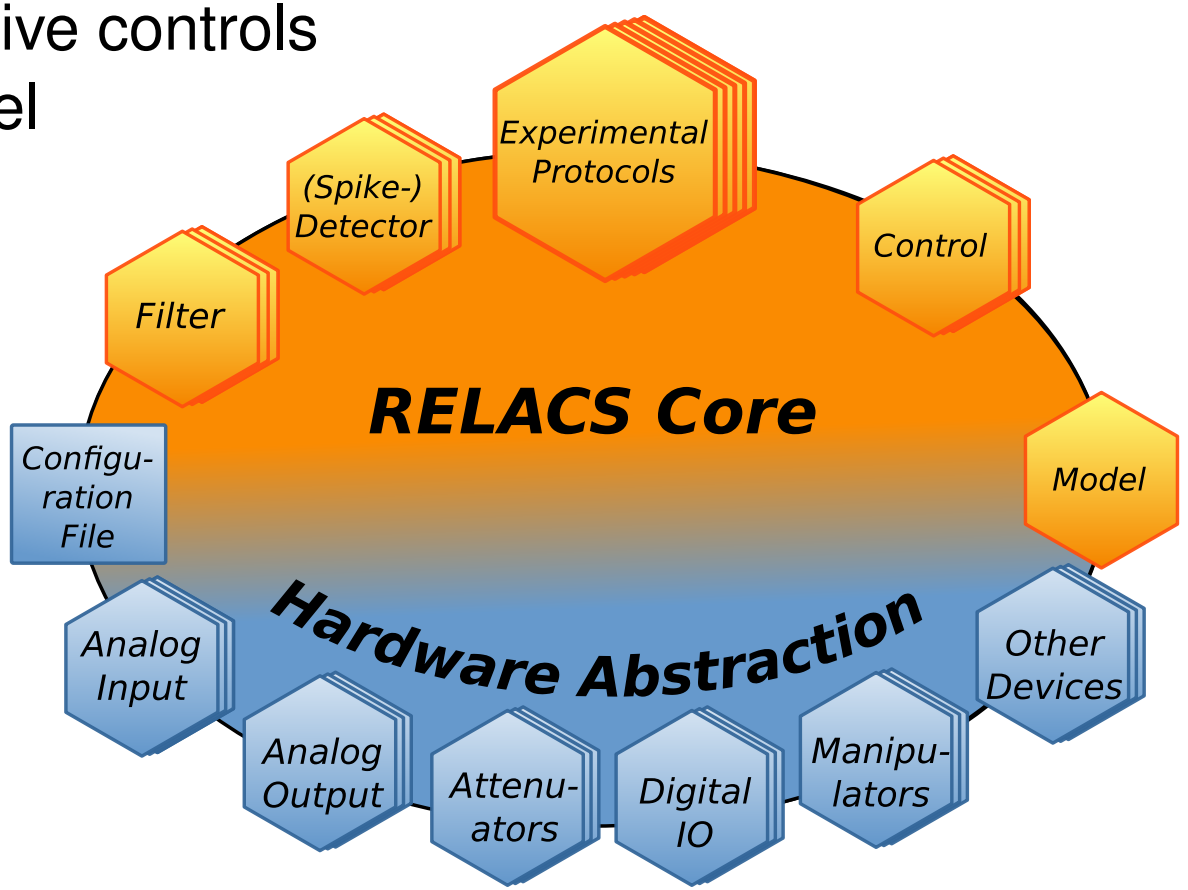


⇒ currently 13 scientific publications based on *RELACS* data in *Neuron, J Neurosci, PLoS Biol, Nat Neurosci, J Neurophysiol, etc.*

Modular design

RELACS core with flexible C++ Plugins for

- hardware abstraction
- data pre-processsing (filter, spike detectors)
- **experimental protocols**
- passive controls
- model

