Neural Networks and Biological Modeling. Spring 2011

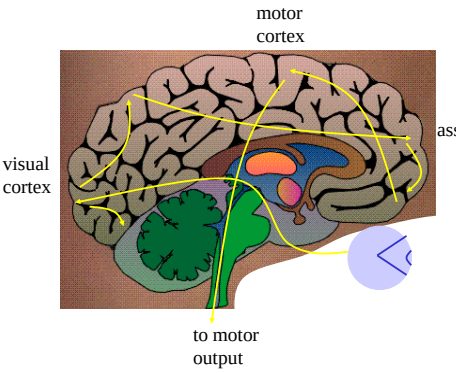
Course for physicists and life scientists

Moodle:

http://moodle.epfl.ch/course/view.php?id=2341

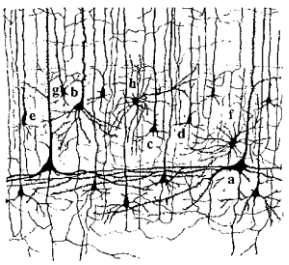
TA's: Felipe Gerhard, Friedemann Zenke, Skander Mensi, Dr. Tim Vogels

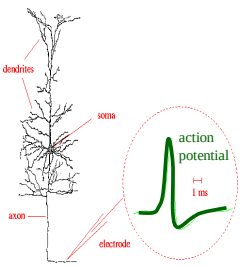
Wulfram Gerstner
http://lcn.epfl.ch/



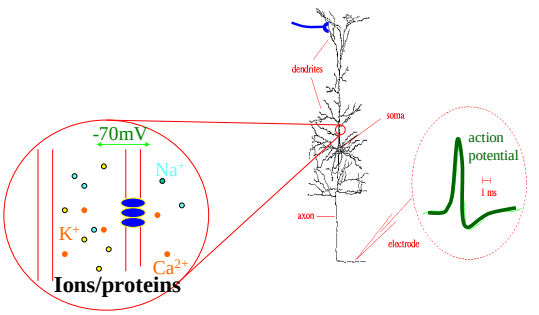
10 000 neurons
3 km wires

Signal:
action potential (spike)

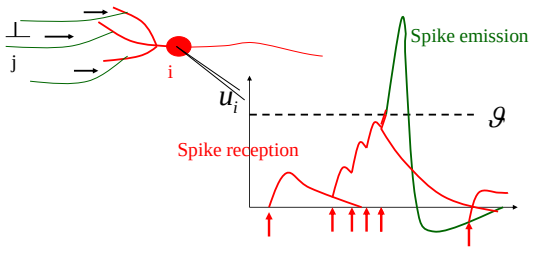




Hodgkin-Huxley type models:
Biophysics, molecules, ions



Integrate-and-fire type models



-spikes are events
-threshold
-spike/reset/refractoriness

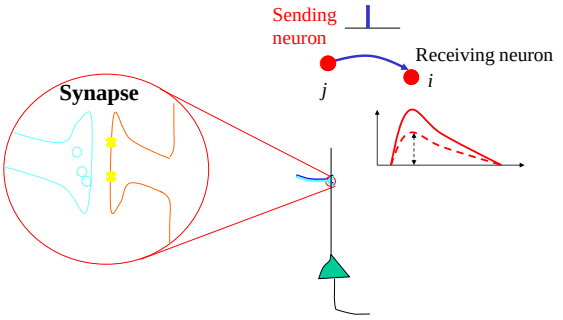
Neural Networks and Biological modeling

Lecture 1: Passive membrane and Integrate-and-Fire model

Lecture 2: Hodgkin-Huxley models (detailed models)

Lecture 3: Two-dimensional models (FitzHugh Nagumo)

Models of synaptic Plasticity



Synaptic changes = basis of learning

Neural Networks and Biological modeling

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Lecture 3: Two-dimensional models (FitzHugh Nagumo)

Lecture 4: Synaptic plasticity

Lecture 5: Network dynamics and Associative Memory

Lecture 6: Reinforcement learning

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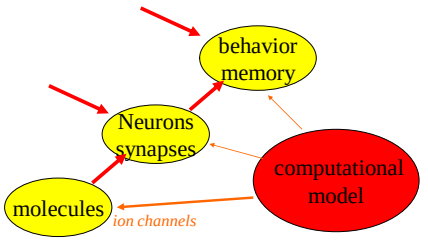
http://lcn.epfl.ch/

Computational Neuroscience

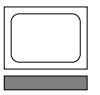


Ecole Polytechnique Fédérale de Lausanne, EPFL
Laboratory of Computational Neuroscience, LCN, CH 1015 Lausanne

Background: What is brain-style computation?


