Bridging scales by modelling and replicating *in silico*

Computational Neuroscience at FIAS

FIAS Frankfurt Institute for Advanced Studies

Multi-scale modelling and simulations of neural systems
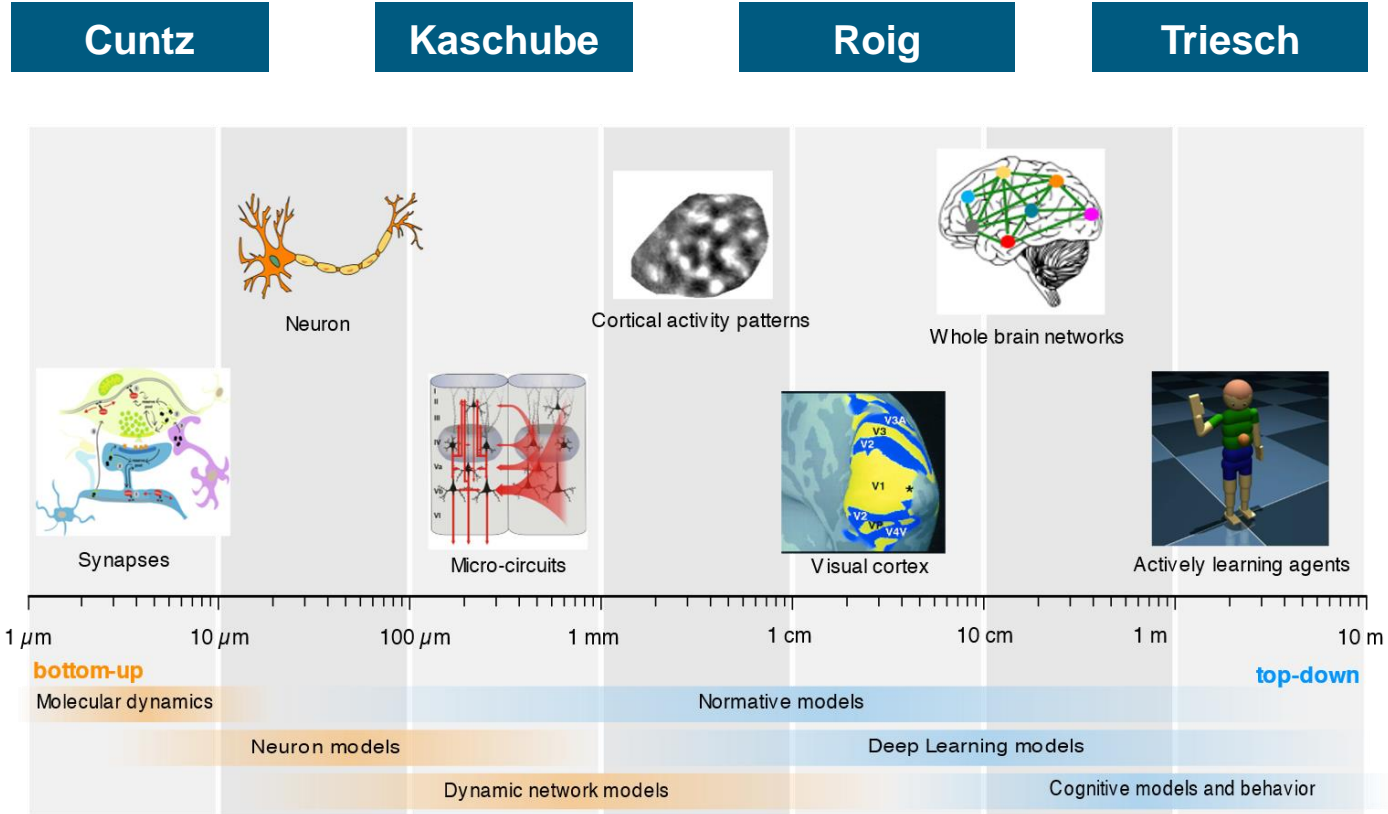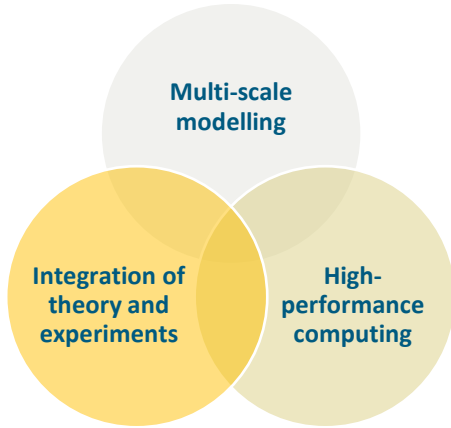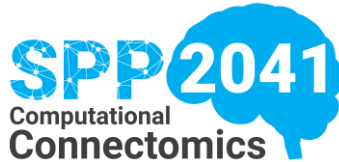
Computational Connectomics