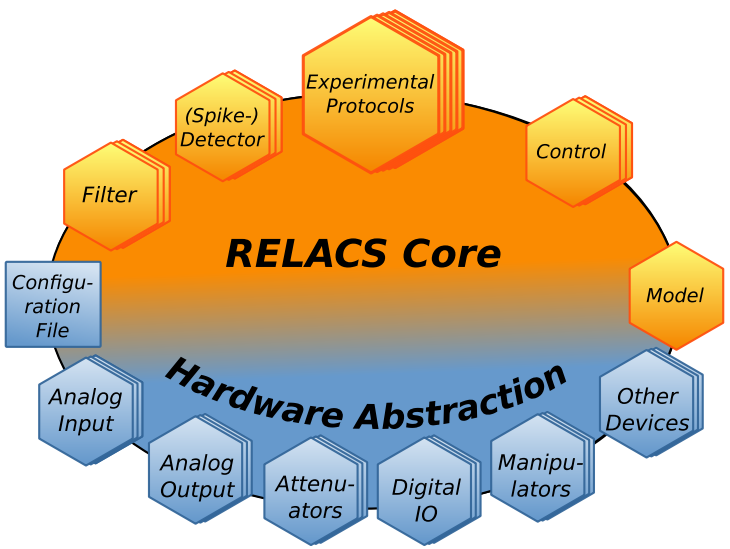


Hardware independent protocols

RELACS integrates all hardware components.

Experimental protocols for *RELACS*

- are implemented independently of specific hardware
- can be used on all the different experimental setups in your lab without any modifications
- can be shared with other labs



Free and open source software

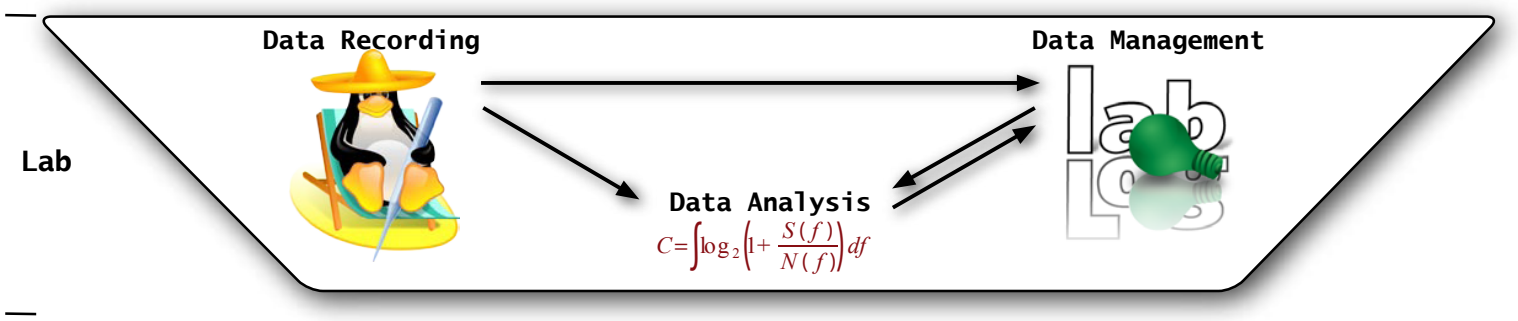
RELACS is open source and free software distributed under the GNU General Public License (GPL).

- No hassle with licenses of commercial software.
- Add whatever new feature you need directly to the program.
- Share the program and your specific experimental protocols with your collaborators.
- Know what the data-analysis algorithms are doing!

