module code / module title

MN-F3 / Theoretical Neuroscience and Methods

date / version of the module description	23.02.2023

1	**INFORMATION ON THE MODULE**	
1a	module code	MN-F3
1b	module title *(German title)*	Klicken Sie hier, um Text einzugeben.
1c	module title *(English title)*	Theoretical Neuroscience and Methods
1d	credit points	9 CP
1e	responsible for the module	Dr. Udo Ernst
1f	type of module	compulsory module
1g	programs using the module	M.Sc. Neurosciences
1h	organizational unit offering the module	Computational Neurophysics Lab, Institute for Theoretical Physics, FB01 Department of Neuropsychology and Behavioral Neurobiology, FB11
1i	content-related prior knowledge or skills	Fundamental knowledge about basic mathematical concepts (equation solving, functions, differential and integral calculus, linear algebra, probability calculus, complex numbers) is recommended.
1j	learning contents	The module comprises three courses which provide students with the basic tools necessary for analyzing neural data, for investigating the dynamics of neural systems, as well as for quantitatively describing information processing and computation in neural networks. A preparatory seminar including exercises at the beginning of the semester rehearses fundamental mathematical methods which are important for understanding all three courses. In particular, the course **Programming** teaches the basics of writing code in the Python programming language, with special emphasis on handling and visualizing neural data. In the **Theoretical Neuroscience** course students learn to mathematically describe neural systems from single synapses up to interacting brain networks, providing the knowledge for formal analysis, modeling and simulation. **Statistics & Data Analysis** completes the module by giving

a focused introduction into descriptive statistics and statistical testing, and presents fundamental methods for neural data analysis.

The courses are designed such that skills acquired in Programming can be directly applied to exercises in Theoretical Neuroscience as well as in Statistics & Data Analysis, and vice versa.

Preparatory seminar:

- Equation solving, functions, complex numbers
- Differential and integral calculus
- Linear algebra
- Probability calculus

Programming:

- Intro: the philosophy of programming and coding
- Variables: precision, range, types (numeric, string, Boolean), scope, casting
- Elementary operations: declarations, assignments, mathematical/logical computations, special math functions, random numbers and distributions, permutations
- Program control: conditional and repeated execution (if, while, for, …)
- Structuring: functions, input & output arguments, modularization techniques, classes (basics)
- Systematic programming: guidelines, examples, debugging, understanding error reports, testing code integrity
- Advanced data types: tuples, lists, dictionaries, sets, list comprehension
- Basic data import/export: binary versus text formats, machine representation, file open/read/write/close, file parsing
- Interoperability and data sharing (i.e. pandas), export/import to/from R/Matlab/text, translation to and from Matlab code
- Arrays and array operations (numpy): creation and initialization, single element and subarray access, augmentation, element-by-element and vector/matrix operations, reshaping/rearranging/tiling, log scaling
- Plots and graphs (matplotlib): single plots, multiple plots/graphs, changing plot appearance, 2D- and 3D-visualization, export to storage and printer

Theoretical Neuroscience (in brackets: mathematical concepts introduced)

- Neurons (differential equations, steady-state solutions): neuroelectronics, ion channels, resting potential, Hodgkin-Huxley-model, leaky integrate-and-fire model, adaptation
- Neural interactions (partial DEQs): cable equations, synaptic transmission and short-term dynamics, learning and plasticity (Hebbian, Window Function), shunting inhibition, divisive normalization
- Spikes (delta-distributions, convolutions): spike trains, rates, rate estimators, spike statistics
- Stimulus-response characteristics & receptive fields (linear encoding and decoding): linear-nonlinear Poisson model, generalized linear model, spike-triggered average, reverse correlations, tuning curves
- Feedforward networks and computation (linear algebra, gradient descent): simple and ML-Perceptron, classification, learning, introduction to deep networks
- Recurrent networks (linear stability analysis): spike-based and rate-based/mean-field, collective phenomena: synchronization, spatial pattern formation, associative memory

