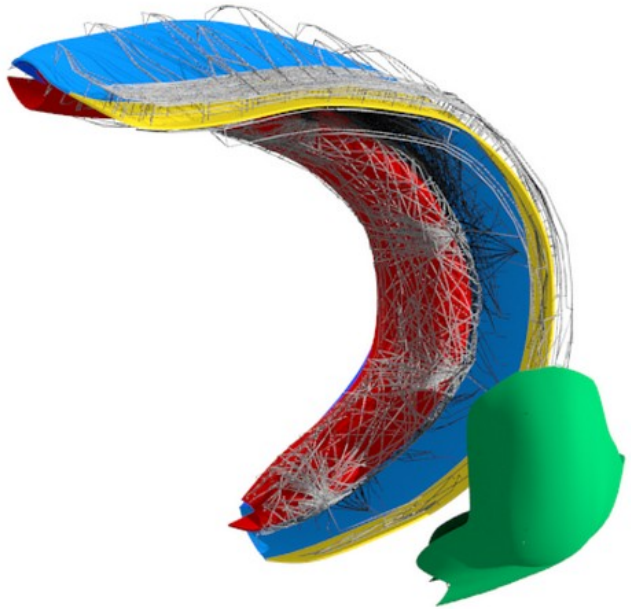
RUHR-UNIVERSITÄT BOCHUM

SFB 874

RUB

Parametric Anatomical Modeling

Creating an anatomically constrained model of the hippocampus



Martin Pyka

Mercator Research Group “Structure of Memory”

Faculty of Psychology

University of Bochum, Germany

m.pyka@rub.de

Introduction

Outline

Motivation for anatomical modeling

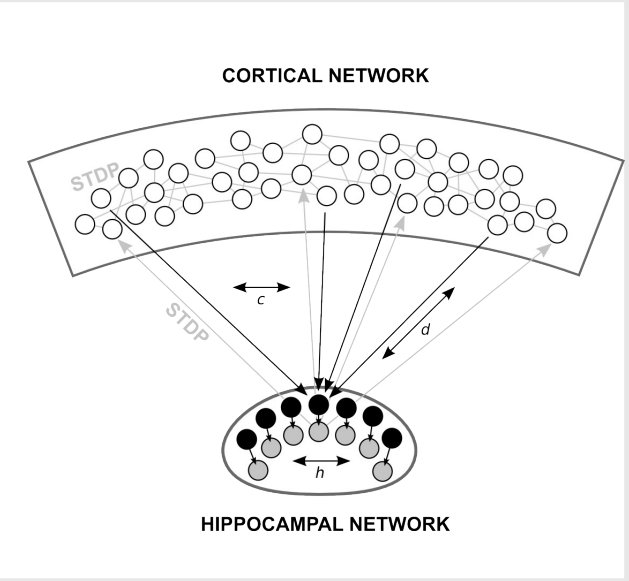
Parametric Anatomical Modeling (PAM)

Projects based on PAM

Generic models of the hippocampus

Ways to test the validity

Does the real neural network implement the properties of the abstract one?



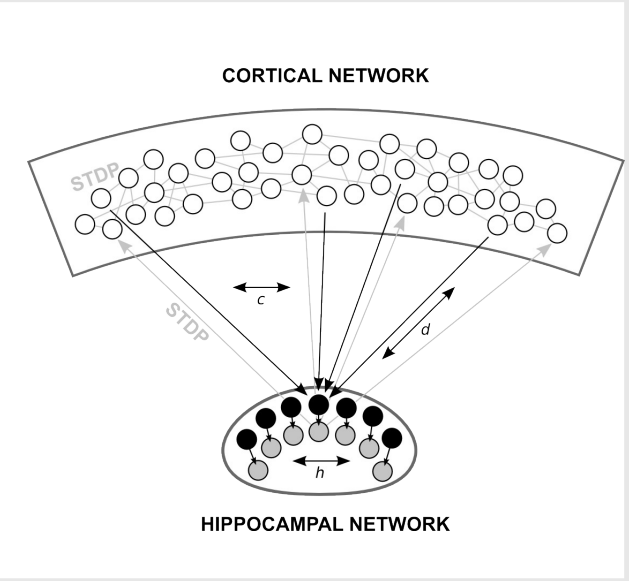
Rat Hippocampus

abstract — real

Generic models of the hippocampus

Ways to test the validity

- Test predictions of the abstract model in real networks



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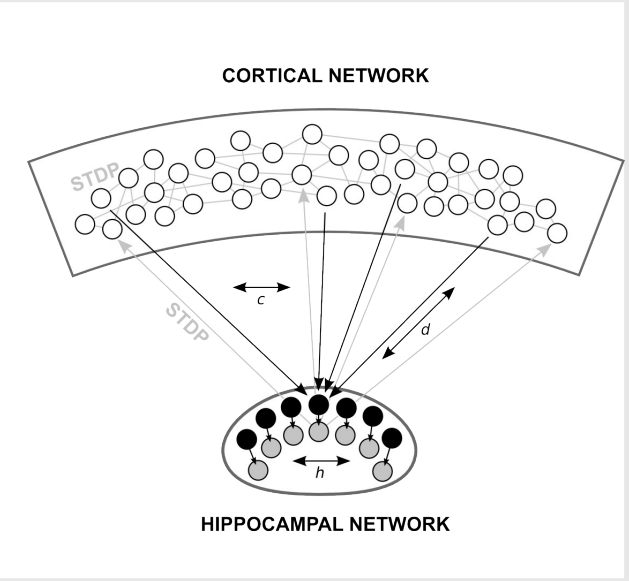


similar results may emerge from different mechanistic reasons

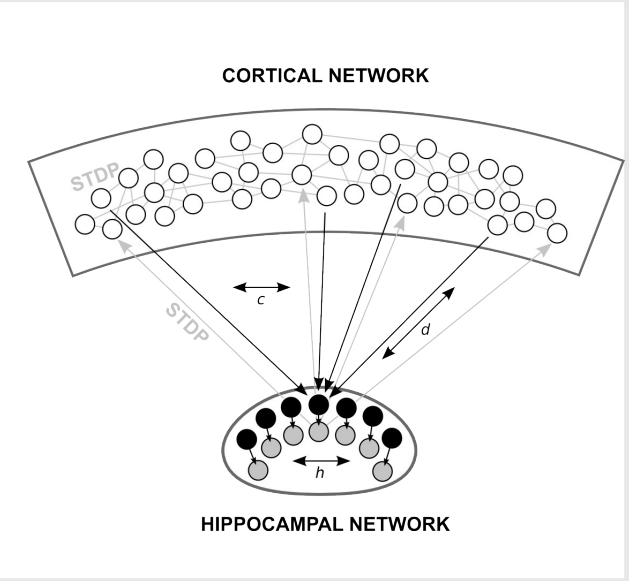
Rat Hippocampus

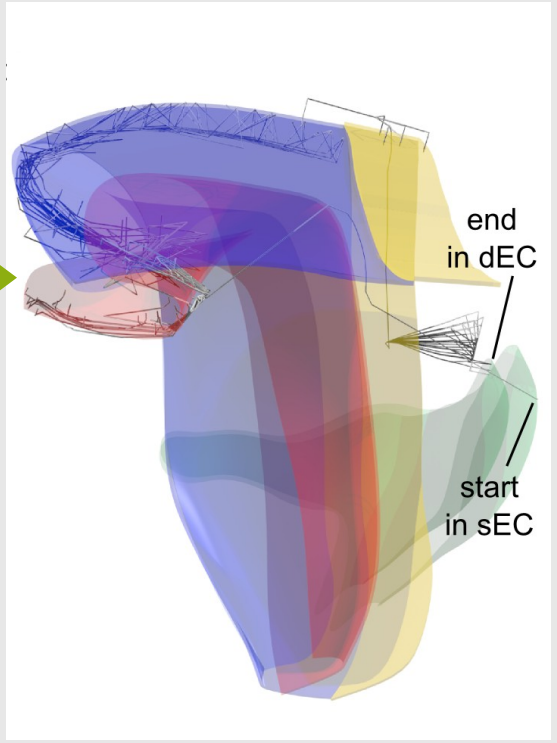
abstract — real

Generic models of the hippocampus

Ways to test the validity

- Test predictions of the abstract model in real networks
- Test a more detailed version of the target network