Talking about data

an extensible framework for metadata exchange

The data-chain



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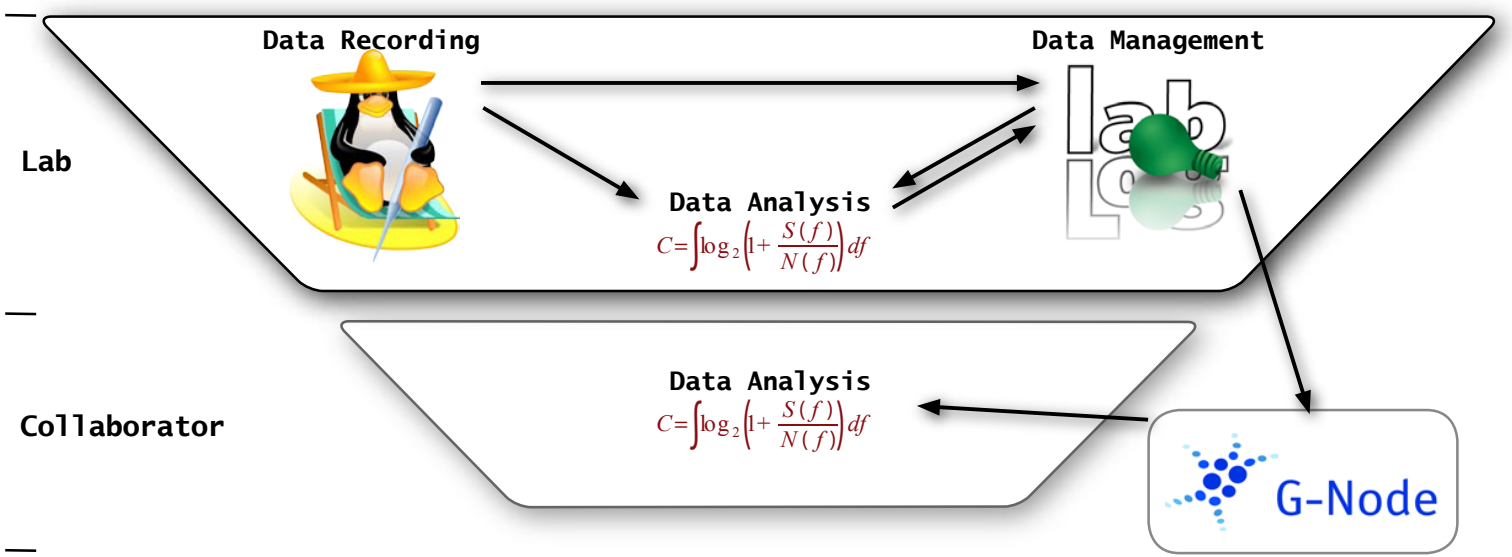

German neuroinformatics node

www.g-node.de

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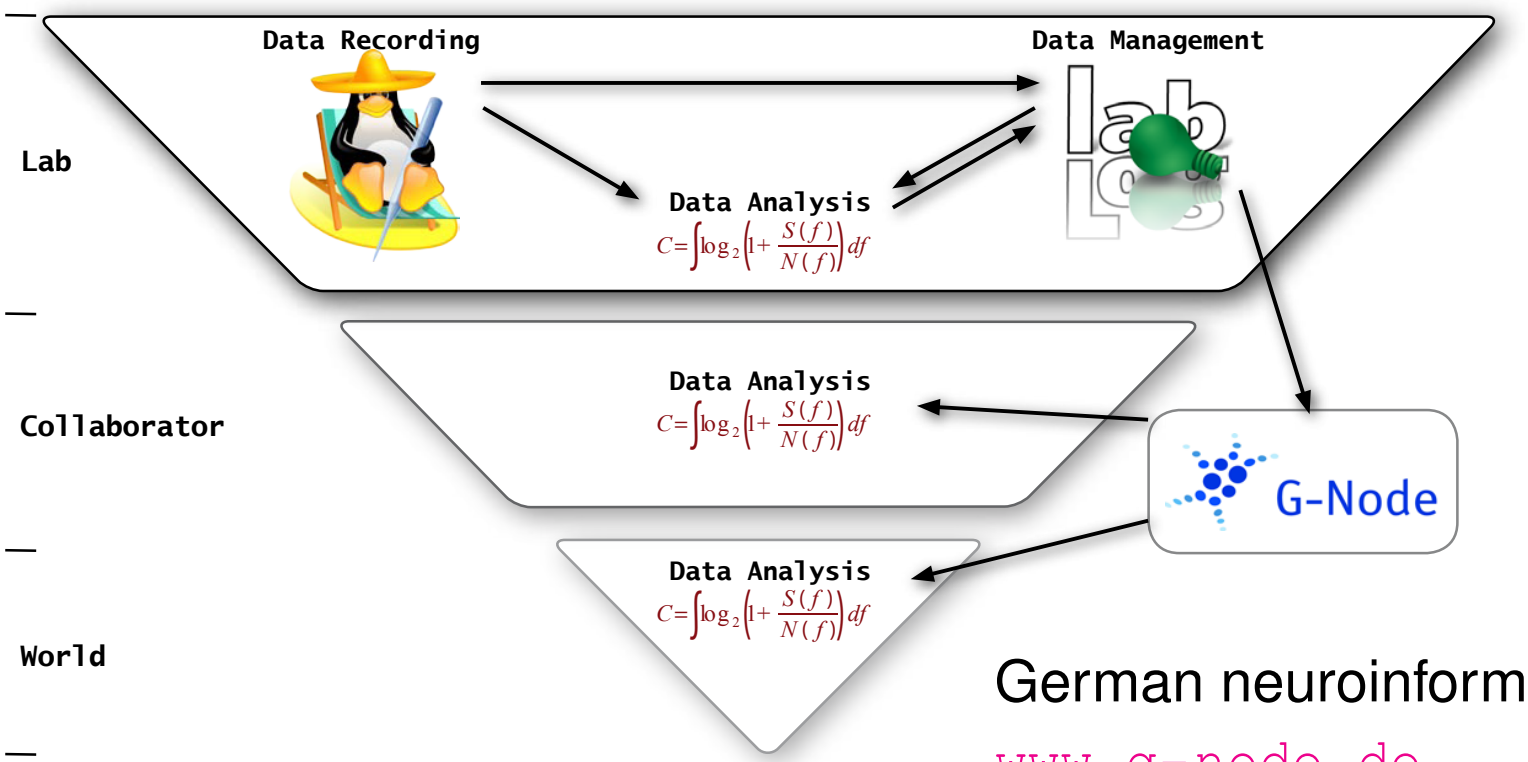