Brain

Computer



Systems for computing and information processing

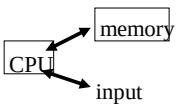

Brain

Computer

Distributed architecture

(10^{10} proc. Elements/neurons)

No separation of processing and memory



Von Neumann architecture

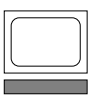
1 CPU

(10^{10} transistors)

Systems for computing and information processing


Brain

Computer



slow

Tasks:
Mathematical
$\sqrt{5}\cos\left(\frac{7\pi}{5}\right)$

fast

fast

Real world
E.g. complex scenes

slow

Systems for computing and information processing

Brain

Computer

Where is the program?

Clear separation:
software (pogram)/hardware

Where is the memory?

In the synaptic connections

Clear separation:
memory/processing

Where is the learning?

In the synaptic connections

Neural Networks and Biological modeling

Course: Monday : 9:15-13:00

Lecture 1: Passive membrane and Integrate-and-Fire model

Lecture 2: Hodgkin-Huxley models
Lecture 3: Two-dimensional models
Lecture 4: Synaptic plasticity
Lecture 5: Associative Memory
Lecture 6: Reinforcement learning

Lecture 7: miniproject handout
Lectures 8-10
Noise and the neural code
Lectures 11-13
Network dynamics

Neural Networks and Biological modeling

Course: Monday : 9:15-13:00

A typical Monday:
1st lecture 9:15-9:50
1st exercise 9:50-10:00 ← *paper and pencil*
2nd lecture 10:15-10:35
2nd exercise 10:35-11:00 ← *paper and pencil*
3rd lecture 11:15 – 11:40
3rd exercise 12:15-13:00 ← *paper and pencil OR interactive toy examples on computer*

Course of 4 credits = 6 hours of work per week
4 'contact' + 2 homework

Wulfram Gerstner
http://lcn.epfl.ch/

moodle.eplf.ch

have your laptop with you

Neural Networks and Biological modeling

Course: Monday : 9:15-13:00

Lecture 1: Passive membrane and Integrate-and-Fire model

Lecture 2: Hodgkin-Huxley models
Lecture 3: Two-dimensional models
Lecture 4: Synaptic plasticity
Lecture 5: Associative Memory
Lecture 6: Reinforcement learning

1st lecture 9:15-9:45
1st exercise 9:45-10:00
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3rd exercise 12:15-13:00
longer exercises
(paper and pencil or interactive toy examples)

Lecture 7: miniproject handout
Lectures 8-10 : Noise in neuron models
Lectures 11-13: Network dynamics

3rd exercise 12:15-13:00
Miniproject

Not a course on Artificial Neural Networks
→ Pattern Classification and Machine Learning

Neural Networks and Biological modeling

Lecture 1:

Passive membrane and Integrate-and-Fire model

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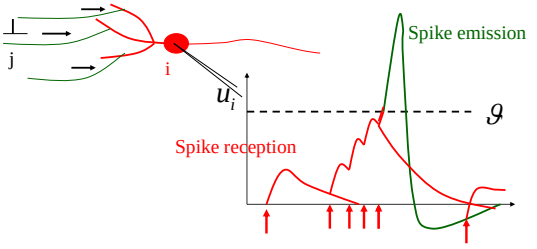
Integrate-and-fire type models



-spikes are events
-threshold
-spike/reset/refractoriness

Subthreshold regime
- linear
- passive membrane

Introduction to computational neuroscience

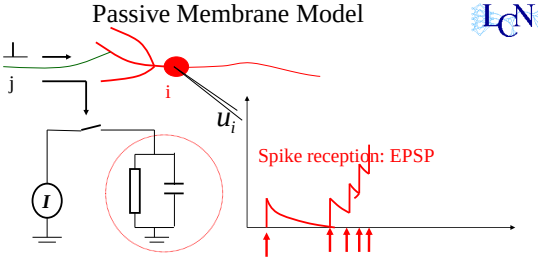
Lecture 1:

Passive membrane and Integrate-and-Fire model

- √ -Intro: subthreshold and spikes
- → -The passive membrae
- -Leaky ingreate-and-fire model
- -Generalized integrate-and-fire model
- -Quality of integrate-and-fire models