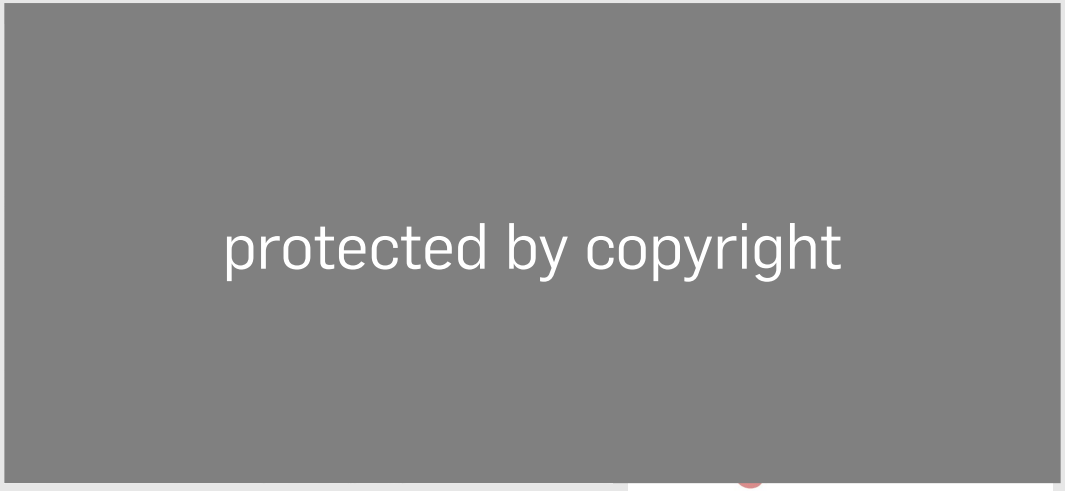
Rat Hippocampus

abstract — real

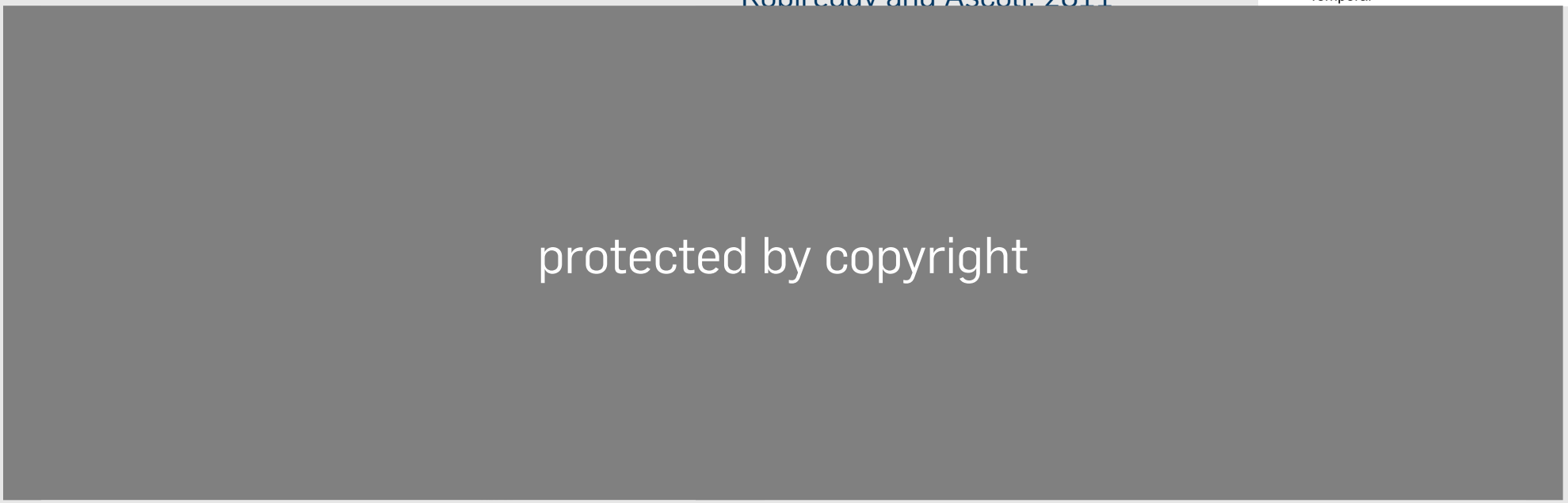
Generic models of the hippocampus

What does “more detail” mean?

- Connectivity
  - topology
  - connection spread



Ropireddy and Ascoli, 2011

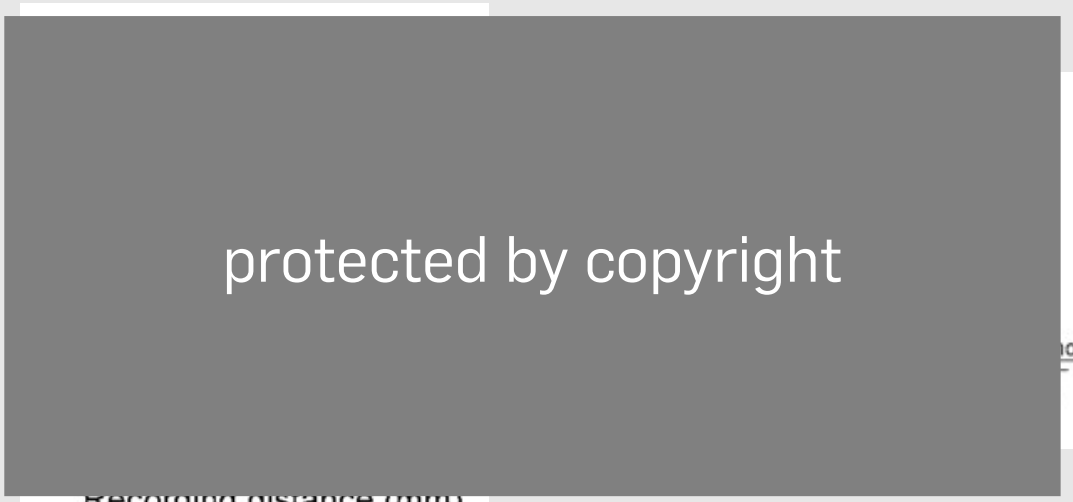


Andersen et al., 2007

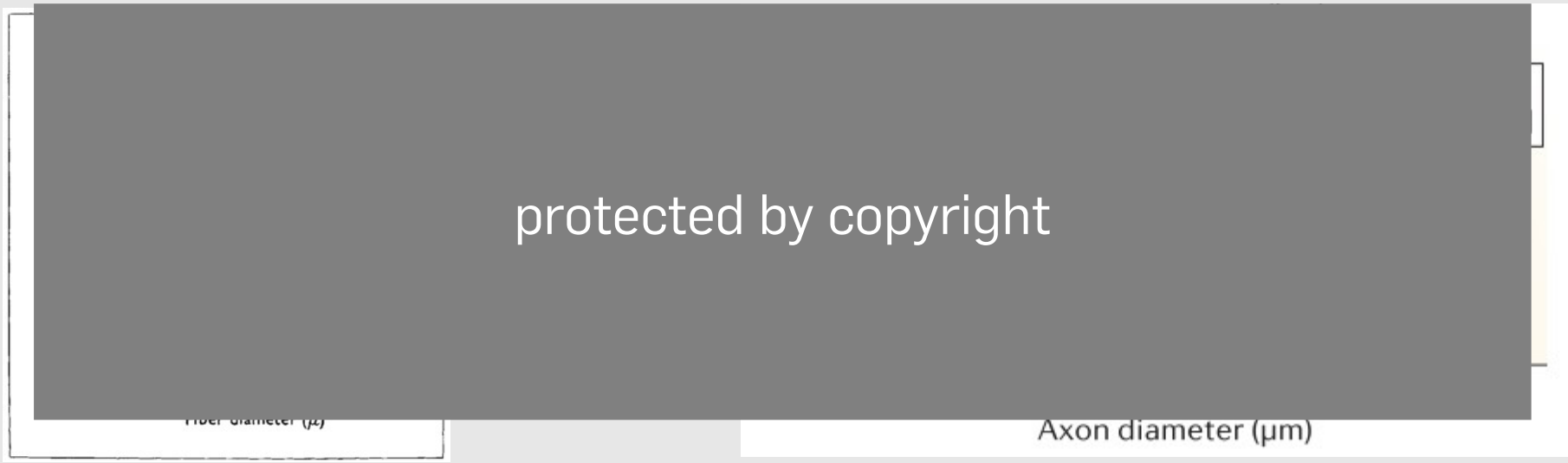
Generic models of the hippocampus

What does “more detail” mean?