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- All data transfer requires talking about data.
- How to exchange metadata?

Metadata

- is “data about data”.
- describe recording conditions.
- essential for data analysis, management, and sharing.

stimulusType = white noise

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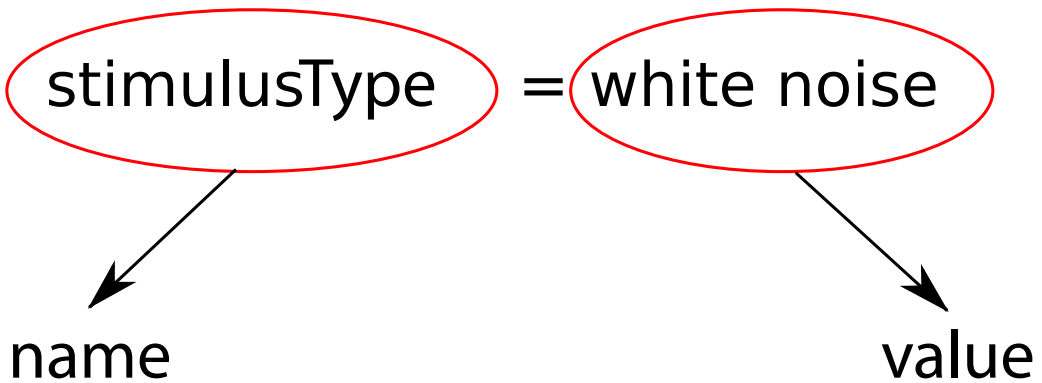