		Statistics & Data Analysis: • Descriptive statistics: discrete and continuous probability distributions (normal, Poisson, Bernoulli), mean, variance, kurtosis and higher moments autocorrelation, cross-correlation, covariance • Probability calculus: Bayes formula and Bayesian estimation, risk, likelihood ratio, objective functions, ML/MAP estimation, receiver operator characteristics, discrimination, classification • Statistical tests (non-parametric/parametric) and models: Wilcoxon, Friedman, Kolmogorov-Smirnov, t-test, ANOVA (basic, multivariate and factorial), surrogate data and bootstrap procedures, regression and statistical modeling • Data analysis: Signal acquisition and sampling, filtering, spectral analysis (Fourier, Wavelet)
1k	learning outcomes/ competencies/ targeted competencies	**Preparatory Seminar:** • Students understand mathematical notation and can interpret expression and equations • Students are able to apply appropriate tools and rules to solve basic mathematical problems in calculus, linear algebra, and probability calculus **Programming:** • Students are able to partition complex tasks into a set of given elementary operations • Students can translate these operations into a working (Python) program code • Students are able to debug and test program code on their own • Students can write programs for solving problems in neural data analysis or for performing simulations of neural (network) models • Students are able to import/export data for file sharing • Students are capable to visualize data and computation results in a form suitable for scientific texts. **Theoretical Neurosciences:** Students are able to select/to use tools from mathematics, physics and information theory to… • …describe dynamical processes in neural systems • …construct simple models of neurons and elementary feedforward/recurrent networks • …analyze neural signals and deduce stimulus-response properties **Statistics and Data Analysis:** • Students are able to compute with probabilities, and to perform statistical inference on data • Students can select appropriate statistical tests and apply them to neural data sets • Students understand the fundamentals of neural signal acquisition, and can apply basic pre-processing techniques on neural data (averaging, filtering, correlation, spectral decomposition)

1l	calculation of student workload *(part a: calculation of presence time and working hours)*	**The total amount of the presence time and working hours of the module has to be calculated additionally in the detailed calculation a) to c).** **a)** detailed calculation: **SWS / presence time/working hours in each course of the module**

☒ 3	lecture(s) with	3	SWS/ contact hours	42	hours of presence time
☐	seminar(s) with		SWS/ contact hours		hours of presence time
☐	exercise(s) with		SWS/ contact hours		hours of presence time
☐	internship(s) with		sum of working hours		
☐	seminar(s) with		SWS/ contact hours		total hours of presence time
☒ 3	laboratory/laboratories with	3	SWS/ contact hours	42	total hours of presence time
☐	tutorial(s) with		SWS/ contact hours		
☐	excursion(s) with		SWS contact hours in total		working hours

☒ other form of course (e.g. block seminar), namely this:

Preparatory seminar including exercises for rehearsing mathematical background knowledge (see 1i) at the start of the semester (see 1i)

with 1 SWS / with totaly 14 contact hours ☐ presence time ☐ working hours

= sum of presence time and working hours:

98 hours in total

	calculation of student workload *(part b: preparation time and follow-up work/self-study)*	**b) working hours for preparation/follow-up work of the course(s) and/or self-study** = sum of working hours: 98 hours in total
	calculation of student workload *(part c: exam preparation etc.)*	**c) exam preparation (incl. examination)** = sum of working hours: 74 hours

	calculation of student workload *(total amount of hours including a) - c))*	**Total amount of the presence time and working hours a) to c):** 270 hours
1m	description of possible optional courses in the module	*Can a student choose between different courses within the module?* NO *Short description of selection option* Klicken Sie hier, um Text einzugeben.
1n	language(s) of instruction	☐ German ☒ English ☐ Spanish ☐ French ☐ Other, namely this: Klicken Sie hier, um Text einzugeben.
1o	frequency	*(regular cycle module is offered) e.g.: winter semester, yearly or summer semester, yearly or each semester* winter semester yearly Klicken Sie hier, um Text einzugeben.
1p	duration	one semester module Klicken Sie hier, um Text einzugeben.
1q	Literature (*optional*)	Klicken Sie hier, um Text einzugeben.
1r	more information on the module (*optional*)	
2	**INFORMATION ON THE MODULE EXAMINATION** (see also AT Art. 5 section 8)	
2a	type of examination	☐ module exam; i.e. exam with only one component (MP) ☒ combination exam, i.e. exam with several components (administered by instructors) (KP) ☐ partial exam; i.e. exam with several components (administered by registrar) (TP)
2b	exam components or prerequisites *(type, number)*	***PL*** *= graded component of the examination* ***SL*** *= ungraded component of the examination, coursework* ***PVL*** *= prerequisite of the examination (see AT Art. 5 Section 10)* ☒ PL | 1 ☒ SL | 3 ☐ PVL | justification If necessary, further explanations: SL1 = Portfolio (consisting of exercises) SL2 = Portfolio, consisting of exercises SL3 = Portfolio, consisting of exercises

2c	Give this information for combination examinations only: Weights (in percentage) of component grades	PL 1: PL 2: PL 3: PL 4: If necessary, further comments: Klicken Sie hier, um Text einzugeben.
2d	form of examination (see AT BPO/AT MPO Art. 8, 9 and 10)	☐ Assignment ☐ Oral examination (single) ☐ Presentation, oral ☒ Written examination ☐ Group examination, oral ☐ Presentation and written assignment ☒ Portfolio ☐ Project report ☐ Bachelor Thesis ☐ Internship report ☐ Colloquium ☐ Master Thesis ☐ Other (concrete definition is given in the examination regulations): The Portfolios are SL
2e	language(s) of instruction	☐ German ☒ English ☐ Spanish ☐ French ☐ Other, namely this: Klicken Sie hier, um Text einzugeben.