- Connectivity
  - topology
  - connection spread
- Delays
  - Connection length
  - axon diameter



Soleng et al., 2003

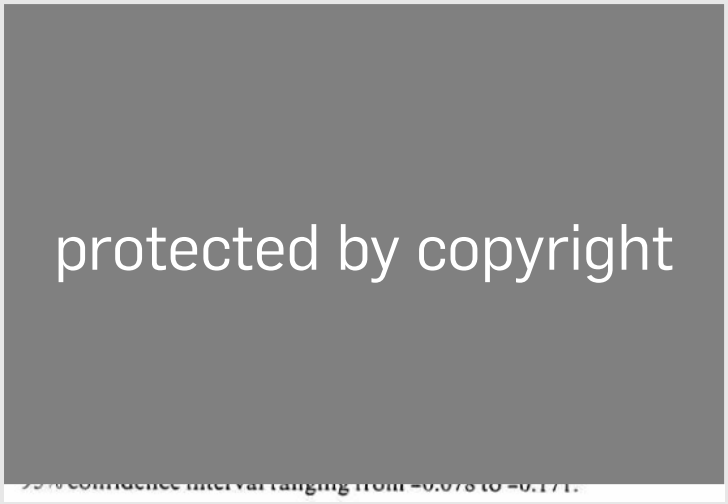


Waxman, 1980

Buzsaki and Mizuseki, 2014

Generic models of the hippocampus

Influence of structure on experimental results



Blumberg, 1989

"A potential argument for the decreasing frequency and irregularity of hippocampal theta oscillations in mammals as brain size increases is that the hippocampus ***is a single cortical module*** *and its growth is limited by the axon conduction delays. Pyramidal neurons of the CA3 region innervate a very large volume of the hippocampus; they connect distant peer neurons and* ***require long axonal lengths*** *and, consequently, have longer delays."*

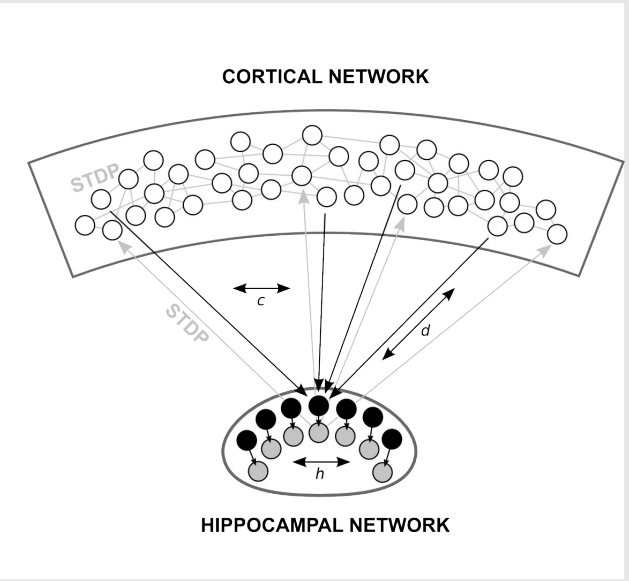
Buzsaki et al., 2014

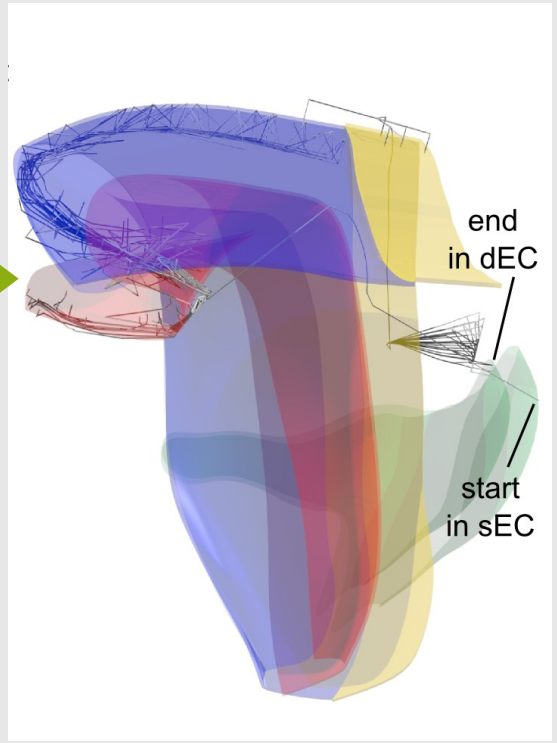
Jakobs, 2014

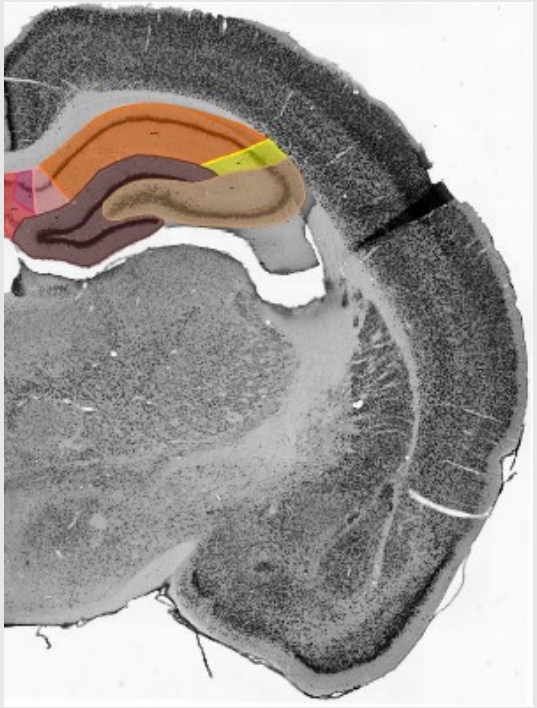
Winson, 1972

Generic models of the hippocampus

Motivation for comparative studies







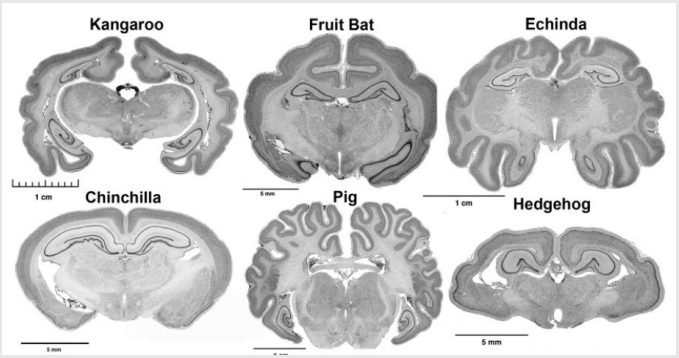
- connectivity
- delays

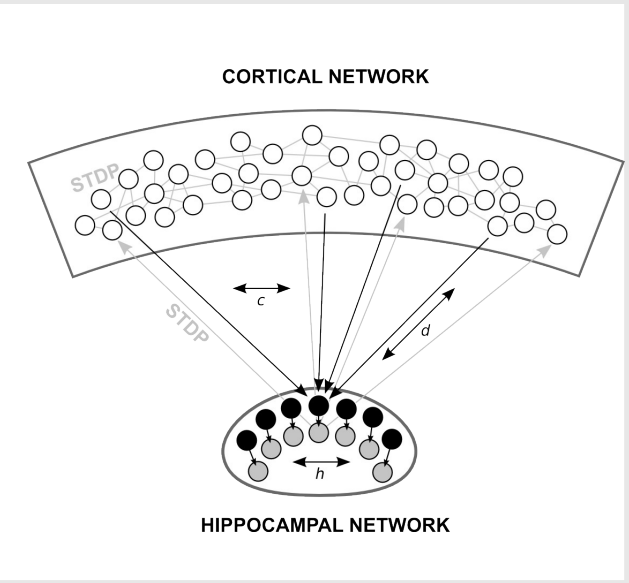
abstract — real

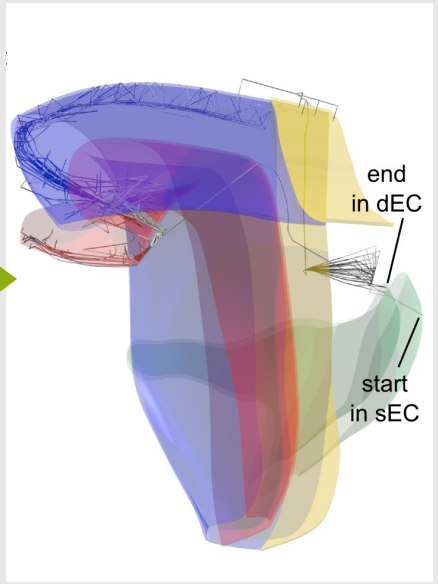
Generic models of the hippocampus

Motivation for comparative studies

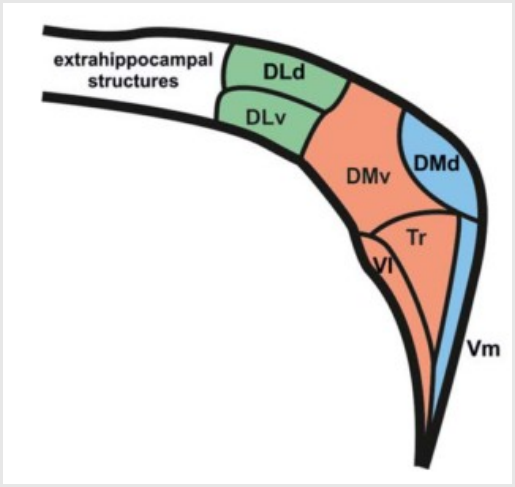
Mammals







Birds



abstract — real

Generic models of the hippocampus

Motivation for comparative studies

Brain, Behavior and Evolution

Highlights and Perspectives on Evolutionary Neuroscience

Brain Behav Evol 2014;83:1–8
DOI: 10.1159/000360152

Published online: February 28, 2014

Striedter et al., 2014

NSF Workshop Report: Discovering General Principles of Nervous System Organization by Comparing Brain Maps across Species