The metadata problem

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- describe recording conditions.
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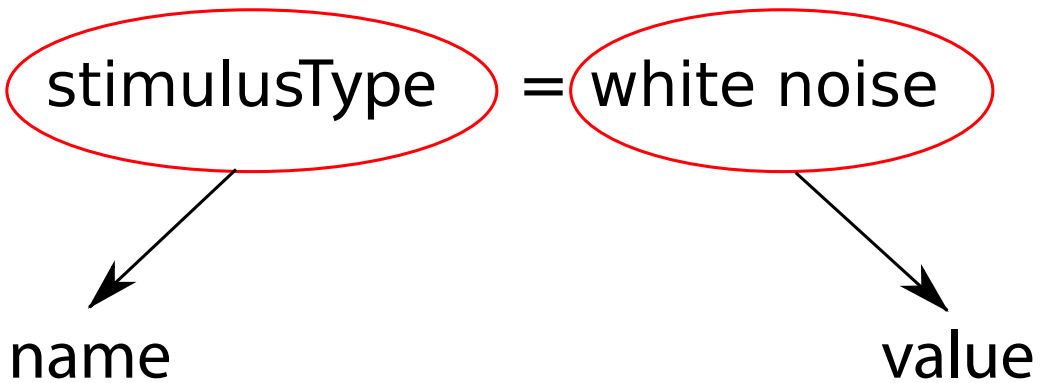
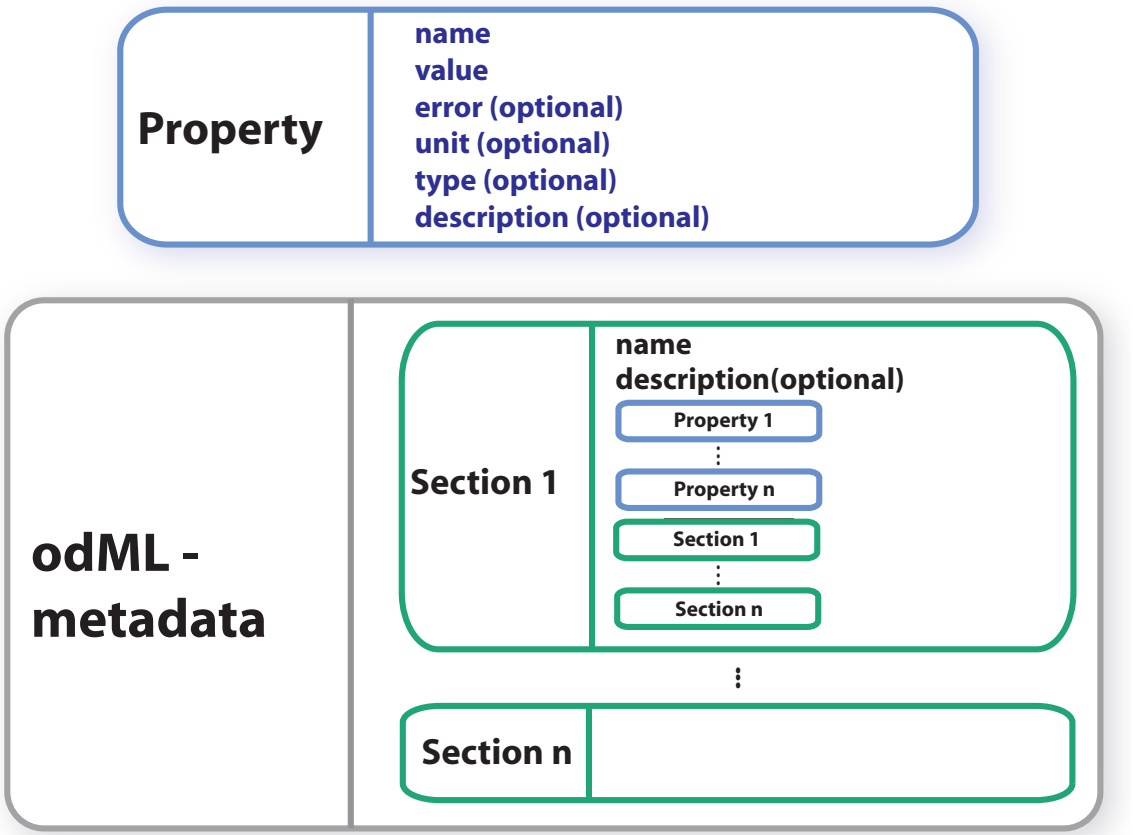


- What name to choose?
- What does it mean?
- How to organize metadata?

odML — open metadata markup language

Structure:



Implemented as the odML XML Schema

Grewe, Wachtler, Benda (2010) *submitted*. www.g-node.org/odml

odML — open metadata markup language

Terminologies: names & definitions

HardwareSettings:

Amplifier:

name	type	description
Gain	float	The amplifier gain.
HighpassCutoff	float	The cutoff frequency of the amplifier's highpass filter. Given in Hz.
LowpassCutoff	float	The cutoff frequency of the amplifier's lowpass filter. Given in Hz.
Mode	string	The amplifier mode. E.g. Bridge, CC, VC etc.

How to use odML?

1. Assemble properties:
   - If you find an appropriate property in the odML-terminologies, use it!
   - Ignore all properties that do not match.
   - Add your own properties that are not yet in the terminology, if possible with a description.