DFG priority program SPP-2041

Who:

- Scientists across Germany

FIAS participants:

- *J. Triesch* (speaker)
- *M. Kaschube*
- *T. Tchumatchenko*

Topics

- Automated reconstruction of brain connectivity
- Curation and open-access distribution of large-scale data sets
- Computational analyses of complex connectivity networks
- Computational models of brain networks and their dynamics and function

Key Results from FIAS

- Spine detection in 3D live cell imaging. Vogel, …, Triesch, …, Kaschube. Sci Rep. (2023)
- V1 connectivity rules from in vivo recording. Kraynyukova, …, & Tchumatchenko. PNAS (2022)
- Simulator development. Vieth, … & Triesch. Front. Neuroinform. (2021)

Emergence of representations during development

## D-US Grants (NSF, NIH / BMBF)

D-US joint grants:

- 2016: with MPI Florida, D. Fitzpatrick
- 2020: with UMN Minnesota, G. Smith
- 2024: with UMN, G. Smith & UC Denver, B. Scholl (under review)
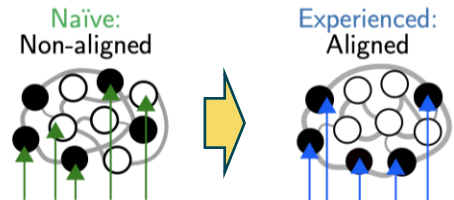
FIAS participants:

- *M. Kaschube*

Key results

- Highly structured spontaneous activty in infant cortex
  Smith et al, Nature Neurosc. 2015, 2018

- Activity structure universal across neocortex
  Powel et al., PNAS 2024
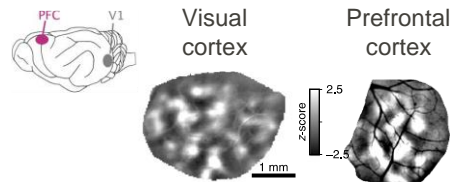
Follow up work

- Universal structure explained by Turing-mechanism
  Nature Com., in rev.

- Reliable representations through feedforward-recurrent alignment:
  Nature Neurosc., in rev.

Abstract Representations in Neural Architectures

DFG FOR 5368 ARENA (2023-27)

Who:

- Psychology, Max Planck Soft. systems and FIAS scientists

FIAS participants:

- *J. Triesch*
- *M. Kaschube*
- *Gemma Roig, co-speaker*

Abstract **RE**presentations in **N**eural **A**rchitectures
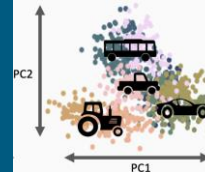
Overall Goals

- Study principles underlying the representation of abstract knowledge in the brain

- How those emerge in the developing brain

- How abstract representations of knowledge are used for behaviors
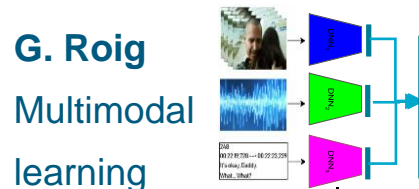
➤ Model *in silico* with AI

Subprojects

J. Triesch:

Active Learning

M. Kaschube:

Cognitive maps

G. Roig

Multimodal learning

The Adaptive Mind (TAM)

Invited for an excellence initiative

Who:

Giessen, Marburg, Darmstadt; participating institutions: Goethe Univ.,

FIAS participants:

- *J. Triesch*
- *G. Roig*

Goals

Understand human perception, thought, action by uncovering how humans **adapt** to changing conditions.