Georg F. Striedter[a] T. Grant Belgard[b] Chun-Chun Chen[c] Fred P. Davis[d]
Barbara L. Finlay[e] Onur Güntürkün[f] Melina E. Hale[g] Julie A. Harris[h] Erin E. Hecht[i]
Patrick R. Hof[j] Hans A. Hofmann[k] Linda Z. Holland[l] Andrew N. Iwaniuk[m] Erich D. Jarvis[c]
Harvey J. Karten[n] Paul S. Katz[o] William B. Kristan[p] Eduardo R. Macagno[q] Partha P. Mitra[r]
Leonid L. Moroz[s] Todd M. Preuss[t] Clifton W. Ragsdale[u] Chet C. Sherwood[v]
Charles F. Stevens[w] Maik C. Stüttgen[f] Tadaharu Tsumoto[x] Walter Wilczynski[o]

Manns and Eichenbaum, 2006

HIPPOCAMPUS 16:795–808 (2006)

Evolution of Declarative Memory

Joseph R. Manns* and Howard Eichenbaum

ABSTRACT: The present review considers research on the hippocampus and related areas from humans and experimental animals and makes three main points. First, many of the anatomical details of the hippocampus and adjacent cortical areas in the parahippocampal region are conserved across mammals. Second, the functional role of these areas in declarative memory is also conserved across species. Third, an evolutionary approach will be key to understanding exactly how the local circuitry of the hippocampus and parahippocampal region supports declarative memory. To highlight the utility of this approach, a schematic model is de-

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Physics of Life Reviews 11 (2014) 329–364

PHYSICS of LIFE reviews

www.elsevier.com/locate/plrev

Review

Toward a computational framework for cognitive biology: Unifying approaches from cognitive neuroscience and comparative cognition

Fitsch 2014

W. Tecumseh Fitch

The evolution of episodic memory

Timothy A. Allen and Norbert J. Fortin[1]

regions responsible for episodic memory in humans have anatomical and functional homologs in other species. We propose that episodic memory capacity depends on a fundamental neural circuit that is similar across mammalian and avian species, suggesting that proto-episodic memory systems exist across amniotes and, possibly, all vertebrates. The implication is that episodic memory in diverse species may primarily be due to a shared underlying neural ancestry, rather than the result of evolutionary convergence. We also discuss

Allen and Fortin, 2013

CellPress

Neuron

NeuroView

Hale 2014

Mapping Circuits beyond the Models: Integrating Connectomics and Comparative Neuroscience

Melina E. Hale[1,*]

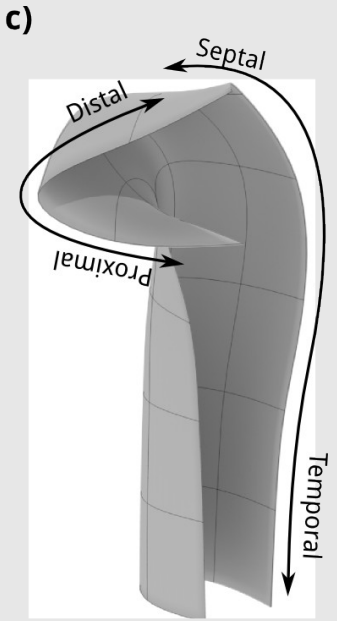
Generic models of the hippocampus

How to use computational models in comparative neuroscience?

- How to create anatomically motivated neural networks?
- How to compare artificial neural networks derived from various species?

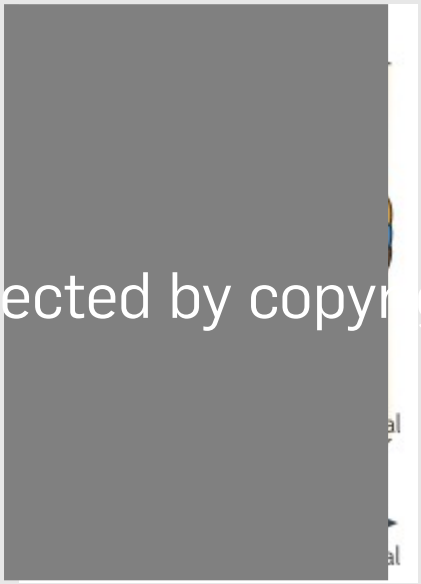
Parametric Anatomical Modeling

Connections in the brain



Main Problem: the formal description of

- mappings on local and global axes
- nonlinear relationships between topological projections and connection distance