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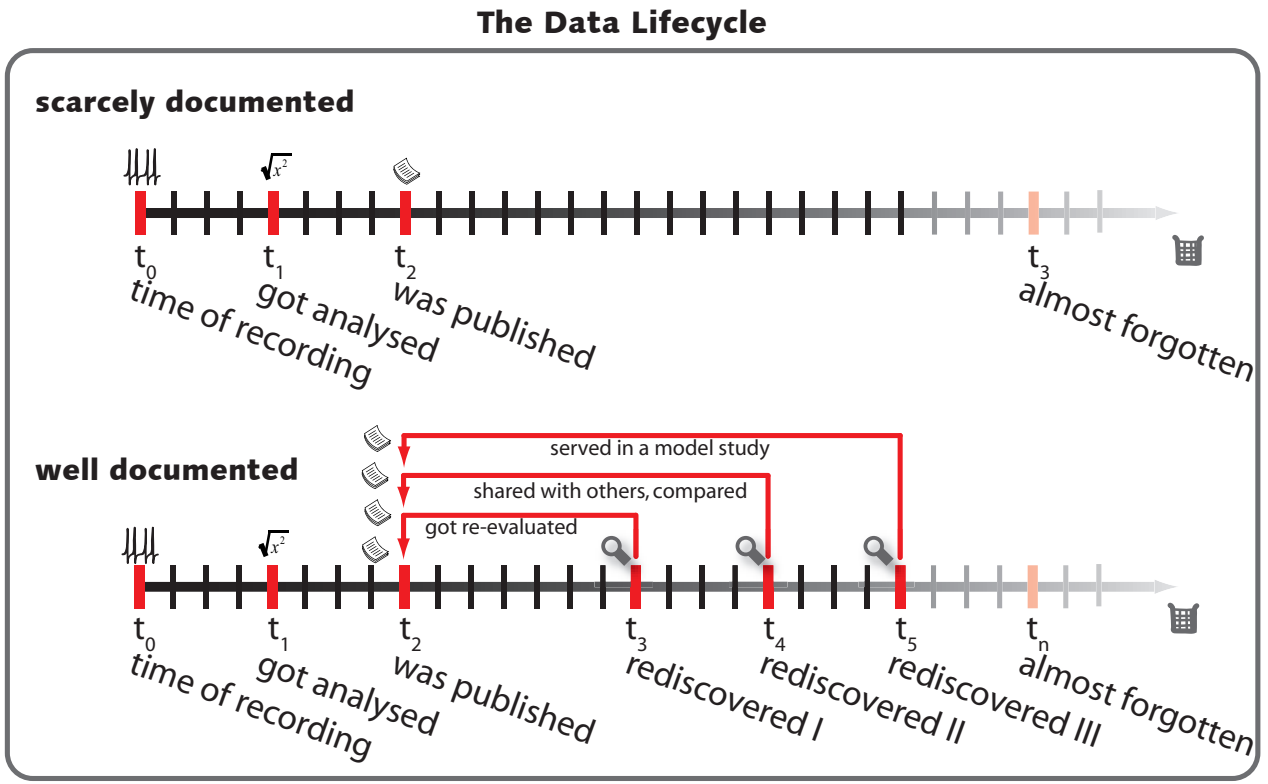
$\Rightarrow$ odML standard: The G-Node electrophysiology database is based on odML `ww.g-node.org`

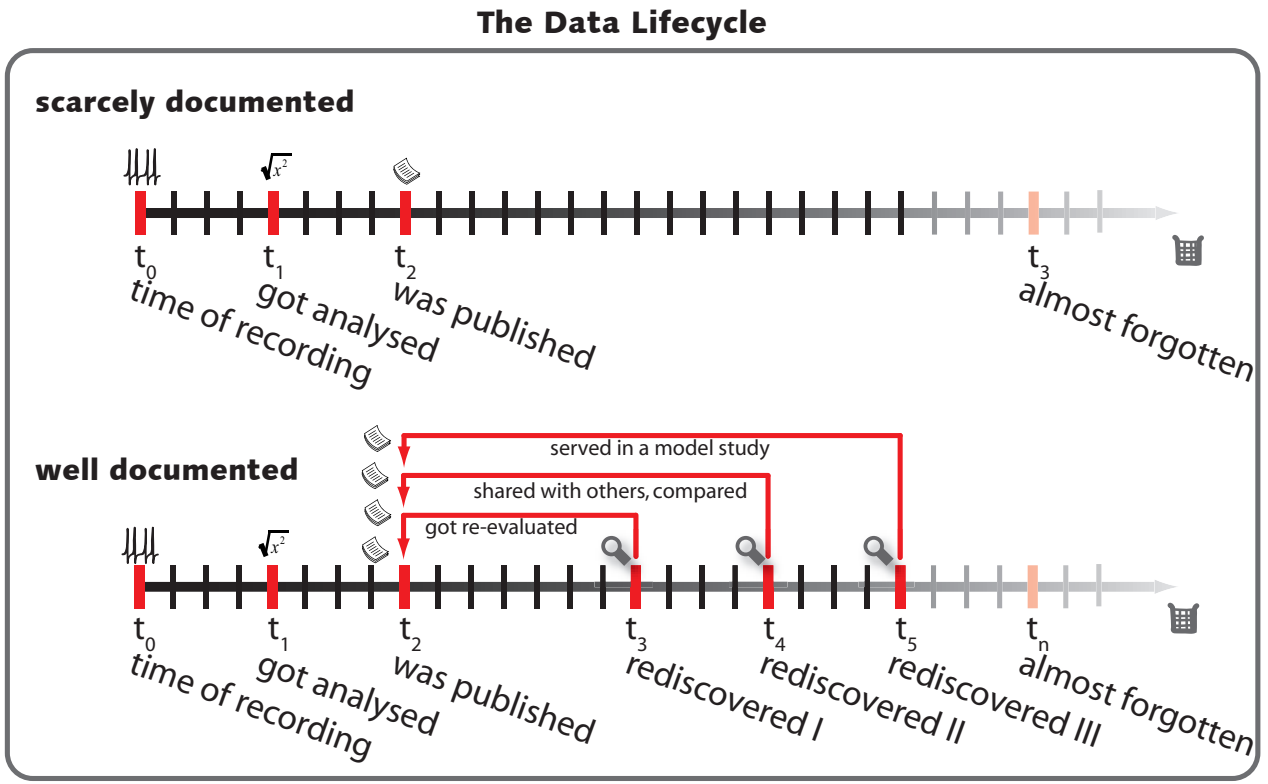
Grewe, Wachtler, Benda (2010) *submitted*. `www.g-node.org/odml`