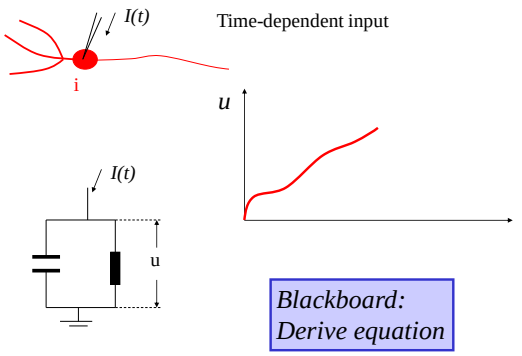
Wulfram Gerstner
http://lcn.epfl.ch/

Passive Membrane Model



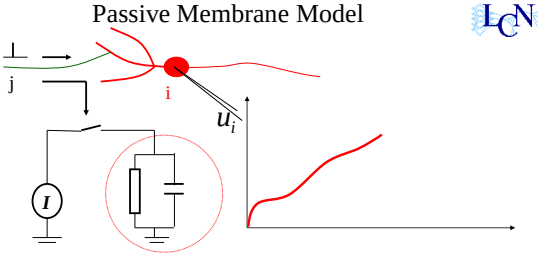
Subthreshold regime
- linear
- passive membrane
- RC circuit

Passive Membrane Model



Blackboard: Derive equation

Passive Membrane Model

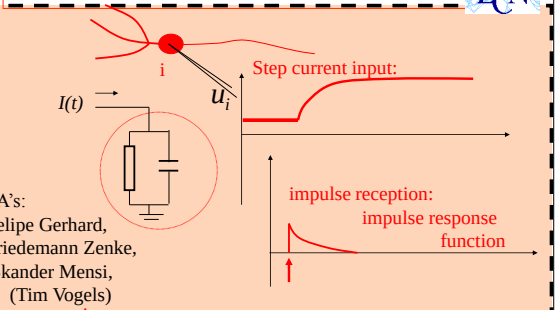


$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest}) + RI(t)$$

$$\tau \cdot \frac{d}{dt} V = -V + RI(t); \quad V = (u - u_{rest})$$

Blackboard: Voltage scale

Passive Membrane Model – exercise 1 now



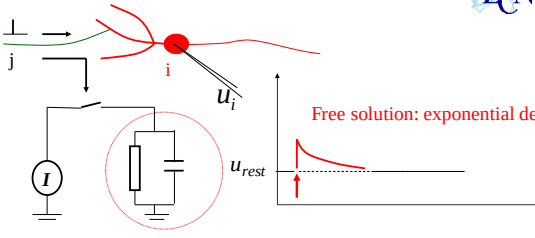
TA's:
Felipe Gerhard,
Friedemann Zenke,
Skander Mensi,
(Tim Vogels)

Linear equation

$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest}) + RI(t)$$

Next lecture at 10h15

Passive Membrane



$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest});$$

$$u(t) = u_{rest} + (u_0 - u_{rest}) \exp(-\frac{t - t_0}{\tau})$$

Start at t_0 with u_1

Blackboard: free solution

Neural Networks and Biological modeling

Course: Monday : 9:15-13:00

Lecture 1: Passive membrane and Integrate-and-Fire model
Lecture 2: Hodgkin-Huxley models
Lecture 3: Two-dimensional models
Lecture 4: Synaptic plasticity
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Lecture 6: Reinforcement learning

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longer exercises
(paper and pencil or interactive toy examples)

Lecture 7: miniproject handout
Lectures 8-10 : Noise in neuron models
Lectures 11-13: Network dynamics

3rd exercise 12:15-13:00
Miniproject

Prerequis: Physics students: NONE (mécanique analytique)
SV students: NONE (Programmation Biomathematique)
Math students: willingness to work for an applied course
other students (IN, SSC,EE) : Dynamical systems for eng.

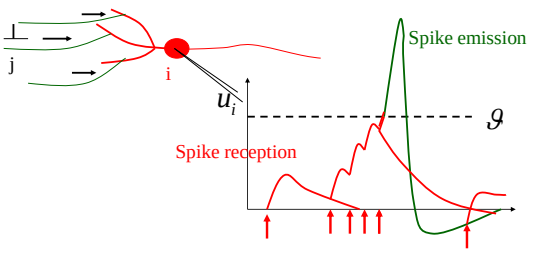
Chapter 4: Formal Spiking models

Integrate-and-Fire model

BOOK: Spiking Neuron Models,
W. Gerstner and W. Kistler
Cambridge University Press, 2002