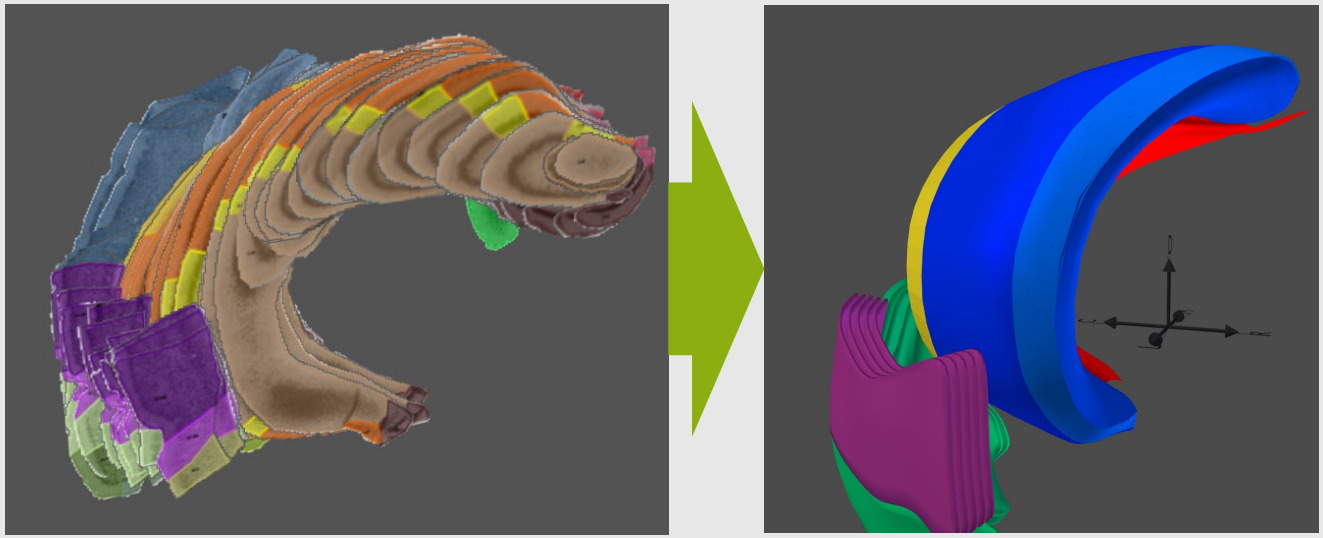


van Strien et al., 2009

Parametric Anatomical Modeling

Main ideas

1. Recreate neural layers in 3D



Rat Hippocampus Atlas

van Strien et al., 2009

Andersen et al, 2007

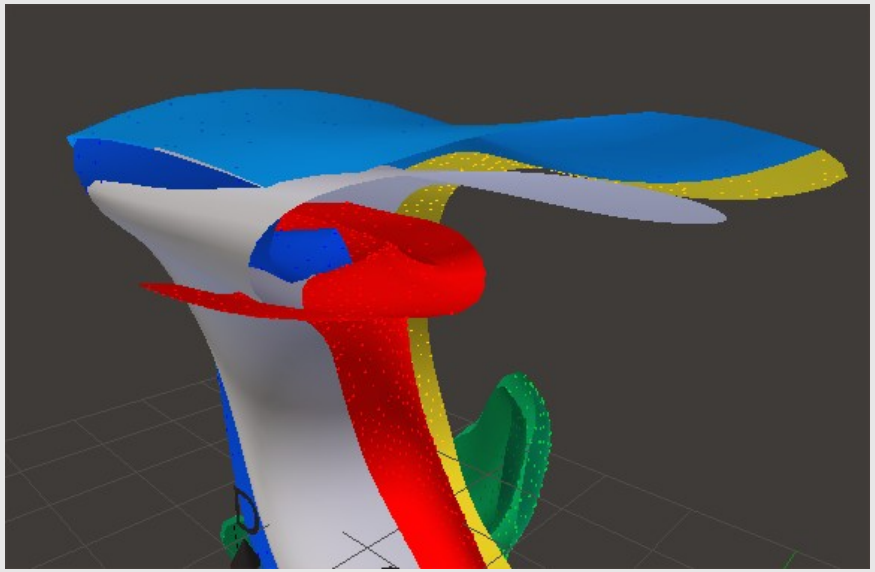
Allen Brain Atlas

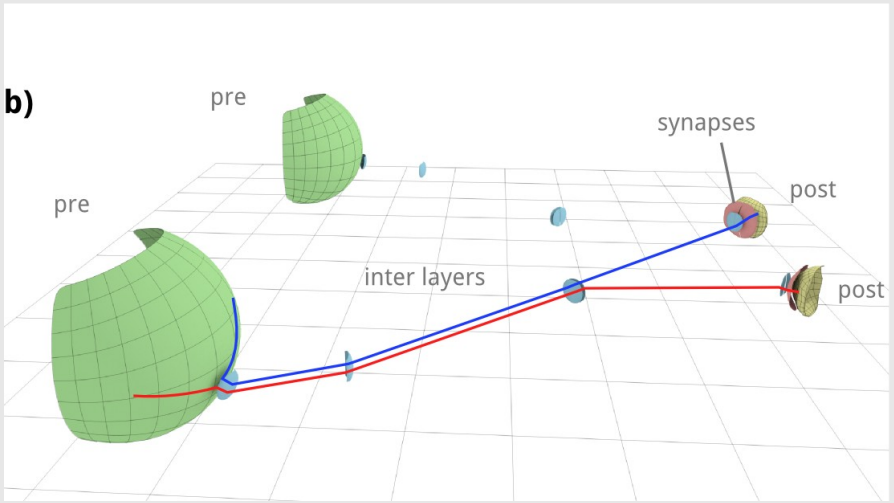
Tracing of neural and synaptic layers

Parametric Anatomical Modeling

Main ideas

2. Add synaptic and intermediate layers

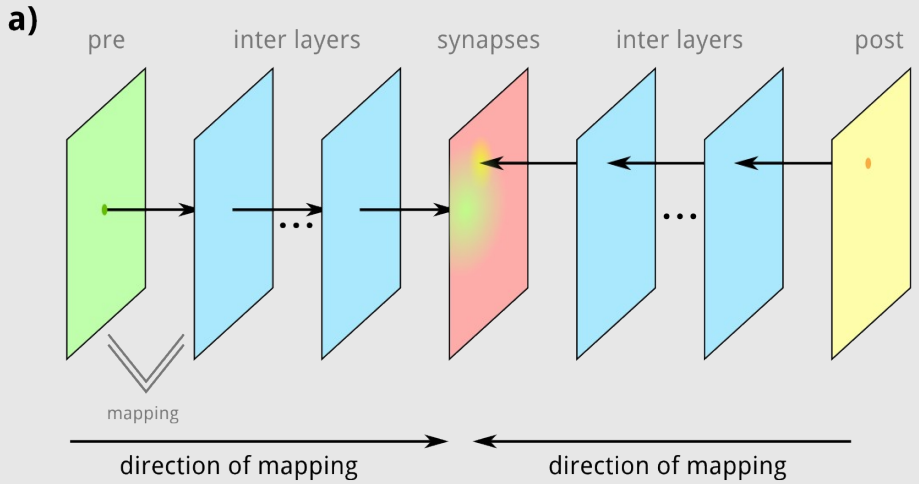


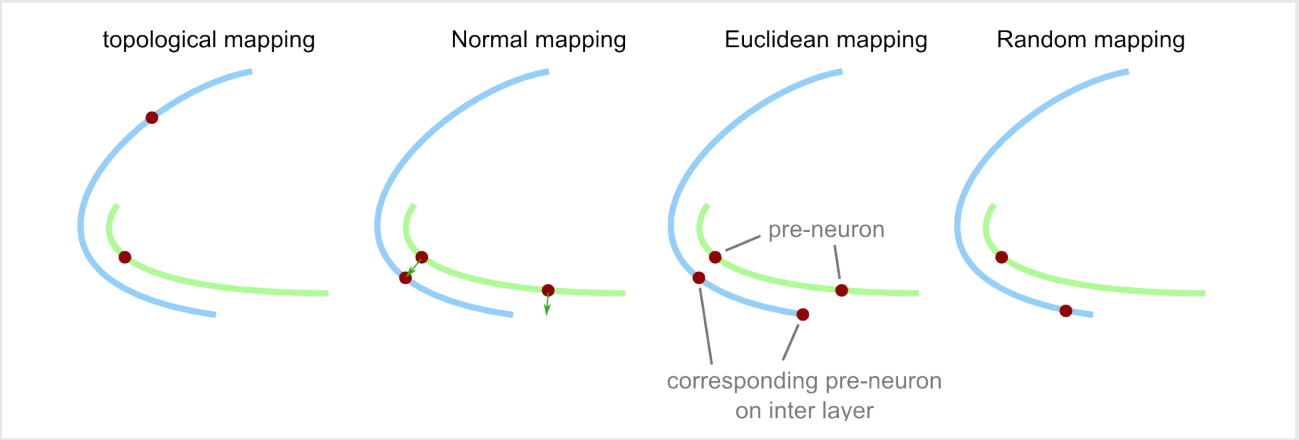


Parametric Anatomical Modeling

Main ideas

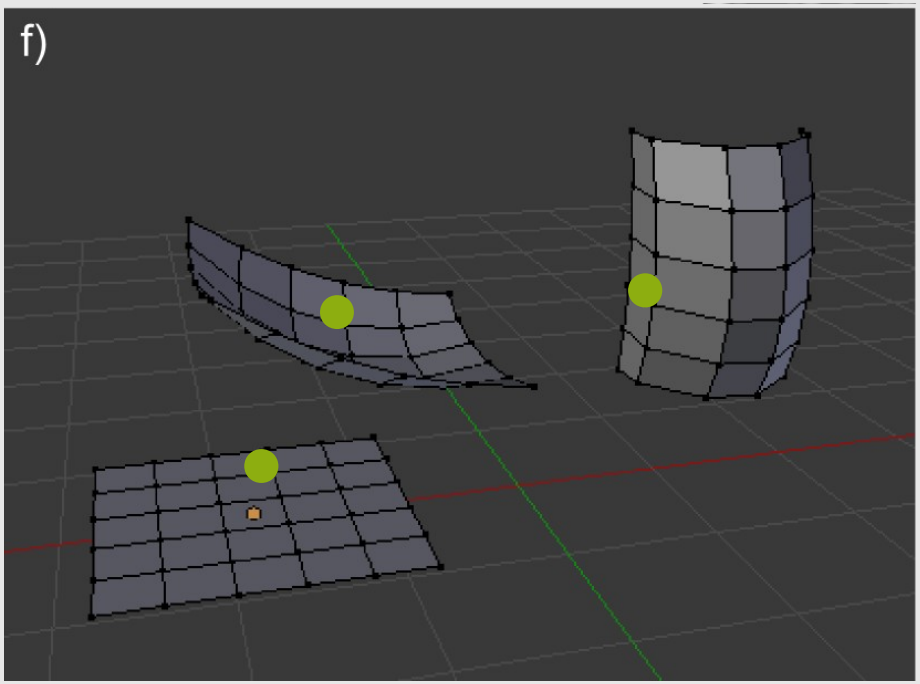
3. Create mappings between layers





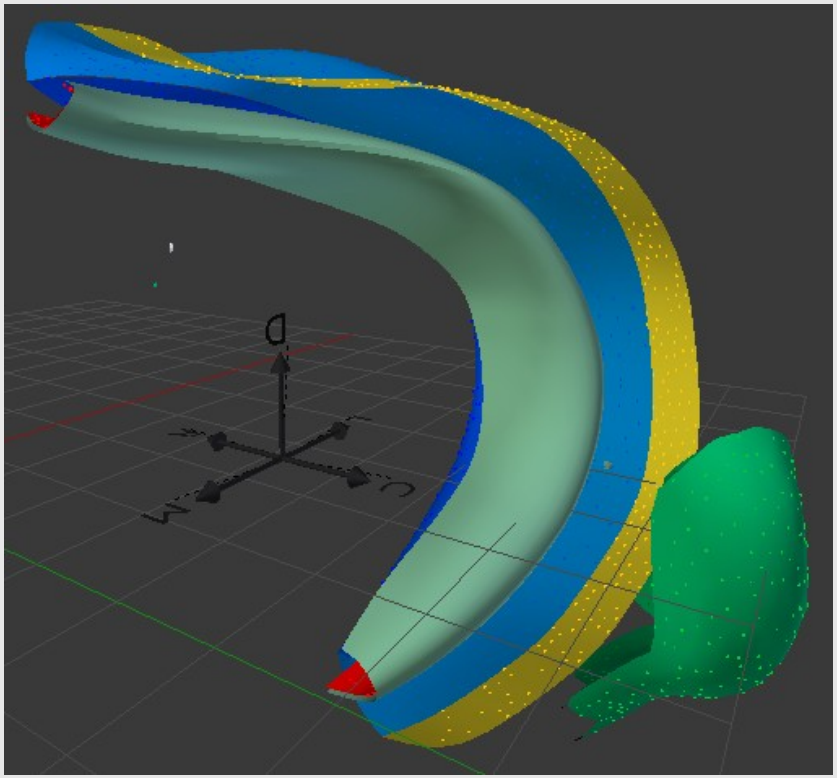
Parametric Anatomical Modeling

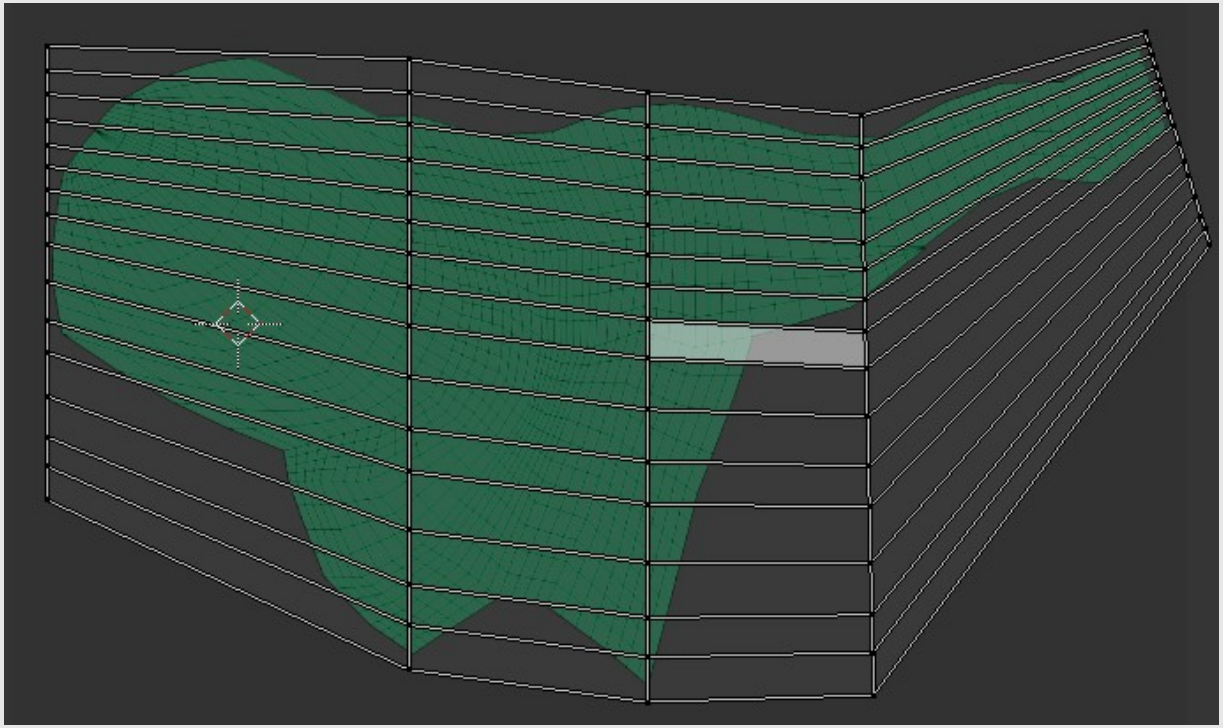
Topological mapping



Parametric Anatomical Modeling

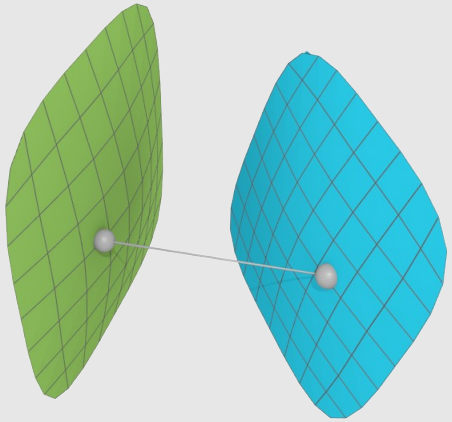
UV mapping



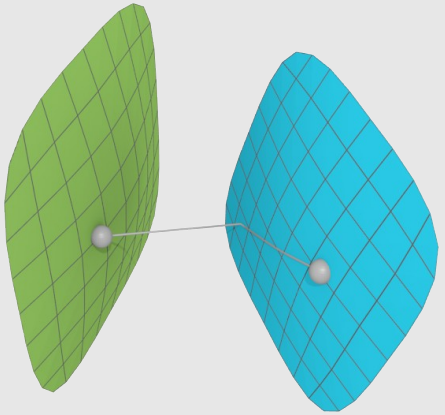


Parametric Anatomical Modeling

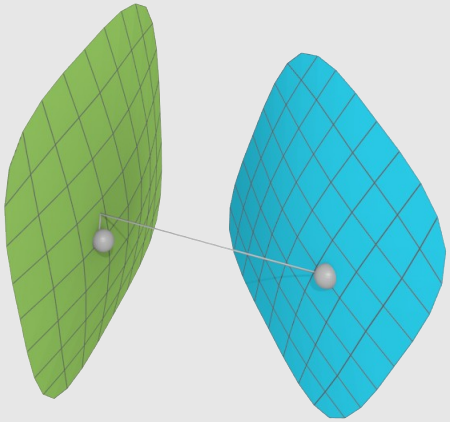
Distance calculation



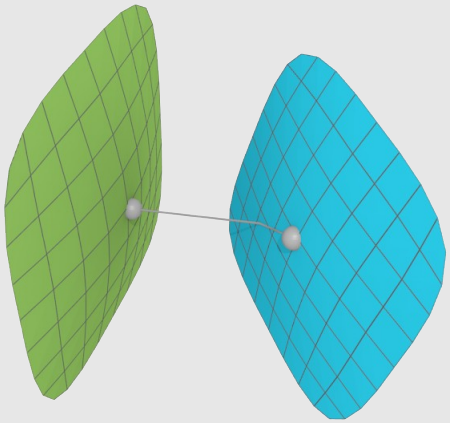
Euclidean distance to target point



Euclidean distance to target layer and UV-distance to target point



UV-distance on source layer and Euclidean distance to target point