The data life-cycle



- Meta information tends to vanish with time.
- Thus, re-using of old data is a tedious business.
- Data should be annotated as early as possible (preferentially at the time of acquisition, e.g. with *RELACS*).

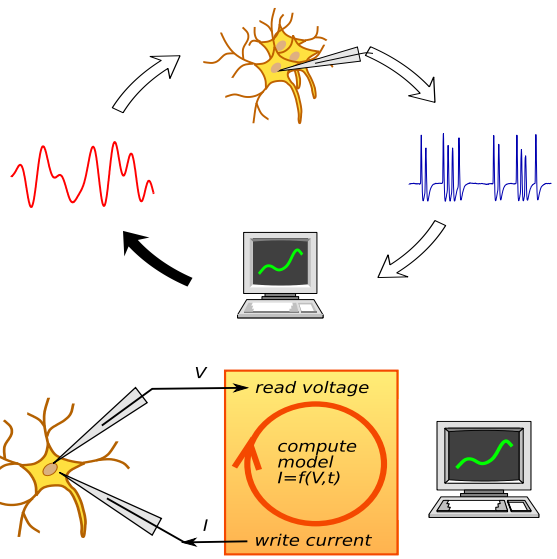
The data life-cycle



- odML provides a simple and flexible standard
- Well annotated data can be found and reused easily

$\Rightarrow$ Your data deserves it!

Summary



Closed-loop experiments

Novel experimental designs

Dynamic clamp

Artificial conductances and hybrid networks

— C. Boucsein, Freiburg

— R. Polder, npi electronic, Tamm

RELACS www.relacs.net

Software platform for closed-loop and dynamic clamp experiments

Metadata www.g-node.org/odml

A standard for sharing data

— J. Grewe, LMU Munich

— T. Wachtler, G-Node, LMU Munich

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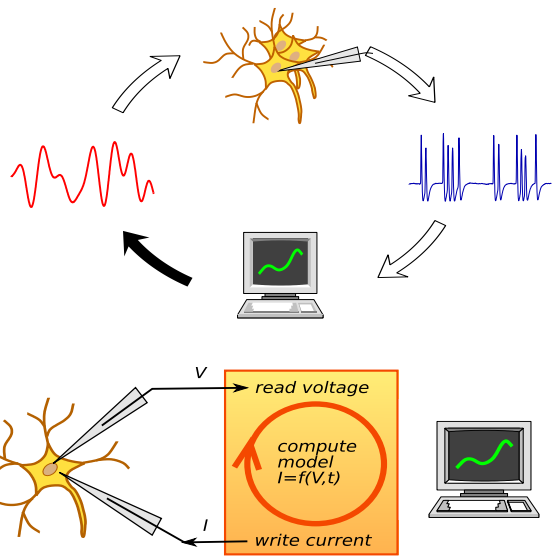

Live Demo
Sunday
morning
INCF Booth
#624

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