Focus on 5 key areas:

- regulation,
- causality,
- categorization,
- prediction,
- reciprocity

System Level Research

Cognitive Development *in silico*
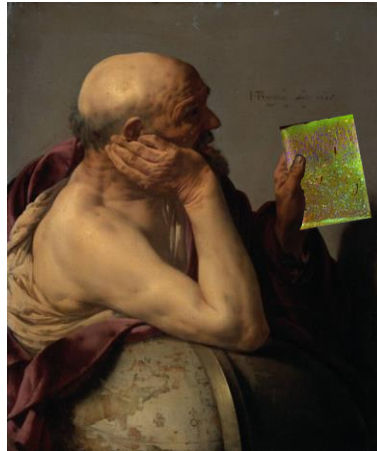

MIMo: Multi-Modal Infant Model

Aubret et al., ICLR (2023); Mattern et al. IEEE TCDS (2024)

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Emerging Initiatives

Circuit mechanisms of creativity

FIAS conference:
Bridging Fields in Creativity Research
Sep 11-13 2024
26 speakers
40 participants

Planned DFG FOR

Bernstein Conference
for Computational Neuroscience

In Frankfurt 2024-2026
World's top 3
+500 participants

Emerging Initiatives

Consciousness in Natural and Artificial Systems

What: "LOEWE Schwerpunkt" pre-proposal selected in internal competition of Goethe University

Who: scientists from Frankfurt and Giessen; at FIAS: **G. Roig, G. Pipa, J. Triesch** (co-speaker)

Goals: better understand the development of different facets of consciousness; explore possibility of conscious AI systems.

Controlled Experiments ⇄ Embodied comp. modelling ⇄ Observation of natural behavior
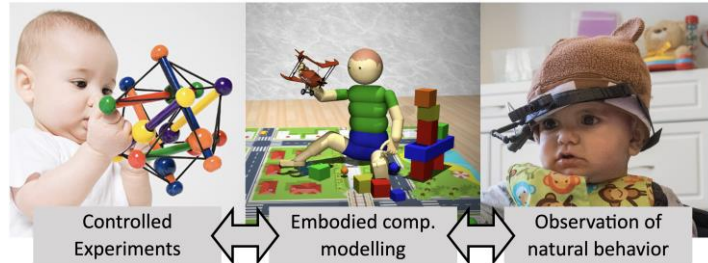
Initiatives in the Area of Mental Health

* *DYNAMIC (LOEWE Center)*
Topic: Psychiatric Disorders,
FIAS participants: **J. Triesch**, **G. Roig** (affiliated)

* *EpiImmune (CRC/Transregio application)*
Topic: Epilepsy,
FIAS participants: **J. Triesch**, **G. Roig**

* *MOPRED (GRK application)*
Topic: Multimodal-Processing
FIAS participants: **M. Kaschube**, **G. Roig**

Dynamic Neural Representations Potential Research Focus

Experimental neuroscience

Computational neuroscience

Representational learning in AI
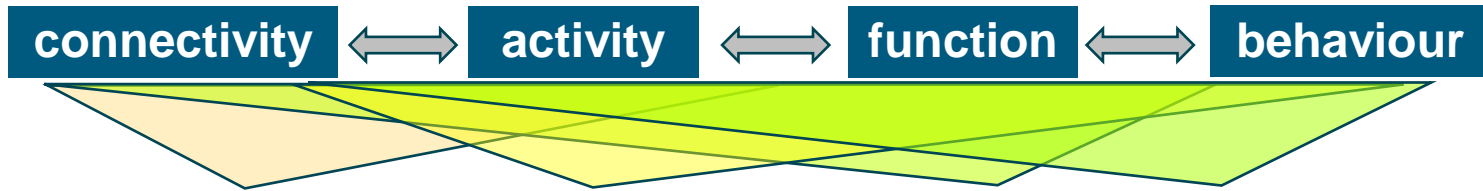
Research focus:
1. Neural mechanisms and implementation
2. Refinement in learning and development
3. Dynamic sequences for reasoning

Foundations in ML

hessian.ai RAI

Cognition and Behavior

FIAS TAM

- Links to newly established brain-imaging center CoBIC
- Collaborative research initiative in preparation
- Long-term perspective: Top-down approach towards a digital twin of the brain

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Overall summary

connectivity ⟷ activity ⟷ function ⟷ behaviour

Bridging scales and levels of understanding, modelling and replicating *in silico*

- **Vibrant environment** (3 Max-Planck Institutes, Ernst Strüngmann Institute, CoBIC, Hessian.AI, RMN2, ICNF)

- **High impact publications** (Nature Communications, Nature human behaviour, Neuron, PNAS (2), Scientific Reports (3), Cell reports (3), Elife (3), PLOS Computational Biology (6), Journal of Cognitive Neuroscience, NeurIPS (2), ICLR, NeuroImage (2), MLHC (2))

- **Multiple ongoing and planned collaborative initiatives**

ARENA retreat 2024

FIAS Frankfurt Institute for Advanced Studies

THANK YOU!