Normal vector to target layer and UV-distance to target point

Parametric Anatomical Modeling

Network calculation and export

- PAM calculates for a given set of neural layers and mappings connections and connection lengths between neurons
- data can be exported as Python binary (pickle-module) or as set of csv-files
- import for PyNEST available

Parametric Anatomical Modeling

Showcase

Parametric Anatomical Modeling

Advantages

- Mapping relations between neuronal layers on the meso- and macroscale level
- ➔ PAM models can be easier compared with real neural networks
- ➔ lesion studies can be easier aligned with the model
- ➔ changes in the network can correspond to evolutionary changes of real networks
  - ➔ size
  - ➔ number of neurons (=> connectivity)
  - ➔ form
- ➔ comparatively low-dimensional representation of complex neural networks

Parametric Anatomical Modeling

Connection to Experimentalists

- PAM could be used to document experimental findings (e.g. from tracer studies) in a formalized and parametric way

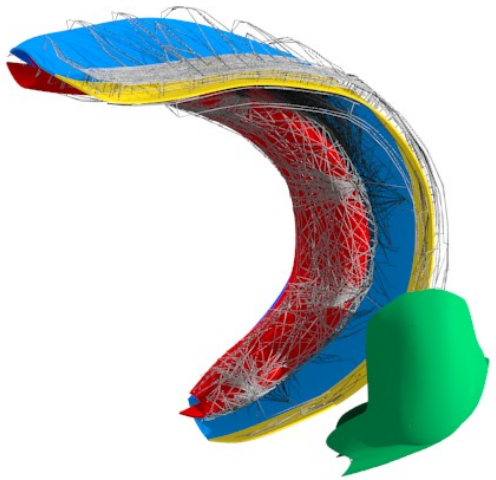
➔ PAM could be helpful to let experimentalists and modelers work together on one model