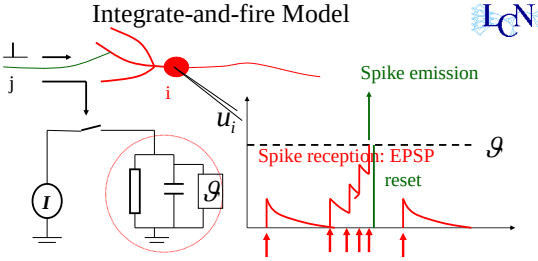
Chapter 4

Integrate-and-fire type models



-spikes are events
-threshold
-spike/reset/refractoriness

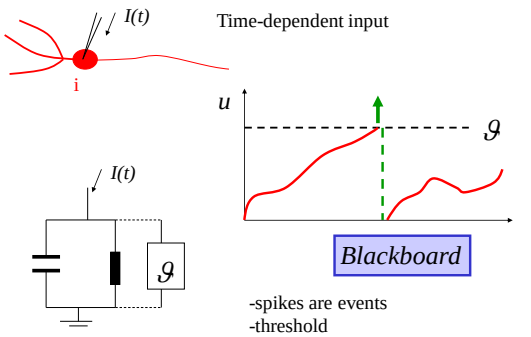
Integrate-and-fire Model



$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest}) + RI(t) \qquad \text{linear}$$

$$u_i(t) = \vartheta \Rightarrow \text{Fire+reset} \qquad \text{threshold}$$

Integrate-and-fire type models

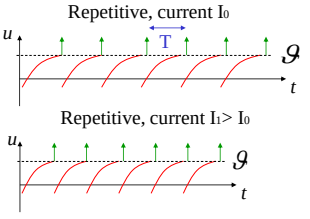


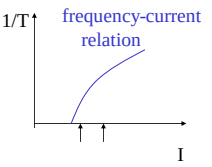
-spikes are events
-threshold
-spike/reset/refractoriness

Leaky Integrate-and-fire Model

$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest}) + RI_0$$

LIF
If firing: $u \rightarrow u_{reset}$





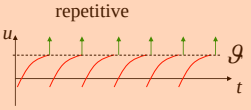
Exercise 2: Leaky Integrate-and-fire Model

$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest}) + R I_0$$

LIF

If firing: $u \to u_{reset}$

repetitive



Next lecture at
11h15

What is the firing rate?
f=g(I)
Exercise 2 now!

Introduction to computational neuroscience

Lecture 1:

Passive membrane and Integrate-and-Fire model

- -The passive membrae
- -Leaky ingreate-and-fire model
- → -Generalized integrate-and-fire model
- -Quality of integrate-and-fire models

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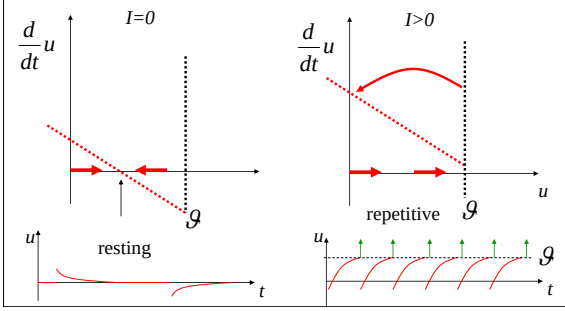
Integrate-and-fire Models