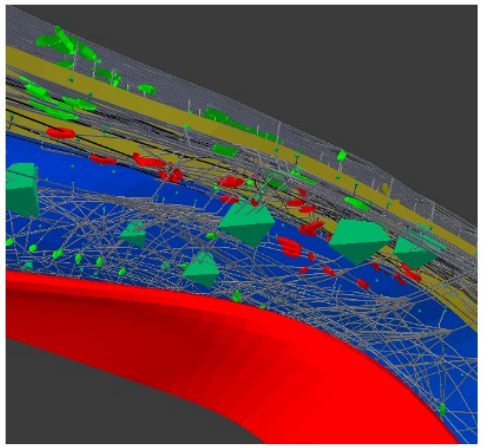
Parametric Anatomical Modeling

Source Code on Bitbucket

PAM (Parametric Anatomical Modeling)

Parametric Anatomical Modeling is a method to translate large-scale anatomical data into spiking neural networks. PAM is implemented as a Blender addon.





`18561aa` Added an option to let the colors …

Patrick Herbers · 2015-05-07

1 commit
Pushed to rub-hippo/parametric-anatomical-modeling

`d94efec` Fixed a timing error for fast spike…

Patrick Herbers · 2015-05-07

pam_vis: implement an easy way to col…
Issue #45 commented on in rub-hippo/parametric-anatomical-modeling

Martin Pyka · 2015-05-05

pam_vis: implement an easy way to col…
Issue #45 updated in rub-hippo/parametric-anatomical-modeling

Patrick Herbers · 2015-05-05

1 commit
Pushed to rub-hippo/parametric-anatomical-modeling

`0ec2697` Added an option for painting all s…

Patrick Herbers · 2015-05-05

1 commit
Pushed to rub-hippo/parametric-anatomical-modeling

`1c0235f` Merge branch 'master' into pam…

Patrick Herbers · 2015-04-30

1 commit
Pushed to rub-hippo/parametric-anatomical-modeling

`ec428fe` Added gui-elements for masking …

Patrick Herbers · 2015-04-30

1 commit
Pushed to rub-hippo/parametric-anatomical-modeling

`2c814f5` Fixed an error that would genera…

Patrick Herbers · 2015-04-30

Information flow in the HPF

Computational Constrains for more abstract models

unpublished

data

Information flow in the HPF

Temporal Correlations between CA3 neurons

unpublished

data

Information flow in the HPF

Temporal Correlations between CA3 neurons

unpublished

data

Information flow in the HPF

Computational Constrains for more abstract models

unpublished

data

Information flow in the HPF

Projection distances

unpublished

data

Information flow in the HPF

Temporal Correlations between CA3 neurons

unpublished

data

Information flow in the HPF

Computational Constrains for more abstract models

unpublished

data

Comparative Computational Neuroscience

Pigeon and Rat Hippocampus

unpublished

data

Comparative Computational Neuroscience

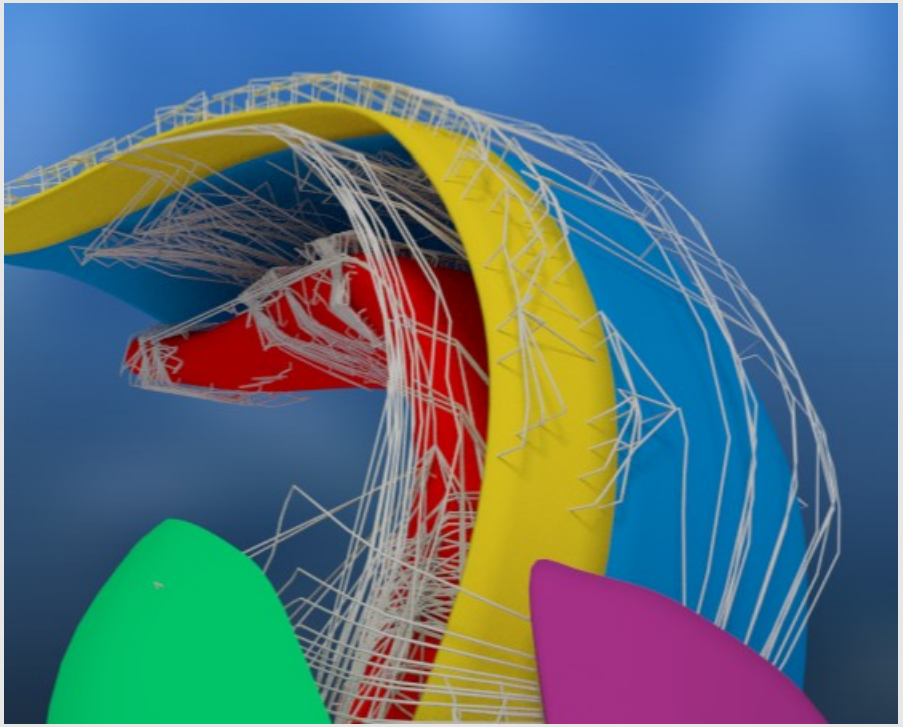
Pigeon and Rat Hippocampus

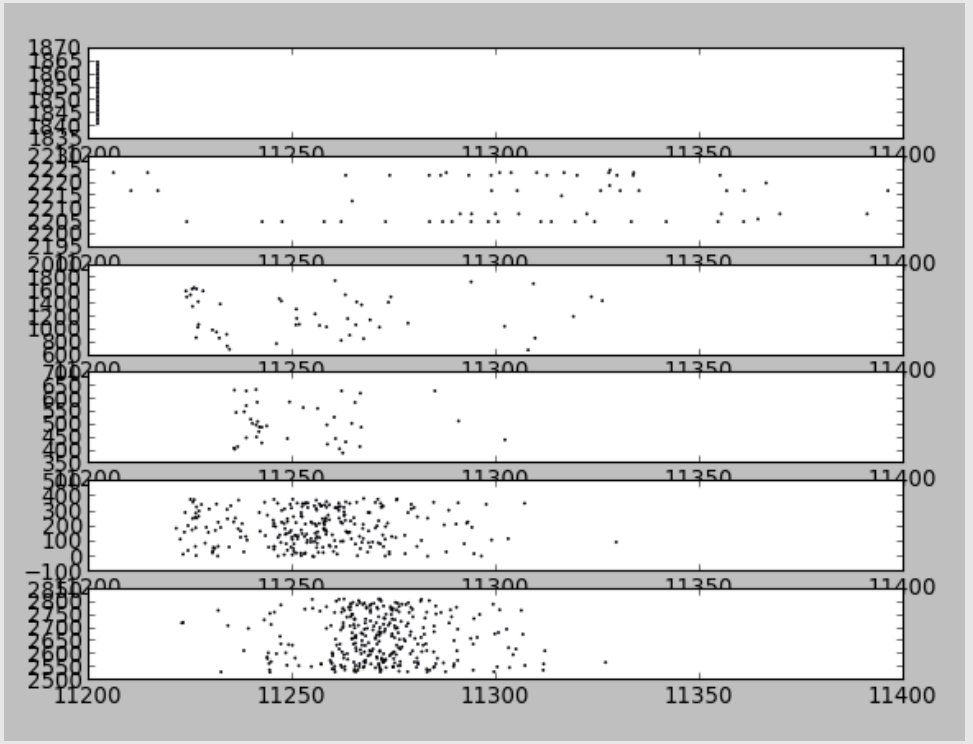
unpublished

data

Temporal dynamics

How to understand, what is going on in the 3d hippocampus?





Temporal dynamics

Showcase

Temporal dynamics

Benefits

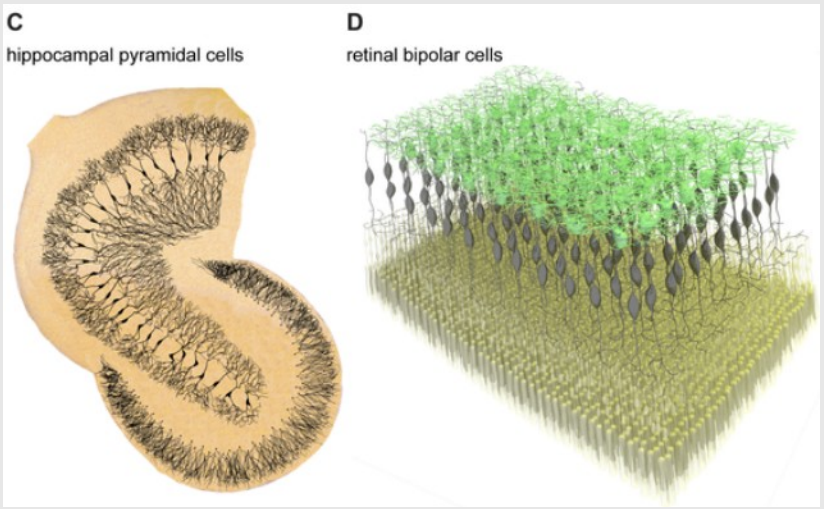
- compare spiking activity in the model with experimental data => theta traveling waves
- faster examination of the network in order to understand, why certain neurons spike
- colored spikes: understand why and when information are (not) combined
- in general: easier to compare with experimental data

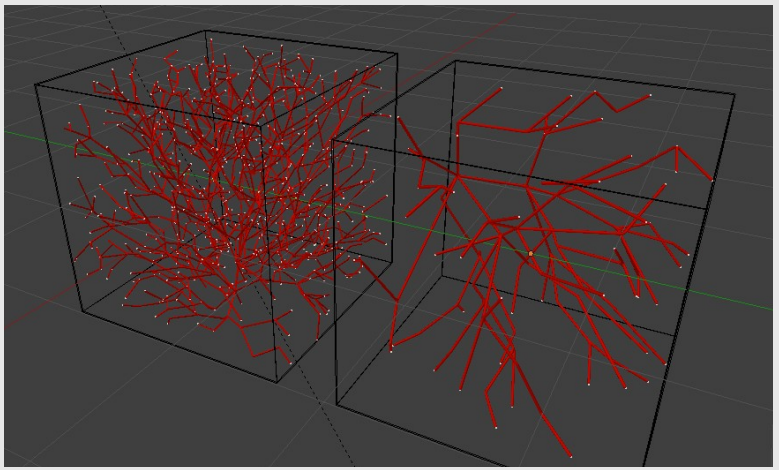
Lubenov and Siapas, 2009

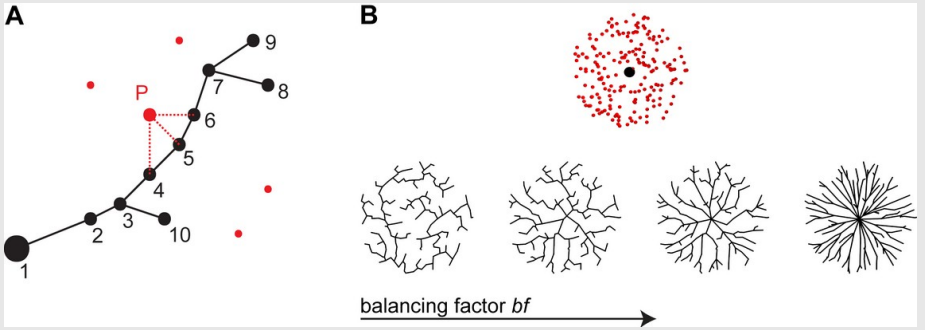
Ongoing projects

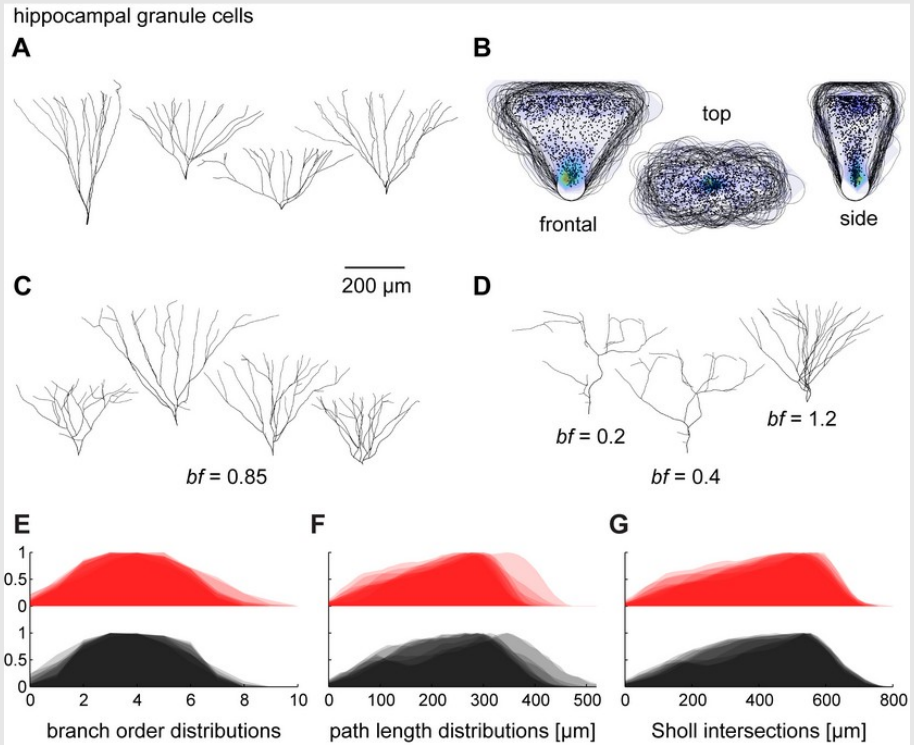
Dendritic morphology

- Implementation of the minimal spanning tree algorithm (TREE Toolbox, Cuntz et al., 2010)







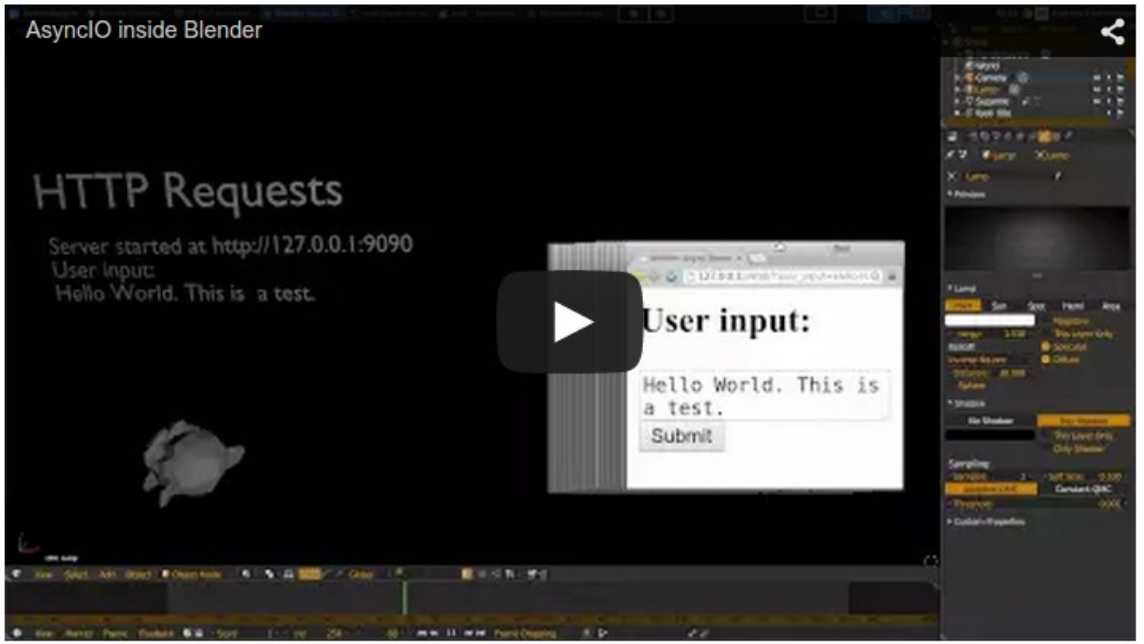


Planned projects

AsyncIO for Blender and parallel computing for HPC hardware

- Implementation of a standard event loop library for concurrency and asynchronous input/output
- ➔ A network simulation can then be started and analysed within Blender
- ➔ faster and more efficient interaction with a network

- Optimization of PAM for parallel computing
- ➔ use HPC for calculating networks of realistic sizes



Conclusion

- PAM allows to model spatial relations between different brain regions
  - ➔ Extends functionality of simulators like **NEST**, Brian, NEURON etc.
  - ➔ Facilitates at one point in the future comparative computational neuroscience
- **We need good data!**
- NeuroML support is underway

Sourcecode is available on

https://bitbucket.org/rub-hippo/parametric-anatomical-modeling

Thank you for your attention!

http://shapeways.com/model/1809522