$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest}) + R I(t)$$

LIF

If firing: $u \to u_{reset}$



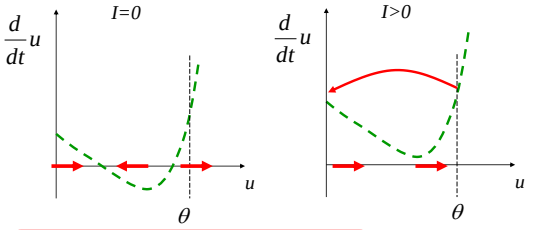
Integrate-and-fire Models

$$\tau \cdot \frac{d}{dt} u = -(u - u_{rest}) + R I(t)$$ **LIF**

$$\tau \cdot \frac{d}{dt} u = F(u) + R I(t)$$ **NLIF**

If firing: $u \to u_{reset}$

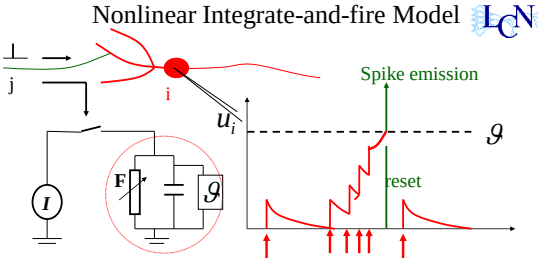
Nonlinear Integrate-and-fire Model



$$\tau \cdot \frac{d}{dt} u = F(u) + R I(t)$$ NONlinear

$u(t) = \theta \Rightarrow$ Fire+reset threshold

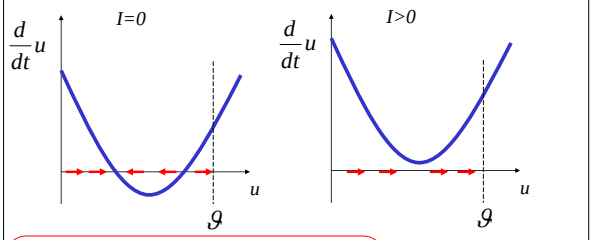
Nonlinear Integrate-and-fire Model



$$\tau \cdot \frac{d}{dt} u = F(u) + R I(t)$$ NONlinear

$u_i(t) = \vartheta \Rightarrow$ Fire+reset threshold

Nonlinear Integrate-and-fire Model



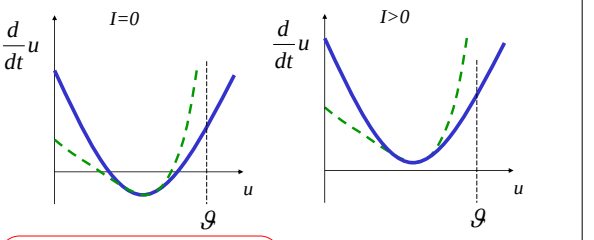
$$\tau \cdot \frac{d}{dt}u = F(u) + RI(t)$$ NONlinear

$u(t) = \vartheta \Rightarrow$ Fire+reset threshold

Quadratic I&F:

$$F(u) = c_2(u - c_1)^2 + c_0$$

Nonlinear Integrate-and-fire Model



$$\tau \cdot \frac{d}{dt}u = F(u) + RI(t)$$

$u(t) = \vartheta \Rightarrow$ Fire+reset

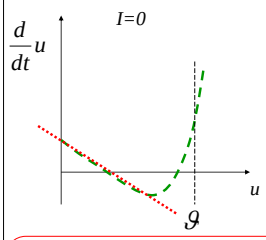
Quadratic I&F:

$$F(u) = c_2(u - c_1)^2 + c_0$$

exponential I&F:

$$F(u) = -(u - u_{rest}) + c_0 \exp(u - \vartheta)$$

Nonlinear Integrate-and-fire Model



$$\tau \cdot \frac{d}{dt}u = F(u) + RI(t)$$ NONlinear

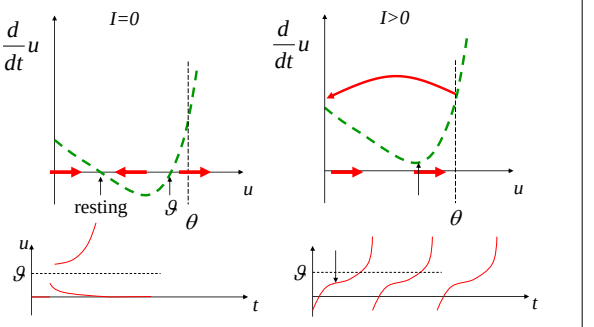
$u(t) = \vartheta \Rightarrow$ Fire+reset threshold

exponential I&F:

$$F(u) = -(u - u_{rest}) + c_0 \exp(u - \vartheta)$$

Nonlinear Integrate-and-fire Model

Where is the firing threshold?



$$\tau \cdot \frac{d}{dt}u = F(u) + RI(t)$$

Integrate-and Fire type models

Where is the firing threshold?

Leaky integrate-and-fire (LIF)

Strict voltage threshold

- by construction
- spike threshold = reset condition

Nonlinear integrate-and-fire (eIF)

There is no strict firing threshold

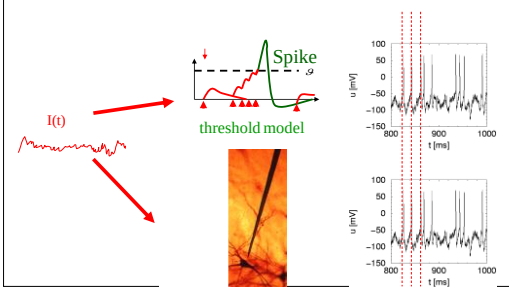
- firing depends on input
- exact reset condition of minor relevance

Integrate&Fire: Where is the firing threshold?

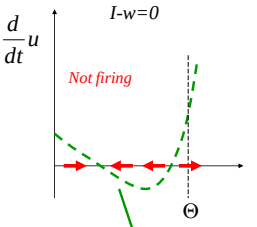
- √ 1: Introduction
- √ 2: Integrate-and-Fire (and generalisations)
- → 3. Quality of Integrate-and-Fire models

Wulfram Gerstner
http://lcn.epfl.ch

Validation of neuron models



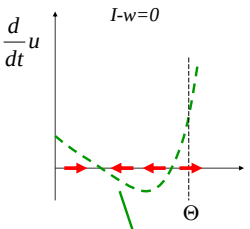
exponential Integrate-and-fire Model



$$\tau \cdot \frac{d}{dt}u = F(u) + R\,I(t)$$

Can we measure ***F(u)?***

exponential Integrate-and-fire Model and IV curve



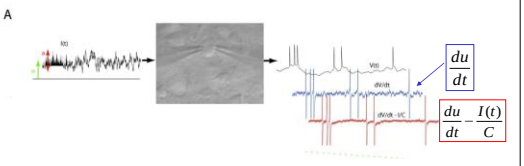
$$\tau \cdot \frac{d}{dt}u = F(u) + R\,I(t)$$

$$\tau \frac{du}{dt} - RI(t) = F(u)$$

$$\frac{du}{dt} - \frac{1}{C}I(t) = F(u)\frac{1}{\tau}$$

Can we measure ***F(u)?***

Exponential Integrate-and-fire Model and IV curve

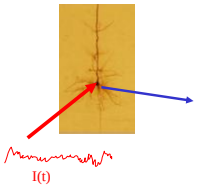


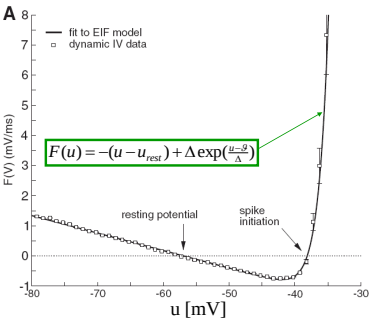
$$\frac{du}{dt} - \frac{1}{C}I(t) = F(u)\frac{1}{\tau}$$

Experiments: *Sandrine Lefort, Carl Petersen*

Theory: *Laurent Badel, Magnus Richardson*

Measurement of *F(u)*

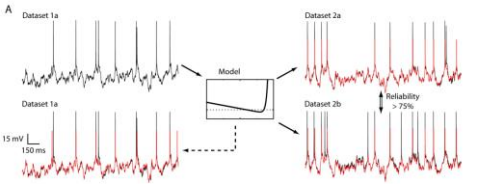




$$\frac{du}{dt} - \frac{1}{C}I(t) = F(u)\frac{1}{\tau}$$

Badel et al., J. Neurophysiology 2008

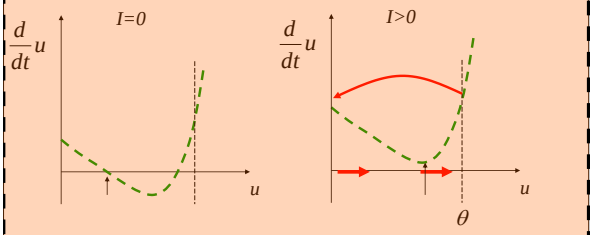
Exponential Integrate-and-fire Model and IV curve



Experiments: *Sandrine Lefort, Carl Petersen*

Theory: *Laurent Badel, Magnus Richardson*

Exercise 3:Nonlinear Integrate-and-fire Model



Exercise 3 now!

We continue at 11:50: Computer show!

$$\tau \cdot \frac{d}{dt}u = F(u) + RI(t)$$

Neural Networks and Biological modeling

Course: Monday : 9:15-13:00

A typical Monday:
1st lecture 9:15-9:50
1st exercise 9:50-10:00 ← *paper and pencil*
2nd lecture 10:15-10:35
2nd exercise 10:35-11:00 ← *paper and pencil*
3rd lecture 11:15 – 11:40
3rd exercise 12:15-13:00 ← *paper and pencil OR interactive toy examples on computer*

Course of 4 credits = 6 hours of work per week
4 'contact' + 2 homework

Wulfram Gerstner
http://lcn.epfl.ch/

moodle.eplf.ch

have your laptop with you

Passive membranes and Integrate&Fire:

The end